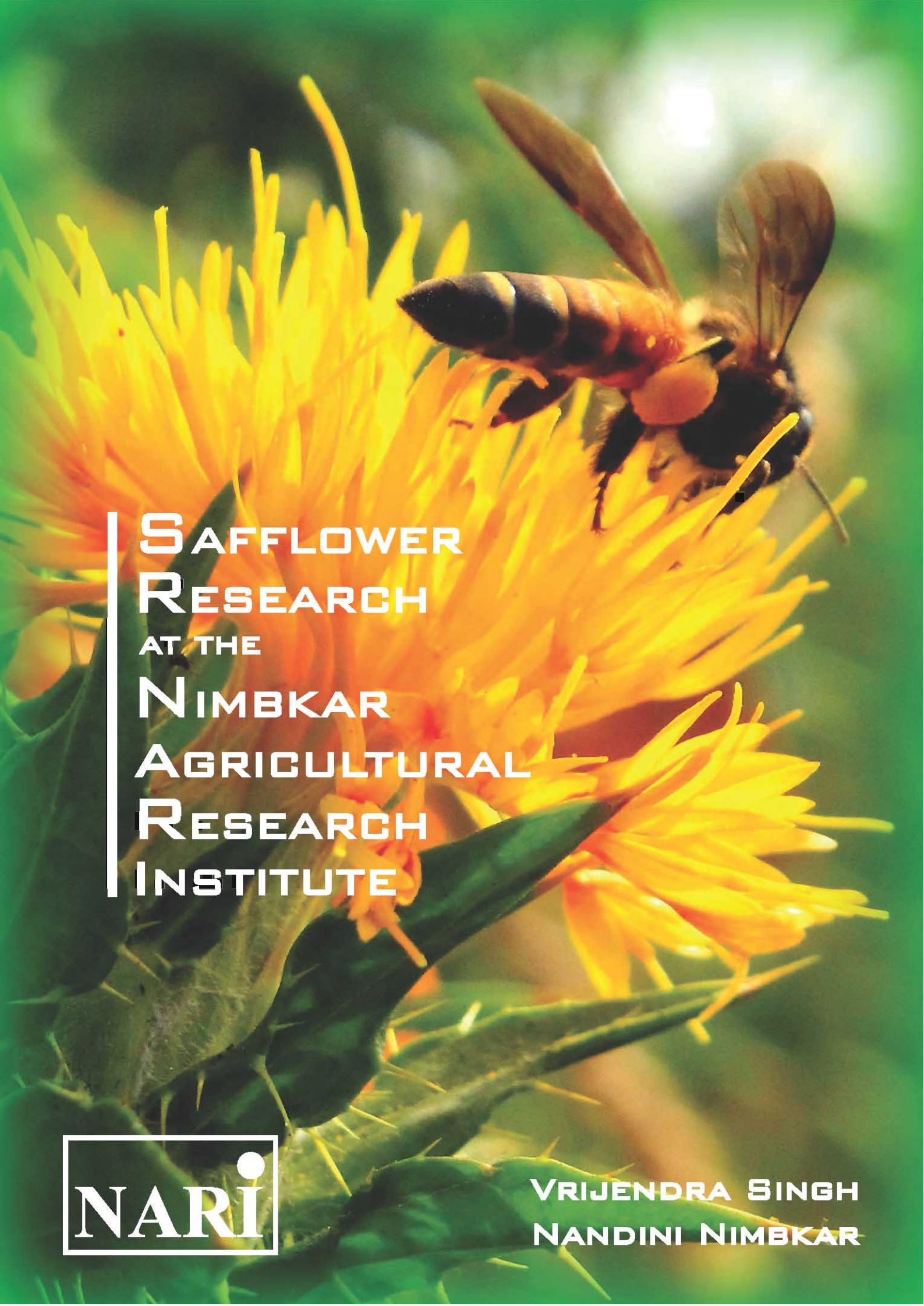

Safflower Research at the Nimbkar Agricultural Research Institute

Vrijendra Singh
Nandini Nimbkar

NARI

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For more details, contact Dr. Nandini Nimbkar (President, NARI) at nnimbkar@gmail.com / nariphaltan@gmail.com

NARI

Contents

Highlights of Safflower Research carried out at NARI

Indian Council of Agricultural Research (ICAR), New Delhi has sponsored safflower research at the Nimbkar Agricultural Research Institute (NARI), Phaltan since 1974, first in the form of an integrated scheme for safflower improvement (1974-1979) and subsequently as an All India Coordinated Research Project on Oilseeds (AICRPO) (1980-till date). ICAR also sanctioned different AP-Cess funded projects on varied aspects of safflower. The safflower research carried out at NARI is summarized below under the following heads:

I. Breeding (Crop improvement)
II. Agronomy
III. Pathology
IV. Entomology

Breeding (Crop Improvement)

