PROCEEDINGS

OF THE

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July 23-27, 2001

PROCEEDINGS

V[th] International Safflower Conference
Williston, North Dakota and Sidney, Montana
United States of America
July 23 – 27, 2001

"SAFFLOWER: A MULTIPURPOSE SPECIES WITH UNEXPLOITED POTENTIAL AND WORLD ADAPTABILITY"

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Welcome Address to the Vth International Safflower Conference Participants

Jerald W. Bergman[1], Chairman
Vth International Safflower Conference

Honorable guests, distinguished scientists, ladies and gentlemen, it is my privilege and honor to welcome you to the Vth International Safflower Conference in behalf of North Dakota and Montana; North Dakota State University and our NDSU Williston Research Extension Center at Williston, ND, USA; and Montana State University and our MSU Eastern Agricultural Research Center at Sidney, MT, USA.

In 1997, during the IVth International Safflower Conference at Bari, Italy, the International Safflower Research and Development Committee graciously accepted our bid to co-host the Vth International Safflower Conference at Williston, North Dakota and Sidney, Montana. I accepted with great enthusiasm this opportunity and privilege to hold this Vth International Safflower Conference in North Dakota and Montana to emphasize the value and potential of safflower in the Montana-Dakota region and the northern Great Plains.

I am pleased to inform you that the Honorable Lt. Governor of North Dakota Jack Dalrymple, NDSU Vice President of Agriculture Affairs Pat Jensen, and MSU Dean of Agriculture and Director of the Montana Agricultural Experiment Station Sharron Quisenberry will also extend their warm welcomes to you as Vth International Safflower Conference participants at our official Conference Banquet on Wednesday, July 25, 2001.

We express a special thanks to our past North Dakota Governor Ed Schafer, Montana Governor Marc Racicot, NDSU President Thomas Plough, the late MSU President Michael Malone, and Williston Mayor Ward Koesser for strongly supporting our bid to host the Vth International Safflower Conference. We also acknowledge and thank the following co-sponsors of the Vth International Safflower Conference for their support of this Conference: Food and Agriculture Organization of the United Nations (and Peter Griffee) that financially supported two safflower scientists, the USDA-Agricultural Research Service, Sidney, Montana (and Neal Spencer), Montana State University, North Dakota State University, the American Society of Agronomy, Crop Science Society of Agronomy, and Soil Science Society of Agronomy.

I also acknowledge the efforts of the committee of reviewers that devoted their time and talent in the review of the papers submitted for inclusion in the Proceedings of this Conference. I express my gratitude to Senior Co-Editor Dr. H.-H. Muendel (Canada), Dr. Richard Johnson (Washington), Professor Neil Riveland and Dr. Don Tanaka (North Dakota), Dr. Elaine Grings and Dr. Charles Flynn (Montana), and A. Barney Hill (California). I extend my special thanks to Janelle Jensen who has worked so hard with me to organize and prepare for this Conference and its proceedings. I acknowledge and express my thanks to the other members of our local organizing committee (Megan Flynn, Kathy Bjorge, Dawn Rustad, Barb Ruzynski, Tom

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Rolfstad, Gordon Bradbury, Kevin Dahl, Chet Hill, Jim Staricka, Neil Riveland, Marilyn Krogen, Andrew Paulson, Leslie Messer, and Charles Flynn).

I express my great appreciation and thanks to Dr. Henning Muendel, Vice-Chairman of the International Safflower and Research Development Committee, who so willingly and generously has provided council and advice in the planning and organization of the Vth International Safflower Conference. I personally acknowledge Henning Muendel as the "Ambassador of Safflower" who so willingly and capably has accepted the role and leadership of assuring that representatives of the international safflower research and development community have continued to come together at International Safflower Conferences at host country sites of Hyberabad, India (1989), Beijing, China (1993), Bari, Italy (1997), and now here in Williston, North Dakota / Sidney, Montana, USA (2001).

Lastly, I thank each of you as participants of the Vth International Safflower Conference for your attendance and contributions to the Conference and to the research, development, production, and utilization of safflower with its mostly unexploited potential and world adaptability. I wish each of you a fruitful conference and hope that all of you and your guests will enjoy the tours of our agricultural lands, historic forts, Theodore Roosevelt National Park, and Medora.

Welcome Address to the Vth International Safflower Conference Participants

Antonio Corleto[1]
Chairman of the International Safflower Research and Development Committee

Dear Chairman of the 5th Safflower Conference, Honourable Guests, Ladies and Gentlemen, I extend a warm welcome to all participants. Welcome to Williston in North Dakota and to Sidney in Montana, two small towns of the North American "legendary West", that have organized this 5th Conference on Safflower in an excellent way. These lands, rich in rivers, lakes, meadows and mountains, remind me of the nice youthful memories when I followed anxiously the heroic feats of General Custer and Sitting Bull. This trip to the West of North America is certainly not my first: in the early seventies I had the chance to study in Davis (California) where I got the Master of Science in Agronomy and I had as major professor Dr.. Paul Knowles who is universally considered as an eminent authority on safflower. On my coming back to Italy I received from him a few samples of safflower seeds that were the starting point of the research work conducted for more than 20 years in large areas of central and Southern Italy.

After this short personal recollection, I feel obliged to thank all the Organizations that have contributed to the great success of this 5th International Safflower Conference. Deep thanks are expressed to Prof. Jerald Bergman, Chairman of the 5th International Safflower Conference, and to his collaborators who have supervised the organization of the Conference and the publication of the Proceedings with great diligence and professionalism.

Special thanks are due to the Governors of North Dakota and Montana States, Mr. Edward T. Schafer and Mr. Marc Racicot for strongly supporting the candidature of Williston and Sidney to host the 5th International Safflower Conference, and to the Presidents of North Dakota State University and Montana State University, Dr. Thomas P. Plough and Dr. Michael Malone who - in co-operation with the North Dakota Agricultural Experiment Station and Montana Agricultural Experiment Station - made possible this conference, which seems to be a great success!

Thanks are also expressed to the FAO, which since 1981 has been contributing to the success of Safflower Conferences, through the financial support for some scientists from Developing Countries.

Lastly, let me thank Dr H.-H Muendel, Vice-chairman of the International Safflower Research and Development Committee, for his skill and energies so generously spent to help organize the Conference, and to all the participants in the International Safflower trials, established in Bari in 1997 and including the following researchers: Barney Hill (USA), Jerry Bergman (USA), Antonio Corleto (Italy), Enver Esendal (Turkey), Jose Fernandez Martinez (Spain), D.M.Hegde (India), Richard Johnson (USA), Dajue Li (China) and Despo Papakosta (Greece).

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Safflower that was defined in the previous conference in Bari as a multipurpose species, used primarily as an oilseed crop, deserves great attention by scientists who should pursue the objectives to increase yields, which are still unsatisfactory, and to shorten the cropping cycle. If varieties and hybrids with a cycle not longer than 200-210 days, for a fall-seeded crop, become available in future, safflower could spread in many hot and dry areas. I am referring to the Mediterranean region, in particular to some Southern Italy areas where the prevailing durum wheat monocropping system has caused a great loss in plant bio-diversity and where a crop more reliable than sunflower, sugarbeet and rape, all of which have already been tested, with poor results, should be introduced. Moreover, unlike other herbaceous oilseed crops, safflower produces oil characterized by a good nutritional value and considerable dietetic and therapeutic properties. So that, with Dajue Li and Henning Muendel, we can state that safflower could play in the near future a major role to improve the living standard and the health of people.

With this in mind, I wish a great success to this 5th Conference.

Global Adaptability and Future Potential of Safflower

Prof. Dr. Enver Esendal[1]

Despite its relatively minor importance in world agriculture, safflower (Carthamus tinctorius L.) has been known for thousands of years and has been used for many purposes. Safflower was cultivated in Egypt, Morocco, China and India for carthamin, a yellow or red colored dye material in ancient times, as early as 4500 B.C. This dye was used in Egyptian mummies and for coloring food and clothes in China and many other countries. Safflower is also important in China as a medicinal plant used for treatment, in the form of infusion, for circulatory system related diseases. Finally, safflower has a long history as an oilseed crop in Ethiopia and India. In recent years, the potential of safflower has increased in recognition in many countries. Safflower meal, remnants of the seed after the oil has been extracted, is a good animal feed especially for polygastric animals. Linoleic acid rich types especially have a large industrial potential to be used in manufacturing of varnishes and surfactants and as oleic acid rich types for biofuel and biolubricants.

During the period of 1995-2000, world safflower acreage was between 1,086,514 and 1,198,980 ha. (Average 1,143,639 ha.), and production was between 852,592 and 1,011,762 metric tons (average 910,545 mts) (FAO data, 2001). Asian countries including Russia have 71 % of the world acreage and 54 % of world production. On the other hand, 21 % of the acreage and 40 % of production belong to North and South America. The remaining countries constitute 8 % of world acreage and 6 % of world production. The leading producer country, India has 63 % of world acreage (718,167 ha.) and 46 % of world production (421,000 mts). India is followed by Mexico. Starting as a commercial oilseed crop in the 1950's in the USA, safflower production in the USA rapidly increased up to 175,000 hectares mainly in California, Nebraska, Arizona and Montana. Today the US has nearly 100,000 ha. of safflower production area and that country is the third in area, after India and Mexico, and second in production. Other producer countries, in decreasing order, are Ethiopia, Kazakhstan, Australia, Argentina, Uzbekistan, China and the Russian Federation. Pakistan, Spain, Turkey and Israel have relatively minor acreages. Thus, FAO statistics show a dozen or so safflower producing countries in the world. In addition Canada, Portugal, Syria, Iran, Czech Republic, Cyprus, Romania and Italy, host of the Fourth International Safflower Congress, are known for their safflower research and development.

Therefore, safflower has a wide adaptation, from 60° North latitude (in Russia) to 45° South latitude (in Argentina and Australia). Safflower can grow in cool and temperate climate zones of the world. Warm weather results in higher oil contents in the safflower seed. Safflower is quite tolerant to subfreezing temperatures as low as -12 °C. This feature of safflower enables winter plantings in many regions of the world, with higher yields than from spring plantings. The winter planted crop exploits winter precipitation better than a spring planted crop. For example, although risky in some years, winter plantings gave better results than spring plantings in Turkey. Nevertheless, diseases caused by Alternaria carthami (leaf spot), Puccinia carthami (rust), Phytopthora dreschsleri Tucker (root rot), Fusarium and

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Verticillium negatively affect safflower production in areas with excessive moisture and high humidity. These diseases are some of the serious constraints limiting safflower production throughout the world.

In order to increase the acreages of safflower, a promising oilseed crop for the countries in cool and temperate zones of the world, disease problems need to be overcome. In addition, high yielding, protein and oil rich hybrid cultivars should be developed. Breeding and spreading of high oleic acid containing varieties are the priorities in safflower breeding. Government participation is also required in setting up the market conditions for safflower, at least at the beginning.

In the last part of my talk, with your permission, I would like to discuss briefly the safflower production in my own country, Turkey. The tale of safflower in Turkey, which started in 1940's, unfortunately, is not a success story. In fact, as a Mediterranean country, Turkey is one of the countries native to wild species of safflower and its soil and climatic conditions are very favorable for safflower production. As in many other countries, failure of safflower to be a major crop in Turkey is mainly due to the fact that its poor yield and oil content are not able to compete to sunflower and other oilseed crops in income.

Safflower could be a good winter rotation crop in vast cereal production areas of the Anatolian plateau. However, state initiative is needed for the establishment of free trade conditions and a marketing system as well as for the production and distribution of good quality seed. In some countries like Turkey, the industrialized people do not take any role in the production of seed and sometimes they even avoid any contact with the farmers. As a result of this, it is a great risk for farmers to abandon traditional crops and to opt for new crops. Realization of such a transition in Turkey is even more difficult since vegetable oil processing technology has mainly been designed for sunflower and cottonseed. I hope that the opportunity to host the next international safflower conference in Turkey will bring attention and show the potential to develop safflower in our country.

I am sure that the conference will yield valuable results for all of us. I wish good luck for everybody, and I thank Dr. Bergman and his team in the United States for being our hosts.

Introduction to the International Safflower Conferences

Hans-Henning Mündel[1]

Vice-Chairman, International Safflower Research and Development Committee

Dr. Jerry Bergman, Chairman of the Local Organizing Committee of the FIFISC; Dr. Antonio Corleto, Chairman of the International Safflower Research and Development Committee, other distinguished guests, ladies and gentlemen:

Twenty years ago, in July 1981, following 20 years and 5 U.S. national safflower conferences, the First International Safflower Conference was held in the U.S., namely in Davis, California, with Dr. Paul F. Knowles as Chairman. The largest numbers of delegates were, not surprisingly, from the U.S. At a research workshop on the day following the official conference, Dr. Knowles entrusted me with ensuring that future international conferences be held. I accepted with considerable trepidation: but now we are here at the Fifth International Safflower Conference: once again in the US, after 20 years.

These safflower conferences bring safflower researchers together to exchange current research findings and issues as well as providing opportunities for networking!. We have in general had participants from 12 to 15 countries at these conferences. The major aims in having different countries host these international safflower conferences are to provide opportunities for safflower researchers from different areas to attend (without having to always incur exorbitant travel costs); to showcase safflower research in different countries. And also, having the conferences in different countries emphasizes the value and potential value of safflower to the decision makers in the country and regions where the conferences are held. A certain prestige is associated with hosting. This may help stimulate further safflower research and development in the regions.

The Second International Safflower Conference was held in Hyderabad, India in January 1989, sponsored by the Indian Council of Agricultural Research. Dr. Ranga Rao was its local organizing chairman. India is the country where more safflower area has been under production and certainly more safflower researchers are found than anywhere else in the world. The majority of delegates were from India. The International Development Research Centre of Canada and the FAO were major contributors in bringing foreign delegates to that conference.

The Third International Safflower Conference was held in Beijing, China in June 1993, sponsored by the Chinese government, through its Chinese Academy of Sciences. Dr. Li Dajue was its local organizing chairman. The majority of delegates were from China. That conference introduced many of us (the non-Chinese speaking participants) to the long tradition in China of safflower use for medicinal purposes, and uses in textile and food dyes over several millennia.

Next, we had the Fourth International Safflower Conference in Bari, Italy in June 1997, sponsored by the Bari University, with Prof. Antonio Corleto as the local organizing chairman. A large number of delegates from Italy attended and participated. Countries surrounding the Mediterranean, or one country removed, had more delegates present than at any other of the

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international safflower conferences. We had the opportunity to compare safflower and olive production, olive processing, and compare the oils. FAO again assisted in bringing several important delegates to the conference. At that conference, we finally had the opportunity to personally thank Dr. José Fernández-Martínez, from Cordoba, Spain, for his years of dedicated editorship of the annual 'Sesame and Safflower Newsletter.' The last time we had met before that was at the 1981 Davis conference! In deciding the venue for holding the following, this present conference, we actually had three applications. As we are aware, the well-developed Williston/Sidney proposal, received the nod. But we had two additional offers: the first time that we had competition for hosting the next conference. Dr. Esendal from Turkey agreed to hold back his offer, in anticipation of having first choice next time round.

And now we are at the NDSU Williston Research Extension Center in Williston, North Dakota and will also travel to the MSU Eastern Agricultural Research Center in Sidney, Montana to tour its safflower research facilities and early generation and variety test plots: here in the US Great Plains, the heartland of dryland safflower production, with active variety development, weed control, agronomic and disease research ongoing for decades.

For 2005 we may expect to be invited to Turkey. Should Turkey not materialize - we are well advised to always plan ahead - can alternate offers be made before we leave Williston? This would serve both as alternate (for 2005) or be offers to host the following (2009) conference. How about Australia, with a resurgent interest in safflower and safflower research? Or Mexico, where at times there has been greater safflower production than in the U.S.? Of course we'd hope the conference language could be English: or bilingual with translations provided.

Happy networking!

Animal Feeding

Effects of Prepartum High Linoleic Safflower Seed Supplementation for Gestating Cows on Performance of Cows and Calves

H. B. Encinias[1], A .M. Encinias[1], J. J. Spickler[1], B. Kreft[2], and M. L. Bauer[1], and G. P. Lardy[1]

ABSTRACT

Effects of prepartum safflower supplementation for beef cows on cold tolerance and performance of calves were investigated in two studies. In Exp. 1, 44 crossbred cows (601.4 ± 46.9 kg initial weight) received isocaloric and isonitrogenous diets containing either 2.5 (LF) or 5.1% (HF) dietary fat beginning approximately 45 d prior to calving. Rolled safflower seeds (32% fat; 80% linoleic acid) were supplemented in HF. Safflower meal was used as protein source in LF supplement. Body weight and condition were similar initially and at weaning, as was final weight. LF cows had more body condition at the end of supplementation ($P = 0.07$). Birth weights and weaning weights of calves were not different. In Exp. 2, 63 cows (729.4 ± 80.0 kg initial weight), 56 ± 7 d prepartum, were allotted randomly to dietary treatment (2 pens / treatment) consisting of HF and LF. Supplement and basal diet composition were similar to Exp. 1. Diet intake, initial and final BW, and body condition of cows were measured. Variables measured in calves included birth weights and weaning weights. High fat cows tended to have higher intake ($P = 0.14$). Body weight and condition of cows were similar. High fat cows tended to gain more throughout the trial ($P = 0.10$). Neither calf birth weight nor weaning weight was different. Supplemental safflower seed fed to cows did not affect cow or calf performance.

Key words: Safflower, Linoleic Acid, Supplementation, Fat, Calf Performance, *Carthamus tinctorius* L.

INTRODUCTION

Postpartum supplementation of dietary fat has been shown to have positive influences on postpartum reproductive performance in cows. Increased follicle number and size, pregnancy rates, and calf gains were observed when dams were supplemented with rice bran (18% fat) beginning 1 day after calving until completion of first estrous cycle (De Fries et al., 1998). The responses of reproduction seem to be weaker and slower when saturated fats are used compared to unsaturated fats (Thomas et al., 1997). It has been speculated the unsaturated fat effect is mainly due to linoleic acid content and its interaction with prostaglandins (Williams and Stanko, 2000) and its glucose metabolism capabilities (Thomas et al., 1997). A concentrated source of linoleic acid for livestock would be the high linoleic variety of safflower seeds.

The above responses have been seen with postpartum supplementation of fat. The effects of prepartum supplementation on performance, however, have not been extensively investigated. Bellows et al. (1999) supplemented prepartum heifers with dietary fat (soybeans, safflower, and sunflower seeds) and observed increased pregnancy rates and a tendency of increased calf weaning weights. Pregnancy rates were highest in the safflower seed supplemented group. Using the mature cow as a model, the objectives of this study were to determine the effect of prepartum high linoleic safflower supplementation on cow and calf performance and subsequent pregnancy rates.

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MATERIALS AND METHODS

In order to achieve the objectives two experiments were used. Experiment 1 was conducted at the North Dakota State University Central Grasslands Research and Extension Center in which 44 mature crossbred cows (601 ± 47 kg initial weight; 2 pens per treatment) received isocaloric and isonitrogenous diets containing either 2.5 (LF) or 5.1% (HF) dietary fat beginning approximately 50 days prepartum. Cows received ad libitum access to a common basal diet of 25% corn silage, 37.5% brome grass hay, and 37.5% alfalfa hay (dry matter basis). In addition, 1.36 kg HF or 1.67 kg LF supplement per cow was topdressed over the basal diet daily. Rolled safflower seeds (80% linoleic acid) were supplemented in HF. Solvent extracted safflower meal was used as protein source in LF supplement (Tables 1 and 2). Trace mineralized salt was available for ad libitum consumption. Measures of cow performance included body weight and condition score collected at the beginning and end of supplementation and at weaning. Birth weights and weaning weights of calves were measured.

Experiment 2 was conducted at the North Dakota State University beef unit in Fargo. Sixty-three cows (729 ± 80 kg initial weight), 56 ± 7 d prior to calving, were allotted randomly to dietary treatment (2 pens / treatment) consisting of HF and LF. Supplement and basal diet composition and delivery method were similar to Exp. 1. Dry matter intake was monitored throughout supplementation. At the beginning and end of supplementation, and at weaning, body weight and condition of cows were measured. Variables measured in calves included birth weights and weaning weights. Percent of cows pregnant and open was observed at the end of the breeding season by rectal palpation.

All data were analyzed with analysis of variance for a completely randomized design using the GLM procedures of SAS (SAS Inst., Inc., Cary, NC). The model contained effects for treatment and pen served as experimental unit. Means were separated by least significant difference. Data for percent bred and percent open were analyzed with arcsine transformation (Sokal and Rohlf, 1995). Means and standard errors of the means were converted back for reporting.

Table 1. Supplement composition (dry matter basis).

	Treatment	
Item	High fat	Low fat
Corn, dry rolled		64.5
Safflower meal, solvent ext.		30.5
Molasses		5.0
Safflower seeds, rolled	100.0	—

Table 2. Diet nutrient analysis (dry matter basis).

	Treatment	
Item	High fat	Low fat
	%	
Dry matter	71.4	70.8
Organic matter	91.5	91.7
Crude protein	10.5	10.1
Ca	0.6	0.6
P	0.3	0.3
Fat	5.1	2.5
	Mcal/kg	
ME†	2.3	2.2

†Metabolizable energy; calculated

Table 3. Effects of safflower supplementation to gestating cow on performance.

Item	Treatment HF	LF	SEM†	Probability‡
Exp. 1				
Body weight, kg				
Initial	601.0	601.8	0.4	0.30
Final	649.2	657.5	5.9	0.43
Weaning	609.7	619.5	7.0	0.42
Avg daily gain, kg§	1.1	1.3	0.2	0.48
Body condition¶				
Initial	5.1	5.1	0.04	0.70
Final	5.9	6.0	0.00	.001
Weaning	5.7	5.8	0.12	0.64
Exp. 2				
Body weight, kg				
Initial	729.6	729.4	7.5	0.99
Final	792.5	788.0	7.9	0.73
Avg daily gain§, kg	1.9	1.7	0.03	0.10
Dry matter intake, kg	15.1	14.3	0.02	0.14
Body condition¶				
Initial	6.8	6.8	0.1	0.84
Final	6.6	6.7	0.1	0.52

†Standard error of the mean; n = 2.
‡Probability of a greater F statistic.
§During supplementation phase
¶1 = emaciated, 9 = obese.

RESULTS

In Exp. 1, cow weight ($P = 0.30$) and condition ($P = 0.70$) at the beginning of the supplementation phase were similar between treatments, as was final weight ($P = 0.43$; Table 3). LF cows had more body condition at the end of the supplementation phase ($P < 0.001$). At weaning, cows from both treatments had similar body weight ($P = 0.42$) and condition ($P = 0.64$). In Exp. 2, no differences were observed for initial or final body weight or condition. High fat cows tended to have higher intakes ($P = 0.14$) and gain more throughout supplementation ($P = 0.10$).

Birth weights of calves were not different ($P = 0.93$) in Exp 1 (Table 4). Actual ($P = 0.80$) and adjusted ($P = 0.52$) calf weaning weights were not different between HF and LF treatment (Table 4). In

Table 4. Effects of safflower supplementation to gestating cows on calf birth and weaning weight.

Item	Treatment HF	LF	SEM†	Probability‡
	----------------kg----------------			
Exp. 1				
Birth weight	41.6	41.5	0.6	0.93
Weaning weight	226.4	228.1	3.9	0.80
Adjusted WW§	241.5	245.8	3.9	0.52
Exp. 2				
Birth weight	39.8	42.4	1.1	0.25
Weaning weight	243.5	237.1	11.1	0.72
Adjusted WW§	262.9	254.4	10.	0.63

†Standard error of the mean; n = 2.
‡Probability of a greater F statistic.
§Weaning weight adjusted to 205 d.

Table 5. Effects of safflower supplementation to gestating cows on open and bred percentages in Exp. 2.

Item	Treatment		SEM[†]	Probability[‡]
	HF	LF		
	%			
Bred[§]	85.4	86.2	0.005	0.93
Open	14.5	13.8	0.005	0.93

[†]Standard error of the mean; n = 2.
[‡]Probability of a greater F statistic.
[§]Includes bred by AI and clean-up bull.

Exp. 2, calf birth weights were not different ($P = 0.25$). Neither actual ($P = 0.72$) nor adjusted ($P = 0.63$) weaning weights were different between treatments.

Subsequent percentages of bred cows ($P = 0.93$) and open cows ($P = 0.93$) in Exp. 2 were similar for cows fed HF or LF treatments during gestation (Table 5).

DISCUSSION

In the current study, in general, body weights and condition of cows were not different. This may be expected as diets were formulated to be equal in energy and protein across treatments. These results are in agreement with prepartum studies with heifers (Bellows et al., 1999) and postpartum studies with cows (Lammoglia et al., 1997). De Fries et al. (1998), however, observed increased body condition of cows fed isocaloric and isonitrogenous diets containing rice bran after calving. In Exp.1, LF cows had more condition ($P < 0.001$) after supplementation which is difficult to explain; however, the difference disappeared by weaning.

Calf performance was unaffected by fat supplementation in the present study. Bellows et al. (1999) demonstrated a tendency of calves from fat supplemented dams to have heavier weights at weaning. Pre- and postpartum supplementation of cows with calcium soaps of fatty acids increased calf weights during supplementation and at weaning (Espinosa et al., 1995). Other postpartum studies have shown an increase in calf weight only during concurrent fat supplementation of the dam, effects disappeared by weaning (De Fries et al., 1998).

Postpartum interval has been shown to decrease with fat supplementation using calcium soaps of fatty acids (Hightshoe et al., 1991; Espinoza *et al.*, 1995). However, it seems plant oils elicit greater responses from the ovary than saturated fats (Thomas et al., 1997). Linoleic acid has been hypothesized to be the vehicle by which this response takes place due to its inhibition of prostaglandin synthesis (Williams and Stanko, 2000) and enhancement of gluconeogenesis and insulin production (Thomas et al., 1997). Increased pregnancy rates have been observed with postpartum fat supplementation (De Fries et al., 1998) which may be due to decreased embryonic mortality (Hawkins et al., 1995) because circulating progesterone levels increase, helping to maintain the corpus luteum. In Exp. 2 of this study, pregnancy rates of cows were not different, unlike results obtained with heifers (Bellows et al., 1999). Postpartum interval is typically longer in heifers than in cows and strategies, like addition of fat to the diet, may have a greater effect on shortening this interval and, thereby, on pregnancy rates in heifers (Wiltbank, 1970).

No statistical differences for cow or calf performance or pregnancy rate were seen in these studies. It is not known whether the responses from feeding fat are due to an increased energy status or by other processes not dependent upon energy intake (De Fries et al., 1998). These studies would suggest supplemental fat may not be advantageous when cows are in adequate energy status. This may also be the reason why responses can be achieved in heifers that have higher energy requirements for growth and maintenance.

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Effects of Prepartum High Linoleic Safflower Seed Supplementation for Gestating Ewes on Cold Tolerance and Survivability of Lambs

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ABSTRACT

Lamb survival during periods of cold weather can be a problem in northern climates. Effects of prepartum safflower seed supplementation for ewes were investigated and effects on lamb survival and performance were noted. One hundred twenty-two gestating ewes (75.8 ± 7.6 kg initial weight) were allotted randomly to one of two dietary treatments (4 pens per treatment). Ewes were fed alfalfa-based, isocaloric and isonitrogenous diets formulated to contain either 4.6 (HF) or 1.9% (LF) dietary fat beginning approximately 45 d prepartum. Rolled safflower seeds (32% fat; 80% linoleic acid) were supplemented in HF, while solvent extruded safflower meal was used as protein source in LF supplement. Energy was balanced in LF with corn. All pens were offered same amounts of feed throughout trial. Initial and final ewe body condition and weights were measured, in addition to birth weights, lamb morbidity, and mortality. Initial and final body conditions were similar ($P > 0.43$). Low fat ewes had gained more weight ($P = 0.05$) at the end of the trial. Incidence of multiple births and birth weights were not different ($P > 0.20$). Although not significant, lambs from HF dams had numerically higher suvivabilities ($P = 0.34$) and tended to have less lambs die due to starvation ($P = 0.20$). High linoleic safflower seeds may be beneficial in improving lamb survivability and further research in this area is warranted.

Key words: Safflower, Supplementation, Cold Tolerance, Lamb Survival, *Carthamus tinctorius* L.

INTRODUCTION

Mortality of lambs due to cold stress is a problem during winters and cold, wet springs. Lambs produce 50 to 60 % of their heat through shivering and 40 to 50% through non-shivering thermogenesis (Alexander and Williams, 1968). Brown adipose tissue (BAT), present in most infant mammals, is the origin of the non-shivering portion. Lambs are born with almost 100% BAT, unlike other species, such as humans and rats which are born with brown and white adipose tissue (WAT; Gemmel et al., 1972; Alexander and Bell, 1975). Research with steers (Cook et al., 1972) and lambs (Gibney and L'Estrange, 1975) has shown that feedstuffs high in linoleic acid increase the linoleic acid content of specific brown fat stores. Brown adipose tissue relies on linoleic acid as a major fuel for heat production (Lammoglia et al., 1999a). Fat supplementation to gestating rats increased the thermogenesis from BAT in the offspring (Nedergaard et al., 1983). Lammoglia et al. (1999 a,b) fed high linoleic safflower seeds to heifers during the last third of gestation and calves were better able maintain body temperature when exposed to cold compared to calves from dams fed conventional supplements.

High linoleic safflower seeds may be an economical source of linoleic acid. Seeds from the high linoleic varieties can contain up to 80% linoleic acid. In addition, the seed, because of the high oil content, is a high energy feed and a good source of rumen degradable protein, making it a good source of supplemental nutrients. The objectives of this study were to determine if feeding high linoleic safflower seed as a fat source to gestating ewes increases the cold tolerance and overall survivability of lambs.

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MATERIALS AND METHODS

Approximately 45 days prior to anticipated lambing date, 122 gestating ewes (75.8 ± 7.6 kg initial weight) were allotted randomly to one of two dietary treatments (4 pens per treatment). Ewes were fed diets formulated to contain either 4.6% (high fat; HF) or 1.9% (low fat; LF) dietary fat. Diets were fed via a self-feeder as a total mixed ration and were calculated to be isocaloric and isonitrogenous. In addition to alfalfa hay, rolled safflower seeds (32% fat; 80% linoleic acid) were supplemented in HF, while solvent extracted safflower meal was used as protein source in

LF supplement. Energy was balanced in LF with corn (Tables 1 and 2). All pens were offered same amounts of feed throughout trial. Ewes were allowed free choice access to trace mineralized salt. At the onset and conclusion of supplementation, ewes were weighed and body condition was scored using a five point scoring system (1 = emaciated, 5 = obese). Upon lambing, birth weights were recorded. Lamb mortality was recorded and separated by cause: born dead, pneumonia, or starvation.

Data were analyzed with analysis of variance for a completely randomized design using the GLM procedures of SAS (SAS Inst., Inc, Cary, NC). The model contained effect of treatment. Pen served as experimental unit for all response variables. Means were separated by the method of least significant difference. Data for lambing (live and dead) were analyzed with square root transformation (Sokal and Rohlf, 1995). Means and standard errors of the means were squared for reporting.

Table 1. Diet composition (dry matter basis).

	Treatment	
Item	High fat	Low fat
Alfalfa hay, ground	81.6	78.3
Corn, dry rolled	5.5	14.0
Safflower meal	2.5	6.6
Molasses	0.4	1.1
Safflower seeds, rolled	10.0	—

Table 2. Diet nutrient analysis (dry matter basis)

	Treatment	
Item	High fat	Low fat
Dry matter, %	90.48	89.21
Organic matter, %	91.12	91.74
Crude protein, %	17.78	17.45
ME†, Mcal/kg	2.27	2.24
Ca, %	1.18	0.96
P, %	0.26	0.38

†Metabolizable energy; calculated

RESULTS

Ewes consumed an average of 2.64 kg dry matter daily. Initial and final body conditions of ewes were similar ($P > 0.43$); however, ewes fed LF gained more ($P = 0.05$) weight during the 45-day feeding period (Table 3). Birth weights of lambs (Table 4) were not different ($P = 0.47$). Although, not significant, lambs from HF dams appear to have numerically higher survivabilities ($P = 0.34$). More lambs from LF dams tended to die due to starvation than from HF dams ($P = 0.20$).

Table 3. Effect of safflower supplementation to gestating ewe on performance.

Item	Treatment HF	LF	SEM†	Probability
Weight, kg				
Initial	75.5	76.1	0.7	0.53
Final	92.2	95.1	1.0	0.09
Change	16.7	19.0	0.6	0.05
Body condition§				
Initial	3.31	3.37	0.05	0.43
Final	3.88	3.89	0.03	0.91
Change	0.57	0.52	0.03	0.25

†Standard error of the mean; n = 4.
‡Probability of a greater F statistic.
§1 = emaciated, 5 = obese.

Table 4. Effect of safflower supplementation to gestating ewes on lamb weight and mortality.

Item	Treatment HF	LF	SEM†	Probability‡
Birth weight, kg	6.0	5.7	0.4	0.47
	----------% of ewes----------			
Lambing percentage	165.45	149.41	0.16	0.31
	--------% of lambing---------			
Mortality	7.10	15.38	0.73	0.34
Born dead	3.14	3.29	1.22	0.98
Starvation	3.69	10.26	0.41	0.20
Pneumonia	0.00	1.65	0.29	0.14

†Standard error of the mean; n = 4.
‡Probability of a greater F statistic.

DISCUSSION

Studies in which rats were fed diets with high concentrations of linoleic acid resulted in increased BAT activity and increased overall thermogenesis (Schwartz et al., 1983; Nedergaard et al., 1983). Calves from heifers supplemented during gestation with high linoleic safflower were able to longer maintain body temperature when exposed to cold (Lammoglia et al., 1999b). Unlike rats, lambs and calves are born with only BAT (negligible amounts of WAT; Gemmel et al., 1972; Casteilla et al., 1987,1989) that morphologically changes to WAT beginning as early as 2 to 4 days after birth (Thompson and Jenkinson, 1969) and this process can conclude within 3 weeks (Casteilla et al., 1987). Rats have both white and brown adipose tissue at birth and maintain depots of BAT into adulthood. During cold stress in lambs, blood flow to brown adipose tissue deposits increases five to six fold (Alexander et al., 1973). These points demonstrate the importance of BAT in neonatal lambs and their dependence upon the tissue for survival during cold stress.

Slee et al. (1980) states that mortality rates on sheep farms tend to be underestimated because of the fact that typical survey data tends to be reported from the 'best managed farms.' Up to 50% of neonatal lamb death is caused by cold stress and what is termed 'undernutrition' or starvation. However, the paper further reviews that lambs classified as 'starved' may have died of hypothermia, which caused immobility and prevented suckling. Even deaths classified as 'born dead' may have occurred from acute hypothermia quickly after parturition. Less severe cold stress at birth can decrease the suckling drive, thereby decreasing nutrient intake at a time when energy expenditure is greatest (Slee et al., 1980). In this study, lambs from dams in HF had a mortality percentage of 7.11% while 15.38% of lambs from LF dams died. Numerically, more lambs from LF were born dead or died due to starvation and pneumonia than did in HF. The difference in starvation may indicate that hypothermia was more of a problem for lambs from LF dams.

The increase in thermogenesis from BAT may be due to the activation of the uncoupling protein-1 (UCP1), or thermogenin. Uncoupling protein is the vehicle for heat production from BAT. Uncoupling protein-1 uncouples oxidative phosphorylation in the mitochondria resulting in heat loss instead of ATP production. Uncoupling protein-1 is stimulated by both cold exposure and free fatty acids (Lowell and Flier, 1997). Upon cold exposure, the sympathetic nervous system stimulates lipolysis and released fatty acids then stimulate the action of UCP1 (Ganong, 1999). Supplementation with a high linoleic feedstuff may increase the BAT content of linoleic fatty acid, a major fuel for BAT thermogenesis (Lammoglia et al., 1999a), which may stimulate UCP1 to increase heat production.

Lambs are most susceptible to hypothermia from birth to five hours of age and again 12 to 36 hours after birth (Eales et al., 1982). Stott and Slee (1985) state "A viable lamb must, therefore, be vigorously homeothermic at birth and possess sufficient energy reserves." Therefore, methods imposed during fetal development to increase the thermogenic capacity and energy reserves of the lamb at the onset of parturition could decrease mortality due to cold stress in the first 36 hours after birth. The present study showed a tendency ($P = 0.34$) of lambs to have greater survivabilities when dams had been fed a high linoleic safflower during the last 45 days of gestation.

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Feedlot Performance, Carcass Composition and Muscle and Fat Conjugated Linoleic Acid Concentrations of Lambs Fed Diets Supplemented with High Linoleic Safflower

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ABSTRACT

The nature of the lipids found in meats can be influenced by the finishing rations used in livestock production. The effects on lamb back fat and loin muscle resulting from the supplementation of feeding rations with Morlin high linoleic safflower seed were investigated. Fifty weather lambs were randomly assigned to one of two different feeding treatments (5 pens per treatment). Both the control diet (CD) and the safflower supplemented diet (SSD) were 80 % concentrate and 20 % pelleted alfalfa, formulated to be isochloric and isonitrogenous. The SSD had an additional 6 % fat supplied by the safflower seed. Following a 48 day feeding period 2 lambs from each of the ten pens were slaughtered. After a 5 day chilling period the carcasses were evaluated for yield and quality factors. The back fat and the loin muscle were evaluated for fatty acid profile and for the quantity of conjugated linoleic acid (CLA) present. The average daily gain and the feeding efficiency of the SSD lambs were better than that of the CD lambs (0.29 vs. 0.25 kg/day) and (6.77 vs.7.95 kg feed/kg gain) respectively. The back fat thickness of the SSD lambs was greater than that of the CD (4.03 vs.3.03 mm). The *cis*-9, *trans*-11 CLA level of the fat extracted from the loin muscle was more than twice as high in the SSD lambs as that in the CD lambs (8491 vs. 3955 ppm).

Key words: High Linoleic Safflower, Conjugated Linoleic Acid, Lamb Feeding, Meat Quality, *Carthamus tinctorius* L

INTRODUCTION

Animal feeding studies are underway to develop "designer" meats and other animal products. Such an option is possible by feeding livestock diets supplemented with safflower whole seed or oil with a very high purity of linoleic fatty acid (more than 80 %) or very high purity of oleic fatty acid (over 80 %) and low in total saturated fatty acid (less than 6 %). Safflower varieties with oil high in purity of either linoleic fatty acid or oleic fatty acid have been developed at the MSU Eastern Agricultural Research Center, Sidney, Montana. These safflower varieties are under further development to also be high in protein content with reduced fiber. These safflower genetic improvements have resulted in safflower that has increased nutritional value for animal feeding.

Previous livestock studies with beef cattle have demonstrated the positive effects of feeding pregnant dams supplemental linoleic safflower fat during late gestation to increase cold tolerance in newborn calves and potentially increase calf survival (Lammoglia et al., 1999). Lammoglia, *et al.* also found that heifers receiving a linoleic safflower supplement prior to breeding time had higher fertility rates and rebred faster than did those not on safflower supplemented diets (Lammoglia et al., 2000). The objective of this study was to determine the affects of feeding diets high in linoleic acid rich oil

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(safflower seeds) to feedlot lambs on animal performance, carcass characteristics and conjugated linoleic acid (CLA) content of lamb muscle tissue.

MATERIALS AND METHODS

Suffolk x whiteface wethers (N=50) born in April and May at the Red Bluff Experimental Ranch grazed native range with their dams until weaned in September. After weaning, lambs were returned to range until late October when the feedlot trial was initiated.

Lambs were assigned to one of 10 feedlot pens (5 lambs per pen), based on lamb weight and fed either a safflower seed supplemented diet (5 pens) or a control diet (5 pens). The safflower supplemented diet was formulated to provide an additional 6% fat from safflower seeds. Safflower seed from the Morlin safflower variety (Bergman, et al., 2001), containing 37% oil with a fatty acid composition of 79.1% linoleic, 6.2% palmitic, 2.1% stearic and 10.3% oleic acid was utilized in this study. Diets were 80% concentrate, 20% pelleted alfalfa and were formulated, on a DM basis, to be isocaloric and isonitrogenous and to meet or exceed NRC (1976) requirements for Ca, P and other nutrients (Table 1). Barley and corn was rolled before mixing diets. Molasses was added to the diets to prevent ingredient sorting by lambs. Safflower seeds were coarsely cracked and mixed in treatment diet just prior to feeding. A commercial mineral mix was added to the diet, daily (1/2 oz per lamb per day). This trial consisted of a 48-day finishing period preceded by a 21-day step up period where the lambs were adjusted to their respective finishing diets. The finishing period was terminated when the estimated average weight of all lambs on trial was approximately 54 kg.

Lambs were given ad libitum access to water and offered feed twice daily at approximately 0600 and 1700 hours. Feed bunks were inspected prior to the 0600 feeding, and the amount offered was adjusted daily to insure ad libitum consumption. Feed refusals were removed from the bunks, weighed and recorded weekly. Random grab samples of the diets were taken throughout the trial. Feed samples were ground through a 1-mm screen and analyzed (Table 1) for DM, ether extract, and N (AOAC, 2000), ADF and NDF (Van Soest et al., 1991). Initial and final lamb weights (at the beginning and end of the finishing period) were taken after an overnight fast without food and water.

Following the 48-day finishing period, 20 wethers (2/pen and 10/treatment) were selected and transported to a local commercial slaughter facility. The two lambs within each pen weighing closest to the overall mean (120 pounds) were selected. Hot carcass weights were obtained on the day of slaughter. After a 5-d chill, carcass measurements taken included 1) longissimus muscle area,

Table 1. Composition of the control fed and safflower supplemented diets.

	Control	Safflower
Ingredient (%)		
Barley	56	62
Corn	15	
Soybean Meal	4	
Alfalfa Pellets	20	19
Cane Molasses	5	4
Safflower Seeds		15
Nutrient Composition (%, Dry matter basis)		
TDN[a]	83.4	83.0
Crude protein[b]	14.4	13.9
Ether extract[b]	2.5	7.3
Acid detergent fiber[b]	11.4	11.5
Neutral detergent fiber[b]	30.0	27.8
Organic matter[b]	95.6	95.8

[a] Calculated based on NRC tabular values of ingredients.
[b] Laboratory analysis

measured by exposing the longissimus muscle at the 12th rib; 2) subcutaneous fat thickness over the longissimus muscle at the 12th rib, measured at ¾ the lateral length from the chine bone; and 3) kidney fat weight, including the kidneys.

Loin muscle samples (12 cm from 13th rib) and back fat samples covering the longissimus were removed from the right side of each carcass at time of cutting and used for fatty acid analysis of lean and fat tissue, respectively. The loin and fat tissues were shrink wrapped and frozen at –40 degrees C until ready for analyses.

Cored samples from the partially thawed loin or fat tissue (approximately 2 g or 15 g respectively) were homogenized in chloroform/methanol using a Brinkman Polytron Homogenizer with PT generator according to the procedure of Bligh and Dyer (1959). The resulting fat in the chloroform extract was then stored at 4° C in sealed tubes. The chloroform from measured aliquots of the extract was removed using a nitrogen stream and the resulting fat was methylated using a base-catalyzed procedure recently reviewed by W. W. Christie (2001). The resulting fatty acid methyl esters, including CLA's, were then analyzed by gas-liquid chromatography (glc) using a Hewlett Packard 5890 GLC equipped with a flame ionization detector and an auto-sampler. The column used for the chromatographic separations was a Supelcowax-10 capillary column (60m x 0.32mm x 0.25um film thickness). Helium was used as the carrier gas. The column temperature was programmed: 50° C initially, increasing to 200° C at 20 degrees/min and then held for 60 minutes at this temperature. The various fatty acids were identified using standard samples from Nu-chek Prep. CLA concentrations were determined using the internal standard method (Ha et al., 1989) with heneicosanoic acid (C21:0) methyl ester being the internal standard.

Data were analyzed as a completely randomized design, using the General Linear Model procedure of SAS (1988) with pen as the experimental unit for feedlot data and animal the experimental unit for carcass data. Hot carcass weight was used as a covariate for analysis of carcass characteristics. Least squares means and the associated standard errors are reported.

RESULTS AND DISCUSSION

The term, conjugated linoleic acids (CLA's) is used to describe one or more positional and geometrical isomers with conjugated double bonds. CLA's are fatty acids with 18 carbons and two double bonds separated by one single bond. The double bonds are predominantly at 9 and 11, 10 and 12, or 11 and 13 carbon atoms with various combinations of *cis* and *trans* configuration at each double bond (Stanton et al 1997a). They were first identified in milk fat in the 1930's (Dann et al., 1935) and have subsequently been identified in dairy and meat products from ruminants (Chin et al., 1992; Lin et al., 1995). CLA's are present in lamb and beef and to a lesser degree in pork, chicken and turkey (Pariza and Ha, 1990a).

Although in small quantities, CLA's occur naturally in meat and milk from ruminant animals. They have been associated with a wide range of positive health benefits. Interest in CLA's began in 1979 with the discovery of an antimutagenic and anticarcinogenic substance in grilled ground beef (Pariza et al. 1979; Pariza and Hargraves, 1985; Ha et al., 1987). Since then, numerous studies have confirmed the anticarcinogenic activity of CLA's in both in-vivo and in-vitro models (Belury, 1995; Banni and Martin, 1998). Ip (1997) reported that even though CLA's are a minor component of the total fatty acid composition of foods, CLA's exhibit protective properties against cancer when included in the diet at very low levels (<1% in the diet). It has been demonstrated (Pariza and Ha, 1990b) that CLA's have unique and potent antioxidant activity, which appears to play a key role in the body's defense mechanism against cell membrane attack by oxygen radicals. Ha et al (1990) concluded that CLA's were more potent antioxidants than alpha-tocopherol (vitamin E). Other positive health benefits include the reduction in body fat accretion and altered nutrient partitioning, antidiabetic effects, a reduction in the development of arteriosclerosis, enhanced bone mineralization and modulation of the immune system (Belury, 1995; Banni and Martin, 1998; Houseknecht et al. 1998; Parodi, 1999).

In general, dietary fatty acids are hydrolyzed by rumen microorganisms to produce free fatty acids. CLA's are intermediary products in the biohydrogenation of linoleic acid ($C_{18:2}$) to stearic acid ($C_{18:0}$) (Kelly et al., 1998). However, it is estimated (Rule, 2000) that about 10% of dietary fatty acids escape rumen biohydrogenation. CLA's found in milk and meat are currently thought to originate from ruminal production and/or from endogenous production from rumen-derived products such as trans-11 octadecenoic acid (Kepler et al., 1966; Grinari and Bauman, 1999.

The effect of oil supplementation on milk composition in dairy cattle and goats and on animal performance in feedlot animals has been the subject of a number of recent studies. Canola oil or full fat rapeseed supplementation of diets fed to goats or dairy cows increased CLA's content in milk from 10.35 to 32.05 and 3.91 to 7.89 mg/g of lipid, respectively (Stanton et al. 1997b and Mir et al. 1999). Italian researchers (Vonghia, et al., 1997) have suggested that diets supplemented with safflower improved both feed efficiency and average daily gains in feedlot lambs. Also, meat from safflower fed lambs tended to have higher crude protein and lower fat content. However, information on the effects of dietary oil supplementation on CLA content of ruminant and in particular sheep muscle tissue is limited. Recent data from Canada (Mir et al., 2000) from a limited number of animals suggested that feeding safflower oil high in linoleic acid raised CLA levels in muscle tissues of lambs while reducing the percentage of other fatty acids that are considered unhealthy. The average CLA content of rib and leg muscle for control vs. safflower supplemented lambs was 76.6 vs. 178.6 mg/100g tissue, respectively.

Previous research on affects of oil supplementation in feedlot rations on lamb performance report varied results. In this study lambs fed the safflower diet had greater ($P = 0.04$) average daily gain (ADG) than weathers fed the control diet (Table 2). These results agree with Vonghia et al. (1997) who reported increased ADG of feedlot lambs, by supplementing them with safflower cake. Zinn (1989) increased ADG by supplementing cattle finishing diets with fat. However, Mir et al. (2000) did not see a difference in ADG when lambs were supplemented with safflower oil. Feed efficiency for wethers fed the safflower diet was approximately 1.0 kg of gain / kg of feed greater ($P = 0.02$) than control wethers, during the finishing period (Table 2). Vonghia et al. (1997) and Mir et al. (2000) increased efficiency of feedlot lambs by supplementing them with safflower products. Krehbiel et al. (1995) and Clary et al. (1993) found that tallow increased the gain to feed ratio of cattle in the finishing period. Furthermore, Zinn (1992) increased gain to feed ratios by supplementing yellow grease to cattle.

Table 2. Effect of safflower seed supplementation on feedlot performance and carcass characteristics in wether lambs.

Parameter	Control	Safflower	SE	P-value
Feedlot Performance				
Number of pens	5	5		
Final weight	54.70	54.66	0.89	0.97
Dry matter intake, kg	2.02	1.98	0.12	0.82
Daily gain, kg	0.25	0.29	0.01	0.04
Feed efficiency, kg feed/kg gain	7.95	6.77	0.31	0.03
Carcass Measurements				
Number of lambs	10	10		
Hot carcass wt, kg	27.50	26.42	0.47	0.12
Dressing percent[a], %	50.85	51.15	0.36	0.57
Fat thicknessa, mm	3.03	4.03	0.48	0.17
Kidney fat[a], kg	0.84	0.96	0.08	0.31
Longissimus muscle area[a], cm2	14.79	14.18	0.50	0.42

[a]Tabular values are least square means adjusted to constant hot carcass weight.

Table 3. Effect of safflower seed supplementation on weight (kg) of wholesale cuts.[a]

Item	Control	Safflower	SE	P-value
Number of lambs	10	10		
Leg	8.63	8.51	.09	.39
Loin	2.48	2.50	.04	.73
Rack	2.00	2.15	.06	.14
Shoulder	6.60	6.60	.11	.99
Other	6.32	6.35	.10	.80

[a]Tabular values are least square means adjusted to constant hot carcass weight.

Safflower supplementation in this study had no affect on dry matter (DM) intake (2.02 kg and 1.98 kg per day for control and safflower diets respectively; $P = 0.82$). This is in contrast to results presented by Clary et al. (1993), Zinn and Shen (1996) and Andrae et al. (2000), which suggest that DM intake will decrease with the addition of animal fat to finishing diets.

Our results showed wethers fed the safflower and control diets selected for slaughter did not differ in dressing percent ($P = 0.57$), longissimus muscle area ($P = 0.42$) or kidney fat weight ($P = 0.31$). Weights that were obtained for kidney fat, when converted to percent of carcass weight, were similar to the values that Vonghia et al. (1997) reported for lambs supplemented with safflower cake. Wethers fed safflower tended ($P = 0.17$) to have greater back fat thickness than wethers fed control diet. Krehbiel et al. (1995) also found a tendency for back fat thickness to increase with oil supplementation. Differences in the weight of wholesale cuts of meat from the control diet fed lambs vs. the safflower supplemented diet fed lambs was not significant, see Table 3.

Concentrations (ppm) of conjugated linoleic acids in lipids extracted from loin and fat tissue are shown in Table 4. Safflower supplemented lambs had approximately twice the level of the *cis*-9, *trans*-11 CLA (8491 ppm vs. 3955 ppm) and four times the level of the *trans*-10, *cis*-12 CLA (478 ppm vs. 95 ppm) in loin tissue than the control lambs. The differences in fat tissue were even more pronounced with over 2¼ times as much *cis*-9, *trans*-11 CLA (11313 ppm vs 4947 ppm) and over 6 times as much *trans*-10, *cis*-12 CLA (934 ppm vs. 150) in the safflower supplemented lambs as the control lambs. The CLA levels found in the lipid extracted from the loin tissue agreed well with the values reported by Mir (Mir, 2000) for rib tissue of lambs fed a diet supplemented with 6% linoleic safflower oil (supplemented 8410 ppm vs. control 3130 ppm). The values reported by Mir are for the total of the CLA isomers.

The fatty acid profiles of the lipids extracted from the loin meat samples from the safflower supplemented diet fed lambs varied less that 1% from the control diet fed lambs except for oleic and linoleic levels (Table 5). In the safflower supplemented diet the meat lipid linoleic fatty acid level was over 2.6 % higher and the oleic fatty acid level was 2.3 % lower than in the meat lipids control diet fed

Table 4. CLA concentrations (ppm) in extracted fat from loin mean and fat tissue.

Item	Control	Safflower	SE	P-value
Number of Lambs	10	10		
Fat extracted from loin tissue				
cis-9, *trans*-11 CLA (ppm)*	3955	8491	648	.0001
trans-10, *cis*-12 CLA (ppm)	95	478	35	.0001
Fat extracted from fat tissue				
cis-9, *trans*-11 CLA (ppm)*	4947	11313	912	.0001
trans-10, *cis*-12 CLA (ppm)	150	934	57	.0001

*The ppm reported also includes the *trans*-9, *cis*-11 CLA isomer which was not separated under the chromatographic conditions used.

Table 5. Effect of safflower seed supplementation on fatty acid profile of loin sample extracts (relative %).

Item	Control	Safflower	SE	P-value
Number of lambs)	10	10		
Saturated fatty acids				
Myristic (C14:0)	2.14	2.24	.10	.51
Pentadecanoic (C15:0)	0.30	0.32	.02	.41
Palmitic (C16:0)	23.3	22.5	.36	.13
Margaric (C17:0)	1.09	1.06	.04	.60
Stearic (C18:0)	13.2	13.6	.38	.44
Arachidic (C20:0)	0.11	0.13	.02	.33
Unsaturated fatty acids				
Oleic (C18:1)	42.9	40.6	.48	.004
Linoleic (C18:2)	5.49	8.11	.31	.0001
Lanoline (C18:3)	.82	.56	.05	.0009

Table 6. Effect of safflower seed supplementation on fatty acid profile of back fat sample extracts (relative %).

Item	Control	Safflower	SE	P-value
Number of lambs	10	10		
Saturated fatty acids				
Myristic (C14:0)	2.25	2.20	.12	.76
Pentadecanoic (C17:0)	0.73	0.58	.02	.0001
Palmitic (C16:0)	21.2	19.4	.58	.04
Margaric (C17:0)	2.69	1.94	.09	.0001
Stearic (C18:0)	15.3	16.8	.52	.049
Arachidic (C20:0)	0.14	0.14	.01	1.00
Unsaturated fatty acids				
Oleic (C18:1)	39.2	40.7	.53	.07
Linoleic (C18:2)	3.43	6.08	.26	.0001
Linolenic (C18:3)	0.57	0.47	.06	.24

lambs. Higher linoleic fatty acid and reduced levels of oleic fatty acid in the safflower supplemented diet fed lambs were also reported by Mir in their feeding trial (Mir, 2000).

The fatty acid profiles of the lipids extracted from the back fat samples from the safflower supplemented diet fed lambs and the control diet fed lambs (Table 6) showed the same general trends as the fatty acids extracted from the loin meat samples, with the exception of the oleic levels. In the loin meat extracts the oleic fatty acid decreased with safflower supplementation (42.9 % vs. 40.6 %) while in the back fat lipid extracts the oleic fatty acid level was not significantly different (39.2 % vs. 40.2 %) at the .05 level.

The results of this study suggest that the inclusion of high linoleic safflower seed in the finishing ration of livestock can have positive effects on meat production and quality. These include improvements in the feeding efficiency and average daily gain of livestock. Also the meat produced will have nutritional benefits as well as extended shelf life because of the potent antioxidant activity of CLA's.

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Citrate Carrier and Lipogenic Enzyme Activities in Liver Subcellular Fractions of Safflower Oil-Fed Animals

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ABSTRACT

The tricarboxylate (citrate) carrier plays an important role in hepatic lipogenesis by exporting acetyl-CoA from the mitochondrial matrix to the cytosol. Here, acetyl-CoA is the primer for the *de novo* fatty acid and cholesterol synthesis. In this study the effect of a fat (high linoleic (n-6) safflower oil [S.O.]) enriched diet both on lipogenic enzymes and on tricarboxylate carrier activities was investigated. Citrate transport was strongly reduced in liver mitochondria isolated from S.O.-treated rats. Kinetic analysis of the carrier activity showed that Vmax was the only parameter decreased, whereas Km was almost unaffected. Apparently, no variation in the overall fluidity of the mitochondrial membrane of S.O.-treated rats occurred in spite of some changes in membrane lipid composition and in the degree of fatty acid unsaturation. Simultaneously, a decrease of lipogenic enzyme activities, i.e. acetyl-CoA carboxylase and fatty acid synthetase, was also observed following S.O. administration. The S.O. effect on hepatic fatty acid synthesis as well as on lipid composition of some lamb tissues was also investigated. In treated lamb tissues an increase in the polyunsaturated fatty acid (PUFA) level together with a decrease in saturated fatty acid and cholesterol content were observed.

Key words: liver mitochandria, oil-fed animals, dietary fat, *Carthamus tinctorius* L.

INTRODUCTION

The type of dietary fat is an important determinant of plasma lipid concentration in both man and experimental animals (Beynen, 1986). It has been shown that at molecular level the dietary polyunsaturated fatty acids suppress the expression of liver lipogenic enzymes and their synthesis (Clarke and Jump, 1994). The decrease in the level of acetyl-CoA carboxylase and of fatty acid synthetase causes a consequent reduction of the hepatic fatty acid synthesis [2]. Moreover dietary lipids can influence the activities of many membrane-associated enzymes by varying fatty acid composition of cell membranes and then their fluidity (Gazzoti and Peterson, 1977). The tricarboxylate carrier, an integral protein of the inner mitochondrial membrane, plays an important role in the hepatic lipogenesis and cholesterologenesis because it catalyzes the transport of acetyl-CoA, which is the primer for both the *de novo* fatty acid and cholesterol synthesis, from mitochondria to the cytosol.

Safflower oil is particularly rich in linoleic acid (18:2, ω-6), an essential PUFA found in plant seed, and it is effective in lowering low-density lipoprotein (LDL) cholesterol (Goodnight et al, 1982).

In this study, we report that the tricarboxylate transport activity is strongly reduced in liver mitochondria of rats fed with a diet supplemented with S.O. In treated rats a parallel decrease of lipogenic enzyme activities was observed. The effect of S.O. on hepatic fatty acid synthesis as well as on lipid composition of lamb tissues was also studied.

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MATERIALS AND METHODS

Male Wistar rats were divided into two groups. Animal of the control group received a basal diet. This diet was enriched with 15% (w/w) safflower oil and, homogenously mixed, was administered to a second group of animals. The treatment lasted for 4 weeks. No significant difference in the food intake between the two groups was observed during treatment. The tricarboxylate carrier activity was assayed in freshly prepared rat liver mitochondria by the inhibitor stop method (Zara and Gnoni, 1995).

In the treatment of lambs, the standard diet was supplemented with 5% (w/w) safflower oil and was administered to the animals for 6 weeks. A blood sample of lambs was immediately taken after killing the animal. Liver and muscle (Longissimus dorsi) samples were kept at –40°C until the assay. Total lipids were extracted and analyzed by high performance liquid chromatography (HPLC), while fatty acid composition was investigated by gas-liquid chromatography (GLC) (Muci et al, 1992).

Mitocondrial, microsomal and cytosolic fractions were obtained by differential centrifugation of liver homogenate. The cytosolic acetyl-CoA carboxylase and fatty acid synthetase activities were assayed according to (Zara and Gnoni, 1995).

RESULTS

GLC analysis of safflower oil showed the following fatty acid % composition: $C_{16:0}$ 7.9; $C_{18:0}$ 2.7; $C_{18:1}$ 17.8; $C_{18:2}$ 68.9; $C_{18:3}$ 0.7; $C_{20:4}$ 0.5; $C_{20:5}$ 1.4; $C_{22:6}$ 0.8.

The time course (Fig.1) of the citrate uptake by rat liver mitochondria shows that the transport was significantly reduced in the safflower oil-fed animals. In the first part of citrate uptake, i.e. during the linear range of this process (15-20 s), the decrease of tricarboxylate transport activity was reproducibly found to be around 50%.

Experiments were then carried out to study the effect of S.O. on lipogenesis in rat liver cytosol. The activity of acetyl-CoA carboxylase, which catalyzes the first enzymatic step of fatty acid synthesis, was reduced by about 40% following dietary PUFA treatment. A parallel decrease of fatty acid synthetase activity was also found in treated animals (data not shown). These results clearly indicate a coordinated modulation of citrate carrier and of lipogenic enzymes by ω-6 supplemented diet.

The kinetic parameters of the carrier protein were measured in mitochondria of control and treated rats. The rate of citrate/malate exchange was studied at different external [^{14}C]citrate concentrations. Data obtained in this experiment were plotted by Lineweaver and Burk method as in Fig.2. Practically no change in Km values (0.11 ± 0.01 mM vs 0.12 ± 0.02 mM) was observed. This indicates that the affinity of the tricarboxylate carrier for its substrate was unchanged following S.O. administration to rats. The decrease in Vmax values in safflower oil-treated animals was reproducibly found to be around 30%.

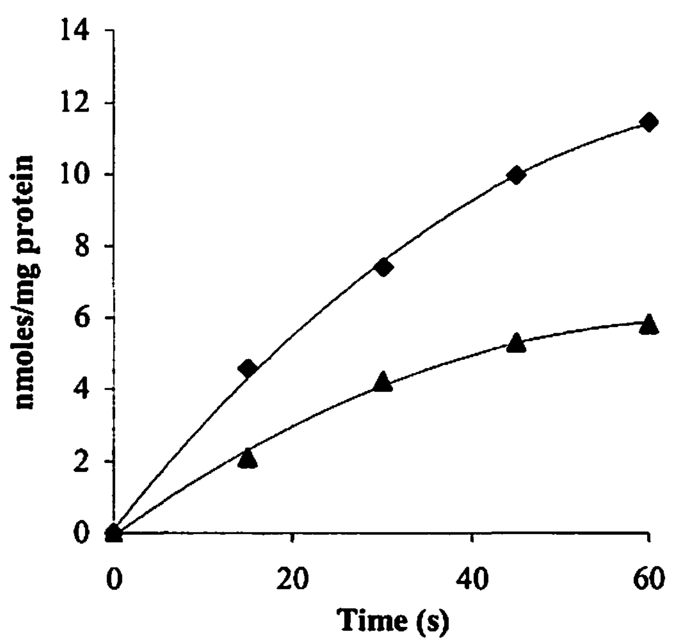

Fig 1. Transport of citrate into rat liver mitochondria

Liver mitochondria freshly isolated from rats fed with basal diet (♦), or with ω-6-supplemented diet (▲) were first loaded with malate and then incubated for 3 min at 9°C in 1 ml of reaction mixture containing 100 mM KCl, 20 mM Hepes, 1 mM EGTA, pH 7.0 and 2 μg rotenone. The citrate/malate exchange was started by the addition of 0.5 mM

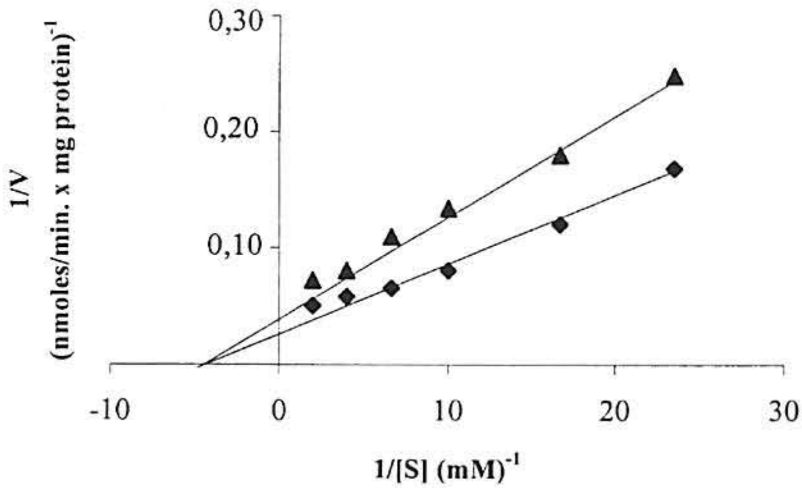

Fig 2. Lineweaver and Burk plot of citrate/malate exchange catalyzed by freshly isolated rat liver mitochondria

[^{14}C]citrate, ranging from 0.04 mM to 0.5 mM, was added to malate loaded liver mitochondria from control (◆) and treated rats (▲). The temperature was 9EC and the citrate/malate exchange was stopped 15 s after the [^{14}C]citrate addition by 12.5 mM 1,2,3-BTA.

It is well known that a PUFA enriched diet, by modifying the lipid composition of the membranes, can influence their fluidity and the activities of many membrane-associated proteins (Gazzoti and Peterson, 1977). Experiments were then carried out to investigate the physical state of the inner mitochondrial membrane. The temperature dependence of the citrate/malate exchange in liver mitochondria from control and S.O.-treated rats show a similar break point, i.e. at 16°C, for both mitochondrial preparations. This indicates that the diet does not appreciably modify the fluidity of the mitochondrial membrane. Thereafter, the effect of S.O.-enriched diet on the phospholipid composition of mitochondrial membranes was investigated. The results obtained indicated that after a four weeks treatment of rats with a PUFA-enriched diet there is no significant change in the phospholipid composition of mitochondrial membranes (data not shown).

Interestingly, in mitochondria from S.O.-treated rats, a noticeable increase (+61%) in the level of cholesterol was found while total phospholipids increased to a lesser extent (+ 19%). Consequently, the cholesterol/phospholipid molar ratio increased by about 35% in the mitochondrial membranes from S.O.-treated rats. The fatty acid composition analysis demonstrated that following dietary PUFA

Table 1. Effect of safflower oil-supplemented diet on fatty acid composition of lamb serum, liver and muscle lipids.

	Fatty acid composition (%)					
Fatty acid	Serum		Liver		Muscle	
	A	B	A	B	A	B
C14:0	6.1	3.9	0.8	1.0	2.2	2.8
C16:0	17.1	15.9	12.6	10.7	22.4	17.4
C16:1 (n-7)	4.3	3.6	2.8	2.1	3.7	3.0
C18:0	18.1	14.6	21.3	16.9	14.0	10.1
C18:1 (n-7)	29.9	30.9	37.9	39.6	40.1	44.6
C18:2 (n-6)	8.0	15.2	11.1	14.5	9.9	18.2
C18:3 (n-3)	1.1	0.9	1.3	0.6	0.6	0.3
C20:4 (n-6)	4.5	5.5	5.5	7.5	3.9	1.9
C20:5 (n-3)	1.9	2.4	0.5	0.5	0.4	0.6
C22:4 (n-6)	2.8	2.2	1.8	2.0	0.6	0.4
C22:5 (n-3)	1.2	2.5	1.3	1.3	0.7	0.8
C22:6 (n-3)	3.3	2.2	1.5	2.6	0.5	0.4
Total saturated	41.3	33.9	34.7	28.6	38.6	29.6
Total unsaturated	57.0	65.4	63.7	70.7	60.4	69.8
Total monoenes	34.2	34.5	40.7	41.7	43.7	47.8
Total polyenes	22.8	30.9	23.0	29.0	20.0	22.2

Results are expressed as area percentages
Control (A) and 5% safflower oil-fed (B) lambs.

Table 2. Effect of safflower oil on the de novo fatty acid synthesis in lamb liver cytosol.

	De novo fatty acid synthesis	
Animal	Acetyl-CoA carboxylase (nmoles $NaH^{14}CO_3$ inc./min x mg protein)	Fatty acid synthetase (nmoles malonyl CoA 2-^{14}C inc./min x mg protein)
Control	0.20 ± 0.03	0.13 ± 0.01
Safflower oil	0.13 ± 0.01	0.10 ± 0.01

Data are the means of 6 experiments ± S.D.

treatment of rats, unsaturated fatty acids and in particular linoleic acid strongly increased in mitochondrial membranes whereas, among saturated fatty acids, palmitic and, to a lesser extent, stearic acid significantly decreased. In mitochondria of treated animals, therefore, a decrement in the total saturated/total unsaturated fatty acid ratio of about 40% was observed (data not shown).

The study of the effect of S.O. administration on tissue lipid composition has been subsequently extended to research on lambs. Table 1 shows that $C_{18:2}$ level remarkably increases in serum, liver and muscle, reaching values almost double, with respect to control, in serum and muscle of treated lambs. These increases probably reflect the high amount of linoleic acid present in the experimental diet. Altogether the amount of total unsaturated fatty acids increases in the serum as well as in liver and muscle of treated lambs. By contrast, the main saturated fatty acids, as palmitic (C16:0) and stearic (C18:0) acid, which are abundant in the triacylglycerol fraction of lipids, are in all the cases significantly reduced in the S.O.-fed lambs.

In mammals, liver is the main site where fatty acid synthesis occurs. In the cell cytosol, de novo fatty acid synthesis catalyzed by acetyl-CoA carboxylase and fatty acid synthetase, which function in sequence, lead mainly to palmitic acid formation. The activity of acetyl-CoA carboxylase is strongly inhibited in liver cytosol of S.O.-fed lambs. Similar behaviour is shown by fatty acid synthetase (Table 2).

In the cell, the de novo synthesized palmitic acid is then elongated and/or desaturated, if necessary, by the microsomal and mitochondrial fraction. Table 3 shows that both microsomal and mitochondrial fatty acid chain elongation systems seem to be almost unaffected by S.O. feeding to the lambs.

Table 3. Effect of safflower oil on microsomal and mitochondrial fatty acid chain elongation in lamb liver.

	Fatty acid chain elongation	
Animal	Microsomes (nmoles malonyl-CoA 2-^{14}C inc./min x mg protein)	Mitochondria (nmoles acetyl-CoA 1-^{14}C inc./min x mg protein)
Control	0.22 ± 0.02	0.57 ± 0.04
Safflower oil	0.24 ± 0.03	0.62 ± 0.05

Data are the means of 5 experiments ± S.D.

DISCUSSION

The results reported in this paper show that diet composition influences the activity of the tricarboxylate carrier in rat liver mitochondria. In fact the activity of this transporter is noticeably inhibited by ω-6 PUFA administration to rats. Furthermore, the decrease of carrier activity is parallel with those of the cytosolic enzymes involved in the lipogenic pathway. All these findings indicate that the observed metabolic changes occurring as a consequence of the nutritional treatment of the animals are strictly integrated. Moreover the kinetic analysis of the tricarboxylate carrier activity revealed that Vmax was the only parameter influenced, whereas Km was almost unaffected.

In the case of an integral membrane protein, such as citrate carrier, an alteration of its function could also depend on a change of physico-chemical properties of the lipid bilayer in which the protein is inserted. Our results indicate (data not shown) that the overall membrane fluidity of inner mitochondrial membrane does not show any appreciable variation in spite of changes in cholesterol and phospholipid level and in their ratio as well as in the degree of fatty acid unsaturation. It can be hypothesized that, analogously to that found for lipogenic enzymes (Clarke and Jump, 1994), the decreased activity of citrate carrier could be ascribed to a reduced amount of the carrier protein occurring following S.O. administration. Further studies are needed to clarify this point.

As regarding safflower-oil treated lambs, the results obtained show that in the treated animals the following main changes occur: i) decrease in cholesterol and triacylglycerol content in serum, muscle and liver, ii) decrease in these tissues of the level of saturated fatty acids with a concomitant increase in that of unsaturated ones, iii) inhibition of the enzymatic activities of the de novo fatty acid synthesis, i.e. acetyl-CoA carboxylase and fatty acid synthetase in lamb liver cytoplasm. The latter observation could explain, at least in part, the reduced amount of saturated fatty acid observed in liver and in other tissues of S.O.-treated lambs (see Table 1).

The changes in the tissue pattern of polyunsaturated fatty acids following safflower oil administration are difficult to explain, since in lambs hydrogenation of PUFA occurs in the rumen. However it is worth underlining that this hydrogenation, even if extensive, is not complete (Moore and Christie, 1984). Moreover, with ruminant species it may occur that, when large quantities of unsaturated fats are fed, as could be the case of our experimental conditions, the hydrogenation capacity of the rumen is exceeded (Andrews and Lewis, 1970). This would result in a certain amount of unsaturated fatty acids arriving at the absorptive sites within the intestine.

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Immature Safflower Forage as a Feed for Ewes

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ABSTRACT

An *in situ* study compared mature, frost-damaged safflower to full-bloom safflower and mid-bloom alfalfa-grass hay, with the full-bloom safflower and alfalfa-grass hay also used in a ewe (n=40) feeding study. Feed refusals were higher ($P < 0.05$) for ewes fed the safflower, but feed conversion efficiency was improved ($P < 0.05$) for the safflower-fed sheep. Ewes were bred shortly after the 9-wk feeding trial and the proportion of ewes lambing was higher ($P < 0.05$) in the safflower-fed ewes. Sheep were able to utilize the safflower forage as thorough chewing of spines likely prevented mouth ulceration and the ewes selectively consumed the most nutrient-dense parts of the forage.

Key words: forage as feed, ewes, *Carthamus tinctorius* L.

INTRODUCTION

Safflower is an oilseed known for a high tolerance to drought and salinity (Dajue and Mündel 1996), with cultivation in North America centred in California and Arizona (Smith 1996). Safflower is also grown in Montana, North Dakota and the southern Canadian prairies, but cultivation in northern regions with short frost-free periods, has remained limited due to the lack of a salvage market should the seed crop fail to mature or prove otherwise unsuitable for crushing.

Although the plant has numerous sharp spines, anecdotal reports exist of sheep relishing safflower stubble (Knowles and Miller 1965). In Australia, stands of young, succulent safflower have been grazed by cattle and sheep (Jackson and Berthelsen 1986). However, reports of the feeding value of safflower forage are limited to one study published 60 years ago (Scharrer and Schreiber 1940).

As safflower seed currently retails for \$0.35 kg^{-1}, using safflower as forage would only be practical when the seed could be predicted to be of inferior quality, either due to frost damage or insufficient heat units for maturity. Accordingly, the objectives of this study were: (1) to determine the feeding value for dry ewes of safflower forage harvested at a stage (full-bloom) when crop failure can be predicted; (2) to determine the level of ewe mouth irritation/ulceration caused by consuming safflower with fully-developed spines; (3) to determine the potential utilization of fully mature frost-damaged safflower forage as a feed for ewes.

MATERIALS AND METHODS

All animals in this study were cared for according to the standards set by the Canadian Council on Animal Care (1993).

Forage Preparation

A commercial-scale, 1.6 ha, field of Saffire safflower 75 km S.E. of Lethbridge, AB was swathed after full bloom was reached on the main stems and baled. A 0.2 ha safflower (multiple varieties) research field in Lethbridge AB was swathed and baled when fully mature and after a killing frost.

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Table 1. Feed analysis (%) of alfalfa-grass hay, immature (full-bloom) safflower forage, mature safflower forage and feed refusals from ewes receiving alfalfa-grass hay or full-bloom safflower.

Feed	Dry matter	Crude Protein	Crude Fat	ADF	NDF	ADIN[z]
Alfalfa-grass hay[y]	90.5	23.6	1.3	29.1	39.2	5.8
Full-bloom safflower[y]	90.1	9.7	1.6	23.3	32.2	3.9
Mature safflower[y]	90.9	13.1	13.1	38.9	50.1	8.0
Feed refusals						
Alfalfa-grass hay	84.9	20.3	NE	36.3	56.8	6.9
Full-bloom safflower	90.5	4.4	NEx	33.3	41.6	5.1

[z] Acid detergent insoluble nitrogen, ADIN.
[y] All forage was harvested to within 8 cm of ground level.
[x] NE, not evaluated.

Both safflower forages were cut to within 8 cm of ground level. A mixed stand of alfalfa and brome grass was swathed when the alfalfa was in mid-bloom and baled. Before use *in situ*, the safflower forages and alfalfa-grass hay were ground to pass through a 2 mm screen. The full-bloom safflower forage and the alfalfa-grass hay were also used in a ewe feeding trial after being coarsely chopped to a length of 4 to 6 cm in a grinder-mixer (New Holland model 359, New Holland PA).

Feed samples were collected each time a new batch of safflower forage or hay was chopped in the grinder-mixer and were later pooled for proximate analyses (Table 1).

Individual Feeding Study

Forty mature ewes (age 2-4 yr, weight 72.1 $\pm$ 3.5 kg) of Suffolk, Dorset and Rambouillet breeding were weighed, condition scored and balanced by breed, parity and weight between alfalfa-grass hay and full-bloom safflower treatments. Ewes were housed in individual pens with access to water at all times and were allowed one week to adapt to experimental diets from a pre-study diet of alfalfa:straw cubes (70:30, 13% CP). Fresh feed was offered to appetite and orts collected and weighed on a daily basis, with samples of orts saved and pooled for subsequent analysis. Ewes were weighed on a weekly basis over the 9 weeks of feeding. At the end of the feeding period, condition score was measured and ewes were checked for mouth abscesses/irritation. Ewes were then turned in with rams for breeding, with lambing occurring during May and June. All ewes received approximately 3.5 kg d^{-1} of the alfalfa-grass hay diet during breeding and gestation, with 500 g day^{-1} barley added to the diet for the last 6 wks before lambing. The lambing date, prolificacy of the ewes at lambing and the proportion of ewes lambing were noted.

Chemical Analyses

Forage samples were dried at 105E for 24 h to determine DM and ashed in a muffle furnace at 500E C for 5 h to determine OM. Prior to analyses for NDF and N, forage was dried at 55E C for 48 h. Dried forage was ground through a 1 mm screen for analysis of NDF and ground for 3 min in a Wig-L-Bug[7] Amalgamator (Crescent Dental Mfg. Co., Lyons IL) prior to N analysis in a Carlo Erba[7] NA 1500 Carbon-Nitrogen elemental analyser (Carlo Erba Srumentazione, Rodano, Milan, Italy). The procedure of Van Soest et al. (1991) was used to determine NDF. Crude fat content of the forages was determined by ether extraction (method 920.39, Association of Official Analytical Chemists (AOAC) 1990). Acid detergent insoluble nitrogen (ADIN) was determined by Kjeldahl analysis of ADF residues (method 984.13, AOAC 1990).

RESULTS AND DISCUSSION

Individual Ewe Feeding Study

Although sheep will graze vegetative safflower forage (Knowles and Miller 1965), pre-bloom safflower is generally not used as forage in order to preserve the future yield and quality of the safflower seed. However, by the date the safflower reaches full bloom, the safflower grower is usually able to predict the quality of the safflower seed and target low-quality crops for use as forage. To our knowledge, this is the first study to address the feeding value of safflower forage past the vegetative stage.

Ewes did not differ across treatments for initial weight and condition score (Table 2). Likewise, there were no differences noted between the treatments in final weight or average daily gain, although both tended ($P < 0.10$) to be higher for the ewes receiving full-bloom safflower forage. Feed intake did not differ between treatments, but a higher ($P < 0.05$) proportion of the safflower forage (3.6%) as compared to the alfalfa hay (2%) was not eaten/rejected by the ewes. In analysis of orts (Table 1), the refused safflower had less than one half the CP of the initial feed and as expected both safflower and alfalfa orts were higher in fibre and acid detergent insoluble nitrogen (ADIN) than the original feeds. Safflower orts were almost exclusively coarse, fibrous stems. Safflower spines were readily consumed by the ewes and were not present in the orts.

Sheep are more selective foragers than cattle (Boever et al. 1990), using their lips and teeth to choose the choicest feed. Accordingly, the ewes consumed the most nutritious parts of the safflower and refused the fibrous stems. Feed conversion efficiency was improved ($P < 0.05$) for ewes receiving safflower as compared to alfalfa-grass hay diets. The improved feed conversion efficiency is likely due to a combination of the marginally higher energy content (2.97 Mcal DE/ kg of the safflower compared to 2.86 Mcal DE/kg of alfalfa-grass hay) and the higher degree of dietary selection/sorting by the ewes receiving the safflower as compared to the alfalfa diet.

The acceptance of full-bloom safflower forage by the ewes in this study would confirm the observations of Knowles and Miller (1965) who reported the preference of sheep for safflower stubble. The rams in the study of Scharrer and Schreiber (1940) readily consumed fresh safflower and safflower silage, the silage being described as "excellent in quality". In India, sheep are commonly grazed on safflower aftermath (Smith 1996), which may be as much due to a limited availability of feed resources as to a high palatability of the safflower forage for sheep.

After receiving safflower forage for 9 weeks (1 week diet adaptation, 8 week feeding period), no abscesses or other irritations were noted in the mouths of any of the ewes, although the full-bloom safflower had fully-developed spines. The rams of Scharrer and Schreiber (1940) were not affected by spines as the fresh safflower was fed prior to maximal spine development, while the ensiling process totally eliminated the presence of spines. Sheep are known for their ability to chew their feed more thoroughly than cattle (Boever et al. 1990). The thorough chewing of the safflower likely limited the possibility of safflower spines causing damage to the mouth, rumen wall or other parts of the digestive system. Growth performance of animals suffering from ulceration of the digestive system would be expected to suffer. However, the ewes receiving safflower forage showed consistent weight gains after one week of adaptation to the diet which did not differ ($P > 0.05$) on a weekly basis from the average gain over the 8 week feeding period (Table 2).

Ewe Fertility

At a latitude of 49E 42' N, the location of the present study, December/January breeding of the ewes would have coincided with the end of the normal breeding season, as peak ewe fertility would have been expected in October and November (Stanford et al. 1998). Lambing rate of healthy mature ewes after breeding during peak ewe fertility generally exceeds 90%. Consequently, the 80% lambing rate of alfalfa-treatment ewes (Table 2) may be attributable to the onset of seasonal anestrus in a proportion of the ewes and was in accordance with typical May/June lambing rates of ewes for this flock (K. Stanford, unpublished data).

In contrast to alfalfa-fed ewes, the proportion of ewes lambing approached 90% for safflower-treatment ewes ($P < 0.05$), although there was no difference between the treatments in

Table 2. Ewe weight gain, condition score, feed intake, feed conversion efficiency and lambing data for the alfalfa-grass hay and full-bloom safflower dietary treatments in a 9-wk feeding trial.

Ewe parameter	Alfalfa-grass hay (n=20)	Full-bloom safflower (n=20)	SEM
Initial weight (kg)	71.3	72.8	2.0
Final weight (kg)	78.7	83	2.1
Average daily gain (g d^{-1})	103	125	10.0
Initial condition score[z]	2.7	3.0	0.1
Final condition score	3.1	3.3	0.1
Feed offered (kg d^{-1})[y]	2.2[a]	2.4[b]	0.1
Feed intake (kg d^{-1})[y]	2.1	2.2	0.1
Feed refusals (% of feed offered)	2.0[a]	3.6[b]	0.3
Feed conversion efficiency (gain g feed kg^{-1})	45[a]	58[b]	4.0
Lambing date after breeding (d)	140.3	140.4	1.4
Prolificacy (lambs born ewe $lambing^{-1}$)	1.6	1.6	0.2
Proportion ewes lambing	80.1[a]	89.7[b]	

[z] Condition score on a 5 point scale with 1=emaciated and 5=obese.
[y] Feed adjusted to a dry matter basis.
[a,b] Values in a row with different superscripts differ (P 0.05).

lambing date or prolificacy. As weight gains during the feeding period and condition scores did not differ between the safflower and alfalfa-fed ewes, the increased lambing rate among the safflower-fed ewes was unexpected. Safflower flowers and leaves have been used in Chinese herbal medicine since ancient times as a treatment for female infertility and menstrual problems (Yang et al. 1993). As reported by Dajue and Mündel (1996), a tea made from safflower foliage has been used to prevent miscarriage and infertility of women in Afghanistan and India. As the ewes were bred shortly after the safflower feeding period, it is possible that safflower contains compounds which mimic or enhance the action of reproductive hormones. However the presence of reproductively beneficial compounds in safflower forage would have to be verified in future studies.

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Fatty Acid Composition of Milk from Mares Fed on a Diet Containing Safflower Oil*

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ABSTRACT

The therapeutic properties of mares' milk, important in the treatment of some illnesses, are partly due to its content of polyunsaturated acids. In order to increase this content, two groups of suckling TPR (Tiro Pesante Rapido) mares were fed on two diets (composed of vetch and oat hay and complementary feeds) with equal fiber and protein content, containing different lipid supplements (4%); the first made up of animal fat (control), the second consisting of safflower oil. A total of 48 milk samples, taken from the 10^{th} to the 90^{th} day of suckling, were subjected to gas chromatography analysis to determine the acidic profile. When compared with the control, the diet containing safflower oil gave milk with a lower content of saturated fatty acids and richer in unsaturated fatty acids, particularly polyunsaturated and linoleic acid.

INTRODUCTION

It is quite evident that fats are important in the diet of livestock, and the importance of a high polyunsaturated fatty acid content is well known. Horses secrete bile salts continually, and for this reason would seem particularly able to tolerate a diet rich in fats, so much so that horses fed on high levels of fats have performed well in sporting events. However, the relation between a fat-rich diet and the quantity and quality of mares' milk is still not well understood (Jamsranjav and Rabinovich, 1974; Bontempo et al, 1994; Salimei et al, 1995; Hoffman et al, 1998; Mariani et al, 1998; Martuzzi et al, 1998; Bontempo et al, 2000). Safflower oil is a potential feed supplement for mares whose milk is destined for foals or, if required, for the pharmaceutical, cosmetic and food industries. Not a great deal is known about the relationship between the final products of the digestion of fats and milk secretion; even today the chemical composition of Murgese mares' milk is not well-known (Pinto et al, 2000), nor is that of the breeds which have adapted well over the years on Apulian farms, such as the Cavallo da Tiro Pesante Rapido (TPR). In order to orient horse-breeders towards new and alternative production, the Dipartimento di Produzione Animale of the University of Bari, in agreement with the Associazione Allevatori of Bari Province, decided to conduct research on mares' milk, and the present study is part of this. The aim in this first stage is to investigate the qualitative characteristics of milk from TPR mares, reared according to local practices. In order to understand the productive potential better, and to better identify feed requirements, the traditional breeders' feeding schedule was supplemented with complementary feed.

MATERIALS AND METHODS

The trial was carried out on 8 clinically healthy TPR mares, subdivided into two groups of four. Mares had not been milked previously, and were reared on the Nunziatella farm, in the countryside around Ginosa (TA). The two groups were homogeneous as regards to physical condition, weight (806

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kg ± 64) and age (8-15 years). After foaling, the mares received two diets with equal fiber and protein contents consisting of 16 kg of vetch and oat hay and 6.5 kg of a complementary feed formulated by us; one feed (control) contained no safflower oil, while the other feed was enriched with 4% safflower oil added at the preparation stage in the factory. The chemical and fatty acid compositions of the two supplements are shown in Tables 1 and 2. All mares were reared in a spacious paddock during the day, and stabled at night with foals on straw in single stalls containing a manger and drinking trough. Feed was given twice a day, at 8 a.m. and 6 p.m., until the end of the trial (90 days). Chemical analysis of the feeds was carried out following the methods proposed by the Commissione Valutazione Alimenti (A.S.P.A., 1980), while nutritional value was estimated according to the indications of the NRC (1989). After foaling and until the end of the trial, the mares' milk was collected every fifteen days by hand milking, in order to evaluate the qualitative parameters (Doreau and Boulot, 1989). The milk samples were refrigerated during transportation and fat separation carried out using the modified Moyonner method by centrifuge (AOAC, 1990). The methyl esters of the fatty acids were prepared with BF3-methyl alcohol at 12%, and analysed using a Chrompack gas chromatograph (model CP 9000) with a silica glass capillary column (length 50 m, internal diameter 0.25 mm, film thickness 0.25 µm), stationary phase in cyanopropyl, operating at temperature programmed from 124°C to 210°C. The data obtained were statistically evaluated using the GLM procedure (SAS, 1990). The statistical differences between the estimated mean values were evaluated using the "t" of Student.

$$Y_{ijk} = M + A_i + B_j + (AB)_{ij} + E_{ijk}$$

Y_{ijk} = experimental observation
M = general average
A_i = effect due to feed (i = 1, 2)
B_j = effect due to period (j = 1, …, 3)
E_{ijk} = residual error

Table 1. Chemical composition of the supplements (%).

	Feed	
	control	safflower oil
Moisture	16.34	15.81
Crude protein	14.17	14.29
Ether extract	2.58	8.29
Ash	4.23	4.29
Crude fiber	9.11	10.47
N-free extract	53.56	46.84
NDF	21.77	22.66
ADF	12.35	13.89
ADL	3.91	4.24
NDS	73.03	67.99
Hemicellulose	9.42	8.77
Cellulose	8.44	9.65
DE (MJ/kg DM)	9.01	9.34

Table 2. Fatty acid composition (% of total fat) of the supplements.

	Feed	
	control	safflower oil
$C_{6:0}$	0.02	0.01
$C_{8:0}$	0.83	0.04
$C_{10:0}$	0.69	0.07
$C_{12:0}$	0.39	0.12
$C_{14:0}$	0.29	0.17
$C_{16:0}$	13.14	11.58
$C_{18:0}$	1.98	3.10
$C_{22:0}$	0.28	0.36
$C_{16:1}$	0.87	0.24
$C_{18:1}$	25.46	19.28
$C_{18:2}$	48.91	62.53
$C_{18:3}$	7.14	2.50

RESULTS AND DISCUSSION

The addition of safflower oil to feed for suckling mares did not make the feed any less appetizing. The mares' milk was characterised by high proportions of two fatty acids, $C_{16:0}$ and $C_{18:2}$, each representing about 20% of the total fatty acids (Table 3). Use of safflower oil in the diet of mares altered milk fatty acid content compared to that of mares fed animal fat; indeed the average levels of acidic composition of the lipids showed a higher content of saturated fatty acids (P<0.01) in the control group than in the experimental group (62.74% vs 55.71%). The most important variations regarded the

Table 3. Fatty acid composition of milk (% of total fat) of mares fed supplements containing either animal fat or safflower oil.

	Feed		Period (days)			DSE
	control	safflower oil	10-30	30-60	60-90	(DF = 18)
No. samples	12	12	8	8	8	
$C_{6:0}$	0.77^{A}	0.58^{B}	0.81^{Aa}	0.65^{b}	0.55^{B}	0.119
$C_{8:0}$	6.43^{A}	4.91^{B}	6.76^{A}	5.68^{a}	4.55^{Bb}	1.063
$C_{10:0}$	12.71^{A}	10.19^{B}	13.40^{Aa}	11.28^{b}	9.67^{B}	1.724
$C_{12:0}$	11.71^{A}	8.99^{B}	11.32^{A}	10.66^{A}	9.07^{B}	0.909
$C_{14:0}$	9.41^{A}	8.32^{B}	8.58	9.12	8.90	0.650
$C_{16:0}$	20.28	20.64	18.74^{Bb}	20.96^{a}	21.68^{A}	1.917
$C_{18:0}$	1.01^{B}	1.56^{A}	1.24^{b}	1.09^{B}	1.52^{Aa}	0.263
$C_{22:0}$	0.41^{b}	0.52^{a}	0.40^{b}	0.46	0.55^{a}	0.121
Total saturated	62.74^{A}	55.71^{B}	61.27^{A}	59.91^{a}	56.50^{Bb}	3.113
$C_{16:1}$	3.63	3.67	3.20^{b}	4.10^{a}	3.66	0.663
$C_{18:1}$	9.39^{B}	11.58^{A}	10.06	10.70	10.70	0.814
$C_{18:2}$	19.96^{B}	23.95^{A}	19.19^{B}	21.25^{B}	25.43^{A}	2.094
$C_{18:3}$	4.27	5.08	6.30^{A}	4.04^{B}	3.71^{B}	1.409
Total unsaturated	37.26^{B}	44.28^{A}	38.73^{B}	40.09^{b}	43.50^{Aa}	3.113
Monounsaturated	13.03^{B}	15.25^{A}	13.27^{Bb}	14.79^{A}	14.36^{a}	0.920
Polyunsaturated	24.23^{B}	29.03^{A}	25.46^{B}	25.30^{B}	29.14^{A}	2.496
Unsaturated/saturated	0.60^{B}	0.80^{A}	0.65^{b}	0.69	0.78^{a}	0.095

A, B: P<01; a, b: P<05

percentage reduction of short-chain saturated fatty acids, from $C_{6:0}$ to $C_{14:0}$ ($P<0.01$), and the increase of $C_{18:1}$ and $C_{18:2}$ ($P<0.01$) among the unsaturated. Such values are in line with those found by Breckendridge and Kuksis (1967), Glass et al (1967), Jamsranjav and Grigor'eva (1973), Jamsranjav and Rabinovich (1974), Nakae et al (1976), Peltonen et al (1980), Jaworsky et al (1982), Mariani et al (1998). The proportion of unsaturated fatty acids was therefore definitely higher in the milk of the mares whose feed contained safflower oil ($P<0.01$) than in that of the control group. Such diet-induced modifications resulted in a more favorable ratio of unsaturated to saturated fatty acids for the group fed safflower oil than the group fed animal fat (0.80 vs 0.60; $P<0.01$).