Varietal development:

AICRP (Safflower) at NARI, Phaltan has made significant contribution in development of high yielding, high oil-containing and wilt-resistant varieties of spiny and non-spiny nature in safflower. The details of the varieties developed are listed below:

Table: Safflower varieties developed at NARI

Variety	Year of release	Spiny/ Non-spiny	Breeding method	Average		Recommended area and production conditions
				Seed yield (Kg/ha)	Oil content (%)	
NIRA	1986	Spiny	Pedigree	1554	32.5	Maharashtra, irrigated
NARI-6	2001	Non-spiny	Pedigree	1024	35	All India, rainfed
NARI-38	2007	Spiny	Pedigree	2038	31	All India, irrigated
NARI-57	2015	Spiny	Pedigree	1519	37	Maharashtra, Karnataka, Madhya Pradesh, Rajasthan, Punjab, Uttar Pradesh, Jharkhand and West Bengal, Irrigated
NARI-96	2018	Spiny	Pedigree	2013	33.2	Maharashtra, Telangana, Andhra Pradesh, Madhya Pradesh, Chattisgarh and Rajasthan, irrigated

High oil safflower variety NARI-57

Safflower variety NARI-96

Hybrid development:

Hybrid development in safflower was pioneered at NARI in 1979 by producing hybrid seed using gamma ray-irradiated seed as female parent combined with pollinating activity of honeybees. Multi-location testing revealed superiority of the hybrid over elite lines under adverse conditions. This study became the basis for hybrid development in safflower in India. Subsequently, in 2001 NARI released the first non-spiny hybrid NARI-NH-1 based on genetic male sterility for commercial production in India. This hybrid established the feasibility of growing non-spiny safflower in India.

NARI also released a spiny hybrid NARI-H-15 in 2006. It was also based on a non-spiny genetic male sterile line to enable commercial production of hybrid seed since roguing of fully grown spiny male fertile plants from a spiny genetic male sterile line during flowering would have been difficult. NARI has also has to its credit the releaseof the first

thermosensitive genetic male sterility-based hybrid NARI-H-23 in 2014. The details of the hybrids released are given below:

Table: Safflower hybrids developed at NARI

Hybrid	Year of release/ notification	Spiny/ Non-spiny	Male sterility system	Average		Recommended area and production conditions
				Seed yield (Kg/ha)	Oil content (%)	
NARI-NH-1	2002	Non-spiny	GMS	1936	35	All India, irrigated
NARI-H-15	2006	Spiny	GMS	2201	31	All India, irrigated
NARI-H-23	2014	Spiny	TGMS	1711	35	Maharashtra, Karnataka, Madhya Pradesh, Chattisgarh, Rajasthan and West Bengal, irrigated

Non-spiny hybrid NARI-NH-1

TGMS-based safflower hybrid NARI-H-23

(i) **Use of gamma ray irradiation for inducing male sterility in M_1 generation:** The efficiency of seed irradiation with gamma rays to induce male sterility in M_1 generation was studied on two safflower varieties N 62-8 and NS 133 using dosages from 5 kr to 50 kr. A few capitula of each M_1 plant were covered by a paper bag for obtaining selfed seed, but seed setting did not take place under the bag, therefore the open pollinated seed was used for raising the M_2 generation to know the extent of out-crossing in it. Performance of the M_2 plants were quite vigorous thereby suggesting the out-crossing of M_1 plants. The out-crossing of safflower genotypes was further confirmed by the genotype NS 133 which is a spineless variety and spineless is known to be governed by a single recessive gene. However, it showed the presence of a large number of spiny plants and the proportion of spiny plants increased with the radiation dose. Therefore the study suggested that seed irradiation rendered the M_1 generation male sterile and that the M_2 generation consisted mainly of hybrid plants, produced

by natural cross pollination of the M_1 plants by pollen from adjacent plots of safflower. The gamma irradiation of safflower seeds with 50 kr exhibited the highest out-crossing of 96% thus revealing thereby the maximum sterility in M_1 generation.

(ii) **Study of stability of hybrids:** The ability of safflower hybrids to perform better under adverse conditions was observed in a multilocational experiment. An experimental hybrid N 62-8 X NS 133 produced by sowing gamma ray-irradiated seed of safflower genotype N 62-8 as the female parent and crossing it with NS 133 with the help of honey bees in isolation, was evaluated with its parents and two elite varieties A-1 and No.83 in a total of 75 trials.

The results show that the hybrid gave significantly higher yield than both the parents and was at par with the elite varieties. As the entry N 62-8 was the locally released variety, the yield data of these trials were used to calculate the regression of the hybrid and the elite varieties upon the yield of N 62-8 (X). The following regression equations resulted from this analysis.

Yield of hybrid (Kg/ha) = 526 + 0.72 X and
Yield of elites (Kg/ha) = 184 + 0.97 X

Since N 62-8 was a locally adapted variety, it could be assumed that locations showing low yields of N 62-8 had adverse growing conditions while locations showing high yields of N 62-8 represented favourable conditions. The results of the solved regression equations showed that at locations with low (less than 1000 Kg/ha) yield of N 62-8, the hybrid outyielded the elite varieties, while at locations with high (above 1000 kg/ha) yield of N 62-8, the elite entries gave higher yield than the hybrid. Since

adverse conditions would be expected to be the rule in safflower cultivation, hybrids would always stand a better chance of giving higher yield than inbred varieties.

(iii) **Development of genetic male sterility systems in safflower:** Gamma-irradiated seed could not be used for commercial scale hybrid seed production due to many difficulties associated with it. Similarly exotic genetic male sterile lines UC-148 and UC-149 procured from USA in 1984-85 could not be successfully used for hybrid seed production due to inherent shortcomings which existed in them. Therefore, it was decided to search for new sources of male sterility in safflower. This resulted in identification of two sources of genetic male sterility designated as MSN and MSV respectively. Male sterile lines of both spiny and non-spiny nature giving high seed yield and having desirable traits were developed from these sources. Male sterility in both these sources was controlled by single recessive genes. The non-spiny hybrid NARI-NH-1 and spiny hybrid NARI-H-15 were developed from the non-spiny genetic male sterile lines developed from each of these sources of male sterility.

(iv) **Development of dwarf male sterility associated with male sterility marker trait in safflower:** Six dwarf plants of 30 cm height were identified in the 100 cm tall genotype BLY 1035 during 1992-93. The dwarf plants were observed to be male sterile during flowering of the crop. Their pollination with tall plants of different genotypes gave tall and fertile plants in F_1. The inheritance of male sterility and dwarfness was observed to be monogenic recessive. The genes expressing both male sterility and dwarfness were found to be tightly linked in coupling phase. This makes it easy to identify male sterile and fertile plants at 40-45 days after sowing (DAS) as

the male sterile plants remain dwarfs of 5-10 cm, but fertile plants attain a height of 15-20 cm. Thus the male fertile plants can be rogued out at 40-45 DAS leaving a pure stand of male sterile plants in the seed production plot. The dwarf male sterility-based hybrid showed a standard heterosis of 15-20%.

(v) **Development of cytoplasmic male sterility in safflower:** Cytoplasmic male sterility was developed at NARI following:

(1) Inter-specific crossing

(2) Induced mutagenesis with streptomycin.

The work on development of cytoplasmic male sterility using interspecific crossing was initiated in 1996-97 and cytoplasmic male sterile plants were identified in F_3 generation of a cross between *C. palaestinus* and *C. glaucus* during 1997-98. Male sterility maintainer and male fertility restorer genotypes were also identified for the male sterile cytoplasm so identified. However cytoplasmic male sterility appears to be temperature-sensitive as the expression of male sterility was excellent at the locations like Indore in Madhya Pradesh and Mauranipur, Jhansi in Uttar Pradesh which have cooler winters than at Phaltan in western Maharashtra.

In order to have diverse sources of cytoplasmic male sterility in safflower a programme to induce cytoplasmic male sterility through mutagenesis with streptomycin was initiated during 2001-02. The seeds of safflower genotype NARI-2 were subjected to streptomycin dosages of 50, 500, 1000 and 2000 mg/l of water for 40 hours. The treatment of 50 mg/l of water to safflower seed gave cytoplasmic male sterile plants. The male fertility restorer genotypes for the male sterile cytoplasm were also identified however male sterility maintainer genotypes identified showed

variable expression in different years. Efforts are underway to identify a genotype with stable expression of male sterility across the environments.

(vi) **Development of thermo-sensitive genetic male sterility (TGMS) in safflower:** Development of TGMS in safflower was an outcome of efforts initiated to explore the possibility of development of cytoplasmic male sterility from the derivatives of a CMS-based hybrid of exotic origin. This exploration of hybrid derivatives during 1998-99 resulted in identification of TGMS during 2005. These express 100% male sterility during winter when average daily minimum and maximum temperatures are <16°C and <32^{0}C respectively in the period from capitula formation to completion of flowering. The fertility is completely restored when they are grown during summer with average daily minimum and maximum temperatures >21°C and >39^{0}C respectively in the period from capitula formation to completion of flowering. The TGMS in safflower is controlled by inhibitory genes. NARI released the first TGMS-based hybrid NARI-H-23 for commercial production in India during 2014.