Analysis of the acidic values from the three sampling periods clearly shows the reduction of short-chain fatty acids during the course of lactation, while the opposite seems to be true for $C_{16:0}$, $C_{18:0}$ and $C_{22:0}$. The percentage content of $C_{18:2}$ increased significantly ($P<0.01$) during the course of lactation, while $C_{18:3}$ was seen to decrease. Finally, in accordance with the findings of Intrieri and Minieri (1970), Antila et al (1971), Csapò-Kiss et al (1995), Salimei et al (1996), Mariani et al (1998), the total unsaturated fatty acids increased significantly ($P<0.05$ and $P<0.01$) as lactation proceeded (38.73% vs 40.09% vs 43.50%), and the same is true of monounsaturated and polyunsaturated ($P<0.05$ and $P<0.01$) fatty acids.

CONCLUSIONS

This research indicates that when concentrated feeds enriched with safflower oil are given to suckling mares milk is obtained which has a higher content of unsaturated fatty acids, especially polyunsaturated and particularly oleic and linoleic acid, compared with the milk obtained giving concentrated feeds enriched with animal fat to the mares. In this study a positive response was seen to the introduction of safflower oil for almost all the fatty acids tested, in contrast with results obtained by other authors using different lipid sources with a high level of unsaturation (Intrieri and Minieri, 1970; Antila et al, 1971; Salimei et al, 1996; Bontempo et al, 2000). We can therefore assert that safflower oil may be used successfully in the feed of suckling mares in order to increase the polyunsaturated fatty acid content of milk fat.

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Biotechnology

Inhibitors of Proteinases in Safflower (*Carthamus* L.) and Other *Compositae*

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Biotechnology

ABSTRACT

Various proteinaceous inhibitors (I) of trypsin (T) and chymotrypsin (C), which are typical digestive enzymes of insects, mammals and microorganisms, and subtilisin (S), a proteinase of *Sclerotinia sclerotiorum* and many other phytopathogenic fungi, were found in seeds and vegetative organs of species representing the main taxa of the *Compositae* using simple and effective methods. Inhibitors with relative molecular mass (M_r) ranging from 7450 to 7800 and combining activity towards two or three proteinases (T/C/SI) appeared to be the most common inhibitor type in the *Compositae* and are presumably involved in plant defense mechanisms. They were found in the majority of representatives of the subfamilies *Carduoideae* (genera *Carthamus*, *Centaurea*, *Cirsium*), *Cichorioideae* (*Lactuca*, *Taraxacum*) and *Asteroideae* (*Helianthus*, *Cosmos*). Trypsin inhibitors with M_r ranging from 1500 to 14750 were found mainly in the *Asteroideae*. Seeds of *Carthamus tinctorius* var. Goldtuft contained single T/C/SI components with isoelectric point (pI) about 7.0 and M_r 7555. All 25 studied cultivated accessions of *C. tinctorius* and representatives of species groups with 2n=24 (*C. oxyacanthus* and *C. palaestinus*), 2n=20 (*C. glaucus*) and 2n=44 (*C. lanatus*) contained the same inhibitor components. The *N*-terminal sequence of the peptide obtained by cleavage of the reactive site of the native inhibitor with subtilisin, DFR(C)DRVWVW, indicated that safflower T/C/SI belonged to the potato I inhibitor family. Species related to *Carthamus* in the genus *Centaurea* possessed T/C/SI with M_r near 7600 but differed in pI. Some other *Carduoideae* (*Cynara*, *Arctium*, *Cousinia* and *Saussurea* species) did not contain serine proteinase inhibitors in their seeds.

Key words: inhibitor, proteinase, subtilisin, safflower, pathogen, *Compositae*

INTRODUCTION

The seeds and vegetative parts of plants contain various proteinaceous inhibitors of insect, fungal, mammalian and endogenous proteinases. These inhibitors may be involved in plant defense mechanisms against harmful organisms and may also play regulatory roles during plant development (Shewry and Lucas, 1997). Furthermore, plant inhibitors are of interest in relation to host/parasite co-evolution (Konarev, 1996), as markers in studies of plant diversity and evolution (Konarev, 1982; Konarev et al., 1999a; 2001; Kollipara and Hymowitz, 1992) and as potential drugs with antiviral and other properties. Genes encoding potent and stable inhibitors can be transferred to other plants to improve their pest or fungal resistance (Ryan, 1990). Proteinase inhibitors (PI) are well studied, particularly in the families *Fabaceae*, *Poaceae* and *Solanaceae*. Some 12 families of inhibitors can be recognized based on their amino acid sequences and target proteinases (Shewry, 1999). Recently, several isoforms of trypsin/subtilisin inhibitors (T/SI) controlled by linked genes and a unique cyclic trypsin (TI) inhibitor of M_r 1500 were identified in sunflower (*Helianthus annuus* L.) seeds using new approaches combining identification of proteinase inhibitors after isoelectric focusing of proteins with protein purification by chromatography (Konarev et al., 1999a, 2000b; Luckett et al., 1999). The T/SI present in leaves and heads of sunflower were also found to inhibit extracellular subtilisin-like proteinases of the white rot fungus *Sclerotinia sclerotiorum*, an important pathogen of sunflower, and

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proteinases of other fungi, indicating a possible protective role (Konarev et al., 1999b). T/SI and TI were also identified in representatives of three subfamilies of *Compositae* including safflower (Konarev et al., 2000a).

In the present study we aimed to (i) determine the distribution, polymorphism and variability of proteinase inhibitors in cultivated and wild safflower (*Carthamus* L.) species, in other representatives of subfamily *Carduoideae* and in some species from other Compositae subfamilies, (ii) purify and characterize novel inhibitor forms and (iii) estimate the evolutionary relationships between inhibitors from safflower and those of other species. Special attention has been given to inhibitors of trypsin and chymotrypsin which are typical digestive enzymes of insects, mammals and fungi, and subtilisin, a proteinase of microorganisms.

MATERIALS AND METHODS

Seeds and Leaves

Seeds of various *Compositae* species were obtained from world collection of the Vavilov Institute of Plant Industry (VIR, St. Petersburg), the herbarium of the Komarov Botanical Institute (St. Petersburg), Long Ashton Research Station (Bristol, UK), "Herbeseed" (UK) and "Nickerson-Zwaan" (UK) or were collected by authors.

Safflower was represented by accessions (acc.) of species with 2n=24: *Carthamus tinctorius* L.: k-18 and k-21 (Afghanistan); k-266 (Czechoslovakia), k-92 and k-95 (Egypt); k-62, k-66, k-69 and k-72 (Ethiopia); k-404 and k-405 (Germany); k-506 and k-503 (Hungary); k-442 (Mexico); k-14 and k-569 (var. Spartak, Russia); k-410 (Sweden); k-11, k-11a, and k-120 (Tadzhikistan); var. Goldtuft (UK); k-4, k-8, k-26, and k-64 (Uzbekistan); *C. oxyacanthus* Bieb, k-169 and k-408 (India); *C. palaestinus* Eig, k-409 (Israel); 2n=20: *C. glaucus* Bieb, k-403 (Israel) and k-407 (USA); 2n=44: *C. lanatus* L., k-190 (Germany) and k-199 (Uzbekistan). Other *Carduoideae* included species of 8 genera: *Arctium tomenntosum* Mill. (5 acc.), *A. lappa* L. (2 acc.), *Carduus acanthoides* L., *C. crispus* L., *Centaurea cyanus* L. (3 acc.), *C. jacea* L., *C. scabiosa* L., *C. triumfettii* All., *Cirsium arvense* (L.) Scop. (2 acc.), *C. vulgare* (Savi) Ten., *Cousinia* Cass. (*C.badghysi* Kult., *C. microcarpa* Boiss., *C. olgae* Regel & Schmalh., *C. raddeana* C. Winkl., *C. shistoptera* Juz.), *Cynara scolymus* L. (k-3 and k-12), *Saussurea* DC. (*S. amara* (L.) DC., *S. parviflora* (Poir.)DC., *S. pulchella* Fish., *S. salicifolia* (L.)D.C.), *Serratula coronata* L. Other *Compositae* were represented by 17 species of 10 genera of subfamily *Cichorioidea* and 93 species of 47 genera of *Asteroideae*. Main taxa were specified according to K.Bremer (1996). Herbarium seed and leaf material collected after 1960 was used. Fresh leaves were stored at -20° C.

Proteins

Proteins were extracted with water (1:4 w/v) from seeds or leaves after milling and then separated by isoelectric focusing (IEF) in Servalyt Precotes gels pH 3-10 (Serva Electrophoresis, Germany). Proteinase inhibitors were detected by the gelatin replicas method (Konarev et al., 2000b). Single inhibitor components were purified by affinity chromatography, micropreparative IEF and reversed-phase (RP) HPLC (Konarev et al., 2000b). M_r was determined by electrospray mass spectroscopy and *N*-terminal sequences by automated Edman degradation.

RESULTS

Twenty-five accessions of cultivated safflower (*C. tinctorius*) originating from various parts of the world and wild *Carthamus* L. species, representing species groups with different chromosome numbers, had the same single inhibitor component active to trypsin, chymotrypsin and subtilisin (T/C/SI) with pI about 7.0 (Fig. 1, 1-13). Species taxonomically close to *Carthamus* in the genus *Centaurea* L. showed variation in inhibitors. Seeds of *Centaurea cyanus* and *C. triumfettii* possessed active T/SI components with pI 7.3 and higher. *C. jacea* and *C. scabiosa* had only weak SI with pI values about 5.5. All studied accessions of *C. cyanus* (from the St. Petersburg region, herbarium and "Herbeseed") had the same single T/SI band with pI near 9.0. Leaves of *C. cyanus* did not contain inhibitors of the serine proteinases studied, in contrast to *C. scabiosa* leaves which had one T/SI and several SI components.

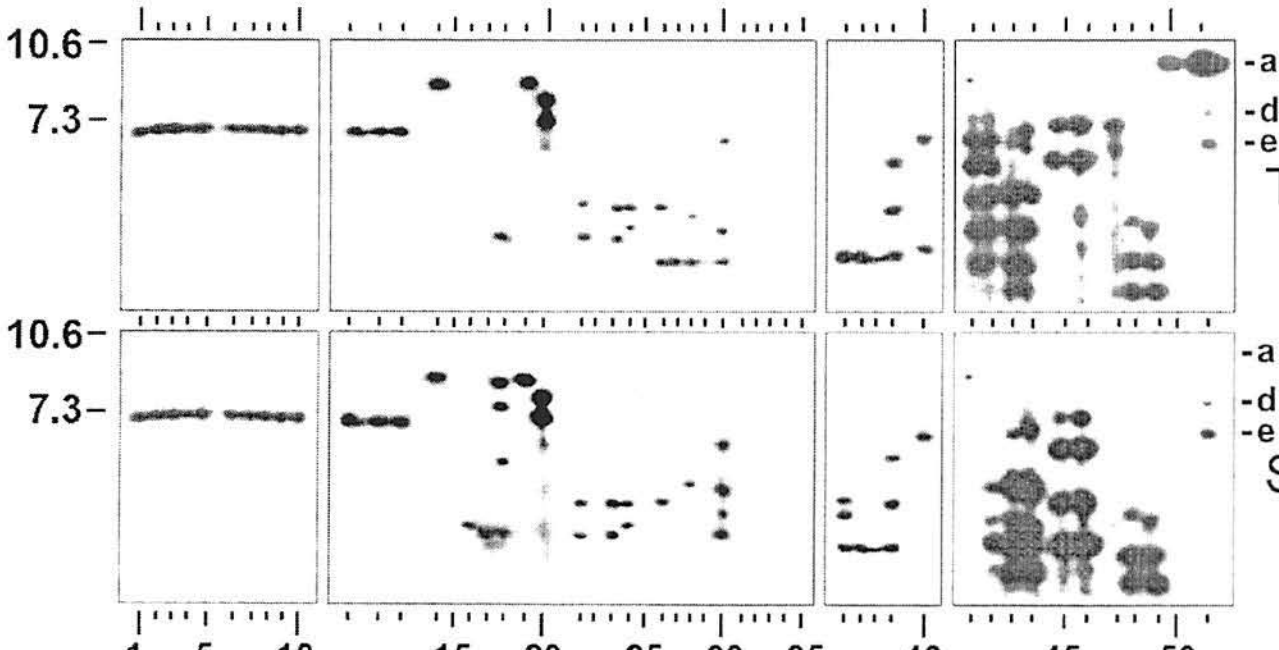

Fig. 1. Polymorphism of proteinase inhibitors in seeds and leaves of representatives of tribes ***Cardueae*** **Cass. (1-35),** ***Lactuceae*** **Cass.(36-40)**, and ***Heliantheae*** **Cass. (41-51)**. Water soluble seed proteins were loaded on gels in volumes of 2-4 µl for *Cardueae* and *Lactuceae* and 0.3-1 µl for *Heliantheae* and separated by IEF in the pH range 3-10. Inhibitors were detected in two gelatin replicas obtained consequently from each gel and developed with trypsin (T) and subtilisin (S). 7.3 & 10.6, positions of pI markers. **a, d & e,** positions of some *Helianthus annuus* inhibitor bands (Konarev et al., 2000a). ***Cardueae*****. 1-13,** *Carthamus* L. species. **1-11,** *Carthamus tinctorius*: **1,** k-18; **2,** k-266; **3,** k-92; **4,** k-62; **5,** k-404; **6,** k-506; **7,** k-442; **8,** k-14; **9,** k-11; **10,** var. Goldtuft; **11,** k-4. **12,** *C. . oxyacanthus*; **13,** *C. lanatus*. **14-20,** *Centaurea* L. **14,15 & 19,** *C. cyanus*: **14 & 19,** acc. of different origin, seeds; **15,** leaves. **16,** C. jacea; **17& 18,** *C. scabiosa*, seeds and leaves; **20,** *C. triumfettii*. **21-26,** *Cirsium* Hill: **21-23,** *C. arvense* (**22,** leaves); **24&25,** *C. vulgare* seeds and leaves. **26-29,** *Carduus* L.: 26, *C. acanthoides*; **27-29,** *C. crispus* (seeds, leaves and stems). **30,** *Serratula coronata*. **31&32,** *Arctium tomentosum & A. lappa*. **33,** *Cousinia badghysi*. **34,** *Saussurea slicifolia*. **35**, *Cynara scolymus*. **Lactuceae. 36-39,***Taraxacum* L. species. **36-38,** *T. officinale*, acc. of different origin; **39,** *T. hybernum*. **40,** *Lactuca serriola*; ***Heliantheae*****. 41&42,** *Gailardia aristata*, acc. **43&44,** *Dahlia variabilis & D. pinnata*. **45&46,** *Cosmos bipinnatus, acc.* **47,** *Zinnia elegans*. **48&49,** *Bidens tripartita & B. radiata*. **50,** *Tithonia diversifolia*. **51,** *H. annuus* VIR-104.

Cirsium arvense (Fig. 1, 21 and 23) and *C. vulgare* (24) differed in their compositions of weak seed T/SI. No inhibitors were found in the leaves of these species. Seeds of *Carduus* L. species (26&27) had weak TI and T/SI. *C. crispus* leaves (28) contained SI and T/SI. *Serratula coronata* seeds (30) contained a heterogeneous mixture of proteinase inhibitors. Inhibitors were not detected in seeds of *Arctium* L., *Cousinia*, *Saussurea* DC. and *Cynara* L. species (31-35).

Some examples of the heterogeneity and variability of proteinase inhibitors in *Cichorioidea* and *Asteroideae* are shown in Fig.1, 36-51. T/SI (36-40), SI (36) and TI (40) were detected in seeds of *Lactuceae*. *Taraxacum* G.H. Weber ex Wiggers species differed in inhibitor composition with accessions of *T. officinale* Wigg. (36-38) also varying.

Many representatives of the *Heliantheae* tribe contained highly active and polymorphic mixtures of inhibitors: *Gailardia aristata* Pursh (41 and 42, T/SI, TI and SI); *Dahlia variabilis* Desf.& *D. pinnata* Cav. (43 and 44, T/C/SI); *Cosmos bipinnatus* Cav. (45 and 46, T/C/SI, C/SI); *Zinnia elegans* Jacq. (47, TI), *Bidens tripartita* L. and *B. radiata* Thuill. (48 and 49, T/C/SI); *Tithonia diversifolia* A. Gray (50, TI) and *Helianthus annuus* L. (51, TI (a) and T/SI (d and e).

Proteinase inhibitors were isolated from seeds of *Carthamus tinctorius* var. Goldtuft and other *Compositae* and purified (Fig. 2 and 3).

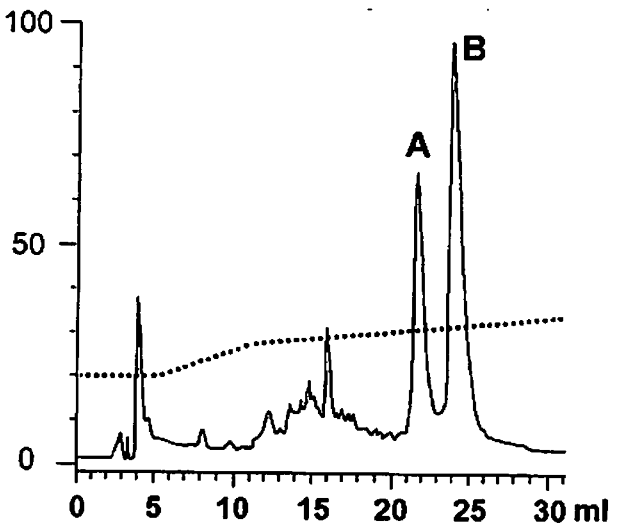

Fig. 2. Purification of proteinase inhibitors from safflower (*C. tinctorius* seeds). The protein fraction eluted from trypsin-Sepharose column was separated by RP-HPLC on a Vidac C18 column with an acetonitrile gradient 20-28-40%

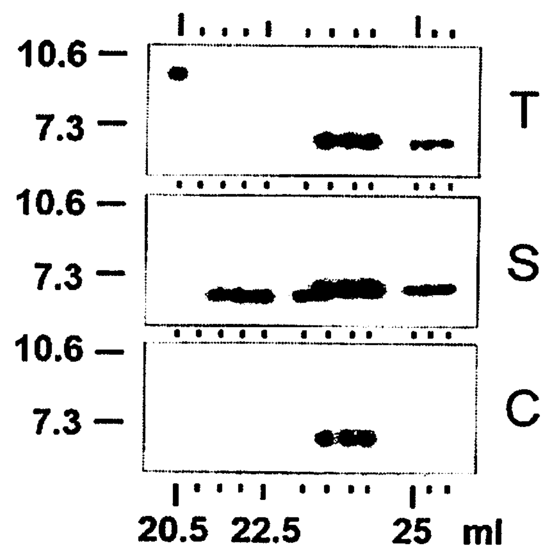

Fig. 3. Detection of trypsin (T), chymotrypsin (C) and subtilisin (S) inhibitors in protein fractions eluted from HPLC-RP (Fig. 2). Proteins were separated by IEF and inhibitors were detected by gelatin replicas method.

Analytical IEF (Fig. 3) showed the presence of T/C/SI in the main HPLC peak B, SI in peak A and weak TI in the fraction eluted earlier. Further purification of inhibitors included micropreparative IEF followed by a second HPLC fractionation of the main components of peaks A and B eluted from IEF gels. Similar approaches were used for the purification of inhibitors from some other *Compositae* (Table 2).

An initial attempt to sequence the native safflower T/C/SI failed because of blocking of the *N*-terminal amino acid residue. The inhibitor was therefore cleaved with subtilisin (1:1, four days at pH 8.0 and 45° C) and possible cysteine residues were blocked by N-isopropyl iodacetamide (NIPIA) after reduction.

HPLC revealed three main peptides (C, D and E) in the reaction mixture (Table 1). Taking into account the addition to M_r for account of NIPIA equal to 199, it was possible to calculate that D corresponded to the native inhibitor with one residue of NIPIA and C and E corresponded to two fragments of chain cleaved at the reactive center. The *N*-terminal sequence of peptide E was determined for 10 residues. Comparison with databases using the BLAST 2.1.1 program (Altschul et al., 1997) revealed homology of this segment with parts of the polypeptide chains of numerous representatives of the potato I chymotrypsin inhibitor family, linked to residue P_1 of the reactive site (which is not known for the safflower inhibitor). The difference in M_r between T/C/SI and SI of safflower is 17, suggesting that the latter is a hydrolyzed form of the former originating during proteolysis *in vivo* or *in vitro* during affinity chromatography (results of sequencing of SI were the same as those for peptide E). The pairs of inhibitors "c2"-"d" and "f1"-"f2" (Table 2) from *C.*

Table 2. Molecular mass values of proteinase inhibitors from some *Compositae*.

Species	Type	*Mr*	Species	Type		*Mr*
Carthamus tinctorius	T/C/SI	7555	*Gailardia aristata*	T/SI		7449
	peptide C	4848	*Zinnia elegans*	TI		11350
	peptide D	7754	*Cosmos bipinnatus*	T/C/SI	(c2)	7722
	peptide E	2923		T/SI	(d)	7740
	SI	7572		C/SI	(f1)	7775
Centaurea cyanus	T/C/SI	7606		C/SI	(f2)	7792
Taraxacum officinale	T/SI (a)	7482	*Helianthus annuus*	T/SI	(c-h)	7593-7723
	T/SI (b)	7542		TI	(a)	1513

a, b, c2, ..., designation of IEF bands

Table 3. Comparison of the amino acid sequences of proteinase inhibitors from safflower (*Carthamus tinctorius*) and other plants.

Fagopyrum esculentum	PI	46	.	L	.	.	.	.	.	.	.	F	55	Belozersky et al., 1995
Cosmos bipinnatus	**T/SI d**	1	.	L	.	.	.	.	.	.	.	F	10	**This paper**
Amaranthus hypochond.	TI	46	.	.	.	.	.	.	.	.	.	V	55	Valdes et al., 1993
Carthamus tinctorius	**peptide E**	1	D	F	R	C	D	R	V	W	V	W	10	**This paper**
Momordica charantia	TI	45	.	.	.	.	.	.	.	R	.	.	54	Miura and Funatsu, 1995
Arabidopsis thaliana	PI	50	.	.	.	.	.	.	.	R	.	F	59	Lin et al., 1999
Cosmos bipinnatus	**C/SI f2**	1	.	Y	.	.	.	.	.	R	.	F	10	**This paper**
Lycopersicon peruvianum	PI	88	.	.	.	.	.	.	.	R	L	F	97	Wingate et al.,1989
Nicotiana sp.	PI	71	.	L	.	.	.	.	.	R	L	F	80	Fujita et al., 93
Hordeum vulgare	CI 2	61	E	Y	.	I	.	.	.	R	L	F	70	Peterson et al., 1991
Solanum tuberosum	CI A	47	.	.	.	.	N	.	.	R	L	F	56	Richardson, 1974
Solanum tuberosum	PI B		.	Y	.	.	N	.	.	R	L	F		Richardson and Cossins, 1974
Cucurbita maxima	PFTI	44	.	Y	.	P	N	.	.	R	.	F	53	Myrray and Christeller, 1995
Hordeum vulgare	CI 1	54	N	.	N	P	N	.	.	F	.	L	63	Svendsen et al., 1982

". ", residues identical to those of safflower inhibitor; 46-55, 1-10, ..., numbers of first and last sequenced residues; F–Y, W–F, evolutionary close amino acid substitutions.

bipinnatus may be similar. Sequencing of 10 amino acid residues of both "d" and "f2" gave results close to those for the safflower inhibitor (Table 3). It is possible that the *N*-termini of the proteins were blocked while the cleaved reactive sites were accessible for sequencing.

DISCUSSION

Seeds of cultivated *Carthamus tinctorius* and some other *Carthamus* species contain monomorphic T/C/SI with M_r of about 7555. These inhibitors appear to contain only one cysteine residue and no disulphide bonds. In the related genus *Centaurea*, a monomorphic inhibitor with similar properties (M_r 7606) is characteristic of *C. cyanus* while *Centaurea* species differ significantly in their inhibitor composition. Inhibitors of this type are absent from seeds of a wide range of *Cardueae* species (*Arctium*, *Cousinia* etc.).

Inhibitors with M_r ranging from 7400 to 7800 such as the T/C/SI of *Carthamus*, combining activity to trypsin, chymotrypsin and subtilisin-like fungal proteinases in various combinations, are most common in the *Compositae*. TIs stand apart from this major group of inhibitors, with highly active TI being characteristic of the *Heliantheae*.

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Fungal proteinase inhibitors were found in leaves of some representatives of *Cardueae* and other *Compositae* including *H. annuus* (Konarev et al., 1999b), suggesting that they are present in the vegetative organs of the whole family. Perhaps, the presence or absence of inhibitors in leaves can be explained by their accumulation in response to damage or infection as in the *Solanaceae* (Ryan, 1990). This analogy seems to be appropriate since we have established the homology of three inhibitors from *Compositae* with the wound-induced inhibitor of tomato (Wingate et al., 1989).

Sequence analysis showed that the three fungal proteinase inhibitors from *Compositae* belong to the potato inhibitor I family. Comparison of short sequences adjacent to reactive sites revealed a strong similarity of *C. tinctorius* T/C/SI to TIs from amaranth and bitter gourd (one substitution), identity of T/SI (d) from *C. bipinnatus* and PI from buckwheat and the similarity of *C. bipinnatus* C/SI (f2) to PIs from *Arabidopsis* and tomato (one and two subsitutions, respectively). It is possible that these data illustrate divergent origins of inhibitor genes from one ancestral gene with various *Compositae* species possessing variants of these genes in differing combinations from one (*Carthamus* species, *Centaurea cyanus*) to several (*Cosmos* Cav., *Dahlia* Cav., *and Bidens* L. species, *Helianthus annuus*).

Studies of proteinase inhibitors can clearly provide information on the evolution of protective protein systems, the mechanisms of resistance to pathogenic organisms and plant evolution in genus *Carthamus* and other *Compositae*.

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In Vitro Studies in the Wild Species of *Carthamus* – *C. Oxycantha* L.

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Biotechnology

ABSTRACT

Cotyledonary leaves of 3, 4 and 5 day old seedlings of *Carthamus oxycantha* L. were cultured on Gambourg's (B_5) modified medium with different levels of 6-benzyladenine (BA) and α- naphthalene acetic acid (NAA). Multiple shoots were induced on B_5 medium supplemented with 2.22 to 8.44 μM l^{-1} 6-benzyladenine (BA). Rhizogenesis was achieved on B_5 with 0 – 2.15 μM l^{-1} NAA supplemented medium. The regenerated plantlets were successfully matured by initially transferring on to filter paper bridges, then on to vermiculite. Finally, plants were transferred to pots for maturation. Presently plants are at flowering stage. Cultures on low levels of cytokinin - auxin supplemented media resulted in capitula formation in *in vitro* cultures.

Key words: *In Vitro* technology, genetic upgrading

INTRODUCTION

In vitro technology has been known to be an alternative and effective means for the genetic upgrading of crop plants. This is possible by trapping the genetic variability by means of somaclonal variation, somatic hybridization and genetic transformations. However, success mainly depends on the availability of efficient protocols for plant regeneration, hardening and maturation of *in vitro* regenerated plants.

Safflower has gained the reputation of being an edible oil of superior quality containing high levels of unsaturated fatty acids (oleic and linoleic acids) and also as a drought resistant crop. *Carthamus oxycantha*, the closely related wild species of the cultivated species- *C. tinctorius*, offers immense use in developing drought resistant varieties and also varieties resistant to various diseases and pests like *Alternaria* leaf spot, *Ramularia* leaf spot, Rust, Powdery mildew and the Safflower fly. Success in plantlet regeneration in safflower has been limited to *Carthamus tinctorius*, while no such attempt has been reported in *C. oxycantha*. The present paper reports on an attempt made on in vitro multiplication of *C. oxycantha* in tissue cultures.

MATERIALS AND METHODS

The seeds of *C. oxycantha*, used in the present experiment were obtained from Project Coordinating Unit (Safflower), Solapur, Maharastra State, India. Healthy seeds of uniform size were surface sterilized according to the procedure described for *C. tinctorius* by Tejovathi and Anwar (1993). Cotyledonary leaves of 3,4 and 5 days old seedlings were inoculated on B_5 medium supplemented with 2.22 to 8.0 μM l^{-1} 6-benzyl adenine (BA) and 3% sucrose. Rooting was initiated on 0 to 2.15-μM l^{-1} α - naphthelene acetic acid (NAA) supplemented medium. Regenerated plants were transferred on to filter paper bridges then in to vermiculite. Finally, these plants were transferred to pots for maturation. All

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the cultures were maintained under continuous fluorescent light at 25 ±1°C. The experiments were repeated and the data were pooled.

RESULTS AND DISCUSSION

Multiple shoots developed from the cut ends of the cotyledonary cultures within two weeks. In general, 2-6 buds developed per explant, which was preceded by slight callusing at the cut ends. The percentage of multiple shoots initiated from 3, 4 and 5 days old explants on different levels of BA supplemented media is shown in the Fig. 1. The data shows that the maximum percentage of multiple shoot initiation from cotyledonary leaf explants was recorded on B_5 + 8.0 µM l^{-1} BA medium.

Regenerated shoots of 1 to 3 cms in size were transferred for rooting on to NAA supplemented medium. Well-developed roots were induced and plantlets were regenerated within 15 – 20 days. The plantlet regeneration frequency, given in the Fig- 2, was at its maximum (35%) in shoots obtained from 3-day-old seedling explants.

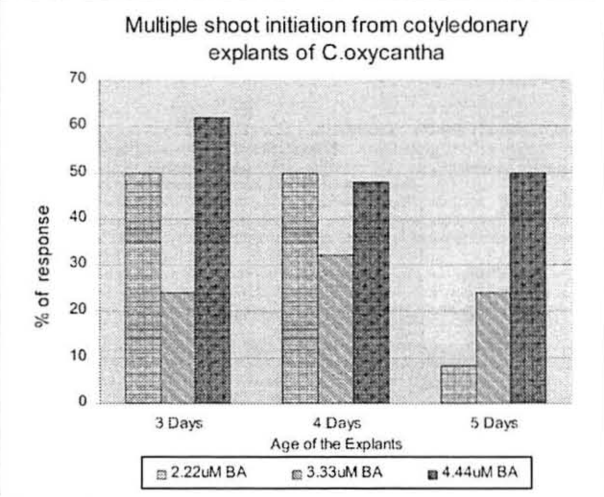

Fig. 1.

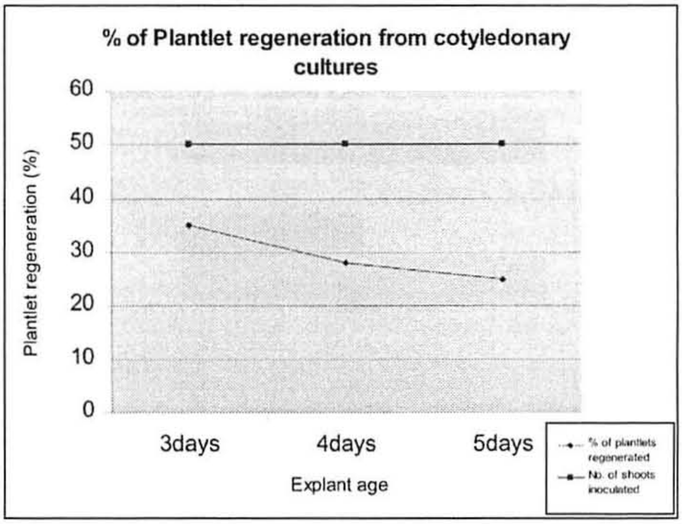

Fig. 2.

Plantlet regeneration from cotyledonary leaves of *C. tincorius* is well documented (Leela and Rao , 1982 ; Tejovathi and Anwar 1993: Tejovathi and Das, 1997 : Nigam and Shitole,1999 and Orlikowska and Dyer, 1993). Maximum number of shoots per culture and percentage of response was reported to be on 1.0 mg/l BAP (Tejovathi and Anwar, 1993; Tejovathi and Das, 1997) or on 4.43 µM BAP (Nigam and Shitole 1999). While, 4-7 days old seedling explants were more regenerative than young and old explants (Nigam and Shitole 1999; Tejovathi and Das, 1997). So far there is no such report on *in vitro* multiplication of *C. oxycantha.*

Trials are under way to improve the regeneration frequency in these cultures. So far, we have transferred almost all plantlets regenerated. Only 10% of the plants survived to maturity.

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Induction of Somatic Embryogenesis from the Root Cultures of Safflower *(Carthamus Tinctorius* L.) Var. Hus- 305

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Biotechnology

ABSTRACT

Healthy seeds of the variety HUS- 305 of *Carthamus tinctorius L.* were germinated under aseptic conditions on filter paper wicks. The roots of 4, 5, 6 and 7 day old seedlings were cut into 0.5- 1.0 cm. long pieces and then inoculated on Murashiage and Skoog's (MS) medium with 1- 10 ppm 2, 4, 5- trichlorophenoxy propionic acid (2,4,5-Cl_3 POP). Within 15-20 days, small yellow colored somatic embryos appeared on the surface of the root explants with minimal or no callus. Induction of somatic embryos was noticed using all concentrations of 2,4,5-Cl_3 POP supplemented media and also from explants of all age groups. However, somatic embryos were superior from the 5th day on 4 ppm 2,4,5-Cl_3POP supplemented medium.

Key words: root cultures, somatic embryogenesis

INTRODUCTION

In vitro technology serves as an alternative means for genetic upgrading. Its successful application mainly depends on the availability of reliable regenerating systems. Substantial progress has been made in this direction in some of the important oil seeds crops like Brassica (Maheshwaran and Williams, 1986), Helianths (Finer, 1987), Peanut (Hazra et.al. 1989), Soyabean (Lazzeri et. al. 1987) etc. Attempts in safflower, an important oil seed crop with high levels of unsaturated fatty acids like oleic acid and linoleic acid, have also been made. Success was limited to 3-10 day old cotyledonary leaf cultures (George and Rao, 1982;

Tejovathi and Anwar, 1984, 1987, 1993; Prasad et al 1991; Mandal et.al. 1995; and Orlikowska et.al. 1995), however, there was no report of any kind from root cultures. The present report describes the somatic embryogenesis, from root cultures in the variety HUS-305.

MATERIALS AND METHOD

Seeds of the Indian safflower (*Carthamus tinctorius* L.) cultivar HUS- 305, obtained from the Project Coordinating Unit (Safflower), Solapur , Maharastra state, India, were used for the present experiments. Healthy seeds of HUS- 305 were surface sterilized and germinated under aseptic conditions, as described by Tejovathi and Anwar, 1993.

Roots were excised from 4, 5, 6 and 7 day old seedlings and about 25 explants per treatment were cultured on Murashiage and Skoog's (MS) medium (1968) supplemented with 0,1.0, 2.0, 4.0 and 10.0 ppm levels of 2,4,5 trichlorophenoxy propionic acid (2,4,5-Cl_3 pop) and 3% sucrose. All cultures were subjected to continuous fluorescent light of 800-1000 lux intensity at a constant temperature of 25±1°C. After 4 weeks, the data for type of response, explant callusing and signs of somatic embryogenesis were recorded. All experiments were repeated and the data was pooled.

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RESULTS AND DISCUSSION

Roots cultured on MS medium with 0,1,2,4 and 10 ppm 2,4,5-Cl_3 pop showed embryogenic response within 2-3 weeks after inoculation. About 3-10 pale to dark yellow colored somatic embryos per explant were noticed from all over the surface of the explants. The results recorded 4 weeks after inoculation, given in the Table-1, show that the induction of somatic embryogenesis was a common response recorded from almost all age groups of explants on all concentration of 2, 4, 5- Cl_3 pop tested. The embryogenic response of explants ranged between 30-80%. Maximum response was recorded on MS + 4 ppm l^{-1},2,4,5- Cl_3 pop supplemented medium (Table 1). Further, the response of explants, in general increased with an increase in the concentration of the growth regulator.

Auxin is an essential component of the medium for the induction of somatic embryos in crop plants. A number of auxins such as 2,4-D, NAA, IAA, Dicamba, Picloram, 2,4,5-Cl_3pop are known to induce somatic embryogenesis (Susan and George, 1993; Prasad et.al, 1991; Lazzeri et.al. 1987). 2,4,5- Cl_3 pop was found to be an effective auxin in inducing somatic embryos in Peanut (Susan and George, 1993), while in safflower, efficient rooting and plantlet regeneration was reported (Tejovathi and Anwar , 1993). Present experimental results in root cultures of safflower also show similar (auxin) effects of 2, 4, 5- Cl_3 pop, i.e. somatic embryos development was favored, which indicates that roots are very efficient explants and 2,4,5 Cl_3 pop is a suitable auxin to induce somatic embryos in safflower root cultures.

Table 1. Somatic embryogenic response of root explants of HUS –305.

Explant age (in days)	MS+ 2,4,5-Cl3pop (in ppm/l)	No. of explants inoculated	Type of response	No. of explants showing embryogenesis	% of embryogenic response
4	1.0	50	$c^{+++} e^{+}$	28	56± 1.49
	2.0	50	$c^{+++} e^{++}$	28	56+1.49
	4.0	50	$c^{++}e^{+++}$	30	60+1.55
	10.0	50	$c^{+} e^{++}$	34	68+1.65
5	1.0	50	$c^{++}e^{+}$	21	42±1.29
	2.0	50	$c^{++}e^{++}$	32	64±1.60
	4.0	50	$c^{++}e^{+++}$	40	80±1.78
	10.0	50	$c^{++}e^{++}$	24	48±1.38
6	1.0	50	$c^{++}e^{+}$	15	30±1.09
	2.0	50	$c^{+} e^{+}$	30	60±1.55
	4.0	50	$c^{+} e^{++}$	31	62±1.57
	10.0	50	$c^{++} e^{+}$	26	52±1.44
7	1.0	50	$c^{+}e^{+}$	22	44±1.33
	2.0	50	$c^{+} e^{+}$	18	36±1.19
	4.0	50	$c^{+} e^{++}$	30	60±1.55
	10.0	50	$c^{+} e^{++}$	27	54±1.47

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Radiations-Induced Somaclonal Variation in Safflower

Tejovathi Gudipati[1]

ABSTRACT

Seeds of 5 cultivated varieties of safflower viz. A-1, Manjira, APRR-3, Tara and BLY-652 were exposed to 0 - 45 Kr gamma radiations and germinated under aseptic conditions on half basal medium. Cotyledonary leaves of 5 days old seedlings were used for the regeneration of plantlets. Cotyledonary explants of higher doses of (- rays (45Kr and 30Kr), completely failed to produce multiple shoots. While, all varieties exposed to lower doses i.e. 10, 5 and 1 Kr, produced multiple shoots. Rhizogenesis was recorded in about 45 % of multiple shoots, which regenerated into plantlets. Of these, about 27.8 % plants survived up to maturity with 0.8 % plants sterile and 24.8% plants produced no seeds. The height of the regenerated plantlets varied between 13.6 and 46.0 cm. While, dry weight ranged from 0.2 g to 3.4 g. Number of heads per plant ranged from 0 – 4 and from each regenerated plant about 1 to 20 seeds were recovered.

Key words: somaclonal variants, induced mutage nesis

MATERIALS AND METHODS

Somaclonal variants were regenerated from 5 day old cotyledonary leaves of 5 safflower cultivars viz– A-1, APRR-3 Manjira, Tara and BLY-652 exposed to 0, 1, 5, 10, 15, 30 and 45 Kr -rays. The protocol given by Tejovathi and Das (1997) was adopted for the present experiments. The regenerated plants were transferred to in vitro cultures for root elongation and acclimatization to less humid conditions. Plants were then transferred to pots with soil for maturation.

RESULTS

Somaclonal variants through induced mutagenesis have been practiced for a long time (Scowcroft, 1983, 1984). In the present studies we have used irradiated seeds as a source for somaclonal variation. The experimental results, given in the Table 1 show that cotyledonary leaves of 30 and 45 Kr completely failed to induce shoots in all the varieties used. Limited results were obtained in 15 Kr cultures. Explants of only Mangira and Tara produced (10-15%) multiple shoots (Table 1). At lower doses (1-10 Kr) 20 to 74 % explants resulted in multiple shoots.

Table 1. Percentage of cotyledons derived from irradiated seeds growing multiple shoots.

S.No.	Dose of r-rays	No.of cotyledons inoculated	Variety / response				
			A-1	APRR-3	Manjira	Tara	Bly-652
1.	45Kr	100	-	-	-	-	-
2.	30Kr	100	-	-	-	-	-
3.	15Kr	100	-	-	12	14	-
4.	10Kr	100	26	26	32	36	24
5.	5Kr	100	30	36	32	68	70
6.	1Kr	100	40	34	24	20	44

Table 2 gives the percentage of plantlets regenerated and the total number of plants surviving to maturity in each treatment and from each variety. The number of plants regenerated and the number of plants matured, decreased with increase in the dose of -rays. The maximum number of plants was

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regenerated from 'Tara' followed by 'Mangira' (Table 2); however the maximum number of plants survived to maturity in 'A-1' followed by Mangira and Tara (Table 2).

Often mutagenesis using physical and chemical mutagens is adopted in tissue cultures so as to enhance the recovery of selected variants. In several species variation has been documented for agronomical traits such as disease resistance, plant height, yield, maturity, quality and plant type (Karp, 1994). In the present study, a total of 450 plants were regenerated from the experiments and out of them 125 plants (27.8%) survived to maturity. The survival of the plants in field conditions was found to be greatly influenced by temperature, humidity and season. Out of these 125 plants – 0.8% plants were sterile (capitula were not developed) and 24.8% plants produced no seeds.

Table 2. Percentage of plantlets regenerated from cotyledonary leaves of irradiated seeds.

Variety/ Dose	No. of Shoots transferred for rooting	% of plantlet regeneration	No. of plants matured
1Kr			
A-1	93	39	12
APRR-3	75	25	15
Manjira	200	57	14
Tara	186	120	23
Bly-652	84	65	13
5Kr			
A-1	60	20	13
APRR-3	45	5	2
Manjira	40	30	10
Tara	60	15	2
Bly-652	33	5	-
10Kr			
A-1	24	15	9
APRR-3	-	-	-
Manjira	42	21	5
Tara	42	15	3
Bly-652	21	18	4

Often mutagenesis using physical and chemical mutagens is adopted in tissue cultures so as to enhance the recovery of selected variants. In several species variation has been documented for agronomical traits such as disease resistance, plant height, yield, maturity, quality and plant type (Karp, 1994). In the present study, a total of 450 plants were regenerated from the experiments and out of them 125 plants (27.8%) survived to maturity. The survival of the plants in field conditions was found to be greatly influenced by temperature, humidity and season. Out of these 125 plants – 0.8% plants were sterile (capitula developed was absent) and 24.8% plants produced no seeds.

Data recorded for some important quantitative characters showed that the height of the regenerated plantlets varied between 13.6 – 46.0 cms; and 0 - 4 and 1-20 seeds were recovered from each head of a regenerated plant.

In vitro multiplication and plantlet regeneration in safflower was reported. However, somaclonal variation in regenerated plants was not reported (Anwar et. al. 1994) reported variation in $F_1$and F_2 hybrids obtained through crosses made with *in vitro* pollen. The present report clearly demonstrated that it is possible to raise large number of somaclonal variants through tissue cultures; and by applying mutagenesis to this technique it is possible to the raise variability for important agronomic characters for practical purposes.

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Safflower Biotechnology: Progress and Prospects

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Biotechnology

ABSTRACT

Safflower (*Carthamus tinctorius*. L) is a valuable oilseed crop and contains high linoleic acid associated with the reduction of cholestrol level in the blood of humans. It is also a source of important biochemicals like α – tocopherol and carthamin. Genetic improvement of safflower products is complicated as it involves the simultaneous improvement of seed yield and oil content. Classical biotechnology, including mutation breeding, holds promise for generating a high degree of genetic variability. Recent advances in biotechnology have made it possible to develop superior safflower varieties through the application of classical breeding techniques together with tissue culture and modern biotechnology (recombinant DNA) tools. To incorporate desirable changes in safflower, it is essential to have good reproducible tissue culture and regeneration systems applicable to a wide range of elite germplasm. In vitro culture systems also provide a faster production of secondary metabolites. The work done in our laboratory on *in vitro* culture of safflower cultivars and also by other research workers elsewhere indicated the possibility for developing useful somaclonal variants with increased contents of stearic and oleic acids, isolation of secondary metabolites, desirable changes in oil composition and in tocopherol content, and the release of new types of isozymes. Specific uses of isozyme polymorphism, molecular markers, molecular mapping, genetic engineering for the development of mutants for biotic and abiotic stresses, improvement in quality, and functional genomics are applicable to safflower improvement.

Key words: Safflower, *in vitro* culture, secondary metabolites, molecular markers, functional genomics.

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Breeding/Genetics/Disease

Biocontrol of Wilt of Safflower caused by *Fusarium oxysporum* f. sp. *carthami*

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ABSTRACT

Safflower is an important oilseed crop grown in India. It can be infected with many fungal, bacterial and viral diseases. Wilt of safflower is one of the most important known disease caused by *Fusarium oxysporum* f. sp. *carthami.* The present study deals with the biological control of wilt of safflower. Fifty one isolates from healthy seeds and rhizosphere of healthy safflower plants, were evaluated for their antagonistic activity, only two, viz., *Aspergillus fumigatus* and *Trichoderma harzianum* were found to produced maximum zone of inhibition and inhibited germination of spores of test pathogen. The *Aspergillus fumigatus* (9.26×10^7 spores/ml) and *Trichoderma harzianum* (8.72×10^7 spores/ml) were found to significantly reduced the disease incidence of safflower in inoculated soil in pots under greenhouse conditions. These antagonists did not show any adverse effect on germination of safflower seeds on sterilized blotter paper and in sterilized sand, at the same time plant height and root length were found to have increased significantly, when antagonists were introduced by seed treatment and soil treatment. This control was probably due to antagonistic action of *Aspergillus fumigatus* and *Trichoderma harzianum.*

Key words: Biocontrol, safflower wilt, *Aspergillus fumigatus, Trichoderma harzianum.*

Breeding/Genetics/Disease

INTRODUCTION

Safflower is an important oilseed crop. It can be infected by many diseases throughout its growth period. Fusarium wilt is considered as one of the most notorious disease caused by *Fusarium oxysporum* Schlecht f. sp. *carthami* (Klisiewiz et al. 1962). Symptoms of the disease are manifested at all stages of growth. Infected plants showed partial recovery between bud formation and early blossoming but the symptoms reappeared afterwards. Acidic soil, coarse textured soil, high nitrogen and warm-moist weather are favorable for disease development (Chakrabarti et al. 1978), Sowing of safflower on 10th October or 1st week of October was comparatively suitable to minimize the yield losses from the disease (Nagale 1989). The disease caused yield losses ranging from 7.2% to 100% (Sastry et al. 1994).

The indiscriminate use of chemical has an adverse effect on beneficial organisms in soil, in addition to creating residual problems. Under these conditions antagonistic mircoorganisms can be effectively used to minimize the inoculum potential of the pathogen. Monaco et al.(1991) introduced *Trichoderma spp.* as a biocontrol agent against *Fusarium spp* and *Sclerotium rolfsii* through seed treatment. Sivan and Chet (1986)) applied *Trichoderma harzianum* through wheat bran per peat preparation (carrier) in soil as an antagonist against *Fusarium oxysporum* f.sp *lycopersici.* The biocontrol agents multiply in soil and remains near the root zone of the plants and protect them even at later stages of the growth. The biocontrol putforth is a low cost technology in controlling the wilt of safflower with organic produce

MATERIALS AND METHODS

The susceptible variety (Cav. Tara) of safflower was used throughout the studies. The pathogen causing wilt was isolated from infected roots and stems of safflower plants and the purified culture was identified. The pathogenicity was proved by soil inoculation technique (Sen et al. 1975), and Koch's

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postulates were confirmed. Martin (1050) Rose Bengal Medium, and Thornton's (1992) Medium, were used for isolating fungi and bacteria, respectively, from different sources viz., rhizosphere soil of healthy safflower plants adjacent to wilted, healthy seeds and diseased seeds of safflower. To obtain the rhizosphere isloate the soil plate technique (Parkinson 1957), was used. Each culture was assayed individually for antagonistic action against test pathogen by dual culture method and method suggested by Wood (1957). The isolates which showed maximum zone of inhibition were tested for their potentiality to inhibit the germination of spores of test pathogen. The antagonists which completely inhibited spore germination were used for further studies. Seeds were soaked in 100% concentration of antagonists, plated on sterilized blotter paper in petridishes and in sterilized sand in plastic pots and observations were taken on percent seed germination, length of plumule, and length of the radical as parameters. Finally, observations were recorded on the effect of seed treatment and soil treatment with antagonists on root length, shoot length and mortality caused by *Fusarium oxysporum* f. sp. *carthami.* The pots containing sterilized soil without antagonist served as a check (control). The experiments were conducted in quadruplicates in pots under greenhouse conditions and observations were recorded after 30 days of sowing.

Pathogenicity of the test pathogen was proved by soil inoculation technique (Sen et al. 1975). Susceptibility was determined on the basis of percent wilting of plants in artificially inoculated soil in pots under controlled conditions. More than 80 percent wilting was noticed at 30 percent inoculated soil (w/w). Hence 30 percent (w/w) concentration of soilinoculum was used for further experiments.

Different microorganisms were isolated from different sources i.e. rhizosphere of healthy safflower plant adjacent to wilted one and from healthy and diseased seeds of safflower on selective media. A total of fifty-one isolates were purified and were assayed individually for antagonistic effects against *Fusarium oxysporum* f. sp *carthami.* Out of 51 isolates only 10 (antagonist) showed the maximum zone of inhibition ranging from 19.3 to 54.5 mm in diameter against the test pathogen (Singh et al. 1980, Rama 1985). The spores of the test pathogen were kept for germination in presence of antagonist suspension (on sterilized cavity slides in moist chamber) for 24 hrs at 27 ± 1°C to observe the effect of antagonist on germination of spores (Arjuna 1970, Sivan et al. 1989).

Another parameter was to determine the effect of antagonist on the germination of safflower seeds. The seeds were soaked in the suspension of the antagonists for 24 hrs and were placed on sterilized blotter paper in petriplates and incubated for 7 days at 27 ± 1°C.

These two antagonists, isolate number B-17 and B-20, were selected to test their effect on seed germination and plant growth. For these experiment seeds were soaked in standardized concentration of antagonist separately for 24hrs and sown in sterilized sand in pots. The seeds soaked in distilled sterilized water served as a check. After 10 days, the germination count, plumule and radical length were recorded.

The concentration of *Aspergillus fumigatus* (9.26 x 10^7 spores/ml) and *Trichoderma harzianum* (8.72 x 10^7 spores/ml) was used as the standard concentration to inhibit spore germination and to control the wilt of safflower.

RESULTS AND DISCUSSION

Four antagonists i.e. B-8, B-17, B-20 and B-30 completely inhibited the spore germination while other isolates that showed the maximum zone of inhibition were unable to check the spore germination (Table 1).

Isolate no. B-17 and B –20 showed no deleterious effect on the germination of seed and showed maximum germination with an increased length of plumule and radical (Table 2). The other antagonists viz., B-8 and B-30 adversely affected the germination of safflower seed (Table 2). A significant reduction in disease incidence was observed due to the antagonists. Therefore, it is concluded that *Aspergillus fumigatus* and *Trichoderma harzianum* were found to check wilt of

Table 1. Antagonistic effect of different isolates on growth and germination of spores of *Fusarium oxysporum* f. sp. *carthami*.

Sr. No.	Isolated Number	Inhibition in (mm)*	Per cent germination of spores*	Per cent inhibition of spores*
1.	B - 6	21.9	79	21
2.	B - 8	45.4	00	100
3.	B - 17	51.1	00	100
4.	B - 20	54.5	00	100
5.	B - 22	26.0	72	28
6.	B - 27	30.5	67	33
7.	B - 30	40.8	00	100
8.	B - 31	22.1	84	16
9.	B - 43	31.3	58	42
10.	B - 46	19.3	85	15
11.	Check (without antagonist)	00.00	100	00

*Average of three replications

Table 2. Effect of antagonist on germination of safflower seeds (on sterilized blotter).

Sr. No.	Isolate Number	Concentration of antagonist Spores/ml	Number of seeds*		Percent Germination	Length of	
			Plated	Germinated		Plumule (cm)*	Radical (cm)*
1.	B-8	(8.62×10^7)	20	05	25	2.24	1.06
2.	B-17	(9.26×10^7)	20	17	85	5.96	3.50
3.	B-20	(8.72×10^7)	20	18	90	6.25	4.46
4.	B- 30	(8.24×10^7)	20	08	40	2.02	1.04
5.	Check (without angonist)	-	20	17	85	5.87	3.42

*Average of three replications and average of 5 seedlings, (Plumule and radical length measured 10 days after germination).

Table 3. Effect of antagonist on germination of safflower seeds (in sterilized sand in pots)

Sr. No.	Isolate Number	Concentration of antagonist Spores/ml	Number of seeds*		Percent Germination	Length of	
			Plated	Germinated		Plumule (cm)*	Radical (cm)*
1.	B-17	(9.26×10^7)	20	18	90	7.32	5.45
2.	B-20	(8.72×10^7)	20	18	90	7.67	5.76
3.	Check (without angonist)	-	20	16	80	6.05	4.77

*Average of three replications and average of 10 seedlings, (Plumule and radical length measured 10 days after germination).

safflower caused by *Fusanum oxysporum* f. sp *carthami* to a large extent and hence, are useful used as bio-agents/ bio-pesticides.

In Table 3, results showed that antagonists B-17 and B-20[1/] did not show any adverse effect on germination of seed and seedling development of safflower. The length of plumule and radical were increased compared to check (Table-3). These two antagonists have been identified as *Aspergillus fumigatus* and *Trichoderma harzianum* by the Division of Plant Pathology, Indian Agricultural Research Institute, New Delhi. In the present investigation, seed treatment and soil treatment with antagonists promoted germination of safflower seeds, reduced wilting percentage and also increased root and shoot length (Table 4).

The two isolates / antagonist No. B-17 & B-20 later identified as *Aspergillus fumigatus* and *Trichoderma harzianum* respectively from, Division of Plant Pathology, I.A.R.I., New Delhi, India.

Table 4. Effect of seed treatment and Soil treatment with *Aspergillus fumigatus* (B-17) and *Trichoderma harzianum* (B-20) on mortality caused by *Fusarium oxysporum* f. sp. *carthami*.

Sr. No.	Treatments	Number of Seeds*		Percent germination	No. of plants wilted	Percent wilting	Shoot length (cm)*	Root length (cm)*
		Sown	Germinated					
1)	Seed treatment with *Aspergillus fumigatus*	15	14	93.33	00	00.00	21.71	12.05
2)	Soil treatment with *Aspergillus fumigatus*	15	13	86.66	01	07.69	19.34	13.30
3)	Seed treatment with *Trichoderma harzianum*	15	14	93.33	00	00.00	23.31	13.00
4)	Soil treatment with *Trichoderma harzianum*	15	14	93.33	00	00.00	20.96	15.90
5)	**Check (without antagonist)**	**15**	**12**	**80.00**	**11**	**91.26**	**14.78**	**8.03**
	S.E.					0.070		
	C.D. at 5%					0.152		

*Average of four replications & 10 seedlings from each pots, 30 days after sowing.

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Characterization and Inheritance of Long Rosette Safflower

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ABSTRACT

Eleven selections of late rosette (winter type) safflower were planted both in early fall and early spring and their growth characteristics recorded and compared with 12 selections and varieties of spring type safflower planted in the spring season. Late rosette safflower developed a very hardy and frost resistant seedling in fall planting at about the six-leaf stage with extensive root growth that could stand temperatures of -20 C. Their growth initiation in spring started somewhat earlier than that of spring type safflower and they matured earlier, escaping the late summer shortage of irrigation water. For the study of the inheritance of the late rosette character, several crosses were made between the spring and winter types and their F1 and F2 progenies were evaluated. Most of the crosses indicated this character to be a polygenic trait. However, in one specific cross between LRV55/292 and Frio 3176, all hybrids grew as spring types and in the F2 generation, recorded in several families, they segregated 3:1 (short rosette: long rosette) in greenhouse evaluations, suggesting the long rosette to be a simply inherited recessive Mendelian trait. Considering the fact that not a single cultivar has yet been bred from the collection of winter type safflower, it appears that the cold resistant character could simply be bred into well-adapted and productive spring cultivars with the possibility of growing safflower as a winter crop in cold regions of the Iranian northwest.

Key words: safflower, cold resistant, rosette, winter type, inheritance.

Breeding/Genetics/Disease

INTRODUCTION

In safflower *(Carthamus tinctorius* L.), seed germination is usually followed by a slow growing rosette stage, during which numerous leaves are produced near ground level. The rosette stage is considered as one of the main phenological phases in the growth of the safflower plant (Tanaka et al., 1997; Uslu, 1997). Generally, in most varieties of safflower, the rosette stage is short, but it may be prolonged by environmental factors such as low temperatures or short days. It has been noted that lower temperature during winter lengthens the rosette period, which is associated with higher grain yields (Insua Munoz, 1986; Salera, 1997). Although most cultivars (with a short rosette) can resist temperatures as low as -6.6 C, some germplasm (with a long rosette) was found and tested in China that could resist temperatures as low as -15 C during the early stages of growth. The cold requirement of long rosette safflower causes these plants to develop a very dense clump of leaves in spring planting with a total lack of stem development or delayed stem elongation (Li, 1989; Li et al., 1997).

In Iran, safflower has a long history of cultivation although its main use has been the extracted dye from its florets for coloring food and textile. Only during the last 35 years has it been evaluated intensively as an oilseed crop. At present, in southern and temperate parts where frost damage is minimal, the usual spring type safflower with a short rosette stage is planted from late fall to late winter, whereas in cold northern regions seeding is essentially carried out in spring with the result of lower yields. As part of the effort by the Seed and Plant Improvement Institute at Varamin, 2812 local populations of safflower were collected in 1969 and evaluated for various agronomic characters including winterhardiness (Ghanavati and Nahavandi, 1974). Plants with a long rosette period were identified in one of the local populations from northwestern Iran that were characterized as LRV lines

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(Ghanavati and Knowles, 1977). Fifty-one lines were originally developed from these plants showing considerable variation in winter hardiness. Other efforts for the selection of seedling cold tolerance have been made (Zimmerman and Buck, 1977) and trials have been carried out to compare spring and winter types of safflower (Yazdi-Samadi and Zali, 1979).

Studies of the inheritance of long rosette character are rare in the *Carthamus* species. The only published work to date (Imrie and Knowles, 1970) reports the inheritance of this character in a cross involving a wild relative of safflower *(C. flavescens* Spreng) and the cultivated species *(C. tinctorius* L.) in which the delayed shoot elongation is attributed to the presence of a recessive *ro* gene. This study reports the developmental characteristics of Iranian long rosette safflower in fall and spring plantings and its inheritance is reported in a cross with a short rosette (spring type) safflower.

MATERIALS AND METHODS

For the initial observation of long rosette safflower, 11 selections received from the Iranian Oilseed Research and Development Company were planted in an observation nursery on October 8, 1994 at the Urmia University experimental farm (northwestern Iran). Ten grams of seed from each entry was planted on two 6 m rows, 75 cm apart. After seed germination, plants were in the 4-6 leaf stage when they stopped developing (Nov. 20) due to the approaching cold winter (min. -20°C). Initial signs of plant regrowth were observed on April 17 of the following year. Another observation nursery was created by seeding both winter type (11 selections) and spring type safflower (12 selections) in the spring season on May 20, 1995. Fall planting of selfed seed obtained from fall planted winter hardy selections were repeated the following two years. Each year, to ensure a better establishment of the rosette stage, the fall planting date was advanced by two weeks. In the following year, selfed seed from the most phenotypically uniform and most winter hardy selection LRV55/292, was planted in the fall. This was followed by spring planting of selfed seed from the short rosette spring type cultivar Frio 3176. With overlap of their flowering periods in late July, reciprocal crosses were made and F_1 seed obtained. Hybrid seed and the parental lines were planted in 5 cm pots in the greenhouse and after four weeks transplanted to the field both in the fall and spring seasons for observation of their winter hardiness, their growth characteristics and to obtain F_2 seed. In addition, some of the hybrid plants were transplanted into larger 25 cm greenhouse pots to obtain F_2 seed. For crossing, emasculations and pollinations were made by standard procedures described previously (Knowles, 1980). Emasculated and pollinated heads, and also heads used as the male parent, were protected against insect visits in the field by paper bags, as were self-pollinated heads. Nine of the F_2 populations were seeded in 10 cm greenhouse pots and five weeks after emergence, plants were recorded for the existence of a strong rosette type of growth. Tests of goodness of fit and heterogeneity of data were conducted by standard procedures.

RESULTS AND DISCUSSION

As expected, considerable variation was observed in winter survival of long rosette selections planted in the fall season (Table 1). Repeated experiments the following two years with two weeks advancement of the seeding date in each year, resulted in an average of at least a 10% increase in winter survival (data not shown). This would indicate that some of the winter type selections, particularly LRV 55/292, have acceptable winter survival under an extended cold period of about five months. The observed increase in winter survival was concurrent with the development of higher numbers of leaves (6-10) at the rosette stage and an increase in the diameter of the crown, which apparently confers a better cold tolerance to the plant. After receiving the cold shock, the winter type selections began their regrowth earlier (April 17) than when these selections were planted in the spring (May 20). As a result, the observations indicate that the winter types reached the 50% bloom stage two months earlier (July 19) from fall seeding than from spring seeding (Sept. 19) (Table 1 and 2). This difference in bloom date

Table 1. Characteristics of 11 winter type (long rosette) selections of safflower planted in the fall season.

Entry[1]	Winter survival(%)	Spininess[2]	Plant height(cm)	Flower color[3]	Days from spring regrowth to: 50% bloom	Maturity
LRV55/292	71	Sp	102	Y, Or, R	75	116
LRV55/65	37	Sp	106	Or, R	91	127
LRV55/277	31	Sp	97	Or, R	90	121
LRV55/46	28	Sp	134	Or	94	126
LRV55/239	27	Sp	105	Or, R	101	123
LRV55/290	27	Sp	96	Or	101	119
LRV55/51	25	Sp	117	Or, R	92	123
LRV55/56	24	Spls	123	Or, R	103	125
LRV55/67	24	Sp	122	Or, R	102	130
LRV 295	23	Spls	98	R	97	128
LRV 697	21	Sp	97	Or	92	116
ESF 25	0	-	-	-	-	-

[1] All entries are winter type, originating from Urmia (West Azerbaijan) and first evaluated at Varamin Agricultural Experiment Station, except ESF 25 which is spring type selection (check) from Esfahan, Iran.
[2] Upper leaves and bracts, Sp= spiny- Spls= spineless
[3] Y= yellow; Or= orange; R= red. The predominant colour is underlined.

Table 2. Characteristics of 11 winter type (long rosette) and 12 spring type (short rosette) selections and varieties of safflower planted in the spring season.

Entry	Plant height (cm)	Flower colour	Spininess	Days to 50% bloom
Winter type				
LRV 697	100	Or	Sp	122
LRV55/67	110	Or	Sp, Spls	122
LRV55/239	110	Or, R	Sp, Spls	122
LRV55/290	110	Or, R	Sp	123
LRV55/46	120	Or, R	Sp, Spls	125
LRV55/292	120	Or	Sp, Spls	111
LRVS5/56	130	Or, R	Sp	128
LRV55/277	130	Or	Sp, Spls	113
LRV55/65	140	Or	Sp, Spls	128
LRV55/51	150	Or	Sp	130
LRV 295	150	Or	Spls	115
Spring type				
Nebraska 10	85	y	Sp	68
Ute 3175	85	Or	Sp	70
Frio 3176	90	Or	Sp	68
V49/236	90	Or	Spls	70
A 2811	95	Y, Or, R	Sp	70
D 51/655	95	Or, R	Spls	70
V 51/211	95	Or, R	Spls	72
ESF 25	100	Or	Spls	82
V 51/241	100	Or	Sp	70
D 51/192	105	Or, R	Spls	74
D 51/666	105	Or	Spls	70
D 51/137	115	Or	Spls	74

has been reported to be less pronounced (1-3 weeks) under mild winter conditions (Yazdi-Samadi and Zali, 1979). The observed earliness was also noticeable when comparing winter types seeded in the fall and spring types seeded in the spring (Table 1 and 2). Average earliness in reaching 50% bloom was calculated to be 11 days. In particular, the most uniform and cold resistant winter type selection LRV55/292 reached this stage about one month earlier than the average of 12 spring type selections.

This observation was reinforced by data obtained from plantings in the following two years (data not shown). When winter type selections are planted in the fall, the average plant height is less (mean= 108.8 cm) than when planted in the spring (mean= 124.5 cm) (Table 1 and 2). In addition, plants in each of the entries showed variation in flower color and spininess, which is an indication of seed impurity. Repeated selfing of these selections showed segregation in the following two years, not only for flower color, spininess, branching height, morphology, texture and colour of bracts, and bloom date, but also for the duration of the rosette stage in spring seeding.

Characterization of Long Rosette Safflower:

Under the environmental conditions of Urmia, the long rosette safflower behaves quite differently when seeded in early fall or early spring. With fall seeding, the pronounced long rosette stage with its characteristic botanical features cannot be observed because of the gradual, steady and continuous weekly lowering of day and night temperatures, which essentially stops the upper plant parts from developing further at a stage when the range of leaf number is 4-10. After receiving the cold shock and an extended growth arrest of about five months, plants are ready to elongate their shoots as soon as temperatures are high enough in early spring. The observed phenologial stages following shoot elongation are similar to those for short rosette safflower grown in the spring after passing the rosette stage. However, under these conditions the flowering and maturity is reached earlier in the long rosette types. On the other hand, when the long rosette safflower is seeded in the spring, shoot elongation is much delayed while the number of fleshy leaf blades continues to increase under favorable growing conditions of spring at the ground level, such that a very dense clump of leaves (20-35) develops by late July. The rosette plant remains close to the soil surface although some stem elongation of less than 5 cm may occur. Subsequently, when the main stem eventually begins to elongate, the plant looks quite different from a regular safflower plant. The main stem is extremely thick and strong and the leaves are huge and fleshy. The main stem is usually unbranched up to at least 80 cm with the primary side branches numerous but short with a plant height ranging 100-150 cm. The 50% bloom date is much delayed and the approaching cold season does not allow all selections to develop mature seeds. Observations indicate that some plants begin to dry out and die during stem elongation before reaching the branching stage for unknown reasons.

Inheritance of Long Rosette Safflower:

Hybrids of the cross LRV55/292 x Frio 3176 grown in the field responded differently in fall and spring seedings. Those grown in the fall were all killed by the cold winter, however, when grown in the spring, they developed much like the spring type parent Frio 3176 and produced F_2 seed. Similar hybrids grown in large greenhouse pots also developed without showing the long rosette character indicating the dominance of short over the long rosette trait. The nine F_2 families grown in the greenhouse segregated for short and long rosette, which could be classified rather easily about five weeks after emergence. The population size in these families ranged from 37 to 133 all of which segregated in the ratio of 3 (short rosette): 1 (long rosette) with an insignificant chi-square value at the 5% level of significance. The heterogeneity was also insignificant and the pooled data of 542:176 gave a good fit to the 3:1 ratio. The observed dominance of short over long rosette has also been reported in an interspecific cross between *C., flavescens* and *C. tinctorius* (Imrie and Knowles, 1970) and it is possible that the same recessive gene *ro* is involved in the present study. It should be mentioned that in similar crosses between other selections of long and short rosette types, no such clear cut differentiation could be observed particularly in the long rosette group because these plants varied extensively in the time of their shoot initiation when planted in the spring. The above results brings up the notion that it should be possible to transfer the cold resistant, long rosette gene into the well adapted and productive spring type cultivars using conventional plant breeding methods. This would enable fall-sown safflower to resist frost damage and to be handled similar to fall sown cereals in cold regions. The observation of early spring regrowth of long rosette safflower seeded in the fall is a significant advantage over the short rosette spring seeded safflower and the earlier flowering and maturity is a noticeable consequence. Lack of adequate water for irrigation is a major limiting factor in the production of spring grown safflower in Iran. Winter safflower can meet its water requirement from snow and rain during the winter and early spring making two irrigations during flowering and seed setting stages sufficient to produce an economic crop.

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Evaluation of Experimental Hybrids Based on Genetic Male Sterility in Safflower

P. K. Naoghare and P. B. Ghorpade[1]

ABSTRACT

Twenty-six selected lines of safflower *(Carthamus tinctorius L.)* were crossed with genetic male sterile line (AKSMS-1) to assess the possibilities of identifying promising experimental hybrids, to evaluate the general combining ability of parental lines and to assess the contribution of genetic divergence to the expression of heterosis. The magnitude of heterosis and useful heterosis was low and differed for different characters. The highest magnitude of useful heterosis was observed for number of seeds per capitulum (34.32%) followed by plant height (19.54%) and seed yield/ plant (16.99%). Only one cross, AKSMS-1 X AKS-96, recorded significant useful heterosis over the check variety, Bhima for seed yield per plant (16.99%). The estimates of general combining ability indicated that only one parent, i.e. AKS-96 recorded a high and significant general combining ability effect for seed yield per plant and for number of branches per plant. The heterosis manifested in crosses of parental lines considered to be the most genetically diverse lines was less than heterosis expressed between varieties considered to be the least genetically diverse.

Key words: *Carthamus tinctorius* L., heterosis

Breeding/Genetics/Disease

INTRODUCTION

Significant breakthroughs in yield advances could be made by the exploitation of heterosis at a commercial level with the use of genetic male sterility (GMS) in safflower (Knowles, 1989). The considerable heterosis and the availability of the GMS system in safflower (Ramchandram and Sujatha, 1991 and Chitanvis *et al*,. 1999) has resulted in the development and release of the first Indian safflower hybrid, DSH-129 for commercial cultivation in India. The development of hybrid varieties of safflower, better than DSH-129, requires very high levels of useful heterosis. Production and testing of large numbers of cross-combinations is the only way to detect a desirable hybrid. One of the major problems facing the breeder is reducing the number of possible hybrids to be tested to a reasonable number. Therefore, at an initial stage of a hybrid breeding program a maximum number of potential germplasm and elite lines may be screened for their general combining ability with locally adapted varieties/ male sterile lines as testers. The parental lines that produce low yield in top crosses should be discarded and the remaining lines with good general combining ability should be utilized in the heterosis breeding program. The magnitude of heterosis increased with increased divergence within a restricted range of diversity and then decreased with further increments of diversity (Gomez, 1966). Therefore, the objectives of this study were to assess the possibilities of identifying promising experimental hybrids, to evaluate the general combining ability of parental lines and to assess the contribution of genetic divergence to the expression of heterosis.

MATERIALS AND METHODS

The experimental material consisted of twenty-two lines selected for high yield, earliness and wide adaptability *viz*., AKS-1, AKS-113, AKS-96, AKS-82, Tara, AKS-65, AKS-91, HUS-305, BLY-652, JLSF-103, AKS-68, AKS-146, AKS-207, AKS-30, CTV-209, AKS-3, JLSF-228, Bhima, A1,

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JLSF-88, Sharda, N-7 and four exotic lines *viz.*, Pl-401473, Pl-401479, Pl-253544 and S-541 supplied by Dr. R.C. Johnson, USDA-ARS, WSU, Pullman, USA. Each line was crossed with a common tester, i.e. AKSMS-1, a genetic male sterile line, during the winter season 1998, to obtain 26 crosses. Thus, a complete set of material, consisting of one tester, 26 lines and 26 crosses were raised in a randomized complete block design with two replications. The plants were spaced 45 cm between rows and plants. Twenty plants per genotype per row were grown. Plants were grown on all sides of the block to avoid border effects. Data were recorded for 10 competitive plants of each family for days to 50% flowering, plant height (cm), number of branches per plant, number of capitula per plant, number of seeds per capitulum, seed yield per plant (g), 100 seed weight (g), oil content (%), and days to maturity. The data were analyzed by top cross analysis (Davis, 1927 and White and Richmond, 1963) and genetic diversity analysis suggested by Mahalanobis (1936).

RESULTS AND DISCUSSION

Heterosis

The analysis of variance for all characters under study revealed significant genetic variability among parental lines and crosses. The phenomenon of heterosis was of general occurrence for all characters under study (Table 1). Significant heterosis was observed for all characters. However, the magnitude of heterosis and useful heterosis (over the check variety, Bhima) was low and differed for different characters. Heterosis has already been reported for various characters in safflower by many workers including Rubis, (1963,1969), Urie and Zimmer (1970) and Pandya and Patil (1994). The commercial value of a hybrid variety will depend on whether it is more profitable than the best available commercial cultivar. In this study, the highest magnitude of useful heterosis was observed in respect to the number seeds per capitulum (34.32%) followed by plant height (19.54%) and seed yield per plant (16.99%). On the basis of the results of this study, only one cross, AKSMS-1 x AKS-96, recorded significant useful heterosis over the check variety, Bhima (16.99%). AKSMS-1 x N-7 showed high and significant useful heterosis for number of seeds per capitulum (34.32%). DSH-129, a safflower hybrid released for commercial cultivation, had a 20 to 22% increase in yield over the National check, A-1. Since the yield test has been carried out in small experimental plots at one location, its true potential should be evaluated in multi-location trials in large plots. Further it is suggested that there is a need to evaluate large numbers of lines with genetic male sterile lines so as to identify hybrid combinations with very high useful heterosis.

Evaluation of parental lines

In a hybrid-breeding program, the objective is to identify parental lines that, when crossed with other parents, will produce hybrids with superior performance. The first step in evaluating the potential of new lines is to cross them to a common parent and compare the performance of their hybrids. The common parent is referred to as the 'tester' and hybrids produced are referred to as 'top crosses'. The tester is the same for all lines being evaluated; therefore, differences in performance among the hybrids reflect differences in general combining ability of parental lines. General combining ability refers to the average performance of a line in crosses with other parents. Testers are most commonly used today for evaluation of combining ability of a line or inbreds with which it would most likely be crossed to produce a commercial hybrid (Fehr, 1989). In this study (Table 1) the evaluation of twenty-six parental lines for general combining ability has been attempted with AKSMS -1, a genetic male sterile line as a tester and one of the female parents in the hybrid-breeding program. The Line x Tester combination may turn out to be a useful commercial hybrid, which shortens the length of time for hybrid evaluation and release. In the present study, only one parent i.e. AKS-96 recorded high significant general combining ability effect for seed yield per plant and number of branches per plant. This indicates that the rest of the lines are not useful for the development of hybrid varieties in safflower particularly with

Table 1. Estimates of heterosis, useful heterosis and general combining ability effects for different characters.

	Days to 50% flowering	Plant height (cm)	No.of branches /plant	No. of capitula/ plant	No.of seeds/ Capitulum	100 seed weight (g)	Seed yield /plant(g)	Oil content (%)	Days to maturity
Heterosis	-8.80**	15.60**	38.62**	31.67**	16.34**	11.13**	30.46**	11.08**	-7.14**
Useful Heterosis	-11.52**	19.54**	---	---	34.32**	7.77**	16.99**	12.76**	---
Parents									
AKS-1	-3.92*	-9.56	-1.08*	3.74	-4.59	-0.25	2.30	-0.05	5.55**
Aks-113	-6.42**	-4.06	1.82**	0.54	-3.78	-0.05	3.40	-1.01	-0.42
Aks-96	-3.92*	-9.61	2.22**	6.49	-0.62	-0.09	16.21*	-1.20	-2.92
Aks-82	-2.92	-3.41	0.07	1.29	-1.52	-0.67**	7.38	-1.51	-0.42
Tara	6.58**	3.94	-0.08	4.09	3.86	0.05	12.30	-2.34**	7.58**
AKS-65	5.08**	-0.86	-0.43	1.54	3.20	0.14	6.34	-3.69**	4.58*
AKS-91	5.58**	9.29	-0.93	0.14	-2.30	-0.09	-1.94	-2.19	4.08*
HUS-305	3.08	7.84	-0.78	0.89	0.51	0.40	1.15	3.44**	-0.42
BLY-652	0.58	-1.06	0.52	1.04	0.49	0.52*	-5.43	3.02**	-2.42
JLSF-103	7.08**	7.09	1.82**	1.29	-2.82	0.03	0.18	-2.47**	-2.42
AKS-68	1.58	-1.46	0.47	3.54	5.49*	-0.43	7.72	0.57	0.58
AKS-146	4.08*	-14.71	-0.02	-0.86	-4.09	-0.16	1.94	-2.80**	-1.42
AKS-207	-1.42	7.79	-0.18	-0.91	-1.78	0.33	7.38	-2.09*	-4.42*
AKS-30	-6.42**	-2.86	0.52	-2.41	-5.57*	0.63*	-4.72	- 0.67	1.58
CTV-209	-4.42*	1.34	1.37*	4.44	-0.56	0.69*	-2.66	0.89	-1.92
AKS-3	-3.92*	2.14	0.43	-6.01	2.09	0.15	-1.15	2.32**	7.08**
JLSF-228	-1.42	-0.91	0.17	-3.81	-4.56	0.56*	-4.56	-3.48**	-1.42
Bhima	12.58**	-3.61	-0.03	-1.66	-1.73	0.21	-5.09	3.01**	-1.42
A-1	1.08	13.79	-1.18*	-8.56*	5.08	0.47	-4.53	0.16	-0.42
JLSF-88	0.58	3.34	-1.08*	2.64	3.79	0.12	5.52	-1.40	-1.42
Sharda	4.08*	21.94**	2.22**	0.84	-2.96	0.27	-3.43	3.74**	-2.42
N-7	-5.42**	6.09	-0.08	0.89	6.50*	-0.87**	0.08	1.77*	7.08**
PI-401473	-1.92	1.14	-0.73	6.84	0.92	-1.28**	-5.73	0.77	-4.42*
PI-401479	-4.42*	9.19	-1.93**	16.56**	-2.21	-0.51*	-10.86	1.80*	-4.42*
PI-253544	-1.42	-11.16	0.98	1.39	4.52	-0.71**	-23.16**	-2.94**	-3.42
S-541	-3.92*	-31.71**	-1.28*	-0.81	2.69	0.54*	1.34*	6.35**	-1.92
SE ±	1.74	7.21	0.52	3.69	2.64	0.24	6.81	0.79	1.72

*, P ≤ 0.05 ; **, P ≤ 0.01

reference to the genetic male sterile line, AKSMS-1. Further, it also suggests that large numbers of lines should be evaluated with the genetic male sterile line to identify a potential cross with very high useful heterosis.

The relationship between genetic diversity and heterosis

The manifestation of heterosis usually depends on genetic divergence of two parental varieties. Genetic divergence among varieties usually is unknown, and the only recourse is to determine the level

Tables 2. The relationship between genetic distance and heterosis in safflower for seed yield/plant.

Clusters	Distance between clusters	F1 seed yield/plant (g)	Heterosis % (Over M.P.)†	Useful heterosis % (Over Bhima)
#II & I	8.135			
PI-401473		54.82	20.10*	-
PI-401479		46.69	28.01**	-
PI-253544		37.39	-28.91**	
S-541		61.89	24.45**	-
# II & VII	8.013			-
AKS-207		67.93	28.45**	3.53
AKS-30		55.83	6.66	-
CTV-209		57.89	16.30*	-
#II & VI	7.445			-
AKS-113		63.95	-3.39	-
AKS-96		76.76	20.00*	16.99*
#II & III	6.644			-
AKS-82		66.93	23.07**	3.53
AKS-65		66.89	17.37*	1.94
JLSF-103		60.73	8.58	-
AKS-146		62.49	8.95	-
N-7		60.63	15.47	-
#II & IV	6.613			-
AKS-1		62.85	16.11	-
Tara		72.85	30.44**	11.03
AKS-68		68.27	17.24*	4.04
AKS-3		59.40	-0.95	-
JLSF-88		66.07	9.58	0.70
#II & V	6.110			-
AKS-91		58.61	30.46**	-
BLY-652		55.12	-4.64	-
# II & VIII	5.870			-
HUS-305		61.70	10.28	-
JLSF-228		56.01	7.92	-
Bhima		55.46	-11.00	-
A-1		56.02	-12.86	-
Sharda		57.12	-8.30	-

*, $P \leq 0.05$; **, $P \leq 0.01$
Cluster II includes only AKSMS-1 – GMS line
† M. P. = Mid-parent

of genetic divergence empirically by means of variety crosses and D^2 statistics. Genetic divergence of the parental varieties is inferred from the heterotic patterns manifested in a series of variety crosses. If heterosis manifested from the cross of two parental varieties is relatively large, it is concluded that the two parental varieties are more genetically diverse than two varieties that manifest little or no heterosis in their variety crosses (Hallauer and Miranda, 1988). The assessment of genetic divergence by D^2 statistic is useful in choosing parents for realizing heterosis and recombination in breeding programmes (Murty, 1965). The crosses between the parents with high genetic distance between cluster II and I (8.135), II and VII (8.013) did not exhibit significant useful heterosis for seed yield per plant (Table 2). Similarly, the crosses with a lower genetic distance between clusters II and IV (6.613), II and V (6.11) and II and VIII (5.87) also resulted in non-significant useful heterosis. However, only one cross i.e. AKSMS-1 x AKS-96 exhibited significant useful heterosis for seed yield per plant (16.99%) between cluster II and VI with a genetic distance 7.445. Therefore, this study revealed that heterosis manifested in crosses of parental lines, which are the most genetically diverse, was more than heterosis expressed between varieties considered to be less genetically diverse. Also these results suggested that the concept of genetic divergence for maximum expression of heterosis has limits. It is a logical conclusion that the parents are genetically divergent when heterosis is realized. But it does not follow that heterosis will result when parents are divergent. The results of this study are in agreement with those of Moll et al. (1965) and Gomez (1966). Their results indicated that the magnitude of heterosis increases with increased divergence with a restricted range of diversity and then decreased with further increments of diversity.

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Application of Simplified Triple Test Cross and Combining Ability Analysis to Determine the Gene Action in Safflower

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ABSTRACT

Highly selected lines of safflower (*Carthamus tinctorius L.*) were investigated to estimate gene action by using the simplified triple test cross and the line x tester analysis approach. The simplified triple test cross and line x tester approaches were equally effective in determining the additive component of genetic variance. The estimates of dominance components obtained in the presence of epistatic interaction, were biased to a greater extent in the line x tester approach than in the simplified triple test cross approach. The dominance component (H_R) estimated from the line x tester analysis was twice that of the dominance component (H_1) estimated from the simplified triple test cross analysis. The simplified triple test cross analysis has been indicated to be a more useful technique for the study of genetic architecture of economically important characters.

Key words: *Carthamus tinctorius* L., gene action.

Breeding/Genetics/Disease

INTRODUCTION

The assessment of the magnitude of gene action for quantitative characters is helpful in deciding the appropriate breeding procedure. Combining ability analysis (Line x Tester, and Diallel analysis) has been quite commonly used in safflower to identify the parents for hybridization programmes and also interpreted in terms of gene action (Makne and Choudhary, 1980; Ranga Rao 1983; Narkhede, et al., 1984; and Pandya et al., 1990). Their results indicated the predominance of non-additive gene action for agronomic traits in safflower. Epistasis was found to be an important part of the genetic system in safflower (Janolkar and Ghorpade, 1993; and Deshmukh et al., 1993), but no test for the presence of epistasis is provided by the combining ability approach, the estimates of general (σ^2_{GCA}) and specific combining ability variances (σ^2_{SCA}), being affected in an unpredictable manner (Baker, 1978). The triple test cross analysis of Kearsey and Jinks (1968) and it's modification by Jinks, Perkins and Breese (1969), however, provide an unambiguous test of epistasis. Therefore, the objective of this study was to find out which of these two approaches was more sensitive to determine the gene action in the presence of epistasis in safflower.

MATERIALS AND METHODS

The experimental material consisted of ten elite lines of safflower *viz.*, Sharda, AKS-68, AKS-146, JLSF-103, AKS-91, AKS-65, N-7, BLY-652, A-1, and JLSF-228. Each line was crossed with two testers (females) *viz.*, Bhima and HUS-305 during the winter season, 1995. The complete set of material under study, consisting of two testers, ten lines and twenty crosses were planted in a single block in which the plants of each family were individually randomized during the winter season 1996 as described by Mather and Jinks (1982). Ten plants were allotted for each of the lines (males), testers (females) and F_1's for randomization. Plants were spaced 45 cm between rows and between plants. Data were recorded for all plants of each family for eight agronomic characters. Statistical and

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Table 1. Analysis of variance for combining ability in safflower.

Source of variation	d.f.	Mean squares							
		Days to flower	Plant height (cm)	No.of secondary branches /plant	No.of capitula/ plant	No.of seeds/ capitulum	100seed weight(g)	Seed yield per plant (g)	Oil content (%)
Between crosses	19	71.16**	48.62**	11.61**	126.13**	17.68**	1.12**	162.28**	10.05**
Males (m)	9	92.36**	16.69*	12.45**	127.90**	14.60**	1.51**	150.56**	6.50**
Females (f)	1	7.65^{NS}	451.43**	0.71^{NS}	23.50^{NS}	35.40**	0.20^{NS}	107.69*	0.003^{NS}
Males vs females	9	57.02**	35.79**	11.98**	135.76**	18.80**	0.84**	180.06**	14.72**
Within family	137†	8.42	6.57	1.19	20.82	2.27	0.22	25.90	1.24
Variance									
$\sigma^2_{GCA(M)}$		41.97	5.06	5.63	53.54	6.16	0.64	62.33	2.63
σ^2_{SCA}		48.60	29.22	10.79	114.94	16.53	0.62	154.16	13.48
Component									
D_R		167.88	20.24	22.52	214.16	24.64	2.56	249.32	10.52
H_R		194.4	116.88	43.16	459.76	66.12	2.48	616.64	53.92

* = $P \leq 0.05$ ** = $P \leq 0.01$ [$2\sigma^2_{GCA}=\sigma^2 A=1/2\ D_R$; $\sigma^2_{SCA}=\sigma^2_D=1/4\ H_R$]
NS – Non-Significant.
† = The degrees of freedom are less than expected due to loss of plants.

biometrical analyses were performed as suggested by Kempthorne (1957) with the fixed effect model, in which the mean squares due to males, and males x females were used to calculate σ^2_{GCA} and σ^2_{SCA} respectively. For direct comparison, the additive and dominance components were transformed into the D_R and H_R as suggested by Kearsey (1965). The analysis of the simplified triple test cross (STTC) was conducted according to the methodology given by Jinks *et.al.* (1969).

RESULTS AND DISCUSSION

The variances due to general (σ^2_{GCA}) and specific (σ^2_{SCA}) combining ability were significant for all the characters studied (Table 1). The magnitude of σ^2_{SCA} was higher than that of σ^2_{GCA} for all characters except 100 seed weight. Further the transformation of additive (D_R) and dominance (H_R) components also indicated the importance of dominance components for all agronomic traits except for 100 seed weight. The analysis of variance for the test of epistasis is based on the comparison $L_{1i} + L_{2i} - P_i$ (Table 2). The mean squares due to epistasis were significant for all traits indicating the presence of epistasis for all traits under study. The analysis of variance for the sums ($L_{1i} + L_{2i}$) and differences ($L_{1i} - L_{2i}$) revealed that the mean squares due to sums and differences were significant for all characters. The estimates of additive (D) and dominance (H_1) components indicated a predominance of additive gene action for days to flower, number of secondary branches per plant and 100 seed weight. However, a predominance of dominance was determined for plant height, number of capitula per plant, number of seeds per capitulum, seed yield/plant and oil content. The estimate of F was non significant for all characters under study indicating that there is a dominance contribution to variation but the dominance is ambidirectional. A wide occurrence of non-allelic interactions warrants their detection, estimation and consideration in the formation of suitable breeding programme. In the present study, epistasis was an important component in the inheritance of quantitative traits under study (Table 2). Epistasis for

Table 2. Test of epistasis and estimates of additive and dominance components for different characters in safflower.

Source of Variation	d.f.	Mean Squares: Days to flower	Plant height (cm)	No.of secondary branches /plant	No.of capitula/plant	No.of seeds/capitulum	100 seed weight (g)	Seed yield per plant (g)	Oil content (%)
Epistasis ($L_{1i}+L_{2i}-Pi$)	9	65.45**	53.32**	6.91**	87.58**	12.04**	1.17**	110.07**	7.25**
Within family	91†	9.45	6.49	1.57	19.65	2.30	0.20	20.97	1.10
Sums ($L_{1i}+L_{2i}$)	9	92.36**	16.69*	12.45**	127.90**	14.60**	1.50**	150.56**	6.50**
Differences ($L_{1i}-L_{2i}$)	9	57.01**	35.78**	11.97**	135.75**	18.80**	0.84**	180.06**	14.72**
Within family	37†	8.42	6.57	1.19	20.82	2.27	0.22	25.94	1.25
Component									
D		167.86	20.24	22.52	214.16	24.66	2.56	249.25	10.50
H_1		97.18	58.42	21.56	229.50	33.06	1.24	308.25	26.94
F		90.76^{NS}	57.02^{NS}	6.24^{NS}	-1.09^{NS}	9.75^{NS}	-0.68^{NS}	-27.08^{NS}	-1.69^{NS}
$\sqrt{H1/D}$		0.76	1.69	0.97	1.03	1.15	0.69	1.11	1.60

*, $p \leq 0.05$; **, $P \leq 0.01$

† = The degrees of freedom are less than expected due to loss of plants.

yield and its components has been reported in safflower by Kotecha (1981), Janolkar and Ghorpade (1993) and Deshmukh et al. (1993).

Therefore, the additive and dominance components were estimated using the epistatic model to determine which of these two approaches was more sensitive to determine the gene action in the presence of epistasis in safflower. As the parents involved in the present study were not a random sample of lines from an originally random mating population, the information obtained is applicable only to this set of selected lines. Perusal of comparative estimates of genetic components (Table 3) revealed that additive components (D_R) from the combining ability approach were as uniformly estimated as those of the simplified triple test cross (STTC) analysis. It may thus be emphasized that the combining ability analysis is quite useful in detecting additive gene action. The estimates of dominance components (H_R) obtained in the presence of epistatic interactions were biased to a greater extent in the

Table 3. Comparative estimates of additive and dominance component for different characters in safflower.

Characters	Combining ability approach		Simplified triple test cross approach	
	D_R	**H_R**	**D**	**H_1**
1. Days to flower	167.88	194.4	167.86	97.18
2. Plant height	20.24	116.88	20.24	58.42
3.Number of secondary branches/plant	22.52	43.16	22.52	21.56
4. Number of capitula/plant	214.16	459.76	214.16	229.50
5. Number of seeds/capitulum	24.64	66.12	24.66	33.06
6. 100 seed weight	2.56	2.48	2.56	1.24
7. Seed yield/plant	249.32	616.64	249.25	308.25
8. Oil content	10.52	53.92	10.50	26.94

line x tester approach than that in the STTC approach. The dominance component (H_R) estimated from the line x tester analysis was twice a large and may be more influenced by epistatic interactions than that of the dominance component (H_1) estimated from STTC analysis. Kearsey (1965) also indicated an inflation of dominance by adopting the North Carolina approach. Therefore, STTC analysis has been indicated to be the more useful technique to study the genetic architecture of economically important characters. In safflower, therefore, the combining ability analysis (line x Tester) should only be used to estimate general combining ability of the parents and crossing may screen a large number of germplasm lines with a tester of a broad genetic base.