TGMS capitulum in flowering

Studies on existence of apomixis in safflower:

Embryological studies of fasciated derivatives of an interspecific cross between *C. palaestinus* and *C. tinctorius* producing twin embryos and fused multiple seeds to determine the origin of such seeds were carried out to determine the origin of such seeds. It was found that there was fusion of two to three ovaries forming uni- or bilocular structures with one to five ovules in each locule. The ovules had both sexual and aposporic embryo sacs. The multiple embryo sacs were found to have originated from nucellar epidermal cells located inside the integumentary tapetum. The presence of both aposporic and sexual embryo sacs in the same ovule suggests the existence of facultative apomixis in safflower.

Capitulum of fasciated safflower

Another genotype 238-14-2 and its derivatives also expressed similar histological characters as those described above for fasciated safflower. Pre-fertilization study of the genotypes showed that mitotic division of somatic aposporous cell led to formation of multiple unreduced embryo sacs. Presence of sexual plants in the genotype confirmed a facultative type of apomixis in it. The frequency of apomixis in genotype 238-14-2 was found to be 13%.

Inheritance of twin-embryo seeds and stem fasciation in interspecific fasciated derivatives was found to be digenic recessive with inhibitory gene action for the control of both the traits. The genes controlling the two traits were found to be closely linked in coupling phase.

Development of promising ideotypes in safflower:

(i) **Development of short duration (SD) safflower:** Development of SD safflower was carried out for rainfed and late-sown irrigated conditions or for shallow soils with length of growing period (LGP) of 70-80 days. The SD safflower flowers in 40-50 DAS and matures in 80-90 DAS as compared to normal duration (ND) safflower which flowers in 75-90 and matures in 125-145 DAS.

Short duration safflower in flowering (Right) and normal duration safflower (Left)

The assessment of SD safflower in comparison to ND safflower under different spacings and fertilizer levels in soybean-safflower cropping system under delayed sown conditions was carried out.

SD safflower out-yielded the ND one by 15% under both the spacings of 30 X 20 cm and 45 X 20 cm. Different levels of fertilizer did not have any effect on the yield of SD safflower indicating the possibility of reducing the fertilizer application to SD safflower thus further increasing the remuneration from the crop to the grower. Therefore SD safflower was highly productive under delayed sown conditions in soybean-safflower double cropping system. Similarly, SD varieties are also likely to be highly productive under soils with LGP of 70-80 days.

(ii) **Development of safflower producing only primary branches:** We have identified a spontaneous mutation resulting in production of only primary branches in safflower.

Safflower producing only primary branches

Screening of these genotypes along with the regular checks having secondary and tertiary branches showed that the promising genotypes with only primary branches out-yielded the regular safflower check A-1 by as much as 60% under irrigated conditions. These genotypes in general showed greater capitulum diameter

and higher number of seeds/capitulum than the check cultivars. The present findings suggest that genotypes producing only primary branches would be more productive under rainfed conditions than the regular genotypes due to their shorter duration and greater harvest index.

(iii) **Development of 60-day duration single-headed safflower:** Single-headed safflower identified and developed in the programme is being transferred to SD background in order to develop single-headed safflower maturing in 60 days. The safflower so developed will be highly productive on poor soils and soils with LGP of 50-60 days. It is likely to fit into many cropping systems and will be amenable to intercropping with different crops in conventional and non-conventional areas of safflower cultivation.

Single-headed safflower

Development of high oleic safflower:

Breeding for high oleic safflower has resulted in the development of eight high yielding F_4 populations giving > 75% oleic acid in the oil. These lines are being advanced and screened for development of high oleic cultivars giving high seed yield and oil content.

Development of mass emasculation technique in safflower: The emasculation technique in safflower has been traditionally a very tedious and time consuming affair as even a well trained worker can emasculate only 6-8 medium sized capitula per hour consequently restricting the number of crosses made and quantity of crossed seed obtained. To overcome this problem, a novel technique known as mass emasculation technique known as mass emasculation technique was evolved at NARI. In this method a capitulum is bagged by a polythene bag at first flower opening. The moisture accumulated in the bag increases humidity inside which in turn prevents the anther dehiscence, while style elongation and stigmata protrusion occur as usual. The pollination is done after 24 hours of bagging the capitulum. The capitulum is enclosed throughout the flowering period, with the polythene bag being removed only for pollination. Finally, the bag is removed after all the florets have wilted. The seed in such capitula is hybridized to an extent of 95-100%. This method works well at relatively low temperatures.

Improvement of seed set in selfing and crossing programme: Safflower is an often cross pollinated crop, therefore selfing of the germplasm lines is a must to preserve and maintain its purity. However, safflower exhibits poor seed setting under bagged conditions which is a major constraint in getting sufficient seeds for germplasm maintenance. Therefore an effort was made to improve the seed setting under the selfing bag. Our study suggested that bagging of 5-6 capitula of a plant and cutting off all other branches at pre-flowering stage increases the seed set/capitulum, seed size, seed weight and seed filling of the plant.