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Combining Hybridization and Irradiation for Enhancing Genetic Variability in Early Segregating Generations of Safflower Crosses

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ABSTRACT

An investigation has been carried out to assess the extent of genetic variability created and possible shifts which occurred in the association of eight quantitative characters in segregating generations of two safflower crosses, with populations generated by irradiation of 40 kr r-rays at F_0 stage (Irradiated series, F_2M_2 and F_3M_3) and untreated normal populations (Selfing series, F_2 and F_3). The number of capitula, capitula weight, seed number, seed weight, and oil content had a higher range and variance in the F_3 M_3 compared to the F_3 population. This is attributed to the release of hidden variability by irradiation at the early stage. Furthermore, there were also changes in inheritability values and genetic advance as seen by higher or lower values in both crosses. The associations of most yield contributing traits with seed yield showed marked changes in degree and direction of correlations in the F_3M_3 population of both crosses. As a result of irradiation, the strong negative relationships existing between hull and oil content, and between seed yield and oil content were decreased. Thus, additional variability created for some of the important yield traits coupled with shifts in correlations from negative to positive would offer greater scope for selection in the irradiated population.

Key words: Safflower, irradiation, hidden variability, associations

Breeding/Genetics/Disease

INTRODUCTION

The undesirable associations existing between important yield attributes of safflower interfere with the simultaneous improvement of seed yield and oil content (Parameswarappa et al., 1984). An attempt to release hidden variability through hybridization alone has not been successful (Ramachandram, 1985). The usefulness of inter-mating in segregating populations (Prakash & Prakash, 1993 and Parameshwarappa, 1997) or combining hybridization and irradiation (Patil et al, 1997) for the release of hidden genetic variability by breaking tight linkages between traits has been well realized. As a result, the variability released in irradiated populations would be more than anticipated by use of the pedigree method adopted in self-breeding crops. This would offer greater scope for selection of traits having a background of correlated responses. Due to the breakage of close linkages between the traits, the genotypes can be restructured to realize improvement for both seed yield and oil content. Therefore, the present investigation has been carried out to assess the extent of genetic variability created and changes which occurred on the nature of correlations in two crosses of safflower by using irradiation of crossed seeds and comparing irradiated and normal populations .

MATERIALS AND METHODS

Two varieties, A-1 (high capitula number, thick hull, low oil and high yield) and A-2 (low capitula number, reduced hull, high oil were crossed with advanced breeding lines CTV-199 (spineless, bold capitula with higher number of seeds) and 425-6 (striped hull, high oil) to develop the two crosses A-I x CTV-199 and 425-6x A-2. Part of the crossed seeds (F_0 seeds) in these crosses were subjected with 40 kr gamma irradiation while the remaining seeds were used for the pedigree breeding procedure. The

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irradiated as well as F_0 seeds were grown in separate rows to F_1M_1 and F_1 generations, respectively. The lines were protected from out-crossing by covering plants with a polythene net. Preliminary observations on germination, seedling mortality and chlorophyll mutations were recorded in both irradiated crosses. The selfed seeds of the corresponding crosses were used to produce large F_2M_2 and F_2 populations during the *rabi* (winter) season of 1995-96 at the Agricultural Research Station, Annigeri, India. In each of the crosses 150 competitive plants were tagged to collect observations on eight quantitative characters. After the analysis, 40 single plants from the corresponding crosses were selected and advanced to raise respective F_3 and F_3 M_3 populations using randomized block design with two replications at Annigeri during the *rabi* 1996-97. Recommended agronomic practices were followed and observations on eight quantitative characters were recorded on five random plants in each treatment and replication. The mean, range and correlations were computed in the populations of the crosses. The genetic variability created and possible shifts that occurred in correlations of characters were assessed by comparing treated and normal populations.

RESULTS AND DISCUSSION

The mean values and ranges of various quantitative characters for the treated populations F_2M_2 and F_3M_3 along with their selfed populations F_2 and F_3 are given in Table 1. The mean values for most of the characters in the irradiated populations were similar to those of their corresponding selfed generations indicating the lack of additional variability over their untreated populations. This is in accordance with earlier results of Saini and Sharma, 1970. However, considerable shifts occurred with respect to the ranges of the characters in both irradiated populations. This was evident by the higher values in the upper limit of the ranges in both the F_2M_2 and the F_3M_3 generations with respect to number of capitula, capitula weight, seed number, oil content, and seed yield. This indicates that although irradiation has not brought in additional variability in every genotype it was evident at least in certain segregants, which was reflected on the ranges but not the mean values. Therefore, it can be hypothesized that the pattern of variability generated due to irradiation is much more important than a mere increase in the value of an individual character.

The variability created and the heritable portion can also be assessed by considering the coefficient of variation and the heritability with genetic advance (Table 2). The magnitude of genotypic as well as phenotypic variance was higher in F_3M_3 for both crosses for all characters studied except for seed number and seed weight in the cross of 425-6 x A-2 and for genotypic variance of seed yield in the A-1 x CTV-199 cross. This was also confirmed by the corresponding values of genotypic and phenotypic coefficients of variation.

Irradiation has also brought about changes in the heritability of a character. Heritability was increased from F_3 to F_3M_3 in the cross A-1 X CTV-199 for seed number (12.3 to 40.50), capitula size (18.30 to 56.4), seed weight (38.6 to 97.5), and capitula weight (30.80 to 65.5). However, the number of capitula (37.8 to 65.5) and oil content (73.8 to 94.4) recorded the highest increase in 425-6 x A-2. A similar trend was also reflected in the estimates of genetic advance of characters in both crosses.

The genetic correlations worked out separately for both populations are presented in Table 3. The important yield components like capitula size, seed number, seed weight and hull content have shown significant positive association with seed yield in F_3. Irradiation created shifts in correlations in both directions. The association was further strengthened in F_3M_3 populations for characters capitula weight cross I. However, there was no favorable change in the relationship of seed yield and oil content due to irradiation in either cross. This is perhaps due to the negative association of hull content with oil content, which was not changed in magnitude or direction in both treated populations. In the present study, hull content was positively and strongly associated with seed yield but negatively with oil content (Parameshwarappa et al., 1984). However, the magnitude of negative association of hull content with oil content was reduced to non significance in F_3M_3 of the cross A-1 x CTV-199 indicating

Table 1. Mean and ranges for different characters in segregating generations of irradiated and normal safflower

Character	Cross		Mean		Range	
			F2 & F2M2	F3 & F3M3	F2 & F2M2	F3 & F3M3
Number of Capitula	I	C	12.14	12.36	13.0-25.0	9.0-17.4
		T	14.12	12.18	12.0-27.0	8.6-20.4
	II	C	13.80	12.05	16.0-26.0	9.8-16.8
		T	16.2	12.62	15.0-27.0	10.0-20.0
Capitula Weight (g)	I	C	27.20	27.95	24.1-40.0	23.3-38.0
		T	26.50	26.21	18.6-40.4	19.2-41.4
	II	C	27.80	27.91	19.3-34.7	20.0-35.6
		T	26.66	27.03	20.5-40.3	19.2-38.0
Capitula Size(mm)	I	C	2.21	2.24	2.0-2.7	2.1-2.36
		T	2.24	2.25	2 0-2.8	2.0-2.52
	II	C	2.30	2.23	2.0-2.6	2.1-2.34
		T	2.28	2.25	2.1-2.7	2.1-2.38
Seed Number	I	C	26.27	26.8	10.0-42.0	21.3-33.5
		T	28.27	27.21	11.0-42.0	18.6-41.0
	II	C	29.84	26.11	17.0-36.0	19.8-27.0
		T	28.76	27.22	14.0-40.0	21.8-26.8
Seed Weight (g)	I	C	4.83	5.39	4.1-7.5	3.3-7.3
		T	5.43	5.09	3.7-7.6	3.3-7.2
	II	C	4.60	4.71	4.7-6.4	3.5-6.5
		T	5.20	4.70	3.9-5.8	3.4-5.7
Hull Content (%)	I	C	47.29	46.28	41.2-50.0	44.6-52.0
		T	46.39	46.00	40.0-52.0	41.0-51.9
	II	C	46.60	43.04	43.2-50.8	40.0-48.0
		T	44.80	43.65	42.0-46.8	39.2-47.2
Oil Content(%)	I	C	29.66	30.26	28.0-30.4	27.0-32.5
		T	30.02	30.43	27.8-31.8	28.6-34.1
	II	C	31.52	32.26	27.4-34.0	25.5-36.0
		T	33.10	33.53	29.5-37.7	29.0-37.1
Seed Yield (g)	I	C	16.20	14.65	10.0-28.0	9.4-23.0
		T	18.03	13.54	10.0-30.0	8.8-23.4
	II	C	15.40	12.28	13.0-21.0	10.0-20.0
		T	17.21	14.81	10.0-25.0	11.0-25.0

Cross I – AI x CTV-199
Cross II—425-6 x A2

C – Control (F2F3)
T - Treated (F2M2 & F3M3)

Table 2: Parameters of genetic variability for different characters in segregating control and irradiated population of safflower

Character	Crosses		No. of Capitula	Capitula weight	Capitula size	Seed No.	Seed weight	Hull content	Oil content	Seed yield
Genotypic variance	I	C	2.29	2.58	0.000	0.73	0.19	3.77	0.40	6.53
		T	4.29	21.11	0.014	14.16	0.63	7.92	2.25	5.41
	II	C	1.80	14.02	0.001	2.43	6.57	2.44	1.66	3.41
		T	3.93	33.01	0.003	1.15	0.38	9.18	3.78	9.64
Phenotypic variance	I	C	4.87	8.39	0.002	5.92	0.49	4.59	1.01	9.74
		T	7.76	32.24	0.024	36.03	0.65	9.68	6.67	12.49
	II	C	4.76	19.17	0.003	6.15	6.73	3.20	2.25	5.04
		T	6.00	39.20	0.014	2.91	0.45	9.59	4.00	11.71
GCV (%)	I	C	12.25	5.76	0.95	3.18	8.09	4.20	2.10	17.44
		T	17.01	17.53	5.22	14.04	15.56	6.12	4.93	17.88
	II	C	10.61	13.42	1.53	6.03	16.28	3.63	4.00	15.05
		T	15.71	20.57	2.59	4.46	13.25	6.94	5.80	20.96
PCV (%)	I	C	17.87	10.37	2.21	9.08	13.01	4.64	3.35	21.3
		T	22.88	21.66	6.96	32.05	15.86	8.49	6.76	26.1
	II	C	17.25	15.69	2.55	9.60	18.26	4.16	4.66	18.3
		T	19.41	22.42	4.67	7.10	14.46	7.10	5.97	23.1
Heritability (%)	I	C	47.00	30.80	18.30	12.3	38.6	82.1	39.6	69.0
		T	53.00	65.50	56.40	40.5	97.5	81.8	33.7	43.0
	II	C	37.80	73.10	35.90	39.4	79.5	76.0	73.8	67.7
		T	65.50	84.20	30.70	39.5	83.9	95.7	94.4	82.3
GA (%)	I	C	17.31	6.58	0.89	2.31	10.38	3.84	2.74	29.8
		T	26.30	29.22	8.00	18.37	31.82	3.69	5.88	23.3
	II	C	13.43	23.54	1.79	7.81	29.93	6.50	7.09	25.5
		T	26.22	38.88	3.11	5.71	24.89	13.99	11.60	39.1

Cross I - AI x CTV-199
Cross II - 425-6 x A2

C – Control (F2F3)
T - Treated (F2M2 & F3M3)

improvement for a character is more independent of the other in F_3M_3. Among the important yield components, the relationship existing between number of capitula with capitula weight and seed number; capitula weight with seed number and capitula size with seed number have not been changed in F_3M_3 (Ramachandram and Goud, 1982). For other traits, the shifts in associations were noticed in either direction irrespective of the crosses. Therefore, irradiation can bring about random changes in the pattern of correlations for potential selection to improve the character of interest.

Analysis of direct and indirect contributions of various yield components to seed yield (Table 4) suggests that number of capitula is one of the most important traits influencing seed yield accompanied by substantial shift in its direct effects towards improvement of the character (0.591 to 0.883) in the cross 425-6 x A-2, which was followed by capitula weight (-0.86 to 0.43) and hull content (-0.61 to

Table 3 : Genetic correlations among different characters in F3M3 populations of safflower

Character	Crosses	Capitula weight	Capitula size	Seed No.	Seed weight	Hull content	Oil content	Seed yield
Number of capitula	I C	0.55**	-0.17	0.09	0.01	0.29	0.33	0.19
	T	0.64	-0.70	-0.35	-0.01	0.02	-0.20	0.52
	II C	0.36**	0.22	-0.02	-0.31	0.11	-0.38	0.34
	T	0.81**	0.19	0.17	0.01	-0.06	-0.16	0.35
Capitula Weight	I C		0.18	0.82	0.41	0.16	0.15	0.14
	T		-0.02	0.31	0.17	0.11	-0.38	0.68**
	II C		-0.09	-0.16	-0.02	0.10	-0.02	-0.18
	T		-0.02	0.13	-0.12	-0.17	-0.15	0.33
Capitula size	I C			0.32*	0.83**	0.16	-0.19	0.64**
	T			-0.01	-0.01	0.37*	0.05	-0.23
	II C			0.31	0.31	0.70	-0.34**	0.71**
	T			-0.39	-0.39	0.09	-0.02	0.17
Seed number	I C				0.77**	0.12	-0.46**	0.86**
	T				-0.06	0.28	-0.09	0.20
	II C				0.34	0.36**	-0.11	0.52**
	T				-0.31	-0.20	0.21	-0.05
Seed weight	I C					0.56	-0.17	0.83**
	T					0.25	-0.28	0.16
	II C					0.31	-0.19	0.69**
	T					0.48	-0.22	0.16
Hull content	I C						-0.64	0.72**
	T						-0.22	0.28
	II C						-0.58	0.53**
	T						-0.65	-0.39
Oil content	I C							-0.66
	T							-0.52
	II C							-0.12
	T							-0.37

Cross I – A-1 x CTV-199 C-Control (F2&F3) *Significant at 5%
Cross II- 425-6 x A-2 T-Treated (F2M2&F3M3) ** Significant at 1%

0.67) in F_3M_3 of the cross A-1 x CTV-199. Similarly, shifts in magnitude and direction of indirect effects of component characters on seed yield have also been observed.

From the results obtained, it can be concluded that combination of hybridization and irradiation can bring about trickled variation in addition to the variability generated by hybridization alone. Nevertheless, a little additional variation generated through irradiation can be suitably exploited in improving both seed yield and oil content by striking a balance between component characters. Breakage of tight linkages between the character of interest such as hull content and oil content helps to improve the characters through selection

Table 4. Path Analysis for different characters in F3 and F3M3 populations of safflower.

Character	Crosses		No. of Capitula	Capitula weight	Capitula size	Seed No.	Seed weight	Hull content	Oil content	r-values
Number of capitula	I	C	**0.75**	-0.48	-0.02	0.03	0.05	-0.18	-0.29	0.19
		T	**-0.42**	0.28	1.00	0.06	0.00	0.01	0.10	0.52**
	II	C	**0.59**	-0.31	-0.13	-0.01	-0.31	0.12	-0.38	0.33*
		T	**0.88**	-0.09	0.01	0.05	0.00	-0.02	0.02	0.35*
Capitula Weight	I	C	0.41	**-0.86**	0.03	0.28	0.39	-0.10	-0.14	0.13
		T	-0.27	**0.43**	0.01	-0.05	-0.01	0.01	0.15	0.57**
	II	C	0.22	**-0.86**	0.05	-0.05	-0.02	0.11	-0.02	-0.18
		T	0.71	**-0.10**	0.00	0.03	-0.01	-0.02	0.03	0.32
Capitula size	I	C	-0.13	-0.15	**0.14**	0.11	0.08	-0.09	-0.18	0.66**
		T	0.29	-0.01	**-1.56**	-0.12	0.00	0.25	-0.02	-0.23
	II	C	0.13	0.08	**0.56**	0.21	0.31	0.76	-0.34	0.71**
		T	0.17	0.01	**0.01**	0.26	-0.01	0.03	0.01	0.17
Seed number	I	C	0.07	-0.70	0.05	**0.34**	0.77	-0.08	0.41	0.86**
		T	0.15	0.13	-1.15	**-0.16**	0.01	0.19	0.03	0.19
	II	C	-0.01	0.14	-0.41	**0.29**	0.34	0.39	-0.11	0.52
		T	0.15	-0.01	0.01	**0.27**	-0.01	0.06	-0.04	-0.05
Seed weight	I	C	0.04	-0.35	0.12	0.27	**0.97**	-0.35	0.15	0.83**
		T	0.01	0.03	0.02	0.01	**-0.12**	0.17	0.11	0.16
	II	C	-0.19	0.02	-0.07	0.09	**1.01**	0.34	-0.19	0.69**
		T	-0.04	0.01	-0.01	-0.08	**0.02**	0.14	0.04	0.12
Hull content	I	C	0.22	-0.14	0.02	0.04	0.55	**-0.61**	0.57	0.72**
		T	-0.01	0.05	-0.56	-0.04	-0.02	**0.67**	0.08	0.28
	II	C	0.06	-0.09	-0.39	0.10	-0.32	**1.09**	-0.58	0.53**
		T	-0.06	0.01	0.01	-0.05	0.01	**0.31**	0.11	-0.39
Oil content	I	C	0.25	-0.13	-0.02	-0.16	-0.16	0.39	**-0.89**	-0.66**
		T	0.11	0.16	-0.01	0.01	0.03	-0.15	**-0.39**	-0.55
	II	C	-0.22	0.02	0.19	-0.03	-0.19	-0.63	**1.01**	-0.12
		T	-0.14	0.02	0.00	0.05	0.01	-0.20	**-0.17**	-0.37

Diagonal : Direct effects

Cross 1 – A1 x CTV-199 C- Control (F2&F3) Residual factors I F3 : -0.49
F3M3 : 0.35

Cross II – 125-6 x A-2 T- Treated(F2M2&F3M3) Residual factors II F3 : -0.70
F3M3 : 0.60

* -Significant at 5% level ** -Significant at 1% level

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Commercialization of Safflower Hybrids

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ABSTRACT

When safflower hybrids are planted at a seeding rate of 10 pounds per acre their yield performance has been very good. Once growers understand the economic returns from hybrid safflower varieties, they are not resistant to purchasing hybrid seed at a higher price. Results of trials from a Provincial Research Organization (EEAOC) in Argentina are summarized. A typical result was a location in northern Argentina where the best variety (S-317) yielded 1,947 kilos per hectare (1,787 pounds per acre) and the hybrid (GW9025) yielded 2,727 kilos per hectare (2,503 pounds per acre)

Keywords: Safflower, Safflower hybrids, planting rate, heterosis

Breeding/Genetics/Disease

INTRODUCTION

Testing hybrid safflower over the years has demonstrated that safflower hybrids MUST be planted at lower seeding rates to allow the heterosis of the hybrid to be expressed. SAFFTECH is recommending a seeding rate of 10 pounds per acre and 11 kilos per hectare for safflower hybrids.

MATERIALS AND METHODS

The 1998 trials shown in Tables 1 and 2 were planted at 11 kilos per hectare by an Estacion Experimental Agroindustrial, Obispo Colombres, Seccion Granos (EEAOC) in the Tucuman and Catamarca provinces in Argentina. Graciela Salas conducted these trials under the direction of Jose Mejail. Oil contents were not available from the Argentina trials. The Argentina research organization reported, however, that the hybrids were at least equal to the conventional varieties in oil content. The 1999 trial shown in Table 3 was planted at 10 pounds per acre in a production field near Sacremento, California.

RESULTS AND DISCUSSION

Table 1. 1998 safflower yield data obtained from trials in Tucuman province, Argentina, under rainfed conditions. Planted 27 June 1998 and harvested 1 December 1998.

Location	Variety	Yield lbs/A	%S-317	%CW-74
Canete	Hybrid GW9025	2503	140%	166%
	S-317	1787	100%	119%
	Sironaria	1606	90%	107%
	CW-74	1505	84%	100%
	S-541	1368	77%	91%
	S-296	1340	75%	89%
La Cruz	Hybrid GW9025	2160	144%	169%
	S-317	1496	100%	117%
	Sironaria	1365	91%	107%
	S-296	1306	87%	102%
	CW-74	1276	85%	100%
	S-541	1126	75%	88%

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Table 2. 1998 safflower yield data obtained from a replicated strip trial in Catamarca province, Argentina, under rainfed conditions. Planted 05 June 1998 and harvested 1 December 1998.

Location	Variety	Yield lbs./Acre	%CW-74
Los Altos	Hybrid GW9025	1482	223%
	CW-74	665	100%

Table 3. 1999 Irrigated yield from a strip trial in a commercial production field near Sacramento, California. Planted 12 April 1999 and harvested 2 September 1999.

	oil content %	Yield lbs./Acre	Yield %S-518
Hybrid GW9025	42.3%	4,120	138%
S-518	41.6%	3,000	100%

The data from the Argentina public trials clearly demonstrate the superior yield performance of the hybrids under rainfed conditions. These trials were planted at 11 kilos per hectare (10 pounds per acre). The rate of 11 kilos has been selected by the local safflower growers after many years of testing and experience on their own farms with conventional varieties. Therefore the economic comparisons between hybrids and conventional varieties shown in Table 4 do not show a reduction in planting rate with the hybrids. Planting at this lower seeding rate is very important. At higher seeding rates other factors limit yield before the heterosis can be expressed. The factors that limit yield at higher planting rates include available water, light and nutrients.

The hybrids give very good yield results where planted at 10 pounds per acre and when there is sufficient growing season to finish the multi bloom pattern of the hybrids. Some years ago a strip trial at an irrigated location showed hybrids with no yield advantage over conventional varieties. After investigation it was determined the lack of yield response of the hybrids was due to the irrigation method used. The grower had made only one large irrigation when the plants were about 10 inches tall without further irrigation. The conventional varieties grew well and produced a good crop. The hybrids, however, made a large burst of growth in response to the irrigation but outgrew the available water supply. On the same farm a trial was planted on pre-irrigated land without any crop irrigation and the hybrids showed a 143% advantage in yield. However, the yield level of the conventional variety in the pre-irrigated area was the same as the conventional variety in the one-irrigation strip test location.

Another observed characteristic of hybrids in variety trials is a higher percentage of outcrossing than conventional varieties. Thus, it is necessary to use selfed seed to assess oil quality of hybrids in hybrid variety trials. Selfed heads from border rows are recommended to provide pure seed for oil quality analysis.

Safflower production has the potential to increase with higher yielding hybrids, but only if the demand for high quality safflower oil increases. An advertising program is needed to sell the advantages of safflower's high quality oil in the vegetable oil markets.

Tables 4 and 5 show the economic returns of growing hybrids compared to conventional varieties based on the expressed heterosis. Table 4 does not include a reduction in planting rate for the hybrids as it was prepared for the growers in Argentina who use 11 kilos per hectare (10 pounds per acre) planting rates already for conventional varieties.

With the current price for safflower seed for crushing at 8 cents per pound the breakeven point with 130% heterosis expression in yield would be about 550 pounds per acre and at 140% heterosis expression in yield the breakeven point would be 400 pounds per acre. The breakeven point for Table 4 with 130% heterosis expression in yield corresponds to 660 kilos per hectare and at 140% heterosis the breakeven point is 500 kilos per hectare.

Table 4a. Economic comparison between hybrid and conventional safflower varieties at different levels of heterosis expression for yield.

HYBRID SAFFLOWER VS CONVENTIONALVARIETIES PER HECTARE

Variety	Planting Kilos/Ha	Cost Per/Kilo	Cost Per/Ha	Heterosis Expression	Yield Kilos/Ha	Income @$0.10/Lb	Added Cost	Added Return	Net Profit
Conventional	11	$2.00	$22.00	0	817	$180	$0	$0	$0
Hybrid	11	$6.00	$66.00	130%	1,062	$234	$44	$54	$10
Hybrid	11	$6.00	$66.00	140%	1,144	$252	$44	$72	$28
Hybrid	11	$6.00	$66.00	150%	1,226	$270	$44	$90	$46
Conventional	11	$2.00	$22.00	0	1,090	$240	$0	$0	$0
Hybrid	11	$6.00	$66.00	130%	1,417	$312	$44	$72	$28
Hybrid	11	$6.00	$66.00	140%	1,526	$336	$44	$96	$52
Hybrid	11	$6.00	$66.00	150%	1,635	$360	$44	$120	$76
Conventional	11	$2.00	$22.00	0	2,179	$480	$0	$0	$0
Hybrid	11	$6.00	$66.00	130%	2,833	$624	$44	$144	$100
Hybrid	11	$6.00	$66.00	140%	3,051	$673	$44	$192	$148
Hybrid	11	$6.00	$66.00	150%	3,269	$721	$44	$240	$196
Conventional	11	$2.00	$22.00	0	3,268	$720	$0	$0	$0
Hybrid	11	$6.00	$66.00	130%	4,248	$937	$44	$216	$172
Hybrid	11	$6.00	$66.00	140%	4,575	$1,009	$44	$288	$244
Hybrid	11	$6.00	$66.00	150%	4,902	$1,081	$44	$360	$316
Conventional	11	$2.00	$22.00	0	4,358	$961	$0	$0	$0
Hybrid	11	$6.00	$66.00	130%	5,665	$1,249	$44	$288	$244
Hybrid	11	$6.00	$66.00	140%	6,101	$1,345	$44	$384	$340
Hybrid	11	$6.00	$66.00	150%	6,537	$1,441	$44	$480	$436

Breeding/Genetics/Disease

Table 4b. Economic comparison between hybrid and conventional safflower varieties at different levels of heterosis expression for yield.

HYBRID SAFFLOWER VS VARIETIES PER ACRE

Variety	Planting Rate/Acre	Cost Per/Lb	Cost Per/Acre	Heterosis Expression	Yield Lbs/Acre	Income @$0.10	Added Cost	Added Return	Net Profit
Conventional	20	$0.60	$12.00	0	750	$75	$0	$0	
Hybrid	10	$2.50	$25.00	130%	975	$98	$13	$23	$10
Hybrid	10	$2.50	$25.00	140%	1050	$105	$13	$30	$17
Hybrid	10	$2.50	$25.00	150%	1125	$113	$13	$38	$25
Conventional	20	$0.60	$12.00	0	1000	$100	$0	$0	
Hybrid	10	$2.50	$25.00	130%	1300	$130	$13	$30	$17
Hybrid	10	$2.50	$25.00	140%	1400	$140	$13	$40	$27
Hybrid	10	$2.50	$25.00	150%	1500	$150	$13	$50	$37
Conventional	20	$0.60	$12.00	0	2000	$200	$0	$0	
Hybrid	10	$2.50	$25.00	130%	2600	$260	$13	$60	$47
Hybrid	10	$2.50	$25.00	140%	2800	$280	$13	$80	$67
Hybrid	10	$2.50	$25.00	150%	3000	$300	$13	$100	$87
Conventional	20	$0.60	$12.00	0	3000	$300	$0	$0	
Hybrid	10	$2.50	$25.00	130%	3900	$390	$13	$90	$77
Hybrid	10	$2.50	$25.00	140%	4200	$420	$13	$120	$107
Hybrid	10	$2.50	$25.00	150%	4500	$450	$13	$150	$137
Varieties	20	$0.60	$12.00	0	4000	$400	$0	$0	
Hybrid	10	$2.50	$25.00	130%	5200	$520	$13	$120	$107
Hybrid	10	$2.50	$25.00	140%	5600	$560	$13	$160	$147
Hybrid	10	$2.50	$25.00	150%	6000	$600	$13	$200	$187

CONCLUSIONS

When growers recognize the superior yield of the safflower hybrids, the hybrids will replace conventional varieties for commercial production. Hybrid production will increase safflower acreage in California if there is a developing and expanding market for the oil. The primary problem with safflower oil sales in the US is a lack of advertising the superior qualities of safflower oil over other vegetable oils. Akkadix Corp. (Global Agro) is the agency for the sales of SAFFTECH safflower hybrids in Mercasur Countries in South America and outside the United States. For further information refer to web site www.akkadix.com under germplasm – safflower.

Correlation Between Traits and Path Analysis for Grain and Oil Yield in Spring Safflower

A. H.Omidi Tabrizi[1]

ABSTRACT

In order to study correlation among seed and oil yield with their components through the path coefficient analysis method, an experiment with 100 Safflower genotypes was conducted at the research farm of S.P.I.I., In 1998. The experimental design was a 10x10 simple lattice. The results showed that there was good agreement between phenotypic and genotypic correlations. For most characters, genotypic correlation coefficients were higher than phenotypic correlation coefficients and there were highly significant positive correlations between biomass and number of heads/plant with seed yield. Stepwise regression for seed and oil yield indicated that 4 traits including biomass, number of heads/plant, number of secondary branches entered to model. The results of path coefficient analysis revealed that increase of oil yield was primarily associated with increasing seed yield which was affected by biomass and number of heads/plant.

Key words: traits, path analysis, phenotypic, genotypic

Breeding/Genetics/Disease

INTRODUCTION

Safflower has been grown since ancient times (4500 B.C.) in Egypt, Morocco, China and India to obtain carthamin a dye from the flowers that may be either yellow or red. India and Ethiopia are the countries with the longest tradition of safflower growing as an oil plant. Safflower has been cultivated in Iran for centuries in small amounts for the extraction of dye from its florets; its importance as an oil seed crop has only been realized since 1970 (Ahmadi and Omidi 1997).

Iran is a rich source of safflower germplasm, for instance of the 2042 safflower genotypes deposited at the Western Regional Plant Introduction Station Pullman, WA, USA, 199 of them are of Iranian origin (Deharo et al. 1991).

Evaluating yield components and their interrelationships is very important in safflower breeding programs, specially the direct components of yield that relate to the various morphological characters regarded as indirect components of yield (Ashri et al 1974, and Corleto et al 1997) reported that the most important yield component in safflower is the number of heads per plant (Abel et al 1976) showed that number of heads per plant or number of seed per head or both traits could be responsible for high yielding safflower lines.

Kang Digming et al (1993) in a study of 30 safflower cultivars reported that the number of the first effective branch, main stem diameter, diameter of top fruit, 1000 seed weight, oil content and angle of the first branch were the six principal components.

OMIDI (1994) reported that the number of seeds per head is associated with increase seed yield in safflower (Uslu et al 1994) concluded that selection for heads per p1mit was effective for the improvement of yield (r=O.8).

Cosentino (et al 1985), showed that the number of heads per plant and seed per head are significantly and positively correlated.

The objective of the research reported in this, paper was to evaluate safflower yield components and their interrelationships.

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MATERIALS AND METHODS

In early spring of 1997 100 Iranian and exotic safflower varieties and advanced lines were evaluated for yield and yield components and other agronomic characters, using a simple lattice design (l0x10) in KARAJ-IRAN.

Experimental plots consisted of rows 3 - m long and 0.5m apart. Data on yield per plant and yield components and other agronomic traits were obtained by calculating the mean of five representative plants. Data collected were: plant height, number of secondary branches, number of heads per plant, number of seeds per head, 100 seed weight, biomass, days to flowering, days to 50 % flowering, days to maturity, seed yield per plant, seed yield per plot, oil yield per plant and plot. Phenotypic and genotypic variances were estimated:

$$\delta^2 g = \frac{(MST - MSE)-[(MSB - MSE)(2/K + 1)]}{2}$$

$$\delta^2 p = \delta^2 g + MSE/r$$

where (MST) is the mean square root of treatment, (MSE)is the mean square of error, (MSB) is the mean square of block and (K) is the number of treatments in a block. Phenotypic and genotypic correlation were calculated on the basis of the formulas:

$$\gamma p = \frac{COVp(x,y)}{\delta px \, \delta py} \qquad \gamma g = \frac{COVg(x,y)}{\delta px \, \delta py}$$

RESULTS AND DISCUSSION

1. Phenotypic and genotypic correlation: The phenotypic and genotypic correlation of yield per plant and yield components with each other are shown in Table 1, these values confirm that the yield of

Table 1. Genotypic and phenotypic correlation of spring safflower traits.

	Seed Yield Per Plant	Seed Yield Per Plot	Biomass	100 Weight Seed	No. Capitula	Number of Secondary Branches	Oil%	Oil Yield Per Plant
Seed Yield Per Plant	0.970 (0.994)	1						
Biomass	0.875 (0.930)	0.822 (0.866)	1					
100 Weight Seed	0.30 (0.30)	0.269 (0.266)	0.307 (0.326)	1				
No. Capitula	0.850 (0.916)	0.874 (0.934)	0.789 (0.879)	(0.266) (0.269)	1			
Number of Secondary Branches	0.547 (0.639)	0.578 (0.644)	0.452 (0.481)	0.059 (0.085)	(0.459) (0.591)	1		
Oil %	-0.101 (-0.101)	0.082 (-0.082)	0.095 (-0.101)	0.223 (-0.231)	0.060 (-0.060)	-0.156 (0.339)	1	
Oil Yield Per Plant	0.963 (0.962)	0.944 (0.966)	0.846 (0.896)	0.236 (0.231)	0.866 (0.931)	0.531 (-0.119)	0.149 (0.155)	1
	-0.117 (-0.139)	-0.076 (-0.082)	-0.105 (-0.113)	-0.179 (-0.186)	0.025 (0.031)	-0.193 (0.222)	0.682 (0.689)	0.066 (0.048)

Significant at 5% and 1% probability levels respectively plant is significantly corrolated with biomass, number of heads, 100 seed weight, number of secondary branches, oil yield per plant and also there is a negative correlation between seed hull and oil content. The highest correlation coefficients were for yield of plant to yield of plot (0.97). Thus the average of traits measured on five single plants can be used as plot representative.

2. Phenotypic and genotypic path analysis: The effects of 4 agronomic characters on seed and oil yield per plant showed that the highest direct effect on seed and oil yield per plant is from biomass which is indirectly influenced by the number of heads per plant, and also seed yield (as an independent variable) has the highest direct effect on oil yield. Thus oil yield will increase with an increase in seed yield (table 2 and 3). As a conclusion we demonstrate that increase of oil yield is primarily associated with an increase in seed yield, which was affected by biomass and the number of heads per plant.

Table 2. Direct and indirect path coefficient using phenotypic correlation.

	Biomass	No. Capitula	No. Sec. Branches	r(Yield)
Biomass	0.501	0.297	0.075	0.875
No. Capitula	0.395	0.377	0.076	0.850
No. Sec. Branches	0.226	0.173	0.166	0.566

U=0.381

	Seed Yield	Biomass	No. Capitula	No. Sec. Branches	r(Yield)
Seed Yield	0.856	-0.022	0.146	-0.019	0.962
Biomass	0.749	0.026	0.136	-0.015	0.846
No. Capitula	0.728	-0.020	0.172	-0.015	0.865
No. Sec. Branches	0.485	-0.012	0.079	-0.033	0.521

U=0.252

Breeding/Genetics/Disease

Table 3. Direct and indirect path coefficient using genotypic correlation.

	Biomass	No. Capitula	No. Sec. Branches	r(Yield)
Biomass	0.579	0.2(A	0.086	0.930
No. Capitula	0.509	0.300	0.106	0.916
No. Sec. Branches	0.278	0.177	0.179	0.63S

U=0.267

	Seed yield	Biomass	No. Capitula	No. Sec. Branches	r(Yield)
Seed Yield	0.801	.0.1031	0.303	-0.042	0.962
Biomass	0.745	-0.110	0.291	-0.032	0.896
No. Capitula	0.734	-0.097	0.331	-0.039	0.930
No. Sec. Branches	0.510	-0.053	0.195	-0.066	0.587

U = 0.238

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Gamma Radiation Induced Polygenic Variation in Homozygous and Heterozygous Genotypes of Safflower

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ABSTRACT

The seeds of the genotype A-1 and of the F_1 of the cross 398-9-15 x 420-24-3 were treated with 30 kr gamma rays. A three way cross hybrid (398-9-15 x 420-24-3) x A-1 was also produced. The treated populations and the three way cross hybrids were advanced to their respective M_2, F_2, F_2M_2 and / three way cross F_2. The mean values of treated populations were compared to F_2 and three way cross F_2 populations. The mean values of the treated populations were reduced compared to F_2 and three way cross F_2 population for the majority of the characters. The magnitude of the induced variation in the pure breeding variety A-1 was lower than the conventional segregation following hybridization for 100 seed weight, head diameter and number of capitula per plant. The variation from the mutation of heterozygous genotypes was found to be more than that in the untreated F_2 population for important characters such as seed weight, number of seeds and yield per plant and vice versa for number of branches, number of capitula and head diameter. The simultaneous introduction of more than two parents in the population also produced increased variability for number of seeds, seed weight and yield per plant.

Key words: Safflower, Hybridization, Irradiation, variability.

Breeding/Genetics/Disease

INTRODUCTION

Safflower (*Carthamus tinctorius* L.) is native to India and known for its high oil quality. However, the low oil content of about 28 to 32 per cent and low yield of 600 kg/ha. (Ramachandram, 1985) makes safflower a poor competitor. The genetic improvement of the ultimate product in safflower, involves the simultaneous improvement of seed yield and oil content. Although, a large variability for oil content and yield components is present in the germplasm, the strong negative association between number of capitula and capitulum diameter and number of seeds per capitulum and seed weight are the major constraints in combining oil and yield components. Hitherto, attempts to generate desirable variability and reconstitution of characters either through recombination or mutation breeding alone were not very satisfactory (Ramachandram, 1985).

Lately, the importance of mutagenesis of segregating generations in increasing recombination rate has been realized (Virk et al 1978, Katoch et al. 1992). Gregory, as early as 1956 and Virk et. al. in (1970) reported that variation induced by radiation of segregating populations is greater than that generated through hybridization or mutation of pure breeding genotypes. In the present study attempts have been made to induce polygenic variability in pure breeding and heterozygous genotypes to derive the benefit of both sources of variation in safflower.

MATERIALS AND METHODS

Three genotypes of safflower A-1 (high yielding, low oil content, national check), 398-9-15 (bold head, medium oil, suited to Karnataka) and 420-24-3 (Breeding line with more number of capitula) were selected. The genotype 420-24-3 was crossed to 398-9-15 to produce hybrid seeds. Fifty per cent of the hybrid seeds produced (about 100 seeds) and about 200 seeds of A-1 were treated with 30 kr dose

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of gamma rays to induce mutations. The treated seeds of the hybrid and of A-1 were sown to raise F_1M_1 and M_1 generations, respectively, while the untreated hybrid seeds produced are F_1 generation during rabi the (Winter) season. Selfed seeds from the surviving M_1 and F_1M_1 plants were used for raising M_2 and F_2M_2 generations during the following rabi season. The F_1 plants were crossed to A-1 to produce a three way cross hybrid (398-9-15 x 420-24-3) x A-1, while the other plants were selfed to produce seeds for raising the F_2 generation. The three way cross hybrid was grown during the kharif and about 20 plants were selfed and seeds from these plants were harvested for growing a three way cross F_2 population.

Large populations consisting of about 1000 plants of F_2, M_2, F_2M_2 and the three way cross F_2 were grown during the rabi season. Each population was grown in a plot of 5m x 18m with a spacing of 20 cm x 45 cm . A total of 92, 60, 60 and 80 plants were randomly selected from M_2, F_2, F_2M_2 and the three way cross F_2 populations, respectively for recording observations on important agronomic characters: plant height (cm), number of branches per plant, number of capitula per plant, head diameter (mm), number of seeds per capitulum, 100 seed weight (g) and seed yield per plant (g). The different populations were compared (t-test) by computing their mean, range and variance.

RESULTS AND DISCUSSION

The mean values of different populations are given in Table 1. A few shifts in the mean values have been observed in the mutated F_2M_2 population compared to the control F_2 population. The plant height, number of branches per plant and yield per plant did not show significant change in their mean. But the other important yield components such as number of capitula per plant, head diameter and number of seeds showed significant reduction due to mutation of the heterozygous genotypes compared to the control F_2 population. However, irradiation of heterozygous seeds resulted in increased seed weight in their progeny compared to the untreated F_2 population. Such significant deviations of the mean in both directions of means have been due to positive and negative mutations occurring in the system (Virk et al. 1978 and Katoch et al. 1992). The deviations in a treated population arise from asymmetrical and directional effects of the mutations as contributions are made by a difference in the frequency of opposite mutations at the mutated loci.

The M_2 population of A-1 and the three-way cross F_2 showed the highest plant yield and seed weight. This is due to the influence of the high yielding potential of the parental variety A-1. It is reported that in safflower, the parental types dominate in the segregating population (Ramachandram, 1985).

Table 1. Mean of different quantitative characters in different populations of safflower.

Treat ment	No. plants	Plant height (cm)	No.of branches/plant	No.of capitulu m/plant	Head dia. (mm)	No.of seeds/ capitulum	100 seed weight (g)	Seed yield/ plant (g)
F_2	60	58.73 $\pm 1.16^{ab}$	9.75 $\pm 0.39^{a}$	25.86 $\pm 1.10^{a}$	23.33 $\pm 0.38^{a}$	25.80 $\pm 0.97^{a}$	3.74 $\pm 0.08^{b}$	17.59 $\pm 1.05^{a}$
F_2M_2	60	60.73 $\pm 0.90^{a}$	9.81 $\pm 0.35^{a}$	21.45 $\pm 0.90^{b}$	21.93 $\pm 0.32^{b}$	22.37 $\pm 1.13^{b}$	4.16 $\pm 0.12^{a}$	16.42 $\pm 1.27^{a}$
M_2	92	52.20 $\pm 0.65^{c}$	7.06 $\pm 0.24^{c}$	23.11 $\pm 0.90^{b}$	20.30 $\pm 0.33^{c}$	21.08 $\pm 0.63^{b}$	5.53 $\pm 0.10^{d}$	19.81 $\pm 0.81^{bc}$
Three way F_2	80	57.58 $\pm 0.56^{b}$	8.59 $\pm 0.27^{b}$	25.18 $\pm 0.88^{a}$	20.66 $\pm 0.28^{c}$	22.96 $\pm 0.98^{b}$	4.93 $\pm 0.10^{c}$	21.67 $\pm 1.10^{c}$

F_2 = 398-9-15 x 420-24-3; F_2M_2 = (398-9-15 x 420-24-3) treated with 30kr
M_2 = A-1 (30 kr); Three way F_2 = (398-9-15 x 420-24-3) x A-1
Values with the same letter in each column are not significantly different.

Table 2. Variance of different quantitative characters in different populations of safflower.

Treatment	No. of Plants	Plant height (cm)	No.of branches/ plants	No.of capitulum/ plant	Head diameter (mm)	No.of seeds/ capitulum	100 seed weight (g)	Seed yield/ plant
F_2	60	80.19[a]	9.05[a]	72.42[a]	8.64[a]	56.52[ab]	0.41[b]	66.55[b]
F_2M_2	60	48.55[b]	7.31[ab]	48.85[b]	6.09[b]	77.00[a]	0.88[a]	96.62[a]
M_2	92	39.46[b]	5.37[b]	74.65[a]	9.92[a]	36.26[b]	0.92[a]	60.11[b]
Three way F_2	80	25.17[c]	5.84[b]	61.94[ab]	6.18[b]	76.98[a]	0.81[a]	95.92[a]

F_2 = 398-9-15 x 420-24-3; F_2M_2 = (398-9-15 x 420-24-3) treated with 30kr
M_2 = A-1 (30 kr); Three way F_2 = (398-9-15 x 420-24-3) x A-1

The variances for different characters such as plant height, number of branches per plant, capitula per plant and head diameter (Table 2) were reduced due to irradiation of heterozygous genotypes (F_2M_2) compared to the untreated control F_2 population. Such decrease in the variation due to irradiation of heterozygous genotypes has been reported for several characters in different crops (Virk et al. 1978 and Katoch et al. 1992). However, the major yield components such as seeds / capitulum, seed weight and yield per plant showed higher variability in F_2M_2 followed by three way cross F_2 population suggesting the release of additional variability due to irradiation of crossed seeds than normal F_2 population in this cross. Such increased variability due to irradiation of segregating generations has been reported in wheat and rice (Virk et al. 1978 and Katoch et al. 1992). Similarly, the simultaneous introduction of more than two parents into the population produced more variability than the two-parent hybridization (F_2) or mutation alone (M_2) for seed yield and number of seeds/ capitulum. However, M_2 had highest variability for 100 seed weight, head diameter and number of capitula per plant. In safflower, the seed weight and seed number are the most important characters contributing directly to seed yield and oil content (Ramachandram 1985). However, a strong negative association between these two is a major constraint in the development of high yielding genotypes with high oil. The generation of wide variability in these characters by mutation of heterozygous / homozygous genotypes or by effecting multiple crosses may offer scope for obtaining rare recombinations of plants having these two principal characters in optimum proportion resulting in desirable plant types.

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Strong Undesirable Linkages Between Seed Yield and Oil Components–A Problem in Safflower Improvement

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ABSTRACT

A combination of number of capitula per plant, capitulum diameter, number of seeds per capitulum, and test weight constitute the most desirable plant type in safflower. However, the strong negative associations between these desirable traits are major problems for the improvement of safflower. An attempt has been made in the present study to change the magnitude and directions of such negative associations through diverse hybridization, mutagenesis of homozygous parental lines and heterozygous hybrids. The study of 10 segregating populations comprising of F_2 /F_2M_2 /M_2 revealed that number of capitula per plant and test weight are the most important characters for seed yield. These two traits were negatively associated with capitulum diameter and seed number, confirming earlier results. In general there were no major shifts in negative associations between desirable traits in any of the populations. However, there were some desirable changes in character associations due to mutations depending on the genetic architecture of the trait, mutagen and genotype. Depending on the changes, the populations are to be carefully selected for developing a desirable plant type.

Key words: Safflower, mutation, homozygous, heterozygous, correlation.

Breeding/Genetics/Disease

INTRODUCTION

Safflower is a crop of antiquity in India known for its quality edible oil. India has about 68 percent of the world acreage and accounts for 60 percent of the production, occupying an area of 700,000 hectares with a production of 342,000 tons (Singhal, 1999). The low oil content of 28-30 percent and low yield of 600 kg /ha of Indian varieties makes safflower a poor competitor. The success of safflower as a commercial crop will largely depend on the genetic improvement of both seed yield and oil content.

The number of capitula per plant, seed number per capitulum, seed weight and capitulum diameter are the principal components of oil yield per unit area (Ramachandram 1985). The number of capitula and test weight positively influence seed yield, while seed number and capitulum diameter influence the oil content positively (Makne et al., 1978). It has been the experience, in the past that the oil content had negative association not only with seed yield but also with important yield components such as number of capitula and test weight. The test weight, an important component of oil content has also been negatively associated with number of seeds per plant, which is an important component of oil content (Ramachandram, 1985). Oil content and seed yield are negatively correlated and thus an attempt to improve one results in the reduction of the other (Ravikumar et al., 2000)

Hybridization of diverse parental lines and mutagenesis of homozygous lines failed to produce desirable changes in character associations between seed yield and oil components. Hence, in the present study attempts were made to change the magnitude and directions of negative associations between important components of seed yield and oil content, by combining the variability generated through recombination and mutation. The character associations in different populations were compared.

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MATERIAL AND METHODS

The high oil genotypes, 90-16 and 576-40 were crossed to two high yielding genotypes 425-6 and A-1 producing hybrids 425-6 x 90-16 and A-1 x 576-40. About 100 seeds from each hybrid and 250 seeds of each parental lines viz. 90-16 and A-1 were treated with the chemical mutagen EMS (0.3%). Similarly, another set of hybrids and parental lines were exposed to 10 KR gamma ray treatments. Following mutagen treatment, the F_1, M_1 and F_1M_1 generations were grown and the plants were selfed to develop respective F_2 - M_2 and F_2M_2 generations. The resulting 10 segregating populations were grown in the field during the post rainy season. Each segregating population was sown in a plot size of 12m x 5m by following the recommended agronomic practices. About 140 plants from each segregating population were randomly selected for recording observations on number of capitula, capitulum diameter, number of seeds per capitulum, test weight, oil content and seed yield per plant. The phenotypic correlation coefficients between the characters studied were calculated for each population separately using the formula suggested by Al-jibouri et al., (1958) and the values were tested for significance at probability levels of P=0.05 and 0.01.

RESULTS AND DISCUSSION

The correlation studies (Table1 and 2) among principal components in all 10 populations suggest that the number of capitula per plant followed by test weight were the most important characters contributing to seed yield per plant. The number of capitula recorded the highest positive correlation values with seed yield in all 10 populations. The strong association of number of capitula with seed yield has been reported by previous workers (Ramachandram, 1985). Similarly, test weight was positively associated with seed yield and negatively associated with oil content in most of the populations studied. Hull content, in general, determines test weight, which is important for both oil content and seed yield. Any increase in test weight through hull content increase seed yield but reduces oil content. It has been reported that increases in test weight were mainly through hull content increases and Indian cultivars contain a large proportion of hull (Ramachandram, 1985). Therefore, any reduction in hull content in order to achieve high oil content, should be compensated for by increased seed number. The seed number was significantly and negatively associated with test weight in all populations. Capitulum diameter showed a significant positive association with seed number, an important oil component. However, it was significant and negatively associated with test weight, which is important for seed yield. It could be concluded that the capitula number and test weight were important for seed yield. The important seed yield component test weight was negatively associated with capitulum diameter and seed number, which were important for seed oil content. (Ramachandram, 1985; Hudge et al., 1993).

Although major shifts in character associations among important traits were not observed in different populations generated using different methods, there were changes in the strength and direction of relationship between characters in different populations. The negative association of seed yield and oil content in the control F_2 shifted to positive values in the F_2M_2 populations. The M_2 (10KR) of A-1 recorded significant positive association between seed yield and oil content. Selection for seed yield may not adversely affect oil content in such populations. Such shifts due to mutagenic treatments of hybrids have been observed previously in safflower (Veena and Ravikumar in press; Patil et al., 1997). Similarly, there were some minor changes from undesirable to desirable directions in other character associations. The significant negative association between test weight and oil content has been changed to non-significant positive in F_2M_2 of A-1 x 576 – 40. The negative association of capitulum diameter and seeds / capitulum with seed yield in F_2 and F_2M_2 populations has been changed to significant positive association in the M_2 population of A-1. The alterations in character associations of treated populations may be due to the release of hidden variability caused by irradiation effects such as point mutations, breaking tightly linked genes and the occurrence of rare combinations due to

Table 1. Phenotypic correlations among important characters of safflower in segregating populations of cross 425-6x90-16.

Trait	Population	Capitulum. Diameter	Seeds/cap.	Test weight	Oil content	Seed yield
No. of capitula	F_2	0.133	0.089	-0.173**	-0.143*	0.717**
	F_2 M_2 (10KR)	-0.274**	-0.197**	0.201**	0.027	0.490**
	F_2 M_2 (EMS)	-0.272**	-0.137**	0.103	-0.007	0.515**
	M_2 (10KR)	-0.285**	-0.209**	0.14	-0.253**	0.397**
	M_2 (EMS)	-0.421**	-0.299**	0.245**	0.084	0.177**
Capitulum diameter	F_2		0.481**	-0.315**	0.101	0.362**
	F_2 M_2 (10KR)		0.517**	-0.137**	-0.127	-0.031
	F_2 M_2 (EMS)		0.495**	-0.252**	-0.034	0.0310
	M_2 (10KR)		0.586**	0-265**	0.302**	-0.044
	M_2 (EMS)		0.528**	-0.230**	-0.021	-0.139*
No. of seeds per capitulum	F_2			-0.474**	0.271**	0.347**
	F_2 M_2 (10KR)			-0.338**	0.025	0.052
	F_2 M_2 (EMS)			-0.362**	-0.039	0.132*
	M_2 (10KR)			-0.259**	0.302**	-0.053
	M_2 (EMS)			-0.342**	-0.027	-0.093
Test weight	F_2				-0.098	-0.189
	F_2 M_2 (10KR)				-0.073	0.309**
	F_2 M_2 (EMS)				-0.053	0.045
	M_2 (10KR)				-0.250	0.302**
	M_2 (EMS)				-0.083	0.303**
Oil content	F_2					-0.068
	F_2 M_2 (10KR)					0.007
	F_2 M_2 (EMS)					0.058
	M_2 (10KR)					-0.118
	M_2 (EMS)					-0.107

F_2 = 425 - 6 x 90 - 16
F_2M_2 (EMS) = 425 - 6 x 90 - 16
F_2M_2 (10KR) = 425 - 6 x 90 - 16
M_2 (EMS) = 90 - 16
M_2 (10KR) = 90 - 16
* Significant at 5% level.
**Significant at 1% level.

enhanced chiasmata formations (Hanson 1959). It can be concluded from the present study that, mutagenic treatment of both homozygous parental lines and heterozygous hybrids shifted the associations among characters in both the directions. Not all shifts were desirable. The shifts in characters associations due to mutation depended on many factors such as the genetic architecture of

Table 2. Phenotypic correlations among important characters of safflower in segregating populations of cross A - 1 x 576 - 40.

Trait	Population	Capitulum. Diameter	Seeds / cap.	Test weight	Oil content	Seed yield
No. of capitula	F_2	-0.209**	-0.362**	0.059	0.001	0.796**
	F_2 M_2 (10KR)	-0.0348	-0.274**	0.069	0.024	0.693**
	F_2 M_2 (EMS)	-0.207**	-0.248**	0.177**	0.008	0.722**
	M_2 (10KR)	0.145*	0.065	0.021	0.036	0.700**
	M_2 (EMS)	0.016	-0.122	-0.054	0.094	0.656**
Capitulum diameter	F_2		0.651**	-0.374**	0.079	-0.102
	F_2 M_2 (10KR)		0.275**	-0.209**	0.106	-0.086
	F_2 M_2 (EMS)		0.526**	-0.360**	0.101	-0.054
	M_2 (10KR)		0.472**	-0.231**	0.049	0.539**
	M_2 (EMS)		0.453**	-0.035*	0.072	0.286**
Seeds per capitulum	F_2			-0.404**	0.060	-0.224**
	F_2 M_2 (10KR)			-0.497**	-0.036	-0.136**
	F_2 M_2 (EMS)			-0.408**	-0.063	-0.179**
	M_2 (10KR)			-0.012	0.0144	0.262**
	M_2 (EMS)			-0.271**	0.0156	0.116
Test weight	F_2				-0.242**	0.135*
	F_2 M_2 (10KR)				0.0273	0.063
	F_2 M_2 (EMS)				-0.0326	0.329**
	M_2 (10KR)				-0.187**	0.177**
	M_2 (EMS)				-0.184**	0.005
Oil content	F_2					-0.039
	F_2 M_2 (10KR)					0.018
	F_2 M_2 (EMS)					0.005
	M_2 (10KR)					0.162**
	M_2 (EMS)					0.019

F_2 = A - 1 x 576 - 40
F_2M_2 (EMS) = A - 1 x 576 - 40
F_2M_2 (10KR) = A - 1 x 576 - 40
M_2 (EMS) = A - 1
M_2 (10KR) = A - 1
* Significant at 5% level.
**Significant at 1% level.

the trait, dosage and efficiency of the mutagen, population size studied and genetic diversity of the population. Hence, depending on the changes in the character associations, the populations are to be carefully selected for developing desirable plant types.

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Developing New Characteristics During 50 Years of Safflower Breeding

David D. Rubis[1]

ABSTRACT

This is a review of many characteristics discovered and developed during a span of 50 years of safflower breeding. I was associated with the U.S. Department of Agriculture from 1952 to 1956, with the University of Arizona 1956 to 1986 and on my own since 1986. Most of the research dealt with breeding to make safflower an important crop for production. Most exciting for me has been the discovery of new mutant genes, thin hull (th), striped-hull (stp, stp^p) and pigmentless (p). The thin-hull character has been indispensable for making crosses and for the development of hybrid safflower. The most interesting long-time program was the development of a wild composite by intercrossing wild species with domestic safflower. The characteristics that came from that program were hybrid females, lygus resistance, spineless pointed bracts, and small birdseed. The most recent and probably the most important character has been the development of day-length neutral safflower.

Key words: seed characteristics, hull mutants, bee pollination, day length, thin hull

Breeding/Genetics/Disease

INTRODUCTION

This manuscript is a review of some of the highlights of safflower breeding by the author during a span of 50 years. In a short manuscript like this only some of the most interesting and important research will be mentioned. Limited remarks will be made on the first four categories below and an expanded discussion will be made on the discovery and development of the thin-hull gene (th):

1. Seed characteristics and hull mutants
2. Bee pollination in safflower
3. Development of special experimental equipment
4. Day-length neutral safflower
5. The discovery, development and use of the thin-hull (th) gene

Seed Characteristics and Hull Mutants

Early investigations were concerned with seed characteristics (Bratcher et al. 1969, Guggolz et al. 1969, Rubis 1967), the hull-to-meat ratio and the oil percentage of commercial varieties. Safflower seeds (achenes) consist of meats containing the oil and hull made up of a pericarp and the seed coat. The sclerenchyma, phytomelanin and integument layers were identified in each of the different hull types (Lockwood 1966). The principal hull types studied were normal hull, thin-hull, gray-striped hull, purple-striped hull, brown-striped hull, and pigmentless hull. More recently new hull types have occurred in which the anatomy has not yet been studied. One new hull type results with seed over 55 percent oil. Research on new hull types is a continuous study.

Honey Bee Pollination in Safflower

Safflower is an entomophilous crop and is very attractive to many pollinating insects. From 1963 to 1970 many experiments were conducted to study the biological basis of the use of the delayed anther

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dehiscence of the thin-hull gene to produce hybrid safflower (Rubis et al. 1966, Rubis 1969, Rubis 1970). Having the cooperation of the USDA Bee Research Laboratory was particularly helpful in understanding the relationship of honeybee activity to safflower. The studies were in research plots, caged plots, and in field scale conditions. It was found that the efficiency of honeybees depended on such factors as plant preferences, foraging habits, and proximity of male and female rows, flower color, and bee population.

Development of Special Experimental Equipment

Developing special experimental equipment is vital to research. Although numerous items of special equipment were developed, three will be mentioned here: first, a seed cutter with multiple razor blades to separate hulls and meats; second, a small oil press with a hydraulic jack to obtain samples of oil to study oil color; and finally, a modified Gleaner combine with a six-foot header to harvest experimental plots.

Day-Length Neutral Safflower

One of the early programs in safflower breeding was the development of earliness. Several very early maturing lines from the USDA Plant Introduction Service were used. After very extensive studies it was terminated because earliness was always associated with low productiveness. In 1994 crosses were made with a very small 8-inch prostrate plant that was flowering very early (probably Gila dwarf). After the first crosses the F_2 segregated into two classes, the very small plant and the normal plant with no recombination. After growing these small plants in spring-planted and summer-planted nurseries the possibility of obtaining a day-length neutral plant became evident. Crossing with regular commercial varieties was very ineffective in making improvements. The first day-length neutrals were poor in seed set, low in oil percentage, lodged badly, and were very poor in productivity. Improvements were made as a result of crossing with very big stiff-stem plants and with tall late plants. Every generation improvements were made with crossing and selection. Day-length neutral plants will be about half the height of normal plants and will be three to four weeks earlier. There is no doubt that in the future many, if not most safflower varieties will be day-length neutral.

The Discovery, Development and Use of the Thin-Hull (th) Gene

At a Crop Science meeting in 1957, the author wrote as follows (*Western Crop Sci. Abstr.* p. 16, 1957): "Safflower seed believed to be from a thin-hull mutant plant was picked out of bulk seed from a yield test in 1955. In the next generation all seeds were normal hull. In the second generation all progenies segregated in a 3 to 1 ratio for thin-hull ..." This was the source of the recessive thin-hull mutant gene "th" in safflower. The first thin-hull plants were weedy-looking, about five inches in height and prostrate. Continued crossing and selection in following generations resulted in stiff stem thin-hull plants. The characteristic that makes thin-hull plants so valuable is the delayed anther dehiscence causing the styles and stigmas of elongated florets to be free of pollen. This is in contrast to the normal plants in which the styles and stigmas are covered with pollen. In the thin-hull plants the delayed anther dehiscence and thin pericarp are pleiotrophic characters.

The thin-hull plants are useful in safflower breeding (Rubis 1969). The delayed anther dehiscence allows crosses to be made without emasculation. Because of delayed anther dehiscence the thin-hull plants can be selected as functional females in producing hybrid seed. The thin-hull plants are also used to create intercrossing populations. The open-pollinated seed of thin-hull plants are all crossed seed and are used to plant the next generation.

The most valuable long-time program was the use of the thin-hull in creating an intercrossing population from wild species and domestic varieties (Rubis 1981). In 1965, twelve wild species were planted in a crossing block as males with a thin-hull female. The crossed plants were planted as males for two generations of backcrossing and then everything was bulked as a wild composite population.

In 1970 a root rot nursery was established in isolation and the wild composite was an entry along with several commercial varieties and breeding lines (Rubis 1981, Thomas et al. 1960). The nursery was flooded at early flowering for two days. After the second year all the safflower varieties and breeding lines were 100% killed. Because very few of the wild composite plants were killed, the succeeding flood irrigation treatments were increased to four days for the life of the experiment. The open-pollinated seed of the thin-hull plants were used to plant the following generation each year. The open-pollinated seed and the thin-hull plants are all crossed seed of heterozygous plants. After numerous generations the nursery was bulked and called the "Arizona Wild Composite." This composite has been grown as a block in the regular nursery to be used to cross on regular safflower lines. This composite population is of a very wild type, mostly bushy, very spiny and very sterile if selfed. Genetically it is heterogenous and very heterozygous and consists of many, many recombination types.

The Arizona Wild Composite is a genetic source for the development of safflower characters that have not previously existed. As an example of such new characters: safflower lines completely resistant to lygus, new spineless types with pointed bracts, and the smallest seed which are only three to four millimeters in size.

Future Safflower

Future safflower will be hybrids, day-length neutral, spineless with seeds consisting of about 20% hull and 55% oil. Safflower oil will be close to zero saturated fatty acid and 85% oleic. There will undoubtedly be special types for birdseed and types for various industrial uses.

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Potential and Variability in Spineless Safflower Varieties Developed for Late Sowing Conditions of Soybean-Safflower Sequence Cropping in Madhya Pradesh

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Breeding/Genetics/Disease

ABSTRACT

The long journey of spineless safflower right from its earlier improvement under stressful rainfed environments to a recent partially stressed late sowing environment in a more viable soybean-safflower sequence cropping in non-traditional Madhya Pradesh has many facets. Not only has the spineless-safflower program at Indore produced suitable varieties for rainfed situations but it also recently identified potential spineless varieties for late sowing conditions for soybean-safflower sequence cropping without in anyway losing the variability generated in the course of improvement.

The results of safflower varietal trials, consisting of 14 recently developed spineless varieties, for 3 years of testing under late sowing environments, after harvest of soybeans, indicated significant superiority of the spineless variety JSI-97 over the spineless check variety JSI-7, with highest average yields of 1492 kg/ha. This variety and the spineless variety JSI-103 are the first varieties developed combining improvements in 6 important traits of high yield potential, bold (filled, plump) seed, earliness, short stature, high harvest index, and low RFP (relative fodder potential). The study further revealed great variability in the improved varieties for different characters amenable for easier identification of important traits. These included a high seed index (JSI-97 and JSI-111), low number of days to 50% flowering (JSI-109 and JSI-113), early maturity (JSI-109 & JSI-113), short stature (JSI-97 and JSI-109), increased numbers of primary branches (JSI-110 and JSI-7-1), more capitula/plant (JSI-93 and JSI-96), more seeds/capitulum (JSI-101 and JSI-109), a high harvest index (JSI-7-1 and JSI-103), reduced hull content (JSI-93 and JSI-73), low fodder potential (JSI-96 and JSI-109) and relative fodder potential estimates (JSI-109 & JSI-113).

Key words: safflower, *Carthamus tinctorius* L., spineless, India, soybean-safflower sequence

INTRODUCTION

Soybean - safflower sequence cropping is the mainstay of the cropping systems involving safflower as a second crop. Since large acreages of over 4.5 million hectares is under soybean in Madhya Pradesh, it is appropriately called "Soybean State." Under the system used, safflower planting is to be completed by the end of October, but since the intervening period is short, there is usually a delay in planting safflower to the 1st week of November (Sawant *et al*, 1998).

The development of spineless safflower varieties for late sowing conditions is therefore the need of the hour (Sawant *et al,* 1998). The long journey of spineless safflower from its earlier improvement under stressful rainfed environments to a recent partially stressed late sowing environment of the more viable, soybean-safflower sequence cropping, has many facets. Not only did the spineless safflower program at Indore produce suitable varieties for the rainfed situation, but it also recently has identified potential spineless varieties for late sowing conditions of the soybean-safflower sequence cropping as

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discussed in this paper. Interestingly, the variability generated in the course of improvement is maintained in the improved varieties evaluated in this study.

MATERIALS AND METHODS

Thirteen recently developed improved spineless safflower varieties and the check variety JSI-7 were grown in a randomized block design with 3 replications, the individual plot being 5.0 m x 1.8 m in size. The experiment was conducted for 3 years from 1996 to 1998. The characters recorded in the individual plot included the following: 100-seed weight, days to 50% flowering, days to maturity, plant height, number of branches/ plant, number of capitula/plant, number of seeds/capitulum, harvest index (%), and hull content (%). The parameters fodder potential (FP) and relative fodder potential (RFP) were estimated as shown by Sawant and Saxena, 1997.

RESULTS AND DISCUSSION

Yield Performance:

It is apparent from Table 1 that varietal performance, particularly of the top yielding varieties, varied from year to year due to fluctuations in environmental conditions, as reflected in general yield levels of the varieties. However, variety JSI-97 and JSI-103 gave relatively consistent performance and as an average of 3 years ranked first and second, yielding 1.492 kg and 1.482 kg/ha, respectively

The varietal testing was carried out under late sowing conditions after the harvest of soybean in the *kharif* (summer) with only one protective irrigation for germination. Although this eliminated initial moisture stress in otherwise rainfed environments, the varieties suffered hastened maturity associated with moisture stress at grain formation due to high temperatures. Some micro level fluctuations in environment in individual years, like temperature variations and intervening showers at critical growth stages, particularly at the reproductive and vegetative phases, brought about variations in performance of varieties in individual years.

Variability in yield component traits:

The range, mean and variance estimated for different characters indicate considerable variability for the characters under study (Table 2). Because of late sowing, the varieties faced hastened maturity

Table 1. Yield performance of spineless safflower varieties at Indore for 3 years under late sowing conditions*

Variety	Grain yield (kg/ha)			Average grain yield (kg/ha)
	1996	1997	1998	
JSI - 111	-	1273	1031	1152
JSI - 7	1143	790	1681	1205
JSI - 93	1272	1256	-	1264
JSI - 109	-	870	1361	1116
JSI - 104	-	1239	1562	1401
JSI - 96	1208	966	1490	1221
JSI - 73	1079	821	1707	1202
JSI - 108	1151	983	1924	1353
JSI - 113	-	1014	1385	1200
JSI - 97	1304	1176	1997	1492
JSI - 110	-	1481	1240	1361
JSI - 103	1329	1304	1812	1482
JSI - 101	1312	-	1739	1526
JSI - 7-1	-	-	2053	2053
SE ±	111.2	134.9	147.3	
CD (5%)	307.4	382.4	417.9	

* Soybean - Safflower sequence cropping (1996 to 1998)

Table 2. Range, Mean and Variance of agronomic characters of spineless safflower varieties studied for 3 years under late sowing conditions*

Character	Range	Mean	Variance
100 Seed Weight (gm)	4.1 - 6.7	5.44	0.072
Days to 50% flowering	82.5 - 107.0	99.65	2.456
Days to maturity	117.5 - 140.0	132.07	1.85
Plant height (cm.)	60.5 - 106.0	92.25	8.065
No. of branches/plant	5.5 - 9.5	7.52	0.094
No. of capitula/plant	13.5 - 26.5	19.66	0.903
No. of seeds per capitulum	17.5 - 29.0	22.89	0.988
Harvest index (%)	14.6 - 24.2	20.37	0.589
Hull content (%)	45.8 - 55.9	51.57	0.607
FP (Q/ha)	39.77 - 91.14	57.12	14.507
RFP (%)	67.5 - 126.4	96.52	21.84

* Soybean - Safflower sequence cropping (1996 to 1998)

due to a sudden rise in temperatures during grain formation. As a result the maturity differences were not very conspicuous. However, flowering to maturity in extra early types such as JSI-109 was also delayed due to cold spells.

Interestingly, with minor exceptions, almost all varieties expressing the highest individual yield components were not the highest for overall yield (Table 3). This included those high in 100 seed weight (JSI-97 and JSI-111), greatest number of branches/plant (JSI-110 and JSI-7-1), most capitula/plant (JSI-93 and JSI-96), highest grains per capitulum (JSI-101 and JSI-109) and highest harvest index (JSI-7-1 and JSI-96). Varieties exhibiting desirable improvement in more than one yield component trait could come out as top varieties for grain yield. Variety JSI-97, the highest yielding variety in the trials, exhibited high 100 seed weight and number of branches/plant. These results indicate the importance of simultaneous selection for a number of traits particularly the technique of "independent culling levels" as currently in vogue in breeding programs at Indore (Sawant, 1991).

Variability generated through "systematic" hybridization (objective-oriented hybridisation) (Sawant, 1985) followed by selection in subsequent generations, is generally eroded when stringent

Table 3. Various agronomic characters of spineless safflower varieties tested at Indore under late sowing conditions✱

Variety	100 Seed weight (gm.)	Days to 50% flowering	Days to maturity	Plant height (cm.)	No. of branches/ plant	No. of capitula/ plant	No. of seeds per capitulum	Harvest index (%)	Hull content (%)	FP (Q/ha)	RFP (%)
JSI - 111	6.7**	98.5	130.0	94.5	6.5	17.5	17.5	14.6	53.6	67.49	111.7
JSI - 7	4.2	102.1	134.3	92.3	7.0	20.3	21.7	18.4	47.3**	54.11	100.0
JSI - 93	5.0	102.5	134.0	95.5	8.5**	26.5**	24.5	21.1	45.8**	47.29*	106.5
JSI - 109	5.2	82.5**	117.5**	60.5**	6.5	13.5	28.5**	21.1	55.9	41.05**	67.1**
JSI - 104	4.1	98.0	131.5	106.0**	7.0	20.5	25.0*	21.1	51.9	52.28	85.1*
JSI - 96	6.6**	101.0	132.0	89.7	8.0**	24.3**	20.3	23.5**	53.2	39.77**	78.3**
JSI - 73	4.2	105.7**	133.7	96.7	7.3	19.0	27.7**	16.0	46.6**	64.82	117.3
JSI - 108	5.5	107.0**	136.0*	94.0	6.3	17.0	22.0	18.5	51.0	60.50	110.4
JSI - 113	6.6**	95.0	129.5	88.0	7.5	23.0	19.5	22.1*	53.8	42.09**	69.6**
JSI - 97	6.9**	99.7	131.3	87.3	8.0**	21.7*	19.3	22.5*	53.7	53.88	97.2
JSI - 110	5.7	99.0	133.5	104.5**	9.5**	18.5	24.5	19.4	53.4	91.14	100.3
JSI - 103	6.1*	98.7	129.7	92.0	8.7**	21.0	19.0	23.7**	53.6	48.12*	91.4
JSI - 101	4.7	102.5	140.0**	92.5	5.5	17.5	29.0**	19.0	52.2	72.85	126.4
JSI - 7-1	4.7	103.0*	136.0*	98.0	9.0**	15.0	22.0	24.2**	50.0	64.30	89.7

✱ Soybean - Safflower sequence cropping (1996 to 1998)
* Significant at 5% level
** Significant at 1% level

selection for grain yield is carried out, and only a few improved varieties remain available for the final testing stages. If selection is simultaneously made for yield component traits as well as for yield, as envisaged in the component breeding plan (Sawant, 1985) considerable variability is retained and could be further used in developing superior genotypes/varieties.

Variability in plant type:

The plant type typical of non-traditional Central India, including Madhya Pradesh, is characterized by excessive vegetative growth which aggravates problems of spines, aphid infestation, foliar disease, and difficulty in harvesting due to increased biomass (high FP and RFP estimates (Sawant and Saxena, 1997)). This plant type has been improved to a considerable extent with the release of the safflower varieties: spiny JSF-1 and spineless JSI-7 and JSI-73, but still there is considerable scope for further improvement.

It is apparent from the data (Table 3) that the high yielding spineless varieties, JSI-97 and JSI-103, exhibit considerable improvement in component traits of plant type i.e. short stature (87.3 cm and 92.0 cm respectively), high harvest index (22.5% and 23.7%), low FP (53.88 kg and 48.12 q/ha) low RFP estimates (97.2% and 91.4%), and earlier maturity (131 and 130 days) compared to check variety JSI-7. Further improvement in plant type comparable to traditional crops i.e. extreme short stature (82.5 cm) and extra early maturity (118 days) is achieved in the spineless variety JSI-109. This variety represents by far the shortest height and earliest maturity recorded in spineless safflower.

The above results clearly indicate the effectiveness of techniques of simultaneous selection for several traits with independent culling levels, not only for the improvement of yield and its component traits but also for the improvement of plant type and its components. Because of the combined selection for grain yield and components of yield and plant type, the high yielding spineless varieties, JSI-97 and JSI-103, show the first ever incorporations of six important traits for high yield potential, bold (filled, plump) seed, earliness, short stature, high harvest index and low RFP estimate.

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Safflower Research & Development at Nimbkar Agricultural Research Institute (NARI)

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ABSTRACT

Safflower improvement program at NARI has been in progress since 1968. The safflower work at NARI has been devoted to developing suitable technologies and varieties and hybrids for limited irrigation situations. A complete technology for growing safflower under limited irrigation has been developed at the Institute. The work carried out on varietal development has resulted in the state level release of a high yielding safflower variety 'Nira' for limited irrigations during 1987-88. Recently NARI-6, a non-spiny variety has been released on the national level. This is a moderately high oil containing variety possessing about 35% oil in the seed. In the hybrid development program, ten spiny and three non-spiny genetic male sterile lines have been developed from two different genetic male sterility sources identified at NARI. In addition, six dwarf male sterile lines possessing a sterility marker have also been developed. The male sterility marker makes it possible to identify male sterile (MS) and fertile (MF) plants at about 40-45 days after sowing, making roguing of MF plants relatively easy during hybrid seed production. A spiny safflower hybrid developed at NARI was found to give an average increase of 19% in seed yield and 32% in oil yield over the national check A-1 over three years. Four non-spiny safflower hybrids developed at NARI were found to give significantly higher seed, oil and petal yield than the non-spiny check JSI-7 in multilocation coordinated trials during 1999-2000. A complete technology of hybrid seed production of both spiny and non-spiny hybrids has been developed at NARI. NARI is trying to popularize herbal health tea prepared from safflower flowers. A battery-operated knapsack type flower collector developed at NARI for this purpose is 2-3 times more efficient than the flower picking carried out by hand in spiny safflower.

Key words: Hybrid, genetic male sterility, variety

Breeding/Genetics/Disease

INTRODUCTION

The safflower improvement program at NARI commenced in 1968. Preliminary studies with safflower production under limited irrigations revealed two to three fold increases in seed yield, over that under rainfed conditions. In view of safflower's high responsiveness to one or two irrigations, the safflower improvement program at NARI was initially focussed on the development of suitable agroproduction technologies and varieties for limited irrigations. As a result, a complete technology of safflower production under limited irrigated conditions; besides, a high yielding safflower variety, Nira, suited to limited irrigations was developed during the 1980's. Presently safflower development at NARI is concentrated on: (1) the development of high yielding and high oil containing spiny and non-spiny varieties and hybrids resistant to *Fusarium* wilt for limited irrigations; (2) identification of male sterile marker traits expressed at early stages of plant growth in genetic male-sterile (GMS) lines; (3) identification and development of cytoplasmic male sterility (CMS) in safflower; (4) development of a suitable technology for hybrid seed production of genetic male sterility- based hybrids of both spiny and non-spiny nature; (5) development of a flower harvesting machine for spiny safflower; and (6) the promotion of safflower utilization for various purposes.

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The progress of the work carried out in safflower improvement in these areas at NARI is as follows:

I. Varietal development:

Safflower is considered to be a low oil-producing crop, highly susceptible to different diseases and pests. Thus the major emphasis in varietal improvement program at NARI, has been given on developing varieties with enhanced oil and seed yield and better tolerance to pests and diseases in addition to responsiveness to limited irrigations. With the above considerations, the work in safflower improvement at NARI has resulted in the development of the following cultivars.

1. **Nira (NRS-209):** As stated earlier, the safflower variety Nira was released for commercial cultivation under protective irrigations in the state of Maharashtra during 1987-88. Nira is a spiny cultivar and gives about 24% higher seed yield than the safflower variety Bhima, which is the most widely cultivated safflower variety in the state. In addition, Nira is 15 days earlier in maturity than Bhima and contains about 32.5% oil in the seed, which is slightly higher than that in Bhima. Due to its earliness it escapes pest infestation and hence is considered as moderately tolerant to different pests, compared to other cultivars.
2. **NARI-6:** This is a non-spiny cultivar and has been released for commercial cultivation in rainfed areas of the country during 2000. NARI-6 on an average produces about 1,025 kg/ha seed yield and about 75-100 kg/ha of flower yield. In addition, this variety contains 35% oil in seeds and produces bright red flowers, which are preferred over those of other colors by the traders. NARI-6 has outyielded the non-spiny variety JSI-7 by an average margin of 20.19 % in seed yield and about 25.97% in oil yield in multilocation coordinated varietal trials.
3. **NARI-2**: This is another spiny variety, which has been developed at NARI. In addition to giving 17% higher oil production than the national check A-1 under irrigated conditions across the locations and years in the All India Coordinated yield evaluation trials, this variety has been identified as one of the most tolerant cultivars for saline soil conditions. NARI-2 contains about 32% oil in the seed. NARI-2 is about 10 days earlier in maturity than A-1.

II. Hybrid development:

NARI has pioneered hybrid development in safflower in India from 1983-84 by using UC-148 and UC-149, the genetic male sterile lines of recessive nature developed by Heaton and Knowles (1980). The preliminary evaluation of GMS hybrids showed them to give about 19% higher seed yield than the national check A-1 in AICRPO multilocation trials (Deshmukh et al., 1989). In spite of the promising performance of the hybrids, these hybrids could not be commercialized due to undesirable characteristics in the genetic male sterile lines, which compelled us to search for new sources of male sterility in safflower. A thorough search of the available germplasm and segregating generation material at NARI resulted in the discovery of three male sterility sources. These male sterility sources are:

1. MSN (Singh, 1996)
2. MSV (Singh, 1996)
3. DMS with associated sterility marker trait (Singh, 1997)

Each of these male sterile sources is governed by single recessive genes and segregates in the ratio of 1 male sterile: 1 male fertile plants. The identification of MS and MF plants in the lines developed from male sterility sources MSN and MSV is possible at flowering by the appearance of a pinched capitulum opening in the case of sterile plants and normal opening in case of fertile plants. However in DMS lines the identification of MS and MF plants is possible at about 30-40 days after sowing. Due to the linkage of sterility and dwarfing genes, MS plants remain dwarf with a height of 5 to 10 cm at the age of 30-40 days, however MF plants attain a normal height of 20-25 cm at this age. This facilitates the roguing of tall MF plants at this stage leaving behind a 100% pure stand of dwarf MS plants.

Under the program of development of genetic male sterile lines in safflower, ten spiny and three non-spiny MS lines have been developed from MSN and MSV sources of genetic male sterility at NARI. In addition to this, six male sterile lines possessing a sterility marker trait have been developed from another source of sterility known as DMS. All male sterile lines thus developed are high yielding, uniform, possess desirable traits and are presently being exploited for hybrid development in safflower.

(a) **Performance of safflower hybrid PH-3:** The safflower hybrid PH-3 has been developed from one of the GMS lines developed at NARI. PH-3 has recorded an average increase of 19% in seed yield and 32% in oil yield over the national check A-1 across the locations and years in All India Coordinated yield evaluation trials carried out for 3 years (Table 1). In addition, it is highly tolerant to safflower wilt (caused by *Fusarium oxysporum*). PH-3 has about 35% oil in the seed. In farmers' fields, this hybrid has recorded seed yield to the extent of 31 q/ha (3100 kg/ha) during 1999-2000. The area of safflower under PH-3 is steadily increasing in the state of Maharashtra.

(b) **Performance of non-spiny safflower hybrids:** The four non-spiny safflower hybrids developed at NARI recorded a significant increase of 14.86 to 21.24 % in seed yield, 17.15 to 27.17% in oil yield and 41.54 to 92.31% in flower yield over non-spiny check JSI-7 in multilocation coordinated varietal trials across the locations during 1999-2000 (Table 2). Non-spiny hybrids exhibited a high tolerance to *Fusarium oxysporum* and possess about 33 to 36% oil in the seed. The exploitation of flower from non-spiny hybrids is expected to double the income generated from the crop.

(c) **Performance of dwarf male sterility (DMS) based hybrids:** Safflower hybrids based on the genetic male steriles having dwarfness as the male sterility marker have also been developed at NARI. The preliminary evaluation of DMS -based hybrids recorded seed yield to the extent of

Table 1. Performance of safflower hybrid PH-3 compared to A-1, in multilocation coordinated varietal trials from 1996 to 2000.

Year of testing	No. of trials	Seed yield (Kg/ha)		Percent increase over 'A-1'	Oil yield (Kg/ha)		Percent increase over 'A-1'
		PH-3	A-1		PH-3	A-1	
1996-97	8	2417	1929	25.3	738	518	42.47
1998-99	11	1476	1320	11.82	449	365	23.01
1999-2000	9	1748	1465	19.32	550	429	28.20
	Mean	1880	1571	19.67	579	437	32.49

Table 2. Performance of non-spiny safflower hybrids in multilocation coordinated trials.

Sr. No.	Entry	Seed yield (Kg/ha)	Percent increase in seed yield over JSI-7	Oil yield (Kg/ha)	Percent increase in oil yield over JSI-7	Flower yield (Kg/ha)	Percent increase in flower yield over JSI-7
1.	PH-4	1366	19.41*	482	27.18*	125	92.31
2.	PH-5	1386	12.15*	489	29.02*	100	53.85
3.	PH-6	1314	14.86*	444	17.15*	92	41.54
4.	PH-9	1387	21.24*	456	20.32*	110	69.23
5.	JSI-7 (check)	1144	-	379	-	65	-

* Significant at 5% Source : Annual Progress Report-Safflower, 1999-2000

Breeding/Genetics/Disease

2616 kg/ha, which was found to be similar to the seed yield of the released safflower hybrid DSH-129. Seed production of the promising DMS based hybrids is being carried out in the 2000-01 season for multilocation evaluation in the All India Coordinated trials in 2001-02.

In addition to the hybrids mentioned above, some other promising hybrids of spiny or non-spiny nature and others based on DMS giving high oil and seed yield in addition to high disease and pest tolerance are in the "pipeline". They are expected to be evaluated in the All India Coordinated varietal trials in 2001-02.

III. Development of technology for hybrid seed production:

The success of hybrids in any crop depends upon the simplicity and cost effectiveness of hybrid seed production. Hybrid seed production in both spiny and non-spiny hybrids is done by sowing female and male parents in a row ratio of 6 female: 2 male. A recommended spacing of 20 cm and 45 cm between plants and rows, respectively, is maintained in the seed production plot. The roguing of fertile sibs in the genetic male steriles in both spiny and non-spiny types is carried out 6 to 7 days prior to flowering of the crop by use of the forced premature opening of the main capitulum of each plant by hand for checking whether the anthers are full of pollen grains. Thus the roguing of the fertile plants among the plants in the female line is completed before flower initiation in the crop. In case of spiny safflower, a pair of scissors may be used to open the capitulum for checking the anthers for the presence of pollen grains. About 4 to 5 persons/day are required for 5 to 6 days to do the necessary roguing of fertile plants in the female line in a one-acre seed production field. The seed production cost has been worked out to be $0.71 U.S. per kg in case of a spiny hybrid (Singh et al., 2000a) and $1.37/kg U.S. in case of a non-spiny hybrid (Singh et al., 2000b).

IV. Identification of early growth male sterility marker in GMS lines:

Efforts are being made to identify a male sterility marker in those GMS sources that lack such a marker. To do so, all the GMS lines of different sources available in India were crossed with fertile genotypes having specific traits identifiable at an early stage of growth to study their possible linkage with male sterility. The specific traits, which have been considered for the study, are: incised leaf, chlorophyll-deficiency, appressed branching, basal branching, non-spininess, earliness and dwarfness etc. All the traits mentioned above are reported to be controlled by oligogenes in safflower except the trait of earliness. The F_2 and backcross populations of all the related crosses are under investigation for the possible linkage of specific traits with male sterility in safflower.

V. Identification and development of cytoplasmic male sterility:

The efforts initiated to identify male sterile cytoplasm in safflower have resulted in the identification of cytoplasm causing male sterility in safflower. Efforts are being made to identify suitable maintainer and restorer genotypes for producing highly productive hybrids in safflower. The details of identification of male sterile cytoplasm in safflower have been furnished in a separate article for presentation in this conference.

VI. Development of battery operated flower collector:

In the last few years, due to increasing demand for safflower flower in India for both domestic use as well as for export purposes, it became necessary to develop a lightweight flower harvester for collection of flowers from a spiny crop as most of the safflower area in the country is under spiny varieties. The manual collection of flowers in a spiny crop is not cost effective due to the presence of spines on the capitulum. The NARI flower collector (Fig. 1) is lightweight and is 2 to 3 times more efficient in flower collection than flower picking done by hand in spiny safflower. Efforts are being made to make it more efficient and comfortable for flower collection in a spiny safflower crop.

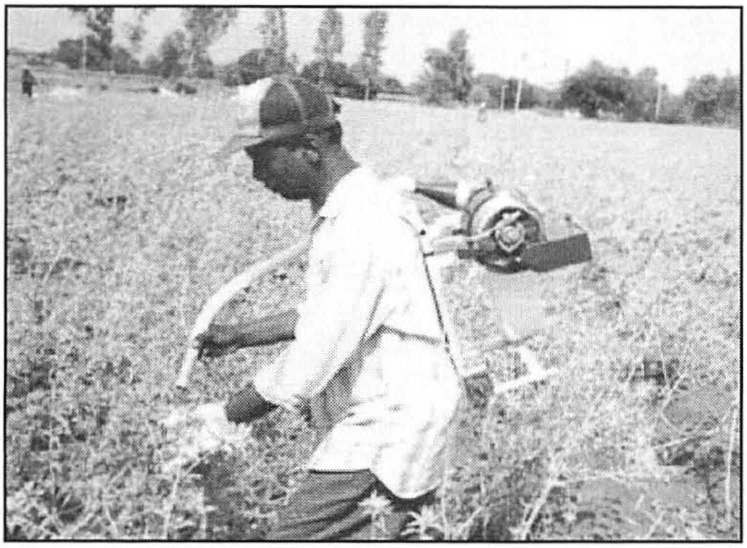

Fig 1. Battery-powered safflower petals collector

VII. Popularization of safflower flowers for various uses:

To commercialize safflower flowers in India, efforts have been initiated to popularize them as a herbal health tea for curing several chronic diseases. An herbal health tea from safflower flowers can be made in the same manner as the regular tea. One-teaspoon flowers are sufficient for preparing one cup of tea. It can be drunk with sugar and milk or with lemon juice. People liked the distinctive taste, color, and aroma of the herbal tea and its popularity among the people is gradually increasing due to its therapeutic effects. The regular users of this herbal health tea have reported its usefulness in curing diseases like hypertension, spondylosis, angina, arthritis, swelling of joints, constipation and menstrual disorders and in reducing cholesterol level.

Thus the improvement of safflower both in terms of seed and flower productivity as also commercialization of safflower flowers being carried out at NARI would help in the considerable enhancement of total remuneration from the crop to the farmer and thus would raise the socio-economic condition of safflower farmers in the country.

Breeding/Genetics/Disease

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Identification of Male Sterile Cytoplasm in Safflower

Vrijendra Singh[1], M. K. Galande, S. R. Deshmukh, M. B. Deshpande, and N. Nimbkar

ABSTRACT

The program for development of cytoplasmic-genetic male sterility in safflower at this Institute has been carried out for the last 4-5 years by following the conventional method of cytoplasmic male sterility development i.e. by transferring the nuclear genotype of the cultivated species into the cytoplasm of a wild relative. While looking at all possible avenues for developing cytoplasmic male sterility (CMS) in safflower, a male sterile plant having rudimentary anthers was noticed in a F_3 population of an interspecific cross. The male sterile plant was maintained by pollination with the fertile sib counterpart as well as with other genotypes of fertile nature. The seeds of each cross obtained from the male sterile plant were sown separately to know the nature of genes that existed in the pollinator parents. The observations on the nature of plants in the crosses exhibited the presence of both sterile and fertile plants. The male sterile plants of each cross were crossed separately with their fertile sibs as well as with several diverse genotypes. The resultant progenies raised in summer 2000 exhibited restoration of fertility in four crosses out of 81 evaluated during the season. The rest of the progenies segregated into sterile and fertile plants. Efforts are underway to confirm the restoration of fertility of the sterile cytoplasm and to identify the maintainer gene for the same. The development of the CMS system in safflower would speed up the process of commercialization of safflower hybrids, which is already in progress using the genetic male sterility based hybrids.

Key words: Cytoplasmic male sterility, nuclear genotype, interspecific, restorer, maintainer, hybrids

Breeding/Genetics/Disease

INTRODUCTION

India is the first country in the world to release hybrids based on the genetic male sterility system in safflower for commercial cultivation, which took place in 1997. In spite of the superior performance of hybrids compared to varieties, the progress of the popularization of hybrids is slow because of a lukewarm response by seed producing agencies to them, due to inherent problems associated with seed production in the genetic male sterility system in the absence of an "early growth male sterility marker trait". Though male sterile lines associated with marker traits are available in safflower (Singh, 1997), as the hybrids developed from them are in preliminary stages of evaluation, commercialization of hybrids developed from them would take about 3-4 years. However, even in this case, the laborious process of roguing male fertile plants from the female population is required for hybrid seed production. Ultimately only cytoplasmic male sterility can provide a feasible and suitable system of hybrid seed production in a spiny crop like safflower. However, there is no report of the availability of a cytoplasmic male sterility system in safflower in India. Therefore, the present study was undertaken with a view to develop cytoplasmic male sterility in safflower by following the conventional method of transferring the genome of a cultivated species into cytoplasm of a wild species by repeated backcrossing with the cultivated species genotype as recurrent parent.

MATERIALS AND METHODS

Four different species of Carthamus i.e. *C. tinctorius* L., *C. palaestinus* Eig., *C. lanatus* L., and *C. glaucus* Bieb., were crossed during 1996-97 to produce five crosses (1) *C. palaestinus* X *C. .tinctorius* (2) *C. lanatus* X *C. tinctorius* (3) *C. palaestinus* X *C. lanatus* (4) *C. palaestinus* X *C. glaucus* and (5) *C. lanatus* X *C. palaestinus*. Each of the five crosses along with their respective parents were grown in a

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single 5 m row during the winter of 1997-98. All plants in interspecific F_1 crosses were observed to be fertile and normal and each F_1 was backcrossed to both its parents. Unfortunately, none of them could produce viable seeds due to a heavy infestation of *Alternaria* leaf spot disease on the crop during flowering. However, a few F_1 plants of some of the interspecific crosses partially escaped the disease attack and produced a few seeds. This seed was used to grow F_2 populations. Each entry was sown in two rows of 5 m length during the summer of 1998 to identify male sterile plants. All the interspecific crosses showed only fertile and normal plants in their F_2 populations. All the F_2 plants of the different crosses were covered with nylon net cages just before flowering to prevent outcrossing. Plants of different crosses were threshed separately to raise individual F_3 progenies the following year. The selfed seed of each plant was sown in two rows of 5 m length during the winter of 1998-99. A wide range in values of different traits was observed among progenies of a cross. Each F_3 progeny was examined for male sterility during flowering. A number of plants having abundant but sterile pollen grains in their anthers were identified in different progenies of the interspecific crosses. These plants were maintained with the help of their fertile sib counterparts as well as both their parents and are being studied separately. However, in one specific case, a plant having rudimentary anthers but a fertile and fully developed stigma was observed in a F_3 progeny *of C. palaestinus X C. glaucus*. For other characteristics the plant was similar to normal safflower plants. A few capitula of this plant were crossed with its fertile sib counterpart and the remaining capitula with *C. palaestinus* and *C. tinctorius* genotype O-S-1-7-1. The seeds of each cross obtained from the male sterile plant were planted separately during the winter of 1999-2000. All three crosses showed segregation for male sterile and fertile plants during flowering of the crop. The rudimentary anthers of the male sterile plants were examined for the presence of pollen grains, which were subsequently subjected to a pollen viability test. The male sterile plants of each cross were crossed individually with their fertile sib counterparts as well as with several other genotypes of fertile and diverse nature. The resulting seeds of 81 different crosses thus produced were planted in two rows of 5 m length, along with their pollinator parents during the summer 2000 to know the nature of genes in pollinator parents i.e. whether they were acting as a maintainer or a restorer of the male sterility identified in the cross. Standard agronomic practices were followed to grow a healthy crop of safflower. Each entry of the trial was screened for plants of sterile and fertile nature in them during flowering.