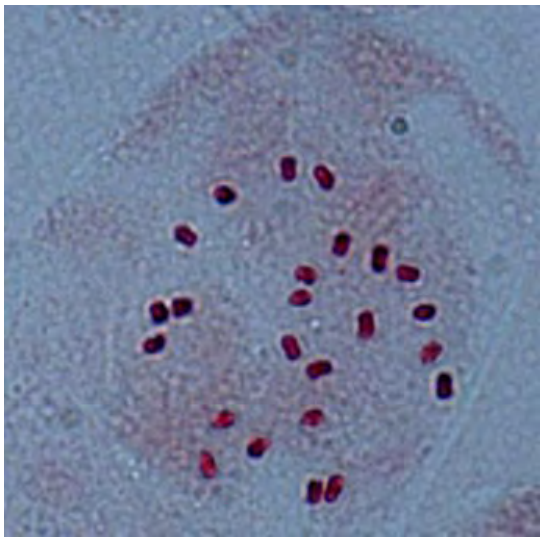
Use of summer season for multiplication and advancing safflower generations: The summer crop of safflower has to be planted as an irrigated crop. In Relatively light soil with good drainage, irrigations should be frequent enough to prevent soil cracking. Ideally, the summer crop should

be planted in the middle of February, so that it is ready for harvest by the end of May or before the onset of monsoon. Trials conducted to test the feasibility of growing a commercial crop of summer safflower showed that a maximum seed yield of only about 2000 kg/ha could be obtained. One of the greatest attractions of being able to grow a crop two or three times is the possibility it offers to the breeder of fast progress through rapidly advanced generations. Advancing of generations also involves selection at each step. It was necessary to find the consistency of expression of the different characters in different season. Characters like flower colour, capitulum size and shape, branch angle, leaf shape and degree of spininess did not show any change over the seasons but many of the important yield contributing traits like days to flower and maturity, plant height, no. of capitula etc. seemed to change from season to season. Our recommendation therefore is to make use of summer season only for multiplication of thermosensitive genetic male sterile lines developed at NARI for planting F_1 hybrid seed of crosses made in winter or for multiplication of selected material.

Rapid ploidy determination using leaf tissue in safflower:

Conventional method of ploidy determination using root tissues in safflower take an approximate period of 96 to 100 hours and that too without any guarantee of getting properly spread chromosomes due to their sticky nature. Our experimentation with processing leaf tissues for chromosome analysis resulted in development of a suitable technique to study chromosomes from a young leaf. This involves fixing of freshly excised pieces from a young leaf of about 1.5 cm length in a regular fixative for a period of four hours followed by 4-5 washings with water and then staining with acetoorcein for a period of 20-30 minutes. In short, the leaf processing enables chromosome analysis to be carried out in 6-7 hours. This technique with slight modifications may also be suitably used for regular karyotype investigations in safflower which in

the root chromosome preparations are very lengthy and difficult due to overlapping of chromosomes at metaphase.



Safflower somatic chromosomes from leaf tissues

Studies with safflower flowers:

Safflower since time immemorial is known around the world for the beauty of its flowers and production of natural colours for food and fabrics from them. In addition flowers also have pharmaceutical properties to cure many chronic diseases such as hypertension, arthritis, spondylosis, coronary heart ailments etc. to name a few. With the rising global demand for safflower flowers, NARI made efforts not only to develop high-yielding non-spiny cultivars, but also to explore uses of safflower flowers such as manufacturing food colourants and development of herbal health tea. If these uses are comercialized income of safflower growers can be enhanced to make the crop more profitable than the competing crops grown in the winter season. The details of the activities undertaken regarding safflower flowers are summarized below:

(i) **Study of variability of flower yield and its components in spiny and non-spiny genotypes in safflower:** At NARI 38 genotypes of spiny

and non-spiny nature were screened for flower yield and its components for two years. This showed high variability for flower yield and its components. Entry 694 recorded the maximum average flower yield of 282 kg/ha. High GCV, PCV, and heritability coupled with high genetic advance (as percent of mean) were recorded for the traits such as flower yield/plant, seed yield/plant, number of primary branches/plant, number of capitula/plant, number of seeds/capitulum and 100-seed weight. These traits may be considered for selection to obtain required genetic improvement of the crop.

(ii) **Study of variability in floral traits and interrelationship among them in spiny and non-spiny genotypes:**

Non-spiny safflower capitulum

Among the floral traits studied number of flowers/capitulum was found to be the most important trait for enhancing the flower yield in safflower. The correlation studies between flower yield and its components showed that the flower yield/plant was significantly and positively associated with both the number of flowers/capitulum and seed yield/plant.

(iii) **Inheritance of flower yield and its components in safflower:** The inheritance of flower yield and its components was studied in 10-parent diallel crosses (excluding reciprocals) for two years in F_1 and one year in F_2 generations. It showed the importance of additive and non-additive gene actions in the expression of different floral traits. Parent MSN-3-8-5 was observed to be the best general combiner for days to 50% flowering, days to maturity, number of flowers/capitulum and % oil in seed in all the three generations, capitulum diameter and number of seeds/capitulum in F_1s of both the years, number of capitula/plant and flower yield/plant in F_1 of first year and in F_2 generation, petal length, anther length, stigma length, petal area/flower, seed yield/plant and oil yield/plant in F_1 of first year and number of primary branches/plant in F_2 generation. The specific cross combinations NARI-6 X GMU-4808 and MSN-3-8-5 X 126-8-2 exhibited the maximum sca effects for flower yield in all the three generations except the latter of the two crosses in F_1 of second year. Thus to exploit both additive and non-additive gene actions, hybrid vigour using genetic male sterility should be harnessed as also biparental mating in the crosses exhibiting dominant X recessive gene action should be resorted to and individual plant selections be made in the crosses showing additive gene actions.

(iv) **Heterosis and inbreeding depression for flower yield and its components in safflower:** Standard heterosis (average of two years) over newly released non-spiny safflower variety NARI-6 was worked out of all the 45 F_1s for flower yield and its components. The maximum standard heterosis of 147% was recorded for flower yield. The crosses which showed high heterosis for flower yield and its components also exhibited high inbreeding depression which may

be attributed to non-allelic interaction of genes in the inheritance of different traits.

AGRONOMY

A package of practices for harnessing the full potential of safflower under limited number of irrigations has been developed. The technologies are describe below :

1. **Effect of planting times and plant populations on safflower yield:** To determine the most suitable time of sowing and a standard plant population level of seed for western Maharashtra, an experiment having four planting dates and three plant population levels, as given in table below, was conducted for five years. The results of the trial revealed that safflower can be planted anytime in the first fortnight of October with plant populations ranging from 74000 plants/ha (45 x 30 cm) to 222000 (45 x 10 cm) plants/ha. The results indicated that a fairly long interval for safflower sowing and a wide range of plant populations per hectare can be used without affecting the seed yield under irrigated conditions.

Table: Effect of planting time and population in irrigated safflower. Pooled mean seed yield (kg/ha) (1982-87).

Planting time	Populations 000's/ha			Mean
	74 (45 x 30 cm)	111 (45 x 20 cm)	222 (45 x 10 cm)	
1st October	1862	1859	1923	1881
16th October	1822	1851	1753	1809
1st November	1267	1470	1451	1396
16th November	896	854	869	873
Mean	1462	1508	1499	

C.D. 0.05 Date of planting = 338
Population = n.s.
Interaction = n.s.

2. **Effect of fertilizers on safflower:** These studies were conducted to determine optimum levels of nutrients (N and P_2O_5). Levels of K_2O were not tested as potassium is deemed to be more than adequate in the vertisols of this area. Three levels of N : 0, 30 and 60 kg/ha and two levels of P_2O_5 :0

and 30 kg/ha were statistically significant for seed yield and gross returns. A dose of 60 kg/ha of N and 30 kg/ha of P_2O_5 gave the highest seed yields, net returns and benefit cost ratio. The results are summarized in Table below.

Table: Response of safflower to fertilizer levels.

Treat ment	Seed yield kg/ha			Gross returns Rs./ha			B:C Ratio		
	P 0	P 30	Mean	P 0	P 30	Mean	P 0	P 30	Mean
N 0	1094	1107	1100	3941	3973	3957	1.39	1.31	1.35
N 30	1024	1309	1166	3941	4713	4382.5	1.36	1.49	1.41
N 60	1077	1675	1376	3881	6030	4955.5	1.83	1.83	1.54
Mean	1065	1363	1214	3958	4905.3	4431.7	1.33	1.54	1.44

	SEM ±	CD 0.05	SEM ±	CD 0.05
N	32.62	65.14	114.00	229.0
P	26.64	n.s.	93.07	187.3
N x P	92.27	185.70	161.20	32.4

3. **Critical stages of crop growth for irrigation:** This study was formulated to find out the most critical stages of crop growth for giving water under minimal irrigation regime. The stages of crop growth at which water was given and their effects are presented in table below. The highest seed yield (1842 kg/ha) was obtained when safflower crop was irrigated before sowing and at the end of rosette (35DAS) and during flowering (75DAS) stages of crop growth. However it was statistically no diffrent the treatments receiving irrigation at (1) presowing + branching + flowering, (2) presowing + branching or (3) presowing + flowering. Thus even one irrigation given at the right stage after planting can make a significant difference in seed yield.

Table: Critical stages of crop growth for irrigating.