RESULTS AND DISCUSSION

All five interspecific crosses showed only fertile and normal plants in their F_1 and F_2 generations, thereby indicating of homology among the chromosomes of the different species for the different traits to a large extent. The occurrence of a plant with rudimentary anthers in F_3 progeny of *C. palaestinus* X *C. glaucus* indicated the possibility of the presence of a distinct type of male sterility different than the genetic male sterilities reported in safflower so far. In all cases of genetic male sterilities in safflower, anthers are reported to be developed fully, but containing only sterile pollen grains (Ebert and Knowles, 1966; Heaton and Knowles, 1980; Joshi et al. 1983; Ramachandram and Sujatha. 1991; and Singh 1996 and 1997). However, Hill (1989) reported the absence of anthers in cytoplasmic male sterile lines in safflower developed by repeated backcrossing of wild species to the cultivated types in safflower. Therefore, in the present case also the role of cytoplasm in inhibiting anther development to cause male sterility is not ruled out.

The examination of the rudimentary anthers for the presence of pollen revealed a few pollen grains of half the size of normal fertile pollen grains. The pollen viability test confirmed the sterile nature of the pollen grains.

The initial crosses of the male sterile plant with rudimentary anthers with the fertile sib counterpart as well as with C. *tinctorius* genotype O-S-1-7-1 and *C. palaestinus* showed both fertile and male sterile plants. The ratio of male sterile to fertile plants in case of crosses of the male sterile plant with either

Table 1. Segregation of F_1 crosses between the male sterile plants and other genotypes evaluated during winter 1999-2000.

Cross	Total no. of plants	Number of plants		Ratio	χ^2	P
		MF	MS			
CMS-1 X CMF [(1)]	54	25	29	1 : 1	0.296	0.70 - 0.50
CMS-1 X O-S-1-7-1 (*C. tinctorius*)	120	64	56	1 : 1	0.533	0.50 - 0.30
CMS-1 X C. *palaestinus*	47	32	15	2 : 1	0.421	0.90 - 0.70

[(1)] CMF is a fertile sib counterpart of a CMS plant, MF = Male fertile, MS = Male sterile

Table 2. Evaluation of CMS based F1 hybrids for their segregation into types having either segregating or non-segregating nature for fertility restoration during the summer of 2000.

Total crosses	Crosses		Range of fertility restoration in crosses segregating for fertility
	Segregating for fertility	Non segregating for fertility	
81	77	4	28 - 93.33%

fertile sib counterpart or *C. tinctorius* genotype O-S-1-7-1 was observed to be 1 sterile: 1 fertile plants, however in case of the cross with *C. palaestinus* it was found to be 1 sterile: 2 fertile plants (Table 1). The variation in the segregation ratio of sterile and fertile plants in different crosses probably indicates the differential fertility restoration ability of the fertile parents. The male sterile plants appearing in the three above said crosses were crossed with fertile genotypes of diverse nature and with fertile sib counterparts during 1999-2000. These crosses were raised in the summer of 2000 and revealed that 77 crosses out of 81 segregated into sterile and fertile plants (Table 2). The fertility restoration in the crosses segregating for fertility ranged from 28 to 93.33%. However, four crosses produced only fertile plants, thereby suggesting the presence of fertility restoration genes in them. The segregation of F_1 hybrids into two classes i.e. non-segregating for fertility and segregating for fertility restoration, indicates the cytoplasmic control of male sterility in the present case. Such segregation is completely ruled out in the case of nuclear gene controlled male sterility of either recessive or dominant nature, which usually produces only one kind of F_1 hybrids i.e. either fertile ones in case of recessive type or ones segregating for fertility / sterility in the case of dominant type.

Therefore, in the present case, male sterility seems to be cytoplasmic in nature. Efforts are being made to identify a suitable maintainer for the male sterile cytoplasm in safflower.

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Inheritance of Wilt (*Fusarium oxysporum* f sp. *carthami*) Resistance in Safflower

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ABSTRACT

An investigation of the inheritance of wilt resistance in safflower to develop wilt resistant cultivars was undertaken at this Institute. Four safflower crosses, involving wilt susceptible, moderately tolerant and wilt resistant genotypes, were attempted during 1996-97. All four crosses along with their parents were screened for wilt resistance in wilt-sick plot conditions during 1997-98 and 1998-99. However, the F_2 s and backcrosses of only two of the crosses were evaluated during 1998-99. The observations on wilt resistance in F_2, F_3 and backcrosses of the crosses under examination revealed the control of inhibitory gene action in the expression of wilt resistance in safflower. The wilt in the present case is caused by a dominant gene, however, its expression is inhibited in the presence of a dominant inhibitor gene. Slight variation in wilt resistance in two years of F_1 evaluation indicated the possible role of modifier genes in altering the expression of wilt resistance in safflower.

Key words: *Fusarium oxysporum*, inheritance, inhibitory gene action, modifier gene

Breeding/Genetics/Disease

INTRODUCTION

Fusarium oxysporum has been found to be the most prevalent pathogen causing wilt in safflower in different safflower growing areas in India. The occurrence of *F oxysporum* has been reported to be as high as 80% with average wilting of 53% in Hingoli and Buldhana areas of Maharashtra State (Sastry, 1996). Similarly, a high incidence of wilt has also been reported from Jalna, Beed, Parbhani and Osmanabad districts of Maharashtra State (Pedgaonkar et al. 1990). The soil analysis of samples of these areas revealed a pathogen population of 4.4×10^2 to 6.8×10^5 per g of soil in these areas considered hot spots for wilt (Sastry, 1996). The factors which caused the increased wilt incidence in these areas were reported as (1) the repeated use of traditional varieties which are known for their susceptibility to wilt; (2) monocropping of safflower year after year on the same piece of land which caused the accumulation of the pathogen and thereby higher incidence of wilt; (3) use of sorghum in rotation with safflower; and (4) the lack of field tillage operations during summer. The cropping system studies indicated that the incidence of wilts was observed to be higher when safflower followed monsoon sorghum as compared to when safflower followed legumes like chickpea, cowpea or pigeonpea. The monsoon legume-safflower system was also associated with high yields, good plant stands and low disease incidence (Sastry et al.1993). Tillage practices like ploughing during summer may expose the pathogen to higher temperatures consequently killing the soil pathogens.

Moreover, there is no wilt- resistant variety of safflower available for commercial cultivation in India, which can minimize the losses caused due to the disease in endemic areas. Research on wilt resistance in safflower in India has been limited only to the identification of wilt resistant / tolerant genotypes and no information is available on the inheritance of wilt resistance in safflower. Therefore, the present study was undertaken to investigate the inheritance of wilt resistance and its incorporation into widely adapted but wilt susceptible safflower cultivars presently used in India.

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MATERIAL AND METHODS

The *F. oxysporum* tolerant safflower genotypes 237550 and C-2614-4-1-7, moderately tolerant genotype HUS-305 and susceptible cultivar Nira were considered for the fusarium resistance inheritance study in safflower. The *F. oxysporum* susceptible parent Nira was crossed with both the fusarium tolerant genotypes 237550 and C-2614-4-1-7. The moderately tolerant genotype was crossed with only one wilt tolerant genotype, 237550. A cross between *F. oxysporum* tolerant parents 237550 and C-2614-4-1-7 was also attempted, to study the nature of *F. oxysporum* resistant genes in them. Thus, in total four crosses were attempted during 1996-97 to study resistance to *F. oxysporum* in safflower. All four crosses along with their parents were planted in a randomized block design with three replications in a naturally wilt-sick plot during 1997-98. The casual organism in the wilt-sick plot was identified as *F. oxysporum* f. sp. *carthami.* The wilt sick plot has developed naturally due to continued cultivation of safflower for several years in the field and causes a very high mortality rate of 99% in the *F. oxysporum* susceptible cultivar Nira. Each entry in the trial was sown in two rows of 5 m length. Standard spacings of 20 cm between plants and 45 cm between rows were maintained in the trial. A fertilizer application of 60:30:30 kg/ha of N, P_2O_5 and K_2O respectively was provided to the crop. The experiment was supplied with two flow irrigations in addition to the irrigation provided for germination of the crop. An interval of 35 days was maintained between two irrigations. An initial plant count of the entries under study was recorded at 15 days after sowing, however the counting of wilted plants was done continuously at an interval of 30 days from sowing till maturity of the crop. The dead plants from each entry were removed immediately after the count. Two to three F_1 plants of the hybrids Nira X 237550 and Nira X C-2614-4-1-7 were backcrossed with both parents and a few plants of each hybrid were selfed to raise the backcross as well as F_2 populations in the following year to study the segregation pattern of fusarium resistant and susceptible plants in each of them. In addition, all four crosses stated above were attempted again to reevaluate them in the next year to confirm their performance against fusarium wilt.

During 1998-99, all four F_1, F_2, backcrosses and their parents were sown in a randomized block design with three replications in the wilt-sick field. The plot size of each F_1, backcross and parent was a single 5 m row. Each F_2 consisted of four 5 m rows. Agronomic practices followed and the method used of recording observations for wilt screening were the same as those described earlier for the previous year's trial. Forty-eight plants in the F_2 population of the cross Nira X C 2614-4-1-7 and 49 plants in the F_2 of the cross Nira X 237550 were selected, harvested and threshed separately. This seed was used to raise the individual F_3 progenies to study the segregation ratio of wilt resistant progenies to the progenies segregating for wilt resistance. The F_3 progenies of each cross were sown in a separate trial in a randomized block design with two replications during 1999-2000. The plot size for each progeny in each trial was two5 m rows. Agronomic practices and methods of recording observations were the same as stated above. The incidence of wilt in all replications in all trials in each year was uniform in the wilt- sick field. For a final figure of wilted plants in a treatment, wilting occurring at different stages of crop growth was summed up and was pooled over the total replications. The segregation of F_2's, backcrosses and F_3's for wilt tolerant and susceptible plants was subjected to a χ^2 test.

RESULTS AND DISCUSSION

The four F_1 hybrids and their parents were evaluated for *F. oxysporum* resistance under natural wilt-sick field conditions during 1997-98 and 1998-99. The safflower cultivar Nira, which is susceptible to fusarium, showed wilting of 99 and 96.61% in the two years of screening (Table 1). The high wilting in the susceptible parent indicates the high sickness of the field with *F. oxysporum.* In two years, the wilt resistant genotypes exhibited wilting of 8.33 and 6.35% for C 2614-4-1-7 and 5.08 and 4.68% for 237550, thus exhibiting high tolerance to the disease. All F_1 hybrids followed the resistant

Table 1. Evaluation of safflower hybrids and their parents for *Fusarium oxysporum* in 1997-98 and 1998-99 Sr. No. Entry 1997-98.

Sr. No.	Entry	1997-98			1998-99		
		Number of plants			Number of plants		
		Resistant	Susceptible	Wilting (%)	Resistant	Susceptible	Wilting (%)
1.	Nira X C 2614-4-1-7	85	11	11.46	63	0	0
2.	Nira X 237550	36	3	7.69	51	0	0
3.	HUS-305 X 237550	98	14	12.50	69	0	0
4.	C 2614-4-1-7 X 237550	91	7	7.14	58	3	4.92
5.	Nira	1	100	99.01	2	57	96.61
6.	C 2614-4-1-7	110	10	8.33	59	4	6.35
7.	HUS-305	89	32	26.44	48	8	14.29
8.	237550	112	6	5.08	61	3	4.659

parents in their reaction to *F. oxysporum* in two years of screening, thereby indicating the dominant nature of *F. oxysporum* resistance in safflower.

In general, the incidence of disease in the entries evaluated during 1997-98 was slightly higher than it was in 1998-99. The variation in the disease incidence in the two years might have arisen because of changes in the environmental conditions, as the sowing of the trial in the year 1997-98 was done about 28 days earlier than that in 1998-99. Because of this, the crop in 1997-98 faced higher mean temperatures at early crop growth than the crop in 1998-99. High temperature has been reported as one of the predisposing factors causing wilting in safflower (Parameshwarappa 1996).

The role of modifier genes causing wilt under specific climatic conditions cannot be ruled out in safflower. The F_2 populations of all four crosses and backcrosses with both parents of the two crosses were evaluated for *F. oxysporum* resistance during 1998-99, which showed that the F_2 populations of three crosses i.e. Nira X C 2614-4-1-7, Nira X 237550 and HUS-305 X 237550 segregated into a ratio of 13 *F. oxysporum* resistant to 3 susceptible plants (Table 2), thereby suggesting a role of an inhibitory gene action in expression of *F. oxysporum* resistance in safflower. As per the inhibitory gene action in the present case it appears that fusarium resistance is conditioned by a recessive gene, however, actually the expression of its dominant allele is inhibited by the presence of a dominant inhibitor gene. This was further supported by the absence of wilting in backcross made with the tolerant parent in the

Table 2. Reaction of F_2 and backcross populations to *Fusarium oxysporum* in safflower.

Cross	Generation	Total number of plants	# of plants Resistant	# of plants Susceptible	Ratio	χ^2 value	P value
Nira X C 2614-4-1-7	F_2	258	208	50	13 : 3	0.067	0.90 - 0.70
Nira X 237550	F_2	201	164	37	13 : 3	0.0154	0.95 - 0.90
HUS-305 X 237550	F_2	265	220	45	13 : 3	0.544	0.50 - 0.30
C 2614-4-1-7 X 237550	F2	231	224	7	15 : 1	4.086	> 0.05
F_1 (Nira X C 2614-4-1-7) X C 2614-4-1-7	BC	53	53	0	-	-	-
F_1 (Nira X 237550) X 237550	BC	53	51	2	-	-	-
F_1 (Nira X 237550) X Nira	BC	52	32	20	1 : 1	2.769	0.10 - 0.05
F_1 (Nira X C 2614-4-1-7) X Nira F2	BC	57	48	9	1 : 1	26.684	> 0.05

BC = Backcross

Table 3. F_3 segregation for *Fusarium oxysporum* resistance in the progenies raised from fusarium resistant F_2 plants in safflower.

Cross	Total lines	No. of F_3 lines		Fit to 7 : 6 ratio	
		True breeding resistant	Segregating for resistance	χ^2	P
Nira X C 2614-4-1-7	48	24	24	0.2856	0.70 - 0.50
Nira X 237550	49	25	24	0.1574	0.70 - 0.50
Pooled	97	49	48	0.4329	0.70 - 0.50

case of F_1 (Nira X C 2614-4-1-7) X C 2614-4-1-7 and negligible wilting in the backcross made with the other tolerant parent i.e. F_1 (Nira X 237550) X 237550 (Table 2). On the other hand a backcross made with the fusarium susceptible parent, in the case of F_1 (Nira X 237550) X Nira, exhibited a segregation ratio of 1 fusarium resistant to 1 susceptible plant. This thus gave the desired results as was expected in such a case. However, in another backcross made with the fusarium susceptible parent Nira, in the case of F_1 (Nira X C 2614-4-1-7) X Nira, 48 fusarium resistant plants and 9 susceptible ones were observed, which was a complete deviation from the 1:1 ratio of resistant to susceptible plants expected from the cross. The deviation in the present case seems to be due to the possible crossing of F_1 with plants left over after wilting in the susceptible parent Nira, which thus were heterozygous for wilt resistance.

The cross between *F. oxysporum* resistant parents C-2614-4-1-7 X 237550 was made to study the nature of genes responsible for fusarium resistance in them. The F_2 population of the cross exhibited very low wilting, which did not fit into any expected ratio, therefore suggesting an allelic nature of genes for fusarium resistance in the two genotypes. The F_3 progenies of Nira X 237550 and Nira X C 2614-4-1-7 raised from selfed F_2 plants tolerant to *F. oxysporum* showed the expected ratio of 7 true breeding fusarium resistant: 6 progenies segregating for fusarium resistance (Table 3), thereby confirming again the role of inhibitory gene action in *F. oxysporum* resistance in safflower.

Thus the study revealed that under natural wilt-sick field conditions, the inheritance of *F. oxysporum* resistance in safflower is conditioned by inhibitory gene action. However, Heaton and Klisiewicz (1981) reported that both fusarium as well as verticillium wilt in safflower are controlled by dominant genes. In another study, Thomas and Zimmer (1970) reported that root rot caused by *Phytophthora drechsleri* in safflower is conditioned by a single recessive factor pair. The results in the present case suggest that the information generated in the study can be utilized for the development of *F. oxysporum* resistant cultivars in safflower by following the backcross method of breeding as usually practised for the transfer of a dominant gene controlled trait.

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Breeding for Oil Quality in Safflower

L. Velasco and J. M. Fernández-Martínez[1]

SUMMARY

A breeding program to improve seed oil quality in safflower was initiated in 1998. Safflower cultivars and breeding lines as well as part of the US safflower germplasm collection were evaluated for their seed oil fatty acid composition, total tocopherol (vitamin E) content, and tocopherol composition. After two selection cycles, lines with high palmitic acid content (10.3% of the total fatty acids), medium stearic acid content (3.9%), high stearic acid content (6.2%), high oleic acid content (>78%), very high oleic acid content (>86%) together with reduced levels of the saturated fatty acids palmitic and stearic acid (<5%), and very high linoleic acid content (>86%) combined with reduced palmitic and stearic acid content (<5.5%) were developed. Furthermore, sources of variation for high total tocopherol content (up to 400 mg kg^{-1} seed) and increased gamma-tocopherol content (up to 9.9% of the total tocopherols) were identified and selection for both traits is in progress. The combination of a higher tocopherol content with specific fatty acid and tocopherol profiles will lead to high-quality safflower oils for food and non-food applications.

Key words: seed oil quality, gas-liquid chromatography, *Carthamus tinctorius* L.

Breeding/Genetics/Disease

INTRODUCTION

Safflower is a minor, underutilized oilseed crop. World acreage in 2000 was of 1.1 million ha, which is about 0.5% of total oilcrops production area. In Spain, safflower cultivation was significant in the late sixties (up to 70,000 ha), but nowadays only a few hundreds ha are dedicated to this crop. This situation is paradoxical taking into account that safflower produces oil types that are demanded by both the oil and food industry, such as very high oleic acid oil or very high linoleic acid oil, the latter not available in any other oilseed crop. Additional characterization and improvement of safflower oil should result in a greater interest by the industry and, consequently, in the promotion of safflower cultivation.

Safflower is one of the best examples of crops with variability for fatty acid composition in seed oil (Knowles, 1989). Standard safflower oil contains about 6 to 8% palmitic acid, 2 to 3% stearic acid, 16 to 20% oleic acid, and 71 to 75% linoleic acid. Variants with increased stearic acid content (4% to 11% of the total fatty acids), intermediate oleic acid content (41 to 53%), high oleic acid content (75 to 80%), and very high linoleic acid content (87 to 89%) have been identified and are currently available in released materials (Fernández-Martínez et al., 1993; Johnson et al., 1999). Additionally, sources of variation for high palmitic acid content (>10%) and very high oleic acid content (>85%) have been reported (Fernández-Martínez et al., 1993; Dajue et al., 1993).

Tocopherols (=vitamin E) are the main antioxidant compounds present in seed oils. Both the total tocopherol content and the tocopherol profile are becoming important traits for determining oil quality. The tocopherols occur in four homologous isomers named alpha-, beta-, gamma-, and delta-tocopherol, which differ in the number of methyl substitutions and the pattern of substitution in the phenolic ring. The four tocopherol derivatives also differ in their *in vivo* vitamin E activity and in their *in vitro* ability to protect oils from autoxidation. Alpha-tocopherol exhibits the highest vitamin E activity, whereas gamma-tocopherol is the most powerful antioxidant *in vitro* (Kamal-Eldin and Appelqvist, 1996). The

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total tocopherol content in commercial safflower oils is relatively low when compared with other oils such as soybean and sunflower. Carpenter (1979) reported a maximum tocopherol content of 410 mg kg^{-1} in commercially processed safflower oil compared with 950 mg kg^{-1} and 1360 mg kg^{-1} in commercially processed sunflower and soybean oils, respectively. Johnson et al. (1999) found a range of variation for alpha-tocopherol content between 180 and 1600 mg kg^{-1} crude oil in accessions from the USDA collection. Safflower contains predominantly alpha-tocopherol, which accounts for about 80-90% of the total tocopherol content (Padley et al., 1994). No safflower types with high levels of other tocopherol derivatives have been described.

In 1998 we initiated a breeding program focused on the improvement of safflower oil quality. In the first step, a germplasm collection was characterized for seed oil fatty acid composition, total tocopherol content and tocopherol composition. The most promising accessions were chosen and a selection program was initiated. The results obtained in the evaluation of the germplasm collection and the first results of the selection program are reported in this paper.

MATERIALS AND METHODS

One hundred and thirty-two accessions were provided by the Western Regional Plant Introduction Station of the US Department of Agriculture in Pullman, Washington State. Several cultivars and breeding lines from our Institute were also included in the evaluation.

For fatty acid analyses, sixteen seeds from each accession were placed on wet filter paper in Petri dishes and maintained in the dark at room temperature. Small cotyledon pieces were cut from the germinating seeds after 24 h, when no substantial modification of the fatty acid profile has taken place (Garcés et al., 1988). The fatty acid composition of the oil in cotyledon tissues from individual seeds was analyzed by simultaneous extraction and methylation (Garcés and Mancha, 1993) followed by gas-liquid chromatography (GLC) on a Perkin-Elmer Autosystem gas-liquid chromatograph (Perkin-Elmer Corporation, Norwalk, CT, USA). A 2-m-long column packed with 3% SP-2310/2% SP-2300 on Chromosorb WAW (Supelco Inc., Bellefonte, PA, USA) was used. The oven, injector and flame ionization detector were held at 185, 275 and 250°C, respectively.

Six seeds per entry were used for tocopherols analyses, following the method of Thies (1997). Half seeds were cut from each seed and the six halves were weighed and placed into a 10 ml tube. After 2 ml of iso-octane were added, the half seeds were crushed with a stainless steel rod as fine as possible. The rod was then washed with 2 ml of iso-octane, which were collected in the tube. The samples were stirred and extracted overnight at room temperature in darkness (extraction time about 16 h). After extraction, the samples were stirred again, centrifuged and filtered. Five microliter of the extract were analysed by HPLC using a fluorescence detector at 295 nm excitation and 330 nm emission and iso-octane/tert-butylmethylether (94:6) as eluent at an isocratic flow rate of 1 ml min^{-1}. Chromatographic separation of the tocopherols was performed on a LiChrospher 100 diol column (250 mm x 3 mm I.D.) with 5 x 10^{-3} mm spherical particles, connected to a silica guard column (LiChrospher Si 60, 5mm x 4 mm I.D.). Quantitative determination of tocopherols was done by using external calibration curves.

Half seeds with fatty acid or tocopherol patterns deviating from standard values were selected and the corresponding plants were grown in pots in a field screenhouse in 1999. The seeds were planted in January and the plants were harvested in July. Before flowering, the heads of the plants were covered with paper bags to ensure self pollination. Half seeds from each of the harvested plants were analysed for fatty acid composition and tocopherol content and composition. Selected half seeds were allowed to germinate and the corresponding plants were grown in pots in 2000 and self-pollinated as in the previous year. Plants of the Spanish cultivar 'Rancho' were used as check. Half seeds from each of the harvested plants were analysed for seed quality traits as in previous years.

RESULTS AND DISCUSSION

The collection showed a great variability for seed oil fatty acids, with an average composition of 5.8% palmitic (from 3.4% to 10.2%), 2.2% stearic (from 0.8% to 9.9%), 26.2% oleic (from 5.6% to 86.9%), and 65.9% linoleic acid (from 7.1% to 88.7%). The average total saturated fatty acids (palmitic and stearic) acid was 7.9%, ranging from 4.9% to 14.8%. Similar variability for fatty acid composition of the seed oil in safflower germplasm has previously been reported (Fernández-Martínez et al., 1993; Johnson et al., 1999).

Total tocopherol content averaged 269.7 mg kg^{-1} seed (from 88.4 to 400.4 mg kg^{-1} seed). Alpha-tocopherol was the predominant tocopherol derivative, accounting for 89.7% to 100% of the total tocopherol content, which is in agreement with the results of Johnson et al. (1999). Beta-tocopherol was identified in most of the entries (115 out of 132), but at very low levels, the maximum value being of 3.3% of the total tocopherols. Conversely, gamma-tocopherol was present at higher concentrations, up to 9.9% of the total tocopherol content, but it was detected in few accessions (37 out of 132). A relationship between gamma-tocopherol content and the area of origin of the entries was observed: all the accessions containing increased levels of gamma-tocopherol (>2%) came from India, Pakistan or Bangladesh. No accession coming from other regions contained more than 2% of this tocopherol. Johnson et al. (1999) reported no data for gamma-tocopherol content in their analysis of 1000 safflower accessions from the USDA world collection.

Total tocopherol content was negatively correlated with alpha-tocopherol content ($r=-0.32$, $p<0.01$) and positively correlated with both beta- ($r=0.31$, $p<0.01$) and gamma-tocopherol content ($r=0.20$, $p<0.05$). Similarly, total tocopherol content was positively correlated with oleic acid content ($r=0.30$, $p<0.01$) and negatively correlated with both stearic ($r=-0.32$, $p<0.01$) and linoleic acid content ($r=-0.29$, $p<0.01$). No relationship between tocopherol and fatty acid profiles was detected.

Germplasm accessions exhibiting the highest total tocopherol content as well as those expressing fatty acid or tocopherol profiles deviating from standard values were chosen and a selection program was initiated. The evaluation of the progenies of selected accessions for tocopherol content or composition has not been completed yet. From the accessions selected for their seed oil fatty acid profile, the following lines were selected: CR-50 (developed from accession PI-306686), with high palmitic acid content (mean value of 10.3% of the total fatty acids; Table 1), CR-58 (PI-311738) and CR-69 (PI-387821), with increased stearic acid content (3.9% and 6.2%, respectively), CR-6 (PI-560177) and CR-102 (PI-537607), with high oleic acid content (>78%), CR-9 (PI-401479) and CR-11 (PI-401474), exhibiting both a very high oleic acid content (>86%) as well as a very low content of the saturated fatty acids palmitic and stearic acid (<5%), and CR-142 (W6-866), showing both a very high linoleic acid content (>86%) and reduced palmitic and stearic acid content (<5.5%). An additional line with very high linoleic acid content and reduced levels of palmitic and stearic acid, CR-3, was developed within this program from the inbred line HL-190. Table 1 shows the fatty

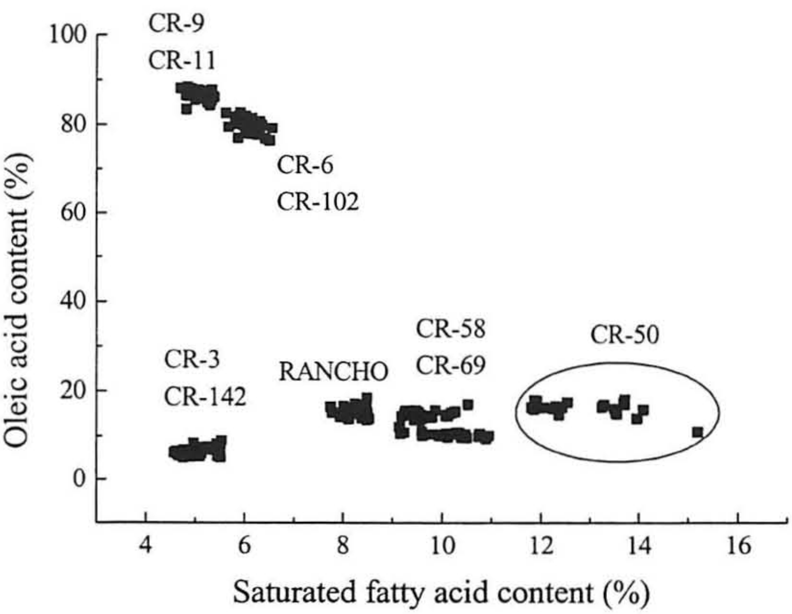

Fig. 1. Scatter plot of saturated fatty acid (palmitic+stearic) content versus oleic acid content in half-seeds of lines with different fatty acid profiles and the cultivar 'Rancho', used as check.

Table 1. Fatty acid composition (given as mean ± standard deviation) of safflower lines with contrasting seed oil fatty acid profiles during three generations of a breeding program.

Line	Generation	n	Palmitic	Stearic	Oleic	Linoleic
CR-50	1	8	7.58 ± 1.69	3.37 ± 0.52	13.11 ± 2.39	75.95 ± 3.50
(PI-306686)	2	24	9.51 ± 0.42	3.25 ± 0.55	14.72 ± 1.04	72.51 ± 1.45
	3	24	10.31 ± 0.55	2.55 ± 0.62	14.38 ± 1.05	72.76 ± 1.28
CR-58	1	8	6.84 ± 0.39	4.63 ± 0.72	14.65 ± 2.15	73.88 ± 2.19
(PI-311738)	2	24	5.90 ± 0.24	4.00 ± 0.30	17.37 ± 2.43	72.72 ± 2.55
	3	24	5.69 ± 0.15	3.93 ± 0.27	14.83 ± 0.64	75.55 ± 0.71
CR-69	1	8	5.46 ± 0.48	6.02 ± 1.79	10.31 ± 1.06	78.28 ± 1.64
(PI-387821)	2	24	5.32 ± 0.23	6.71 ± 0.79	14.01 ± 1.42	73.96 ± 1.31
	3	24	4.33 ± 0.13	6.16 ± 0.40	11.48 ± 1.04	78.03 ± 1.35
CR-6	1	12	4.51 ± 0.48	1.21 ± 0.23	73.24 ± 17.16	21.04 ± 16.75
(PI-560177)	2	24	5.71 ± 0.23	1.07 ± 0.12	78.79 ± 0.84	14.44 ± 0.82
	3	24	5.25 ± 0.19	1.12 ± 0.10	78.37 ± 1.61	15.25 ± 1.49
CR-102	1	8	6.05 ± 1.03	1.54 ± 0.52	49.73 ± 32.81	42.69 ± 31.54
(PI-537607)	2	24	5.41 ± 0.26	1.15 ± 0.11	78.63 ± 1.08	14.81 ± 1.22
	3	24	5.29 ± 0.19	1.09 ± 0.10	79.45 ± 0.94	14.17 ± 0.83
CR-9	1	10	4.79 ± 0.45	1.51 ± 0.54	73.55 ± 25.39	20.14 ± 24.50
(PI-401479)	2	24	4.29 ± 0.09	1.94 ± 2.49	75.55 ± 27.88	18.22 ± 25.38
	3	24	4.11 ± 0.16	0.88 ± 0.08	86.39 ± 0.65	8.62 ± 0.60
CR-11	1	9	4.72 ± 0.26	1.55 ± 0.42	78.34 ± 21.09	15.38 ± 20.60
(PI-401474)	2	24	4.86 ± 0.45	0.81 ± 0.15	85.35 ± 2.39	8.99 ± 2.15
	3	24	4.23 ± 0.22	0.78 ± 0.09	86.20 ± 1.25	8.79 ± 1.10
CR-142	1	6	4.00 ± 0.34	1.85 ± 0.23	6.75 ± 0.93	87.41 ± 1.19
(W6-866)	2	24	4.37 ± 0.34	1.95 ± 0.17	7.24 ± 1.41	86.43 ± 1.54
	3	24	3.62 ± 0.16	1.70 ± 0.13	7.08 ± 0.93	87.60 ± 0.97
CR-3	1	7	4.33 ± 0.25	1.51 ± 0.17	6.82 ± 0.67	87.34 ± 0.92
(HL-190)	2	24	4.31 ± 0.22	1.34 ± 0.17	5.92 ± 0.61	88.43 ± 0.62
	3	24	3.95 ± 0.16	1.02 ± 0.19	6.42 ± 0.69	88.62 ± 0.83

acid composition of the lines during the selection process. The contrasting fatty acid profiles are most clearly observed in Fig. 1, which represents saturated fatty acid content versus oleic acid content in single seeds of the third generation of the selection program. Some of the above accessions are breeding materials or cultivars, as for example PI-311738 (a cultivar from Poland), PI-560177 ('Oleic Leed'; Urie et al., 1979), PI-537607 and HL-190 (both breeding materials). Others, however, are unimproved materials, as for example PI-401474 and PI-401479, both of them collected from Bangladesh. Additional information on the accessions can be found by searching the GRIN system (http://www.ars-grin.gov/npgs/).

Safflower accessions with increased palmitic (Fernández-Martínez et al., 1993), stearic (Knowles, 1965), oleic (Knowles and Mutwakil, 1963; Fernández-Martínez et al., 1993), or linoleic acid content (Futehally and Knowles, 1981) have been previously reported. Lines with all these fatty acid characteristics have been selected in the present work. Additionally, lines with increased levels of stearic acid (CR-58, CR-69), and lines with reduced levels of the saturated fatty acids palmitic and stearic acid, both in high oleic (CR-9, CR-11) and high linoleic acid (CR-3, CR-142) backgrounds are reported here. The present work stresses that safflower germplasm also contains variation for other seed quality traits such as the tocopherol content and composition. For the latter components, a selection program is ongoing.

Future research in our group will focus on the genetic and molecular characterization of the lines with different fatty acid profiles, selection for high total tocopherol content and modified tocopherol profile, and combination of different fatty acid and tocopherol patterns.

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Chemical Control of Alternaria Blight of Safflower in Northern Karnataka

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ABSTRACT

An experiment on the control of Alternaria blight of safflower (carthamus tinctorius L.) caused by Alternaria carthami Chowdhury was carried out for 4 consecutive years from 1995-96 to 1998-99 at Agricultural Research Station, Annigeri, Of the five fungicides evaluated against the disease, carbendazim (0.1%) was found quite effective in controlling disease (37.9% disease index) followed by the combination of carbendazim (o.1%) + mancozeb (0.2%). However, the disease pressure was quite high in case of untreated check (65.1%). The treatmental efficacy was reflected in the seed yield. The highest yield (505g/5 plants) was recorded with the carbendazim treatment compared to 302g/5 plants in the untreated checks. The next most effective treatments in disease control were carbendazim + mancozeb (486g/5plants), Rovaral (465g/5plant) and mancozeb (436g/5plants). The other fungicides viz., thriophonate methyl, copper oxychloride, chlorothalonil did not give satisfactory results.

Key words: Alternaria blight, chemical control, *Carthamus tinctorius* L.

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Breeding/Genetics/Disease

Association Analysis in Safflower Under Rainfed Conditions

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ABSTRACT

An investigation was carried out with 25 F_1's to determine the association of grain yield, plant height, number of branches/plant, number of heads/plant, main head diameter and number of seeds/head under rainfed conditions. Grain yield contributing characters such as plant height were significantly correlated with number of branches/ plant and main head diameter. Number of branches/plant had a positively significant association with number of heads/ plant, main head diameter and number of seeds/head. A path coefficient analysis revealed that number of branches/ plant and number of heads/ plant were the most important characters because these characters had the highest positive indirect effect on seed yield.

Key words: grain yields, rainfed conditions

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Germplasm

Managing the U.S. Safflower Collection

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ABSTRACT

There are currently 2,288 accessions of safflower (*Carthamus tinctorius* L.) in the United States germplasm collection. The collection is maintained at the Western Regional Plant Introduction Station in Pullman, WA, USA. Major objectives in managing the collection include providing high quality seed and useful documentation and evaluation data to the germplasm user community. Accessions from the collection are distributed to scientists worldwide upon request and at no charge. Accessions must be regenerated when seed quantity or quality is low. In past regeneration nurseries, as many as 15 plants within a plot were covered with a single 1.25 meter-long, unsupported, screen bag. This practice reduced the quality of harvested seed. A new method of caging an entire regeneration plot in one screen cage, 7.5 meters long and supported by fence posts and wire, has been developed. Data on crop specific descriptors have been gathered on a large number of the accessions in the collection and entered into the Germplasm Resources Information Network (GRIN). Although these data reflect diversity among accessions they do not always reflect the within accessions diversity often observed. Therefore, the method of recording some of the descriptors has been modified. Images of 86 accessions have been downloaded into GRIN, allowing scientists to view morphological traits of individual accessions and provide visual clarification of descriptor data. Photographing and downloading images of the collection is an ongoing project. Improving the regeneration protocol and clarifying data in GRIN are key issues in the management of the U.S. safflower collection.

Key words: *Carthamus tinctorius* L., regeneration, descriptors, diversity, safflower

INTRODUCTION

The Western Regional Plant Introduction Station (WRPIS), located in Pullman, Washington, is part of the United States National Plant Germplasm System (NPGS) and the United States Department of Agriculture. The WRPIS staff manages almost 69,000 germplasm accessions representing more than 2,600 plant taxa. The mission of the unit is to acquire, regenerate, evaluate, document, and distribute plant germplasm for research purposes. Upon receipt of seeds from collectors or donors, information, which describes their origin, as well as any other data available, is entered into the Germplasm Resources Information Network (GRIN, http://www.ars-grin.gov/npgs/). Seed is stored in a cold storage vault maintained at 4° C and 30 percent relative humidity (dewpoint -10° C). When seed quality or quantity is low, an accession is planted for regeneration.

Safflower (*Carthamus tinctorius* L.) is a major collection at the WRPIS and consists of 2,288 accessions from more than 50 countries. The WRPIS sends an average of about 1,000 packets of safflower seed per year to scientists worldwide. Rarely do researchers wish to evaluate all available accessions of safflower, so it is desirable to have basic "passport" data such as country of origin and collection information as well as descriptor data to enable them to select materials appropriate for their research.

Safflower is largely self-pollinated, however, insect cross-pollination does occur and leads to varying amounts of outcrossing (Li and Müendel, 1996). It is therefore desirable to exclude insects from plants in safflower regeneration plots in order to insure self-pollination and the genetic integrity of accessions. It is possible for certain accessions to exhibit some degree of self-incompatibility that may reduce yield (Rubis et al. 1966), but this is normally not a major concern. Both descriptor data and

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regeneration protocol are key elements in managing the safflower collection, which are currently being improved.

Descriptor Data

Data on some of the descriptors listed in GRIN have been entered for safflower accessions planted in regeneration nurseries. Evaluation data from studies by other scientists have also been entered into this database. Although 54 descriptor fields are listed in GRIN, data for only 25 have been collected on one or more accessions (Table 1). Some of these descriptors, and others not currently listed in GRIN, were developed by the International Board for Plant Genetic Resources (now International Plant

Table 1. Safflower descriptors currently listed in the Germplasm Resources Information Network (GRIN, 2000).

Abbreviation	Explanation	Number of data points‡	Code Values
ALPHATOCO	Milligrams alpha-tocopherol per 100 grams of oil	1000	
BETATOCO	Milligrams beta-tocopherol per 100 grams of oil	999	
DELTATOCO	Milligrams delta-tocopherol per 100 grams of oil	4	
GAMMATOCO	Milligrams gamma-tocopherol per 100 grams of oil	264	
HYDROXYARC	percent 2-hydroxyarctiin in flour meal	1000	
IODINE	Iodine number	985	
LYSINE	ratio values table values divided by 16 = grams lysine/16grams nitrogen	685	
LINOLEIC	percent linoleic acid in seeds	1000	
MATAIRESIN	percent matairesinol in flour meal	1000	
OIL	percent of oil in the seed	2122	
OLEIC	percent oleic acid in seeds	1000	
PALMITIC	percent palmitic acid in seeds	1000	
STEARIC	percent stearic acid in seeds	1000	
HABIT	growth habit of the accession	1728	E=erect, S=sprawling
HEIGHT	height of the plant in centimeters	3329	
BRANCHING	degree of branching	2917	1=upper 1/5 of plant 2=upper 2/5 of plant 3=upper 3/5 of plant 4=upper 4/5 of plant 5=whole plant
FLOWERCOL	flower color	3110	C=cream O=orange R=red W=white Y=yellow
HEADSIZE	diameter of head in millimeters	2704	
IMAGE	photograph of accession	87	
SPINES	amount of spines	2949	0=no spines 1=few spines 2=less than average spines 3=average spines 4=more than average spines 5=many spines
UNIFORMITY	general uniformity of the morphological characteristics	155	scale of 1 (uniform) to 9 (variable)
BLOOMDATE	relative time of flowering	2953	E=early M=medium L=late
BLOOMDAY	numeric date when approximately 50% flowering begins	1710	
CORE	a flag to indicate the accession is part of the core subset	210	Y=yes, accession is in the core
SEEDWGT	weight of 100 seeds measured in grams	2065	

‡Multiple evaluations for one descriptor may have been completed on a given accession resulting in data points exceeding the total number of safflower accessions.

Genetic Resources Institute) in 1983, while others were developed by NPGS personnel prior to 1983. These accession characteristics are valuable for determining overall diversity and in helping scientists to determine which germplasm is best suited for inclusion in their research projects.

More than 2,100 of the 2,288 safflower accessions in the WRPIS collection are not cultivated varieties. Many of these wild accessions may have plants which exhibit variation in morphological traits such as flower color, spines, height, and head size. The manner in which safflower descriptors are currently reported in GRIN limits a user's ability to understand or utilize this diversity. In some accessions the information may even be misleading, especially if data have been recorded in more than one year, or recorded by different evaluators. For example, flower color was recorded in more than one year for PI 199874. The data indicates that this accession had yellow and orange flowers in 1986, but white flowers were noticed in another year (Table 2).

Table 2. PI 199874 evaluation data for the descriptor flower color.

Descriptor	Value	Study
FLOWERCOL	yellow	1986
	orange	1986
	white	YEARS
	yellow	YEARS
	orange	YEARS

Regeneration protocol

Prior to 1990, five plants within a single row of 30 plants of each safflower accession were individually bagged with a cloth bag. The seed harvested from these five plants was saved for the regeneration sample and the open pollinated seed harvested from the remaining 25 plants was distributed to the user community. This bagging resulted in poor seed quality and quantity and produced a regeneration sample that represented an unacceptably small plant population.

This paper reports, 1) improvements in recording and entering safflower descriptor data in GRIN, and, 2) safflower regeneration protocol modifications developed by WRPIS staff.

MATERIALS AND METHODS

Descriptor data

An ongoing project to evaluate safflower accessions for ornamental potential brought the need to modify descriptors to the forefront. Safflower accessions for field observation were chosen from the WRPIS collection based on information listed in GRIN. All safflower accession data were reviewed for the presence or absence of narrative descriptions. Of the almost 800 accessions that had such information, 80 were selected each year for evaluation. Selections were based on the narrative description indicating they were used for flowers, were relatively spineless, or had flowers of an unusual color such as pink or white.

Evaluation nurseries were planted in 1998 and 1999 at the WRPIS Central Ferry Research Farm, Washington, U.S.A., located in the Snake River Canyon at 46.7 degrees N latitude, 200 m above sea level. Prior to planting, approximately 67.2 kg/ha of nitrogen and 10 kg/ha of sulfur were applied and incorporated into the soil, as was a pre-emergence herbicide. Seeds were treated with a fungicide prior to being planted in 3-meter long single rows, on 1.5 m centers in 1998, and in four 1.5-meter long rows, 0.3 meters apart in 1999. Rosette-stage plants were thinned to 10 cm apart within a row, and irrigated at a rate of approximately 20 mm per week in both nurseries. Field evaluation data for bloom day, height, headsize, spines, uniformity, and flower color were recorded.

Photographs were taken of the accessions in the 1999 nursery. Two images, one of the accession in the field, and one of heads selected to represent diversity in flower color and spines, were linked to each Plant Introduction (PI) number in GRIN.

Regeneration protocol

A new safflower regeneration protocol was initiated in 1990 in order to better conserve the diversity of the original population of each safflower accession. Original seed, when available, was planted 2 cm deep in single rows 6 meters long spaced 1.5 meters apart, in a sprinkler-irrigated nursery at Central Ferry, Washington. The rows were thinned to a plant spacing of approximately 8 cm for a plant population of about 80. Grey fiberglass mesh screening material was used to construct bags that measured 1.25 meters long by 0.75 meters tall. Six or fewer of these bags were placed over all the plants in an accession, depending on number and spacing of plants, when flowering first began. Often as many as 15 plants were covered with a single bag. The bags were tightly secured with large safety pins at the base of the plants and the bags remained on the plants until harvest. When dry, plants were broken off at the base and threshed with a spike-drum "vogel"[2] thresher.

RESULTS

Descriptor Data

While evaluating the 1998 and 1999 nurseries for ornamental potential it became apparent that changes to the descriptors were necessary to better reflect the diversity in individual accessions and to clarify discrepancies. The major goal is to record percentages of the occurrence of a factor when more than one descriptor value is present in an individual accession, as in the flower color example described above (Table 2). It would be helpful for example, in the case of PI 199874, to know what fraction of white flowers were observed. If they occurred at a low frequency, this could explain why white flowers were not observed in 1986. Expanding the range of color descriptor values is also needed as it is possible that one evaluator would report a very light yellow flower as being white where another would simply report it as yellow. Data for descriptors that are listed in GRIN (Table 1), and for which we have taken little, if any, data in the past, also need to be collected. The first priority will be to record corolla color at bloom (CORCOLBL) and corolla color of dry flower (CORCOLDRY). We will also continue to take photographs of accessions as they are evaluated for a range of descriptors and post them on GRIN.

Regeneration protocol

Although the number of plants harvested for regeneration and distribution samples was much higher using screen mesh bags to cover an entire regeneration plot than it was prior to 1990, this protocol reduced seed quality when compared to unbagged plants. Bagging caused an average reduction in germination of 10% (Johnson et al., 1997).

A subsequent study indicated that a supported mesh cage; that is, one that does not confine plants, is a good alternative to bagging accessions in regeneration plots. As a result, the WRPIS staff has developed a system in which an entire regeneration plot is covered with a single tent-like screen cage, 7.5 meters long. The cage is supported by two strands of heavy wire, approximately 30 cm apart that is supported by four metal fence posts. The bottom of the cage is buried and both ends are closed with safety pins.

DISCUSSION

Descriptor data

A wealth of information about the U.S. safflower collection has been recorded and entered into GRIN. This information is easily available to users with access to the Internet. Researchers without

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[2] Mention of trademark or proprietary product does not constitute a guarantee or warranty by the USDA and does not imply its approval over other suitable products.

ready access to the Internet may request copies of pcGRIN from the Database Management Unit, National Germplasm Resources Laboratory, 4th Floor, Building 003, BARC-West, 10300 Baltimore Avenue, Beltsville, MD 20705-2350, U.S.A. (dbmu@ars-grin.gov). This is a stand-alone version of the GRIN database that contains data for individual crops. It may be downloaded to a PC and then searched offline if an individual desires to limit time spent connected to the Internet.

Some safflower descriptor data currently available may be misleading or may not reflect the diversity within individual safflower accessions. It is possible that early descriptor information was incorrectly recorded, or that errors were made when it was entered into the GRIN database several years later. Another concern is that previous descriptor data was recorded for accessions that had cross-pollinated during regeneration prior to 1990, when the mesh-bagging system was implemented. The WRPIS staff is working to remedy these problems by modifying current descriptors and by increasing the number of descriptors evaluated and entered into the GRIN database.

Images of some of the safflower accessions have also been posted in the GRIN database. These pictures were taken with the specific intention of displaying the diversity of morphological characters within an accession. Scientists may view these images by clicking on a thumbnail image that is displayed along with other accession information. A list of the accessions for which there are images may be found by going to the URL http://www.ars-grin.gov/cgi-bin/npgs/html/desc_form.pl?108 and clicking on Picture/Image, then clicking on the term displayed in hypertext listing the number of accessions.

Regeneration protocol

Although plant population was increased by using mesh bags in 1990, this system reduced the quality of the seed when compared to unbagged plants. A new method of covering an entire safflower regeneration plots with one mesh cage has been developed. Compared with previous methods, this method has produced seeds with higher quality in the year 2000 nursery. The WRPIS staff will continue to monitor the success of the safflower regeneration program to improve the quality and quantity of descriptor data and seed samples.

Germplasm

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Evaluation of the USDA Core Safflower Collection for Seven Quantitative Traits

R. C. Johnson[1], P. B. Ghorpade[2], and V. L. Bradley[1]

ABSTRACT

The United States Department of Agriculture maintains a safflower (*Carthamus tinctorius* L.) germplasm collection of more than 2,300 accessions from which a core collection of 207 accessions was developed. To enhance characterization and determine diversity, the core collection was evaluated for numerous crop descriptors at the Western Regional Plant Introduction Station in Pullman, Washington USA. This paper reports evaluation results for seven quantitative factors: outer involucral bract (OIB) width, OIB length, primary head diameter, date of 50% flowering, plant height, weight per seed, and yield per plant. Accessions were highly variable for all factors measured indicating considerable diversity within the core collection. Correlation analysis showed the strongest associations were between plant height and flowering ($r = 0.62$), and between OIB width and OIB length ($r = 0.54$) ($P<0.05$). To test regional differences, accessions in the core collection were partitioned into ten major regions (the Americas, Australia, China, E. Africa, Europe, Japan, the Mediterranean, S. Central Asia, and S. West Asia, and Thailand). Significant differences were found among regions for all factors except OIB length and yield per plant. Canonical discriminant functions showed that the first and second functions explained 83% of the total variation. Among the regions, accessions from SW Asia were the most distant from other regions, but S. Central Asia and E. Africa grouped closely together. The results showed that the core collection was a highly diverse germplasm source, and that agronomic attributes could often distinguish regional differences.

Key words: quantitative traits, international testing, *Carthamus tinctorius* L.

Germplasm

INTRODUCTION

Safflower (*Carthamus tinctorius* L.) is one of our oldest domesticated crops. Weiss (1971) reports that safflower probably originated as a crop in the Euphrates basin and was certainly grown more than four thousand years ago in Egypt. Historically its flowers were used to prepare fabric dyes, food coloring, and for medicinal purposes. Most production today is for seeds used to extract its high quality edible oil, but there is also a market for seeds as bird feed (Li and Mündel, 1996).

Germplasm collections will continue to play a vital role in providing the genetic resources needed for improving safflower. The USDA, Agricultural Research Service (ARS) maintains a collection of safflower germplasm at the Western Regional Plant Introduction Station (WRPIS), Pullman WA. This collection currently includes about 2300 accessions. These accessions, representing germplasm from more than 50 countries, are available without charge to scientists worldwide upon request. Evaluation of these accessions for oil content and iodine number has been completed on about half the collection (Johnson et al., 1993). Additional information on oil content along with fatty acid composition and other value-added factors such as vitamin E and phenolic glucosides has been collected for 1,000 accessions and entered into the Germplasm Resources Information Network (GRIN) (http://www.arsgrin.gov/npgs/) (Johnson et al., 1999).

In 1993 a safflower core collection representing about 10% of the total accessions was developed from the entire collection of more than 2,000 accessions based on country of origin and morphological

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data (Johnson et al., 1993). However, the core has not been characterized for many basic crop descriptors (Safflower descriptors, 1983). The objective of the current work was to evaluate the diversity of USDA safflower core collection for numerous agronomic descriptors and determine if regional differences in agronomic factors could be distinguished.

MATERIALS AND METHODS

The USDA safflower core collection, consisting of 207 accessions, was grown at the irrigated Central Ferry Research Farm at Central Ferry, WA, USA in 1996. The Farm is located in the Snake River canyon (46E 40' 13" N, 117E 45' 8" W) at an elevation of 200 m, and receives an average of 370 mm of precipitation per year. The soil is a fine-silty, mixed, mesic Natrixeroll. Prior to spring planting approximately 50 kg/ha of nitrogen and 15 kg/ha of sulfur are applied and incorporated into the soil. Periodic soil tests have indicated sufficient P and K.

On 8 April 1996, accessions were planted in randomized complete blocks with two replications. Seeds were drilled approximately 2 cm deep and planted about 5 cm apart. A plot consisted of single 3-m long rows, with rows centered 1.5 m apart. Prior to anthesis, screen mesh was placed over the plants to prevent insect cross-pollination. Irrigation from sprinklers was applied as needed.

Seven quantitative descriptors were evaluated as outlined by the International Plant Genetic Resources Institute (IPGRI) (Safflower descriptors, 1983). These were outer involucral bract (OIB) width, OIB length, primary head diameter, date of 50% flowering, plant height, weight per seed, and yield per plant. An analysis of variance was conducted for each factor using SAS general linear models (GLM) (SAS Institute, 1985) with treatment differences declared at $P<0.05$. In addition, the accessions were divided into ten geographic regions based on their country of origin and analyses of variance conducted for each factor evaluated to determine differences among regions. The regions were: the Americas (17 accessions), Australia (6), China (12), East Africa (Kenya, Ethiopia, and Sudan)(14), Europe (excluding countries bordering the Mediterranean Sea) (30), Japan (3), the Mediterranean (countries bordering the Mediterranean Sea) (61), South-Central Asia (Bangladesh, India, and Pakistan) (28), South-West Asia (Afghanistan, Iran, Iraq, Kazakhstan, Kuwait, Tajikistan, and Uzbekistan) (34), and Thailand (2). In addition to univariate analyses, data for regions were standardized to have a mean of zero and a variance of one, and multivariate analysis was completed using canonical discriminant functions (CANDISC, SAS Institute, 1985).

Table 1. Basic statistics for seven agronomic factors measured on the USDA safflower core collection of 207 accessions at Central Ferry WA, USA (1996).

	†OIB width	OIB length	Primary head diameter	Days to flowering	Plant height	Wt. Per seed	Yield Per plant
	-------------mm-------------				--cm--	mg/seed	g/plant
*Mean	14.6	31.9	31.3	89.9	76.5	40.9	7.3
‡Variance	14.5	49.3	30.5	11.2	130.7	58.3	4.3
‡CV %	26.9	22.0	17.6	3.7	14.9	18.7	28.5
Range	24.0	39.5	28.5	20.5	65.5	34.1	11.2

*Mean differences among accessions were significant for all factors measured.

†OIB, outer involucral bract.

‡Variance among accessions, and CV, coefficient of variation associated with the variance and overall means of accessions for a given factor.

Table 2. Correlation matrix for seven agronomic factors measured on the USDA safflower core collection of 207 accessions. Data was taken at Central Ferry WA, USA, 1996.

	†OIB width	OIB length	Head diameter	Days to flowering	Plant height	Wt. Per seed	Yield per plant
OIB width	___						
OIB length	0.54**	___					
Head diameter	0.27**	0.21**	___				
Days to flowering	0.09	0.06	0.18**	___			
Plant height	0.04	0.03	0.20**	0.62**	___		
Wt. Per seed	0.20**	0.16*	-0.03	-0.29**	-0.16*	___	
Yield per plant	-0.01	0.13	0.11	0.08	0.20**	0.17*	___

†OIB, outer involucral bract
*, **Significant at P.05 and P.01, respectively.

RESULTS AND DISCUSSION

As expected, significant variation among accessions was observed for each quantitative factor measured (Table 1). The coefficient of variation (CV) associated with the overall mean and the variance of core accessions was calculated to indicate the relative variability for each descriptor. The highest CV values were for yield per plant, OIB width, and OIB length, all with CV's greater than 20% (Table 1). The remaining factors had CV values between 14% and 19%, except for days to flowering, which had a very low CV. Although days to flowering had a low CV, its range was more than 20 days, showing there was still considerable variation for this factor in the core collection. The ranges for all factors were high, showing the high diversity for each factor measured.

Although significant correlation coefficients were observed between several factors (Table 2), the r-values were generally less than 0.50, indicating that correlation did not explain a large fraction of the total variation. Days to flowering and plant height were the most strongly correlated factors (Table 2), and days to flowering was also correlated with head diameter and with weight per seed. Thus, accessions with later flowering tended to be taller with wider heads, but with lower weight per seed. Perhaps the later flowering reduced the seed filling time period and the capacity for seed development, leading to lower seed weight. A higher weight per seed was also associated with lower plant height and with wider and longer OIB (Table 2).

Yield was positively correlated with weight per seed, and also with plant height. So even though taller plants tended to have less weight per seed, they also tended to yield more, suggesting than taller plants may have produced more heads or seeds per head (Table 2).

All factors showed regional differences in means except OIB length and yield per plant (Table 3). Since both Japan and Thailand were represented by only three and two accessions, respectively, comparisons using those regions should be considered preliminary. Accessions from the Mediterranean region had generally greater OIB width and head diameter than other regions. Accessions from South-West Asia were typically tall, late developing, and with low weight per seed (Table 3).

The canonical discriminant analysis of regions showed that the first two functions explained 83% of the total variation. The first canonical function explained 60% and the second function 23% of the variation. Among the regions, S. West Asia and S. Central Asia were distinctly separated from other regions. The Americas, E. Africa and China tended to group together.

An examination of the canonical coefficients showed days to flowering and plant height had the most influence on the first canonical function. For canonical function 2, head diameter, OIB width, and weight per seed had the most influence.

Table 3. Regional means for seven agronomic factors measured on the USDA safflower core collection of 207 accessions at Central Ferry WA, USA (1996).

Region	n	†OIB width	OIB length	‡Head dia.	Days to flower	Plant ht.	Wt. per seed	Yield per plant
		----------------------	mm	----------------------		cm	mg/seed	g/plant
Americas	17	14.1	33.4	32.3	89.2	69.7	39.1	7.0
Australia	6	12.4	32.3	30.1	90.5	77.8	39.9	7.1
China	12	13.3	29.8	29.7	89.1	76.4	41.3	6.5
E. Africa	14	12.7	33.9	26.8	88.6	72.4	43.0	7.6
Europe	30	14.6	29.4	29.5	89.6	71.9	37.1	6.6
Japan	3	15.2	34.5	29.5	85.5	70.7	47.1	9.4
Med.	61	16.1	32.6	33.9	89.8	76.6	43.3	7.9
S.C Asia	28	13.6	32.6	27.8	87.0	67.3	45.2	6.8
S.W. Asia	34	15.5	31.2	33.6	93.1	88.0	35.8	7.4
Thailand	2	12.0	29.5	30.8	92.5	84.3	39.0	7.3
F-value		*	NS	*	*	*	*	NS
¶LSD	0.05	7.21	13.9	9.87	5.57	18.8	13.8	4.04

*Difference among regions were significant at P<0.05 or NS, not significant.

†OIB, outer involucral bract.

‡Diameter of primary head.

¶LSD values require multiplication by $[(n_1+ n_2)/n_1n_2]^{1/2}$ where n_1 and n_2 are the number of accessions in the two cluster to be compared.

The results showed that for each factor measured there was a high amount of variably among accessions, indicating that the core collection was highly diverse. Regions were found to differ for most factors measured and some separation of regional groups was observed with canonical discriminant analysis. The safflower core collection offers a highly diverse set of genetic material that is especially useful when evaluation of the total collection is impractical or prohibitively expensive.

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A Study of the Safflower Collection in the Krasnodar Territory in Southern Russia

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ABSTRACT

Under the conditions of the Krasnodar Territory in southern Russia (42°-48° N. Lat.) in the plain-steppe zone, with typical and southern chernozem soils, 24 new safflower accessions from 7 countries have been evaluated in the field for the complex of biological and agronomical characters.

Key words: agro-climatic conditions, earliness, Krasnodar Territory, oil, precipitation, productivity, protein, safflower, temperature, world collection, *Carthamus tinctorius* L.

INTRODUCTION

A study of the N.I. Vavilov All-Russian Research Institute of Plant Industry (VIR) safflower collection was carried out in the recent past, before the disintegration of the USSR, near the city of Tashkent (41° N Lat.) in the zone of dry subtropics. The experiment was conducted under irrigation. The collection accessions were studied mainly in the Krasnodar Territory in Southern Russia.

MATERIALS AND METHODS

The VIR collection includes 429 safflower accessions from 46 countries. The study was carried out according to the VIR Classifier (1985). In 1998, 24 accessions from Poland, Hungary, Russia, France, Canada, USA, and Mexico were evaluated for the complex of characteristics. The cultivar Milyutinskij 114 (k-262) was used as a standard. The plants were studied for the following characteristics: morphological - main stem height (cm), presence of spines, the number of branches of the first and second orders, the number of heads per plant, the diameter of the central head; biological - duration of a vegetation period; agronomical characters - plant productivity, 1,000 seeds mass; and oil and protein content (in % of absolute dry matter).

RESULTS AND DISCUSSION

The northern border of safflower cultivation passes through the territory of Russia. The Krasnodar Territory, where the collection was studied, presents the zone of dry steppes with common and southern chernozem soils, located within 42° – 48° Northern Latitude. The sum of active temperatures (> 10° C) in the Gulkevichi region accounts for 3450° (Krasnodar, 1961). The Krasnodar Territory is located at the border of two belts: temperate and subtropical. The climatic conditions of the Territory ensure ripening of even late safflower accessions. On the one hand, the climate here is influenced by the Black Sea, which presents an additional source of humidity; on the other hand, it is influenced by the mountainous hills of the Great Caucasus, which are extended in its southern part. The mountains hinder penetration of the cold air masses from the North to the South and increase the amount of precipitation when cold air masses intrude into the Territory. Absolute annual amplitude of air temperature on the plain area of the Territory is 72° C.

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Germplasm

Winters with little snow and frequent thawing are typical for the vast areas of the Territory. The winds are mainly of eastern orientation. In summer, the western humid flows of wind are increased repeatedly. The summer is usually hot, and in northern regions droughts are common (Figures 1 and 2).

One of the main features of safflower produced at the boundary is earliness. The experiment at the Kuban station showed that the duration of a vegetation period in safflower was shorter when grown under arid conditions than under irrigation. The majority of the accessions appeared to be early or medium early with a vegetation period of less than 100 days being the standard. The sample Lesaf 175 from Canada (i-538874) was distinguished for its earliness. The plant height of the studied accessions was less than the variety Milyutinskij 114 main stem of 98 cm. The accessions from Hungary (ii-529436, 529437) appeared to be exceptionally tall with the height of their main stem between 96-103 cm. However, in the majority of the experimental accessions a greater number of branches and heads were produced than the standard. The heads were small: 1.6 cm – 1.9 cm in diameter in most accessions compared to the standard of 2.2cm. Productivity of the accessions varied from 4.5g – 15.8g per plant compared with 8.5g for the standard. The accessions from Hungary and France (ii – 529436 and 527706) and the accession Kino from Mexico (i-536356) surpassed the standard by 4-8%. As regards to the size of grains, the studied samples were at the level of the cultivar Milyutinskij 114 with 1,000 seed weight of 33.5g. The Hungarian accessions surpassed Milyutinskij 114 by 6-8%, as did the native cultivar Spartak (k-569), with a 1,000 seed weight of 44.1g.

The chemical composition of oil was studied in the biochemical laboratory of VIR. By a number of characters, the cultivar Spartak was distinguished and its indices were as follows: oil content – 21.9%, the sum of saturated acids palmitic and stearic – 10.3%, the sum of unsaturated acids – 89.7%, for fatty acids (% of the sum): palmitic acid (C 16 : 0) – 6.8%, stearic acid (C 18 : 0) – 3.5%, oleic acid (C 18 : I) –

Table 1.Complex evaluation of some new safflower accessions, the Kuban experimental station of VIR, 1998.

Cat. No.	Accession	Origin	Vegetation period, (days)	Main stem height (cm)	Height of the first branch embedding (cm)	Number of branches 1	Number of branches 2	Number of heads per plant	Central head diameter (cm)	(g) Prod-duction (g)	1000 seeds mass (g)
262	Milyutinskij	Russia	100	98.2	87.3	5.0	1.2	8.0	2.2	8.5	33.5
538874	Lesaf 175	Canada	97	80.4	56.4	6.3	5.9	13.8	1.6	8.2	32.0
529437	-	Hungary	99	103.1	78.2	6.8	7.5	12.5	1.9	9.3	41.5
536356	Kino	Mexico	102	93.0	62.4	6.9	4.7	11.8	1.8	8.9	34.2
569	Spartak	Russia	98	101.5	85.1	7.0	5.1	14.2	2.4	9.5	44.1

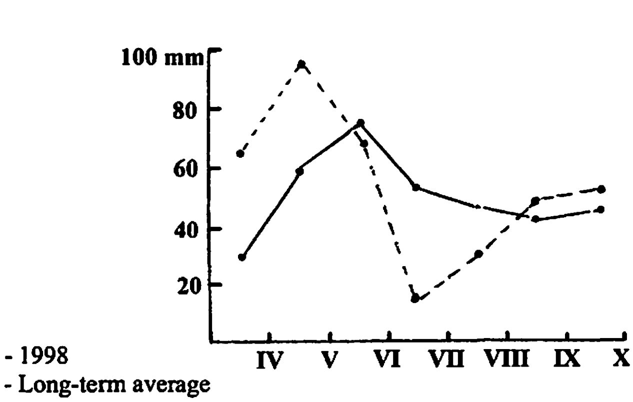

Fig.1. Precipitation at the Kuban experiment station of VIR, Krasnodar Territory (VIR meteostation)

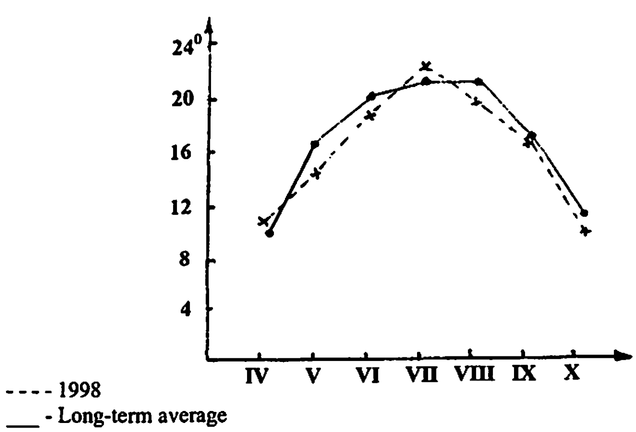

Fig. 2. Air temperature (°C) during the vegetation period at the Kuban experiment station of VIR, Krasnodar Territory (VIR meteostation)

14.7%, and linoleic acid (C 18 : 2) - 75.0%. The content of protein was 15.2% when calculated per air-dried weight portion, and 16.1% when calculated per degreased mass.

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Germplasm

Genetic Diversity and Classification of Safflower (*Carthamus tinctorius* L.) Germplasm by Isozyme Techniques

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ABSTRACT

Genetic diversity of 89 accessions of safflower originating from 17 countries was assessed using isozyme markers. Four isozymes, esterase (EST), alcohol dehydrogenase (ADH), acid phosphatase (ACP) and shikimate dehydrogenase (SKDH), were analysed. Among 8 loci identified, 7 were polymorphic (87.5%) and among the 25 alleles identified, 15 were polymorphic (60%). The materials from East Asia had the highest value for both the mean allele frequency (0.014) and the mean gene diversity (0.54). For different loci, the gene diversity ranged from 0.16 for ACP1 to 0.87 for ACP3. The 89 accessions were classified into 4 groups by cluster analysis with isozyme data. The results of the classification showed that accessions from India possessed high diversity, accessions from Turkey were closely related to those from the other Middle East countries, and the accessions with unknown origin were more closely associated with India, Turkey and the Middle East than Europe and the USA. The results showed isozymes are useful for characterization of safflower genetic resources.

Key words: Safflower, Germplasm, Isozyme, Genetic diversity, Classification

INTRODUCTION

Safflower has many uses, including as an edible oil, a medicinal, and as an industrial oil. It is widely grown throughout the world. The cultivated area is about 1.1 million ha annually with seed production of 0.89 million tons worldwide. India is the biggest safflower producing country, followed by the USA and Mexico. Safflower has tolerance to drought and is suitable for growing in dry and marginal areas (Wang, 1993, Li and Mundel, 1996). Therefore, it has high economic value and potential for income generation for local farmers in these areas.

Safflower originated in the Middle East (Wang, 1993). According to the early studies, there were 7 –10 centres of similarity of safflower in the world. In each centre, the types of safflower populations were very similar. However, these centers were not associated directly with the geographic origin of safflower (Knowels, 1969, Ashri, 1975). With the loss of genetic diversity of safflower, efforts have been made to collect and conserve safflower germplasm by relevant institutes in the world (Rao and Zhou, 1993). It is estimated that a total of 25,179 samples of safflower germplasm are stored in 22 genebanks of 15 countries (Zhang and Johnson, 1999). A world safflower collection was characterized for agroeconomic characters and the data were made available through a catalogue database (Li et al., 1993). Carapetian and Estilai (1997) had identified hybrid individuals from safflower populations using isozyme genetic markers. The present study aims to assess the genetic diversity of safflower with isozyme techniques and classify accessions according to the genetic structure of the safflower populations.

MATERIALS AND METHODS

Experimental materials: The experimental materials were 89 accessions of safflower germplasm obtained from Institute of Oil Crops of Yunnan Academy of Agricultural Sciences, China and the

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Directorate of Oilseeds Research, Hyderabad, India. Records showed that 67 accessions originated from 17 countries and 22 accessions have unknown origin. For easy comparison, the 89 accessions were divided into 6 groups according to their origin: 1) East Asia (5 accessions), 2) India (39 accessions), 3) the Middle East (11 accessions), 4) Turkey (7 accessions), 5) Europe and USA (5 accessions) and 6) unknown (22 accessions).

Experimental methods: The analyses were carried out for esterase (EST), alcohol dehydrogenase (ADH), acid phosphatase (ACP) and shikimate dehydrogenase (SKDH) using thin-layer polyacrylamide gel electrophoresis (PAGE) –isoelectric focusing (IEF).

Isozyme protein was extracted from a sample of 10 seeds for each accession. The seeds were removed from their coats, ground with a small volume of distilled water in a mortar, and transferred into a 1.5ml tube. Then 400μl of 20% glucose solution were added to the tube and the samples were soaked for 1 hour before loading for electrophoresis.

The gel was prepared for each electrophoresis with 1.6 ml polyacrylamide (Acry:Bis=28:1), 9.0ml glycerine (16%), 400μl amphoteric electrolyte, 18.4μl TEMED and 200μl ammonium supersulphur.

Electrophoresis was run with an electric current of 25 W in electrode buffer of 0.5M HAC at anode and 0.5M NaOH at cathode. It was pre-run at 4°C for 500 Vh, followed by 4000Vh after the samples were loaded.

After electrophoresis, gels were stained for different isozyme systems. For EST, α- and β-naphthyl acetate 75mg each, fast garnet R salt 150mg, resolved in acetone, added with phosphonate buffer to 200ml. For ADH, NAD 50mg, NBT 30mg, PMS 2mg, 95% ethanol 4ml, 0.2M Tris-HCl (pH8.0) 14ml, added with distilled water to 100ml. For ACP, 1M MgCl 1ml, fast garnet GBC salt 100mg, 1% α-naphthyl phosphate 3ml, added with 50Mm NaAc (pH5.5) to 100ml. For SKDH, shikimic acid 100mg, NADP 15mg, MTT 20mg, PMS 4mg, dissolved in 200ml 0.1M Tris-HCl (pH8.5) (Lang et al., 1999).

Methods for data analysis: The banding patterns were determined for all isozymes according to relative distance of the bands on the gel and interpreted into enzyme loci. The percentage of polymorphic loci and the frequency of alleles were calculated. The diversity gene index of safflower populations was determined with the following formula: $H_t = 1 - \Sigma_i\Sigma_{j\rightarrow m}P_{ij}^2/m$, here P_{ij} is the frequency of the i^{th} allele at the j^{th} of m loci (Nei, 1972). The Cluster Analysis was carried out on 89 accessions with the Ward linkage method and Euclidean distance of SYSTAT version 8.0, SPSS Science, Chicago, USA, 1998. The means of morphological characters of groups formed by cluster analysis were compared using a t-test.

RESULTS AND ANALYSIS

The four isozymes resulted in a total of 25 alleles at 8 loci, of which 7 were polymorphic, represented by 15 alleles.

Allele frequencies among accessions from different origins: The frequencies of alleles were different within materials from different groups (Table 1). The two alleles of ACP1 had a frequency of 0.5 each for accessions from East Asia, 1.0 and 0 for accessions from Europe, 0.6 and 0.4 for the unknown accessions, but no alleles of ACP1 were observed in the accessions from India, Turkey and Middle East. ACP2 had 3 alleles that were not significantly different among accessions from different groups. All alleles of ACP3 had frequencies of 0.19-0.26 among accessions. ACP3 had more alleles, of which a-f had a frequency of 0.14-0.15 while g-h were relatively lower, between 0-0.1. EST1 had 3 alleles. The frequency of EST1-a was higher than EST1-b and EST1-c. EST2-b was not present in the Middle East accessions while EST2-a reached 1.0. The alleles of ADH1 were evenly distributed among

Table 1. Distribution frequency of alleles for accessions of different origins

Loci	Alleles	East Asia	India	Middle East	Turkey	Europe & USA	Unknown
ACP1	a	0.50	0.00	0.00	0.00	1.00	0.60
	b	0.50	0.00	0.00	0.00	0.00	0.40
ACP2	a	0.22	0.20	0.19	0.26	0.09	0.22
	b	0.39	0.40	0.41	0.37	0.46	0.39
	c	0.39	0.40	0.41	0.37	0.46	0.39
ACP3	a	0.16	0.14	0.15	0.16	0.14	0.16
	b	0.16	0.14	0.15	0.16	0.14	0.16
	c	0.16	0.14	0.15	0.16	0.14	0.16
	d	0.16	0.14	0.15	0.16	0.14	0.16
	e	0.16	0.14	0.15	0.16	0.14	0.16
	f	0.16	0.14	0.15	0.16	0.14	0.15
	g	0.06	0.10	0.09	0.04	0.11	0.05
	h	0.00	0.04	0.03	0.02	0.03	0.00
EST1	a	0.25	0.15	0.19	0.24	0.17	0.16
	b	0.33	0.34	0.39	0.35	0.42	0.34
	c	0.42	0.51	0.42	0.41	0.42	0.50
EST2	a	0.50	0.41	1.00	0.50	0.50	0.33
	b	0.50	0.59	0	0.50	0.50	0.67
ADH1	a	0.30	0.34	0.37	0.33	0.42	0.36
	b	0.50	0.40	0.37	0.33	0.33	0.36
	c	0.20	0.26	0.26	0.33	0.25	0.29
ADH2	a	1.00	1.00	1.00	1.00	1.00	1.00
SKDH1	a	0.00	0.05	0.00	0.00	0.17	0.11
	b	0.50	0.42	0.50	0.46	0.42	0.40
	c	0.50	0.53	0.50	0.54	0.42	0.49

materials from different groups. SKDH1-a had no distribution among accessions from East Asia, the Middle East and Turkey.

The allele frequencies were different among groups of different origin. The average frequency of alleles was 0.014 in the materials of East Asia, which was higher than those of any other origins. The standard deviation also showed that the allele frequency of different loci varied greatly in the material from East Asia. However, a t-test on the mean allele frequency between East Asia and India (t = 1.086, DF =24) showed that there was no significant difference.

Genetic diversity of safflower populations: The gene diversity of loci is given in Table 2. It can be seen that the overall mean gene diversity was 0.49. ACP3 had the highest mean gene diversity of 0.87 followed by 0.65 for ADH1, 0.63 for ACP2, 0.63 for EST1, 0.54 for SKDH1, 0.16 for ACP1, and 0 for ADH2. For the materials from different origins, the highest gene diversity was in East Asia (0.54), while the lowest was found in the Middle East countries (0.41). However, a t-test showed that the difference between East Asia and India was not significant. It can be seen from Table 2 that ACP1 was

Table 2. Gene diversity of isozyme loci in accessions from different regions

Origin	ACP1	ACP2	ACP3	EST1	EST2	ADH1	ADH2	SKDH1	Average
East Asia	0.50	0.65	0.88	0.66	0.50	0.62	0.00	0.50	0.54
India	0.00	0.64	0.87	0.60	0.49	0.65	0.00	0.54	0.47
Middle East	0.00	0.63	0.87	0.63	0.00	0.65	0.00	0.50	0.41
Turkey	0.00	0.65	0.88	0.65	0.50	0.67	0.00	0.50	0.48
Europe & USA	0.00	0.57	0.88	0.63	0.50	0.66	0.00	0.63	0.48
Unknown	0.48	0.65	0.83	0.60	0.45	0.66	0.00	0.59	0.53
Average	**0.16**	**0.63**	**0.87**	**0.63**	**0.41**	**0.65**	**0.00**	**0.54**	**0.49**

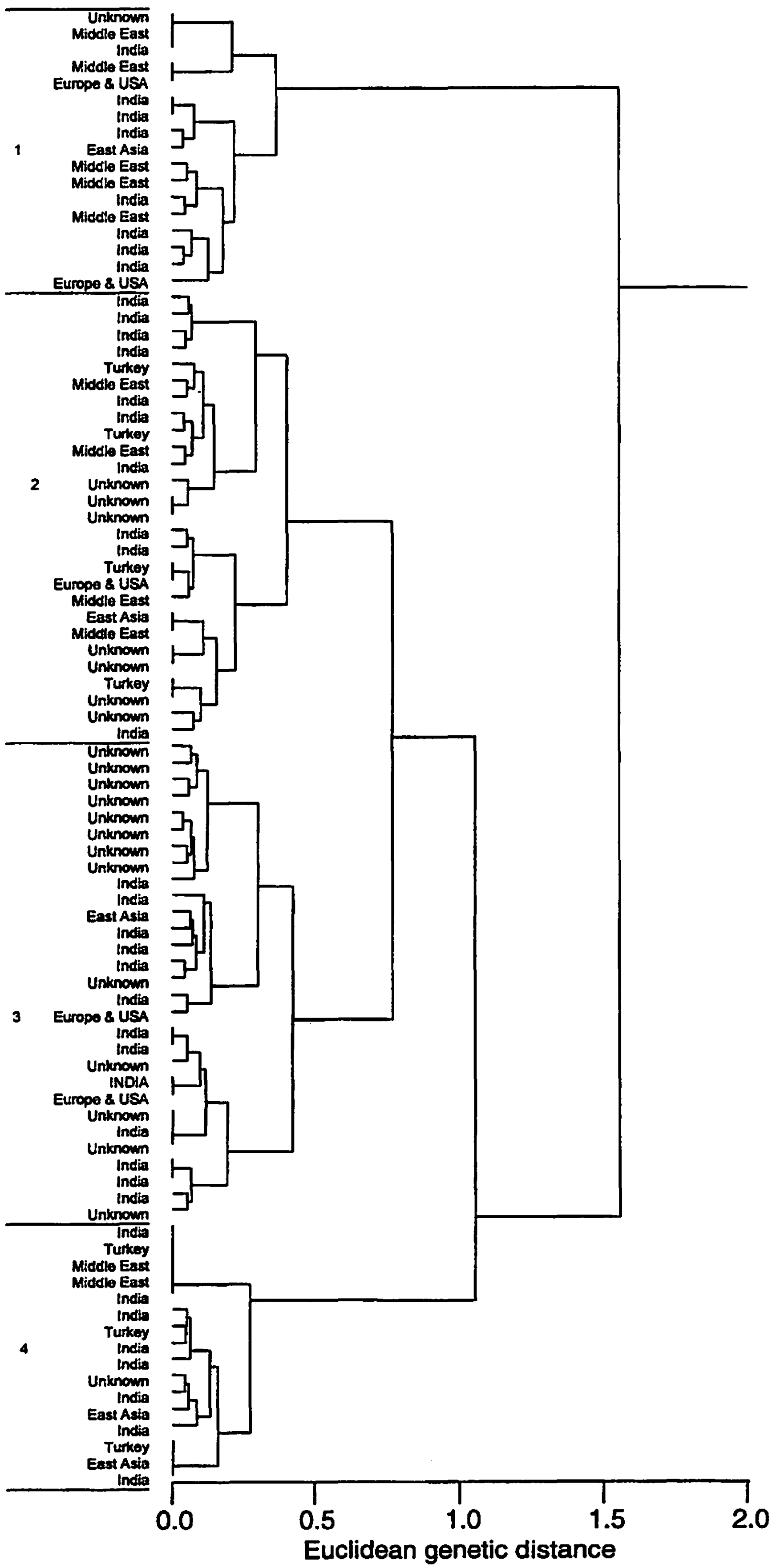

Fig. 1. Dendrogram of cluster analysis on 89 safflower populations

not represented in the materials from India, the Middle East and Europe. ADH2 had a diversity value of zero, and ACP3 had the highest diversity in all materials sampled.

Classification of safflower accessions: The cluster analysis showed that genetic distance between accessions ranged from 0 to 1.568. It can be seen that 89 accessions of safflower germplasm were classified into 4 main groups (Fig 1). The materials from India were distributed across the 4 groups, i.e. 8 accessions in group 1, 10 accessions in group 2, 6 accessions in group 3 and 9 accessions in group 4. Group 1 was the most distinct from other groups and contained accessions from India, Europe, the Middle East, and East Asia. In group 2 accessions from Turkey, the Middle East and unknown origin predominated. In group 3, accessions of unknown origin were concentrated and group 4 was represented by accessions predominately from India, Turkey and East Asia. It was clear that Indian safflower materials had high diversity as they were well represented in the different groups. It can be seen from the clustering dendrogram that groups 2 and 3 were more closely related to each other than other groups.

For morphological characters, there was no obvious difference between the 4 clusters. However, group 1 was characterized by the lowest 100-seed weight and oil content; group 2 by the shortest growth period and the lowest branching number, but the highest oil content; group 3 by the shortest plant height and the highest 100-seed weight; and group 4 by the highest values for plant height, internode length, capitulum diameter, number of seeds per capitulum and yield.

DISCUSSION

Genetic markers are useful tools to describe the characteristics and genetic components of different materials, and comparing the extent of genetic differences and the patterns of genetic diversity (Bretting and Widrechner, 1995). In this study, the results showed that the polymorphic loci identified by isozyme analysis reached 87.5%, and various genotypes had different allele frequencies. This proved that the isozymes used for this study were useful for characterization of safflower accessions. Some alleles had very low frequencies in some populations. Hence, the regeneration of these materials should use a large population size in order to capture the rare genes in these accessions.

Isozyme techniques are an important tool, which can be used effectively to determine the genetic structure of accessions and new types derived during the evolution of populations. This study was an attempt to use isozyme techniques to assess the genetic diversity of safflower germplasm and find the relationships between materials with different origins. It was interesting to find that both the mean allele frequency and the mean gene diversity were higher in the accessions from East Asian countries. Further studies are needed to explore the roles of these genes in the evolution and diversification of safflower diversity.

The classification of accessions aims to understand the population types and their relationships. The results did not show a close relationship between clusters and origins of the materials. This might be caused by a limited number of samples which represented a large geographical coverage used in this study. However, it concurred with the research of Patel et al. (1997) that many factors aside from geographical isolation contribute to the diversity of safflower germplasm.

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Evaluation of Accessions from World Collection of Safflower for Alternaria Incidence and Seed Oil Content

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With the objective to find safflower germplasm with resistance to *Alternaria* leaf spot caused by *Alternaria carthami* and high oil percent, 721 accessions from U.S. world collection were evaluated during the 2000 winter growing season at Cuauhtémoc, Tamaulipas, Mexico (22°34'10''NL; 98°09'20''WL). Each accession was planted in a row two meters long and 0.76 m wide. All accessions emerged very well, but high heterogeneity intra-accession was observed. From the total genetic material, eighty-four accessions were detected tolerant to *Alternaria*. Moreover, 377 accessions selected for good agronomic characteristics had seed oil percent values ranging from 12.79 to 42.03%. From this material, 37 accessions yielded above 32.1% seed oil content. These preliminary results suggest that some interesting accessions from the U.S. safflower collection can be used as a source of *Alternaria* resistance and high oil percent in breeding purposes.

Keywords: *Carthamus tinctorius* L., *Alternaria* resistance, seed oil content, Mexico

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Detection of DNA Polymorphism in Landrace Populations of Safflower in Iran Using RAPD-PCR Technique

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Germplasm

ABSTRACT

The RAPD technique was used to detect genetic diversity of 28 safflower genotypes including Iranian landraces, wild and several exotic genotypes. One hundred random decamer primers were used in amplification reactions. Eleven of the primers produced polymorphic bands and 283 RAPD markers were found. Amplified DNA fragments ranged in size from 300 to 2400 bp. Jaccard's similarity coefficient and Euclidean distances were used to produce a cluster diagram by means of the unweighed pair-group method with arithmetic averages (UPGMA). Cluster analysis divided the genotypes into 5 clusters, using Jaccard's similarity cofficient. Clusters consisted of exotic genotypes, Iranian landraces, wild genotypes, winter and Sarband types. To confirm the obtained phenogram, cluster analysis was used based on Euclidean distance method and the UPGMA algorithm. It was found that distant matrices based on Jaccard's similarity and Euclidean distance produced similar results. In both cases, no relationship was found between genetic and geographical diversity. The clusters based on RAPD markers correlated fairly well with classification scheme based on morphological traits. In clusters, produced by both techniques, some landraces and exotic genotypes are classified together within one group. The approach used holds promise for the classification of safflower germplasm, identification of safflower landraces and its wild relatives and applications of molecular markers in safflower breeding programs. It is suggested that RAPD markers are useful to characterize safflower diversity at the DNA level.

Key words: Safflower, DNA, PCR, RAPD

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Production Management

Prospects of Safflower (*Carthamus tinctorius*) Production in Dryland Areas of Iran

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ABSTRACT

In Iran, national production of edible oil is insufficient to meet the demand. Thus, increasing the area of oil crops utilizing fallow land is very important. The winter rains in the highland areas of Iran start when temperatures are low and crops like safflower *(Carthamus tinctorius)* either cannot germinate, or if planted after the rains, germination is low and crop stand poor due to frequent frost events. Alternatives are early planting in September (with initial irrigation) so that the crop is at the rosette stage by the time the low temperatures with frost events occur, or planting in the spring when average temperatures are above 5 ^{0}C. However the spring-planted crop often faces drought at the end of the growth cycle, that can considerably reduce yield. Thus, in this last instance, there may be a need for supplementary irrigation during very dry years. Two trials were conducted to evaluate the potential of safflower under rainfed conditions in Iran. The first trial was to evaluate 24 lines of safflower for the seed yield potential as a spring crop during the 1999/2000 season in the Northwest of Iran, at the Agricultural Research Station, Sararood, Kermanshah. The second trial was conducted to assess the response to a minimum supplementary irrigation during April, May, or June. Planting was done on 23rd February, and harvesting on 8th August 2000. The average yield of lines and varieties from the first trial was 0.48 t/ha, i.e., from 0.38 t/ha for Cyprus Local to 0.79 t/ha for Lesaf 34. The yield of some safflower varieties gave a better economic return than winter crops such as wheat, barley and chickpea grown in the area. The results from the second trial have shown that yields are not significantly affected by an irrigation of about 20 mm, because of the high evapotranspiration during the end of spring. There was 300 mm of precipitation during the 1999/2000 growing season compared to the long-term average of 478 mm. The yields obtained for spring-sown safflower are thus very promising, particularly as a fallow replacement and to replace edible oil imports.

Key words: Iron, safflower, *Carthamus tinctorius* L., spring-sown, edible oil, irrigation

INTRODUCTION

There is a critical shortage of edible oil in Iran as well as in the other WANA countries (Beg, 1992). Therefore, it is very important to increase the offer of edible oil by increasing the production through increasing the area of these oil crops in the cropping systems, where large areas are under fallow with low land-use efficiency (FRMP, 1997). Most of the cultivated area in Iran is rainfed with low rainfall, with high spatial and temporal variability. Safflower has been reported to be a suitable crop under rainfed conditions as autumn or spring-sown crop with a quite wide adaptability to climatic variations, and it may grow on a wide range of soils (Esendal, 1997). An economical crop can be grown, and raised without supplementary irrigation when the rains in the months of spring are sufficient. When there is drought, supplementary irrigation in the dry months at elongation and/or flowering is needed (Agasimani et al., 1997).

Previous work initiated at the International Center for Agricultural Research in the Dry Areas (ICARDA) research farms at Tel Hadya, Breda and Jindiress during early 1990's (FRMP, 1993 and 1994; Pala and Beg, 1997; Beg and Pala, 1997) to evaluate the world collection of safflower lines and varieties has identified 100 lines suitable under Syrian conditions, where ICARDA is located. These

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varieties were sent out to national programs to be tested under local conditions. The long-term objective was to increase productivity of rainfed cropping systems in the West Asia and North Africa (WANA) regions through the introduction of high-yielding and high quality safflower lines (Pala and Beg, 1997). Today, ICARDA serves also the Central Asia and Caucasus region and oilseed could also be used in this region to diversify cropping systems.

As a follow up of such work, the national program in Iran initiated oilseed crops research under irrigated and rainfed conditions through the Regional Coordination Office of ICARDA in Tehran. In highland areas of Iran, especially Kermanshah region, northwest Iran, where fallow is already replaced partially with food legumes (chickpea in particular), there is a need for diversification of cropping systems for diversion of the production risk for farmers against drought. In these areas the rainfall ranges from 200 to 500 mm. Under these conditions, safflower could be a good oil crop to replace fallow as its deep rooting system shows a good level of drought tolerance (Knowles, 1989). Therefore, safflower became an important part of this research program.

Experiments were carried out during the 1999/2000 cropping season at the experimental farm of the Dryland Agricultural Research Center at Sararood, Kermanshah, Iran to evaluate the response of safflower lines to the local agro-ecological conditions as a spring-sown crop. At the same time, some of the promising safflower varieties from this work have been evaluated in a preliminary study under rainfed and supplementary irrigation conditions for further understanding of the research need and priorities of safflower production.

MATERIALS AND METHODS

Location and Climate

The station where the trial was conducted is situated in a valley of the Northern Zagross mountain range, at an elevation of 1351 meters (34° 20' N, 47° 19' E). The pH of the soil is between 7.2 and 7.8. The soil is a silty clay loam, with deep sandy loam texture and with moderately high water storage capacity, which is classified as Calcixerollic Chromoxererts (Shahoei et al., 1991). The climate is continental-Mediterranean, with mild winter temperatures. The occurrence frequency of frost is not high, and temperatures in summer are high. The rainfall was concentrated between late autumns to late spring (October to May) in the 1999/2000 growing season. The total seasonal rainfall during the crop-growing period was 303.4 mm, which was about 37% less than the long-term average of 478 mm. The rainfall during the pre-planting months, October to January, was 183.4 mm. In February, the planting month, 37.2 mm rainfall was received. After crop emergence during the months of March,

Table 1. Meteorological details for crop growing season for Sararood Station, 1999-2000.

Month	Rain (mm)	Mean T (°C)	Frost days	Mean RH %	Evaporation mm/day
October	16.1	17.75	0	31.67	6.98
November	28.3	9.5	9	45.16	1.29
December	40.7	5.16	19	57.10	0.00
January	98.4	1.75	24	58.70	0.00
February	37.2	2.1	25	46.16	0.00
March	46.1	7.58	17	27.25	0.00
April	24.1	15.73	0	29.03	2.41
May	12.5	14.23	0	21.13	9.62
June	0.0	25.67	0	20.67	10.23
July	0.0	23.35	0	13.35	12.01

T= Temperature, Frost days= days with below zero T, RH= Relative humidity

April, and May, rainfall received was 46.1, 24.1, and 12.5 mm, respectively. Prevailing weather data during the1999-2000 cropping season are given in Table 1.