Sr. No.	Irrigation Treatments	No. of irrigations after planting	Days after planting	Depth of water applied (cm)	Seed yield (kg/ha)	B:C Ratio
1.	Presowing	-	-	-	1521.52	1.63
2.	Presowing + rosette stages	1	35	3.92	1587.71	1.67
3.	Presowing + stages	1	60	14.98	1821.47	1.92
4.	Presowing + flowering stages	1	75	14.96	1658.72	1.75
5.	Presowing + milk stages	1	90	15.37	1450.57	1.53
6.	Presowing + rosette + branching stages	2	-	7.03	1531.59	1.59
7.	Presowing + rosette + flowering stages	2	-	13.66	1842.22	1.93
8.	Presowing + rosette + milk stages	2	-	12.68	1537.46	1.14
9.	Presowing + branching + flowering stages	2	-	14.64	1792.71	1.86
10.	Presowing + branching + milk stages	2	-	14.97	1626.10	1.69
11.	Presowing + flowering + milk stages	2	-	19.60	1450.76	1.51
12.	Presowing + rosette + branching + flowering + milk stages	4	-	21.97	1569.78	1.61
	General mean				1615.88	
	SEM ±				69.44	
	CD 0.05				203.68	
	C.V.%				7.45	

4. **Yield maximization trial under irrigated conditions:** Various inputs were assessed for their influence on safflower production under irrigation. Two safflower varieties Nira and Bhima were used in the study. The results presented in table below reveal that fertilizers exerted pronounced effect on seed yields, net returns and B:C ratios, especially with increasing levels of irrigation. Irrespective of varieties and levels of fertilizers adopted, plots protected against pests and diseases yielded higher (to the extent of 19.5%) than the unprotected plots.

Table: Impact of variety, fertilizers, plant protection and irrigation levels on seed yield and economics of safflower.

Plant protection level	Variety	Irrigation level	Net returns (Rs./ha)			B:C Ratio		
			FRD	HRD	Mean	FRD	HRD	Mean
NP	NRS 209 (Nira)	I	3433	2863	3148	1.99	1.90	1.94
		II	5762	4428	5095	2.54	2.28	2.41
		III	7032	4658	5858	2.87	2.34	2.60
		Mean	5409	3992	4700	2.47	2.17	2.32
OP	NRS 209 (Nira)	I	3937	2602	3269	2.30	1.94	2.12
		II	4338	2475	3406	2.30	1.84	2.07
		III	4562	4841	4701	2.36	2.21	2.28
		Mean	4279	3306	3792	2.32	2.00	2.16
NP	Bhima	I	2861	1099	1980	1.83	1.23	1.53
		II	3206	2552	2879	1.86	1.74	1.80
		III	4292	2559	3425	2.13	1.74	1.93
		Mean	3453	2070	2761	1.94	1.57	1.75
OP	Bhima	I	1453	1552	1502	1.48	1.57	1.52
		II	2670	2120	2120	1.80	1.51	1.65
		III	3106	3369	3369	1.93	2.18	2.05
		Mean	2410	2252	2331	1.74	1.75	1.74

OP = No plant protection, NP = Need-based plant protection
FRD = 100% fertilizers dose (N 60, P_2O_5 30, K_2O 30 kg/ha)
HRD = 50% fertilizer dose, I = No irrigation, II = One irrigation, III = Two irrigations

5. **Methods of planting in irrigated safflower:** Safflower gives good response to irrigation but the stem is sensitive to excessive soil moisture if it remains in contact with it for prolonged periods of time. Therefore, different planting methods were evaluated for finding out the most suitable one for irrigated safflower and to overcome the wilt problem in the crop. The mean results of four years' experiments are furnished in table below. It shows that using one deep furrow after every 3 rows of safflower gave the highest seed yield, net returns and B:C ratio among all the planting methods evaluated. This method also required comparatively less water for irrigation than the traditional flat bed method.

Table : Economics of different planting methods of irrigated safflower (Mean of 4 years)

Sr. No.	Treatments	Seed yield (Kg/ha)	Gross returns (Rs/ha)	Cost of cultivation (Rs/ha)	Net returns (Rs/ha)	Benefit: cost ratio
1.	Deep furrow after two rows of safflower	1583.35	10589.46	3181.86	7407.60	2.33
2.	Deep furrow after three rows of safflower	1681.30	11697.57	3163.12	8534.45	2.70
3.	Deep furrow after four rows of safflower	1524.66	10663.60	3141.24	7522.36	2.39
4.	Ridges and furrows method	1459.79	9710.06	3394.13	6315.93	1.86
5.	Flat bed method	1482.96	10337.64	3146.87	7190.77	2.28
	Mean	1546.41	10599.67	3205.44	7394.22	2.31

6. **Phosphorus management in safflower-based cropping system:** The effect of phosphorus (P) use has been studied in safflower-soybean cropping system to minimize P use without affecting the productivity of the system

and to make the safflower cropping system sustainable. The pooled results of safflower and soybean trials for five years showed that by considering the system productivity as a whole the treatment of 100% P application to soybean and an application of 5 Tons FYM/ha to safflower recorded the maximum average aggregate net return of Rs. 43028/ha. This was at par with the application of 100% P to both the crops, 100% P application to safflower and 5 tons FYM to soybean and 5 Tons FYM + PSB to safflower and 100% P to soybean.