At the research station, the long-term (last 25 year) absolute minimum temperature is -27 ^{0}C, absolute maximum is 44 ^{0} C, and the annual mean temperature is 13.8 ^{0} C, while long-term rainfall is 241 mm and minimum is 783 mm with a maximum mean rainfall of 478 mm.

Experiment 1

The seeds were sown on 23rd February 2000. The experimental area was ploughed in the late summer (August/September) to incorporate the previous crop, chickpea stubble before the rains started.

Twenty-four lines of safflower were included in this trial (Table 2). Most of these lines belong to the ICARDA collection. The planting was done using a small plot planter (the power driven Wintersteiger). The plot size was 6 m x 1.2 m. Each plot had six rows, 20 cm apart. Planting was done to depth of 4-5 cm into moist soil; moisture is stored during the winter months. The experimental design was a randomized complete block with three replicates.

Grain yield and data on yield components were taken from the four central rows, and the rows were trimmed 0.5m at each end. Plant height, number of heads per plant, and number of seeds per head were collected before harvest;1000-seed weight was recorded from each plot. Hull percentage was taken when the seeds were dry enough to allow the splitting and the detachment of the kernel and the papery kernel cover. Hull of 10 achenes was weighed to estimate hull percentage.

The safflower lines were harvested on 8th August, though the safflower had reached physiological maturity by 15th July. The harvesting was done using a small cereal plot combine. The standing crop was directly combined.

Experiment 2

This trial was conducted in the same location to evaluate safflower lines under rainfed and supplementary irrigation conditions. The lines tested were the followings: CW 4440, CW 74, Cyprobregon, Cyprus local, Gila, Hartman, S 541, and Syrian. All the varieties are from the ICARDA collection.

Sowing was carried out on 24th February 2000 on land which was first ploughed and then pressed with a leveler. The plot size was 100 m x 2.7 m. There were 9 rows, 30 cm apart per plot. The seeding rate was 20 kg/ha. A small grain seed drill was used. The crop started emerging on 15th March. Twenty mm water was applied on the irrigated plots by sprinkler on 16th May, when the crop had completed stem elongation and started head formation. Experimental design was split plot (irrigation was main plot and safflower lines were sub-plots) with three replications. Plots were harvested by the cereal plot combine on 9th August. There was no shattering or any other problem in using a cereal combine for the harvesting in both experiments.

RESULTS

Experiment 1

Yield and other yield component data are given in Table 2. Lesaf 34 had given the highest yield (about 0.8 t/ha), which is a good yield for late winter planting on stored moisture without fertilizer and with minimum tillage. The yield of the other varieties did not differ statistically from Lesaf 34. Cyprus local and PI 250833 showed the lowest yield (0.38 and 0.39 t/ha). There were 5 lines giving more than 0.6 t/ha seed yield to be considered further for wider testing.

Hull content of the safflower seeds is an important quality trait, as less hulls are associated with more kernel and oil content in a seed. Twelve lines of the 24 showed 50 % or more hull content. The promising lines, which showed the lowest hull content, are: Kino 76 (37.5 %), CW 4440 (35 %), Hartman (38.1 %), and Cyprus local (37%).

Plant height ranged from 36 to 52 cm with no correlation with the seed yield.

Experiment 2

Data on plant height, number of heads per plant, and number of seeds per head from 10 plants were taken before the harvest. Yield and some yield components are given in Table 3.

Variety CW 4440 produced the highest yield of 0.78 t /ha under limited irrigation and 0.73 t/ha under purely rainfed conditions, which also mean that the small quantity of irrigation was not able to affect the yield performance of this variety significantly. The lowest yielding variety in this test was CW 74 (0.45 t/ha) under irrigated conditions.

Under rainfed conditions with 300 mm seasonal rainfall (37% less than the long term average of 478 mm), Hartman produced the lowest yield of 0.34 t/ha. The average yield of 8 varieties under irrigation was 0.63 t/ha and under rainfed condition was 0.53 t/ha in a very dry year, which shows a potential for safflower production in the dry areas.

All yield components except 1000-grain weight was affected positively with a limited supplementary irrigation compared with those under rainfed conditions. The mean plant height were 62 cm and 52 cm, heads per plant 13 and 8, seeds per head 23 and 19, respectively, and 1000 seed weight was 37 g for both conditions. The results showed that the higher yield under limited supplementary irrigation was because of higher heads per plant and seeds per head compared with the rainfed condition.

Table 2. Late winter sown safflower genotypes, yield and other characteristics at the Agricultural Research Station, Sararood, Kermanshah (1999/2000 growing season).

Safflower Lines	Plant ht. (cm)	Head per Plant	Seed per Head	Hull (%)	1,000-seed Weight (g)	Yield (kg/ha)
Lesaf 34	45	6	18	40.0	39	794
P1250540	40	8	18	47.6	39	639
Girard	36	4	18	60.0	38	628
S 541	45	6	20	45.5	38	622
PI198290	40	6	26	50.0	40	606
Dinger	52	8	28	53.4	38	561
PI537598	42	6	20	43.5	38	550
Zarghan	42	5	20	69.0	37	539
Rinconada	42	6	18	50.0	37	528
Ch-65\	53	6	24	48.1	40	528
PI251982	45	6	22	62.0	36	522
CW 4440	48	8	20	35.0	36	511
Cyprobregon	48	8	22	50.0	39	506
Hartman	50	6	22	38.1	39	500
Gila	51	6	22	47.1	33	494
PI199887	50	6	28	43.0	38	494
PI250537	38	5	22	52.6	33	489
Sindh Dh	44	4	18	50.0	40	483
CW 74	39	5	20	61.0	33	478
PI537636	52	8	26	45.0	37	478
Syrian	52	5	28	50.0	35	472
Kino 76	50	6	24	37.5	34	428
PI250833	50	6	26	50.0	40	389
Cyprus local.	50	8	22	37.0	33	383
LSD (0.05)						280
LSD (0.01)						374
CV %						16.8

Table 3. Yields and some yield components of safflower varieties under supplementary irrigation and rainfed conditions, 1999/2000.

	Plant ht. (cm)	Head per Plant	Seed per Head	1000-seed weight (g)	Yield (kg/ha)
Irrigated:					
CW 4440	62	9	19	38	775
Gila	62	11	22	40	756
Cyprus local.	67	17	28	42	747
Syrian	61	11	25	40	622
S 541	58	9	20	33	599
Hartman	56	10	20	37	578
Cyprobregon	62	12	24	36	507
CW 74	66	12	25	32	454
LSD (0.05)					211
LSD (0.01)					285
Rainfed:					
CW 4440	55	6	18	37	729
Gila	48	9	19	38	665
Cyprus L.	57	10	17	40	589
Syrian	52	8	20	42	469
S 541	50	8	19	37	417
Hartman	50	8	18	36	344
Cyprobregon	51	6	20	34	499
CW 74	56	7	19	35	548
LSD (0.05)					211
LSD (0.01)					285
CV %					15.5

DISCUSSIONS

In the Kermanshah area of Iran, safflower cultivation is possible as a spring-sown crop under rainfed conditions in as low a rainfall as 300 mm as indicated by preliminary trials in a single season only. A spring-sown crop in general will not need irrigation, as usually there are rains in the months of March, April and May at Kermanshah. In some areas like Maragheh, which ~~is~~ located further north, rain may occur in June as well. The major beneficial result from this research is that safflower can produce a good yield of about 0.7-0.8 t/ha under good management. Thus there is a potential that safflower can take a place among the oilseed crops, which are going to become commercial in Iran, especially in the dry rainfed region mainly as spring-sown crop.

For example, in 1997, India has grown 0.704 million ha of safflower with an average yield of 0.7 t/ha, Ethiopia got an average yield of 0.51 t/ha from 69 000 ha and Australia had an average yield of 0.59 t/ha from an area of 34,000 ha. The yields in the USA and Mexico were substantially higher with 1.98 and 1.18 t/ha, respectively (FAO, 1997). Nevertheless in all these countries, but USA safflower is grown as autumn crop with the addition of fertilizer and irrigation. Thus, the yield performance shown by these evaluation trials seems encouraging. However, sowing date is a crucial aspect for optimum safflower performance as earlier studies have shown the superiority of autumn planting in the Mediterranean areas (Beg and Pala, 1997; Cazzato et al., 1997). Thus, future research is planned to focus on selecting lines with high yield, low hull as well as high oil percentage for commercial use with comparisons of autumn and spring-plantings to increase the potential of the crop.

Through testing of promising safflower varieties with 30-40 percentage of oil in the seed as on-farm trials in several locations in several years, there will be a potential for adoption of the crop by farmers to increase land utilization ratio and alleviate the deficit in edible oil. Another potential economic benefit, which could be provided by cultivation of safflower are the use of petals for the food and the chemical industry. Moreover, all the plant's organs are utilized in the herbal sector as a medicinal plant and the residual meal after oil extraction may be used as nutritious feed (Corleto et al. 1997). Therefore, awareness of the decision makers should be considered through the assessment of full utilization of safflower for the development of new agricultural policies in increasing the productivity and systems sustainability by utilizing fallow areas with high value oilseed crops such as safflower.

In summary, there was 300 mm of precipitation during the 1999/2000 growing season compared to a long-term average of 478 mm. The yields obtained for spring-sown safflower were very promising, particularly as a fallow replacement and to replace edible oil imports. Thus, some good varieties from similar environments of the world should be imported for larger area testing directly by farmers together with the researchers and extension agent to help ameliorate the edible oil shortage in the country.

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Safflower Production in Argentina: Future Prospects

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ABSTRACT

The trend towards continuous cropping in semiarid Argentina has highlighted the lack of alternative species, particularly in drier areas. There is considerable interest in the development and application of plants more effectively able to tolerate semiarid conditions. The agronomic performance of safflower in this respect has shown definite promise and the crop is seen as a source of high quality oil. Owing to its yield characteristics, short growth cycle, low water requirements and tolerance to salinity, safflower could be an ideal crop for making semiarid areas more productive. Central semiarid Argentina covers an area of 17.2 million hectares. From this area about 128,000 ha could be in safflower crops. Safflower may induce diversity of agricultural commodities, improving the economic profile of the whole region. The current report summarizes the possibilities of introducing safflower in this region.

Key words: safflower, central semiarid region, soil, climate, agronomy, production in Argentina.

INTRODUCTION

As reported by Luayza et al (1997), the cultivation of safflower in Argentina takes place in the northwest region of the country. Production has not increased to any significant extent since then, and the total area in safflower cultivation is 20,000 hectares.

As indicated in the cited report, the agroclimatic conditions of the central semiarid region of the country make it potentially apt for safflower production. Covering an area of more than 17,2 million ha, this region largely coincides with the sunflower belt, and it is the concentration on this latter crop and the lack of adequate market conditions that determine the absence of safflower. The region lies between latitudes 34° and 39° S and longitudes 63°30' and 66° W.

Edaphic and climatic characteristics of the eastern and northeastern part of the region (8 million ha) made it particularly suitable for safflower production, as shown in numerous experiments. The adoption of new technologies (no tillage planting and fertilization) would improve water use efficiency and soil nutrient availability and allow expansion of safflower cropland.

DISCUSSION

Analysis of the feasibility of introducing safflower production into the central semiarid region of Argentina:

Physical Aspects

The study area corresponds to the center of the Semiarid Pampa Region (Fig. 1), with the following characteristics (Moscatelli and Puentes, 1996):

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Edaphic

Figure 2 shows four large areas within the study region: 1) center of the Province of Córdoba; 2) perihill plain; 3) sand dune plain; and 4) plain with hardpan. The principle features of these four areas are as follows:

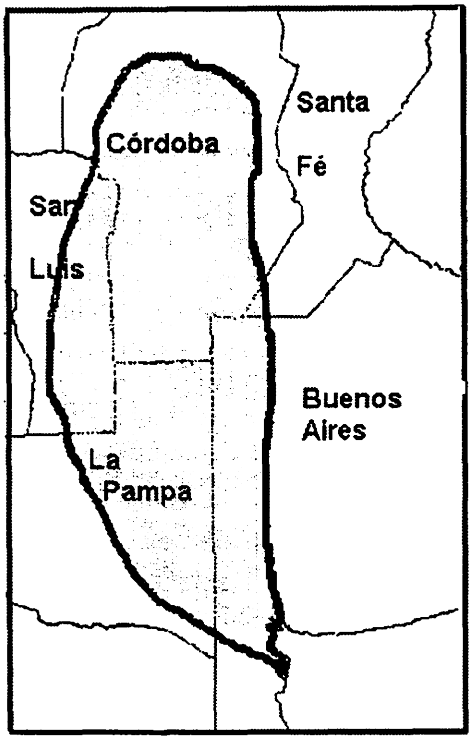

Fig. 1. Central Semiarid Region of Argentina.

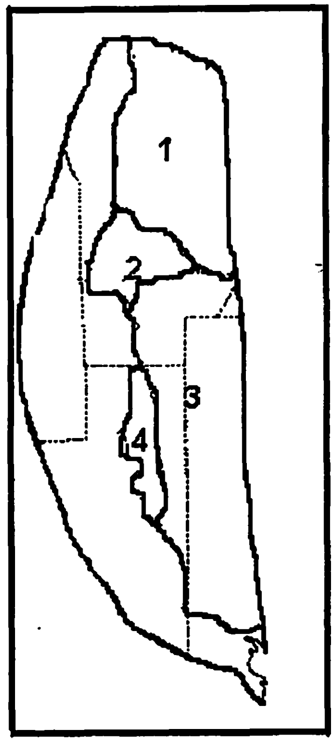

Fig. 2. Soils of the Central Semiarid Region of Argentina.

1) Center of the Province of Córdoba:

Tthe western sector is a high plain sloping eastwards, totally covered by a considerable aeolian accumulation of muddy loam. Erosion is frequent owing to excess tilling. The predominant soils are entic and typic. Haplustolls and to a lesser degree typic Arguistolls, lithic Ustorthents, typic Hapludolls and sodic soils.

High lying areas have deep, well-drained, moderately fertile, productive soil. Adequate management of this type of soil can keep the adverse effects of asynchronous variations in precipitation to a minimum, helping to retain the water and thus give stability to crop production.

The relief of the eastern section is flat with gradients towards the east up to 0.5%. The predominant materials are large aeolian deposits of muddy loam.

The main soils are entic, udic and typic Haplustolls, typic Natraqualfs and typic Natrabolls, with presence of entic and typic Hapludolls in the southeastern section. The sandy loam to loam texture of entic and typic Haplustolls and Hapludolls is not an impediment to crop cultivation, though it does mean that their capacity to retain water is lower. Hapludolls and udic Arguistols are considered to be good for agricultural production. The soils of the lower and depressed areas are subject to frequent flooding, which together with their alkaline nature limit their use as natural pastures (Moscatelli and Puentes, 1996). This region covers 5.9 million ha with a 14.3 and 18.1% of the area as cereal and oilseed crops, respectively. About 0.90% can be planted with safflower.

2) Perihill Plain:

Tthe western sector of the area (east of the Comechingones Hills) has slopes of 1 to 3 % with fine loamy sand aeolian sediments and sandy loam towards the south along the border with the Sand dune Plain. The soils are predominantly entic and udic Haplustolls and udic Argiudolls, all naturally fertile and apt for agriculture. The eastern sector exhibits the same characteristics as sector 3. There are 2.4 million ha with 14.0 and 16.4% of the area for cereal and oilseed cultivation, respectively. Here, 0.82% could be sown with safflower.

3) Sand dune Plain:

This is a wide sector covering the northwest of the province of Buenos Aires and continuing into the northeast of La Pampa Province and southeast of Córdoba province. The surface sediment is fine sand. The landscape is more undulating towards the west, where earlier dune formations are now stabilized by vegetation and are oriented southwest and northeast, in the direction of the wind that formed them.

The soils in the higher sectors show little differentiation between horizons; they are deep, neutral, loosely structured and susceptible to wind erosion (entic and typic Hapludolls) and as such are recommended for agricultural use only under conservationist management (vertical tilling and direct sowing).

The entic Hapludolls in the west and in the higher sections of the dune formations are of limited agricultural use because of their excessive permeability, high susceptibility to wind erosion and relatively low organic matter content. The main limiting factor in the soils of the depressed areas is their inadequate drainage. This plain covers 8.1 million ha with 21.0 and 12.5% of the land for cereal and oilseed cultivation, respectively. About 0.63% can be planted with safflower.

4) Hardpan Plains:

A flat area with an aeolian sand sediment 0.4 to 2 m deep, resting on a thick layer of hardpan which crops out in several places.

The soils are predominantly entic Haplustolls and although they are used for agricultural purposes, their yield is limited by the lack of moisture associated with the granulometry of the material and the presence of hardpan. Areas with ustic Torripsaments and typic Ustortent soils are used as rangeland owing to their inadequacy for crop production. This is the smallest area with only 756,000 ha. From these hectares, 38.4 and 10.9% are cereal and oilseed crops, respectively. About 0.54% of the total could be sown with safflower.

Main climatic features

Thermal regime

The thermal characteristics for summer crops expressed in terms of Degree Day Development (DDD) for a threshold of 10ºC shows a minimum availability for the frost-free period in the area of 2000 DDD. The average frost-free period is 191 days measuring from the average date of the last frost -11th October- to the average date of the first frost -21st April.

The above conditions indicate that from the thermal point of view the area is adequate for crop production.

Water availability

The water balance for the whole region shows an average annual water deficit of around 252 mm in the north (Manfredi) and 582 mm in the south (H. Ascasubi) (Casagrande and Vergara, 1996). There is a significant water deficit in the area during the warmest months, soil water reserves and appropriate crop management thus being the determining factors in crop yield. In view of the sharp variations in climatic events, in particular rainfall, safflower constitutes a highly viable alternative crop since it grows well in areas with low water availability.

Radiation

Figure 3 shows the average overall level of radiation for a typical zone in the study area. From August through to March overall radiation levels are adequate both to cover increased requirements during the last development stages of winter crops and to ensure high levels of dry matter production in summer crops. There is optimum availability of radiation in particular for the reproductive stages of safflower cultivation.

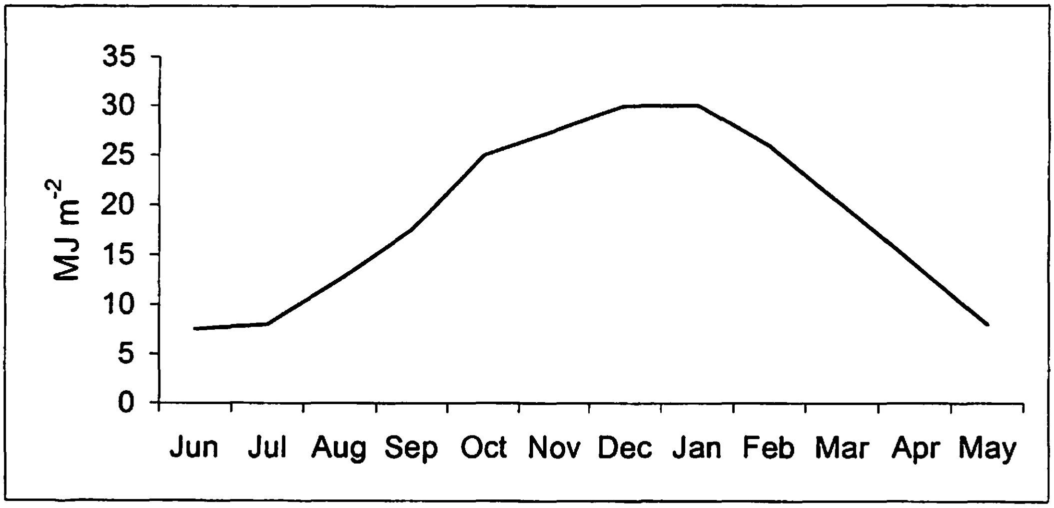

Fig. 3. Average overall radiation at Anguil (36° 30'S 64° W).

Technological Aspects

Tillage:

As stated above, in the face of asynchronous variations in semiarid regions, particularly as far as rainfall is concerned, management techniques aimed at conserving water in the soil are essential (Buschiazzo *et al*, 1996). In recent years farmers in the region have shown a marked preference for vertical instead of conventional tillage and even more recently, for direct sowing. Nowadays, this latter technique is used in 20% of the total surface area under cultivation. Taking into consideration the structure of the crop, sowing density and the almost non-existence of pests associated with safflower production, direct sowing offers promising possibilities for safflower cultivation in the region. Areas 1,2 and 3 in Figure 2 are highly adequate for direct sowing. Owing to the higher content of fine material in the soil, area 4 is more suited to vertical tillage during the initial years before incorporating direct sowing on a permanent basis.

Fertilizer use:

The considerable improvements in yield achieved through the application of fertilizers to a variety of crops in the study region and to agricultural production in general in Argentina have made such application standard practice, to the point that high yield expectations are almost inextricably bound to fertilizer use. One of the salient features of the central semiarid region of Argentina is the low level of organic matter in the soil, which further underlines the importance of fertilizer use.

Table 1. Yield performance of different varieties and hybrids at different locations and years.

Cultivar	Type	Origin	Season	Experimental site	Yield Achenes (kg ha-1)	Yield Oil (%)
IPORA GUAZU	Var	Argentina	1984/85(3)	CSR(1)	2599	32.4(9)
SAFOLA	Var	Australia	1986/87(4)	NW(2)	2389	W/d(9)
IPORA GUAZU	Var	Argentina	1986/87(5)	NW(2)	2046	W/d(9)
SAFOLA	Var	Australia	1988/89(6)	CSR(2)	1790	29.6(9)
ALCAIDIA	Var	Spain	1989/90(6)	CSR(2)	1920	46.7(9)
RIO DULCE INTA	Var	Argentina	1989/90(6)	CSR(2)	1520	28.6(9)
ALCAIDIA	Var	Spain	1999/00(6)	CSR(2)	2329	32.5(9)
IPORA GUAZU	Var	Argentina	1999/00(7)	CSR(2)	2222	31.4(9)
AÑAMEDA	Var	Spain	1999/00(7)	CSR(2)	3480	29.7(9)
D1	Hib	USA	1998/99(8)	NW(2)	2550	W/d(9)
D2	Hib	USA	1998/99(8)	NW(2)	2727	W/d(9)
D3	Hib	USA	1998/99(8)	NW(2)	2500	W/d(9)
D4	Hib	USA	1998/99(8)	NW(2)	2690	W/d(9)
D5	Hib	USA	1998/99(8)	NW(2)	2333	W/d(9)

(1)Central semiarid region, (2)Northwestern region, (3)Mirasson, H. (not published), (4)Salas et al. (1998), (5)Galván et al. (1988), (6)Cholaky et al. (1996), (7)Giayetto et al. (1999), (8)Devani et al. (1999), (9)W/d: without data.

Cultivars:

The genetic improvements developed in Argentina for safflower, particularly at the National Institute of Agricultural Technology (INTA) Experimental Station at Las Breñas, and the appearance in recent years of commercial hybrids produced in the USA, augur well for safflower production in the country. This promising outlook is backed up by excellent experimental yields achieved in various sectors of the study area and in the northwest region of Argentina (Table 1).

Adverse factors:

The growing agricultural activity in the region has been accompanied by technological advances such as those mentioned above as well as the incorporation of agroinputs which are indispensable to adequate crop management. The widespread use of herbicides and agrochemicals in general indicates that any possible adverse factors affecting the incorporation of safflower into the region can be controlled without too much difficulty, thus removing any limitations on the cultivation of this crop under normal management techniques, time of sowing, density etc. (Cholaky *et al*, 1996; Giayetto *et al*, 1999).

Use:

In view of the agricultural and livestock characteristics of the region, the incorporation of safflower varieties apt for forage could constitute an interesting option for local farmers and a possible way of disseminating the crop.

Marketing:

This is a fundamental aspect to be taken into consideration in the development of safflower in the region. Though there are currently three private companies involved in activities related to the production and commercialization of safflower in Argentina, none of them are engaged in promoting the crop, nor is there any policy at government level designed to include this crop in agricultural preferences. If this situation were to be reversed, and an active effort were to be made at both levels –private enterprise and government- to promote the crop and make known definite market possibilities, there is no doubt that safflower could become a significant crop in the region. Previous efforts to promote the incorporation of the crop have failed because of the lack of adequate policies on the part of the government and adequate commitment on the part of private enterprise.

CONCLUSION

Once adequate safflower hybrids become available, making it a more remunerative crop, there are good chances that traditional sunflower farmers will switch to safflower. The environmental conditions are favorable for its cultivation, the crop is easy to manage and has low production costs, and farmers nowadays are more inclined than previously to incorporate new technologies.

The crop can be promoted through the joint efforts of institutions and official bodies such as universities, the National Institute of Agricultural Technology and the Secretariat for Agriculture as well as private enterprise. The key element in the successful incorporation of safflower production in the region is the question of market opportunities.

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A Safflower Project: On-Farm Introduction of Safflower as an Alternative Oil Crop in Southern Italy

Antonio Corleto[1]

ABSTRACT

This work illustrates an experimental project involving the on-farm introduction of safflower in dry and irrigated agricultural areas in Southern Italy. The safflower project (PRO.CART.) is designed both to assess the crop yield potential in terms of grain and oil yield per hectare, and to study the whole process from the cold extraction of the oil (for dietetic and medicinal uses) to the bottling and marketing of the product. The project, which started in 1999 and will complete its first phase at the end of 2001, involves the growing of 2 safflower varieties (Montola 2000 and Centennial) and of 3 commercial hybrids (AGI123, AGI124, AGI126). It will extend over a total area of about 61 hectares, located in rain-fed areas (about 80% of safflower cropped areas) of 3 Southern Italy regions (Apulia, Basilicata, Campania) and in some irrigation schemes of Apulia and Basilicata. Some agriculture-related public bodies acting in the areas concerned with this experimentation are financially supporting the project. The results, if satisfactory, will be good grounds for requesting the E.U. (European Union) to subsidisze safflower, as it does for sunflower and rape.

Key words: Safflower, alternative crop, farm introduction, Southern Italy

INTRODUCTION

The area grown with oil crops in Southern Italy is currently very limited, accounting for 6% of the total oilseed Italian area. Most of this small area constitutes sunflower that in most cases necessitates irrigation to produce acceptable yields. Nevertheless, sunflower is often grown without irrigation and provides low yields, which would not be economically viable without the financial support of the European Community. Such a policy involves a large waste of public funds without a significant return. Another species, the rape, supplies very low field yields that in 1999 equalled 0.2 t ha^{-1} of seeds in Apulia as an average of about 25,000 cultivated hectares (Marzi, 1999).

For Southern Italy, characteriszed by a typically Mediterranean climate, it is important to find a species to be grown as winter crop under rain-fed conditions. This species could be safflower; indeed using special technical precautions and by a more appropriate knowledge of the organoleptic properties of oil and other by-products to use for animal feeding, safflower could be, in the near future, an effective alternative to the prevailing durum wheat monocropping for many Southern Italy areas.

Safflower, which is not currently cultivated in Italy, was extensively studied in the '80s (Corleto et al. 1980, Corleto 1984, 1991; Lo Cascio et al., 1984) within research projects funded by the Ministry of Agriculture and Forestry of that time. The poor diffusion of the crop in Central-Southern Italy cropping patterns may be basically related both to the lack of the Community support which is, instead, provided to other crops such as soybean, rape, sunflower and maize, and to the lack of information at the farm level.

New safflower hybrids have been developed over the last few years (Corleto and Mündel, 1997; Hill, 1997) that are able to increase the yields of this crop, ranging between 0.5 and 2.5 t ha^{-1} (yield range observed in the plot tests conducted in Southern Italy since 1975 till now). A cause of the great variability that is observed in grain production with the change in the environmental conditions is related to an excessive length of the growing season that could include 240 days for fall-sown

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Production Management

safflower, and 130-150 days for spring-sown safflower. Fall-sown safflower is harvested between the third decade of July and the first decade of August with about one-month delay as compared to durum wheat harvest. This may cause considerable yield reductions, notably in the southern plain due to the severe water deficit occurring starting from June, whereas in cooler hilly and mountain areas, the crop could be more successful.

The introduction of a new crop always entails many problems that cannot be easily predicted based on the information collected from the experimentation conducted on small plots. The experimental approach is obviously essential when one has to compare many cultivars or to test a high number of experimental treatments obtained from the combination, sometimes factorial, of different agronomic techniques (nitrogen amounts, plant density, row spacing, etc.). If you have to draw information on the actual yield potential of a crop, the experimental approach on small plots is often not very reliable. This depends on many factors that may be summariszed as follows. The plot trial is usually more cared for than what is normally done by farmers to field crops. The estimate of production on small plots is often affected by the "border effect" that, if not adequately neutraliszed, is likely to increase the yield per hectare. The choice of the area where the trial is carried out does not often reflect the field environmental conditions where the crop is grown. Moreover, carrying out research including the entire crop process till the final product (the bottled oil in this case) necessitates the production of a substantial amount of seeds to use for the industrial processing.

For the above reasons it seems useful to promote a "Safflower project " (acronym: PRO.CART) involving public bodies (Mountain Communities, Reclamation Consortia and Extension Service agencies) and farms falling within the land areas relevant to the public bodies concerned in the project. The latter have ensured to a varying extent the financial support to the project and the willingness to co-operate in the extension service that is relevant to the Department of Plant Production Science of Bari University.

Objective of the project

The basic objective of PRO.CART.is both to assess the crop yield potential in terms of grain and oil yield per hectare and to study the whole process including the oil cold extraction (used for dietetic and medicinal purposes), the bottling and an assessment of the oil popularity rating among consumers. Results, if satisfactory, will be good grounds for requesting the E.U. to subsidisze this crop, as it does for sunflower and rape.

Structure of PRO.CART

a. Propagation, selection and bagging of safflower seeds

In the 1999-2000 cropping year the seed of 2 safflower cultivars (Montola 2000, high oleic and Centennial, high linoleic coming from the Williston Research Extension Center – North Dakota, USA) was propagated on 4 hectares at the demonstrative experimental farm "Gaudiano", located at Gaudiano di Lavello (PZ) and run by ALSIA (Lucanian Agency for Development and Innovation in Agriculture). The obtained product, about 4 t of seed, after being appropriately selected, was put in bags at the seed department of the "Consorzio Agrario" of Gaudiano di Lavello and stored till autumn 2000 when seeds were distributed to the farms participating in the project.

b. Public bodies involved in PRO.CART

Among the various public bodies being consulted, only some have taken part in the project. The participating bodies operate on a total scheme of about 650,000 hectares and fall within 3 Regions of continental Southern Italy, namely Apulia, Basilicata and Campania. They include 2 Mountain Communities (Mountain Community "Alta Irpinia" – Campania, Mountain Community "Monti dauni meridionali" – Apulia) 2 Reclamation Consortia ("Capitanata" – Apulia, "Vulture/Alto Bradano" –

Basilicata) and ALSIA. The latter ensures a financial aid to the Department of Plant Production Science that will ensure the implementation of all the operating steps of the project and the carrying out of all yield measurements planned.

By public announcement, each body (Mountain Communities and Reclamation Consortia) invited farms to grow safflower on a maximum of 5 hectares, pledging an aid of 350 euros per hectare, substituting the subsidy the E.U. normally provides for sunflower and rape or for forage crops.

Each body has fixed a maximum limit of growing for the relevant geographical area, not exceeding 20 hectares.

As a whole, 61 hectares are concerned with safflower cropping.

c. Soil and climatic features of the area involved in the project

The project area is characteriszed by deep soils with a texture varying from silty-clay to sandy-clay, well supplied with K_2O and deficient in N and P_2O_5. The climate is Mediterranean with rainfall being concentrated in the period from November to April and a severe water deficit in the June – September period. The total annual rainfall ranges from 500 to 800 mm. Temperature varies with the altitude. For the areas within an elevation range of 500 m, the annual mean temperature is about 16° C with extreme values (observed within a thirty-year period) between 45 and –6°C; in the areas of 900 m a.s.l., the annual mean temperature is about 13°C whereas absolute values are between 40°C (maximum) and –10 °C (minimum).

d. Criteria for the selection of farms and agronomic techniques

For each geographical area the selected farms fall within different elevation ranges. As a whole the farms participating in the project are 24 and are located at varying elevations from a minimum of 70 m to a maximum of 900 m. a.s.l.

To prevent improper mixtures of seeds at harvest, each farm grows a single type of safflower (high oleic or high linoleic). Each participating farm also received some hybrid seeds (hybrids AGI 126 and AGI 123, high oleic, and hybrid AGI 124, high linoleic, supplied by the SAFFTECH Company from Davis - CA) to assess any difference in the yield potential of the latter as compared to pollinated conventional varieties.

The proposed agronomic technique is identical for all farms and involves the sowing by a mechanical or pneumatic drill of 22 kg of seed/hectare for open-pollinated varieties and 18 kg of seed/hectare for hybrids. The sowing, accomplished by rows 50 cm apart, was most effected in November and December 2000 and completed for some farms in January 2001. The fertiliszation involved the application of 90 kg ha^{-1} of P_2O_5 (at sowing) and 80 kg ha^{-1} of N (1/3 at sowing and 2/3 at stem elongation stage).

Weed control will be mechanical by hoeing the row space or if necessary by using a teletoxic phytocide to be indicated according to the prevailing weeds. Excellent results are obtained by pre-emergence weeding using propyzamide (800 g ha^{-1}) + Diuron (1600 g ha^{-1}) mixtures diluted in 300-400 litres of water per hectare. The crop will be mostly grown under rainfed conditions; supplemental irrigation will be provided only on some farms, in other farms few hectares will be grown with sunflower and rape for comparative purposes.

e. Utilization of the produced seed

The expected total seed production is about 70-90 t, assuming a yield range of 1.2- 1.5 t of seed per hectare.

The product obtained from the 2001 harvest will be bought by an Italian seed breeding company (Euroagro,Reggio Emilia) which has formally pledged to pay to producers the current Italian market price, as there is no market price for safflower in Italy. Part of the seed produced will be submitted to cold extraction in an oil firm that will also provide the separate bottling of the two oil types (high oleic and high linoleic, respectively).

The type of extraction adopted involves the use of temperatures not exceeding 35-40 °C and ensures an oil yield not greater than 20%. Therefore, processing a presumed seed amount of 50 t will result in 10 t of oil, which will be bottled in dark glass bottles of 50 cl. The packing will show on the label the logo of participating bodies and will contain information on the dietetic and pharmacological properties of the product. The estimated total production is 20,000 oil bottles.

The seed that is not processed will be used in the poultry feed industry.

~~f. Aid to the~~ oil firm for the product extraction and bottling

The Mountain Communities and the Reclamation Consortia pledge to buy, each, a minimum amount of 2,000 packings of 50 cl at a pre-established price of 1.5 Euros per packing (including VAT).

Each public body will distribute free to hospitals, public and private catering structures and research bodies acting in the agro-food and dietetic areas, an appropriate amount of safflower oil together with a questionnaire to know the oil popularity rating among users.

g. Criteria for assessing field yield results

The benefit/cost analysis is the most reliable way to judge the cost effectiveness to grow the crop. For safflower, cropping costs are similar to those of durum wheat except for the seed that should be sharply lower for safflower due to the low amount of seed/hectare that is used (25-30 kg/ha). The market price of durum wheat in the 2000 cropping year was 14.7 euros per 100 kg of seed; safflower is supposed to have the same price as sunflower, namely 15.5 euros per 100 kg of seed.

The suggested criterion for an overall assessment is the ratio of safflower grain yield to durum wheat grain yield (Rs/w), both expressed as farm average. If Rs/w were < 0.5 the safflower crop should not be recommended for that environment. If Rs/w ranges between 0.6 and 1 safflower could be recommended and with Rs/w >1 it would be highly recommended. Another good criterion could consist in comparing safflower grain yields with those of sunflower and rape, both grown in Apulia, Basilicata and Campania.

For sunflower, usually grown under irrigated conditions, the farm yield (average of the 95-97 three-year period) is around 1.8 t ha^{-1} whereas for rape, sown in autumn and under rain-fed conditions, the farm yield (average of the 95-99 five-year period) is 0.9 t ha'1 (Sources: ISTAT and AISO).

These data are largely indicative and may refer to completely different environmental conditions from those concerning safflower experimentation. Therefore, the project involves the growing of sunflower and rape, next to safflower fields, in adequately selected farms.

Safflower may be considered as a crop with a good ability to improve some physical soil properties (porosity) thanks to its strong taproot system.

These properties, added to the lower nitrogen fertilisszer requirement than durum wheat, play a major role in favour of a good habitability of the soil as a consequence of a higher soil permeability, with a subsequent reduction of erosion in hilly areas and a lower nitrate concentration in groundwater.

For human nutrition, safflower oil has a nutritional value that is similar to that of olive oil; moreover, the high oleic type is very suitable for hypo-cholesterol diets, for frying and in the preparation of frozen food; it is very stable at high temperatures and does not produce any smoke or bad smell during frying (Li and Mundel, 1996). The high linoleic type may also be used for industrial purposes such as the preparation of varnishes, the production of biodiesel and alcohols to use in producing surfactants (Li and Mundel, 1996).

After oil extraction, the residual cake may be used for animal feeding. Research in Southern Italy has pointed out a reduction in the LDL cholesterol content in the meat of lambs fed by rations containing 1-2% of safflower oil (Marsico et al. 1995); moreover lambs fed with foodstuffs containing 10% safflower meal lowered cholesterol levels in blood serum, meat and liver (Vonghia et al., 1997). Safflower is also an excellent forage plant. It is good for grazing during the early stages and shows a fast regrowth; it may be grown as forage crop providing hay productions similar to those of oats and barley. Safflower stubble is highly desired by sheep and goats (Smith, 1996).

Safflower seeds are an excellent food (chicken feed) for poultry and there is a good market in Italy with a price around 40 euros per 100 kg of imported seed.

Safflower flowers, made of petals intensely yellow, red or orange-coloured, are also used for dry flower production (Hofbauer and Pelikan, 1997; Uher, 1997) and there are still small areas of land grown for this purpose in some Central and Southern Italy regions like Marche and Apulia (Gargano). An additional product extracted from safflower flowers, is carthamin; it is a dye used to colour food and beverages (yellow carthamin) and in cosmetics (red carthamin)

The evaluation criteria also include the medicinal uses safflower has had since ancient times. In this connection, a recent and exhaustive publication by LI and Mündel (1996) on safflower lists many curative properties of safflower oil and tisanes obtained by safflower flower infusion. They include the attenuation of arterial hypertension and heart arrhythmia, the reduction in the bad cholesterol content (LDL) of blood, the removal of kidney stones, the stimulation of menstrual flow and some effectiveness in tumour pathologies like leukemia.

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Grain Yield, Oil Content and Earliness of Flowering of Hybrids and Open-Pollinated Safflower in Southern Italy

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ABSTRACT

A one-year trial (1998) was conducted in 2 different environments of Southern Italy (Oppido Lucano and Gaudiano di Lavello, in Potenza province, characterised by different elevations: 550 and 180 m a.s.l, respectively) with the purpose of assessing the earliness of flowering, the yield potential and the oil content of 4 hybrids (GW 9022, GW 9023, GW 9003, GW 9005) and 12 open- pollinated cultivars: Montola 2000 (USA), Montola 2001 (USA), Centennial (USA), C9305 (USA), Benno (Italy), Belisario (Italy), Roberto (Italy), Bacum (Mexico), Esfehan (Iran), BJ 774 (China), BJ 1023 (China), and BJ 1063 (China). No differences were found between the 2 tested environments in the character under analysis. For earliness of flowering, counted as number of days from seedling emergence (first week of January) to 50% blooming, hybrids showed an average value of 163 days vs. 160 days of open-pollinated cvs. Grain yield ranged from 0.99 to 2.4 t ha^{-1}. BJ 774 and Bacum gave the highest production; Esfehan the lowest. The cultivars from China and the hybrid GW 9022 from the USA showed the lowest oil content (around 27%) while C9305 and Centennial, the highest (around 40%). The fatty acid composition was also determined.

Key words: safflower hybrids, open-pollinated safflower, earliness of flowering, grain yield, oil content.

INTRODUCTION

Safflower shows interesting characters such as an autumn-spring cycle and high quality oil which, combined with good adaptation of the crop to Southern Italy environments, as shown by several experimental works (Corleto et al., 1980; 1986; 1988; Corleto and Mündel, 1997; Corleto et al., 1997a; Leto, 1986, Leto and Monti, 1990; Lo Cascio et al., 1984), make this crop potentially interesting to be introduced in dry cropping patterns of Southern Italy, currently characterised by a durum wheat monocropping system.

A special experimental project involving the on-farm introduction of safflower to Southern Italy is currently under way (Corleto, 2001).

Within this framework, it is crucial to identify germplasm suitable for the specific environmental conditions and able to enhance the yield potential of the species. The moderate yield superiority of some experimental hybrids over open-pollinated varieties, as shown in recent research (Corleto *et. al*, 1997b), arouse a new interest towards this crop.

The objective of the current research is to assess, in two Southern Italy locations, the yield potential and the adaptive capacity to those environments for some new American experimental hybrids together with open-pollinated varieties of different origin, chosen among those which had already supplied good yield performances.

Production Management

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MATERIALS AND METHODS

The trial was run in 1997-98 in two localities in Potenza province, characterised by different elevations: Gaudiano di Lavello (GLF), 180 m a.s.l. and Oppido Lucano (OLF), 550 m a.s.l. In GLF the soil was loamy (53.4% sand, 20.7% silt, 25.9% clay), low in total nitrogen (0.78‰), high in available phosphorus (143 ppm P_2O_5) and exchangeable potassium (210 ppm K_2O), with a field capacity of 22.0% and wilting point of 12.8 % on d.w. basis; in OLF, instead, the soil was sandy (69.4% sand, 20.4% silt, 10.2% clay), high in exchangeable potassium (243 ppm K_2O), low in available phosphorus (13.5 ppm P_2O_5) and total nitrogen (0.58 ‰), with field capacity and wilting point of 16.9 and 10.1% respectively on d.w. basis.

12 open-pollinated safflower varieties of different origin (Montola 2000, Montola 2001, Centennial, C9305 – USA; Benno, Belisario, Roberto – Italy; Bacum – Mexico; Esfehan – Iran; BJ 774, BJ 1023, BJ 1063 - China) and 4 American experimental hybrids (GW 9022, GW 9023, GW 9003,GW 9005) were compared.

In both locations the randomised block design with 3 replicates was adopted with a plot area of 6 m^2.

The trial was seeded in rows spaced 50 cm apart, on 9/12/97 and 15/12/97 in OLF and GLF respectively, on ploughed soil, fertilised with 100 kg ha^{-1} of P_2O_5, using 30 kg $ha^{-1}$of seeds.

At the start of stem elongation (on 18/2/98 in GLF and on 17/3/98 in OLF) 60 kg ha^{-1} of N was applied as ammonium nitrate.

Weeds were controlled mechanically between rows and manually within rows, in March 1998.

At harvest, which was effected on 30/7/98 in GLF and on 7/8/98 in OLF, on a plot area of 3 m^2, grain yield, plant height and no. of plants/m^2 were determined. Moreover, on 3 plants/plot chosen randomly, no. of heads/plant (distinguished as secondary, tertiary and total heads), average no.of seeds/head and 1000 seed weight were also determined.

Seed oil content (% of dry matter) was determined by extraction using the Soxhlet method. The fatty acid composition was determined by flame gas chromatography SHIMADZU GC-14 A; integrator SHIMADZU C-R6A; capillary column: 50m; Carrier: hydrogen; pre-set temperature from 170 °C to 225 °C; injection of 0.3 µL of oil/N-eptan solution after methylation of fatty acids with potassium hydroxide.

All data were submitted to the analysis of variance. The data of the 2 localities were included in a single statistical analysis after the variance homogeneity of single locations was tested using Bartlett's test. The significance of differences between the means was assessed by the SNK test. For comparing hybrids and varieties, the comparison of means of unequal numbers test was adopted (Snedecor and Cochran, 1956)

In general, the temperature pattern throughout the cropping cycle did not show any noticeable difference from the mean annual temperatures. Marked deviations were observed for GLF relative to June and July 1998, when monthly mean temperatures were above the means (25.2 vs. 22.1 °C in June and 28.1 vs. 25.0 °C in July), whereas for OLF the temperature was considerably colder in March '98 (4.4 vs. 7.5 °C).

Total rainfall values were 484 mm in OLF and 532 mm in GLF, respectively.

RESULTS

– Date of flowering

The different cultivars tested reached 50% flowering between June 13 and 18 in GLF and from June 15 to 20 in OLF, pointing out a degree of earliness that did not change from one location to another; Fig. 1 shows the dates when this stage was reached as average of the 2 localities. Among the earliest cultivars, there are those of Chinese origin BJ 774, BJ 1023 and the American Montola 2000 (50%

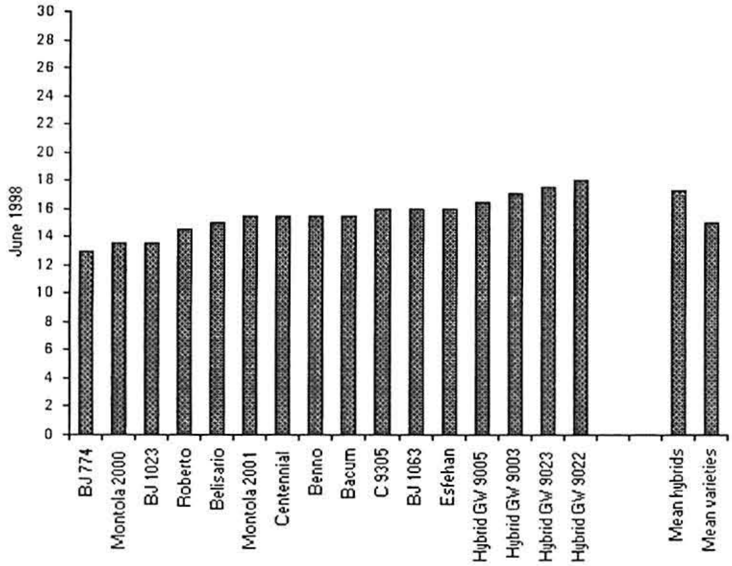

Fig. 1. Date of 50% blooming as a mean of the 2 localities.

Table 1. Achene yield, oil content and oil yield of different safflower varieties and hybrids as mean of 2 localities. (1)

Cultivars	Achene yield ($t\ ha^{-1}$)	Oil content (%)	Oil yield ($t\ ha^{-1}$)
BJ 774	2.43 A	27.5 E	0.668 BC
Bacum	2.31 AB	34.2 C	0.791 A
BJ 1063	2.05 BC	26.7 E	0.548 CD
Hybrid GW 9003	2.04 BC	34.6 C	0.708 B
BJ 1023	1.95 BD	27.6 E	0.539 D
Belisario	1.87 CE	35.7 BC	0.667 BC
Roberto	1.87 CE	34.7 C	0.647 B-D
Benno	1.84 CE	35.2 BC	0.648 B-D
Hybrid GW 9005	1.79 CF	35.5 BC	0.636 B-D
Hybrid GW 9023	1.76 CF	30.6 D	0.538 D
Montola 2000	1.63 CG	36.8 BC	0.599 B-D
C 9305	1.55 DG	40.5 A	0.628 B-D
Hybrid GW 9022	1.45 EG	27.1 E	0.393 E-D
Centennial	1.39 FG	40.0 A	0.556 CD
Montola 2001	1.24 GH	34.6 C	0.428 E
Esfehan	0.99 H	29.6 D	0.294 F
Mean Hybrids	1.76	32.0	0.569
Mean varieties	1.76	33.6	0.584
Overall mean	1.76	32.8	0.577

(1) Values not having any letter in common are significantly different at 1.01 P - SNK' test.

blooming between June 13 and 14) whereas the four tested hybrids were the latest ones (50% flowering occurring, on average, between June 18 and 19). In general to reach this growth stage it took 160 days from emergence (occurring during the first week of January) for varieties, and 163 days for hybrids.

– Seed yield, oil content and oil yield

For these traits, no statistical differences were found for the mean effect of localities and the locality x cultivar interaction. Table 1 shows the values for seed yield, oil content and oil yield of the 16 cultivars as average of the localities. Seed yield showed a wide range from 0.99 to 2.43 t ha^{-1}, with a mean of 1.76 t ha^{-1}. The highest yields were provided by the Chinese cv. BJ 774 and the Mexican cv. Bacum (2.43 and 2.31 t ha^{-1} respectively) whereas the highest yielding hybrid (GW 9003) ranked only 4th with a yield of 2.04 t ha^{-1} of seed.This yield is not statistically different from those provided by BJ 1023, Belisario and, Benno, Hybrid GW, Hybrid GW 9023 and Montola 2000. The mean yield of hybrids and of varieties was identical (1.76 t ha^{-1}).

A great variability was observed in the oil content of the cultivars tested. C 9305 and Centennial showed the highest oil yields (40%); BJ 774, showed a low oil content (27.5%), similar to that of the other Chinese cultivars under test (BJ 1063 and BJ 1023 with 26.7 and 27.6% respectively) and to the hybrid GW 9022 (27.1%). The Italian varieties, Belisario, Roberto and Benno, showed an oil content around 35%.

Bacum in general showed the highest oil yield per hectare (0.791 t ha^{-1}).

– Yield components

The main yield components tested (table 2) showed great variability. Hybrids showed, on average, a higher number of total and tertiary heads per plant, than varieties, whereas for the other parameters under analysis, no noticeable difference was observed.

The results of the correlation analysis between grain yield and the tested parameters are shown in Table 3. A high degree of association between seed yield and 1000 seed weight (r = 0.81 and P< 0.001)

Table 2. Main yield components of different sfflower varieties and hybrids as mean of the 2 localities. [(1)]

Cultivars	Total heads/ plant (n.)	Secondary heads/plant (n.)	Tertiary heads/plant (n.)	Seeds/head (n.)	1000 seed weight (g)
Hybrid GW 9023	21.0 A	7.9 BC	11.7 A	22.6 A-C	31.6 EF
Esfehan	20.2 AB	9.7 A	9.5 AB	23.5 A-C	25.1 I
C 9305	15.6 BC	8.1 B	6.5 BC	22.3 A-C	31.1 FG
Hybrid GW 9022	15.2 BC	6.3 BC	7.7 A-C	18.4 C	30.5 FG
BJ 1023	14.1 C	6.2 BC	6.9 BC	28.4 AB	36.1 B
Montola 2001	14.1 C	6.4 BC	6.8 BC	17.9 C	30.5 FG
BJ 774	13.7 C	5.8 C	6.9 BC	21.2 A-C	40.0 A
Hybrid GW 9003	13.6 C	6.1 BC	6.5 BC	25.7 A-C	32.6 DE
Hybrid GW 9005	13.5 C	6.1 BC	6.4 BC	21.6 A-C	30.8 FG
BJ 1063	13.1 C	6.0 BC	6.1 BC	21.7 A-C	39.9 A
Montola 2000	12.0 C	5.8 C	5.2 BC	20.2 BC	28.5 H
Roberto	12.0 C	6.6 BC	4.4 BC	25.2 A-C	36.6 B
Belisario	10.7 C	6.1 BC	3.7 C	22.2 A-C	33.4 CD
Bacum	10.6 C	6.6 BC	3.0 C	30.1 A	33.4 CD
Centennial	10.5 C	6.2 BC	3.3 C	17.9 C	30.2 G
Benno	9.7 C	6.2 BC	2.6 C	23.1 A-C	34.3 C
Mean hybrids	15.8 a	6.6	8.1 a	22.1	31.4
Mean varieties	13.0 b	6.7	5.3 b	23.6	34.0
Overall mean	14.4	6.7	6.7	22.8	32.7

(1) Values not having any letter in common are significantly different at 0.05 P (small letters) and at 0.01 P (capital letters)-SNK' test.

Table 3. Correlation between seed yield and the main yield components.

Parameter	r	Probability
Total heads / plant	-0.359	0.171
Secondary heads / plant	-0.472	0.063
Tertiary heads / plant	-0.263	0.323
Seeds / head	0.529	0.034
1000 seed weight	0.806	0.001

Table 4. Main fatty acids (%) of different safflower cultivars. Mean of the 2 localities.

Cultivars	C 16:0 (%)	C 18:0 (%)	C 18:1 (%)	C 18:2 (%)
Hybr. GW 9005	8.0	2.2	10.1	78.8
BJ 1023	6.6	2.2	13.3	77.0
BJ 1063	7.0	1.9	13.1	77.0
Esfehan	6.8	2.1	13.5	76.7
BJ 774	6.5	2.2	14.4	76.0
C9305	8.9	2.3	11.8	75.1
Centennial	8.3	1.9	13.9	75.0
Bacum	7.7	2.7	15.1	73.6
Belisario	7.7	2.1	15.8	73.6
Hybr. GW 9003	7.6	2.4	16.8	72.3
Benno	7.1	2.2	19.3	70.3
Hybr. GW 9023	6.0	1.8	62.7	28.4
Hybr. GW 9022	5.6	1.7	64.2	27.5
Montola 2000	7.0	1.7	78.1	13.3
Montola 2001	5.4	1.6	82.1	9.9

was found. A significant correlation was also found between seed yield and the number of seeds per head, despite the low correlation coefficient (r = 0.53).

– Fatty acid composition

Most of the tested cultivars (Tab. 4) are of the "high linoleic " type with linoleic acid values ranging from 70.3% (Benno) to 78.8% (Hybrid GW 9005). Among the "high oleic cultivars", Montola 2001 showed the highest oleic acid value (82.1%) whereas the hybrid GW 9023 showed the lowest value (62.7%).

DISCUSSION

This research has not confirmed the results of a previous study (Corleto *et. al* 1997b) that showed a yield superiority of hybrids over open-pollinated varieties. This is presumably due to the different yield potential of the hybrids and varieties tested in the 2 studies, and to the limited number of tested cultivars.

As to earliness of flowering, which is of great importance in the Mediterranean climate, where autumn sowing is preferable, some lines of Chinese origin such as BJ 774, showed good earliness compared to the other cvs. under test (about 6 days earlier in flowering than the hybrids). Moreover, BJ 774 proved to be the line with the highest yield and the highest 1000 seed weight but with only moderate oil yield.

In future plant breeding programmes, Bacum, which stands out for its high oil yield and seed yield, could constitute the starting genetic material for more suitable cultivars for Southern Italy environments.

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Potential Yield of Fall and Spring-Sown Safflower as Compared to Sunflower, Durum Wheat and Barley

A. Corleto, E. Cazzato, and V. Annese[1]

ABSTRACT

A two-year research study was conducted in two different localities of Southern Italy: Gaudiano di Lavello, PZ (180 m a.s.l.), in 1998 and 2000, and Oppido Lucano, PZ (550 m a.s.l.) in 1998 only, with the purpose of assessing the yield potential of fall and spring-sown safflower (2 cvs: Benno and hybrid GW 9003) under rainfed and supplemental irrigation (800 m^3 ha^{-1} $year^{-1}$) regime. The experimental design also included sunflower hybrid Sanbro (only spring-sown with and without irrigation), durum wheat cv. Simeto and barley cv. Arda, both sown in fall and under rainfed conditions. As an average of the 3 different environmental conditions, winter cereals gave the highest grain yield (4.9 t ha^{-1} for barley and 4.2 t ha^{-1} for durum wheat). Among oilseed species, fall-sown safflower produced, on the average, the highest grain yield (2.6 t ha^{-1}), followed by sunflower (2.2 t ha^{-1}) while spring-sown safflower showed the lowest grain yield (1.4 t ha^{-1}). Fall-sown safflower gave higher grain yield than sunflower both under rainfed (2.3 vs. 1.8 t ha^{-1}) and irrigated (2.8 vs. 2.6 t ha^{-1}) conditions; this trend was more evident in the year characterised by lower rainfall (19 mm) during the May-July period. The grain yield of safflower hybrid GW 9003 was, on the average, about 20% higher than open-pollinated Benno. Sunflower showed higher oil content (36.9%) than safflower (33.8%); this in turn reduced the differences in oil yield between fall- sown safflower (947.2 kg ha^{-1}) and sunflower (882.7 kg ha^{-1}).

Key words: Grain yield, Oilseed species, Winter cereals, Sowing time, Supplemental irrigation

INTRODUCTION

Safflower is not currently cultivated in Italy, but it has been experimentally studied in Southern Italy for about thirty years (Corleto et al., 1997). These studies have pointed out a great yield variation depending on the soil and climatic conditions (Corleto et al., 1980; Leto and Monti, 1990; Lo Cascio et al., 1984). A species-related factor, which largely limits production, is the cropping cycle length that covers 250 days when the crop is sown in autumn (about 30 days more than durum wheat) and 130-150 days when it is sown in spring; the reproductive cycle (flowering – seed ripening) mostly occurs under severe water deficit conditions. In this connection, previous research (Knowles and Miller, 1965; Knowles, 1980; Marchione and Corleto, 1993) reported that safflower necessitates a total rainfall of 650 mm to produce 3 t ha^{-1} of seeds and that the rainfall in the May-July period is particularly important.

In the future, introduction of safflower in Southern Italy cropping patterns could be a sound alternative to the prevailing durum wheat monocropping system, thus favouring a beneficial increase in crop biodiversity. This would also enhance oilseed resources, which are presently insufficient, adding safflower, a species that, contrary to sunflower, can provide acceptable and more stable yields without supplemental irrigation.

The latter aspect is crucial for Southern Italy where a significant reduction of total rainfall is expected in the future that is likely to result in a more rational use of irrigation water.

The purpose of this research was to compare the potential yield of a safflower crop with the Southern Italy traditional crops (barley and durum wheat) and with sunflower (spring-summer crop),

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which due to the E.U. (European Union) financial support, that is not provided to safflower, is now cultivated, with unsatisfactory results, in the dry and irrigated areas of Southern Italy.

MATERIALS AND METHODS

The trial was conducted for two years in two different locations of Southern Italy: Gaudiano di Lavello (GLF), PZ (180 m a.s.l.), in 1998 and 2000, and Oppido Lucano (OLF), PZ (550 m a.s.l.) only in 1998. In GLF the soil was loamy (53.4% sand, 20.7% silt, 25.9% clay), poor in total nitrogen (0.78‰), rich in available phosphorus (143 ppm P_2O_5) and exchangeable potassium (210 ppm K_2O), with a field capacity of 22.0% and wilting point of 12.8 % on dry weight basis; in OLF, the soil was sandy (69.4% sand, 20.4% silt, 10.2% clay), rich in exchangeable potassium (243 ppm K_2O), poor in available phosphorus (13.5 ppm P_2O_5) and total nitrogen (0.58 ‰), with field capacity and wilting point of16.9 and 10.1% on d.w. basis, respectively.

The trial involved the comparison of 12 different types of crop, including 10 oil crops and 2 winter cereals (barley and durum wheat). The 10 oil crops derive from the combination of 2 watering regimes (dry and with supplemental irrigation at flowering) applied to 4 safflower crops (2 different cvs grown at 2 sowing times) and 1 sunflower crop (sown in spring only).

The split-plot experimental design with 3 replicates was adopted, with the "irrigation" effect in large plots and the crop type effect in 18 m^2 elementary plots. Durum wheat and barley did not receive any supplemental irrigation.

For safflower, the Italian variety "Benno" and the American experimental hybrid "GW 9003" were used, for sunflower, the hybrid "Sanbro", for durum wheat, the cv "Simeto" and for barley the cv "Arda".

For autumn crops, sowing was effected in the third week of November; for spring crops, in the first week of March.

Sowing was made by rows spaced 20 cm for winter cereals, 40 cm for safflower and 60 cm for sunflower, using 240, 30 and 5 kg ha^1 of seed, respectively. After emergence, manual thinning was used to obtain a plant density of 300, 30 and 6.5 plants m^{-2} for winter cereals, safflower and sunflower, respectively.

For all crops, 100 kg ha^{-1} of P_2O_5 were supplied prior to sowing and 70 kg ha^{-1} of nitrogen at the start of stem elongation.

Weeds were controlled by manual weeding before stem elongation.

Irrigation was applied to oil crops at a total amount of 800 m^3 ha of water in two applications of 400 m^3 ha^{-1} each, at the start and at full flowering.

At harvest, on a test area of 8 m^2, the grain yield was determined for all crops. Moreover, for oilseed species, the seed oil content was determined (% of d.m.) using Soxhlet method; moreover, on 3 plants/plot chosen randomly the following yield parameters were measured: for safflower the number of heads/plant, the number of seeds/head and the 1000 seed weight. For sunflower the head diameter, the number of seeds/head and the 1000 seed weight.

Data were submitted to the variance analysis following the randomized block design for the comparison of the 7 crops under dry conditions, and according to the split-plot design for the comparison between oilseed species. The significance of the differences between the means was assessed using the SNK test.

Climatic pattern

In general, the temperature pattern throughout the cropping cycle has not shown any marked difference from the plurennial means. Noticeable deviations are to be pointed out for GLF relative to June and July 1998, when monthly mean temperatures were above the the plurennial means (25.2 vs.

22.1 °C in June and 28.1 vs. 25.0 °C in July) whereas for May and June 2000, the values were below the plurennial means (14.2 vs. 17.8 °C in May and 15.3 vs. 22.1 °C in June). For OLF, temperature was sharply colder in March '98 (4.4 vs. 7.5 °C).

Total rainfall values were 484 mm in OLF 97-98, 532 mm in GLF 97-98 and 284 mm in GLF '99-'00. In the latter environment, a much lower rainfall was observed in the May-July period (only 19 mm) as compared to OLF 97-98 (135 mm) and GLF '97-'98 (193 mm).

RESULTS

- Length of cropping cycle

The length of the cropping cycle (mean of the 3 environments), expressed as number of days from sowing to harvest (Fig. 1) was - for autumn-sown crops -199 days for barley, 210 days for durum wheat and 247 days for safflower, whereas for spring crops it was 145 days for safflower and 150 days for sunflower.

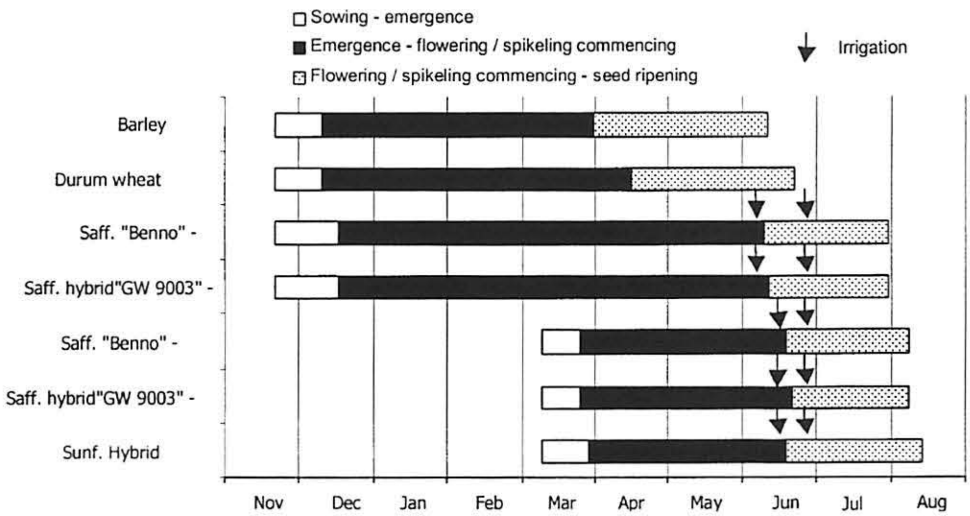

Fig. 1. Length of vegetative and reproductive stages of plant development as a mean of 3 environments.

For the growth stages under analysis, fall-sown safflower showed a mean time of emergence (25 d) greater than winter cereals (19 d), a vegetative stage (emergence-start flowering) that is much longer (173 d on average) than for barley (109 d) and durum wheat (124 d). The reproductive stage (flowering - grain ripening) was about 20 d shorter (on average 48 d) than winter cereals.

The comparison between spring-sown safflower and sunflower showed a vegetative stage that was 5 d shorter for sunflower (80 d), whereas, safflower had a shorter reproductive stage (48 d) than sunflower (55 d).

– Grain yield

Grain yield under dry conditions

Fig. 2 the grain yield potential, as the average of 3 environments, of the crops being tested under dry conditions. Winter cereals expressed a yield potential equal to 4.93 t ha^{-1} for barley and 4.17 t ha^{-1} for durum wheat, which was always much higher than for oilseed species, whose yields ranged between 2.57 and 1.03 t ha^{-1} of grain. Within oilseed crops, fall-sown safflower showed the best yield results with the hybrid "GW 9003" (2.57 t ha^{-1} of grain) followed by "Benno" (2.07 t ha^{-1}). Spring-sown sunflower hybrid "Sanbro" showed a higher yield potential (1.78 t ha^{-1}) as compared to the hybrid "GW 9003" (1.30 t ha^{-1}) and to "Benno" (1.03 t ha^{-1}).

Production Management

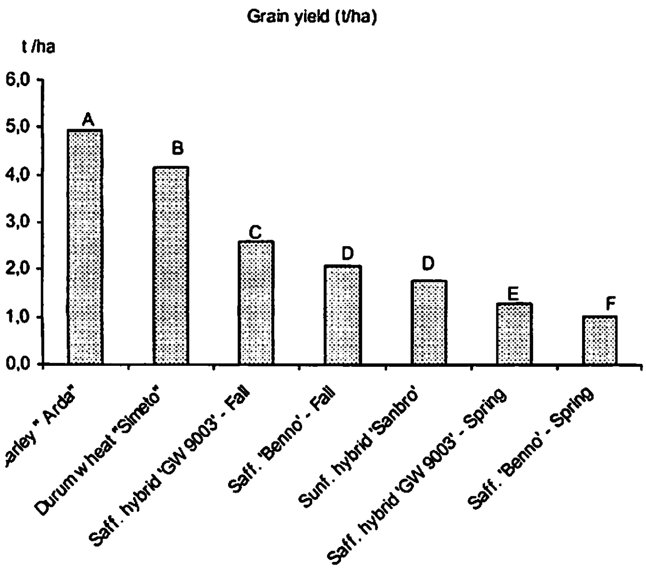

Fig. 2. Grain yield (t ha^{-1}) under rainfed condition.*
* Values not having any letter in common are significantly different at 0.01 P.

Table 1. Effect of supplemental irrigation on grain yield (t ha^{-1}) of Safflower (fall and spring-sown) and Sunflower (spring-sown) [(1)]. Mean of 3 environments.

Crops	Watering regime		
	Dry	Irrigated	Mean
Fall-sown safflower	2.32 c	2.78 a	**2.55 A**
Spring-sown safflower	1.16 f	1.62 e	**1.39 C**
Sunflower	1.79 d	2.57 b	**2.18 B**
Mean	**1.76 B**	**2.32 A**	**2.04**

[(1)] Values not having any letter in common are significantly different at 0.05 P (small letters) and at 0.01 P (capital letters).

Table 2. Grain yield (t ha ^{1}) of Safflower (fall and spring sowing) and Sunflower (spring sewing) in 3 different environments. [(1)]

Crops	Environments		
	OLF 1998	GLF 1998	GLF 2000
Fall-sown Safflower	2.64 AB	2.77 A	2.24 BC
Spring-sown Safflower	1.18 E	1.91 CD	1.08 E
Sunflower	1.88 CD	2.95 A	1.69 D
Mean	**1.90 B**	**2.54 A**	**1.67 B**

[(1)] Values not having any letter in common are significantly different at 0.01 P

Effect of irrigation on oilseed species

Supplemental irrigation with a seasonal volume of 800 m^3 ha^{-1} applied in two waterings at the start and at full flowering of crops, induced (Table 1) a 32% mean increase in grain yield of oilseed species (from 1.76 to 2.32 t ha^{-1}); fall-sown safflower always showed higher yields (2.55 t ha^{-1}) than sunflower (2.18 t ha^{-1}) and spring safflower (1.39 t ha^{-1}). The yield differences between fall-sown safflower and sunflower are more evident under dry conditions (2.32 vs. 1.76 t ha^{-1}) than under irrigation (2.78 vs. 2.57 t ha^{-1} (crops x watering regime interaction).

Comparison between safflower variety and hybrid

The safflower hybrid GW 9003 showed, on average, under all trial conditions, a higher yield potential than variety Benno (2.14 vs 1.79 t ha^{-1}).

Effect of environments on oilseed species

The rainfall pattern largely influenced oilseed crop yields. In the more rainy environment (GLF '98: total rainfall = 532 mm and rainfall in the May-July period = 193 mm) the mean grain yield of oilseed crops was higher and equalled 2.54 t ha^{-1}. Under less rainy conditions: OLF '98 with a total rainfall of 434 mm and 135 mm in the May-July period; GLF '00 with a total rainfall of 286 mm and only 19 mm observed in the period from May to July, the mean yields were 1.90 and 1.67 t ha^{-1}, respectively (Table 2). It is noteworthy that fall-sown safflower showed less variability in production in different environments (in a decreasing order 2.77, 2.64 and 2.24 t ha^{-1} of grain) with respect to the more rainy environment (GLF '98), a yield reduction between 5 and 24%; for spring-sown crops, instead, the yield variations observed range from 62 to 67% for safflower and from 56 to 75 % for sunflower, as compared to the more rainy environment. Moreover, sunflower in the more rainy environment, showed yields (2.95 t ha-1) that are equal to those of fall safflower (2.77 t ha^{-1}).

Table 3. Effects of sowing date on main yield components of safflower. (1) Mean of 3 environments.

Sowing date	Heads per plant (n.)	Seeds per head (n.)	1000 achene weight (g)
Fall	13.5 A	29.3 A	36.2 A
Spring	9.6 B	18.5 B	33.9 B

(1) Values not having any letter in common are significantly different at 0.01 P.

Table 4. Effects of supplemental irrigation on main yield components of sunflower. (1) Mean of 3 environments

Watering regime	Head diameter (cm)	Seeds/head (n.)	1000 seed weight (g)
Dry	12.9 B	856 B	39.8 B
Irrigated	15.2 A	1080 A	42.1 A

(1) Values not having any letter in common are significantly different at 0.01 P.

Table 5. Oil content and oil yield of Safflower and Sunflower (1) Mean of 2 environments: OLF 1998 and GLF 1998.

Crops	Oil content (%)	Oil yield (kg ha^{-1})
Fall-sown Safflower hybr. "GW 9003"	32.3 B	947 A
Sunflower hybrid "Sanbro"	36.9 A	883 A
Fall-sown Safflower "Benno"	33.6 B	829 A
Spring-sown Safflower hybr. "GW 9003"	33.8 B	584 B
Spring-sown Safflower "Benno"	33.4 B	470 B

(1) Values not having any letter in common are significantly different at 0.01 P.

– Yield components

As for safflower, the sowing time was the only factor, among those under study, which influenced the yield components being tested. Shifting from fall-sown to spring-sown crops (Table 3) the following was observed: a reduction in the number of heads/plant (from 13.5 to 9.6), in the number of seeds/head (from 29.3 to 18.5) and in the 1000 seed weight (from 36.2 to 33.9 g).

For sunflower, where the irrigation effect only was assessed, results showed (Table 4) a beneficial effect of the watering application on the head diameter (from 12.9 to15.2 cm), on head fertility (from 856 to 1080 seeds/head) and on the 1000 seed weight (from 39.8 to 42.1 g).

– Oil content and oil yield

The oil content (Table 5) did not show any notable variation as influenced by the trial environment. The sunflower oil content was higher (36.9%) than for safflower that is around 33% and for which no noticeable variation was observed in relation to the sowing date, the watering regime and the cultivar. The highest oil yields were obtained from fall-sown safflower hybrid (947 kg ha^{-1}), sunflower (883 kg ha¯1) and fall-sown safflower "Benno" (829 kg ha^{-1}).

DISCUSSION

The results obtained in this research have pointed out a higher yield of winter cereals (barley and durum wheat) as compared to safflower and sunflower.

Safflower yield potential is affected by the too long cropping cycle and by the occurrence of the reproductive stage in June when the evapotranspirative demand increases and rainfall is sharply reduced.

Safflower comparison with sunflower, in terms of yield and oil yield, is in favour of fall-sown safflower whereas spring-sown sunflower is always preferable to spring-sown safflower.

Fall-sown safflower showed good yield stability even in the years characterised by low rainfall in the spring-summer period. This is presumably related to a deeper root development allowing the plant to uptake water from the deep layers of the soil.

Based on the results obtained, this crop might be proposed in many hilly and mountain areas in Southern Italy, especially if earlier cultivars become available in future.

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International Safflower Trials in China, India and Thailand[a]

Li Dajue[1] and Peter Griffee[2]

ABSTRACT

The Asian International Safflower Trials were carried out in Thailand, India and China in 1999-2000. The locations range from latitude 14°30' to 44°00'N and longitude 77°55' to 103°16'E. Nine cultivars (cvs) and a local cv were tested. The results showed that the highest oil yield is 1353 kg/ha for the cv KU-4038 in north China. If safflower is used as an oil crop, the cvs GW-9023, KU-4038 and GW-9007 can be popularized in India, the oil yield increased 17.6%, 12.4% and 5.9%, respectively, over the local cv. The cvs GW-9023, GW-9025, and GW-9024 and Acc 407 can be popularized in Thailand, as their oil yields are 342.6%, 50.2%, 25.6% and 7.0%, respectively, higher than that of the local cv. The cv GW-9025 and KU-4038 can be popularized in north China as it increased oil yields 19.2% and 11.0%, respectively, in comparison to the local cv. In consideration of the customs in China and India, the corolla is picked off for medicinal purposes; the cv with a red flower, spinelessness, and narrow branching angle would be much better than the cvs with the spiny and yellow flower. The price of safflower products in north China made by the farmer will be 4307 US$/ha for growing the cv KU-4038 while the best spiny cv, GW-9024, will be 3158 US$/ha.

INTRODUCTION

Safflower is a medicinal and high quality oil crop (Li and Mündel, 1996). New and promising cvs have been bred in several countries. Regional testing of these will help to promote safflower development. Under this situation, FAO organized and supported the International Safflower Trails in Asia, which were organized by Prof. Li Dajue. The purpose was to find some cvs, which have high seed yield, high oil content and other promising characters for popularizing in the areas of safflower production.

The locations and institutes in charge of the experiments:

India: Dr. Anjani, Directorate of Oilseed Research, Hyderabad 500 030, India (18°59′ N, 77°55′ E; Elevation: 534 m).

Thailand: Dr. Wasana Wongyi, Kasetsart University, Bangkhen 10903, Thailand and Mr. Surapol Chowchong, National Corn and Sorghum Research Centre, 298 Klabgdibg, Pakchong, Nakornratchasima, 20320, Thailand (14°30′ N, 101°0′ E; Elevation: 360 m).

South China: Dr. Li Liping, The Research and Development Centre of Special Economic Plants, Shilin County, Yunnan Province 652200, China, (24°44′ N, 103°16′ E; Elevation: 1690 m).

North China: Dr. Pei Dapeng, Seed Research Station, Jimusaer County, Xinjiang Uighur Autonomous Region, 831700, China (44°00′ N, 89°01′ E; Elevation: 2500 m)

Production Management

MATERIALS AND METHODS

Nine cvs and a local cv were used for the trials. The cvs FO-4, FO-15 and FO-17 were bred by the Beijing Botanical Garden, Institute of Botany. All of them have red flowers, are spineless and have

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striped seed hulls. Among them, the cvs FO-4 and FO-15 have a narrow branching angle. The cvs Acc-407 and KU-4038 were contributed by Kasetsart University. Acc-407 has very large capitula, white flowers and many spines. The cv KU-3048 has red flowers and a normal seed hull. The cvs GW-9007, GW-9023, GW-9024 and GW-9025 were introduced from the USA, kindly supplied by Globagro, and all hybrids have yellow flowers and many spines, their main characters are having higher seed yield and oil content.

The entries were planted in a randomized block designs with 3 replications. Plots consist of 3 rows each 3 m long. The spacing between rows was 50 cm and between plants 10 cm. The total trial area was 135 m^2.

The descriptors were recorded according to the "Descriptors for Safflower" (IBPGR, 1983).

RESULTS AND DISCUSSION

1. The Main Phenotypic Period

The sowing dates are different as the latitudes are located from 14°30′ N to 44°00′ N. Generally speaking, safflower is autumn sown (India, Thailand, and S. China) in low latitudes and spring sown in high latitudes (N. China). The growing period of spring-sown safflower is shorter (92-94 days) than that fall-sown (104-249 days). In the tropical zone, the growing period is shorter than that in subtropical. For example, the growing period of cv Acc-407 was 104 days in Thailand, and it was 249 days in Yunnan Province, China. The reason is that the temperature is much lower in Shilin County, Yunnan Province, China (24°44′ N, and elevation 1690 m) than that in Suwan Farm, Suwan Buri, Thailand (24°44′ N, and elevation only 360 m). The days from sowing to 50% emergence, 50% branching, 50% flowering, physiological maturity and the total growing period for all cvs in the 4 locations are listed in Table 1.

2. The main characteristics

The cv GW-9023 is the shortest; the mean height was 80.9 cm for the 4 locations. FO-15 is the tallest at 159 cm. The same cvs in different areas have different heights. For example, FO-15 in north China was only 75 cm, while it reached 158 cm in south China. The head diameter ranged from 16.5 mm (GW-9025) to 35.5 mm (Acc-407). The mean head number per plant ranged from 18.7 (Acc-407) to 37.9 (GW-9024). There was a large difference for the head number among cvs in different areas. In spring-sown areas, the head number is much less than that in autumn sown areas. For example, the head number was 12.2 in north China and 78.0 in south China for the cv GW-9007. The mean seed number per head ranged from 19.1 (FO-15) to 57.7 (Acc-407). The weight of 1000 seed rang 1 from 25.8 g (FO-4) to 61.0 g (Indian local cv). The flower colour, angle of branching degree and extent of leaf spinelessness are listed in Table 1.

3. The seed oil content

The highest oil content was 34.0% for cv GW-9007 in north China. The oil content in seed for the trials in India and in north China was higher. The mean oil content in seed for the 9 cvs at the 4 locations was 25%. The details of 9 cvs in the 4 locations are presented in Table 4.

4. The oil fatty acid composition

The mean content of palmitic, stearic, oleic and linoleic acids in the seed oil was 7.8, 1.8, 29.3 and 60.3% respectively (Table 5). Cv GW-9024 possessed the highest oleic acid (59.0%) and cv KU-4038 has the highest content of linoleic acid (79.0%). The cvs FO-4, FO-15, FO-17, KU-4038 and GW-9007 belong to the high linoleic acid type and the cvs GW-9023, GW-9024 and GW-9025 belong to the high oleic acid type. The oil of cvs with high oleic acid can be used for frying as it tolerates high temperature.

Table 1. Main plant characteristics of safflower cultivars

Cultivar	Plant height		Diameter of head		Head number Per plant		Seed number Per head		Seed yield Per plant		1000-seed yield		Oil content in seed		[1]Color of corolla	[2]Angle of Branch	[3]Spine - scent
	cm	Ran.	mm	Ran.	Head	Ran.	No.	Ran.	g	Ran.	g	Ran.	%	Ran.			
FO-4	116	79-129	21	20-21	35	16-68	22	8-43	25	1-72	26	15-34	27	26-28	7	4	0
FO-15	129	75-158	21	21	24	15-38	19	16-22	11	1-24	29	14-40	26	22-30	7	3	0
FO-17	104	68-142	19	17-20	30	15-57	28	17-42	27	1-56	27	19-35	28	26-30	7	5	0
GW-9007	93	52-140	22	22	36	12-78	20	12-31	24	7-49	36	25-50	24	16-34	4	5	7
GW-9023	81	48-98	22	21-22	30	15-53	32	17-49	33	3-78	36	27-43	23	6-33	4	5	7
GW-9024	90	67-121	21	20-22	38	22-72	32	15-41	36	4-86	34	22-45	24	9-32	4	5	7
GW-9025	91	65-124	17	15-18	35	24-61	26	15-46	24	3-45	38	25-53	22	8-29	4	5	7
Acc-407	98	62-122	36	34-37	19	9-31	58	32-89	25	4-58	34	22-45	21	7-30	1	5	7
UK-4038	95	69-109	22	20-23	29	12-54	29	15-44	34	2-66	38	20-54	26	19-30	7	5	0
CK	91	75-114	21	20-21	39	11-92	31	14-53	40	3-87	60	23-61	24	8-32	-	-	-

* Ran. =Range

1 3=Light yellow; 4=Yellow; 5=Light orange base; 7=Red-orange.

2 3= 15-20°; 5= 20-60°; 7= 60-90°; 9= >90°;

3 0= Non-spiny; 3= Few spinies; 5= Intermediate; 7= Many spinies

Table 2. The average seed yield in plots of cvs in the 4 locations (kg/ha)

	FO-4	FO-15	FO-17	GW-9007	GW-9023	GW-9024	GW-9025	Acc-407	KU-4038	CK	Mean
India	500	500	1000	1800	2000	1100	1000	1594	1900	1700	1309
Thailand	48	9	21	27	1049	298	356	260	126	237	243
South China	1155	1110	1178	666	1844	1223	2511	1623	732	2934	1498
North China	2956	3233	2822	2047	2598	3898	4511	3753	4202	3784	3380
Mean	1165	1213	1255	1135	1873	1630	2095	1808	1740	2164	1608

Table 3. The average oil yield in plots of cvs in the 4 locations (kg/ha)

	FO-4	FO-15	F0-17	GW-9007	GW-9023	GW-9024	GW-9025	Acc-407	KU-4038	CK	Mean
India	143	136	291	562	588	312	292	461	528	490	380
Thailand	13	2	6	5	66	26	28	63	11	41	26
South China	297	246	305	103	467	316	613	308	207	692	355
North China	822	960	855	696	847	1263	1164	1122	1353	1154	1024
Mean	319	336	364	342	492	479	524	489	525	594	446

Table 4. The oil content in safflower seed of cultivars in different locations.

Cultivar	Locations				Mean
	India	Thailand	South China	North China	
FO-4	28.5	27.8	25.7	27.8	27.45
FO-15	27.2	25.5	22.2	29.7	26.2
FO-17	29.1	28.1	25.9	30.3	28.4
GW-9007	31.2	17.0	15.5	34.0	24.4
GW-9023	29.4	6.3	25.3	32.6	23.4
GW-9024	28.4	8.8	25.8	32.4	23.9
GW-9025	29.2	7.8	24.4	25.8	21.8
Acc-407	28.9	24.1	19.0	29.9	25.5
Ku-3048	27.8	8.4	28.3	32.2	24.2
Local CV	28.8	17.1	23.6	30.5	25.0

Table 5. The composition of fatty acid in the cultivars.

Cultivar	Palmitic acid (%)	Stearic acid (%)	Oleic acid (%)	Linoleic acid (%)
FO-4	6.9	1.7	17.2	74.2
FO-15	6.8	1.4	16.8	74.9
FO-17	6.9	1.2	14.9	77.0
GW-9007	8.3	2.6	17.0	71.7
GW-9023	7.8	1.4	55.9	32.7
GW-9024	7.6	1.5	59.0	30.5
GW-9025	9.0	1.9	54.7	32.8
Acc-407	9.6	2.1	17.3	69.5
KU-4038	7.3	2.0	10.9	79.0
Mean	7.8	1.8	29.3	60.3

The cvs with high linoleic acid can be used as health-care oil for making medicine for decreasing the cholesterol in order to help prevent atherosclerosis and heart disease. (Song and Li, 1999).

5. The yield of safflower seed

The mean seed yield of all the safflower cvs was only 1607.63 kg/ha in the 4 locations. The yield of GW-9024 was highest at 4511 kg/ha in north China. The yields of all cvs in the areas are listed in Table 2. The results of the trials showed that there was a significant difference among locations ($P>0.01$) and there was a difference among cvs ($P>0.05$).

6. The yield of safflower oil

The highest oil yield was 1353 kg/ha for cv KU-4038 in north China. The mean oil yield in seed for all cvs was 1024 kg/ha in north China, while it was only 26 kg/ha in Thailand. The analysis showed that there was a significant difference among cvs ($P>0.01$) and among locations ($P>0.01$). The data are shown in the Table 3.

7. The flower yield

Safflower flowers are usually used as a traditional herbal medicine in China. It has such properties as relaxing muscles, encouraging the circulation of blood etc. It can be used to help cure heart diseases and bruises. Generally speaking, the flower yields with spineless cvs such as KU-4038 and FO-4, FO-5 and FO-17 were much higher than the spiny cvs GW-9007, GW-9023, GW-9024 and GW-9025. According to custom, the yellow flower cannot be used as a medicine but is used as a materials source for extracting yellow pigment.

CONCLUSIONS

If safflower is used as an oil crop, the cvs GW-9023, KU-4038 and GW-9007 can be popularized in India, the oil yield increased 17.6%, 12.4% and 5.9% that of the local cv, respectively. The cvs GW-9023, GW-025, and GW-9024 and Acc 407 can be popularized in Thailand, as their oil yields are 342.6%, 50.2%, 25.6% and 7.0% higher than that of the local cv, respectively. The cv GW-9025 and KU-4038 can be popularized in north China as they increased 19.2% and 11.0% respectively in comparison with the local cv. In consideration of the customs in China and India, the corolla is picked off for medicine; the cv with red flower, spinelessness, and a narrow branching angle would be much better than the spiny cvs with yellow flowers. Suppose the price of the oil is 2.5 US$/kg and the price of the dry flower is 3.6 US$/kg, in the highest oil yield location in north China, the price of safflower products made by the farmer will be 4307 US$/ha (1353 kg/ha oil and 264 kg/ha dry flower) for growing the cvs KU-4038. For the best spiny cvs GW-9024 (1263 kg/ha) it will be only 3158 US$/ha.

There is a large potential to be tapped for increasing the seed and oil yields through improving the cultural practices under normal climatic years.

RECOMMENDATIONS

Safflower can be grown in dry areas or in the dry season successfully. It is ~~a~~ sensitive to water; high soil moisture will facilitate root-rot (*Phytophthora* sp.) and high humidity will lead to infection by *Fusarium* sp., *Puccinia carthami*, *Verticillium albo-atrum*, *Botrytis cinerea* and *Alternaria carthami*. The use of spray irrigation twice every week in the experimental station in Thailand resulted in almost of all cvs being destroyed by diseases and the seed yield was only 27 kg/ha and the oil yield 5 kg/ha for GW-9007. It is advisable to conduct a training course on safflower cultivation before growing it.

There is still a potential to increase the seed yield of safflower. Early maturity cvs should be selected and used in south China. In north China, the sowing date should be earlier than it is. Safflower is sensitive to temperature and photoperiod. It needs a period of low temperature and short days for vegetative growth and a high temperature and long days for reproductive growth. The plant height is only 48 cm for the cv GW-9023 in north China, showing that the seedling lacks the environmental conditions for vegetative growth. If the sowing date would be advanced from May 8 to April 15, the plant height and seed yields would be significantly increased.

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Safflower Production and Research in Turkey

Enver Esendal[1]

INTRODUCTION

Safflower, *Carthamus tinctorius* L. has been grown for centuries, primarily for its colorful petals to use as a food coloring and flavoring agent, for vegetable oil and also for preparing textile dye in the Far East, Central and North Asia, America, North Africa, Europa and Caucasia. The principle countries where safflower is grown are India, USA., Mexico, and in lesser extent Kazaghistan, Ethiophia, Argentina, China, Uzbekistan Australia, Russian Federation, Pakistan and Spain (Dajue and Mündel, 1996; Anon., 2001). However, Turkey is one of the small scale safflower producers.

From 1995 to 2000, world production of safflower has varied from 852,592 to 1,011,762 tonnes annually, grown on 1,086,516 and 1,198,890 hectares of harvested area with a yield of 711.1-847.5 kg/ha, (Anon., 2001). India is the largest safflower producing country with 383,300-430,000 tonnes of production each year on 684,000-791,000 ha. This is almost half of the the world's production. The USA. is the second largest producing country with a 180,000-195,070 tonnes of yield per year on 84,580 to115,340 hectares. Safflower production in Mexico is between 109,020-262,740 tonnes per year on 93,152 to166,338 ha, followed by Kazakhistan (15,700 to 36,000 tonnes per year), Ethiopia (35,000 to37,000 tonnes per year), Argentina (6,000 to31,000 tonnes per year), China (20,000 to29,000 tonnes per year). Safflower is mainly grown in China for its florets rather than as an oilseed (Dajue and Müller, 1996).

The reported highest yields are over 2,100 kg per hectare in China, and 1,900 kg per hectare in the USA.

PRODUCTION

It is believed that cultivated safflower was first introduced into Turkey from Western Thrace in the 1930's by Turkish imigrants (Dincer, 1964). In fact, it is believed that safflower has its origin in Euroasia, including Turkey and the neighboring countries. The existence of some wild *Carthamus* species, such as *Carthamus dentatus* Vahl. (2n = 20), C. *glaucus* Bieb. (2n = 20), *C. flavescens* L. (2n = 24), *C. lanatus* L. (2n = 44), and *C. turkestanicus* L. (2n = 64) was reported in Anatolia by Knowles and Esendal, 1974; Esendal, 1988; and Aydem, 1979.

Preliminary studies on safflower in Turkey was initiated at the Sazova Seed Breeding Station, Turkish Ministry of Agriculture, in Eskiscehir, in 1929-1930. Safflower production began slowly in the 1950's with seeds supplied by this institute. Today many introductions are available along with a few land races (local populations). New varieties are usualy tested in yield trials with these local populations.

Dincer and Yenice are two of the released (certified) local varieties and their characteristics are given as below:

Dincer: Spineless, orange flowered, mid-late, medium tall, high yield and high seed oil (38 %). The original accession number given at the Eskisehir Institute of Agricultural Experiment is 5-118.

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Yenice: Spineless, orange flowered, late maturing, tall, low in yield and seed oil (28 %).

The safflower growing area is located west and southwest of Ankara, and is called *The Transitional Zone*. It extends from Central Anatolia and west, including Balikesir, Burdur, Eskisehir, Kutahya, Bursa, Isparta and Konya districts.

In the 1970's the total acreage grown was only about two thousand hectares and decreased further in subsequent years to 100 hectares (Anon., 1999). The primary reason for the reduction was that its small acreage is scattered over a large area. Therefore, safflower did not have a well organized market. Since there was no organization producing and distribution the high quality seeds, the farmers used seed from their own fields or from their neighbors. These local populations yield well but the seed oil content is low (28-38 %) because of their high percentage of hull.

Modern oil seed processing plants have been designed mostly for processing sunflower or cotton seeds. Safflower seeds are processed for family needs by primitive implements belonging to the farmers. Therefore, safflower is one of the cheapest oilseed in Turkey (sold at 25-30 thousand TL. or 5-6 cents per kg., approximately 1/5 of sunflower cost, 1/6 – 1/3 of soybean cost or 1/25 – 1/13 of flax seed cost).

Safflower is not competitive to the other oilseeds in terms of net income. Therefore, the farmers grow it on the marginal land areas (poor soils), usually ignore irrigation for supplementary water, and refuse to use plant nutrients and pesticides in safflower fields. Safflower is grown as a rainfed crop in Turkey. Although pests and diseases are few their influence on yield and quality is considerable. Another constraint is an effective market for the safflower oil is available. Therefore, safflower oil is consumed locally for the family need of the growers.

In order to overcome all these constraints, The government should support and encourage the safflower growers by providing a market premium, distribution of quality seed, and obtaining and providing technical information and assistance. It hoped that safflower production can help reduce an oil deficit, equal to about half of the 1.6 million tonnes of total need. The major oilseed crops are sunflower and cotton. Production of these crops has reached saturation point at the present time. However, safflower and rape can be produced as a winter crop. The high yields produce up to 2,000-2,500 kg/ha with no irrigation.

SAFFLOWER RESEARCH IN TURKEY

Very limited research has been done on safflower in Turkey, because of its small acreage and lesser economic importance.

The first research study on safflower was carried out in thirties at the Eskisehir Institute of Agricultural Experiment in Central Anatolia (Dincer, 1964). Later, the Atatürk University Agricultural Faculty Plant Science Department in Erzurum, in Eastern Anatolia had lead the preliminary studies on safflower (Esendal, 1974). In this first scientificaly evaluated work, some new varieties were introduced from the USA. and some lines from different locations of the country were collected. Promising varieties like BC-7, Pacific-7, N-8, and some introduction accessions were put into yield trials with the local varieties (Dincer, Yenice, and others) during a two-year period between 1969 and 1970. The introduced varieties yielded less than an early maturing local line, 5-62, while the Pacific-7 and BC-7 had an oil content higher than the local lines.

In the following years, M.S. or/and Ph.D. programs have evaluated about 56 research works carried out in different parts of country (Erzurum, Samsun, Ankara, Adana, Isparta, Van, and Tekirdag). An inventory of these studies has been reported by Esendal (2001). The research in terms of subject and the goal is classified below:

Studies concerning;	% -	Project No.
a) Sowing time	9.1	5
b) Plant fertigation and fertilization (majority on nitrogen)	14.5	8
c) Plant stand, row spacing	12.7	7
d) Soil preparation and other agronomic works	1.8	1
e) Plant breeding and variety improvement	7.2	4
f) Safflower florets use as dye source	9.1	5
g) Oil and oil quality of seed	1.8	1
h) Yield and plant characteristics	27.3	15
i) Plant rotation	1.8	1
j) Research on other subjects	16.4 ~~1.8~~	9
	100.00%	56 studies

Table 1. Safflower production in Turkey in comparison with the other oilseed crops, (1994-1998).

Oil Crops	1994	1995	1996	1997	1998
Safflower					
area harvested*	100	134	81	74	
production**	90	125	74	65	72
yield***	900	933	914	878	
Cotton seed					
area harvested*	581	491	756,694	743,775	721,723
production**	929,902	1,287,527	1,219,579	1,193,286	1,318,485
yield***	1,599	1,702	1,640	1,653	
Sunflower					
area harvested*	585,700	584,757	573,782	556,430	
production**	740,000	900,000	780,000	900,000	860,000
yield***	1,263	1,539	1,359	1,617	
Groundnut					
area harvested*	30,000	29,000	33,910	32,000	
production**	70,000	70,000	80,000	82,000	90,000
yield***	2 333	2,414	2,359	2,563	
Soybeans					
area harvested*	29,000	3,1000	20,507	19,000	
production**	70,000	75,000	50,000	40,000	60,000
yield***	2,414	2,419	2,439	2,105	
Sesame					
area harvested*	84,706	72,414	73,436	67,995	
production**	34,000	30,000	30,000	28,000	34,000
yield***	401	411	409	412	
Poppy seed					
area harvested*	25,321	60,052	11,492	29,681	
production**	14,000	28,249	5,346	10,948	27,964
yield***	553	470	448	369	
Hemp seed					
area harvested*	2,500	1,600	2,450	1,600	
production**	400	360	400	230	300
yield***	160	1,225	163	144	
Flax seed					
area harvested*	6	650	355	355	
production**	10	390	228	228	185
yield***	1,667	604	642	662	
Rapeseed					
area harvested*	6	7		2	10
production**	10	9	5	10	300
yield***	1,667	1,286	2,500	1,000	

* area in 000 ha; ** production in 000 tons; *** yield in kg/ha

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EcoPort: The Access Portal to Ecology Knowledge for Natural Resource Managers and its Relation to Oil Seeds, Including Safflower; An On-Line Presentation

P. Griffee[1], T. Putter[1], M. Marsella[2], and P. Diemer[1]

ABSTRACT

FAO and the University of Florida are developing a system called EcoPort, launched at http://www.ecoport.org in January 2000; the Smithsonian Institute is the third EcoPort Consortium member. It deals with the management of ecological knowledge and the interactions between entities such as plants, pests, vertebrates, places etc. The associated website EcoCrop (http://ecocrop.fao.org) matches plants to environmental conditions and plant uses. The on-line presentation will demonstrate oilseeds in relation to these sites, with particular reference to safflower.

Key words: EcoPort, on-line resource

DISCUSSION

In 1998 FAO created a Global Plant Production and Protection Information System (GPPIS) that established a network of individuals and institutions that agreed to freely share their separate knowledge to create a communally owned database on the Internet.

Very soon we realized the limitations of seeing the world only in terms of pests and crops, and decided that we need to **PRACTICE** holistic ecology as comprehensively as we **PREACH** it. Accordingly, FAO formed a consortium with the University of Florida (UF) and the National Museum of Natural History of the Smithsonian Institution (SI) in the USA, to build EcoPort: a service similar to GPPIS, but this time widened to **ECOLOGY AS CAUSE** and the pooled information power and institutional perspectives and mandates of FAO, UF and SI as a foundation to exploit and deliver the benefits of the Internet. Over 90 associates and 500 editors also contribute.

EcoPort went public on 1 January 2000 and in June 2001, 127,000 entity records were established, including 42,000 plants. There are over 510,000 references, many slide shows, 35,000 glossary terms, 18,000 pictures, etc. We now have records on over 100 plants that are (also) oil producers in the Products & Uses Field plus descriptions and pictures and this will reach 200 by the end of 2001. This on-line demonstration will show the power of the 'knowledge sponge'; the EcoPort-associated analytical database EcoCrop will also be demonstrated. EcoCrop searches for species (and their uses) potentially adapted for local ecologies.

Each contributor receives a username and password that enables us to write information into the shared database, much as a group of authors write chapters for a book, except that the 'book' we are writing is a public database on the Internet. This process uses methods and tools invented at FAO, which allow editors (not only webmasters) to write HyperText directly.

Data quality is maintained by the same process of peer review that has kept scientific publishing going ever since it started by automatic email notification to supervisors. Each contributor's shared

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information is displayed under a banner and logo that reflects ownership and responsibility, and we clearly demonstrated that sharing and generosity does not threaten identity.

As we all put sharing ahead of copyright and many other territorial aspects that unnecessarily increase the transaction costs associated with using data, our pooled knowledge grew very rapidly. And, because many users either do not have Internet access or have slow and expensive connections, we will distribute EcoPort data sets on free CD-ROMs as well.

Many of these oil plant records need editors. Please contact peter.griffee@fao.org if interested. He will explain the procedure for registering in order to edit EcoPort and will present this procedure at the conference. You are invited to join the EcoPort community.

Integrated Phosphorus Management in Safflower Based Cropping Systems

D. M. Hegde[1]

ABSTRACT

The studies were carried out in permanent plots under All India Coordinated Safflower Improvement Project to optimize P requirement of safflower based cropping systems *viz*., mungbean – safflower at Annigeri (Karnataka), soybean – safflower at Parbhani (Maharashtra) and sorghum (F) – safflower at Arnej (Gujarat). There were 12 treatments comprising application of 100% recommended P to both the crops and reducing P application to 50 or 0% to either of the crops with the other crop receiving 0, 50 or 100% P. When any of the crop in the system received 100% P, the phosphorus solubilizing bacteria (PSB) and farm yard manure (FYM) were included either singly or in combination for the other crop in the system along with 0 or 50% P. The average data for three years indicated that on Typic Chromusterts with high available P, there was no response to P in both crops at Annigeri. However, on clay Chromusterts at Parbhani, it was possible to substitute 100% P needs of either of the crops with FYM without any adverse effect on productivity. On Vertic Ustochrepts at Arnej, application of PSB to both the crops could substitute 50% P needs in both the crops. Further, application of PSB along with FYM could substitute 100% P needs of the crop. The system productivity and net returns also followed a similar trend.

Key words: phosphorus management

INTRODUCTION

Safflower is one of the important oilseed crops of India raised during the winter season. It is generally taken as single crop in a year on stored soil moisture in a two-year rotation with sorghum and chickpea or preceded by short duration legumes like mungbean and soybean during the rainy season. Phosphorus is a costly input among major nutrients. Any economy in its use will go a long way in increasing the profitability of this crop. Since, less than 25 to 30% of applied P is taken up by the current crop (Hegde, 1998), there is a need to make use of residual P fertility by the succeeding crop by employing biological/organic amendments to increase P availability (Rokade and Patil, 1992). Present studies were, therefore, carried out to optimize P use for safflower based cropping systems through integrated P management.

MATERIALS AND METHODS

The experiment was conducted in permanent plots under the All India Coordinated Safflower Improvement Project on three safflower based cropping systems *viz*., mungbean – safflower at Annigeri (Karnataka), soybean – safflower at Parbhani (Maharashtra) and sorghum (Fodder) – safflower at Arnej (Gujarat). Mungbean – safflower and soybean – safflower were one year crop sequence while sorghum (F) – safflower was of two-year crop rotation. The study was initiated during 1996-97 at Annigeri and Arnej and 1997-98 at Parbhani. The soil types were clay loam Typic Chromusterts at Annigeri, clay Chromusterts at Parbhani and clay Vertic Ustochrepts at Arnej. The soils at three sites had pH values of 8.1, 8.7 and 8.0; available N content of 142, 117, and 220 kg/ha, available P content of 20, 15, and 4.8 kg/ha and available K content of 588, 950, and 651 kg/ha, respectively.

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There were 12 treatments (Table 1) comprising 100% recommended P to both crops and reducing P application to 50 or 0% to either of the crops when the other crop received 0.50 or 100% recommended P. When one crop in the sequence received 100% recommended P, PSB (2 kg/ha) and FYM (5 t/ha) were included either singly or in combination for the other crop along with 0, or 50% recommended P. Treatments were arranged in randomized block design (RBD) with three replications. In case of sorghum (F) - safflower rotation, the experiment was carried out in RBD in series with two replications for each crop.

The total rainfall of 1252, 644 and 439 mm during 1996-97, 1998-99 and 1999-2000 at Annigeri; 934, 1475 and 961mm during 1997-98, 1998-99 and 1999-2000 at Parbhani and 692, 693, and 681mm during 1996-97, 1997-98, 1998-99 at Arnej were received.

The recommended fertilizer levels ($N:P_2O_5:K_2O$, kg/ha) were 20:40:20 (mungbean) and 40:40:20 (safflower) at Annigeri; 30:60:30 (soybean) and 60:40:0 (safflower) at Parbhani and 15:15:0 (sorghum – F) and 25:25:0 (safflower) at Arnej. Mungbean (cultivar - China mung) and soybean (cultivar - JS 335) were planted with the onset of monsoon during July with row spacing of 30 and 45 cm respectively. All the fertilizers were applied by placing in furrows 5 cm away from seed rows and covered before planting. Mungbean was harvested in September and soybean in October and seed yields were recorded on air-dry basis.

Land was prepared for planting succeeding safflower without disturbing the bund between plots. Safflower was planted during second fortnight of September at Annigeri and Arnej in all the years and during second fortnight of October or first fortnight of November at Parbhani by dibbling seeds every 20 cm in rows 45 cm apart. Thinning was done two weeks later to keep only one seedling per hill. Sorghum (F) was planted during second fortnight of September at Arnej at the same time as safflower with a row spacing of 45 cm using cultivar "Solapuri". The safflower varieties, Annigeri-1, Sharda and Bhima were used at Annigeri, Parbhani and Arnej, respectively. All the fertilizers for safflower at Annigeri and for sorghum (F) and safflower at Arnej were applied before planting. At Parbhani, 50% N and full dose of P (as per treatment) and K were applied before planting and the remaining 50% N was top dressed 5 weeks later. The crop at Parbhani received three irrigations of 75 mm each at planting, 5 and 10 weeks after planting. The PSB (2 kg/ha) and FYM (5 t/ha) as per the treatment were applied during land preparation. Land was prepared by bullock drawn plough and harrow to bring the soil to good tilth. Sorghum (F) was harvested during dough stage and the fresh weight was recorded. Safflower was harvested during February/March at different places and seed yield was recorded on air-dry basis. Both mungbean and safflower crops failed at Annigeri during 1997-98 due to soil moisture stress and *Alternaria* incidence, respectively.

The yield data were pooled over years and treatment means were compared at 5% level of significance using least significant difference. To compare total system profitability, the average yields of mungbean, soybean and sorghum (F) were converted into safflower equivalent yields based on market prices and added to safflower yields. The net returns from different treatments were also calculated based on input cost and output value.

RESULTS

Yield: The average data of three years indicated that on Typic Chromusterts at Annigeri, there was no significant response to P application both in mungbean and safflower (Table 1). Nevertheless, application of 50% P along with PSB for both crops resulted in highest system productivity.

On clay Chromusterts at Parbhani, there was significant response to P and any reduction in P to either of the crops had adverse effect on productivity. However, application of PSB along with FYM could easily substitute 100% P to soybean or safflower when the other crop received recommended P. The system productivity also showed a similar trend and clearly indicated the possibility of substituting 100% P needs of one of the crops by FYM or PSB+FYM.

Table 1. Effect of P management on productivity of safflower based cropping systems.

Treatment			Average yield (kg/ha)								
			Annigeri			Parbhani			Arnej		
S. No.	Mung bean/ Soybean/ Sorghum (F)	Safflower	Mung bean	Safflower	Safflower equivalent	Soybean	Safflower	Safflower equivalent	Sorghum (F)	Safflower	Safflower equivalent
1.	Control (No P)	Control (No P)	730	964	1774	2154	1270	3000	4447	854	1743
2.	100% P	100 % P	719	1074	1872	2600	1763	3851	6103	1229	2450
3.	50% P	100% P	644	1010	1725	2335	1673	3548	5731	1300	2446
4.	50% P	50% P	664	1007	1744	2293	1540	3381	5429	1270	2356
5.	50% P + PSB	50% P + PSB	932	1019	2054	2355	1567	3458	6145	1413	2642
6.	Control (No P)	100% P	803	1002	1893	2193	1526	3287	4153	1086	1917
7.	FYM (5 t/ha)	100% P	784	1007	1877	2564	1738	3797	6411	1418	2700
8.	PSB + FYM (5 t/ha)	100 P	824	1058	1473	2670	1759	3903	6381	1498	2774
9.	100% P	50% P	784	946	1816	2703	1630	3801	6103	1303	2524
10.	100% P	Control (No P)	460	1021	1532	2540	1392	3432	6363	1030	2303
11.	100% P	FYM (5t/ha)	766	1041	1891	2584	1760	3835	5836	1351	2518
12.	100% P	PSB + FYM (5t/ha)	680	1111	1866	2596	1774	3859	6173	1516	2751
	LSD (P=0.05)		NS	NS	NS	269	198	217	841	134	155

Table 2. Effect of P management on net returns from safflower based cropping systems.

	Treatment		Net returns (Rs/ha)		
S. No.	Mung bean/Soybean/ Sorghum (F)	Safflower	Mung bean -safflower (Annigeri)	Soybean-safflower (Parbhani)	Sorghum-safflower (Arnej)
1.	Control (No P)	Control (No P)	9775	24492	9217
2.	100% P	100 % P	10228	32494	15451
3.	50% P	100% P	8966	29693	15629
4.	50% P	50% P	9398	28114	15014
5.	50% P + PSB	50% P + PSB	12836	28918	17833
6.	Control (No P)	100% P	10537	27105	10649
7.	FYM (5t/ha)	100% P	9837	31488	17106
8.	PSB+FYM (5t/ha)	100 P	10829	32666	17804
9.	100% P	50% P	9717	31591	16191
10.	100% P	Control (No P)	8024	28104	13978
11.	100% P	FYM (5t/ha)	8698	31783	15425
12.	100% P	PSB + FYM(5t/ha)	8931	32032	17880

Rs. 46 = $1 U.S.

On Vertic Ustochrepts at Arnej, there was significant response to P application in both sorghum (F) and safflower. Application of PSB could easily substitute 50% P requirement for both the crops. Likewise, application of FYM to either of the crops could substitute 100% P needs of the succeeding crop. The system productivity also indicated possibility of saving 50% P needs of both the crops when PSB was applied along with 50% P. Further, application of FYM could substitute 100% P needs of either sorghum (F) or safflower when the other crop received the recommended P.

Net returns: In the mungbean – safflower sequence at Annigeri, highest net returns (Rs. 12836/ha) from the system was recorded when 50% P was substituted by PSB in both the crops (Table 2). In the soybean – safflower sequence at Parbhani, application of PSB + FYM to either soybean (Rs. 32666/ha) or safflower (Rs.32032/ha) when the other crop received recommended P, recorded as much net return (Rs. 32494/ha) as application of 100% P to both the crops. At Arnej, application of PSB along with 50% P to both the crops (Rs. 17833/ha) and PSB + FYM to either of the crops (Rs. 17804 to 17880/ha) recorded highest returns.

DISCUSSION

There was significant response to P application in both the crops at Parbhani and Arnej as available P status was medium and low, respectively. It is quite natural to expect significant response to P application when its availability in the soil is low, especially in crops like soybean (Hegde, 1998). Application of PSB or FYM recorded significant increase in yield and could substitute 50 to 100% P requirement of either soybean or sorghum (F)/safflower when the other crop received 100% P. The role of PSB and FYM in converting fixed P to soluble forms to help to reduce P needs has been well documented (Rokade and Patil, 1992; Tiwari, *et al*, 1993; Modak, et al., 1994). The PSB was not effective at Parbhani because of higher pH (8.7).

This study clearly shows the possibility of substituting 50 to 100% P needs of one of the crops in the safflower based cropping system by PSB or PSB + FYM without any adverse effect on the system productivity and net returns in soils of low to medium available P.

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Safflower (*Carthamus tinctorius* L.) production and research in southern Australia

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ABSTRACT

A number of challenging issues face farmers in the southern cropping zone of Australia. These include extending cropping into high rainfall environments prone to waterlogging, managing herbicide resistant weeds, producing crops on sodic and saline subsoils and the need for additional break crops, especially in areas affected by the root lesion nematodes, *Pratylenchus spp.*

The major safflower production area in Australia is in Victoria where it is grown mainly as an opportunity crop, sown in years of high winter rainfall which result in delayed sowing of crops until late winter or spring. This means that safflower is sown into sub-optimal conditions with little consideration given to its wider and continuing role as a crop in sustainable cropping systems. Safflower has many features that may address the above-mentioned issues. For example, safflower has an extended sowing window (July to October), is salt tolerant, has a deep taproot, and appears to be resistant to *Pratylenchus neglectus and P. thornei*. Because of these features, safflower may have certain tactical roles in southern Australian farming systems that may have wider benefits to the whole rotation. As there has been no research on safflower in Australia for over 10 years, it is now timely to assess the role safflower may play in addressing some of the emerging issues in southern Australian farming systems. This paper will discuss current safflower production and research that is underway in southern Australia.

Key words: safflower, Australia, research, production, tactical crop

INTRODUCTION

Safflower (*Carthamus tinctorius* L.) is a minor crop in Australia (35,100 ha, 1998-99 statistics) when compared to wheat (11,583,000 ha) and canola (1,270,200 ha) (ABARE 1999a). Most safflower production occurs in southern Australia and the state of Victoria is the largest producer (18,600 ha) (ABARE 1999a). Reduced gross margins for wool and the cost/price squeeze has not only caused higher cropping intensity in southern Australia, but also extended cropping into non-traditional areas. With increased cropping intensity there is a need for crop diversity in rotations to minimise disease risk and manage herbicide resistant weeds. A small research group at the University of Melbourne, Longerenong College, is developing a research profile in alternative crops to increase crop diversity in southern Australian. Safflower is one species included in this work.

Production Management

DISCUSSION

Grain production in southern Australian

Australia's traditional grain production region is located in a crescent within 500 km of the southeastern coast, and includes a range of environments. Soil types range from light sands to heavy clays, pH from very acid to very alkaline and average annual rainfall from less than 300 mm to greater than 1000 mm. The Grains Research and Development Corporation, Australia's national grains research funding body has divided Australia into 3 agroecological zones of grain production to focus research on issues of regional priority (Figure 1).

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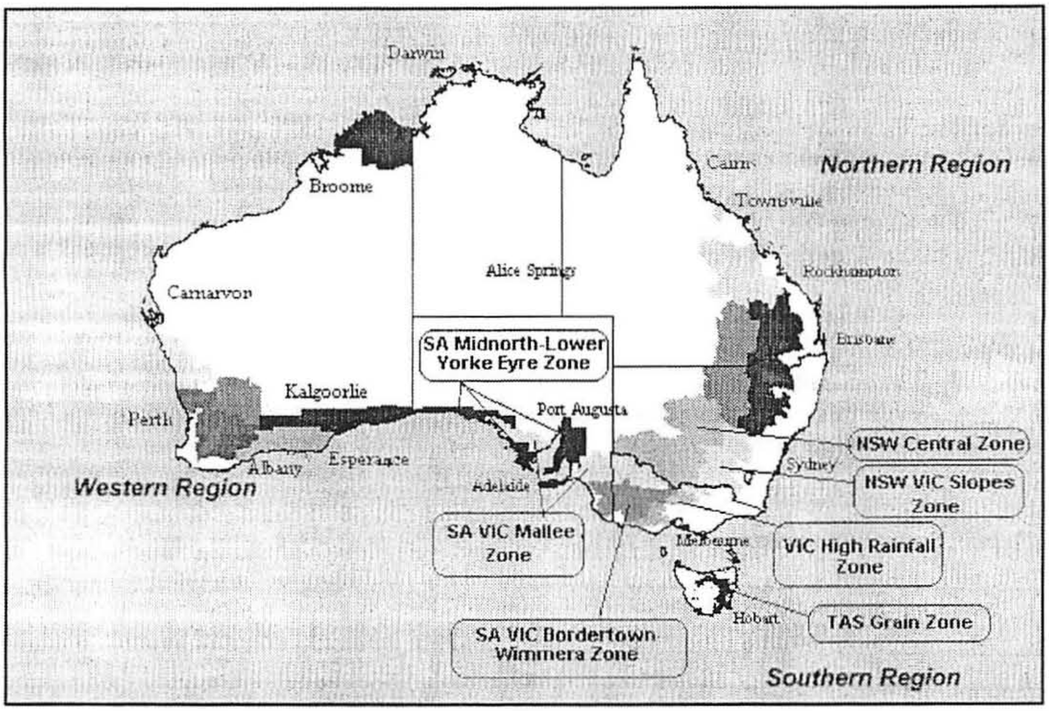

Fig. 1. Grains research and development southern region zones of Australia.

The southern region of Australia is characterised by:

- A temperate, mediterranean climate with winter dominant rainfall
- Relatively infertile soils
- Crop yields dependent on reliable spring rainfall
- Smaller enterprise size than the other 2 regions
- Produces the most canola within Australia (Table 1)
- Diverse production patterns and opportunities (GRDC, 1999)

Safflower production in southern Australia

Australian safflower production commenced in the 1950s, initially mainly in southern and central Queensland and northwestern New South Wales (NSW). In NSW, production was low until 1969 when the introduction of wheat quotas stimulated interest in safflower and other alternative crops (Colton, 1988).

Between 1985/86 and 1997/98 safflower has had an average gross value of production to Australia of $Aus 8.8 million compared to $Aus 79 million for canola and $Aus 2.5 million for linseed (ABARE, 1999a). As safflower is frequently grown as an opportunity crop in seasons where cereal sowing is delayed, production areas have varied from 30,000 ha to 54,400 ha. With an average yield of 0.7 t/ha, Australian production can therefore vary from 20,000 t to 38,000 t (ABARE 1999b).

Table 1: Grain statistics for Northern, Southern and Western regions of Australia (source ABARE, 1999b).

	Northern Region	Southern Region	Western Region
Average farm size (ha)[1]	1,743	1,339	3,100
Cropping intensity on farm (%)[1]	25	28	36
Wheat produced (kt)[2]	2763.1	1019.6	1399.9
Canola produced (kt)[2]	5.2	27.9	7.5

[1] 1997-98 Figures, [2] Average 1986/87-1996/97

Table 2: Average area, yield and production of safflower in southern Australia (1986-1999) (source ABARE, 1999b).

Zone	Average area ('000ha)	Average yield (t/ha)	Average production (kt)
NSW Central	3.3	0.7	2.4
NSW Vic Slopes	0.8	0.4	0.3
Vic High Rainfall Tas	1.1	0.6	0.7
SA/Vic Bordertown- Wimmera	13.0	0.8	9.7
SA/Vic Mallee	6.0	0.5	3.6
SA Midnorth-Lower Yorke, Eyre	0.9	0.6	0.5

Major safflower production areas in southern Australia are SA VIC Bordertown-Wimmera zone followed by NSW Central zone and SA Vic Mallee zone (Figure 1). Safflower is produced in other zones but the areas are very small (Table 1). Average annual rainfall in the SA VIC Bordertown-Wimmera Zone is approximately 350mm, in NSW Central zone it is approximately 600mm and in the SA Vic Mallee zone it is around 300mm.

Currently the most commonly grown safflower variety is Sironaria, which was developed by the CSIRO and released in 1987. Although more recent lines have been introduced from the United States and marketed under the name Saffola, there are anecdotal reports that they do not yield as well as Sironaria. These imported lines have been introduced to meet a market demand for high oleic acid gift oils for the Japanese market.

Current reasons for growers to produce safflower

A survey was undertaken by Wachsmann et al. (2001) to establish prevailing reasons why growers are incorporating safflower in their cropping rotations in southern Australia. Forty-one completed surveys were returned from 150 safflower growers. It was established that growers incorporated safflower into cropping rotations to control weeds (39%), spread sowing and harvesting work loads (22%), break cereal disease cycles (20%), water use (15%), financial gain (15%) and to open soil with roots (12%). Several growers used safflower strategically in rotations specifically to control herbicide resistant weeds (10%) or to dry soil profiles for subsequent crops (10%). In drier environments, safflower was sometimes sown as the final rotation species before fallow or pasture, as excess water use resulted in poor subsequent crops. Thirty-nine percent of respondents mainly sowed safflower in spring if winter conditions became untrafficable, preventing the sowing of winter crop species. Two growers planted safflower for the first time last year to replace pulse crops that failed due to disease during winter. A further two growers only planted safflower as a cover crop for lucerne (alfalfa) establishment.

Changing farming systems in southern Australia and the role of safflower

During the 1990's southern Australia has witnessed a trend towards more continuous cropping. This change has driven a search for more diversity in the crop species available to producers. The need for more crop options has been demonstrated by the rapid adoption of the new crop canola, which occurred during this time, facilitated by varieties resistant to blackleg and improved agronomy. By the late 1990's, canola had become a major crop for farmers in southern Australia, and the area sown is 46% of the non-cereal component of the rotation (Salisbury et al. 1999).

Additionally, the move to more continuous cropping has lead to an increasing reliance on herbicides to control weeds and the consequent problem of herbicide resistance (to selective herbicides). One method to help overcome this problem is to sow winter crops later, and use 'knockdown' herbicides and cultivation to control resistant weeds before sowing. These late sown crops are likely to be lower yielding than earlier sown crops, especially in drier environments, and safflower may provide a more profitable alternative.

Other changes emerging in southern Australia include declining terms of trade for grazing industries, which fuel an increase in cropping in areas of the cool climate, high rainfall area of south west Victoria. New farming systems are being developed to address the significant limitations that waterlogging present in these areas. The combination of high rainfall through the winter months with low subsoil permeability results in the root zone of crops becoming saturated for long periods. An innovative farmer group in southern Victoria is developing new cropping systems with raised beds throughout the paddocks (fields) to allow for excess water to flow off the paddock during the growing season, thereby reducing waterlogging of soils. This system is promising, but further research is required to identify crops adapted to such a system. Safflower production after the beds are formed in spring may capitalise on winter and spring rainfall.

Safflower is commonly planted during spring in low lying areas of clay soils prone to waterlogging where farmers are unable to sow crops during autumn or there has been a crop failure during winter. Periodic waterlogging is also a significant problem on duplex and heavy clay soil types throughout NE Victoria and Southern NSW. Successful safflower production in these situations depends on the selection of appropriate sowing times and varieties to utilise water. Sowing time will affect the leaf area available for transpiration during periods of high vapour pressure deficit during summer. There could be potential for soil profile dewatering in these areas, however little is known about the dewatering benefits that safflower may provide to following crops.

Sodic soils (ESP > 6%) occur extensively on the agricultural lands of Australia. This is an area of research of growing interest in southern Australia and sodicity is a key abiotic constraint identified in problem 'hostile subsoils'. The poor crop productivity of sodic soils is often associated with their low infiltration rates and restricted drainage. In such soils, particularly those sodic at depth, crops with a strongly ramified root system could be used for biological soil loosening, which would lead to deep soil profile draining (Jayawardane and Chan, 1994). This would break up hard-pans in soil profiles and provide macropores for subsequent crops. Subsequent crops would benefit from the improved drainage and aeration and the pores may also help in moving applied gypsum down the soil profile. Safflower, being a tap- rooted crop, may have a role to play in ameliorating these soil types.

Root lesion nematodes are present in a wide range of soil types in southeastern Australian cropping areas. There are two species of Pratylenchus (*P.thornei* and *P.neglectus*), and both species are found in a range of soil types and are often found together. There is currently a lack of break crops for areas affected by *Pratylenchus spp*, because crops, which are moderately resistant to one species, can be a host for the other eg. canola (Hollaway et al., 1998). Current research in Victoria and South Australia involves assessing field crop varieties for resistance and tolerance to *Pratylenchus spp*. Preliminary results have shown safflower to be resistant to both species.

Current research

The major aim of a current research project underway at the University of Melbourne, funded by the Grains Research and Development Corporation, is to evaluate the potential roles for safflower in southern Australian cropping systems. The objective is to provide agronomic information to support the production of safflower as a 'tactical' crop to address the emerging challenges in Australia's southern region cropping systems.

At present growers have a limited number of cultivars available to them: Sironaria is related to and is agronomically similar to Gila, which was introduced from Arizona over thirty-eight years ago (Harrigan and Sykes, 1987). Horowitz and Beech (1974) proposed that earlier maturity and drought escape during flowering and grain filling in southern areas would require photoperiod-insensitive cultivars that mature at the same time as wheat. This project will evaluate a range of lines accessed from overseas collections and private organisations (Wachsmann et al., these proceedings).

The lines will be evaluated in terms of the proposed tactical roles that they might play in the changing farming systems of southern Australia described in the previous section. Investigations will be carried out to determine their phenology and water use and any rotational effects that they might have on ensuing crops. Interestingly, the dewatering potential of safflower was an area of research identified for future research by Ken Harrigan, the CSIRO safflower breeder, before his retirement in 1987 (Harrigan and Barrs, 1984).

Another aspect of this work is to investigate the environmental effects on oil content and fatty acid composition, with particular interest in developing high oleic acid safflower cultivars.

CONCLUSION

Although safflower is a minor crop in southern Australia and often grown on an opportunity basis, it is possible that the crop may have more of a tactical role in these faming systems. It may have a role where cropping is extending into high rainfall, waterlogging-prone environments and also low-lying clay soils prone to waterlogging. Safflower could be utilised as a late sown crop option to enable control of herbicide resistant weeds. It may aid in ameliorating hostile soils, in particular sodic and saline subsoils and it may provide an additional break crop, especially in areas affected by *Pratylenchus spp*. To address some of these issues, a project is underway at the University of Melbourne in the Wimmera region. Improved agronomic information, together with information on imported safflower varieties adapted to specific growing conditions in the southern region of Australia could result in a yield increase and greater returns to farmers.

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A Computer Program[z] to Assist Safflower Producers

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ABSTRACT

A computer program entitled "Crop Sequence Calculator" is designed by USDA Agricultural Research Service (ARS) scientists to help assess crop production and the potential returns of growing safflower (*Carthamus tinctorius* L.) in a diverse cropping system rotated with other crops. The program can calculate the expected yield of ten crops grown in any two-year combination. Expected crop prices and expected loan deficiency payments (LDP) can be entered to provide rapid calculation of potential returns. The program contains information on crop production, plant diseases, weeds, crop water use, and surface soil properties to aid producers in their evaluation of management risks associated with different crop sequences. Information is only applicable to the Northern Great Plains with precipitation averaging less than 17 inches (43 cm), annually.

Key words: computer program, crop production, assessment, *Carthamus tinctorius* L.

INTRODUCTION

The semi-arid environment of the Northern Great Plains has placed greater emphasis on the retention of crop residues on the soil surface, thereby increasing water storage and minimizing soil erosion (Peterson et al., 1996). Improved methods of soil water storage have led to the development of more intensive cropping systems than the alternate crop-fallow system (Greb, 1983; Tanaka and Anderson, 1997). With the adoption of conservation or reduced tillage systems, annual cropping, which includes alternative crops such as oilseeds, pulses, and forages, has become a viable option for producers. The influence of the previous crop and crop residues on crop production, plant diseases, weeds, residue persistence for erosion control and soil quality need to be more fully understood in order to develop effective crop sequences for diverse cropping systems. A project was established in 1998 to determine the benefits and/or disadvantages of previous crop and crop residues in diverse cropping systems. A multi-disciplinary team of scientists is conducting a research project with early- and late-season grass and broad leaf crops. The team is evaluating the components of crop production, crop residue, root growth, crop-water use, soil quality, plant disease, weeds, and economics to develop guidelines for long-term diversified crop production systems and to provide producers with a flexible method (management tools) for developing their own cropping systems. After ARS scientists were asked by users of ARS research technology to make research results available in a more timely manner, researchers took the initiative to produce a computer program to transfer research data. The objective of this paper is not to present research results from the research project itself but rather to present an innovative way to transfer research technology to producers in a timely manner for assessing crop production in a diverse cropping system.

MATERIALS AND METHODS

A computer program entitled "Crop Sequence Calculator" is based on a research project being conducted at the Area IV Soil Conservation Districts/Agricultural Research Service Research Farm near the Northern Great Plains Research Laboratory, southwest of Mandan, North Dakota, USA. The

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soil is a Temvik-Wilton silt loam (Fine-silty, Mixed Typic and Pachic Haploboralls). A crop X crop residue matrix is formed so that ten crops can be seeded into the crop residue of the same ten crops (Figure 1). During the first year, ten crops (barley [*Hordeum vulgare* L.], bean [*Phaseolus vulgaris* L.], canola [*Brassica napus* L.], crambe [*Crambe abyssinica* Hochst. ex R.E. Fr.], flax [*Linum usitatissimum* L.], pea [*Pisum sativum* L.], safflower [*Carthamus tinctorius* L.], soybean [*Glycine max* (L.) Merr.], sunflower [*Helianthus annuus L.*], and wheat [*Triticum aestivum* L.]) are no-till seeded in strips (9 m wide) with a no-till drill into a uniform cereal residue. During the second year, the same crops are seeded no-till perpendicular over the residue of the previous year's crop. This is repeated so the crop X crop residue matrix is present in the field for two consecutive years. Ten crops (barley, canola, crambe, dry pea, dry bean, flax, safflower, soybean, sunflower, and spring wheat) are seeded in a strip-block design with four replicates. This establishes a 10 X 10 matrix with 100 treatment combinations, where each crop is grown on ten crop residues (Figure 1). Each experimental unit is a 9 X 9-m plot. The ten cultivars are: 'Montola 2000' safflower, 'Stander' barley, 'Dynamite' canola, 'Meyer' crambe, 'Shadow' Black Turtle dry bean, 'Profi' dry pea, 'Omega' flax, 'Jim' soybean, 'Cenex 803' oilseed sunflower, and 'Amidon' spring wheat.

1999

2000

Replicate 1

709	719	729	739	749	759	769	779	789	799	6
708	718	728	738	748	758	768	778	788	798	2
707	717	727	737	747	757	767	777	787	797	5
706	716	726	736	746	756	766	776	786	796	10
705	715	725	735	745	755	765	775	785	795	8
704	714	724	734	744	754	764	774	784	794	7
703	713	723	733	743	753	763	773	783	793	3
702	712	722	732	742	752	762	772	782	792	9
701	711	721	731	741	751	761	771	781	791	1
700	710	720	730	740	750	760	770	780	790	4
6	8	4	9	2	7	3	5	1	10	

2000 Crops

Replicate 2

809	819	829	839	849	859	869	879	889	899	1
808	818	828	838	848	858	868	878	888	898	2
807	817	827	837	847	857	867	877	887	897	5
806	816	826	836	846	856	866	876	886	896	9
805	815	825	835	845	855	865	875	885	895	7
804	814	824	834	844	854	864	874	884	894	10
803	813	823	833	843	853	863	873	883	893	6
802	812	822	832	842	852	862	872	882	892	3
801	811	821	831	841	851	861	871	881	891	4
800	810	820	830	840	850	860	870	880	890	8
5	2	7	1	8	4	6	9	3	10	

2000 Crops

Fig. 1. The crop X crop residue matrix used to evaluate the influence of crop sequence on crop production. During the first year (1999), ten crops are no-till seeded into uniform cereal residue. During the second year (2000) the same crops are no-till seeded perpendicular over the residue of the previous year's crop. Individual plot numbers are assigned for each replication.

Replicate 3

509	519	529	539	549	559	569	579	589	599	8
508	518	528	538	548	558	568	578	588	598	10
507	517	527	537	547	557	567	577	587	597	1
506	516	526	536	546	556	566	576	586	596	4
505	515	525	535	545	555	565	575	585	595	5
504	514	524	534	544	554	564	574	584	594	2
503	513	523	533	543	553	563	573	583	593	9
502	512	522	532	542	552	562	572	582	592	7
501	511	521	531	541	551	561	571	581	591	6
500	510	520	530	540	550	560	570	580	590	3
3	9	7	6	10	2	5	4	1	8	

2000 Crops

Replicate 4

609	619	629	639	649	659	669	679	689	699	7
608	618	628	638	648	658	668	678	688	698	8
607	617	627	637	647	657	667	677	687	697	10
606	616	626	636	646	656	666	676	686	696	5
605	615	625	635	645	655	665	675	685	695	1
604	614	624	634	644	654	664	674	684	694	9
603	613	623	633	643	653	663	673	683	693	4
602	612	622	632	642	652	662	672	682	692	3
601	611	621	631	641	651	661	671	681	691	6
600	610	620	630	640	650	660	670	680	690	2
9	1	2	10	3	6	8	4	5	7	

2000 Crops

CROPS SEEDED:

1) **Canola** – Dynamite
2) **Crambe** – Meyer
3) **Dry Bean** – T-39 (1999), Shadow (2000)
4) **Dry Pea** – Profi
5) **Flax** – Omega
6) **Safflower** – Montola 2000
7) **Soybean** – Jim
8) **Sunflower** – Cenex 803
9) **Wheat** – Amidon
10) **Barley** – Stander

Various types of research data are obtained from the crop X crop residue matrix for inclusion in the Crop Sequence Calculator. Crop yield and residue production are measured. Concentrations of nitrogen and phosphorus in seed and residue are determined. Root growth of crops is measured. Soil-surface residue coverage is determined. The impact of the ten crops on weed populations is evaluated. Spring wheat and barley crops are evaluated for foliar diseases. Sunflower, canola, crambe, and safflower crops are evaluated for sclerotinia disease (white mold; *Sclerotinia sclerotiorum* (Lib.) De Bary). A standard set of soil quality indicators are measured in treatments where the same crop was planted in consecutive years. Crop, weed, plant disease and soil data are used to assess the management impact and predictability of crop production.

RESULTS AND DISCUSSION

The Crop Sequence Calculator is a user-friendly program that runs directly from a CD-ROM eliminating the need for additional disk space or installation procedures. The program is designed for computers running Windows® (3.1/95/98/ME/NT/2000) and works best with a screen area of 800 X 600 pixels or greater. The program contains information on crop production, plant diseases, weeds, crop water use, and surface soil properties to aid producers in their evaluation of management risks associated with different crop sequences. Once the previous crop (residue producing crop) and the expected crop are entered with a click of the mouse, summary statements appear with information on crop production, plant diseases, weeds, crop water use, and surface soil properties. By selecting the "More Info" buttons adjacent to each summary statement, graphs, photos, and additional information is easily accessed, which is usually not readily available in a single resource. For example, numerous photographs of weeds are included to aid in their identification. Additional information concerning plant diseases includes an introduction to plant diseases, information on the plant disease triangle and management for plant disease risks, websites for plant disease information, and photographs of plant diseases to aid in their identification.

The program is designed to help producers assess safflower production and the potential returns of growing safflower as a component in a diverse cropping system rotated with other crops. For example, safflower crop production was best following barley and worst following safflower in 1999. The program can calculate the expected yield of ten crops (barley, canola, crambe, dry pea, dry bean, flax, safflower, soybean, sunflower, and spring wheat) grown in any two-year combination. Expected crop prices and expected loan deficiency payments (LDP) can be entered to provide rapid calculations of potential returns. Information is only applicable to the northern Great Plains with precipitation averaging less than 43 cm (17 in), annually.

Since its release in mid-January, 2001, over 2000 copies of the Crop Sequence Calculator have been distributed (as of June, 2001). The number of requests for this CD-ROM demonstrates this program fulfills a need for user-friendly technology transfer. In addition to its acceptance by producers, it has also been accepted by commodity groups. For example, the National Sunflower Association promoted the Crop Sequence Calculator in The Sunflower Magazine (Anon., 2001). Additional copies have been requested by other commodity groups, extension and National Research Conservation Service personnel, seed companies, banks, and other researchers.

Copies of the Crop Sequence Calculator can be easily obtained from: Crop Sequence Calculator, Northern Great Plains Research Laboratory, Agricultural Research Service-USDA, Box 459, Mandan, North Dakota 58554-0459; Phone: 701-667-3000 or 701-667-3001; FAX: 701-667-3054; or ordered from the ARS website: www.mandan.ars.usda.gov. A preprinted postcard is supplied with the CD-ROM to encourage users to register their copy. When a new version of the program is produced registered users will receive an upgraded copy.

ACKNOWLEDGEMENT

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Contribution of Production Factors on Yield of Safflower Under Rainfed Conditions

V. S. Kubsad, C. P. Mallapur, and C. P. Mansur[1]

ABSTRACT

An experiment was conducted at Agricultural Research Station, Annigeri during *Rabi* 1996 to 1998 to know the contribution of production factors to the yield of rainfed safflower. The pooled results indicated that adoption of full package of the use of recommended fertilizers, adaptation of timely thinning, weeding and pest control recorded significantly improved seed yield (1558 kg/ha), oil yield (442 kg/ha), net returns (Rs. 12087/ha) and B:C ratio (2.88) compared to poor management practices. The lack of thinning, weed control, fertilizer application and pest control reduced the safflower yield to 16, 28, 29 and 58 percent respectively over full package. The effect of production factors was not significant on oil content of safflower. Among the production factors, pest control component was found to be most critical.

Key words: Contribution, Production factors, Constraints, Safflower

INTRODUCTION

Safflower is one of the important *rabi* oil seed crops in India occupying an area of 7.04 land hectares with a production of 4.30 million tones (Damodaram and Hegde, 1999). Since the crop is being cultivated on available moisture and/or rainfed conditions under poor management practices the crop productivity is low (733 kg/ha) in India compared to 2604 kg/ha in U.S.A. and 2126 kg/ha in China (Reddy, et al., 1996). Safflower requires adequate supply of nutrients for its full production potential even under limiting moisture conditions (Rao, 1985). The full production potentiality of the crop can be exploited only under good management practices. The yield levels obtained at research farms are an indication that the productivity can be increased to a great extent if proper technology is used. It was however known that farmers are unable to adopt the entire package as per recommendation due to certain difficulties, sometimes beyond their control. Hence the present investigation was under taken to assess the relative efficiency of component production technology (use of recommended fertilizer, adoption of thinning, weeding and pest control) so as to identify them in order of economic importance for increasing the yield and returns.

MATERIALS AND METHODS

The experiment was conducted during *rabi* 1996-97 and 1998-99 at Agricultural Research Station, Annigeri (Karnataka) under rainfed conditions. The soil of the experimental site was deep black (vertisols) with 8.1 pH, having low available N (251 kg/ha), medium in P_2O_5 (14 kg/ha) and high in K_2O (754 kg/ha). The experiment was laid out in randomized block design with three replications. The total rainfall received was 1190 mm during 1996 and 649 mm during 1998. The safflower cultivar A-1 was drill sown on 12th October 1996 and 24th October 1998 at a row spacing of 45cm and 20 cm between plants and fertilized with 40-40-20 kg NPK/ha (fertilizer component) at sowing. The thinning (thinning component) was done at 15 days after sowing (DAS) to have a required plant population of 1,111,111 / ha. One hand weeding and three intercultivations (weed control component) were done to control the weeds. The crop was dusted with melathion @ 25 kg/ha, sprayed with Nuvacron @ 2 ml/l

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and Rogor @ 1.7 ml/l (pest control component) for the control of leaf eating caterpillars, aphids and heliothis pests. The full package [FP] treatment included all these four production components viz., fertilizer [F], thinning [T], weed control [W], pest control [P] and other plots received the production components as per the treatments, viz., FP- F means full package without fertilizer, FP- [F+P+W+T] means full package without fertilizer, thinning, weed control and pest control] etc. At harvesting, five plants were randomly selected from each treatment for recording the data of growth and yield components. The crop was harvested on 12th March 1997 and 6th April 1999. The net plot yields were recorded and economics of each practice on hectare basis was calculated and statistically analysed. During 1997-98, the experiment was invalidated due to the severe incidence of *Alternaria* and *Cercospora* foliar diseases.

RESULTS AND DISCUSSION

Seed and oil yield

The results indicated that the seed yield and oil yield differed significantly due to different production factors, while the oil content was not significantly affected (Table-1). The seed and oil yield during 1996 were lower compared to 1998 due to excess rains received during the cropping season, which might have hindered the crop growth due to disease. When averaged over year's results indicated that the adoption of full package recorded significantly higher seed yield (1558 kg/ha) (Table-1) over the rest of the treatment variables. Among the different production factors, the treatment without pest control resulted in significantly reduced seed yield (655 kg/ha) compared to other production factor like thinning (1313 kg/ha), weed control (1109 kg/ha) and fertilizer (1108 kg/ha). This indicated that, the plant protection was an important critical input and agrees with the beneficial effects of plant protection were reported by Reddy and Rastogi [1985] in safflower under dryland conditions. The plot that did not recline any of the improved production factors had a yield of 318 kg/ha (80% less than full package). The same trend was observed in both the years. The effect of production factors either individually or in combination was not significant on seed oil content. Nevertheless, the oil yield was significantly influenced (Table 1) and the full package recorded significantly higher oil yield (442 kg/ha) and the plot without any production factors recorded significantly lower oil yield (90 kg/ha) over other production factors (Table 1). The higher oil yield during 1998 was due to higher seed oil content and seed yield compared to 1996.

Economics

The gross returns and net returns were significantly affected by different production factors during both the years (Table 2). The gross returns and net returns were higher during 1998 compared to 1996

Table 1. Seed yield, oil content and oil yield of safflower as influenced by production factors.

Sl. No.	Treatments	Seed yield (kg/ha)			% Yield reduction over FP	Oil content (%)			Oil yield (kg/ha)		
		1996	1998	Pooled		1996	1998	Pooled	1996	1998	Pooled
1.	Full package [FP]	1326	1791	1558	-	28.1	28.5	28.3	372	511	442
2.	FP- Fertilizer [F]	934	1281	1108	29	27.6	28.5	28.1	257	365	311
3.	FP- Thinning [T]	1078	1547	1313	16	27.4	28.4	27.9	295	439	367
4.	FP- Plant protection [P]	461	939	655	58	27.4	28.5	27.9	126	267	197
5.	FP- Weed control [W]	907	1309	1109	28	27.7	28.4	28.1	251	371	311
6.	FP- [F + P]	319	468	393	75	27.3	28.4	27.9	87	133	110
7.	FP- [W + T]	886	1119	1003	36	27.6	28.3	27.9	245	318	282
8.	FP- [F+P+W+T]	285	351	318	80	27.9	28.4	28.2	79	100	90
	C.D.(5%)	184	228	214	-	N.S.	N.S.	N.S.	60	63	61

N.S. - Non significant

Table 2. Economics of safflower as influenced by production factors.

Sl. No. Treatments	Gross returns (Rs/ha)			Net returns (Rs/ha)			B : C ratio		
	1996	1998	Pooled	1996	1998	Pooled	1996	1998	Pooled
1. Full package [FP]	13260	23288	18272	7270	16719	12087	2.21	3.54	2.88
2. FP- Fertilizer [F]	9340	16657	12997	2385	11131	7758	1.88	3.02	2.46
3. FP- Thinning [T]	10780	20110	15445	5190	13941	9563	1.93	3.26	2.60
4. FP- Plant protection [P]	4610	12202	8408	820	6754	3622	0.85	2.24	1.55
5. FP- Weed control [W]	9070	17014	13046	3680	11049	7368	1.68	2.85	2.27
6. FP- [F + P]	3190	6092	4368	1205	1686	991	0.72	1.38	1.06
7. FP- [W + T]	8860	14552	11868	3870	8986	6590	1.77	2.61	2.20
8. FP- [F+P+W+T]	2850	4561	3702	545	1150	850	0.84	1.34	1.09
C.D.(5%)	1967	2918	2387	1967	2918	2388	-	-	-

Market prices for safflower [Rs/q] : 1996 - 1000, 1998 - 1300

due to higher market prices (Rs. 1300/q and Rs. 1000/q respectively). The average data indicated that the gross returns followed a similar trend to seed yield. Significantly higher net returns of Rs. 12087/ha and lower net returns of Rs. 3622/ha were recorded for full package and without pest control treatment respectively compared to other production factors. Furthermore, the plot devoid of all the production factors recorded the lowest net returns and B:C ratio of Rs. 850/ha and 1.09 respectively. The plot with full package recorded highest B:C ratio of 2.88 (Table 2). The results were in conformity with the findings of Reddy (1986). A similar trend was observed during both the years.

Thus it may be concluded that the pest control component was the most important constraint limiting yield at this location and thus needs to be applied whenever necessary to avoid yield and monetary losses. Thinning, being a non-cash input could also be adopted at 15 DAS.

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Safflower Root Growth and Water Use in Comparison with Other Crops

S. D. Merrill[1], D. L. Tanaka, J. M. Krupinsky, and R. E. Ries

ABSTRACT

Root growth of safflower was studied with a minirhizotron-microvideo system in field studies conducted on Typic and Pachic Haploborolls. The system consists of clear plastic tubes, 2- or 3-m long, installed in the field and read with a miniature video camera that magnifies images. Root growth was measured for two years in Study 1 with three seeding date treatments. The average median depth (half of total root length above, half below) observed at root growth maximum was 1.02 m, and average maximum depth was 1.65 m. In Study 2, median and maximum root growth depths of safflower were found to be greater than those of seven other crops: dry bean (Phaseolus vulgarus L.); dry pea (Pisum sativum L.); soybean (Glycine max (L.) Merr.), canola (Brassica rapa), crambe (Crambe abysinnica), spring wheat (Triticum aestivum L.), and sunflower (Helianthus anuus L.). Average median depths at dates of greatest root growth for 1995, 1996, and 1997 were 1.09, 0.75, and 0.90 m, respectively; greatest maximum depths were 1.77, 1.52, and 1.64 m, respectively. Soil water depletion measured by a neutron moisture meter was added to seasonal precipitation to quantify water use. Of the seven crops observed in Study 2, only sunflower had greater water use than safflower during the three years. Measurements of water use by 10 crops in Study 3 confirmed that sunflower was the greatest water user and that safflower was the second greatest, and both crops were shown to withdraw from 3 cm to greater than 10 cm more water than did other crops. Safflower, with its taproot-organized root growth system, is the most deeply rooted of the crops commonly grown in the Northern Great Plains, and has the capability of extracting subsoil water at greater depths than all other crops studied.

Key words: root growth, water use, *Carthamus tinctorius* L.

INTRODUCTION

There is generally less information about the belowground growth and activity of safflower in comparison to major world crops. Knowles (1958) cites observations of safflower root growth to 2-m depth. Bergman et al. (1979) give the range of field observations of maximum safflower rooting under Northern Great Plains conditions as 2.0 to 2.2 m. Alessi et al. (1981) measured soil water extraction to a depth of 1.5 m by safflower in North Dakota.

Clear, plastic tubes, known as minirhizotrons, installed in the field are used to study rhizosphere growth dynamics (Taylor, 1987). One of the most functional versions of this methodology is the use of a miniaturized video camera to record observations from minirhizotrons for subsequent analysis (Upchurch and Ritchie, 1984).

Production Management

METHODS

Root growth of safflower and other crops were observed with a minirhizotron-microvideo system. Roots growing against minirhizotron walls were observed with a microvideo camera fitted with viewing optics that magnifies approx. 15-fold. Two types of minirhizotrons were used. Standard type minirhizotrons were of durable, clear plastic, 5.6 cm in diameter and 2 m in length, and were forced into access holes that were slightly lesser in diameter than the minirhizotrons. Pressurized-wall minirhizotrons (Merrill, 1992) were 9.6-cm in diameter and 2- or 3-m in length, and each had a flexible

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outer wall kept under constant, low air pressure that was concentric with a clear, acrylic plastic inner wall. Pressurized-wall minirhizotrons could better maintain soil-wall contact as soil wetted and dried and should have reduced compaction and soil smearing at the wall. Standard minirhizotrons offered clearer viewing. All minirhizotrons were installed in the soil at a 30-degree angle with respect to the vertical. The length of roots in a video image was estimated by intersections with lines, and these values were converted to bulk soil root length density through a theoretical conversion algorithm (Merrill and Upchurch, 1994). The conversion algorithm has been validated by comparisons in four, independent field studies of minirhizotron observations with direct determinations of roots extracted from samples (Merrill and Upchurch, 1994).

Field studies were conducted at the Area IV SCD - ARS Cooperative Research Farm, located near the Northern Great Plains Research Laboratory, Mandan, North Dakota. The predominant soil type was Temvik-Wilton silt loam (fine silty, mixed Typic and Pachic Haploborolls). In Study 1, conducted in 1992 and 1993, safflower was grown under minimal tillage with three planting date treatments. Root growth observations were made in two replications of this study, in non-fertilized plots, with four minirhizotrons per replicate plot (8 total). In Study 2, conducted in 1995 through 1997, root growth observations were conducted on safflower and six other crops (dry pea, soybean, canola, crambe, and sunflower), which were grown in strips under no-till cultural practices with 54 kg N ha^{-1} and 9 kg P ha^{-1} fertilization. Four minirhizotrons were installed in each of two replicate crop treatment plots (8 total), while in 1997; six minirhizotrons per replicate plot were installed (12 total). Minirhizotrons (8 total) were installed in spring wheat on land fallowed the previous year for comparison. Soil water content was measured in Study 2 on three replicates using a neutron moisture meter.

Study 3 consisted of the eight crops listed above with the addition of flax and barley. Crops were grown in strips under no-till culture. Soil water measurements were taken in 1999 and 2000 in four replicate plots of each crop. Water content measurements were in 0.15-m depth increments for the uppermost two increments, and then in successive 0.3-m increments to a depth of 2.4 m. Three types of soil and crop water usage parameters were calculated: (a) water use consisted of soil water depletion and precipitation both measured between times of seeding and harvest for a given crop; (b) comparative water use – like water use, but with the same precipitation amount for all crops taken approx. from last seeding to first harvest; (c) full season soil water depletion – same for all crops, taken from May to October.

RESULTS AND DISCUSSION

Successive profiles of safflower root length density measured in the first planting date treatment in 1992 and 1993 are displayed in Fig. 1. The root system reached its greatest depth by late July or early August. The earliest planting starts to show root disappearance by August (as in 1992), or for the later plantings, by September. Growing season precipitation in 1992 over the 4-month period May-August was 261 mm, near the 4-month, long-term average of 242 mm, but 1993 May-August precipitation of 572 mm was considerably above the average. Excess precipitation prevented root growth measurements during August 1993. Safflower shows the ability to proliferate fine root growth in subsoil at depths exceeding one meter (Fig. 1). It is evident that safflower root decay was not as great during the wet year (1993) as compared to an average year (1992), in which the fine root mass, which dominates minirhizotron-viewed roots, exhibited large-scale apparent decay.

The ratios of median root length growth depths range from approx. 0.5 to over 0.6 (Table 1). In general, median-to-maximum ratios were greater in Study 1 than values measured in Study 2. The seeding date treatment did not appear to have any apparent effect on summary rooting depth parameters (Table 1). Excess precipitation, which would presumably raise subsoil water availability, did have an apparent effect on maximum rooting depth. The average maximum value (1.72 m) in the wet year (1993) was greater than the average maximum (1.58 m) in a normal year (1992). Also, the maximum

Table 1. Median and maximum depths of safflower root growth, ratio of median to maximum, biomass yield, precipitation and agronomic information for Study 1 and Study 2. Long-term May-to-Aug. (4 mo.) mean precipitation is 242 mm. Cultivar: C = Centennial; M = Montola 2000.

Year, Seeding Date	Median Depth	Median Maximum Depth	Above to Max. ratio	Ground Biomass	Cultivar	May to Aug. Precip.	Seed Date	Harvest Date
	------ m ------			kg.ha^{-1}		mm		
1992 1st	0.963	1.630	0.591	11,350	C		24 Apr	05 Oct
2nd	1.046	1.565	0.668	11,290	C		05 May	06 Oct
3rd	0.892	1.544	0.578	11,240	C		18 May	14 Oct
1992 Avg	0.967	1.580	0.612	11,290		261		
1993 1st	1.003	1.738	0.577	10,060	C		11 May	28 Oct
2nd	1.078	1.760	0.613	8,820	C		19 May	28 Oct
3rd	1.116	1.652	0.676	9,530	C		02 Jun	28 Oct
1993 Avg	1.066	1.717	0.622	9,530		572		
1995	1.086	1.765	0.615	5,020	M & C	434	30 May	20 Sep
1996	0.745	1.516	0.491	3,020	C	267	29 Apr	10 Sep
1997	0.898	1.646	0.546	7,000	C	181	12 May	18 Sep
5-yr Avg	0.952	1.645	0.577					

depth observed (1.77 m) in wetter than average 1995 was greater than that observed (1.52 m) in an average year (1996), and was also greater than the depth observed (1.65 m) in a relatively dry year (1997).

Safflower is the deepest rooted of the crops in Study 2 (Fig. 2). The maximum and median depths show that safflower root length growth occurred, on average, at consistently greater soil depths than did sunflower root growth.

The observations of maximum safflower rooting depths have been confirmed by direct observations made at a trench wall during Study 1 using the so-called trench profile procedure (Bohm,

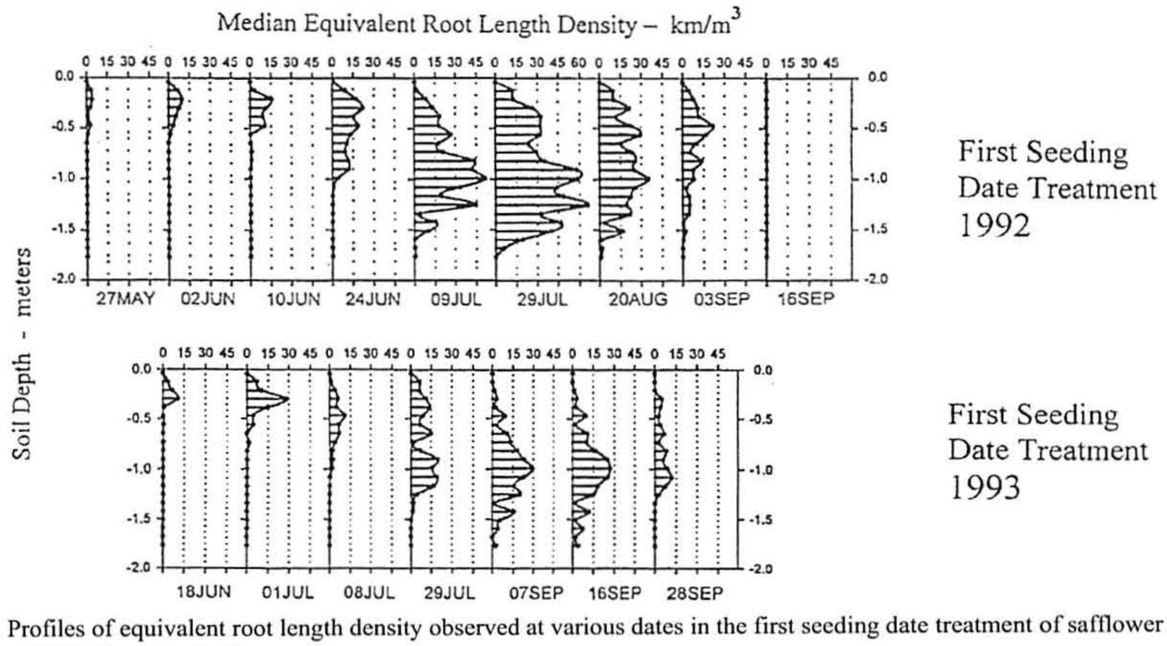

Fig. 1. Profiles of equivalent root length density observed at various dates in the first seeding date treatment of safflower in 1992 and 1993 (from Study 1).

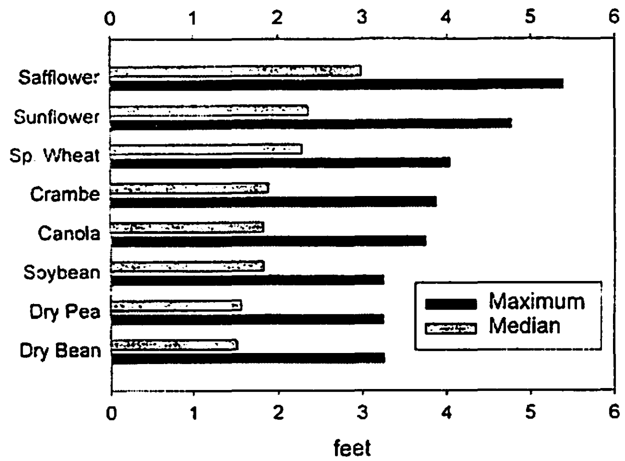

Fig. 2. Average median and maximum depths of root length growth observed 1995 through 1997 at dates of greatest root system extension for alternative crops (from Study 2).

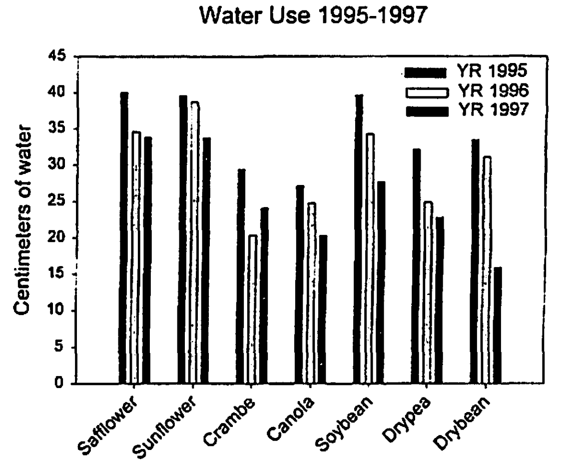

Fig. 3. Water use measured for alternative crops during 1995 through 1997 (from Study 2.

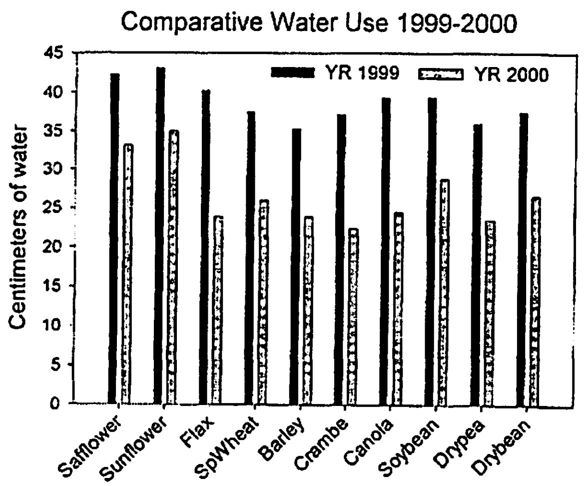

Fig. 4. Comparative water use measured for alternative crops during 1999 and 2000 (from Study 3).

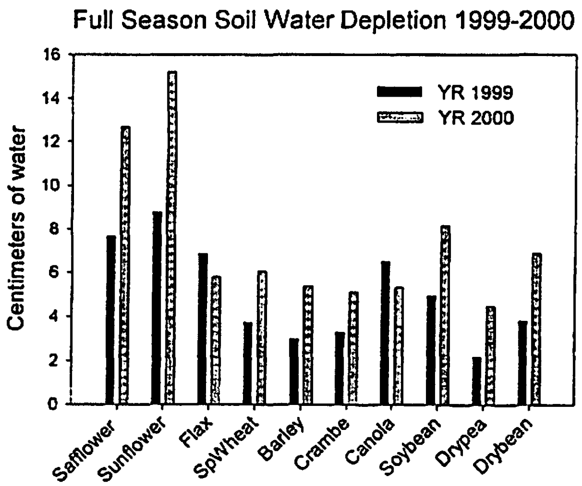

Fig. 5. Full season (May through October) soil water depletion measured for alternative crops during 1999 and 2000 (from Study 3).

1979). Merrill et al. (1994) reported direct trench observations of safflower rooting at 1.9 m depth. It should be noted that the maximum depth of observation in 3-m long minirhizotrons is approx. 1.8 m.

Both safflower and sunflower consistently use more water than the other crops in Study 2 (Fig. 3). Data indicate that sunflower consistently uses more water than safflower. Although safflower roots have been observed in subsoil deeper than those of sunflower, it is a more xeric plant than sunflower and consequently uses less water. Soybean does not root as deeply and ranks third in water use because of its longer growth season, and its non-xerophytic, relatively leafy growth habit.

Measurements of comparative water use (Fig.4) and full season soil water depletion (Fig. 5) on a set of ten crops during Study 3 consistently confirm the water use results of Study 2: sunflower was shown to be the highest water user, while safflower consistently ranked second. Although soybean ranked third in 2000, flax ranked third in 1999.

Safflower is the deepest-rooted annual crop of those commonly grown in the Northern Great Plains. In the design of diverse cropping systems, safflower can play the role of a water scavenger, and by way of inference, a nitrogen scavenger. If conditions indicate the relative availability of subsoil water, safflower can exploit this water resource, whereas more shallowly rooted crops (see Fig. 2) would be expected to be less able to exploit subsoil water and nitrogen. Safflower is a xeric crop, and does not have high seed yield if late summer humidity is elevated. Our results show that it is moderately thriftier in its water use compared to sunflower — which is shown to be the greatest water user of annual crops commonly grown in the semiarid-subhumid Northern Great Plains. Thus, safflower should perhaps fit in better than sunflower in dryland cropping systems in more semiarid parts of the region.

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Prospects of Safflower as a Minor Oilseed Crop in Bangladesh

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ABSTRACT

Oilseed crops have always been an important segment in Bangladesh agriculture. In the last decade, total production of oilseed crops has increased, but the per capita availability and consumption has declined due to high population pressure. Bangladesh is facing an acute deficit in edible oil. Every year it produces 0.16 million ton of edible oil compared to the consumption of 0.50 million ton. The country has to import oils and oilseeds by expending 160 million US dollar every year. Rapeseed/mustard, sesame and groundnut are the major oilseeds, and safflower, sunflower, linseed, soybean are the minor oilseed crops grown in Bangladesh. Among these, safflower is hardier and more tolerant to drought conditions; with high yield potential (safflower productivity is 25 -30 % higher) compared to other oilseed crops except groundnut. A wide variable of exotic and local lines/varieties were tested in the last decade in the Agricultural Research Organizations. It is clearly indicated that safflower could contribute significantly to meeting the large requirement of oilseed crops in Bangladesh. There is also a great potential to increase safflower area by adopting inter- or mixed cropping with other short duration winter crops like chickpea, lentil, etc.

Key words: Safflower, minor, oilseed, Bangladesh

INTRODUCTION

Oilseeds are the important group of crops in Bangladesh. The bulk of vegetable oil production in Bangladesh is derived from seven oilseed crops viz. mustard, groundnut, sesame, safflower, niger, soybean and sunflower. These crops fall under the edible oilseed group while linseed and castor are in the non-edible group (Table 1).

An acute shortage of edible oil has been prevailing in Bangladesh during the last several years. The total internal oilseed production in the country was only 0.085 million metric tons (mmt) in the year 1981-82, but it increased up to 0.394 mmt in 1997-98 (Mondal 2000). However, in the year 2000, about a 6.0 % increase in the production of oilseeds was observed. Present per capita oil consumption is about 10.6 g per day. Only 3.6 g comes from our internal oilseed production and the rest is imported oil. Major imported oils are soybean, rapeseed and palm oil. Therefore, our oil consumption deficit is about 70 %. To meet the demand, Bangladesh has to import oils and oilseeds at a cost of about 160 million U.S. dollar every year (Mondal, 2000). Thus, there is an urgent need to take immediate actions for increasing oilseed production through growing underutilized and minor oilseeds like safflower. Increased safflower production will reduce the import of oilseeds/oils and help meet our domestic oil requirement.

Area and Production of Different Oilseed Crops

Out of the total cropped area (13.53 million ha), oilseed crops occupy only 0.53 million (m) ha which is only 3.92 % of the total cropped area. In 1997-98 out of total oilseed cropped area, rape seed/mustard occupied 0.344 m ha (65 %), sesame 0.080 m ha (15 %), groundnut 0.035 m ha (6.6 %), linseed 0.07 m ha (13.2 %) and safflower 0.001 m ha (0.19 %) (Table 2).

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Table 1: Sources of edible and non-edible oilseed crops in Bangladesh.

English name	Local name	Scientific name	Remarks
Edible oilseed crops			
1. Turnip rape	Sarisha	*Brassica campestris* L.	Widely cultivated (70-75%)
Indian mustard	Rai Sarisha	*Brassica juncea* Coss.	Covers 20-25% area of mustard
Rape/Rapeseed	Nap Sarisha	*Brassica napus* L.	Prospective
2. Sesame	Til	*Sesamum indicum* L.	Prospective
3. Groundnut	Cheenabadam	*Arachis hypogeae* L.	Prospective
4. Niger	Garzon Til	*Guizotia abyssinica*	Minor oilseed crop (Quality oil)
5. Safflower	Kusumful	*Carthamus tinctorius* L.	Minor oilseed crop (Quality oil)
6. Sunflower	Surjomukhi	*Helianthus annuus* L.	Minor oilseed crop (Quality oil)
7. Soybean	Soybean	*Glycine* max (L) Merril.	Minor oilseed crop (Quality oil)
Non-edible oilseed crops			
8. Linseed	Tishi	*Linum usitatissimum* L.	Industrial oil; 4th in area and production among oilseeds
9. Castor	Bharenda	*Ricinus communis* L.	Industrial oil

The total production of oilseeds of the country stands at 0.394 mmt. Out of total oilseed production, rape seed/mustard produces 0.254 mmt (64.50 %), sesame 0.049 mmt (12.44 %) groundnut 0.04 mmt (10.15 %), linseed 0.050 mmt (12.69 %) and safflower 0.001 mmt (0.25 %). The oilseed crops area is static but the production level is in an increasing trend over time (Table 2).

Table 2. Area (m ha) and production (mmt) of different oilseed crops in Bangladesh from 1993 through 1998 (BBS, 1998).

Oilseed crops	1993-1994		1994-1995		1995-1996		1996-1997		1997-1998	
	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.
Rapeseed/mustard	0.337	0.239	0.337	0.245	0.336	0.246	0.336	0.249	0.344	0.254
Sesame	0.080	0.048	0.080	0.050	0.084	0.049	0.080	0.049	0.080	0.049
Groundnut	0.036	0.041	0.036	0.040	0.036	0.040	0.035	0.040	0.035	0.040
Linseed	0.075	0.048	0.073	0.049	0.070	0.046	0.070	0.050	0.070	0.050
Safflower	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Total	0.529	0.377	0.527	0.385	0.527	0.382	0.522	0.389	0.530	0.394

Yield Gap between Research Plot and Farmer's Field

The Oilseeds Research Center, Bangladesh Agricultural Research Institute; Bangladesh Institute of Nuclear Agriculture and Bangladesh Agricultural University have developed a number of oilseed crop varieties having high yield potential (HYV) with an improved package of management practices. Although the performance of these new varieties of oil crops are very good at research stations their performances in farmers fields were not up to expectations (Table 3).

Table 3. Yield gap in different oilseed crops (Mondal, 2000).

Crops	National average (t/ha)	Potential Yield of HYV (t/ha)
Mustard	0.74	2.40
Sesame	0.63	1.40
Groundnut	1.14	2.75
Sunflower	0.85	2.25
Niger	0.30	1.30
Linseed	0.35	1.25
Safflower	1.00	2.50

Major Cropping Patterns of Safflower

In Bangladesh, the cropping patterns vary with location and land type viz. high, medium and low. In high land as well in medium-high land, the dominant cropping pattern is Jute/Aus-Fallow-safflower. In this pattern, replacing the local variety by HYV safflower with improved management practices can increase the yield. In sugarcane growing areas, safflower can be intercropped with sugarcane. This will help increase the safflower growing areas thereby increasing the total production (Table 4).

Table 4. Major cropping patterns of safflower in Bangladesh.

Kharif - 1 (April - June)	Kharif -11 (July - September)	Rabi Season (October - March)	Remarks
Jute/ Aus rice	Fallow	Safflower	For medium high land areas of Jessore, Kushtia, Rajshahi, Dinajpur, Rangpur, Faridpur, Pabna, Comilla, Jamalpur, Dhaka and Mymensingh districts.
Fallow	T.Aman	Chickpea + Safflower Lentil + safflower	Mixed cropping at Faridpur, Pabna and Rajshahi
Sugarcane + Safflower			Intercropping at Faridpur, Pabna, Rangpur and Thakurgaon districts.

Present Safflower Research Activities

Limited research efforts have been made on safflower. Only 17 exotic lines with a local check were tested at Oilseeds Research Center, Bangladesh Agricultural Research Institute since 1996. Only 4 lines viz. K-1, Saf-1, Syria - 2 and Turk - 6 showed improved performance in respect to yield, days to flowering, and maturity (Table 5). Experiments are underway for selection of suitable varieties.

Table 5: Seed yield, days to flowering and maturity of safflower lines tested at the Oilseed Research Center, Bangladesh Agricultural Research Institute, 1998.

Lines/ Entries	Days to flowering	Days to maturity	Seed yield (t/ha)	**Lines/ Entries**	Days to flowering	Days to maturity	Seed yield (t/ha)
BTC 0951	91	132	1.44	Syria	2 95	141	2.71
BTC 0952	96	131	0.71	Iran	7 96	141	2.29
Thai - 1	97	134	2.00	Syria	3 92	141	2.04
Thai - 2	92	135	2.29	Turk 1	113	142	1.87
S - 12	91	136	1.87	Turk 2	110	150	1.89
K - 1	92	137	2.71	Turk 3	101	144	2.00
Saf - 1	94	138	2.69	Turk 4	94	141	2.64
Lybiya - 1	92	140	2.49	Turk 6	100	144	2.11
Morroc - 1	98	140	1.33	Dhamrai (Local)	102	137	2.40
CV (%)	18.0	20.0	35.0		18.0	20.0	35.0

Safflower Chickpea Mixed Cropping System

Safflower can be successfully grown a mixed crop with chickpea. The mixed crop of chickpea (100 %) with safflower (25 %) recorded the highest chickpea equivalent yield (1.89 t/ha) and benefit cost ratio (BCR) compared to sole chickpea or safflower (Table 6). This combination also gave the highest land equivalent ratio (LER).

Table 6. Equivalent yield, LER and BCR of Chickpea Safflower mixed cropping systems.

Treatment	Chickpea equivalent yield (t/ha)	BCR	LER
Sole chickpea	0.92 d	1.16	1.00
Sole safflower	0.75 d	1.12	1.00
Chickpea (100%) + Safflower (25%)	1.89 a	2.05	2.14
Chickpea (100%) + Safflower (50%)	1.66 b	1.75	1.98
Chickpea (100%) + Safflower (75%)	1.38 c	1.70	1.65
Chickpea alternate with 1 row safflower	1.43 c	1.74	1.70 8

Intercropping Groundnut with Safflower

Two rows of groundnut in between two paired rows of safflower can be grown. In a previous work, the distance between the two-paired rows of safflower was 100 cm. In this space (100 cm) two rows of groundnut were planted. The distance between one row of safflower to the other in each paired row was 50-cm. The seed yield of groundnut and safflower was 1.60 t/ha and 1.35 t/ha, respectively (BARI, 1998).

Constraints of Safflower cultivation

The major constraints of safflower cultivation in Bangladesh are as follows:

Cultivation problems:

1) Safflower is grown in the rabi/winter season so safflower competes for land with major rabi (winter) crops like boro rice, wheat, winter pulses and vegetables, which are widely grown in Bangladesh.
2) Farmers have a problem fitting safflower into existing cropping systems (T. aman rice -
3) Boro rice) because safflower is a long duration crop.
4) Use of traditional low yielding safflower varieties. Seeds of high yielding safflower varieties are not available to the farmers.
5) Insufficient extension education activities. Extension personnel devote their efforts to the major crops like rice, wheat, pulses and major oilseeds like mustard.
6) Cultivation with minimum inputs and low management practices (without irrigation, without or imbalance of plant nutrients and less plant protection measures).
7) As an edible oil, safflower is not very popular although it is good quality oil.
8) Seed increase of safflower is almost absent due to lack of high yielding varieties (HYV) seeds and,
9) Marketing of safflower seeds and oils in the local market is a problem.

Technological constraints:

1) The lack of high yielding varieties suited to existing cropping pattern, particularly those, which could give higher yield under short winter conditions,
2) Shortage of improved farm implements,
3) Lack of low cost technology for the control of pests and diseases and inappropriate post-harvest technology to prevent stored grain pest, and
4) Oil extraction facilities are not well equipped.

Organizational and infra-structural constraints:

1) Inadequate arrangements for production and distribution of quality seeds and supply of other inputs in time like fertilizers, irrigation and credit,

2) Poor technology transfer activities from researcher to farmers,
3) Insufficient seed storage and grading, and
4) Poor marketing coupled with lack of awareness of farmers about safflower.

Socio-economic constraints:

Most Bangladeshi farmers are small and in poor economic condition so they cannot afford to invest in various inputs. Due to the poor crop management, the yield level of safflower is poor. The non-realization of the benefit of improved safflower production technology is therefore attributed to the poor economic condition of the farmers.

Minimizing the Yield Gap

Results of on-farm trials conducted by On-Farm Research Division, Bangladesh Agricultural Research Institute showed that average grain yield of different exotic lines/varieties to be 1.8 - 2.5 t/ha. But the national average yield is only 1.00 t/ha, which is far below the potential yield of safflower. By taking the following steps, this yield gap may be reduced.

1) HYV seeds of safflower should be available to growers for commercial production.
2) Seed multiplication programmes for HYV should be strengthen. Research organizations and Non Government Organization's (NGO's) should be involved in the seed production programme.
3) An extension-training programme is needed to motivate farmers for cultivating HYV safflower with improved management practices. A training programme on oilseeds/safflower for all levels of extension agents needs to be organized.
4) Intensive research based demonstration trials in farmers' fields should be arranged in the different parts of the country, to show the performance of new safflower varieties, particularly in the oilseed crop growing areas.
5) Early maturing T. Aman rice varieties should be cultivated where safflower will be grown.
6) A short duration variety needs to be developed so that it could be easily fitted in the cropping pattern.
7) Yield potentials of promising exotic safflower lines are >2.0 t/ha. So, the traditional varieties need to be replaced with improved varieties to increase production.
8) Cultivation with proper cultural management practices and use of balance fertilizer will help increase yield.
9) Optimum sowing time, application of macro and micronutrients, controlling pest and disease and harvesting at appropriate time will increase production.
10) Increasing safflower cultivation in new areas after harvesting early maturing T. Aman varieties could be expanded in different parts of the country especially in northern and southwestern parts of Bangladesh.
11) Safflower is fairly tolerant to drought and can be introduced in drought prone area of Barind tract (Northwestern part of Bangladesh)
12) A germplasm exchange programme needs to be established with safflower growing countries

CONCLUSION

Safflower is a minor oilseed crop grown in Bangladesh, but it has higher yield potential than the other major oilseed crops. There is a wide scope for yield improvement by adopting HYV varieties. Using mixed and intercropping systems with chickpea, lentil, groundnut and sugarcane could increase the area as well as the yield of safflower. Safflower is fairly tolerant to drought and could be introduced in drought prone areas. Whenever sowing of rape seed/mustard crops are delayed due to late receipt of rains (beyond middle of November), cultivation of safflower in such areas would be more beneficial. Additional research and technology transfer activities could popularize the crop among the farmers. A rapid seed multiplication and distribution programme of high yielding varieties involving Government and non-Government organizations would improve production and ensure credit facilities for the oilseed growers for using required inputs through different banks and other credit giving agencies.

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Weed Control in Safflower in the United States Northern Plains Region

Neil R. Riveland[1]

ABSTRACT

Many herbicides have been tested and evaluated for broadleaf weed control in safflower during 30 years of weed control research conducted at the North Dakota State University Williston Research Extension Center (WREC). Most herbicides tested were rejected because of excessive crop injury, inconsistent weed control or both. Post emergence herbicides that show promise for controlling broadleaf weeds in safflower include the sulfonylurea herbicides chlorsulfuron, thifensulfuron and metsulfuron. Safflower varieties grown in the Northern Plains are quite tolerant to these herbicides but safflower injury can occur at excessive use rates. Thifensulfuron was the least injurious to safflower. Each of these herbicides controlled Russian thistle satisfactorily but kochia was best controlled by chlorsulfuron and metsulfuron. Sethoxydim, quizalofop and clethodim herbicides that control grassy weeds including volunteer cereal grains showed good potential for grassy weed control in safflower.

Key words: Russian thistle, *Salsala iberica*, Kochia, *Kochia scoparia* (L.), Redroot pigweed, *Amaranthus retroflexus* L., Common lambsquarters, *Chenopodium album* L., Safflower, *Carthamus tinctorius* L., weed control.

INTRODUCTION

Safflower (*Carthamus tinctorius*) is adapted to the semi-arid cereal grain production area of the Northern Great Plains (Berglund, et al, 1998). Safflower has been grown commercially in western North Dakota and eastern Montana since the late 1950's when a oilseed processing plant was built by Pacific Vegetable Oils of California at Culbertson, MT. (Smith, 1996). Safflower is a proven alternative cash crop for this area but annual crop production fluctuates, resulting in a variable supply of safflower seed for the oil and birdseed market. Lack of consistent weed control is one of the primary reasons for fluctuating production. Until trifluralin became available for use on safflower in 1966 no pesticides were registered for weed control in this crop (Smith, 1996). Trifluralin is still used widely on safflower and provides consistent grassy weed control but erratic control of some broadleaf weeds such as kochia and Russian thistle. These two broadleaf weed species have been and still are the primary broadleaf weeds in safflower in North Dakota and Montana.

Poor stand establishment also contributes to the fluctuating production and yield in the northern plains region. Since trifluralin is a pre plant incorporated (PPI) herbicide, soil moisture content, depth of incorporation and thoroughness of incorporation affect its ability to control weeds. Tillage required for proper incorporation tends to deplete soil water in the seeding zone and makes it difficult to plant safflower less than 4 cms deep into moist soil usually necessary for good stand establishment. Therefore there is a need and farmer interest in post emergence (POST) herbicides to control broadleaf weeds in safflower. Eliminating PPI herbicides would allow for improved seedbed preparation, more consistent stand establishment and more consistent yields and production. PPI herbicides would also allow safflower production in minimum till or no till cropping sequences. This paper provides an overview of some of the weed control research conducted at the North Dakota State University Williston Research Extension Center (WREC).

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MATERIALS AND METHODS

Each year field experiments were established on a Williams-Bowbells loam soil (fine, loamy, mixed, superactive, frigid pachic or typic argiustolls) with a range in pH of 6.5 to 7.0 and an organic matter content of 1.8 to 2.2%. Different commercially grown varieties of safflower were used. Seed was planted in rows 2.4 cms or 2.8 cms apart with a plant density ranging from 101,000 plts/ha to 142,000 plts/ha. Plot dimensions were 3 m by 7.6 m, of which a 2 m x 7 m area was treated with herbicide. Experimental design was a randomized complete plot with four replications. A tractor mounted sprayer delivering 9 L/ha at 2.11 Kg/cm^2 pressure was used. Weed control and crop injury were recorded visually, usually 4 to 6 weeks after application and just before harvest, based on a rating scale of 0 (no effect) to 100% (death of the weed or crop). Yield, test weight and seed oil percent were usually collected unless the production year did not allow it. Data obtained were subjected to analysis of variance.

RESULTS AND DISCUSSION

Over the years many herbicides have been tested and evaluated but discontinued from further research for a number of reasons (Table 1) (Riveland and Bradbury, 1985-1991). Most of the pre emergence (PE) herbicides were dropped from further testing because of inconsistent weed control. These herbicides usually require significant rainfall within a few days of application for activation.

Table 1. Herbicides tested on safflower having negative commercial potential, WREC.

Herbicide	USA Trade Name	Years Tested	Application Type[a]	Reason for Discontinued Research[b]
Acifluorfen	Blazer	1981	POST	CI
Alachlor	Lasso	1981	PE	IWC, CI
Bifenox	Modown	1981	PE	IWC
Cinmethylin	Cinch	1987	PE	IWC
Chlorsulfuron	Glean	1981-84	PPI, PE	CI
Dinoseb	many	1981	POST	CI
Diuron	Karmex	1991	POST	WC
Fluorochloride	Racer	1982-83	PPI	IWC
		1986-88	PE	IWC
Imazethapyr	Pursuit	1989	POST	CI
Isoxaben		1985	PPI	IWC
Lactofen	Cobra	1990	POST	CI
Linuron	Lorox	1981	PE	IWC
Oxyfluorfen	Goal	1981, 2000	PE	CI
Nicosulfuron	Accent	1991	POST	CI
Rimsulfuron	Matrix	1991	POST	CI
Primisulfuron	Beacon	1991	POST	CI
Quinclorac	Facet	1991	POST	CI
Tribenuron	Express	1991	POST	CI
Triosulfuron	Amber	1991	POST	CI
Clopyralid	Stinger	1991	POST	CI
Picloram	Tordon	1991	POST	CI
Dicamba	Clarity, Banvel	1991	POST	CI
MCPA	many	1990	POST	CI
2,4-D	many	1990	POST	CI
2,4-DB	many	1991	POST	CI, IWC
Propanil	Stampede	1989-90	POST	IWC
Pendimethalin	Prowl	1981-88	PE, PPI	IWC
BAS-514	Paramount	1998	POST	CI

[a] POST = post emergence; PE = pre emergence; PPI = pre plant incorporated.
[b] IWC = inconsistent weed control; CI = crop injury or stand reduction.

Table 2. Herbicides tested on safflower having potential for commercial usage, WREC.

Herbicide	USA Trade Name	Application Type[a]	Weeds Controlled[b]
Chlorsulfuron	Glean	POST	most bl, including kochia
Metsulfuron	Ally	POST	most bl, including kochia
Thifensulfuron	Harmony GT	POST	most bl, including Russian thistle and wild buckwheat
Ethametsulfuron	Muster	POST	wild mustard
Imazamethabenz	Assert	POST	wild oats, wild mustard
Fenoxaprop	Puma, Dakota	POST	grass, except volunteer wheat
Diclofop	Hoelon	POST	grass, except volunteer wheat
Quizalofop	Assure II	POST	all grasses
Sethoxydim	Poast	POST	all grasses
Clethodim	Select	POST	all grasses
Pronamide	Kerb	PE	bl
Fluroxpyr	Starane	POST	kochia
Ethafluralin	Sonalan	PPI	bl, grasses

[a] POST = post emergence; PE = pre emergence; PPI = pre plant incorporated.
[b] bl = broadleaf

Since significant rainfall in our region does not always occur to activate these herbicides, PE herbicides often do not provide adequate weed control. PPI herbicides usually have not been tested because of the availability of trifluralin and the production difficulties associated with incorporation of these herbicides. However, ethafluralin was extensively tested and has an emergency registration for use in safflower for 2001. Excessive injury has been the primary reason for discontinuing the evaluation of most post emergence herbicides.

A few herbicides have emerged as possible candidates for use as post emergence herbicides in safflower (Table 2). The sulfonylurea herbicides chlorsulfuron, thifensulfuron and metsulfuron have the greatest potential for broadleaf weed control on safflower. Chlorsulfuron and metsulfuron have long-term soil residuals and do not fit well in a crop rotation that includes broadleaf crops. However, thifensulfuron has a short term soil residue carryover and fits well into most crop rotation sequences. All of these herbicides when used at excessive rates can injure safflower. This injury often is accentuated during drought stress conditions. All commercial varieties grown in the Northern Plains are quite tolerant to these herbicides except Oker (Riveland and Bradbury, 1989).

These sulfonylurea herbicides may cause the safflower foliage to lighten from dark green to light green after application. This symptom is temporary and usually disappears within 14 days of application. Safflower yields were improved considerably with the use of these herbicides compared to weedy safflower (Table 3). Delayed maturity, plant stunting and reduced secondary branching are

Table 3. Safflower injury ratings and yields after application of chlorsulfuron, thifensulfuron and metsulfuron, WREC.

Herbicide[a]	Rate Range	# of	CI[b] Avg	CI[b] Range	Treatment Yield	Weedy Check Yield[c]	Yield in % of Weedy Check
	g ai/ha	Tests		%	kg/ha	kg/h	
Chlorsulfuron	8 - 13	16	6	0-10	500	308	162
Thifensulfuron	8 - 13	18	3	0-9	612	438	140
Metsulfuron	3 - 4	14	8	0-20	614	462	133

[a] All treatments contained 0.25% (v/v) non ionic surfactant
[b] CI = crop injury
[c] These yields are averaged over the same number of tests as the treatment yields.

Production Management

severe injury symptoms that may infrequently occur. Metsulfuron is the most likely to cause crop injury while thifensulfuron is the least likely (Table 3). These herbicide test results generally agree with the results reported by Anderson, 1987. Based on our research, suggested use rates on safflower would be as follows: chlorsulfuron at 10.5g ai/ha, thifensulfuron at 13g ai/ha and metsulfuron at 3.5g ai/ha. Applied to small young weeds these herbicides will control many broadleaf weeds including Russian thistle (Table 4). Kochia is the most difficult weed to control and may require a higher use rate than shown above for consistent control. Results demonstrated that chlorsulfuron and metsulfuron provided the best control of kochia (Table 4). Fluroxpyr, which provides good control of kochia in cereal grains, has promise, but may be too injurious to safflower. More testing of this herbicide is needed to assess its control and phytotoxicity to safflower.

Other herbicides listed in Table 2 as having potential for use on safflower include pronamide, a PE herbicide, and ethafluralin, a PPI herbicide. Ethafluralin controls wild oats, Russian thistle and kochia slightly better and with more consistency than triflurolin.

Herbicides that control grassy weeds, including volunteer cereal grains, have an obvious advantage over those that do not control volunteer cereals (Table 2). None of the herbicides listed in Table 2 are registered for use on safflower in the United States. Thifensulfuron, ethafluralin and pronamide currently are in the initial stages of the registration process. Sethoxydim is in the final step of registration for use in safflower.

Table 4. Control of four weed species by chlorsulfuron, thifensulfuron and metsulfuron, WREC.

		Avg Weed Control[b]			
Herbicidea	Rate Range	Ruth[c]	Kocz[d]	Rrpw[e]	Colq[f]
	g ai/ha	%			
Chlorsulfuron	8 - 13	93 (16)	70 (5)	96 (3)	99 (3)
Thifensulfuron	8 - 13	95 (20)	54 (7)	92 (5)	99 (4)
Metsulfuron	3 - 4	95 (16)	76 (8)	96 (4)	98 (2)

[a] All treatments contained 0.25% (v/v) non ionic surfactant.
[b] The number of ratings included in the average are in ( ).
[c] Russian thistle [d] Kochia [e] Redroot pigweed [f] Common lambsquarters

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Systems Analysis of Forecasting of Safflower Production in India

R. Kalpana Sastry, D. Rama Rao, V. Kiresur, and R. Vijayakumari[1]

ABSTRACT

The paper attempts to analyze the future scenario of safflower in India and provides strategies to enhance its production. The historic data obtained from secondary sources was analyzed using statistical forecasting tools. The quantitative data is supplemented with qualitative assessment based on opinions of oilseed experts through brainstorming and delphi methods. The forecast indicates that average production of safflower will increase from the present 0.42 mt to about 0.48 mt by 2010 A.D. The crop will be grown under sub-optimal conditions.

Limited results of dryland research, uncertain weather, low yields, lack of access to germplasm and a lack of appreciation for basic research were some major deterrents identified. Sunflower and gram will be the major competing crops for safflower. Production of an adequate quantity of quality seeds of new varieties/hybrids will continue to be a major constraint as the public sector will not be able to meet the quality seed requirement and the private sector may not evince interest in seed production. However, it is forecasted that about one fourth of the hybrids in use by 2010 A.D. may come from private sector.

Some major challenges for safflower research and development identified through this work are as follows: Development of cytoplasmic male sterility based hybrids which can be commercially exploited; identification of seedling markers in GMS based hybrids; developing pest- resistant varieties/hybrids; establishing strong seed production chain to ensure adequate production of quality seeds; and development of value added products from safflower.

Strategies for increasing the production of the crop have been identified. A policy to focus basic research on safflower in rain-fed areas is considered critical to sustain the growth of safflower production in India.

Key words: forecasting production, *Carthamus tinctorius* L.

INTRODUCTION

Safflower (*Carthamus tinctorious)* is grown mostly in black soils in southern (deccan) plateau region of India during the post rainy (*rabi*) season primarily as a rainfed oilseed crop. It is often grown as a mixture with wheat, barley, gram and sorghum. As a pure crop it is rotated with wheat, gram, cotton and post rainy sorghum. Being drought hardy, safflower responds well to moisture, nutrients and management practices even in dryland cultivation. While the world production of safflower went up from 6.2 lakh tons in 1991 to 9.5 lakh tons in 1998 because of increase in productivity from 535 to 845 kg/ha, the area under its cultivation in the world is now on the decline (FAO, 2000).

India became self-sufficient in edible oils by 1991 as a result of launching a technology mission on oilseeds in 1986 (Prasad *et al*, 1994) by the national government. The enhanced oilseed production came largely from rapeseed and mustard, soybean and sunflower (Virupakshappa, and Kiresur, 1997; Rama Rao *et al*, 2000). However, among different oilseed crops, safflower could not register significant gains, and the area and production under this crop have not shown adequate growth rate with the yield levels becoming stagnant (Singh *et al*, 1997; and Paroda, 2000). Our studies based on simple statistical analysis of secondary data could not provide adequate answers to understand this situation. In an effort to provide plausible answers to this, it was found necessary to analyze the safflower system in a holistic manner.

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The future of a commodity not only depends on the need for the commodity but also on other competing crops or choices available to farmers, socio-economic factors, consumer habits, state policies, trade and private sector role. In-depth analysis of such a system would have to integrate quantitative with qualitative information. In such a scenario, the future projections need to integrate statistical (historic) data with qualitative information. Systems approach coupled with technological forecasting provides a means to achieve this. This study is aimed to fulfill this felt need so as to identify the constraints and potentials of safflower in the future, i.e., by 2010 A.D.

METHODOLOGY

The data were collected from a range of primary and secondary sources. The primary data was collected with the help of oilseed experts across the country. Secondary data on oilseeds was collected from (GOI, 1999; CMIE, 2000; Damodaram & Hegde, 2000; and FAO, 2000).

The key issues for quantitative and qualitative information were identified through brain storming sessions and discussions with experts. The issues comprised various aspects of oilseeds such as cultivation, research and development, seeds, marketing, consumption, alternate uses, processing, food habits, trade, and state policies.

A blend of forecasting techniques was used to integrate qualitative and quantitative information in making the forecasts. The forecasts were made based on statistical analysis of secondary data for trend and growth (Makridakis, 1983) in conjunction with brainstorming and Delphi methods (Rohtagi *et al*, 1979 and Josef Martino, 1991).

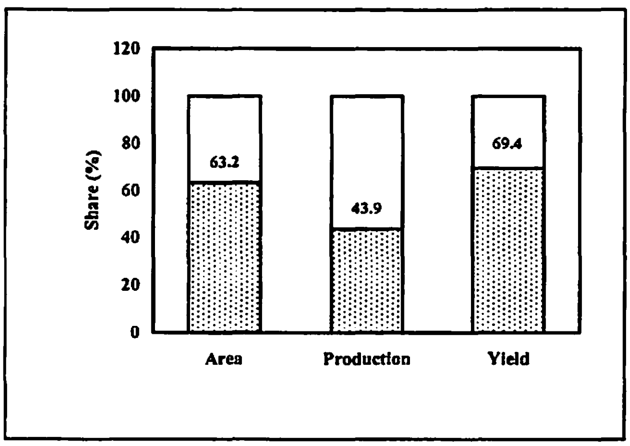

Fig. 1. India's share in global safflower area, production and yield during 1996-98

RESULTS AND DISCUSSION

India has 63.2 per cent of the world acreage under safflower, and accounts for 43.9 per cent of world production and 69.4 per cent of the world yield during 1996-98 (Figure 1).

In India, safflower occupies seventh place in terms of its area share under oilseeds. Nearly 99 per cent of the area under the crop is located in the southern plateau. The share of safflower to total oilseeds area and production in India are given in Table 1. Though the safflower area is about 2.7 per cent of total oilseed area in the country in 1990-93, the production share is 1.5 per cent only. This indicates that the safflower production share is not commensurate with its area share. In addition to this, the area declined from 2.7 per cent in 1990-93 to 2.6 per cent in 1995-98, while production declined from 1.5 to 1.4 per cent during the same period.

Table 1. Share of safflower to total oilseeds area and production in India.

Year	Total oilseeds*		Per cent share of safflower in total oilseeds	
	Area (million hectares)	Production (million tons)	Area	Production
1990-93	25.1	19.1	2.7	1.5
1995-98	26.2	22.8	2.6	1.4

* Three-year average

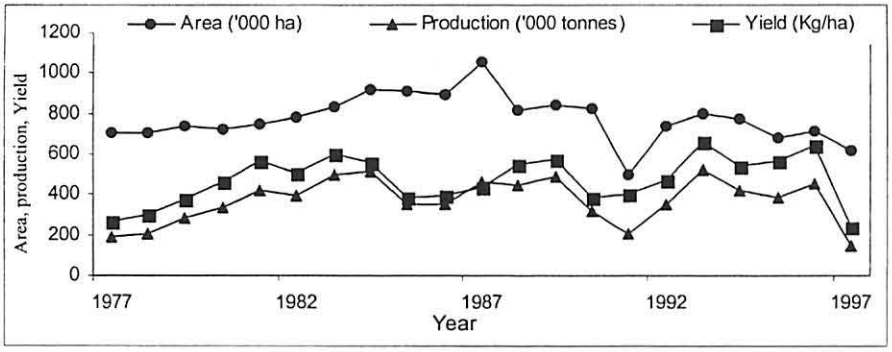

Fig. 2. Trends in area, production and yield of safflower crop in India (1977-97)

The trends in area, production and yield of safflower in India from 1977 to 1997 are presented in Figure 2. The changes in area and production under safflower are discussed at left.

Growth

The data in Figure 2 establishes the fact that there are significant changes in area, production and yield of safflower in India before and after 1987. Hence, the data was analyzed accordingly for growth for the two periods, i.e. 1977-87 and 1987-97. The compound annual growth rates of area, production and productivity of safflower (Table 2) show that there is sharp fall in the growth rate in the decade 1987-97. Growth rates in 1977-87 for both area (2.51%) and production (2.48%) decelerated to negative growth rates (–2.61% and –1.31%, respectively) in the decade i.e., 1987-97. Growth rate for yield too declined from 1.91 per cent in 1977-87 to -0.28 percent in 1987-97.

Table 2. Compound annual growth rates of area, production and yield of safflower.

Period	Compound annual growth rate (%)		
	Area	Production	Yield
1977-87	2.51	2.48	1.91
1987-97	-2.61	-1.31	-0.28

Incidentally, the technology mission on oilseeds (initiated in 1986) yielded significant gains in certain oilseed crops like rapeseed & mustard, soybean and sunflower. Apparently, the mission could not achieve the same in case of safflower.

Exploitable yield

The research claims on safflower yield (productivity) is at variance with real farm situation. Though the mean realizable yield with improved technology is 1349 kg/ha, the national average yield during 1995-97 was 584 kg/ha (Table 3). Thus the realizable yield gap was to the tune of 765 kg/ha accounting to 131 per cent of the realizable yield.

Table 3. Exploitable yield reservoir in safflower.

Mean realizable yield with improved technology (kg/ha)	1349
National average yield (1995-97) (kg/ha)	584
Realizable yield gap (kg/ha)	765 (131%)
Years to achieve realizable yield (Years)	50

Time to achieve the realizable yield was obtained by using growth model forecasting as illustrated in Figure 3.

At the present pace of efforts and growth of this crop, it will take about 50 years to achieve the realizable yield. This is a challenge for the development agencies to look forward for the ways and means to exploit the realizable yield potential in this crop. Disparities between realizable and actual yields of safflower have thus been recognized, and there is abundant scope to tap the unexploited potential of this crop.

Quality seed

Availability of quality seed is the most important criteria for the sustainable production of a crop. In case of safflower, during 1995-96, the quantity of seed required in the country was about 10,500 tons (@ 15 Kg/ha) against the actual availability of 1,500 tons (Table 4). Thus only 14.3 per cent of total seed needed for use is available from the domestic system. Since availability of hybrids in India is still

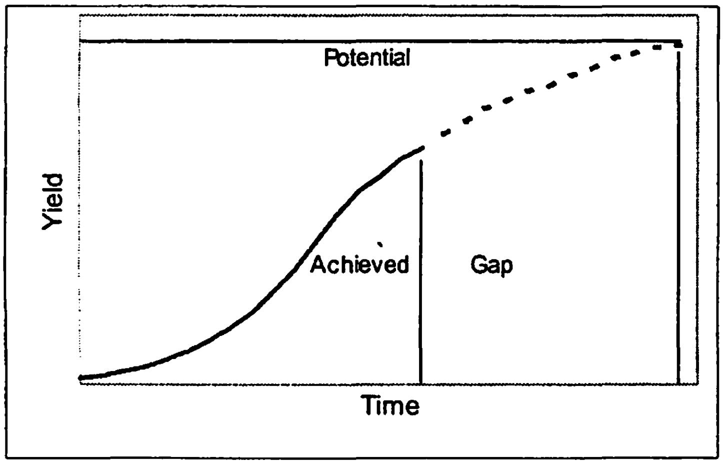

Fig. 3. Growth model for depicting time for realizing yield

Table 4. Seed need and availability during 1995-96 in India.

Seed rate	15 Kg/ha
Seed needed	10500 tons
Seed production	1500 tons
Seed availability	14.3 %

in infancy, growers can multiply and use quality seed of improved varieties for 4 to 5 seasons by traditional growing methods. Under this scenario also, there will be about 30 per cent shortage of quality seed.

The production of an adequate quantity of seeds of new varieties/hybrids will continue to be major constraint as the public sector will not be able to meet the quality seed requirement and the private sector will not evince much interest in seed production of varieties as it is economically not attractive. But, by 2010 A.D., it is forecasted that about 25 per cent of the hybrids in use would come from private sector.

Price

The government support price provides assurance from market risk. However, growers feel its support price is not remunerative. The difference in price of safflower seed in one leading market, Beed in Maharashtra, and the prevailing support price of government are shown in Fig 4. Government support price gradually rose from Rs 400/qunital in 1985-86 to Rs. 910/quintal in 1997-98 (at present one US dollar equals 46 Indian rupees). On the other hand, the open market price showed wild fluctuations year to year; ranging from - Rs 320/quintal to +20 Rs./quintal from the support price; with the support price being lower than the open market price in most years.

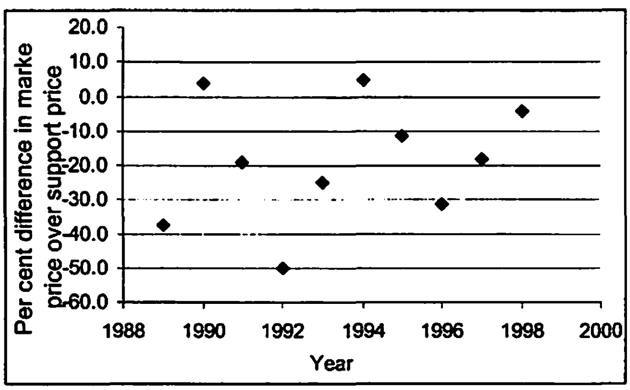

Fig. 4. Price fluctuation of safflower seed

Growers feel that the government support price is not remunerative and in absence of more realistic support price, the market prices too remained low. Low market prices have fuelled the domestic consumption of edible oils in India (World Bank, 1997). Besides, the year-to-year fluctuation in the prices has not encouraged growers. In international perspective too, the average world export price of safflower of 436 US dollars per ton during 1996-98 (FAO, 2000) is much higher than the open market price in India during the same period. Creating better remunerative price perhaps is necessary for sustaining the growers' interest in safflower.

High yielding varieties / hybrids

The number of safflower varieties / hybrids released during 1976-2000 is depicted in Fig 5. During the last 25 years, only 16 improved cultivars/ hybrids have been developed in safflower.

Considering the diversity in agro-climatic zones in the country and the need for location specific high-yielding varieties, the number of new varieties generated by the research system is rather low. The

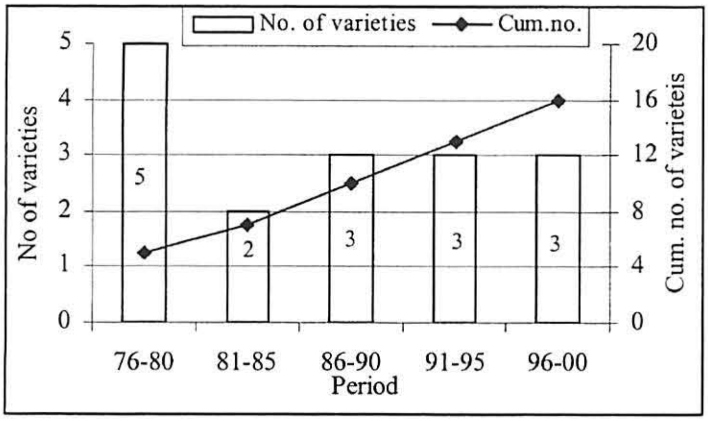

Fig. 5. Varieties and hybrids released in safflower (1976-2000)

number of varieties released does not show any impact of the technology mission program initiated in 1986. This low number of new varieties released may also have contributed to the productivity plateau and dwindling acreage of the crop.

It is noteworthy to note the release of two hybrids in 1997, for the first time in the country (Damodaram & Hegde, 2000). This sets in a new era in safflower cultivation in the country.

The research system needs considerable time to develop specific varieties for commercial exploitation. The relation between yield and spininess is already reversed. In some experimental safflower hybrids, non-spiny hybrids are as high yielding as spiny hybrids. The predicted time to evolve spineless safflower varieties would be 5 years. Major research breakthroughs that are possible in the next decade are identification of cytoplasmic/ genetic male sterility system and standardization of hybrid seed production technology. Some of these technologies can also be patented.

Publications

Research results are generally disseminated through publications, which is a good measure of research effort. Since varietal release is a long drawn process and depends on resources, number of publications is another means to reflect the research output. Manpower being a key resource in research, publications per scientist provides a measure of their efforts.

An analysis of the average number of scientists working in the national agricultural research system on safflower during 1985-97 and publications for the two representative biennial periods, i.e. 1989-91 and 1997-99 shows a weak relation between number of scientists and number of papers published (Table 5). Though there are good numbers of scientists working in safflower research over a long period, the low number of papers per scientist per year of 0.11 is of concern.

Table 5. Research publications in safflower.

Number of scientists during 1985-97	Papers published during 1989-91 and 1997-99		Per cent basic papers
	Total papers	Papers per scientist per year	
40	18	0.11	28

The proportion of basic research publications reflects the inherent strengths of the knowledge in the research system. Out of 18 papers published during the period, only 28 per cent (five papers) are of basic research. This is inadequate and perhaps answers to the low number of varieties being released over time. Concerted efforts are needed to look at this gap.

Dryland research

The research contribution has enabled the increase of production of crops like rapeseed and soybean. However, there have not been many major breakthroughs in evolving suitable varieties for dryland agriculture. But the scientists in research are not optimistic on this, and the reasons for their apprehensions on this in the order of their importance are as follows.

Factors affecting dryland oilseed research	Rank
Limited results of the dryland research	1
Insufficient resources	2
Uncertain rainfall	3
Lack of access to germplasm	4
Lack of appreciation for basic research	5
Lack of interest in researchers	6

Since safflower is largely grown under rainfed conditions, the future breakthrough depends on additional dryland research. Without a proactive approach by the policymakers, planners, and researchers, the situation is unlikely to change.

Technology transfer

Research has shown that safflower raised as a sole crop is more productive and remunerative than most of the rainfed post rainy *(rabi)* crops. In drylands, reducing traditionally low yielding crops in favor of safflower will improve the farm and oilseed economy. Such cropping patterns evolved through research call for early adoption in key areas. Thus, the importance of technology transfer is paramount for better response by growers to adoption of safflower.

The sub-systems associated with oilseeds that are likely to have more impact on overall oilseed situation by 2010 A.D. in the order of importance are:

Important subsystems influencing oilseeds	Rank
* Technology transfer (Development)	1
* Research and education	2
* Marketing and trade	3
* Processing	4

Even if there are breakthroughs from the research system, the technology transfer to farmers will be of paramount importance to exploit the yield potential. In addition, the forecasted time lag between technology development and adoption by 2010 A.D. will be about 3 to 5 years. Besides, adoption of production technology components will be slow in safflower, as it is predominantly a rainfed crop. Improved communication for faster dissemination of research output to the end users needs to be given priority in technology transfer.

Consumer preferences to oils

With the advent of liberalization, role and recognition of health foods and relative price, there has been a shift in consumption of edible oils in India.

The poor income group mostly prefer cheaper rapeseed/ mustard oil (R&M) and palm oil, while middle income group prefers groundnut oil and sunflower oil and the high-income group prefers sunflower and safflower oil (Table 6). The results indicate that the high-income group prefers sunflower and safflower oil primarily due to their health consciousness and aggressive marketing by certain branded oils. On the other hand, poor income groups do not prefer safflower due to its relative high cost.

Although safflower oil is one of the best oils nutritionally, it does not command adequate premium price in the market commensurate with its quality. With increasing health consciousness in the years to

Table 6. Preferences for type of oils by different income groups.

Preference	Preferences of consumption by income groups		
	Poor	Middle	Rich
1.	R&M & Palm oil	Groundnut &Sunflower	Sunflower & Safflower
2	Groundnut	R&M	Groundnut
3	Soybean	Soybean &Safflower	R&M

Table 7. Forecasts for safflower area, production and yield by 2010 AD.

Forecast Method	Area (million hectares)	Production (million tons)	Yield (t/ha)
Trend	0.8	0.56	0.7
Delphi	0.5-0.8	0.4-0.7	0.8-0.9
Combined forecast	0.6	0.5	0.8

come, hopefully, this gap may reduce. Besides the research system should gear up dissemination of the use of this oil. Further, blending with traditional and cheaper oils may offset the high price of the oil.

Forecasted production

Forecasts for safflower area, production and yield by 2010 A.D. were made by the trend based on past two decades data and experts opinions through Delphi. Some of the above concerns were taken into consideration while seeking opinions from Delphi experts. Finally, a combined forecast was developed based on the trend and Delphi results in consultation with oilseed experts.

The mean area and yield of safflower projected for 2010 A.D. are 0.6 million hectares and 0.8 t/ha (Table 7). The average production of safflower by 2010 A.D. would be 0.5 million tons which is 80,000 tons higher than the average production of 0.42 million tons during 1995-97. This (80,000 tons) additional production would come from only yield enhancement, i.e. from 0.6 t/ha in 1995-97 to 0.8 t/ha by 2010 A.D.

In the world, India will continue to be a major safflower producing country, ranking number one in terms of acreage. India's share by 2010 A.D. will remain at about 60 per cent of world safflower area as at present, but the production would increase from 44 per cent at present to 55 per cent.

The net additional production by 2010 A.D. will be about 80,000 tons and this will come by enhancement of productivity as given in Table 8. This additional production would come from yield enhancement rather than from area expansion; additional production from yield increase (192 percent) will offset the negative contribution from decreasing area (- 92 percent). Thus in the coming decade, the yield is expected to show a growth rate of 1.7 per cent per annum. Hence, safflower's contribution to total oilseeds production in the country would increase from present 1.4 per cent to 2.5 per cent by 2010 A.D.

Table 8. Safflower production enhancement from productivity and area changes.

Average production during 1995-97 ('000 tons)	Compares to 1995-97 change in production ('000 tons) by 2010 A.D. due to			Per cent change in production with respect to 1995-97 level due to	
	Area	Yield	Net change	Area	Yield
425	-75	157	82	-92	192 1

Strategies and recommendations

Based on the above results and discussions the following strategies are recommended for achieving the sustainable production of safflower in the coming decade.

- Production of adequate quantity of seeds of new varieties/hybrids will continue to be major constraint. The private sector will not evince interest in seed production of varieties, as it is not economically attractive. Establishment of a strong seed production chain, which can ensure adequate multiplication, and production of quality seeds of improved varieties/hybrids is needed. It is possible to associate seed companies for multiplication of the varieties released from the public system. This entails greater partnership between the public sector research and the agri-business sector.

- Safflower petals have tremendous potential for value addition, as it is an excellent source of different medicines and also food dyes. Technologies such as safflower tea, food colors and textile colors need to be developed in the public research system.
- There is need for basic research for developing pest-resistant varieties/ hybrids of safflower. Strengthening basic research by providing more funds and amending mandates of the national research system is critically essential. This would also help alter the low output of publications and varieties from research system. Thus, this is to be viewed as a necessary long-term investment for sustaining future production of safflower.
- Available cultivars of safflower have low seed oil content (30%) with high percent hull (50%) unlike the varieties grown in other important safflower growing countries. Replacement of such low seed-oil content cultivars should be achieved much faster, to increase not only vegetable oil production but also to make the meal fractions more valuable with less fiber and more protein.
- The government needs to establish a realistic remunerative support price mechanism and market environment for safflower. Creating better remunerative price is necessary for sustaining the growers' interest in safflower.
- Technology dissemination using modern communication media is rather weak. Since the private sector and non-government organizations are more effective in the transfer of technologies in India, involvement of these partners in technology dissemination would be more effective.

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Management of Safflower Aphid (*Uroleucon compositae* Theobald) Through Botanical Insecticides

G. S. Bharaj and A. R. Sawant[1]

ABSTRACT

Safflower aphid is a serious pest of safflower in Madhya Pradesh, particularly of late sown crops, causing serious damage to the crop during January-February every year. Chemical insecticides are very effective against aphid but since insecticides cause serious environmental pollution bio-products in different forms and concentrations for aphid control are considered beneficial.

In the present study 4 bio-products of neem (*Azadirachta indica*) neem seed kernel extract (NSKE) 5%, neem oil 1%, neem cake 5%, and neem ark (commercial formulation) were compared against dimethoate 0.05% in regards to their efficacy in controlling safflower aphid. These treatments were studied for a 3-year period from 1996 to 1998 using a randomized block design with 3 replications and safflower variety JSF-1.

The lowest aphid population was observed in treatment with Dimethoate 0.05% (28 aphids) followed by neem oil 1% (72 aphids) and neem ark (97 aphids). No significant differences among these treatments in regards to average aphid number were found, but the treatments significantly declined aphid number compared to the control (346 aphids). This indicates that even phyto (botanical) insecticides could control aphid though not as efficiently as chemical insecticides. It is felt that efficiency of phyto insecticides could be increased by adding a small quantity of chemical insecticides in the former.

Key words: aphid, safflower, phyto insecticides, *Carthamus tinctorius* L., neem *Azadirachta indica*

INTRODUCTION

Safflower aphid (*Uroleucon compositae,* Theobald) is the serious pest of safflower in non-traditional Madhya Pradesh (MP) particularly under late sowing conditions causing serious damage to the crop during January-February every year. Early/optimal planting (end of September), however, minimizes aphid infestation (Sawant, 1984; Sawant and Moghe, 1985). The extent of damage by aphid to the safflower crop under optimal planting condition was estimated to be about 17% at Indore (MP) (Sawant and Nadkarni, 1987). But under the prevalent soybean - safflower cropping sequence, safflower planting usually gets delayed until the 1st week of November due to late harvesting of soybean so the crop becomes more vulnerable to aphid attack. Chemical insecticides are very effective against aphids but since these insecticides cause serious environmental pollution, bio-products in different forms and concentrations could be used for aphid control. The efficacy of bio-products derived from "neem" (*Azadirachta indica*) is evaluated in this paper.

MATERIALS AND METHODS

In the present study 4 bio-products of neem (*Azadirachta indica*) seed kernel extract (NSKE) 5%, neem oil 1%, neem cake 5%, and neem ark (commercial formulation) were compared against diamethoate (0.05%) in regards to their efficacy in controlling aphid. These treatments were studied for the 3-year period from 1996 to 1998 using a randomized block design with 3 replications and safflower

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Table 1. Aphid control in safflower variety JSF-1 by different phyto (botanical) insecticides during the 1996 to 1998 period.

Treatment	Aphid number*			Average aphid number	Grain yield (kg/ha)			Average grain yield (kg/ha)
	1996	1997	1998		1996	1997	1998	
NSKE (5%)	116	116	55	96	513	1065	1732	1103
Neem oil (1%)	64	74	78	72	568	648	1233	816
Neem cake (5%)	155	159	69	128	219	787	1139	715
Neem ark**	96	114	81	97	525	833	2556	1305
Dimethoate (0.05%)	23	22	39	28	639	1250	1823	1237
Control	490	415	133	346	102	556	1005	554
SE ±	19	16	5	43	29	214	137	170
CD (5%)	57	48	14	135	88	NS	207	NS

* after two sprays.
** commercial neem formulation.

variety JSF-1. The individual plot size was 5.00 m x 2.25 m. Spraying was applied one week after first incidence of aphid and again 15 days after the first spraying. The numbers of aphids were counted on 5 cm. apical twig. Observations were recorded before spray application and 72 hours after the spray treatment. Grain yield was obtained from each individual plot.

RESULTS AND DISCUSSION

The results presented in Table 1 indicate that the chemical insecticide diamethoate was the most effective treatment in reducing the aphid count (28 aphids). Among the phyto (botanical) insecticides, neem oil 1% appeared to give the best control and ranked 2nd in effectiveness in two out of 3 years. Based on an average of 3 years, this treatment was not significantly different (72 aphids) from dimethoate (28 aphids) in regards to effectiveness. The other phytoinsecticides in order of effectiveness were NSKE 5% (96 aphids), neem ark (commercial formulation) (97 aphids), and neem cake 5 % (128 aphids). All the insecticide treatments produced a significant decline in aphid number as compared to the control (346 aphids).

The grain yields for the different treatments (Table 1) indicate that in the initial two years, diamethoate treatment resulted in the highest grain yield but no significant yield differences were found between the diamethoate treatment neem oil 1% or NSKE 5%. In the third year, however, neem ark recorded the highest yield (2556 kg/ha) which was significantly higher than the diamethoate treatment (1,823 kg/ha). The average grain yield for 3 years, however, did not show significant yield differences between the neem ark, diamethoate and NSKE 5% treatments.

It is interesting to note that in the present study, phytoinsecticides are at par or next to the chemical insecticide diamethoate in regards to their efficacy in control of aphids. Venkatesan et al (1987) studied different neem products and the chemical insecticide endosulfan against cotton aphid (*Aphis gossypii*) and also found that the treatments were equally effective in controlling aphids. Lawrey and Ismam (1993) also reported neem seed oil and neem seed extract as effective aphicides. These results support a greater scope to screen a large number of phytoinsecticides against aphid. The efficacy of phytoinsecticides could be enhanced by adding a small quantity of appropriate chemical/chemical insecticides.

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Intercropping of Safflower in Toria (Indian rapeseed) and Mustard

S. L. Deshpande and A. R. Sawant[1]

ABSTRACT

Intercropping of safflower in base crops of toria and mustard did not provide much ease in handling of spiny safflower but increased to some extent the relative yield efficiency (RYE) and provided some deterrent for the spread of aphid on safflower intercrop.

The intercropping experiment was conducted for 3 years (1993 to 1995) and included 2 rows of safflower alternating with 2,4 and 6 rows of toria and mustard. The safflower sole crop gave the highest monetary return followed by mustard - safflower intercropping in a 6:2 proportion of rows for all 3 years. Mustard based sole and intercropping systems gave higher total returns than that of toria. Land equivalent ratio (L.E.R.) and benefit cost (B.C.) ratio and RYE estimates of base crop and intercrop were highest at 6:2 proportion of rows and gradually declined through 4:2 and 2:2 proportions.

Key words: *Carthamus tinctorius* L., safflower, intercropping toria, mustard

INTRODUCTION

Introduction of safflower in the non-traditional region is expected to be easier through intercropping in traditional base crops (Deshpande and Sawant, 1997). A number of intercropping system experiments involving base crops such as gram, linseed, lentil and Amaranthus have been reported earlier (Sawant et al, 1993 and Deshpande and Sawant, 1997). However, the base crops in such intercropping systems were short statured, a favourable feature that made handling of spiny safflower crop easier and increased it's relative yield efficiency (RYE) in this non-traditional region of Madhya Pradesh (Sawant, et al, 1993).

The intercropping system in this study included the base crops of toria and mustard.

MATERIALS AND METHODS

The intercropping system experiment includes 9 treatments; three with sole crop each of safflower, toria and mustard and 6 intercropping treatments, formed by alternating 2 rows of safflower with 2,4 and 6 rows of toria and mustard base crop. The experimental design had a randomised complete block design with 3 replications and had a plot size of 5.0m x 5.4m. JSF-1 safflower, T-9 toria and Varuna mustard were the varieties used in the experiment. Fertilizers were applied to toria and mustard at the rate of N30:P20 kg/ha,. and to safflower at the rate of N40: P40 : K20 kg/ha. Toria and mustard were planted at a distance of 30 cm. between rows and 10 cm. between plants. Safflower was planted at a distance of 45 cm. between rows and 20 cm. between plants. The B.C. ratio and L.E.R. were calculated along with RYE estimates as suggested by Sawant et al, (1993) for intercropping studies.

RESULTS AND DISCUSSION

The results summarized for 3 years (Table 1) indicated that the highest average total return (Rs. 18698) was significantly higher for sole crop of safflower than other sole crops or intercropping combinations. The treatments mustard - safflower and toria - safflower intercropping in 6:2

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Table 1. Total returns in toria/mustard - safflower intercropping, summarized for 3 years (1993-94 to 1995-96).

Sr. No.	Treatments	Total Return (Rs/ha) 93 - 94	94 - 95	95 - 96	Average Return (Rs./ha)	Rank
1.	T:S 2:2	9770	11151	10149	10357	7
2.	T:S 4:2	14482	16123	14831	15145	5
3.	T:S 6:2	17063	18921	16894	17626	3
4.	M:S 2:2	9775	10688	11282	10582	6
5.	M:S 4:2	14860	17210	15813	15961	4
6.	M:S 6:2	17537	20149	17910	18532	2
7.	Safflower (Sole)	17633	20290	18170	18698	1
8.	Toria (Sole)	5220	8957	3565	5914	9
9.	Mustard (Sole)	6597	9559	7639	7932	8
	S.E. ±	411	516	337		
	C.D. (5%)	1232	1547	1012		

T = Toria; S = Safflower; M = Mustard.
4:2 = 4 rows of base crop (Toria or Mustard) alternated with 2 rows of intercrop (Safflower).

Table 2. Economics of toria/mustard - safflower intercropping.*

Sr. No.	Treatments	LER	Total cost (Rs/ha)	Net return (Rs/ha)	Benefit cost ratio
1.	T:S 2:2	0.87	3595	6762	2.88
2.	T:S 4:2	1.24	3595	11551	4.22
3.	T:S 6:2	1.46	3595	14031	4.91
4.	M:S 2:2	0.78	3595	6987	2.94
5.	M:S 4:2	1.14	3595	12366	4.45
6.	M:S 6:2	1.37	3595	14937	5.16
7.	Safflower (Sole)	-	4134	14563	4.19
8.	Toria (Sole)	-	3119	2795	1.91
9.	Mustard (Sole)	-	3119	4813	2.54

LER = Land equivalent ratio
* based on 3 years (1993-94 to 1995-96)

Table 3. Agronomical observations on different treatments in toria/mustard - safflower intercropping*.

Sr. No.	Treatments	Safflower Grain yield (kg/ha)	Safflower Plant height (cm)	Safflower No. of branches / plant	Safflower No. of capitula/ plant	Toria Grain yield (kg/ha)	Toria Plant height (cm)	Toria No. of branches / plant	Toria No. of pods/ plant	Mustard Grain yield (kg/ha)	Mustard Plant height (cm)	Mustard No. of branches / plant	Mustard No. of pods/ plant
1.	T:S 2:2	957	83.3	7.3	22.7	253	91.3	5.3	106.3	-	-	-	-
2.	T:S 4:2	1447	84.3	7.7	22.3	330	88.7	5.3	116.3	-	-	-	-
3.	T:S 6:2	1640	83.0	7.3	22.3	421	89.7	6.0	124.0	-	-	-	-
4.	M:S 2:2	925	82.3	7.3	21.3	-	-	-	-	298	133.7	5.0	124.0
5.	M:S 4:2	1467	81.0	7.0	23.3	-	-	-	-	394	132.3	5.7	131.7
6.	M:S 6:2	1634	82.7	7.0	20.0	-	-	-	-	514	136.3	5.7	137.3
7.	Safflower (Sole)	2293	84.7	7.0	20.7	-	-	-	-	-	-	-	-
8.	Toria (Sole)	-	-	-	-	577	92.0	6.3	140.3	-	-	-	-
9.	Mustard (Sole)	-	-	-	-	-	-	-	-	781	135.3	6.7	153.3

* based on 3 years (1993-94 to 1995-96)

proportions gave average total return of Rs. 18532 and Rs. 17626/ha., respectively. Similar trends were recorded in all the 3 years. Highest total returns from 6:2 combinations have also been reported in intercropping of safflower with base crops of linseed, lentil and Amaranthus (Sawant et al, 1993 and Deshpande and Sawant, 1997).

Table 4. Relative yield efficiency in toria/mustard-safflower intercropping (1993-94 to 1995-96).

Sr. No.	Treatments	Crop	Relative yield efficiency 93 - 94	94 - 95	95 - 96	Average
1.	T:S 2:2	Toria	97	76	92	88
		Safflower	82	75	93	83
2.	T:S 4:2	Toria	112	106	133	117
		Safflower	132	112	137	127
3.	T:S 6:2	Toria	152	132	160	148
		Safflower	149	127	154	143
4.	M:S 2:2	Mustard	74	92	70	79
		Safflower	83	66	95	81
5.	M:S 4:2	Mustard	101	108	91	100
		Safflower	131	118	135	128
6.	M:S 6:2	Mustard	135	146	108	130
		Safflower	148	131	148	142
7.	Safflower (Sole)	-	-	-	-	-
8.	Toria (Sole)	-	-	-	-	-
9.	Mustard (Sole)	-	-	-	-	-

In general the sole crop of mustard and mustard-safflower intercropping gave higher total returns, respectively, than that of sole crop of toria and toria-safflower intercropping. In both of the intercropping systems, the highest total returns were recorded in 6:2 combination of rows with returns gradually declining through 4:2 and 2:2 combinations. The L.E.R. and B.C. ratio also followed similar trends, with highest values for 6:2 proportions and gradual reductions through 4:2 to 2:2 proportions.

The parameter RYE estimated the yield potential of a given crop in intercropping system compared to that under sole cropping (Sawant, 1982). Higher RYE is indicative of greater yield efficiency of the crops under intercropping (Sawant et al, 1993). Higher RYE estimates for safflower intercrop in the base crops of linseed, lentil and Amaranthus have already been reported (Sawant et al, 1993 and Deshpande and Sawant, 1997). The reason for the higher RYE estimates was mainly due to the short stature of the base crops that provided the most favourable environment for the tall growing safflower intercrop. Contrary to this, the base crops of toria and mustard, in the present study, were tall in stature. Unfortunately this resulted in some difficulty in handling of spiny safflower but interestingly did increase, to some extent, relative yield efficiency of two crops in the intercropping. It also provided some deterrent for the spread of aphid on safflower intercrop. RYE estimates of base crop and intercrop were highest at a 6:2 proportion of rows and gradually declined through 4:2 to 2:2 proportions. Similar findings have been reported where safflower was intercropped into lentil and Amaranthus (Deshpande and Sawant, 1997). However, despite the tall stature of the base crops, higher RYE were recorded for both the base crop and intercrop in the present study which may be attributed to the mutually conducive differential growth rhythm of the two crops.

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Safflower Production as Influenced by Previous Crops

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ABSTRACT

Safflower is a good crop to include in cereal based cropping systems in the Northern Great Plains of the USA and Canada because it is adapted to semi-arid regions of the world. No-till field research was conducted 11 km southwest of Mandan, ND to determine the influences of previous crop and crop residue on safflower (*Carthamus tintorius)* production. Four replicates of safflower were seeded over ten crop residues [(canola (*Brassica napus)*, crambe (*Crambe abysinnica*), dry pea (*Pisum sativum L.*), dry bean (*Phaseolus vulgaris L.*), flax (*Linum usitatissimum L.*), safflower, soybean (*Glycine max (L.) Merr.)*, sunflower (*Helianthus annuus L.*), wheat (*Triticum aestivum L.*), and barley (*Hordeum vulgare L.*)] in 1999 and 2000. Averaged over the two years, surface residue cover after seeding safflower was the highest for wheat, barley, and flax (95 to 86%) and the lowest for dry pea, dry bean, and sunflower (82 to 31%). Safflower production after flax, barley, wheat, and dry pea was 220 to 150% greater than safflower production after safflower. The sustainability of diversified cropping systems that include safflower will be determined by the previous crop and crop residues and the crop sequence in which safflower is grown.

Key words: previous crop influences, ceral based, *Carthamus tinctorius* L.

INTRODUCTION

Great Plains agriculture has evolved on the premise that water is the driving variable. Since the 1930's, crop-fallow has been a way of life for the Great Plains producers. Fallow is a practice where no crop is grown and all plant growth is controlled with chemicals or cultivation during the season when a crop would normally be grown. Fallow is used to store soil water, but improved techniques and technologies have resulted in movement of water and nutrients below the rooting depth of cereals (Halvorson and Black, 1974). To make more efficient use of incident precipitation, producers have intensified and diversified their cropping systems. Instead of just one crop in their cropping system, many producers are now growing 3 or 4 crops. The more dissimilar the crops and their management practices are in a rotation system, the less opportunity an individual pest has to become dominant (Lyon et al., 1996). Safflower is an oilseed crop that can improve precipitation use, the use of water and nutrients below the rooting depth of cereals, and provide agricultural sustainability by adding diversity and intensity to cropping systems. Safflower is very diverse and adapted to many semi-arid regions of the world including the Northern Great Plains of the USA and Canada (Knowles, 1989). Where to put safflower in the sequence of crops in a cropping system is a question many producers and researchers have asked. Objectives of our research were to determine if previous crop and crop residue influences safflower plant stand and production and where to put safflower in a cropping system to take advantage of the synergism among crops.

MATERIALS AND METHODS

The research was conducted 11km southwest of Mandan, ND USA on a Temvik-Wilton silt loam (fine silty-mixed Typic and Pachic Haploborolls). In 1998, a field was divided into an east and west side to provide a location for two years of data collection. On the eastside, four replicates of ten crops (canola, crambe, dry bean, dry pea, flax, safflower, sunflower, soybean, wheat and barley) were no-till

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seeded in 9.1 m randomized strips in an east-west direction. In 1999, safflower was no-till seeded perpendicular over the residue of the previous years crop in a north-south direction. This created a situation were safflower was seeded on each of the ten crop residues. The plot size was 9.1x9.1 m. The same type of management was carried out on the west side of the field in 1999 and safflower was seeded over the ten crop residues in 2000 to provide two years of data for safflower on each of the ten crop residues. All crops received 67 kg N/ha plus 12 kg P/ha at seeding. Appropriate cultural practices were used for all crops to control pests.

After safflower seeding, the percent soil surface residue cover was determined using line transect techniques. A 7.6 m cable with 25 marks was stretched accross each plot four times and the number residue-mark intersections counted. Seven days after safflower emergence, plant stands were determined from one 0.5 m^2 sample in each plot. Seed yield was determined using a plot combine to harvest 12 m^2. Seed weight was determined on 1000 seeds from a clean combine sample. Precipitation during the growing season was measured at the research site by an automated tipping bucket rain gauge. Statistical analysis using ANOVA and Dunnett's one-tailed mean comparison test were used to determine crop and crop residue influences, using safflower after safflower as the control, on seed yield, plant stand, and safflower seed weight.

RESULTS AND DISCUSSION

Soil surface residue cover after seeding the 1999 crop was not significantly different among crops except for dry bean and wheat residues (Figure 1A). This trend carried over to safflower plant stand with all previous crops having plant stands similar to the plant stand where safflower was the previous crop (Figure 2A). After seeding the 2000 crop, surface residue cover was the greatest where the previous crops were flax, wheat, barley, and canola residues (Figure 1B). Plant stands were significantly lower where the previous crop was flax, when compared to where the previous crop was safflower. This suggests that flax residue can result in lower plant stands because it decomposes slowly and interferes with seeding (Figure 2B). This problem may be alleviated by use of residue managers to move part or all the residue from the seed row or by using a drill that has an opener that would move the flax residue.

Safflower seed production in 1999 was significantly less where the previous crop was safflower than for safflower on all other previous crops (Figure 3A). Safflower production on previous crops, other than safflower, was at least 65% more than where the previous crop was safflower, illustrating the importance of crop rotation. Production differences in 1999 may not have been influenced by the stored soil water since growing season precipitation was 177% of the long-term average of 29.2 cm (Figure 4). About 33% of the growing season precipitation occurred in August when safflower was pollinating or going through seed fill. The excess precipitation may have caused reduced seed weights because of greater incidences of plant diseases that may have been harbored in the safflower residue (Figure 6A).

In 2000, precipitation during the growth season was more like the long-term average than 1999 (Figure 4). Safflower seed production was significantly greater where the previous crop was flax than where the previous crop was safflower even though safflower plant stands were significantly less after flax (Figures 3B and 2B). Flax residue is more resistant to decomposition than other residues and the greater soil surface cover during the below-average precipitation month of August (Figure 4) may have suppressed soil water evaporation and increased plant transpiration which resulted in greater yields than where the previous crop was safflower. Even though safflower after flax had significantly less plants per m^2 than safflower after safflower, safflower plants were able to compensate. The reduced safflower plant stands may have permitted better air movement, reducing environmental factors ideal for plant disease. Safflower production after canola was the lowest and may be the result of volunteer canola from shattering problems the previous year and the increase disease probability due to sclerotinia (*Sclerotinia sclerotiorum*) in canola the previous year. Seed weight was not influenced by

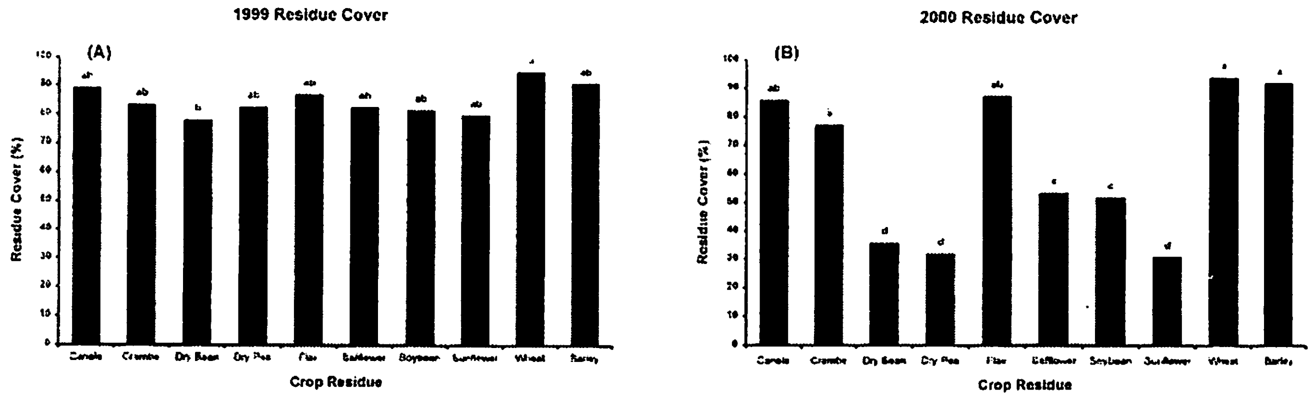

Fig. 1. Soil surface residue cover for each crop afterr seeding in 1999 (A) and in 2000 (B). Bars with different alphabetic letters were significant at the 0.05 probability level.

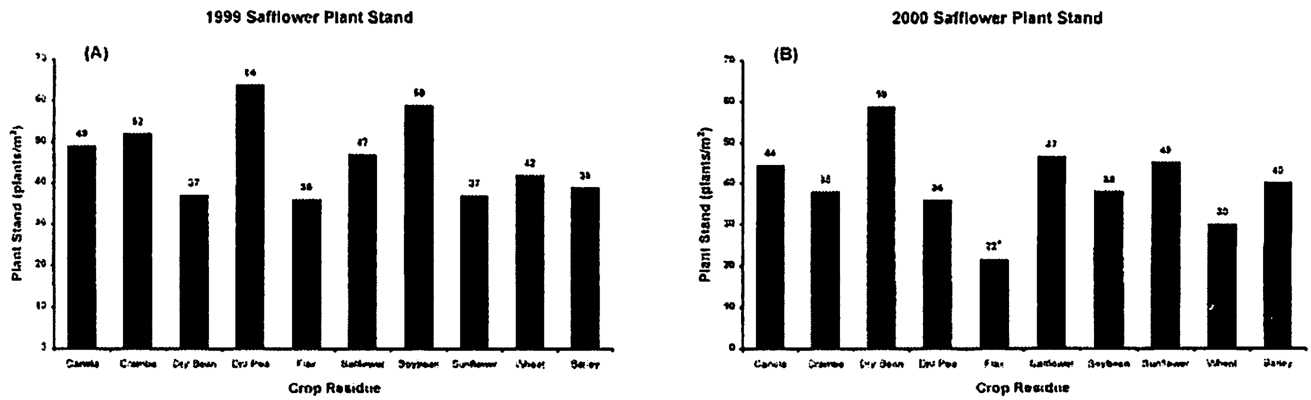

Fig. 2. Safflower plant stand as influenced by previous crop and crop residue for 1999 (A) and 2000 (B) crop years at Mandan, ND.

* Significantly different than safflower on safflower residue at the 0.05 probability level.

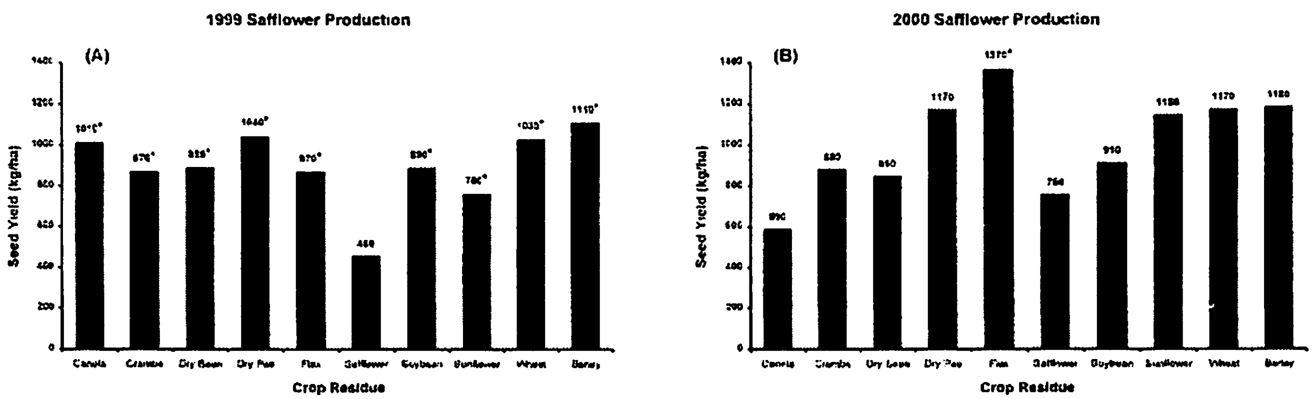

Fig. 3. Safflower seed yield as influenced by previous crop and crop residue for 1999 (A) and 2000 (B) crop years at Mandan, N.D.

* Significantly different than safflower on safflower residue at the 0.05 probability level.

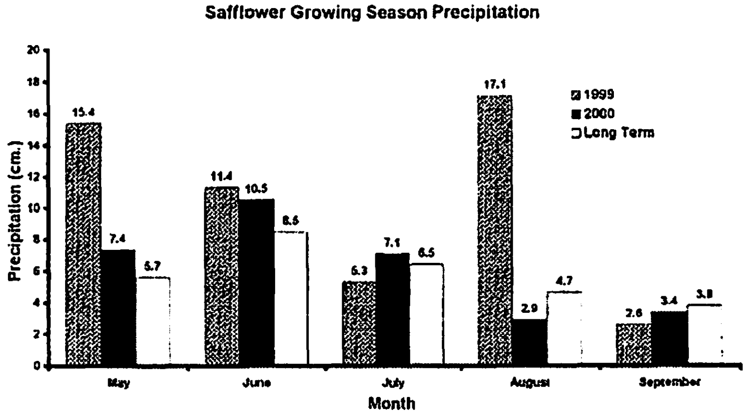

Fig. 4. Growing season precipitation (May - September) for 1999, 2000, and long term average (1914-2000) at Mandan, ND.

* Significantly different than safflower on safflower residue at the 0.05 probability level.

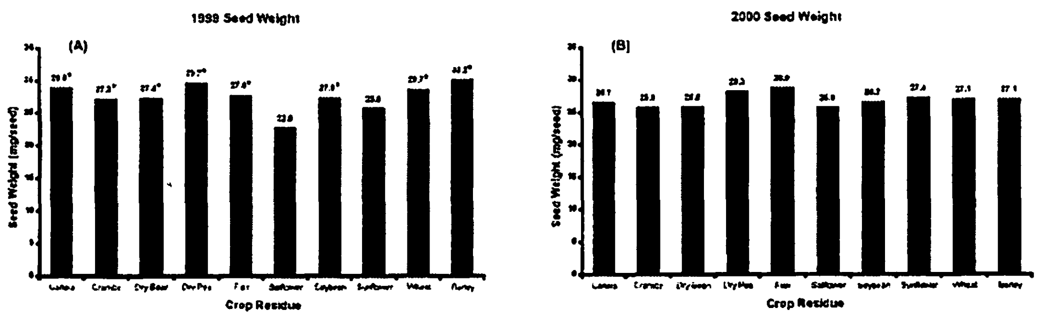

Fig. 5. Safflower seed weight as influenced by previous crop and crop residue for 1999 (A) and 2000 (B) crop years at Mandan, ND.

* Significantly different than safflower on safflower residue at the 0.05 probability level.

crop residue in 2000; this could be a result of the dry August (Figure 6B). While the below-average precipitation in August (Figure 4) may have benefited the seed fill period, the above-average precipitation in July along with morning dew was detrimental to safflower production.

After the two research years, some generalizations can be drawn from the research information on the crop sequence of safflower in cropping systems. First, trends suggest safflower production is best when the previous crop was flax, barley, wheat, or dry pea. Second, trends suggest safflower production is lowest when the previous crop was safflower or sunflower. In 2000, safflower production where sunflower was the previous crop is an anominally due to good soil water storage during the winter between sunflower and safflower crops. Third, safflower production, during below-average August precipitation years, may be increased when surface residue cover is increased, but surface residues can interfere with safflower stand establishment.

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Phenotypic Variation of a Selection of Safflower (*Carthamus tinctorius* L.) Lines and their Potential in Southern Australia

N. G. Wachsmann[1], S. E. Knights[1], and R. M. Norton[1]

ABSTRACT

The potential of 18 safflower (*Carthamus tinctorius* L.) lines for adaptation to southern Australia was evaluated in a glasshouse experiment. The lines tested included Australian cultivars, Australian breeding lines, overseas cultivars and hybrids. The lengths of various phenophases were recorded in days and growing day degrees (GDD). The potential of these lines to match the climatic limitations imposed on southern Australia's cropping systems was considered. The experiment showed a range of 26 days (216 GDD) for flowering on primary branches between the earliest and latest line. In the field, this additional 26 days of evapotranspiration would be desirable where dewatering benefits the rotation, but could be detrimental to the safflower crop in dry environments. Early maturing lines *e.g. UC-1* (104 days; 704 GDD to flowering on primary branches) are likely to be adapted to drier environments where limited water late in the growing season prevents long season lines from maturing. The ability to sow short season lines in late spring allows the use of cultivation and broad-spectrum herbicides for weed control during the autumn/winter period and so provides a means for controlling weeds resistant to selective herbicides. Late maturing lines *e.g. 120043* (130 days; 920 GDD to flowering on primary branches) would be better suited to higher rainfall environments or where soil profile dewatering is required.

Key words: safflower, phenology, adaptation, water use, tactical crop

INTRODUCTION

The southern grain-growing regions of Australia incorporate a range of environments. Soil types range from light sands to heavy clays, pH from very acid to very alkaline and average annual rainfall from less than 300 mm to greater than 1000 mm. Water deficit is a major limitation to grain production and up to 65% of variation in wheat yield has been associated with variability in April to October rainfall (French and Shultz 1984). An understanding of the phenological development of annual crops is particularly important to assist growers make decisions about selecting appropriate varieties and sowing times, which should ensure sufficient time for grain fill before summer drought.

Farmer interest in safflower is increasing due to a need for alternative rotation crops as cropping intensity increases and cropping is extended into nontraditional areas. A recent survey of safflower growers in southern Australia (Wachsmann et al. 2001) showed that safflower also has a range of tactical applications in some rotations. Safflower's deep taproot and high water use enables it to dewater soil in high rainfall environments and ameliorate soil structure (Harrigan and Barrs 1984). Because of this deep tap root system, safflower is one of the few crops that yields well when sown in spring in southern Australia. It is therefore sometimes grown where wet or dry winters have delayed sowing of winter crops. Furthermore, a later sowing can assist the management of herbicide resistant weeds by allowing additional cultivation during winter.

Breeding programs for the major crops (wheat, barley, canola and grain legumes) have developed a range of cultivars adapted to specific environments, with disease resistance and meeting the needs of different markets. However, safflower (*Carthamus tinctorius* L.) is a minor crop with only four

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Table 1. Safflower lines included in the experiment.

Line	Origin	End use	Notes
Gila 27	Arizona	Birdseed/oil	Susceptible to *Phytophthora* and *Alternaria* spp.
Saffola 517*	United states cultivar	Oleic oil	
Saffola 555*	United states cultivar	Linoleic oil	
Sironaria*	Australian cultivar	Birdseed/oil	Most frequently sown cultivar in Australia
Auslin 7			
Bhima	Indian cultivar		
CO_1	Indian cultivar		Spineless, high early vigour
GW 9009	Californian experimental hybrid	Linoleic oil	Cytoplasmic male sterility produced Hybrid
GW 9023	Californian experimental hybrid	Oleic oil	Cytoplasmic male sterility produced Hybrid
GW 9024	Californian experimental hybrid	Oleic oil	Cytoplasmic male sterility produced Hybrid
GW 9025	Californian experimental hybrid	Oleic oil	Cytoplasmic male sterility produced Hybrid
Lesaf 35	Canadian line		
Lesaf 175	Registered Canadian germplasm		
AC Stirling	Canadian cultivar	Birdseed/oil	
S5125			
UC-1	United states cultivar	Oleic oil	Early maturing
120043	Australian breeding line		Line with an extensive root system
120045	Australian breeding line		

* Lines currently commercially available in Australia

cultivars commercially available, only one of which was specifically bred for Australian conditions. There is a need for additional safflower cultivars adapted to different environments and possibly cultivars tailored to particular tactical roles. To this end, a preliminary glasshouse investigation of 18 safflower lines was undertaken to determine the development pattern of these lines with a view to predicting the range of environmental adaptation and their suitability for various tactical applications.

METHODS

A glasshouse experiment was established to compare the development pattern of 18 safflower lines (Table 1). The randomised block experiment with 6 replications was planted in 150 mm × 1000 mm PVC tubes filled with potting mix containing slow release fertiliser. Blocks were arranged as 2 rows with 300 mm between pot centers and were spaced 1 m apart. Three seeds were sown at 15 mm depth on the 5 May 2000. Plants were thinned to the strongest seedling in each pot on the 22 May 2000. Pots were irrigated to field capacity as required (2-3 times/week after establishment). Thrips were regularly sprayed with recommended insecticides and subsequently caused negligible damage.

Temperature and day length were adjusted according to Table 2 to give higher temperatures later in the season, reflected as a constant diurnal cycle of 25 °C days and 15 °C nights. These temperatures are lower than would normally be encountered in the field. Two 1000-watt halogen globes mounted above the experiment provided additional daylight hours.

Table 2. Glasshouse temperature and light details.

Month	Temperature settings °C		Measured mean daily temp. °C	Sunrise	Sunset	Additional Light (h)	Total daylight hours
	Day	Night					
May	20	10	15.4	7:20	17:33	1:38	11:51
June	20	10	17.0	7:39	17:22	3:16	12:59
July	25	15	18.4	7:38	17:34	4:06	14:02
August	25	15	18.1	7:12	17:57	3:51	14:36
September	25	15	18.1	6:30	18:21	2:31	14:22
October	25	15	19.1	5:47	18:46	0:27	13:26

Table 3: Days after sowing and GDD to critical growth stages (based on primary branch capitula).

Line	Elongation		Start of flowering Primary branch capitula		Anthesis Primary branch capitula	
	DAS	GDD	DAS	GDD	DAS	GDD
UC1	33.8 ^{bc}	187.8 ^{cd}	103.7 ^{ab}	704.3 ^{ab}	114.3 ^{a}	791.0 ^{a}
Lesaf 34	33.5 ^{ab}	184.9 ^{ab}	104.9 ^{ab}	714.2 ^{ab}	116.1 ^{ab}	806.0 ^{ab}
GW 9024	30.9 ^{a}	171.2 ^{a}	106.0 ^{ab}	724.2 ^{ab}	116.8 ^{abcd}	812.0 ^{abc}
GW 9023	31.7 ^{ab}	175.2 ^{ab}	105.3 ^{ab}	717.9 ^{ab}	118.3 ^{abcd}	823.5 ^{abcd}
Stirling	32.8 ^{ab}	181.5 ^{ab}	110.1 ^{bcd}	756.9 ^{bcd}	118.8 ^{abcd}	829.6 ^{abcd}
Bhima	32.5 ^{ab}	180.6 ^{ab}	107.1 ^{ab}	732.1 ^{abc}	121.6 ^{abcde}	840.9 ^{abcde}
GW 9025	31.0 ^{a}	171.6 ^{ab}	103.7 ^{ab}	717.6 ^{ab}	122.2 ^{abcde}	855.8 ^{abcde}
Sironaria	32.5 ^{ab}	179.7 ^{ab}	108.2 ^{abc}	741.4 ^{abc}	122.3 ^{abcde}	856.6 ^{abcde}
Saffola 517	32.3 ^{ab}	178.8 ^{ab}	109.2 ^{abcd}	749.8 ^{abcd}	124.3 ^{bcde}	874.3 ^{bcde}
S5125	32.8 ^{ab}	181.5 ^{ab}	102.9 ^{a}	698.0 ^{a}	124.5 ^{bcde}	877.0 ^{bcde}
Lesaf 175	36.3 ^{cd}	200.5 ^{ab}	110.3 ^{bcd}	758.9 ^{bcd}	124.5 ^{bcde}	879.0 ^{bcde}
GW 9009	33.0 ^{ab}	182.4 ^{ab}	106.5 ^{ab}	728.3 ^{ab}	125.0 ^{bcde}	886.1 ^{cdef}
Saffola 555	33.8 ^{bc}	186.9 ^{bc}	114.0 ^{cd}	788.4 ^{cd}	127.0 ^{def}	896.2 ^{def}
CO 1	31.7 ^{ab}	175.2 ^{ab}	109.3 ^{abcd}	749.5 ^{abcd}	127.2 ^{def}	898.6 ^{def}
Gila 27	34.2 ^{bcd}	188.7 ^{cd}	115.7 ^{de}	805.0 ^{de}	128.5 ^{ef}	910.1 ^{efg}
120045	43.1 ^{e}	240.3 e	122.0 e	853.0 ^{e}	135.0 ^{ef}	963.5 ^{fgh}
Auslin 7	42.6 ^{e}	234.0 e	123.5 ^{f}	838.5 ^{e}	139.7 ^{g}	987.6 ^{gh}
120043	36.5 ^{d}	201.3 ^{d}	129.7 ^{fg}	920.4 ^{f}	143.3 ^{g}	1030.9 ^{h}
P	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
LSD $P \leq 0.05$	2.59	13.98	6.970	56.83	9.371	78.64
CV %	6.6	6.4	5.5	6.5	6.5	7.8

NB: Means with same subscript are not significantly different at the 0.05 level

Due to the relatively cool conditions and adequate water supply, axillary buds continued to form and flower even after some primary capitula had matured. Watering was therefore terminated on the 23 October 2000. Plant growth stages were assessed three times per week using the safflower growth stage key developed by Uslu (1997). As the experiment did not allow for destructive sampling, it was assumed that physiological maturity occurred 30 days after anthesis (Uslu 1997). Plant growth in response to temperature was assessed in terms of growing degree days (GDD), using mean daily temperatures recorded by a data logger suspended within the trial. As used by Tanaka et al. (1997) for safflower, a base of 10 degrees was used to calculate GDD. Data were analysed by ANOVA with the software package, Genstat 4.1.

RESULTS

The times from sowing until the various phenostages for the 18 lines are given in Table 3. All lines had fully emerged by 12 days after sowing (DAS) (78 GDD). Dates refer to the development of capitula on primary branches, as they make up a greater proportion of yield than capitula on main stems and some lines failed to produce capitula on secondary branches.

Where present, capitula on secondary branches completed flowering 11 to 27 days after capitula on primary branches. Capitula on main stems flowered between one and nine (mean = 4.2) days before capitula on primary branches. For capitula on primary branches, there was a range of 29 days between anthesis on primary branch capitula between the earliest and latest line.

DISCUSSION

The results show that genetic variation between safflower lines causes different phenological responses in a given environment. If the additional 30 days for maturation were added to anthesis dates, the earliest maturing line in the glasshouse trial would be UC-1 (144 days) and the latest 120043

(173 days). Generally, earlier maturing lines were also earlier at other developmental stages than late maturing lines, *e.g.* flowering on secondary branches. Disparity in relative order of flowering and anthesis are due to differences in length of flowering. For example, for the line S5125, capitula on primary branches flowered for 22 days, but AC Stirling only flowered for 9 days. These figures refer to all primary branches, not individual capitula and there was some variation in the flowering pattern of different primary capitula on individual plants.

Primary capitula for UC-1 flowered 26 days (216.6 GDD) before 120043. In the field situation during December at Horsham, Victoria, 216.6 GDD is equivalent to about 21.7 calendar days. If UC-1 commenced flowering in early December at Horsham when daily evaporation averages 7.5 mm/day and we assume a crop factor of 0.9 for safflower, 120043 could potentially utilise an additional 162.3 mm of water to reach the same developmental stage. Although additional water use and soil profile dewatering is desirable in high rainfall zones or environments prone to waterlogging, it could be detrimental to safflower crops and perhaps subsequent crops in dry environments. The latter scenario was reported by a number of southern Australia growers in a recent survey (Wachsmann et al. 2001.). It is therefore important to match crop maturity requirements to the environment, particularly to available water during the growing season. Early maturing cultivars such as UC-1 are likely to be more adapted to dry environments and intermediate cultivars such as Saffola 555 to medium rainfall environments. Safflower's high salt tolerance combined with deep rooted, high water use genotypes may also have benefits for lowering water tables, reducing dryland salinity (Mündel et al. 1992).

A further observation from the glasshouse trial is that on average, flowering on primary branches commenced 114 DAS in replicates 1 to 4, but only 102 DAS in replicates 5 and 6. Replicates 5 and 6 were subjected to additional light from a neighboring trial, suggesting a photoperiod response. To explain different phenotypic responses due to environmental effects for a particular genotype, it is useful to examine causative factors. Colton (1998) suggests that safflower requires long days to initiate flowering, however from field observations and a phytotron experiment (18/13, 24/19, 33/28 ° C day/night; 16 hours daylight; cultivar Gila), Sterne and Beech (1965) concluded that safflower was more sensitive to temperature than to day length. Esendel (1997) argues that safflower is day neutral, but some genotypes may have a photoperiod response when grown at the limitations of their normal range. Although Esendal (1997) concluded that temperature is more important than day length in influencing safflower development, it appears that further work is required to clarify reproductive phase initiation stimuli for safflower.

Within the water limited cropping environment of southern Australia, sowing time is a major determinant of crop water use and yield. Safflower yields are related to moisture and highest yields will occur when rainfed crops are sown on a full profile of stored soil water (Harrigan and Barr 1984). Sowing too early can produce excessive vegetative growth and water use, resulting in insufficient moisture to produce mature grain (Colton 1998). A further risk with the early sowing of sensitive species such as safflower is frost risk during the reproductive phase (Colton 1988). The development of short season cultivars may enable safflower to be extended to areas with fewer frost-free days (Beech 1969). Sowing too late may result in low yields due to premature flowering before sufficient biomass has accumulated. Late maturing safflower cultivars should be sown early, and as sowing is extended later into spring; early maturing cultivars should be selected. Where safflower is sown as an opportunity crop to replace failed winter crops, short season cultivars are necessary to ensure adequate water for grain maturation. Consequently, a range of maturity types will be required to support the further development of the safflower industry,

Early maturing safflower lines have a potential role in the management of herbicide resistant weeds. Spring sowing allows cultivation and broad-spectrum herbicides to be used to control weeds resistant to selective herbicides from autumn until spring. Safflower is one of few crops available to farmers in southern Australia that can provide an economic yield when sown in spring under rainfed conditions. Short season cultivars would allow maturity before high transpiration rates and summer drought are encountered. Cultivars adapted to this role would ideally have deep roots to obtain moisture and be vigorous to smother late germinating weeds. The hybrid GW90024 may be more adapted to this role than other genotypes tested as it is relatively early maturing and vigorous which may help smother late germinating weeds.

CONCLUSION

Although this paper reports the results of a single glasshouse experiment, it showed that there is significant variation in the phenological development of a range of safflower lines due to genotype in terms of time and GDD. Literature suggests that temperature is a major determinant influencing safflower development, but this response is possibly modified by photoperiod. Sironaria is the main cultivar grown in Australia. The glasshouse experiment showed that both earlier and later maturing genotypes are available. A range of cultivars with different maturities are required in Australia to allow safflower production to expand into the range of environments available, with particular emphasis on matching crop water requirements to available water in different agro-ecological zones. Early maturing cultivars are likely to be adapted to drier environments or late sowings, *e.g.* replacing failed winter crops or managing herbicide resistant weeds. Late maturing cultivars should be more adapted to early sowing in high rainfall environments. Deep rooted, high water use cultivars may offer significant benefits to rotations in environments prone to waterlogging or where water tables need to be managed to reduce dryland salinity. Further work is required to test the phenological responses of these cultivars in the field under a range of environments and ultimately to compare the suitability and effectiveness of these cultivars in addressing the proposed tactical roles.

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Assessing the Forage Production Potential of Safflower in the Northern Great Plains and Inter-Mountain Regions

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ABSTRACT

Safflower (*Carthamus tinctorius* L.) is an oilseed crop that is well adapted to the semi-arid Northern Great Plains. Cool growing seasons in the Northern Great Plains, which occur infrequently, can result in an insufficient number of heat units needed to mature quality oilseed safflower. Utilization as forage is currently the only alternative use known for the immature safflower crop. Forage production is often limited in the Northern Great Plains and forage safflower may provide a means of increasing the forage supply, particularly in dry years. However, it is difficult to market the safflower forage because the quality of safflower forage has not been established with area forage buyers. The objective of this work was to assess the forage production potential of safflower and evaluate safflower forage quality in the Northern Great Plains and Inter-Mountain Regions. Safflower forage yields across eight sites were comparable with average dryland and irrigated alfalfa yields in Montana. Earlier seeding dates and later harvest dates generally produced higher forage yields. The crude protein content of safflower forage ranged from 7.2 to 20.5 % and was highest at the earlier harvest dates. Protein content changed little between the late August and September harvests. The relative feed value of safflower forage from the bud, bloom, and seed fill growth stages was generally above the standard value (RFV=100) for full bloom alfalfa forage.

Key words: Safflower, Forage, Forage Quality.

INTRODUCTION

Safflower (*Carthamus tinctorius*) originated around 1600 BC in South Asia and Egypt, and was first cultivated in Eastern and Central Montana in the 1950's. It has traditionally been used as an oilseed crop, but has also been used as a dye and as a substitute for saffron.

Safflower has also been used as a forage crop. In India, safflower was found to be a high protein indigenous feed easily grown in most soils (Ranjhan et al, 1959). Sown in October, it supplied two cuttings of green feed between January and April. The green fodder was highly palatable to sheep with average consumption of 1.2 kg per 4.5 kg body weight. Ewes fed chopped safflower in Alberta had higher lambing percentages than ewes fed alfalfa/grass hay (Stanford, 1997). Studies in Queensland, Australia showed safflower forage comparable in yield and feeding value (crude protein and total digestible nutrients) to oats (Brauns & Rudder, 1963). Safflower tolerated heavier initial grazing than oats, and regrew rapidly with adequate moisture. Weanling heifers (156 kg initial weight) averaged 0.70 kg d^{-1} gain on safflower compared to 0.88 kg d^{-1} on oats. As a winter crop in Australia, safflower produced large amounts of green material in the April to September period when other pasture

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productivity was low. After several days, cattle readily consumed the crop in spite of the spines. A farmer in Montana found that his heifers preferred early bloom safflower hay over mid bloom alfalfa hay (Morse, 1996). In Israel, safflower silage had good appearance, odor, quality, and palatability for calf feed (Lachover & Kostrinski, 1965). Safflower silage fed to cows in Germany slightly depressed milk yields but slightly increased fat content (Scharrer & Schreiber, 1942).

Lachover & Kostrinski (1965) looked at four different safflower timings for forage harvest (35, 55, 75, and 122 days after emergence) and three seeding rates (30, 60, & 90 kg ha^{-1}). Dry matter yield was not affected by seeding rate. Yields ranged from 6.7 Mg green matter/ha at 9.1 % dry matter to 60.0 Mg/ha at 22.3 % dry matter. Crude protein ranged from 19.2 % in the immature forage to 8.4 % in the most mature forage. Acidic detergent fiber (ADF) ranged from 12.8 to 35.3 % and neutral detergent fiber (NDF) was unaffected as maturity increased. At the stage of maximum yield, feeding value compared favorably with other forage legumes, grasses, and cereals. To evaluate palatability, 120-day old forage was fed to several animals. Sheep and cattle consumed it without difficulty.

Safflower needs a relatively long frost-free period, greater than 120 days, with around 2200 growing degree days (GDD) to mature to quality seed (Helm, et al., 1991). When a cool, wet growing season and an early killing frost prevented safflower seed from maturing in Montana in 1992 and 1993, farmers grazed the crop or put it up as hay or silage. Yield and nutritional quality was reported to be comparable to traditional annual forages and no sore mouth was reported from consuming the thistle-like head. Our objective in this study was to assess the forage production potential of safflower and evaluate safflower forage quality in the Northern Great Plains and Inter-Mountain Regions.

MATERIALS AND METHODS

This study was conducted in 1995 with safflower (*Carthamus tinctorius* cv. Centennial) seed treated with Vitavax 200 and seeded at 28 kg pure live seed (PLS) ha^{-1} for a plant population goal of 66 plants m^{-1}. The study sites represented a cross section of forage production areas in the Northern Great Plains and Inter-Mountain regions (Table 1). The sites were fertilized as for small grains (56 kg N + 34 kg P_2O_5 + 22 kg S ha^{-1} at Kalispell and 67 kg N+ 25 kg P_2O_5 ha^{-1} at the other locations). The experimental plots were arranged as a 3x3 factorial in a split-plot design with four replicates. The three planting dates were the main plots randomized within each replicate. Harvest dates were arranged randomly within each main plot. Harvest dates were scheduled on calendar dates of 01-August, 01-September, and 01-October. Each plot consisted of 7 rows 6 m long with 15-cm row spacing. The experiment was conducted at Bozeman, Corvallis, Huntley, Kalispell, Moccasin and Sidney, Montana and Williston, North Dakota. The Sidney location had both a dryland and an irrigated site.

Weeds were controlled by hand or with registered herbicides. At harvest time, growth stage and plant height were recorded. Forage yields were obtained by swathing the entire plot to a stubble height of 10 cm with a small plot forage harvester and weighing the entire sample. Dry matter content was determined by sub-sampling a 500-g portion of the cut forage in each plot, oven drying at 32°C for 5 days, and weighing the resultant dry material. The material was then ground in a Wiley mill, passed through a 2-mm screen, and analyzed for total Kjeldahl nitrogen (TKN), ADF, and NDF content. Crude protein content (protein) was calculated as 6.25 x TKN, digestible dry matter (DDM) as 88.9 – (0.779 x ADF), and dry matter intake (DMI) as 120/NDF. Relative feed value (RFV) was obtained as (DDM x DMI) / 1.29 (where RFV of 100 compares to full-bloom alfalfa).

The data were subjected to analysis of variance (Snedecor and Cochran, 1967) for a 3 x 3 factorial in split plot design, with multiple comparisons of fitted treatment means based on least significant difference (LSD, Student's t). All statistical analyses were conducted using MSUSTAT Version 5.22 (Lund, 1994).

RESULTS AND DISCUSSION

Safflower forage yield potential was evaluated at eight locations in the Northern Plains and Inter-Mountain region. The safflower forage yield range for each location is presented in Table 1. The safflower forage yield levels compared favorably with Montana's 1995 statewide average dryland and irrigated alfalfa forage yields of 5.44 Mg ha^{-1} and 7.62 Mg ha^{-1}, respectively (Montana Agri. Statistics, 1999). The May through August precipitation and mean temperatures in the crop year were not overriding factors affecting safflower forage yields. The deep rooting character of safflower permits the plant to extract soil water stored below the use depth of cereals. However, the Sidney irrigated site had higher dry matter yields than the dryland (rain fed) site.

The statistical summary of the effects of seeding and harvest dates on safflower forage yield and crude protein content at three sites is presented in Table 2. These sites represent high (Kalispell), intermediate (Corvallis), and low (Sidney) yield environments. The early May, late May and early June seeding dates are relatively late compared to the mid April through mid May seeding period recommended for oilseed safflower in the Northern Plains. The purpose of the delayed seeding date strategy was to evaluate safflower's forage potential in a manner that minimized the need for synthetic weed control and provided the opportunity for fall grazing. The early August, early September, and early October harvests coincide with typical peak flower, seed fill and seed ripening growth stages for safflower seeded in May in the Northern Plains.

Seeding date had a significant (LSD =0.05) impact on yields at Kalispell and Corvallis but not on the yields at the Sidney site. Generally, the later seeding dates had lower dry matter yields at each harvest date. Having a warmer mean May-August temperature may have made the seeding date less critical at the Sidney site. The Sidney site averaged 4.7° and 2.9° C higher mean temperature than the Kalispell and Corvallis sites, respectively, in the May through August period.

Protein levels increased with later seeding dates, an exception was at the Sidney site. The Sidney early June seeding forage protein content was significantly lower than that of the early May seeding for the August 21 harvest. This may have been an aberration or due to immature plant responses to shorter and cooler days.

Harvest date had a significant affect on both yield and quality at all three locations. The earliest harvest date had the lowest yields and highest protein contents for all three locations. The yields of the second and third harvest dates were more similar than yields of the first and second harvest dates. There were instances of dry matter yield reduction occurring by the third harvest date indicating significant leaf loss occurring either naturally or during the harvesting process. The protein content decreased with later harvest dates. The protein content for the second and third harvest dates was more similar than the protein contents of the first and second harvest dates.

Table 1. 1995 Safflower forage yields in the Northern Plains and Inter-Mountain Regions.

	Dry Matter Yield		May - August	
Location	High	Low	Precipitation	Temp. (mean)
	Mg ha^{-1}	Mg ha^{-1}	mm	C
Bozeman, Mt.	9.93	4.48	239	12.4
Corvallis, Mt.	9.64	2.49	209	16.0
Huntley, Mt.	10.24	4.53	308	16.8
Kalispell, Mt.	12.15	3.61	265	14.2
Moccasin, Mt.	4.30	1.46	330	14.3
Sidney, Mt.	6.10	2.46	263	18.9
Sidney, Mt. Irrigated	10.24	4.53	na[1/]	18.9
Williston, N.D.	8.05	1.32	296	17.4

[1/] na – Location received irrigation water in addition to precipitation.

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Table 2. 1995 Dry matter yield and protein content of safflower in high, moderate, and low yield environments planted on three dates and harvested on three dates.

	Dry Matter Yield			Crude Protein Content		
	Seeding Date					
Harvest Date	Early May[1/]	Late May	Early June	Early May	Late May	Early June
	$Mg\ ha^{-1}$	$Mg\ ha^{-1}$	$Mg\ ha^{-1}$	%	%	%
High Yield[2/]						
01-Aug.	9.15	6.21	3.61	11.7	14.6	20.5
01-Sept.	12.15	9.60	6.48	9.9	10.5	12.7
28-Sept.	11.55	9.08	6.66	10.8	11.3	12.4
Intermediate Yield						
01-Aug.	8.27	4.57	2.49	7.6	12.0	15.3
01-Sept.	9.24	9.48	5.85	7.2	7.9	10.5
01-Oct.	11.55	9.08	5.69	7.4	7.6	9.0
Low Yield						
20-July	4.19	3.36	2.46	10.1	12.9	15.7
07-Aug.	5.64	6.09	5.06	8.8	10.1	9.7
21-Aug.	5.49	5.62	5.78	9.8	9.4	8.6

Analysis of variance LSD (0.05 level)

Source of variation	Yield	Crude Protein
High Yield		
Seeding Date:	1.30	0.8
Harvest Date:	0.67	0.8
Planting x Harvest Dates:	NS[3/]	1.5
Intermediate Yield		
Seeding Date:	1.75	0.8
Harvest Date:	1.03	0.5
Planting x Harvest Dates:	2.26	0.8
Low Yield		
Seeding Date:	NS	0.8
Harvest Date:	0.27	0.5
Planting x Harvest Dates:	0.54	1.1

[1/] Early May = 01 to 10-May; Late May = 18 to 25-May; Early June = 01 to 10-June.
[2/] Site environment yield level, High = Kalispell, Moderate = Corvallis, Low = Sidney dryland.
[3/] NS, no significant difference.

Safflower forage intake and digestibility are of concern to producers because of the spines and coarse appearance of safflower plants in the bloom to seed development growth stages. Relative feed value (RFV) is derived using calculated dry matter intake and digestible dry matter values with full bloom alfalfa as the standard. The RFV for the safflower forage from the three sites analyzed ranged from 96 to 187 with an average of 133 (summary tables not presented). The mean safflower forage RFV across the three sites at the bud, bloom, and seed fill growth stages were 136, 146 and 116, respectively (32 samples per mean). These RFV values are above (better than) the standard for full bloom alfalfa (RFV =100).

CONCLUSIONS

This initial study finds safflower to be a viable forage crop for the Northern Great Plains and Inter-Mountain regions. The high yields for each site exceed Montana's 1995 statewide dryland alfalfa yield average with the exception of the Moccasin site. Dry matter yields were as high as 12.15 Mg ha^{-1} in the high yield environment at Kalispell. There is a risk of reduced yield potential when safflower seeding is delayed till early June. The risk of reduced forage yields due to late planting would be greater in areas with cooler growing seasons. Safflower dry matter protein content declined with later harvest dates. However, the decline was marginal between the late August and late September harvests.

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Comparison of Different Methods of Weed Control in Safflower

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ABSTRACT

Safflower could be a profitable new crop for Lebanon. However, safflower competes poorly with weeds at the early stage of growth. The objective of this study was to find an effective weed-control method to help attract farmers' acceptance of the crop. A rainfed trial was planted at the Agricultural Research and Education Center (AREC) in the Bekaa in 1999-2000. There were six treatments of weed management: weedy check, weed free check (hand-weeding 3 times), pre-emergence herbicide (pendimethalin + pronamide), inter-row cultivation (end of Mar, 2000), delayed-planting (to allow cultivation of emerged weeds), and delayed planting with inter-row cultivation. The herbicide and the delay-planting plus cultivation treatments significantly reduced the weed population in comparison with the weedy check. Relative to the checks, all treatments did not affect safflower seedling emergence and stand. Seed yield of delayed planting was the highest whereas the weedy check gave the lowest seed yield. Relative to the checks, date of flowering was delayed by late planting and by cultivation. This study indicated that in Lebanon delayed planting and spraying of pendimethalin + pronamide could be two useful ways for weed-control in safflower crops.

INTRODUCTION

Safflower (*Carthamus tinctorius* L.) could be a profitable winter crop for the Bekaa Plain of Lebanon (Yau et al., 1999). Introduction of the crop may help to solve one social problem. The problem was that since the Lebanese government's crack down on illegal crops, no replacement crops have been successfully introduced and farmers in the Bekaa have suffered economically. It is still too early to determine whether safflower can be a partial replacement for the illegal crops. However, results of the 1997/98 and 1998/99 already showed that safflower could yield as much as barley under non-irrigated conditions and be much more profitable than growing barley in northern Bekaa (Yau, 1999; Yau and Tannous, 2000).

Although safflower may be as high yielding as barley, it has a slow early growth, which renders it to compete poorly with weeds at the early stage of growth. Much research has been conducted on screening herbicides suitable for use in safflower (Montemurro and Fracchiolla, 1997; Salera, 1997). In a study on the effectiveness of four soil-applied herbicides and their combinations on weed control in safflower in Lebanon, Haidar and Yau (2000) reported that pendimethalin/pronamide mixture, especially at 2.0/0.5 and 3.0/0.5 kg/ha, gave the best weed control without any effect on the safflower plants.

In developing a good strategy of weed control, other techniques besides the use of herbicides need to be considered and compared. Herbicides may be effective and economical in weed control, but they usually are not environmental friendly. As environmental concern is increasing, we need to give more attention to the use of inter-row cultivation for weed control. However, inter-row cultivation is unable to remove weeds from within rows, and may cause damage to the crop plants. In addition to herbicide spraying and inter-row cultivation, there may be a simple, environment-friendly, and effective way of weed control in safflower, i.e., delayed planting for preparation of a weed-free field. In northern Bekaa, crops like barley and wheat should be sown as early as possible, otherwise grain yield will decrease

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(Yau, 2000). However, unlike barley or wheat, delayed planting up to mid-January did not reduce seed yield of safflower in Syria (Beg and Pala, 1997). The senior author also found that January sowing of safflower gave similar seed yield as November sowing in Lebanon (unpublished data). Thus, it seems that delayed planting to allow cultivation of weeds after the opening rains may be a good strategy of weed control in safflower.

The objective of this study was to find an effective weed-control method to help attract Lebanese farmers' acceptance of safflower. Specifically, the study aimed to test the hypothesis that in northern Bekaa delay planting to prepare a weed-free field could be a successive way for weed control in safflower.

MATERIALS AND METHODS

The non-irrigated trial was conducted in 1999/2000 at the university's Agricultural Research and Education Center (AREC) in the northern Bekaa Valley (33° 56′ N, 36° 5′ E, 995 m above sea level) which has a relatively cool Mediterranean climate. The long-term mean annual temperature is 13.9 °C. The long-term annual precipitation is 513 mm with 58% of this falling in December to February. The 1999/00 season had close to average temperatures in the winter but received below average precipitation (440 mm). The soil was an alkaline (pH 8.0), clayey, vertic xerochrept formed from fine textured alluvium derived from limestone (Ryan et al. 1980). Barley was the previous crop grown at the experimental site.

The safflower line PI 301055, originated from Turkey, was used for the experiment at a seeding rate of 40 kg/ha. A randomized complete block design with three replicates was used. Plots were 8m x 1.2m (4 rows spaced 30 cm apart) in size. A total of 60 kg N/ha was applied: one-third as ammonium sulfate before planting, and two-thirds as ammonium nitrate in spring prior to planting.

There were six treatments of weed management: weedy check, weed-free check, pre-emergence herbicide, inter-row cultivation, delayed planting, and delayed planting with inter-row cultivation. The weed-free check received three weedings by hand on February 29, April 4, and May 1. The pre-emergence herbicide consisted of a tank mixture of pendimethalin and pronamide at 2.5 and 0.5 kg a.i./ha, respectively. The herbicide mixture was applied on December 6, 1999 before safflower emergence. The herbicide was applied by a CO_2 pressurized backpack sprayer that delivered 360 l/ha at 138 kPa through flat-fan spray tips. The trial, except the delayed planting treatments, was planted on November 18, 1999. The opening rains came unusually late on December 14 and emergence started from January 7, 2000. Delayed planting was carried out on January 14, 2000 and seedlings emerged on February 16, 2000. On the day before the late planting, the plots receiving the late planting were rotivated by a small machine to control weeds. Inter-row cultivation using tynes 11 cm wide was conducted on March 30, 2000.

The following safflower traits and weed counts were recorded during the growing seasons:

1. Safflower seedlings/m - average based on two central 1 m rows counted on February 11 (March 6 for the delayed planting)
2. Safflower stand % - visual score of the plots on March 10 (before cultivation)
3. Weed plants/m^2 - counted on April 18 and May 23 (quadrate placed randomly within plot)
4. Date of 50% flowering
5. Plant height near maturity - from ground level to the top of the head of the main stem of a representative plant
6. Seed and shoot yield - based on 3 m from the two central rows harvested after physiological maturity. Plants were hand-harvested by cutting at the ground level. After weighing, plants were threshed by a small-plot thresher.
7. Straw yield = shoot yield – seed yield
8. Harvest index = seed yield / shoot yield *100

Table 1. Safflower seedlings/m, safflower stand, and weeds count/m² for the six treatments of weed management.

Treatment	Safflower seedlings/m	Safflower stand (%)	Weed count /m² on Apr 18	Weed count /m² on May 23
Weedy check	17	93	108	92
Weed-free check	15	90	3	0
Herbicide	14	83	1	0
Inter-row cultivation	16	93	56	32
Delayed planting + inter-row cultivation	19	100	8	0
Delayed planting	16	90	61	38
SE Mean	1.1	4.8	16.8	13.7

RESULTS

There were significant differences among treatments in weed count but not in safflower seedlings/m and stand percentage. Table 1 shows that the herbicide and the delay-planting plus cultivation treatments were as effective in weed control as the weed-free check in both dates of recording. Inter-row cultivation and delayed planting also reduced weed numbers in May, but they were not significantly different from the weedy check in April. Major weeds were volunteer barley (*Hordeum vulgare*), oats (*Avena* spp.), and *Papaver* spp. The herbicide and delayed-planting treatments did not have an adverse effect on seedling emergence relative to the checks.

Table 2. Seed yield, straw yield, harvest index, plant height near maturity, and date of flowering for the six treatments of weed management.

Treatment	Seed yield (kg/ha)	Straw yield (kg/ha)	Harvest index (%)	Plant height (cm)	Flowering date in June
Weedy check	880	2550	26	85	7
Weed-free check	1470	5580	21	97	7
Herbicide	1340	4770	22	95	7
Inter-row cultivation	1090	4510	19	85	10
Delay planting + Inter-row cultivation	990	3940	19	90	13
Delay planting	1630	4490	27	92	10
SE Mean	214	551	1.8	2.9	0.7

There were significant differences among treatments in straw yield and harvest index but not in seed yield. The weedy check gave the lowest seed yield as expected (Table 2). Delayed planting gave the highest seed yield, followed by the weed-free check and the herbicide treatment. The weed-free check, herbicide, cultivation, and delayed-planting treatments gave higher straw yield than the weedy check. The harvest indices of the delayed-planting treatment and weedy check were higher than those of the weed-free check, cultivation, and delayed-planting plus cultivation treatments.

Relative to the checks, date of flowering was delayed by late planting and by cultivation (Table 2). The delayed-planting plus cultivation treatment flowered the latest. For plant height near maturity, differences between treatments were non-significant.

DISCUSSION

This experiment showed that delayed planting gave the highest seed yield, which was nearly one fold higher than that of the weedy check. The higher yield under delayed-planting was not due to planting-date effect, because an experiment on planting date conducted next to the present trial did not show any differences in seed yield between November planting and January planting. The senior author also found that November, December, and January plantings of safflower gave similar seed yield in the previous year at the same site (unpublished data). Since delayed planting was not as effective as the herbicide treatment and the weed-free check, the higher yield under delayed-planting probably was not completely due to weed control. Rotivation before the delayed planting could have increased rainfall infiltration into the soil. The higher harvest indices under delayed planting and the weedy check seemed to suggest that competition with weeds led to an increase in harvest index of safflower and indirectly led to higher seed yield.

Inter-row cultivation by itself was not an effective technique in weed control in this study. Inter-row cultivation became effective under delayed planting. However, seed yields under these two treatments were not significantly higher than that of the weedy check, probably because too many safflower plants were uprooted or damaged by cultivation. An inter-row spacing of 30 cm probably is too narrow for safe cultivation. Inter-row cultivation may need to be further evaluated under a wider inter-row spacing.

In this study, the pre-emergence herbicide treatment was the most effective in weed control without any apparent adverse effects on safflower. Pendimethalin alone was found to be ineffective against *Avena ludoviciana, Sinapis arvensis, Lolium* and *Cruciferae* by Montemurro and Fracchiolla (1997) and Salera (1997). These earlier studies suggested that pendimethalin needs to be complemented with another herbicide to be effective against different types of weeds. The effectiveness of the mixture of pendimethalin and pronamide confirmed the result of our earlier experiment (Haidar and Yau, 2000). These two compounds are the active ingredients of two common herbicides in Lebanon – Stomp[R] and Kerb[R]. Stomp[R] is widely used in potato and tomato fields and Kerb[R] is widely used in legume crops. This means that fortunately no herbicides need to be ordered and imported specially for safflower.

In conclusion, this one-year study suggested that delayed planting and spraying of pendimethalin plus pronamide would be the two best choices for Lebanese farmers to control weeds in safflower based on their effect on seed yield and effectiveness of weed control.

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The Effects of N Application Times on Morphology, Yield and Quality Characters of Safflower

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ABSTRACT

This research was carried out to determine the effects of nitrogen application times on the morphology, yield quality characters of safflower under Van ecological conditions between 1997 and 1998. In the study, amonium nitrate (33%) were used as fertilizer. 12 kg N/da of each fertilizer was applied in the one application time (all in sowing), in the two application times (in sowing and in periyod of branching-stem elongation), and in the three application times (in sowing, in period of branching-stem elongation and in period of setting of head-flowering).

The effects of application times were found significant (P<0.01) especially on the plant height, branch number, seed yield, crude oil content and crude oil yield in both experimental years. While the highest seed yield was obtained in three application times in 1997 and 1998 years as 206.59 and 232.12 kg/da respectively. On the other hand, crude oil content and crude oil yield was obtained in three application times increased in both years 26.26 and 28.16% oil content; 54.41 and 65.35 kg/da oil yield respectively.

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The Effects of Late Harvest on Some Yield and Quality Characters of Safflower

B. Arslan[1], E. Gunel[2], and T. Eryigit[1]

ABSTRACT

In this study, it was aimed to determine the problems being faced with in case of late harvesting time of safflower (*Carthamus tinctorius* L.). The trial was conducted in production area of Agricultural Faculty of Yüzüncü Y2l Univercity in 1997 and 1998. The safflower varieties (5-118, 5-154) were placed in the main plots and the harvest times (30 September, 15 October, 30 October and 15 November) were placed in the subplots of trial which was made according to split plots of randomized blocks by three replicates.

As a result of the study, while significant differences (P<0.01) were found between varieties in terms of crude oil rate in 1997 and crude oil yield in 1998, seed yield were significant in two experiment years (P<0.01). Concerning harvesting times, it was monitored that the result obtained from the years of 1997 and 1998 were parallel to each other and differences among characteristics tested were obtained significant (P<0.01), except 1000 seed weight. The highest oil yield (39.6 kg/da) was obtained on 15th November and seed yield (143.6 kg/da) was obtained on 30th September and the lowest oil and seed yields (33.7 kg/da and 133.9 kg/da) were found on 15th November in the first year. In the second year of the experiment, the highest oil and seed yields (39.1kg/da and 139.5 kg/da) were found on 30th September and the lowest oil and seed yields (36.0 kg/da and 133.6 kg/da) were monitored on 15th November. On the other hand, in the late harvesting time; while defect head and seed number increased, seed and crude oil yield decreased.

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Planting Patterns of Three Safflower Cultivars in Southern Iran

A. H. Jelali and M. J. Bahrani[1]

ABSTRACT

Three autumn safflower (*Carthamus tinctorius* L.) cultivars were planted as single row (60 x 10 cm) and double row (60 x 20 cm) at Kushkak Agric. Exp. Sta., Shiraz Univ., Iran in 1998. The experiment was conducted as factional (3 x 2) in randomized complete block design with 3 replications. The fertilizers, herbicides and irrigation were applied to all treatments as usual. The results showed that double row planting had higher seeds per head and seed yields. LRV 51/11 cultivar had higher yield than LRV 51/51 and Zarghan 279 cultivars mainly due to higher heads plant-1 and seeds head-1. Plant height and growth period were significantly higher in LRV 51/11 and Zarghan 279 for double row planting with no significant effect on LRV 51/51 cultivar. Thus it is recommended that safflower can be efficiently planted as double row, particularly in saline regions.

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Best Planting Time of Safflower in Southern Iran

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ABSTRACT

The effects of six plating dates (Sept. 22, Oct. 6, Oct. 22, Nov. 5, Nov. 21 & Dec. 5) were evaluated on an autumn safflower (*Carthamus tinctorius* L.) cultivar, namely Zarghan 279 in 3 years (1995-98) at Fars Agric. Exp. Sta., Shiraz, Iran. The experiments were conducted as a complete block design with 4 replications. Results showed that the highest seed (1276 kg ha-1) and oil (330 kg ha-1) yields were obtained when it was planted in Oct. 22 and the lowest seed and oil yields were obtained in Nov. 21. The sooner the planting time the more rapidly it emerged, and the greater the seed numbers head-1, and plant height increased. The higher the 1000-seed weight, the more seeds were also present in each head.

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Effects of different sodium choloride levels on some agronomic traits and chemical composition of two safflower (*Carthamus tinctorius* L.) cultivars

H. Sadeghi and M. J. Bahrani[1]

ABSTRACT

In order to determine the effects of sodium chloride levels on the growth of two safflower cultivars, a greenhouse experiment was conducted as factorial (4 x 2) arranged in randomized complete block design, with 3 replications. The salt (sodium chloride) levels were 0, 4, 8, and 12 ds m-1 of the soil saturation extract. The results showed that increasing salinity levels decreased leaf area(LA) and dry weight (DW) in 51/51 cultivar. Increasing salinity from 0 to 4 ds/m-1 increased LA and DW but increasing salinity from 4 to 12 ds/m-1 decreased LA and DW in 51/11 cultivar. There was no significant difference for LA, DW and Na+ concentration between the two cultivars. Increasing salinity levels increased Na+ and decreased K+ concentrations of both cultivars.

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Safflower Management and Adaptation for the High Plains

David D. Baltensperger[1], Glen Frickel[2], Drew Lyon[1], Jim Krall[3], and Tom Nightingale[2]

ABSTRACT

Over the past 10 years several management, variety and systems trials have been conducted using safflower, *Carthamus tinctorius* L., in the High Plains region. All trials incorporated safflower behind a winter wheat, *Triticum aestivum* L, crop harvested the previous summer. Yield trials on deeper soils have consistently averaged in the 1,200 kg/ha range while yield trials on shallower, higher elevation sites have been significantly lower yielding (500 kg/ha). Drill opener-type and row-spacing studies have been conducted. Best stands and yields averaged over years have been produced with double-disk drills with 18 cm spacing. With favorable conditions, little difference occurred between opener types, but in years that thunderstorms occurred soon after emergence, stands were reduced by soil covering when hoe openers were used. During years with hot dry periods at the end of the season, plants senesced more rapidly with 18 cm rows than with 31 cm rows. Wheat yields in the wheat-safflower-fallow rotation were similar to wheat yields where corn, *Zea maize* L, sunflowers, *Helianthus annuus* L, or proso millet, *Panicum miliaceum* L, were substituted for the safflower. In continuous crop systems when comparing safflower to spring wheat, safflower reduced both proso yields the following year and wheat yields two years later.

Key words: rotation, high elevation, row spacing.

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Safflower Production and Research in México: Status and Prospects

J. E. Cervantes-Martínez[1]

ABSTRACT

In the last three decades, Mexico has been one of the most important countries in safflower production. Safflower was introduced in the late 40s, and cultivated areas increased at such level that in the growing season of 1979-80, 528,000 hectares were harvested with more than 600,000 tons. However since this period, the area decreased dramatically to only about ten percent of the record cultivated area. Low grain yields caused by diseases, drought, and low commercial prices of safflower seed have been the main factors affecting planted area. There are three production regions in Mexico: the Northwest, the Northeast and the Western region. In the Northwest, safflower has been cultivated in an extensive area under irrigated and fertilized conditions with high grain yields, but wheat, maize, cotton and vegetable crops now occupy this production area. In the Northeast and the Western regions, safflower is cultivated mainly under rainfall and non-fertilized conditions with low yields, with sorghum as the competing crop. The availability and use of technologies that allow good yields under high incidence of diseases and water-limited environments will be the main factors stimulating an increase in cultivated area. Moreover, these technologies must include varieties yielding near 40% seed oil content.

Key words: *Carthamus tinctorius*, production problems, safflower research, Mexico.

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Comparison of Yield Components and Oil content of Selected Safflower (*Carthamus tinctorius* L.) Accessions in Tunisia

Hamadi Ben Salah[1], Hamrouni Ibtissem[2], and Marzouk Brahim[2]

ABSTRACT

Safflower (*Carthamus tinctorius* L.) is an oleaginous plant, cultivated by small growers and managed by family units. The petals, colored orange, are used mainly as the condiment (false saffron) in food preparation. This plant is well adapted to harsh conditions and has a potential to be cultivated under arid conditions. Interest in its oil, especially the linoleic acid content (C18 :2) which is an essential fatty acid, took place when the amount of edible oil used in food preparation started to increase sharply. The objective of this study was to compare yield components and oil content of four safflower accessions in Tunisia. Screening of safflower accessions showed its good yield under Tunisian conditions. There was a strong positive association between the number of primary branches and yield. There was a significant positive correlation between seed yield and the number of seeds per capitulum. The total grain yield among the four accessions did not show a significant difference, however there were differences in thousand seed weights. Differences were also observed on the total oil content.

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Response of Safflower to Saline Soils and Irrigation

Elias S. Bassil and Stephen R. Kaffka[1]

ABSTRACT

Salt tolerant crops can be grown with saline water from tile drains and shallow wells as a practical strategy to manage salts and sustain agricultural production in the San Joaquin Valley of California. Safflower was grown using a salinity gradient in previously salinized plots that varied in ECe from 1.8 to 7.2 dS m^{-1} (0 to 2.7 m depth) and irrigated with either high quality (ECi < 1 dS m^{-1}) or saline (ECi 6.7 dS m^{-1}) water. Safflower tolerated greater levels of salinity than previously reported. Plants in less saline plots recovered more water (515 mm ± 18 SE) and at a greater depth (below 1.5 m) than in more salinized plots (435 mm ± 9 SE). Differences in pre-dawn and mid-day plant water potential, between plants in high and low salt plots, were significant at several dates. Leaf area index was reduced by 1 unit over this salinity range. Plant populations were not affected, however plant height was reduced by 32 cm at higher salinity. Seed, oil yield and oil quality were not affected by increasing ECe, but oil percent and 1,000-seed weight increased slightly. Plants adjusted to increasing salt stress in saline soils and water by increasing harvest index. Harvest index increased due to a reduction in the stem to total biomass ratio. Bud weight per m^2 was less affected by salinity. Low temperatures and higher than average relative humidity in spring likely moderated the effects of salinity.

Key words: Safflower, saline irrigation, water use, seed yield, oil quality, harvest index

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Uptake of Residual Soil Nitrogen by Safflower Following Cotton In Rotation

Elias S. Bassil and Stephen R. Kaffka[1]

ABSTRACT

Utilization of deep-rooted crops in rotation can improve the overall water and N use efficiencies of cropping systems, and minimize nitrate leaching to groundwater. Safflower (*Carthamus tinctorius* L.) is the deepest-rooted annual crop grown in California. Response to residual soil N and consumptive water use (0 to 2.7 m) by safflower was evaluated in field plots previously used for cotton trials, and treated with nine fertilizer N rates (0 to 230 kg N/ha) over a nine year period. Pre-plant residual soil NO_3 (0 to 2.7 m) increased with increasing cotton N fertilization rates. Safflower responded favorably to prior cotton N fertilization and available residual N. Seed yield rose from 1,700 kg ha^{-1} in the unfertilized control to 2,200 kg ha^{-1} but declined to 1,800 kg ha^{-1} at the highest residual N level. Oil percent and oil yield were not affected by soil N except at the highest residual N level. Consumptive water use, when adjusted for spatial variability by covariate analysis, increased with increasing residual N levels. Seed yield also increased with water use at a rate of 4.8 kg seed mm^{-1} of water used. The use of residual N can result in economic safflower yields and should be considered in growers N management programs, provided that enough water is available to the crop.

Key words: Safflower, residual nitrogen, water use, seed yield, oil yield, oil quality

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Management of Safflower Aphid Through Peripheral Application of Insecticides

C. P. Mallapur[1] and Y. P. Patil

ABSTRACT

An experiment on the management of safflower aphid, Uroleucon compositae Theobald was carried out from 1997-98 to 1999-2000 at Agricultural Research Station, Annigeri. The application of dimethoate [@ 1.7 ml/lt of water] around the field [4 rows or 1.8 metre peripheral region] on a need basis was compared with the whole field application of the insecticide and the untreated check. Three years of experimentation on a large-scale basis confirmed that the application of insecticide at the peripheral region only was as effective as the whole field treatment. The peripheral region treatment not only delayed the initial appearance of the pest for 75 days, but also resulted in a negligible pest population infestation of 10-22 aphids/5 cm bud, even during the peak period of infestation. Further, the treatment also produced a seed yield at par with the whole field treatment. The peripheral application treatment recorded a very high insect cost-to-benefit ratio of 13.5 compared to 3.7 for the whole field control treatment. Thus, it was concluded that the safflower aphid would be managed by applying the insecticides only at the peripheral region [4 rows or 1.8 m] of the field.

Key words: Safflower aphid, Uroleucon compositae Theobald, Aphid management, Peripheral application, Dimethoate

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Management of Safflower Aphid Through Seed Dressers

C. P. Mallapur[1], V. Rudra Naik, G. G. Gulaganji, and S. G. Raju

ABSTRACT

Various seed dressing chemicals were evaluated in their effectiveness against the safflower aphid Uroleucon compositae Theobald under field conditions at Agricultural Research Station, Annigeri. The results of two years experimentation [1998-99 and 1999-2000] indicated that the seed dressing chemicals viz., Imidachloprid 70 SP (5 g / kg seed), Carbosulfan (20 g / kg), Endosulfan 50 WP (10 g / kg) and Chlorpyrifos 50 WP (10 g / kg) were as effective as Carbofuran soil application (10 kg / ha) in reducing the initial pest load on safflower. The treatmental effect was reflected in the seed yield wherein the above-mentioned seed dressers recorded significantly more yield (8.1 to 8.4 q/ ha) than the untreated check (6.2 q/ ha). Although the yield response was marginal, these seed dressers may be efficiently used in reducing the aphid build up on the crop due to the low treatment costs.

Key words: Safflower aphid, Uroleucon compositae Theobald, aphid management, seed dressers, Carbosulfan

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Safflower Aphid Management Through Botanical Insecticides

C. P. Mallapur[1], V. S. Kubsad, and U. K. Hulihalli

ABSTRACT

The experiment conducted over a two-year period (1996-98) at the Agriculture Research Station in Annigeri, India on the utilization of plant products in the management of safflower aphid clearly indicated that the botanical pesticides Neem seed kernel oil extract (5%) and Neem cake extract (5%) were sufficiently effective to manage the pest when compared to chemical insecticides. Since these plant products are ecologically and environmentally safer and possess better benefit to cost ratio than chemical insecticides, these botanical insecticides may be efficiently utilized in the management of safflower aphid.

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Safflower Products

High Oleic Safflower as a Diesel Fuel Extender – A Potential New Market for Montana Safflower

J. W. Bergman[1*] and C. R. Flynn[1]

ABSTRACT

High oleic safflower (*Carthamus tinctorius* L.) oil has promise as a pollutant-reducing diesel fuel additive to reduce smoke and particulate emissions. High oleic safflower oil as a diesel fuel additive would also reduce acid rain, the greenhouse effect, and surface pollution because safflower oil is virtually free of sulfur, totally lacks fossil carbon dioxide, and is biodegradable. High oleic safflower oil offers a promising technology for further research and development as a fuel extender and is adapted to Montana's growing conditions. Growing safflower in Montana and other northern Great Plains states is highly desirable as an alternative crop for inclusion in rotation with dryland wheat to break wheat disease and pest cycles. Montana dryland farms have the potential to produce more oil on a per acre basis from high oleic safflower than Iowa farms can produce from soybeans. Research in Montana is continuing to make high oleic safflower oil more economical for use as a biofuel by adding value to safflower meal through genetic breeding and improvement.

Key words: Safflower, biofuel, oil, fatty acids, high oleic, diesel fuel extender, *Carthamus tinctorius* L., safflower meal.

INTRODUCTION

The cost of energy is a major factor in the economics of Montana agriculture. Petro-chemicals provide most of the fossil fuel energy used on Montana farms. The percentage of diesel fuel used in Montana agriculture has increased to surpass gasoline and propane use.

The use of high oleic safflower (*Carthamus tinctorius L.)* oil to replace petroleum-based diesel fuel is a promising technology to develop an ag-based diesel fuel blend or extender. Research has demonstrated pure vegetable oil can run medium-speed diesel engines like those used by railroads or electric generating plants, proving the process is technically feasible. The key is to produce high oleic safflower oil that can be used as a fuel extender or additive in existing diesel engines, and do it economically.

Safflower oil appears to be more economical to use as a fuel than other Montana crops such as wheat because it produces a higher energy content yield per energy unit used in production. Safflower oil, being liquid, also requires less processing than wheat before it can be used as a transportation fuel. A national vegetable oil conference held in Bozeman, MT in 1983 identified safflower oil as the oilseed crop that is closest to commercial development for fuel and suited to Montana's growing conditions. Growing safflower is compatible with wheat farming and also produces a protein meal by-product for livestock use. Many of eastern Montana's dryland farms have the potential to produce more oil on a per acre basis from safflower than Iowa farms can produce from soybeans. Sustained applied research is needed to develop an economical safflower oil fuel. Safflower research has been directed to high oleic safflower fuel use in diesel engines and the breeding of safflower to make high oleic safflower oil more economically viable as a fuel extender. Safflower oil with a high oleic fatty acid content has less problems in a diesel engine than regular safflower oil with a high linoleic oil content. High oleic safflower biofuel economics will be improved if the seed oil and meal protein content and quality are

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increased to add value. Both fuel and livestock feed uses must be improved to make high oleic safflower biofuel more economically viable.

Completed research funded by the Montana Department of Natural Resources and Conservation under its Renewable Energy and Conservation Program and current research has been directed to the development and improvement of high oleic safflower oil and its co-products.

METHODS AND MATERIALS

Chemistry laboratory analytical equipment was utilized to focus genetic improvement and selection on specific chemical constituents and properties of high oleic safflower oil and safflower meal to add product value and develop more economical alternative uses of safflower including biofuel, bio-based lubricants, and related products. Sophisticated computer-aided laboratory equipment has permitted us the opportunity to evaluate thousands of early generation safflower genetic lines for value added oil and meal traits (Methods are described in another paper in this proceedings by Flynn and Bergman). These value added traits included meals with reduced fiber content, increased protein levels, improved palatability, reduction of growth inhibiting agents, and diarrhea causing agents, and oils high in oleic fatty acid, natural antioxidants, B-carotene and other desirable qualities for industrial, feed, and food uses.

Safflower varieties under development were also tested and selected for disease resistance, high oil yielding ability and other desirable agronomic characteristics for production in Montana and other northern Great Plains states.

RESULTS AND DISCUSSION

By extensive multiple crosses, the use of automated gas liquid chromatography to test for fatty acid composition of half-seeds and recurrent selection for small genetic improvements for oleic fatty acid, high-purity strains of high oleic safflower oil with more than 85 percent oleic fatty acid and low levels of total saturated fatty acids (less than 6%) have been developed. One of the high oleic safflower lines, Montola 2000 (Bergman, et.al.) was released in 1991, grown commercially and tested in diesel engines by North Dakota State University (Ziejewski, et al, 1995). In a comparative analysis of plant oil based fuels Ziejewski, et.al evaluated six high oleic safflower oil blends, six high oleic sunflower blends, and six regular sunflower blends. The plant oil concentration in the diesel mixture was 0, 5, 15, 25, 50, 75, and 100 %. Ziejewski, et al reported the best alternative fuel was the 25% high oleic safflower/ 75% diesel fuel mixture and that high oleic safflower oil had the lowest cumulative carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO_x), and hydrocarbon (HC) emissions. Fuels in order of decreasing levels of polycylic aromatic hydrocarbon (PAH) emissions were diesel, high oleic sunflower, regular sunflower, high oleic safflower, both 100% or in combinations with diesel. In an Engine Manufacturers Association Durability test on high oleic safflower oil in diesel engines, Ziejewski, et al, also evaluated a 25% high oleic safflower oil/ 75% diesel fuel mixture compared to a standard diesel fuel. Ziejewski, et al, reported no significant differences for carbon deposits and lacquer residue, no deterioration in engine emissions, and no significant change in engine performance in comparison to standard diesel fuels. The high oleic safflower oil also did not create the typical vegetable oil deposits of carbon or polymer nor interact with lubricants to produce lube oil thickening. These results demonstrated that the Montola 2000 high oleic safflower oil is compatible with diesel fuel and tested well as a diesel fuel blend or extender.

Other high oleic safflower genetic lines have been further developed in our research and development project having high seed oil content, high meal protein content and reduced meal fiber content to enhance the product value of safflower and improve the economics of high oleic safflower oil for Montana biofuel production. Genes available in safflower to reduce the seed coat and pericarp tissue were incorporated into the high oleic safflower genetic lines to decrease hull percentage and

Table 1. Seed, Oil and Meal Yields, and Break-even Price for Seven Safflower Genetic Oilseed Stocks.

								Break-even Price of Safflower Oil[5]			
Oil Content Dry Seed Basis (%)	Protein Wt % Meal [2]	Fiber Wt % Meal[2]	Predicted Seed Yield Lbs/A	Oil Yield Gal/A[3]	Meal Yield Lbs/A[4]	Meal Price $/Ton	Meal Value $/A	Prod Cost[1] Basis	Prod Cost[2] Basis	Cost[2] w/o Land Rent & Mgmt	Prod Cost[2] Variable Costs Only
36.0	22.0	35.0	1290	59.4	793	60	23.78	2.48	1.92	1.19	0.71
38.0	32.0	32.0	1251	60.8	745	110	40.96	2.14	1.59	0.88	0.42
40.0	34.0	29.0	1213	62.0	698	120	41.91	2.09	1.55	0.85	0.40
42.0	36.0	26.0	1174	63.1	654	130	42.49	2.05	1.52	0.82	0.39
44.0	40.0	22.0	1122	63.2	603	150	45.25	2.00	1.48	0.78	0.34
47.0	44.0	18.0	1071	64.4	545	170	46.31	1.95	1.44	0.75	0.32
50.4	36.4	27.2	1189	76.7	566	132	37.38	1.79	1.36	0.74	0.42

[1] Oil content reported on a dry basis, average moisture is 4 to 8%.
[2] Meal protein and fiber values are the weight percentages in the meal, not the whole seed.
[3] Oil extraction is assumed to recover 98.5% of total oil. One gallon is 7.7 lbs., or (lbs/acre x % oil x .985)/7.7
[4] Meal yield = [(lbs seed yield) x (1 - % seed oil)] x .96 dry/wet meal.
[5] Break-even oil price = [(Production cost – meal value)/oil yield] + process cost.
Production cost[1] = $157.93, Production cost[2] = $124.56, Production variable cost = $53.04/acre
Processing cost = $0.22/gal or $20/ton
No processing cost reduction figured for higher oil content oil seed.

increase oil percentage up to 50% and meal protein content up to 35%. The higher oil yield and higher meal protein of these improved high oleic safflower genetic lines will greatly diminish the cost difference between diesel fuel and high oleic safflower oil for use as a fuel extender and biofuel.

Table 1 shows the seed oil, meal protein and meal fiber contents, seed, oil and meal yield, meal price and value, and the break-even oil price for 7 safflower genetics lines tested in this project. The analysis illustrates the break-even cost of high oleic safflower oil of these existing safflower genetic lines that will compete with diesel fuel if land rental and management costs are removed from production costs. This break-even cost would represent a producer who owns the land and does his own farming. The far right column in Table 1 shows the break-even production cost based on variable costs only when biofuel is needed for an emergency energy crisis situation. As seen in Table 1, the break-even cost of producing safflower for fuel is significantly reduced by increasing the oil yield per acre and enhancing the meal co-product value. The analysis in Table 1 reflects a reduction in seed yield per acre as a result of the reduction in seed hull percentage of higher seed oil content lines. Also, the added meal value of $ 5 for each 1% increase in meal protein would need to be achieved utilizing new safflower meal marketing methods. Based on the production cost 2 basis shown in Table 1, the break-even production cost of safflower oil could be reduced by $0.44 per gallon from $1.92 to $1.48 a gallon with the improved safflower genetic lines. New air pollution restrictions, especially in urban areas, may increase the cost of diesel fuel to this range and/or establish a requirement for a diesel fuel extender such as high oleic safflower oil to reduce engine emissions. Safflower production in the northern Great Plains states will permit more intensive cropping than a strict spring wheat – fallow rotation to consume more carbon dioxide to improve the environment and the economic performance of our agricultural lands. Biodiesel usage in Europe is expanding to improve air quality and increase the use of renewable fuel. Future oil fields in the United States may be harvested, not drilled, to produce biodiesel fuel or biofuel extenders for petroleum diesel substitution to reduce air particulate emissions and provide cleaner burning fuels. The research conducted in this project is also applicable to food safflower oil as well as biofuel safflower. Montana will benefit by improving the economics of growing high oleic safflower either as a renewable biofuel or as a high quality food oil. As the per-gallon cost of high oleic safflower oil drops, high oleic safflower oil will become more attractive as an industrial chemicals feedstock and petroleum substitute.

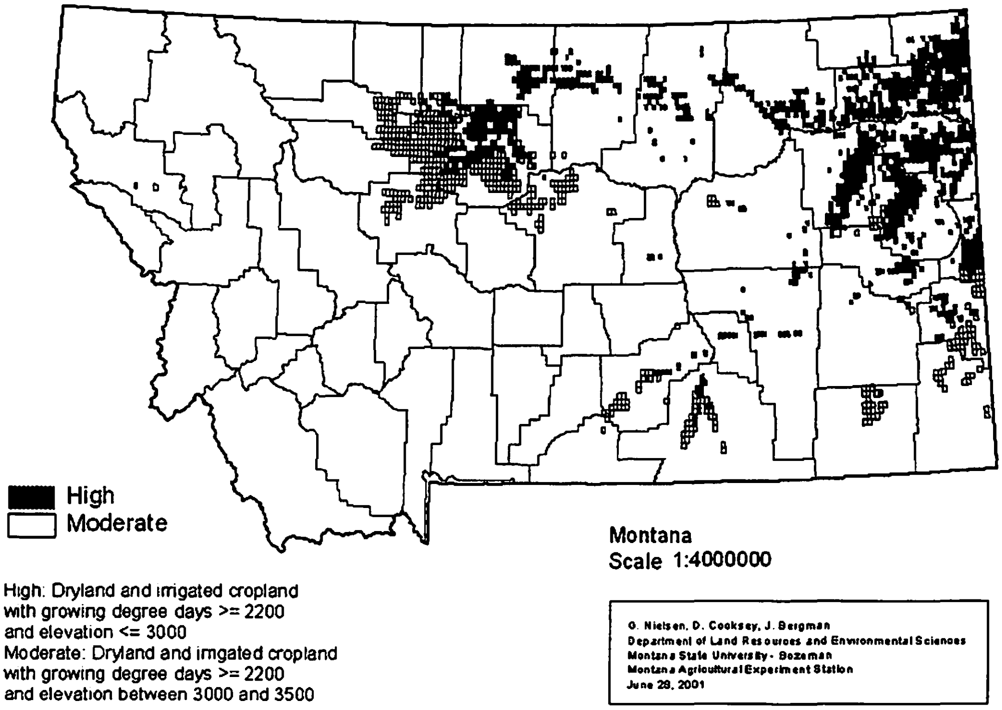

Fig. 1. Areas with Safflower growing potential.

Safflower is a proven alternative crop in Montana as shown in Figure 1. At Sidney, Montana, the long-term dryland safflower mean yield of 1,211 pounds per acre (Figure 2) compares very favorably to the long-term dryland spring wheat mean yield of 35.1 bushels per acre (Figure 3). Higher oil purity and yield, improved meal by-products, more efficient and improved production technologies, development of new and expanded energy, industrial and food users, and expanding market opportunities will continue to improve the economics of safflower production and reduce our dependence on monoculture wheat production. High oleic safflower offers consumers a non-GMO,

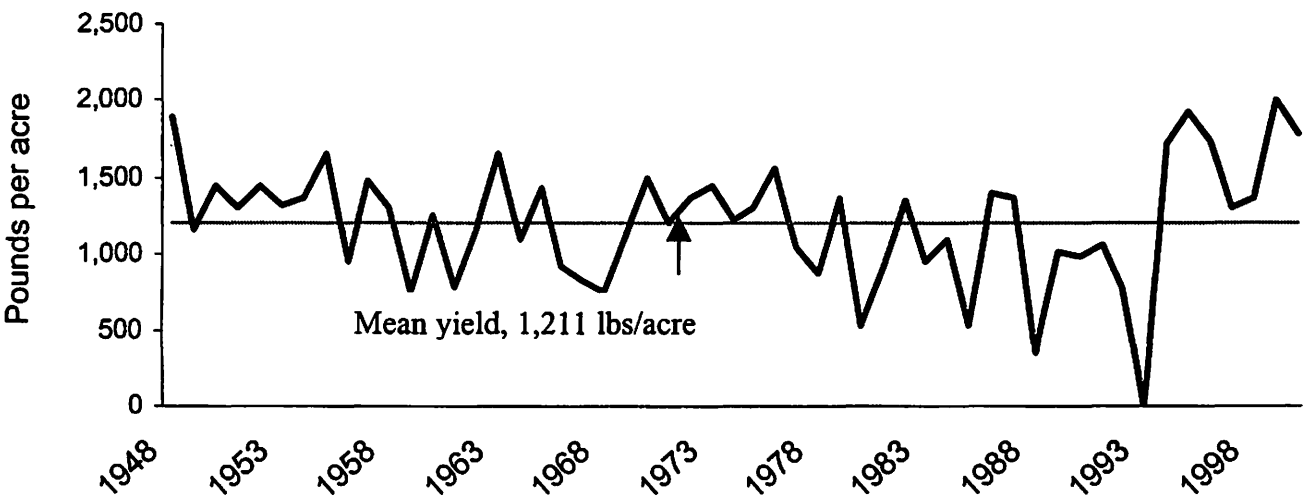

Fig. 2. Montana safflower dryland yield, pounds per acre, 1948-2000.

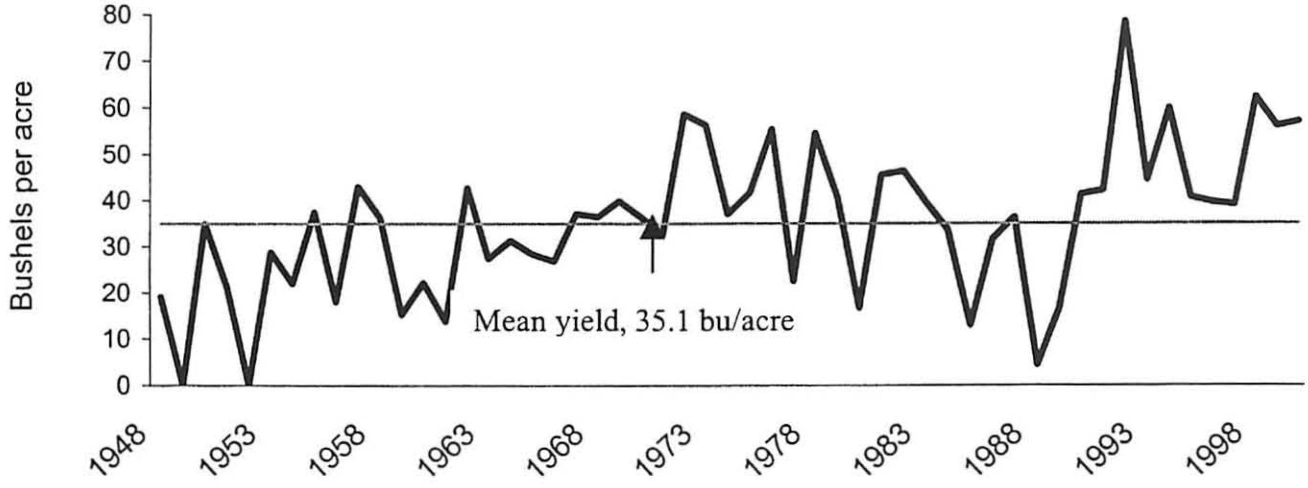

Fig. 3. Montana spring wheat dryland yield, bushels per acre, 1948-2000.

non-transfat, low saturate, edible health food oil, and a renewable biooil and biofuel to replace or extend fossil fuels and lubricants. Expansion of safflower can be expected with newly developed high oleic safflower cultivars having superior oil quality and yield for food and nonfood uses, value-added safflower meal for livestock uses, and improved safflower production technologies. Safflower oils and meals offer versatile products that will find many applications in livestock nutrition, human nutrition, and in technical industries. Research and development will continue to make safflower more cost-competitive.

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Analytical Chemistry Methods Used in the Research and Development of Safflower Varieties for the United States Northern Great Plains Region

Charles Flynn[1] and Jerald Bergman[1]

ABSTRACT

The Montana State University Eastern Agricultural Research Center (MSU-EARC) at Sidney, Montana has been actively involved in a safflower breeding and development program since 1973, with the North Dakota State University Williston Research Extension Center cooperating. Dr. Jerald Bergman, the principal safflower breeder, has been selecting and crossing safflower genetic lines to improve agronomic characteristics, disease resistance, seed oil content, yielding ability, and value added characteristics of safflower oil and meal. Dr. Bergman and Dr. Charles Flynn, research chemist, have developed and adapted a number of analytical chemistry techniques that have been critical to the advancement of this safflower research and development program. While some of these techniques were reported elsewhere by Bergman et al in 1997, and Daun and Mazur in 1983, the procedures used were detailed in this paper, so that other safflower scientists in the field have a single reference to assay seed oil contents, fatty acid compositions, tocopherols and meal phenolic glucosides.

Key words: *Carthamus tinctorius* L., high performance, liquid chromatography, nuclear magnetic resonance spectroscopy, gas liquid chromatography, tocopherol, phenolic glucosides

PROCEDURES

OIL CONTENT

Two procedures were used to determine the oil content (percent by weight) of safflower seed. One procedure was a wet chemistry technique while the second procedure was based on a whole seed determination.

Wet Chemistry Method

The safflower seed (at least 15-20 grams) was dried at 60° C. for 4 hours in an open metal container. The seed was then ground with a Krups (model KM 50) coffee grinder for approximately 1 min. An accurately weighed ground portion (3 to 5 grams) of this material was extracted using a Tecator HT 1043 Soxtec extraction system. The solvent used for extraction was hexane and the extraction time was 1.5 hours. The resulting oil extracted was weighed and this weight and the ground seed weight were used to calculate the oil content %. The oil obtained was frozen and stored in the dark for other analyses. The meal remaining after extraction was dried and also stored for analyses of chemical constituents.

Whole Seed Non-Destructive Method

The non-destructive technique utilized a Newport 4000 Nuclear Magnetic Resonance Spectrometer (NMR). This instrument was calibrated using both a high oleic safflower seed standard and a high linoleic type safflower seed of known oil content (from the wet chemistry method). Before the measurements were made the seed was thoroughly cleaned, volumed to 40 ml, and then dried at 40 C for a minimum of 4 hours. Approximately 40 ml of seed sample was used for the NMR oil analyses.

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The seed samples were weighted just prior to the NMR readings. Two 32 second reading were taken and the average of the NMR readings was reported. Seed oil content was reported on an oven-dried basis. The high oleic safflower seed standard was used to determine the oil content of the oleic safflower genetic lines and the high linoleic seed standard was used for the linoleic genetic lines as the fatty acid profile of the oil influences the NMR readings. A high linoleic standard used for a high oleic variety will over-predict its oil content as the oleic fatty acid contains 2 additional hydrogen atoms and NMR reads the number of hydrogen atoms in the oil (Lilleboe, 1998).

OIL TYPE IDENTIFICATION AND RELATIVE FATTY ACID PERCENTAGES

From 1 to 3 safflower seeds were cut in half with a razor blade and placed in a 2 ml aliquot of hexane in a 13mm x 100mm test tube. Only fully mature and developed cut seeds were used. Half seeds often were saved for future planting purposes (embryo end). The cut seeds were placed in hexane in the test tubes and then crushed with a glass rod for approximately 10 seconds. The mixture was allowed to stand (tube capped) for 1 hour and agitated every 15 minutes. The safflower oil in the solvent was then methylated using sodium methoxide. A 0.5 ml aliquot of the hexane containing oil was treated with 0.5 ml of benzene and 2 ml of 0.37 M sodium methoxide in methanol (20 g sodium methylate, Fischer Scientific, in 1 liter of anhydrous methanol). After standing covered with a Teflon stopper for 15 minutes, 2 drops of bromophenol blue indicator (100 mg. in 100 ml of absolute ethanol) were added to the test tube containing the mixture. The excess methoxide was neutralized with 1.0 M HCL until the indicator turned yellow. The excess HCL was then neutralized with drops of a sodium carbonate solution (5.3 g per 100 ml) until the light blue color reappeared. Water was added to the test tube until the liquid line was approximately 1 cm from the top. Approximately 0.5 ml of the resulting upper organic layer that separated, containing the methylated fatty acids, was removed with a disposable pipette and placed in a 2 ml crimp top auto-sampler vial, sealed and analyzed by gas-liquid chromatography (glc). The instrument used for glc analyses was a Hewlett Packard 5890 GLC equipped with a flame ionization detector (hydrogen was supplied with by a Packard hydrogen generator, Model 9200), auto-sampler and a J&W DB-225 glc capillary column (15m X 0.25mm ID, 0.25um, part no.123-2212). Helium was the carrier gas and nitrogen was the detector make up gas. The column temperature was programmed: 170° C initially and held there for two minutes then increased to 190° C at 3 degrees/min and held for 1.5 minutes at this temperature. Following the 1.5 min time period the column temperature was elevated to 220° C at 20 degrees/min and held at that temperature for 3 minutes to purge the column. Peak identification and response factors were determined using known samples of the appropriate methylated fatty acid esters, obtained from Nu-Chek-Prep, Inc., P.O. Box 295, Elysian, Minnesota, 56028.

The major fatty acid esters found in the safflower oil samples were the methyl esters of palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1) and linoleic acid (C18:2). The relative percentages of each of these esters were determined by integrating the area under each peak in the chromatogram. The area under each peak was found to be directly proportional to the percentage of each ester present, as confirmed by known standards. A group of minor fatty acid esters were also identified having relative percentages of .05 to 1.0%, and were determined to be methyl linolenate (C18:3), methyl arachidate (C20:0), methyl eicosenate (C20:1), methyl behenate (C22:0), methyl erucate (C22:1), methyl lignocerate (C24:0) and methyl nervonate (C24:1). Figure 1 shows a typical high oleic safflower oil chromatogram.

TOCOPHEROL MEASUREMENTS

Utilizing a High Performance Liquid Chromatograph (HPLC) manufactured by Waters Chromatography Division of Millipore Corp, the isomers of vitamin-E (α-tocopherol, β-tocopherol, γ-tocopherol and Δ-tocopherol) present in the safflower oil obtained by soxtec extraction, as described in the *Oil Content* section above, were identified and quantified.

The HPLC analytical procedure involved a Waters High Performance Liquid Chromatographic System including a high-pressure pump, an auto-sampler, a constant temperature column oven, and an adjustable fluorescent detector. An isocratic elution with .3% isopropyl alcohol in isooctane on a Waters Nova-Pak Silica, 60A, 4μm, 3.9 x 150 mm column (Part # 10025) at 35° C and a flow rate of 1.0 ml/min was used. With each chromatographic run of 40 samples, a set of concentration standards and an internal standard were included. The calibration samples of α, β, γ, and Δ-tocopherol as well as the internal standard 2,2,5,7,8-pentamethyl-6-hydroxychromin were generously provided by Eisai U.S.A., Inc., Glenpointe Centre, 4th Floor, 300 Frank W. Burr Blvd., Teaneck, New Jersey, 07666-6741. The sample injected was a 20 ul aliquot of the safflower oil diluted 1 to 10 with .3% isopropyl alcohol in isooctane containing 0.0144 mg/ml of the internal standard. Concentrations were calculated in mg. of tocopherol per 100 grams of safflower oil. Prior to analyses, the standards and the oil samples were kept cold and in the dark to prevent degradation of vitamin-E. Figure 2 shows the chromatogram obtained for Morlin variety safflower oil (Bergman et al., 2000).

PHENOLIC GLUCOSIDE MEASUREMENTS

Safflower meal obtained as described in the *Oil Content* section above was analyzed for the phenolic glucosides 2-hydroxyarctiin (1) and matairesinol mono-glucoside (2) by HPLC. These two compounds have been reported in the literature, with (1) having a cathartic effect on rats and (2) as the major constituent responsible for bitter taste of safflower meal.

The defatted safflower meal was screen through a 120 mesh screen. The screening was performed to effectively remove the safflower hull pieces from the seed flour. It had been shown by Lyon (Lyon et al., 1979) that the glucosides (1) and (2) were found only in the flour and not the hull. The flour (100 mg) was extracted with 3 ml of HPLC grade methanol (1 hour at 60°C) containing kinetin-riboside (Sigma Chemical cat. # k-3000, 150 mg./L) as a chromatographic internal standard. An aliquot of the extract was diluted in half with deionized water and analyzed by HPLC for the phenolic glucosides present.

An HPLC analytical procedure was developed that separated (1) and (2) as well as several other phenolic compounds present in safflower meal flour extract. The chromatography performed used a Water's HPLC system. This system consists of two high-pressure pumps, an autosampler, a constant temperature column oven, and an adjustable ultra-violet detector. A Waters Nova-Pak C-18, 60A, 4μm, 3.9 x 300mm column (Part # 11695) maintained at 34° C was utilized to effect the separations. The solvent system included solvent A - 0.020 M ammonium phosphate (pH adjusted to 3.5 with phosphoric acid) and solvent B - HPLC grade methanol. A computer controlled gradient elution pattern started with a solvent A/solvent B ratio of 69/31 and ran for 28 minutes. The ratio then went to a 10/90 ratio (solvent A/solvent B) over a 6-minute period where it was held for 12 minutes before returning to the original ratio. The detector was set at 280 nm. The compounds of interest eluted over the first 30 minutes.

Approximately 8 major peaks were found in the initial 30 minutes of the chromatographic run (Figure 3). Of the 8 peaks separated, 5 were identified using known samples generously provided by Hideya Saito, Department of Pharmacology, Hokkaido University, School of Medicine, Sapporo 060, Japan. Using the known samples of (1) and (2) that were provided, a set of concentration standards was made and this set was included with each chromatographic run. The other three peaks identified were N-feruloylserotonin (4), N-(p-coumaroyl) serotonin (5), and N-(p-coumaroyl) serotonin mono-β-D-glucopyranoside (6) as shown in figure 3. The areas of the peaks of (1) and (2) as compared to that of the internal standard were then used to construct a concentration calibration for measuring the amounts of these phenolic glucosides present in the flour. These values were calculated as a weight % of the flour weight.

RESULTS AND DISCUSSION

These analytical chemistry techniques have been critical to the early generation selections and use of multiple crosses among genetic lines to improve safflower for value added oil and meal characteristics. Approximately 12,000-15,000 samples are analyzed for value added oil and meal characteristics each year. Emphasis has been placed on the fatty acid composition of safflower oil, but the potential exists for the genetic improvement of safflower oil tocopherols, safflower meal phenolic glucosides, and other chemical constituents of these safflower products to further enhance the value of safflower for identity preserved products markets and specialty uses.

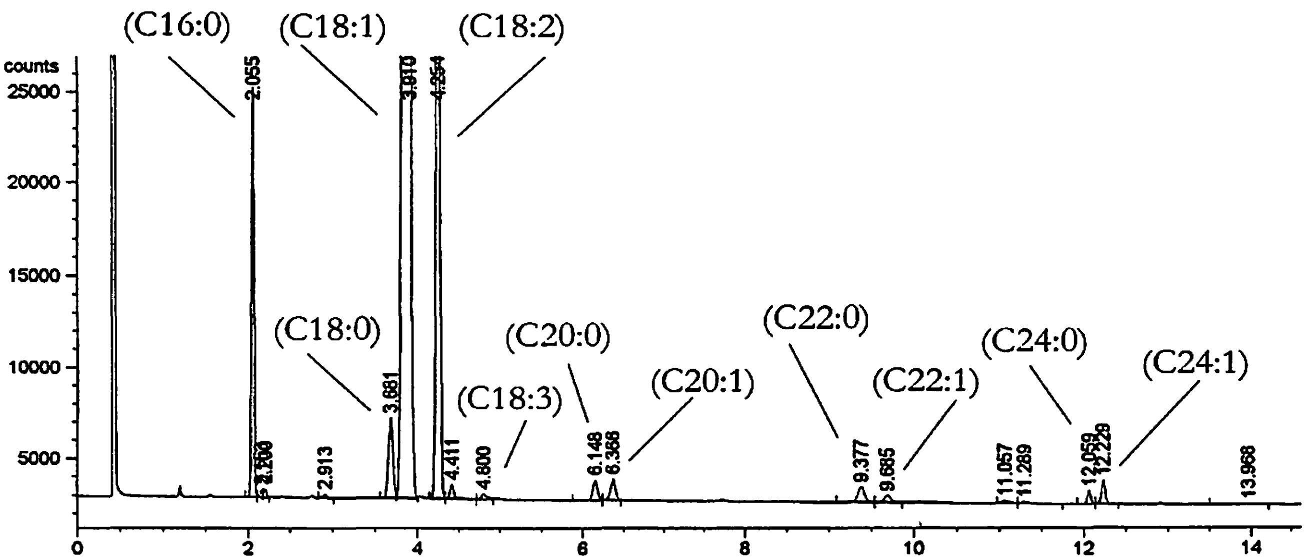

Fig. 1. Gas Liquid Chromatogram showing peak identification and fatty acid profile oil from a high oleic safflower breeding line.

PeakNumber	RetTime (min)	Peak Identification	Area %
1	2.055	(C16:0)	3.68964
2	2.153		0.07439
3	2.200		0.08388
4	2.913		0.05775
5	3.681	(C18:0)	1.3799
6	3.910	(C18:1)	81.75485
7	4.254	(C18:2)	10.49787
8	4.411		0.24014
9	4.800	(C18:3)	0.12371
10	6.148	(C20:0)	0.38789
11	6.366	(C20:1)	0.40844
12	9.377	(C22:0)	0.38178
13	9.685	(C22:1)	0.18185
14	11.057		0.07021
15	11.289		0.05584
16	12.059	(C24:0)	0.18661
17	12.229	(C24:1)	0.33848
18	13.968		0.08671

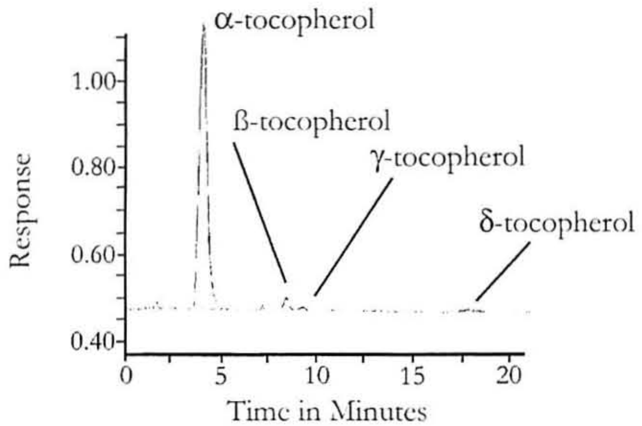

Fig. 2. High Performance Liquid Chromatogram showing peak identification and tocopherol profile of Morlin variety safflower oil.

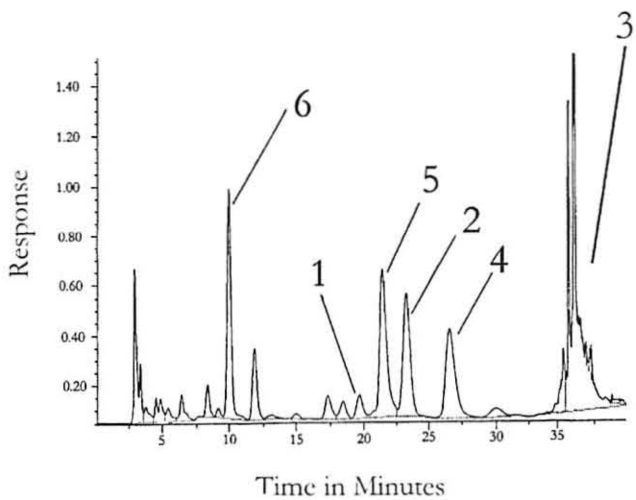

Fig. 3. High Performance Liquid Chromatogram of phenolic glucosides in defatted Morlin variety safflower meal.

1. matairesinol mono-β-D-glucoside
2. 2-hydroxyarctiin
3. Acacetin eluded in final wash phase
4. *N*-feruloylserotonin
5. *N*-(*p*-coumaroyl)serotonin
6. *N*-(*p*-coumaroyl)serotonin mono-β-D-glucopyranoside

Some of these procedures have been reported elsewhere by Bergman et al 1997, and Daun and Mazur in 1983. However, the procedures used have been detailed in this paper to assist other safflower scientists in the field.

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Safflower Petals and Their Chemical Composition

G. Nagaraj[1], G. Nirmala Devi and C.V.S. Srinivas

ABSTRACT

Safflower petals have immense medicinal and therapeutic properties as revealed by Chinese researchers. Petals of safflower from India were analyzed for carthamin (red pigment) (0.83%), oil (5.0%), protein (1.9%), ash (10.4%), fiber (12.2%), and fatty acid composition. The petal oil was shown, for the first time, to contain some short chain fatty acids (10:0, 12:0 and 14:0), gamma linolenic acid (GLA) along with fatty acids such as palmitic, stearic, oleic and alpha linolenic acids. Similarly the petals were rich in Ca (530 mg), Mg (287 mg), and Fe (7.3 mg/100 g) along with lower levels of Cu, Zn, and Mn. The organic and inorganic constituents together may provide the nutritional and medicinal values to the petals.

Key words: safflower petals, carthamin, fatty acids, minerals, protein, oil, fiber, ash moisture, *Carthamus tinctorius* L.

INTRODUCTION

Safflower has been under cultivation for centuries for its red and yellow pigments that are derived from the petals. Their importance continued until the synthetic dyes pushed them to the background and the seed oil gained its importance as a source of the unsaturated fatty acid linoleic acid. However, renewed interest in natural products and use of safflower petals by Chinese for varied medicinal purposes, have spurred interest in the utilization of petals in recent years. Many papers, in this regard, have been published at the Third International Safflower Conference, China, 1993 (Li Dajue et al) and Fourth International Safflower Conference, Italy, 1997 (Corelto A., et al). In view of the importance of safflower as a pigment source and for medicinal uses, the following studies were carried out to examine safflower petals for their minerals and fatty acid composition.

MATERIALS AND METHODS

Safflower petals were collected from the Directorate of Oilseed Research (DOR) farm, Rajendranagar, Hyderabad-during February-March, 2000 from the post rainy season crop raised during November 1999-March, 2000. The petals were mostly hand picked mostly after fertilization. They were oven-dried at 60° C and the samples were powdered in a Knifetec sample mill. The samples were frozen and stored in a freezer until analysis. The protein content (Nx6.25) was determined based on nitrogen analysis utilizing the Kjeltech system (AOAC, 1984). The oil content was estimated following the Soxtlet extraction procedure. Dry ashing was carried out in a muffle furnace at 600° C. The ash was utilized for determination of the minerals in an atomic absorption spectrophotometer. Crude fiber was also determined (AOAC, 1984).

The petal oil was esterified using methanolic KOH (Paquot, 1988). The methyl esters were separated using a AMIL-NUCON gas chromatograph with a flame ionization detector (FID) on two columns, namely DEGS and Silar 10C maintained at 180° C at a nitrogen flow rate 40 ml per minute. The FID and injectors were maintained at 220° C. Authentic methyl ester (Sigma Chemicals) standards were utilized for identification of the individual fatty acids. Carthamin was estimated using alkali extraction (Li Dajue et al., 1993).

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Table 1. Proximate composition of safflower petals.

Constituent	Composition
Moisture	4.9%
Protein	1.9%
Oil	5.0%
Ash	10.4%
Crude fiber	12.2%
Carthamin	0.83%

Table 2. Fatty acid composition of safflower petal oil.

Fatty acid	Composition
Decanoic (10:0)	3.9
Lauric (12:0)	1.8
Myristic (14:0)	3.4
Palmitic (16:0)	15.3
Stearic (18:0)	3.1
Oleic (18:1)	7.8
Linoleic (18:2)	46.7
Gamma linolenic (18:3) (n-6)	2.7
Alpha linolenic (18:3) (n-3)	16.8

Table 3. Mineral composition of safflower petals.

Minerals	mg/100g
Ca	530
Mg	287
Fe	7.3
Cu	0.8
Zn	1.0
Mn	0.8

RESULTS AND DISCUSSION

Safflower petals contained 1.9% protein, 5.0% oil, 10.4% ash, 12.2% crude fiber and 0.83% carthamin (Table 1). It is significant to note that petals had a higher level of ash and somewhat lower level of fiber as compared to that of seeds reported by (Nagaraj, 1990). The ash content in turn was rich in calcium, magnesium, and iron as well as the microelements copper, zinc and manganese (Table 3).

The fatty acid composition revealed the presence of short chain fatty acids (decanoic, dodecanoic and tetra decanoic acids) and the pharmaceutically important n-6 fatty acid gamma linolenic acid. These are in addition to the fatty acids palmitic, stearic, oleic, linoleic and alpha linolenic acids. The major fatty acid was, as expected, linoleic acid (47%) followed by alpha linolenic acid (16.8%) and palmitic acid (15.3%). The short chain fatty acids are easily digestible while the gamma linolenic acid (2.7%) has anti-fungal and anti-microbial activity for treating skin infections (Gurr, 1997, Lapinskas, 1993). The essential mineral nutrients along with the fatty acid composition of the petals may impart the medicinal properties to the safflower petals. Many people have started using safflower tea or decoction to treat rheumatism, for body invigoration and good health.

Safflower petals can be harvested at the rate of 96 kg per ha, under the present standards of cultivation in India, but this is currently not being done. There is potential to utilize the petals and their products for health foods as well as textile dyes (Sarojini et al., 1995). Additional detailed pharmacological evaluation is needed before the products would be recommended on a wider scale. Already some Indian pharmaceutical companies are showing interest to utilize safflower petal products.

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Nutritional Characteristics of Three Indian Safflower Cultivars

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ABSTRACT

Three Indian safflower cultivars were examined for their seed and oil quality characters. The oil content ranged from 26-32% and the protein content from 21-23%. Linoleic acid ranged from 74-78% of the fatty acid composition. Mineral constituents like Zn, Cu, Mn and Fe levels along with the vitamins thiamine, B-carotene and the tocopherols were estimated. The anti-nutrients phenolics, oxalic acid and phytic acids were also studied. Among the three cultivars examined HUS 305 had the highest oil, protein, linoleic acid and thiamine contents. The cultivar A1 had a lower oil content and lower linoleic acid content, but had higher total tocopherols and gamma tocopherol.

Key words: Seed quality, oil quality, nutrients, anti-nutrients, linoleic acid, safflower, *Carthamus tinctorius* L.

INTRODUCTION

Safflower seeds provide a health promoting oil rich in the essential fatty acid linoleic acid. India is the world's major safflower producing country, accounting for a production of 0.325 million tons (34.3% of the world production) from an area of 0.53 m ha (47% of the world safflower production area). Safflower is cultivated in the post-rainy season during October to March in some states in India. A large number of cultivars have been released for cultivation (Hegde, 1995). The general seed and oil quality characteristics of the Indian safflower genotypes have been studied (Nagaraj, 1993, 1994), but the nutritional and anti-nutritional constituents have not been examined in detail. In the following study an attempt in this direction has been made. For this purpose three cultivars were selected. The cultivar A1, released for cultivation all over India, the cultivar Manjira, released for cultivation in the state of Andhra Pradesh, and the cultivar HUS 305, a thin hull, high oil cultivar, tolerant to salt and wilt (Hegde, 1995).

MATERIALS AND METHODS

Seeds of the cultivars Manjira, HUS 305, and A1 were collected from the crop grown during 1997-98 from the Rajendranagar farm of the Directorate of Oilseeds Research, Hyderabad. Prior to analysis the sundried seeds were powdered in a knifetech mill and frozen. The oil content was estimated in a nuclear magnetic resonance oil analyzer (NMR) Model Oxford MQA 6005. The protein content was calculated based on nitrogen content (Kjeltech estimation, with a factor 5.3). The oil for determination of fatty acids was extracted using a Komet oil expeller. The oil was esterified using methanolic-KOH (Paquot, 1988).

The methyl esters were separated using a AIMIL-NUCON 5700 gas chromatograph fitted with a flame ionization detector (FID) on a DEGS column maintained at 180° C. Using nitrogen as carrier gas with a flow rate of 40 ml/min, authentic methyl esters (Sigma chemicals) and their retention times were utilized for identifying the fatty acids. A high performance power pack integrator was utilized for quantification of fatty acid data. Minerals were estimated as per the Association of Official Analytical

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Chemists procedure (AOAC, 1984). Phenolics as given by Swain and Hillis, (1959), tocopherols as by Indyk, (1990), thiamine and B-carotene as by Raghu Ramulu et al., (1983) in the seed oil samples were also determined.

RESULTS AND DISCUSSION

The seed protein content ranged from 21 to 23% while the seed oil content was 26 to 32% (Table 1). HUS 305 had the highest protein content and Manjira the lowest. A1 had the lowest linoleic acid content, an essential fatty acid, which was the major fatty acid, ranging from 74-78% with the maximum being in HUS 305. The range of the other fatty acids were palmitic = 5.5 to 7.5%, stearic = 1.9 to 3.2%, and oleic = 11.7 – 17.0%. Oleic acid was maximum in A1 while it was least in HUS-305. The protein content of the Indian cultivars were in agreement with those reported earlier (Guggolz, et al., 1968) while the oil contents were lower, which might be due to higher hull and less kernel content (Nagaraj and Reddy, 1997). Among the micronutrients analyzed A1 had higher levels of Zn (92.4 mg/kg) and Mn (37.4 mg/kg while HUS 305 had the highest level of Cu (26.6 mg/kg) (Table 2). Manjira had a higher level of Fe (31.0 mg/g). The mineral contents reported here were higher than those reported earlier (Deosthale, 1968). This may be due to soil differences where the safflower was grown. Total phenols in the three cultivars were in the range of 59-64 mg/100g Oxalic acid content ranged from 9 to 12 mg/100 g while phytic acid levels were very low at 0.2 to 0.3 mg/100 g (Table 2). In general these anti-nutrients (phenols, phytic acids and oxalic acids) are low and since safflower seed meal is rarely a consumed food item, one need not give much importance to these constituents.

The total tocopherols ranged from 554 (Manjira) to 594 (A1) mg/kg oil (Table 3). Alpha tocopherols were the main constituents (450-486 mg/kg). A1 cultivar had higher gamma tocopherol.

Table 1. Seed and oil quality of three Indian safflower cultivars.

			Fatty Acid Profile Percentage			
Cultivar	Protein	Oil	16:0 Palmitic	18:0 Stearic	18:1 Oleic	18:2 Linoleic
Manjira	21.0	28.1	5.5	2.3	15:1	77.0
HUS 305	23.0	32.1	6.3	3.2	17.7	78.0
A1	22.1	26.5	7.5	1.9	17.0	74.0

Table 2. Minerals and antinutrients in the seeds of three Indian Safflower Cultivars.

	Minerals (mg/kg)				Phenols mg/100g	Oxalic Acid mg/100	Phytic acid mg/100g
Cultivars	Zn	Cu	Mn	Fe			
Manjira	72.0	24.0	17.8	381.0	62	10	0.3
HUS 305	62.8	26.6	8.0	103.0	59	12	0.2
A1	92.4	25.8	37.4	167.0	64	09	0.3

Table 3. Tocopherols and Vitamins in three Indian Safflower Cultivars.

	Tocopherols mg/kg oil				Thiamine mg/kg	Beta carotene mg/kg
Cultivar	Alpha	Beta	Gamma	Total		
Manjira	450	56	48	554	480	750
HUS 305	470	48	46	564	500	740
A1	486	44	64	594	472	755

Based on the studies carried out it is inferred that HUS 305 is better with respect to oil, protein, linoleic acid and thiamine contents. The cultivar A1, though it had lower oil content, could be considered better with respect to oil stability, since it had the lowest level of linoleic acid (74%) along with higher levels of oleic acid, total tocopherols and gamma tocopherols. The variations with respect to other constituents were not very wide. A1 is a popular cultivar grown all over India. Manjira, another important cultivar, had characteristics that were intermediate between the above two cultivars. HUS 305, a thin-hulled cultivar, is well known for its higher oil, but is a low yielder, however, its other nutritional characteristics should prompt its wider cultivation.

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Morphological Structure and Topography of Nectaries in *Carthamus tinctorius* L. Flowers

L. F. Kharitonova[1] and T. E. Vakhrusheva[2]

ABSTRACT

Research has been carried out on the morphological structure of nectaries in safflower (*Carthamus tinctorius* L.) flowers. An original drawing of the flower is presented. The nature of blooming the *C. tinctorius* L. flowers under the conditions of the Leningrad Region is reported in the paper.

Key words: blooming, *Carthamus tinctorius* L., flower, morphological structure, nectar, nectar-bearing tissue, nectary, safflower, topography

INTRODUCTION

Excretion of nectar by nectar-bearing tissue is an important condition for accomplishing the processes of pollination and fertilization in the flowers of *Carthamus tinctorius* L. It is directly related to seed productivity. Besides that, the morphological structure of nectaries can be employed as a diagnostic character in the plant systematics, and can serve as an additional characteristic feature in the definition of species.

MATERIALS AND METHODS

The study of the morphological structure of nectar-bearing tissue and its topography in the flowers of the species *C. tinctorius* L. was conducted on living material and on material fixed in 70% alcohol solution. A binocular lens MBI-I and a drawing apparatus RA-4 of home construction was used. The plants of two accessions available in the N.I.Vavilov All-Russian Research Institute of Plant Industry (VIR) collection were employed in the experiment: Tashkentskij-51 (k-261) and Milyutinskij-114 (k-262). The plants were grown in the Pushkin laboratories of VIR (Leningrad Region) from the seeds reproduced at the Astrakhan experiment station of VIR.

RESULTS AND DISCUSSION

The flower of *C. tinctorius* L. was described and the nature of safflower blooming under the conditions of the Leningrad Region was studied. For the first time the morphological structure and topography of nectaries were investigated and defined as individual systematic characters in the definition of the species.

The flower of *C.tinctorius* L. is tubular-shaped, and symmetric. The poppus is reduced up to transparent long hairs. The tube of the corolla is formed by 5 petals, which are fused. The tube is dark-yellow at the place of its attachment to the apex of the ovary. The petals are spreading, 5mm in length, typically orange-red inside. Five stamens with fused anthers are located inside the tube of the corolla. Filaments are yellowish, anthers are white, and pollen is 3-pored. The pistil is formed by two joint carpels. The style of the pistil ends with protruded pubescent stigma. The flower is typical, and the ovary is inferior. Under the conditions of the Leningrad Region the achenes are left abortive.

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In safflower the floral nectaries are 1.5 – 2 mm long. Morphologically the nectaries are very clearly expressed. The nectaries are dark-yellow and located on the apexes of inferior ovaries. The nectaries, stuck together into a ring at the base of the pistil's style, repeat the tubular form of the corolla (see Fig. 1). This form of the nectary appears to be the most typical diagnostic character in systematics of flower plants. Nectar excreted from the cells of the nectar-bearing tissue is accumulated in the tube of the corolla. According to many authors' opinion, the excretion of the great amount of nectar takes place due to a ring form of the nectary.

The possibility of revealing polymorphism in the morphological structure of nectaries in the genus *Carthamus* L. is of special interest in finding out new systematic characteristics. Further scientific activities are related to these aims.

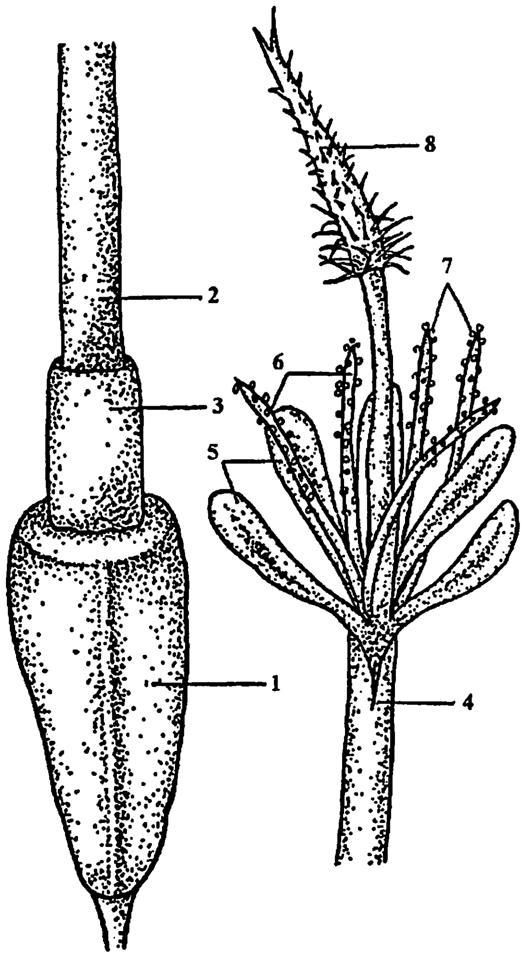

Fig. 1. Morphological structure of the flower and nectar-bearing tissue in the safflower (original).

1. inferior ovary
2. abstyle of the pistil
3. abnectary
4. abtube of the corolla
5. abspreading of petals
6. abstamens
7. abpollen grains
8. abstigma of the pistil

Method of Isolation and Identification of Carthamin in Safflower. Application's Perspectives in Russian Food Products

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ABSTRACT

Carthamin and yellow pigments were extracted from safflower florets of different colors (from yellow to red) and were identified by using thin-layer chromatography and spectrophotometry. It was shown that safflower flowers contain carthamin and yellow pigments in different proportions depending on the color of the flower. Because these dyes are natural, they are potentially useful for dying different food products in cases where other synthetic dyes are undesirable as an additive.

Key words: thin-layer chromatography, spectrophotometry, food dye, *Carthamus tinctorius* L.

INTRODUCTION

In most cases, synthetic, mineral and natural pigments are used as dyes for food products. Most synthetic pigments have carcinogenic properties, whereas natural pigments have biological value and belong to natural components of food products.

In the future, natural food dyes will continue to be widely acceptable in food products due to their non-allergic and non-carcinogenic properties. In Russia and elsewhere, there is an active search of natural sources for food dyes. The problem of extracting natural pigments from safflower (*Carthamus tinctorius* L.) is very interesting for many branches and departments of Russian Academy of Agricultural Sciences.

Safflower has floret types ranging in color from yellow to red. Two water soluble yellow pigments and one water insoluble red pigment (carthamin) can be extracted from safflower florets. These pigments have some medicinal values and are very promising for uses in food products. The structure of carthamin was studied and reported (Obada and Onodera 1979).

MATERIALS AND METHODS

Plant material. Yellow, yellow-orange, and orange-red samples of safflower florets were provided by N. I. Vavilov of All-Russian Research Institute of Plant Industry. They were obtained from Krasnodar (Russia) and Uzbekistan. Florets were picked one day after flowering, subjected to drying in shade. Then, safflower florets were ground to a powder, packed in paper packets, and stored at room temperature.

Chemicals. The chemicals used in the present study were obtained from the following sources: cellulose microcrystalline LT Chemapol (Czechia), silica gel plates for thin-layer chromatography "*Sorbfil*" Sorbpolimer (Russia). All other chemicals used were of an analytical grade of purity.

Extraction of water insoluble carthamin and yellow water-soluble pigment from safflower florets was done as described previosly (Kulkarni D.N. et al. 1997). Then, water extract used for

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spectrophotometric measurement and extract of water insoluble carthamin used for adsorption of carthamin.

Adsorption of carthamin from acid extract. This was done using a modified method (Kulkarni D.N. et al. 1997). Cellulose powder (0.5 g) was suspended in acid solution, stirred with a magnetic stirring apparatus for 30 minutes at room temperature, and centrifuged at 3500 rpm for 15 minutes. Supernatant was discarded. The pellet was resuspended in distilled water and centrifuged. The washing was repeated 5-6 times under the same conditions until a colorless supernatant was obtained. The reddish cellulose pellet was suspended in 10 ml of acetone, intermixed for 5 minutes, then centrifuged for 5 minutes at 3500 rpm. The acetone layer was filtered through cloth and used for spectrophotometric measurement.

Chromatography and spectrophotometric. Thin-layer chromatographic identification was employed as reported (Olshanova K.M. et al. 1970). R_F values of yellow pigment and carthamin were examined on silica gel thin-layer plates using (v/v): pyridine: isoamyl alcohol: isobutanol: ethanol: distilled water (3: 3: 3: 4: 4); pyridine: isoamyl alcohol: isobutanol: ethanol: 25% ammonia (3: 3: 3: 4: 4); 2-propanol: ethanol: distilled water: formic acid (10.0: 11.7: 10.0: 1.7); 2-propanol: ethanol: distilled water: formic acid (10.0: 11.7: 10.0: 11.7); distilled water: isobutanol: ethanol: pyridine (4: 7: 4: 4); distilled water: isobutanol: ethanol: formic acid (4: 7: 4: 4); distilled water: isobutanol: ethanol: formic acid (4: 14: 4: 4).

Spectrophotometric measurement of carthamin (acetone washing of reddish cellulose) and yellow pigment (water extract) was followed from 350 nm to 650 nm in a 1.0 cm light path cuvette (SF-46, Russia).

RESULTS AND DISCUSSION

The experiments showed that some additional operations were needed to obtain carthamin in the concentration and purity needed for analysis. These were increasing the amount of sorbent - cellulose powder from 1.0 g, magnetic stirring for 30 minutes after suspended filtration through filter cloth, and increasing the number of repeated elutions.

The carthamin content in extract depends on the color of the flower. Thus, the extract from orange-red flowers contained the maximum amount of carthamin, whereas carthamin was not detected

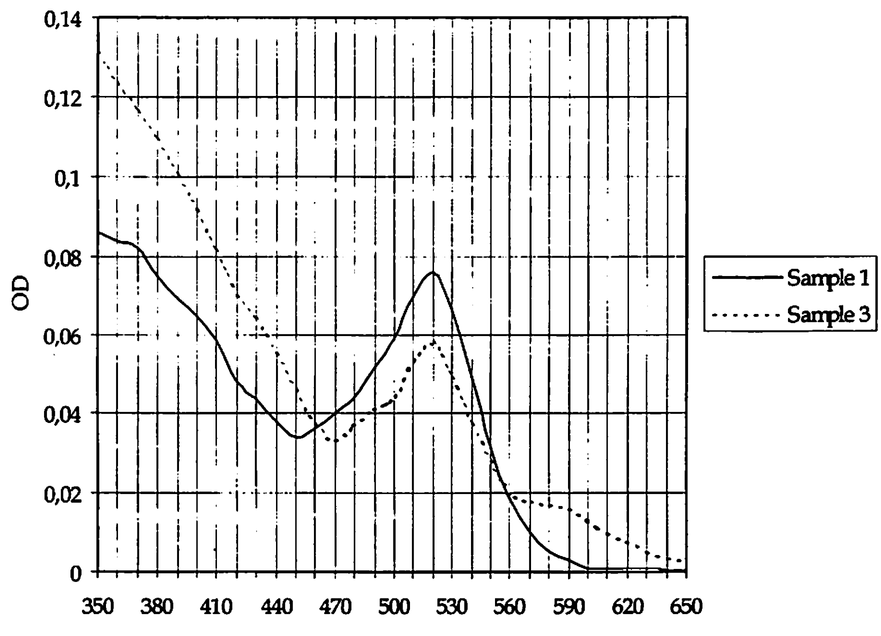

Fig. 1. Optical density (OD) of acetone washing of reddish cellulose (sample 1 and 3.)

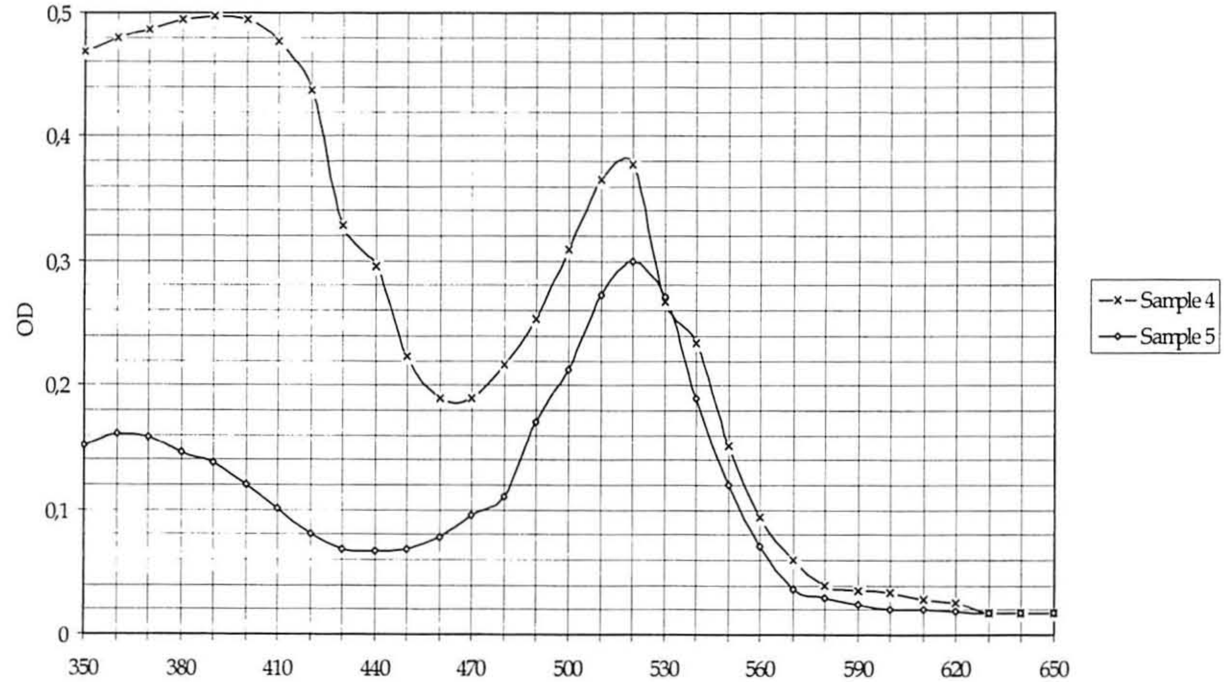

Fig. 2. OD of carthamine of acetone washing of radish cellulose (Sample 4 and 5).

in the extract from yellow flowers. This is confirmed by the spectrophotometric properties of extracts. Spectrums of extracts of sample m 1, 3, 4, 5 (Fig. 1, 2) have distinctive maximum peak of light absorbing at 520 nm. This peak is typical for carthamin (Saito K., Takahashi Y. 1985). The spectrum of sample m 2, presented on Fig. 3, has an exception. It doesn't have a peak at 520 nm, thus can be explained by the absence or trace amount of carthamin and a high amount of water soluble yellow pigment or pre-carthamin.

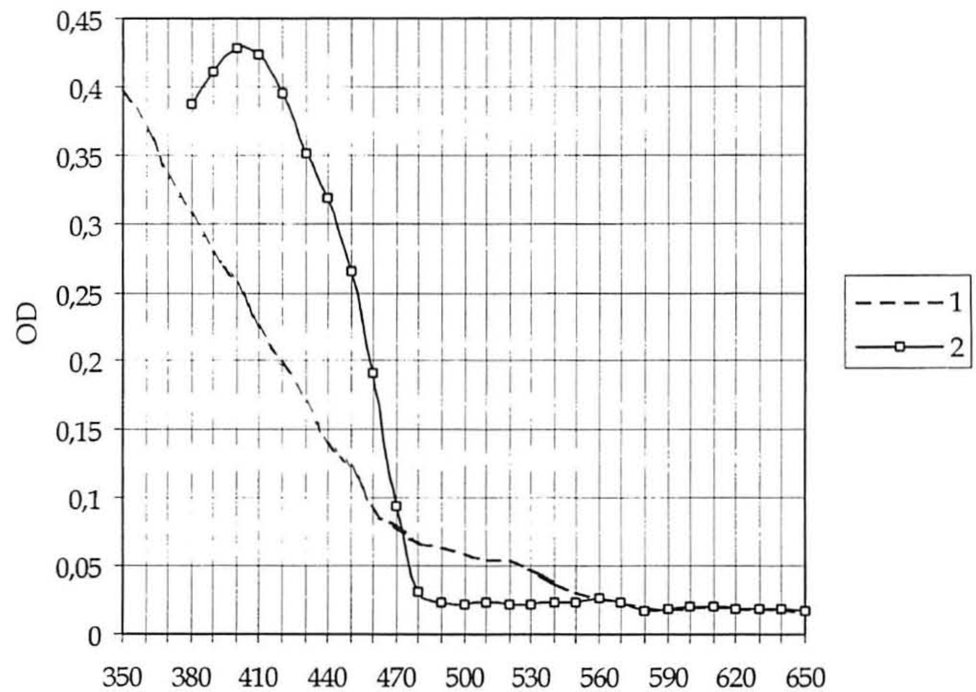

Fig. 3. Optical density (OD) of acetone washing of reddish cellulose (1) and of water extract (2) (sample 2)

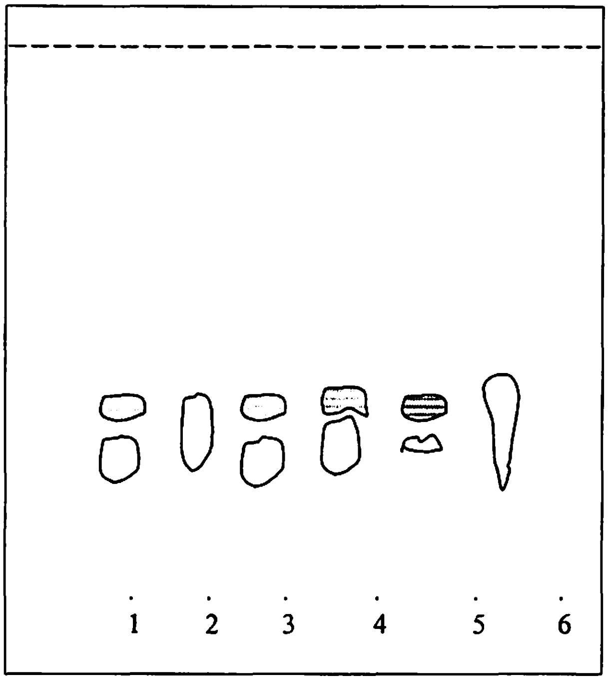

Fig. 4. Colorific pigments from safflower flowers in thin layer chromatogram. Positions 1-5 represent pigments from acetone washing of reddish cellulose. Position 6 represents water-soluble yellow pigment from safflower.

For the purpose of confirmation, the results of the spectrophotometric analysis of extracts went through chromatic division on silica gel plates for thin-layer chromatography. Different elution systems were examined and the best was defined: distilled water: isobutanol: ethanol: formic acid (4: 7: 4: 4). The chromatogram of the extracts made of samples of safflower flowers is presented on Fig. 4. The ratios of the distances covered by the center of the spot which belong to component of chromatographic mixture to the distances covered by the front of dissolvent (R_F) are given in the table 1. Besides carthamin there are yellow pigments in acetone washing of reddish cellulose. This can be connected with inadequate purity of acetone washing of reddish cellulose.

Table 1. The results of chromatographic and spectrophotometric research of acetone washing of reddish cellulose

Sample	Color	Pear of light absorbing		The value of R_f	Remarks
		max, nm	min, nm		
1) Flowers (Uzbekistan, 1992)	orange-red	520	450	0.54 0.63	Yellow pigment Carthamin
2) Flowers (Russia, 1994)	yellow	400	-	0.58	Yellow pigment
3) Flowers (Russia, 1994)	orange - yellow	520	470	0.54 0.63	Yellow pigment Carthamin
4) Flowers (Russia, 1994)	orange-red	390 520	440	0.54 0.63	Yellow pigment Carthamin
5) Flowers (Russia, 1996)	orange-red	360 520	465	0.60 0.54	Yellow pigment Carthamin

Thus, the potential of carthamin and yellow pigments extraction from safflower grown in Russia is shown. The relation between the color of the florets and the amount of carthamin in these florets is determined. These pigments may be used as food dyes.

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Current Situation and Prospects of Safflower Products Development in China

Wang Zhaomu[1] and Du Lijie[2]

In recent two decades, the agricultural production and farm economy developed rapidly, much progress has been made in safflower research, and its production also expand fast. In view of the high content of linoleic acid (about 80%) of safflower seeds, it can control arteriosclerosis, reduce serum cholesterol, and has significant curative effect to hypertension, high blood fat, coronary heart disease, the middle-aged and old obesity. It can control blood pressure, enhance physique, improve microcirculation, and recover nerve function if taken for long. Chinese experts think highly of the future of safflower industry, some curative medicines have been developed, such as Yi-Shou-Ning, Mai-Tong, Xin-Nao-Kang, Safflower injection, Safflower powder injection, etc.; health care medicine, such as Safflower oral solution, Safflower emulsion, Safflower tea, Safflower cola; health care food, such as Safflower capsule, Safflower health care oil, health oil, Mixed oil, etc. Development of safflower industry exist large market in China, it will bring with the glad tidings for 200 million of patients suffered heart and brain vascular disease, it is also good news for the middle-aged and the old. Safflower industrialization in China can surely be realized, and will also make contribution to the health of mankind.

1. Current situation of safflower research and production in China

Since reform and opening up in China, the agricultural production and farm economy developed rapidly, we have the population amount to 22% of the world, but live on only 7% of the arable land of the world, and have made great achievements for worldwide attention. Agriculture has broken through the situation of "single-product economy", modernization level was heightened further, and the agricultural development began to step into new stage of "high yield, good quality and high efficiency." Due to the special function, safflower research and production have got rapid development.

Progress of safflower research

Since 1970s of twenty century, on the basis of collection, collation, study and utilization of 1000 accessions of Chinese local varieties by domestic safflower experts, the Botany Garden, Institute of Botany, the Chinese Academy of Sciences introduced more than 1500 accessions safflower germplasms from the Introduction Station of Western Part, Department of Agriculture of America, mediated by world-famous safflower expert—professor P.F. Knowles. Institute of Botany, CAS, and Institute of Industrial Crops, Xinjiang Academy of Agricultural Sciences, as well as Institute of Oil Crops, Yunnan Academy of Agricultural Sciences have systematically studied 2700 accessions of domestic and abroad safflower germplasms in eight years, obtained several hundreds million data, and published two books on safflower in 1992(Characterization and Evaluation of Safflower Germplasms, Evaluation and Utilization of World Safflower Germplasms). Bank of National Variety Resources of CAAS has collected those valuable resources. World safflower germplasms have rich genetic diversity, concerning to the quality, content of linoleic acid distributed in 11.13%~85.60%, oleic acid in 6.74%~81.84%, stearic 0.01%~5.70%, palmitic 0.03%~29.03%. The average oil content of 2002 accessions germplasms from 47 countries is 28.70%, the range is 11.48%~47.45%. With these valuable

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resources, we have developed more than 10 new varieties of high yield, good quality and disease resistance by systematically breeding, hybridization breeding and recurrent selection methods. This progress greatly promoted safflower production in China. In recent years, based on improvement and creation of excellent genetic resources, the emphasis was laid on developing hybrid. On high yield cultivation research, taking water and fertilizer as center, density and variety as basic content, increasing yield and improving quality as objective, carried out research of technical system of integrated cultivation, and achieved valuable results.

General survey of safflower production

In China, safflower cultivation have long history, it was introduced early in Han Dynasty. In that time, the functional part used as dye and medicine was florets. Since 1970's of twenty century, people began to cultivate it as oil crop. In China, safflower resources distributed widely around the country, and had many varieties. From Hilongjian, located on the edge of sub-cold zone to Hainan Island, located on the edge of tropical zone, from the Qinghai-Xizang Plateau, which has high elevation to Jiangsu, Zhejiang, Fujian that have low elevation, all cultivated safflower.

The sowing area of safflower in China is about 36~55 thousand ha, purchasing dry florets is 1800~2600t, seeds 50~80 million tons annually, not only can meet the need domestically, but export about 1/4~1/5 of total. Concerning to the cultivation area and production, Xinjiang ranked in the first in China, its dry florets and seeds production amounted to about 80% of the total of China, the next were Yunnan, Sichuan, Henan, Hebei, Shandong, Jiangsu, Zhejiang, etc. In recent years, because of spreading good variety, improving cultivation conditions, not only the growing area enlarged 40~50%, but the dry florets and seeds yield increased 34~46% and 18~27%, respectively, the florets yield reached to 140~270 kg/ha, seeds yield to 1360~1700kg/ha, the highest to 3800 kg/ha. In China, in order to increasing the value per unit area, farmers more like to grow spine-free varieties which combine high florets yield with high oil content integrity, the spiny varieties were only grown in area where people have no time to pick the florets. To develop safflower industry, it is expected that the growing area of safflower in China will surpass 100 thousand ha.

2. Safflower products and development prospects in China

It was estimated by WHO that people who died of heart and brain vascular disease annually exceeded 12 million, and still had the trend of ascendant, at present, the heart and brain vascular diseases have become the most important two killers in various human diseases, they raised up from 6.6% and 5.5% to 22.7% and 21.1%, respectively. Since reform and opening-up for 20 years in China, national economy grew rapidly, living level was continuously improved, the consciousness of health care have significant strength. In aspect of disease prevention and cure, the cure pattern has been changed to prevention pattern. In diet structure, the pattern has changed from eating one's fill and eating for taste to pattern of diet therapy. Looking forward to health and promise longevity have become the common desire and aim of modern society of China.

2.1 History and current situation of safflower products development

Safflower is a kind of special industrial crop which sum up all of medicine, dye, oil crop and feed in one, its floret, seed, stem, leaf and stalk all can be utilized.

In China, safflower is regarded as "the most important medicine for invigorating the circulation of blood and reducing stasis," and its applying has had long history. Chinese traditional medicine is treasure of China, this great achievement have been admitted, applied and developed by many foreign countries. The dry florets of safflower are mainly used to cure amenorrhoea, dystocia, postpartum lochia not going, feeling ache of blood stasis, injuries from falls, fractures, contusions and strains, etc.. In recent years, safflower also was made as tablet, injection and oral liquid, etc., applied to cure coronary heart disease, brain thrombus, and vasculitis, etc. In China safflower was taken as one of 62 species edible Chinese traditional medicines. Safflower can be taken as both curative medicine and health care medicine, even as functional food, and widely used in prevention and cure of disease of heart and brain blood vascular, high blood pressure, diabetes, microcirculation block, blood stasis, etc., it is a good health care product which worth to spread.

In the past half century, many countries take the safflower seed oil as edible and high grade cook oil, while in China it is just the thing of recent few years that safflower seed oil is taken as valuable edible oil. Because unsaturated fatty acids of safflower are so high (more than 90%, in it linoleic acid amount to 80%) that it is regarded as "king of the linoleic acid," it is the best edible oil in the world, and it has significant function to control the arteriosclerosis, decline the triglyceride and cholesterol, so the medical value of safflower should be universally accepted. The safflower preparation and products of China should go out of the country and head for the world, and make contribution to the health of mankind. Safflower products in China are mainly developed from dry florets and seed oil.

2.2 Development of safflower dry florets and its products

Florets of safflower can be made to many products, besides dyes, Chinese traditional medicine, pollens and natural pigments, it can also be processed to various products for different uses, this make safflower increase its value highly, and bring benefit to mankind.

2.2.1 Medicinal use

It can be made into various types of medicines and health care products to control disease of heart and brain blood vascular, gynaecology, such as Chinese medicine pill, medicinal powder, tablets, injection and oral liquid, etc. It can also be made into various medicinal extract, used in massage, injury, arthritis, frostbite, burn and scald, swelling and ache, etc. for invigorating blood and reducing stasis; medicinal liquor; various Chinese medicinal pills and sugarcoated pills, etc.

2.2.2 Food use

It can be used as dyes in candy, cake, drink, dairy products, spice, wine, paste, flour food, tin, etc.

2.2.3 Cosmetics

It can be used as dye in the hair milk, face oil, perfumed and bath soap, and it can also dye the furniture.

2.3 Development of safflower seed oil and its products

Besides used as edible oil, safflower seed oil also has other development and utilization value. Safflower oil contains unsaturated fatty acid more than 90%, while linoleic acid belong to n-6 series active substance of essential fatty acid for human body, it has important physiological function for human body to form cell and promote lipid metabolism. Therefore, based on safflower seed oil, Chinese scientists have developed many other products, such as safflower salad oil, mixed oil, health oil, health care oil, safflower emulsion, safflower capsule, linoleicide ethylester, Yi-Shou-Ning, Mai-Tong, Xin-Nao-Kang, oil for injuries of falls and fractures, nail oil, skin care cream, oil color, etc. series products. It brought with the glad tidings for patients suffered heart and brain vascular disease, it was also good news for the middle-aged and the old, and it has splendid future of development.

3. Problems and strategies of developing safflower industry in China

3.1 Problems and challenge which developing safflower industry faced

3.1.1

Development of modern agriculture has broken through the narrow extent of past, various agricultural by-products circulated not only by trans-region, trans-province, but trans-nation, especially after China joins WTO, the price will get in touch with that of international, thus it will face the shock of safflower import and severe challenge of international price.

3.1.2

In China, the relation between supply and demand of market of agricultural products has changed essentially, the era of shortage ended, most of the agricultural by-products have changed from "sale market" to "buy market". Because of the surplus of edible oil, will undoubtedly cause the safflower oil slow selling.

3.1.3

The industry development of safflower is short of fund for products exploit, lack the developmental program for agriculture, industry and trade unifying, lack organic combination and planning work of industrial chain for pre-, medium- and post-production.

3.1.4

The conditions of equipment and technique for products processing are poor, small but all-round decentralized management, the situation of equipment obsolete and technique lagging behind have not yet been changed, the first grade row material produced third grade products, the consciousness of famous brand is not strong, products lack competitive capability in market.

3.1.5

In western region, the consciousness of scientific farming is not strong in safflower production, the quality of laborer and skill for production are poor, the gap between east and west continuously enlarge, lacking the policy of good quality matching high price, seriously restrain the spreading and applying speed of new varieties and new techniques.

3.2 Measure and strategy for realizing safflower industrialization

In China, safflower production mainly concentrated in west region, we should get the chance of "west region development,", readjust the farming structure, to accelerate development of the dominant industrial is the main content of agricultural exploit in west region.

3.2.1

Taking road of combination, developing safflower industry. Middle and small enterprises for safflower developing should combine, putting the farming of decentralized management together, broadening investment channels according to the developing pattern of scientific research with systematization, row material from breeding base, market forming network, taking in funds from various aspects, establishing Chinese safflower group. Realizing the effective combination models that are: market unites enterprises, enterprise promotes agricultural bases, company plus farmers. Forming some kind of safflower industry that take market as guide direction, benefit as center, realizing management of enterprise pattern, standardized running, specialized development, socialized serve.

3.2.2

Taking high content of science and technology as the starting point to realize development of safflower industrialization and competition. The exploiting of safflower products should insist on high start point, high standard, and high quality. In aspect of types for exploitation, we should follow that we should have what others have not, and get better one if others have, all of these should have our own characteristics, to promote China to take a better situation in safflower market of the world.

3.2.3

We should take the market sale of safflower products as the key of development of safflower industry. Market is cruel, only make effort in market sale, can we occupy the leading position in market competition. In new products development in future, we should recommend "market sale go ahead," adjust production plan according to of market need, develop the products that production match the sale. When working out plan of safflower production, we should mainly focus on domestic market, gradually open up and occupy abroad market. Still more, we should meet the need of different level consumers for safflower products.

3.2.4

We should watch out the image of the enterprise, put into effect of brand strategy. The enterprise, which would not like to become famous brand one, is not possible success. Whether safflower products can occupy market or not, besides guarantee the quality of products, still need pay much attention to create famous brand. Today consumer's consciousness and concept of famous brand are stronger and stronger, especially in international market, this phenomena is more significant.

3.2.5

To realizing safflower industrialization, we should aim to establish modernized enterprise. To organize qualified scientists of different subjects, not only heighten the scientific quality of the public, but more the staffs. It should introduce the competitive mechanism, raise the image and quality of enterprise, and cause it form group and specialization.

To develop safflower industry in China, we should at first free ourselves from old idea, accelerate our step of reform. The second we should deal with the key problems of funds, qualified personnel and techniques. The third is to work out concrete design seriously, and put into effect with the best of care organization, the safflower industrialization in China will definitely be realized.

Studies on the Extraction of Safflower Yellow B and Carthamin Red Pigments From Safflower Florets as Food Colorant

D. N. Kulkarni[1], K. D. Kulkarni, and S. B. Tathe

Safflower floret pigments are good replacements for synthetic food colors. Studies were conducted for the standardization of extraction conditions for water-soluble safflower yellow B and carthamin red/orange pigments. The extraction conditions included solvent ratio, extraction time, temperature, pH, shaking time and speed. The colors extraction levels were monitored using spectrophotometric analysis of pigments. The colors characterization with respect to absorption and reflectance characters and tintometric performance was evaluated. The colors stability under various model systems was evaluated and compared. The colors stability under various conditions was affected by the storage. The possible applications of safflower pigments in various food systems have been recommended. The paper describes the chemistry and the industrial utility of safflower pigments.

Key words: safflower, *Carthamus tinctorius* L., carthamin, yellow B, pigments, floret

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