7. **Integrated nutrient management in safflower-based cropping system:** The experiment was carried out to integrate different sources of plant nutrients for safflower-based cropping system in order to economize on inorganic fertilizer use and sustain productivity. The trial consisted of 12 different combinations of fertilizer dosages with biofertilizers. Soybean was the other crop which was included in the safflower-based cropping system. The results of the trial from 2002-03 to 2006-07 showed that the differences due to treatments were significant for seed yield, gross returns and net returns in all the 5 years of study for safflower. However, the differences due to treatments were observed to be non-significant for seed yield, gross returns and net returns in all the 5 years of experimentation for soybean.

   Therefore the study indicated that to obtain the maximum seed yield in safflower it is important to provide 100% of NP to the crop. Any reduction below 100% in NP levels to safflower leads to reduction in productivity of the crop. No response of soybean, which is a sequence crop in the cropping system, to fertilizer levels suggested that the residual fertility available in the soil after the harvest of safflower is sufficient for growing soybean and productivity of the crop does not suffer.

PATHOLOGY

Main objective of this programme was the identification of sources resistant to *Alternaria leaf spot and wilts* and control measures for both the diseases. The trials conducted were as follows :

(i) **Effect of planting time on the incidence of foliar diseases:** Sowing of safflower in the first fortnight of october was found to give the highest seed yields in spite of the disease severity.

(ii) **Estimation of yield losses due to foliar diseases:** Unfertilized and unprotected plots exhibited 116% loss in seed yield over unfertilized and protected plots. The plots given fertilizers but no plant protection measures registered 54% loss in seed yield over fertilized and protected plots.

(iii) **Effect of fungicidal control of foliar diseases in safflower**: Two or three sprays of Carbendazin 0.1% gave the maximum yields and returns over untreated control. Next in order was Dithane M-45 0.25% (2 sprays).

(iv) **Control of root rots and wilts through seed treatment:** The seed treatment with fungicide combination of Thiram + Carbendazim (1:1) gave the minimum wilting of 26.57% followed by Thiram 0.3% (27.10%).

(v) **Test tube method of seedling screening against wilt:** Screening of safflower lines by using test tube method resulted in identification of 11 lines tolerant to wilts. This method was found to be reliable, accurate and efficient.

(vi) **Leaf extract bioassay method:** The leaf extract biomassay method for foliar disease screening was developed. This method deals with the study of germination of pathogen spores in the leaf extracts of the

test plants. The susceptible plants showed higher percentage of spore germination and resistant plants showed lower percentage of germination.

(vii) **Biochemical studies for testing resistance in plants:** Since phenolic compounds often act as antifungal compounds in plants, efforts were made to determine the total phenols, sugars and activity of enzyme polyphenoloxidase (PPO) in leaf extracts of different safflower varieties. The results revealed that the sugar content of the leaves did not show any association with the reaction of plants to *Alternaria carthami*, whereas concentration of phenolic compounds, especially in the case of young leaves was higher in leaf extracts of resistant varieties than in leaf extracts of susceptible ones. Similarly the PPO activity also appeared to be higher in the case of resistant varieties than in the susceptible ones.

(viii) **Alternaria-tolerant lines:** Following entries were found to be tolerant to Alternaria : (1) C-2603 (2) NS 999 (3) NS 1574 (4) CO-1 (5) 233-4 (6) HUS-140 (7) CTS 7218 (8) 237550A (9) 708.

(ix) **Wilt-tolerant lines:** Following entries registered less than 10% wilting as against 51% wilting of the susceptible check : (1) HUS 3143 (2) HUS 3123 (3) NC 1646 (4) 625 (5) BSF-3 (6) 237550 A.

(x) **Survey of safflower diseases:** The survey of safflower diseases on farmers' fields in the districts of Satara and Sangli indicated that in almost all the fields surveyed, leaf spot caused by *Alternaria carthami* was the only disease observed. In irrigated crops, the disease intensity ranged between 5-50% during button formation stage, whereas it was about 30-35% in rainfed crops, except a few cases where it was less than 5%. No wilt incidence was observed in the fields. In short none of

the diseases posed any serious problem for safflower cultivation during the season.

(xi) **Fungicidal management of *Alternaria leaf* spot of safflower:** Eight newly developed fungicides were evaluated for their efficacy against *Alternaria* leaf spot in safflower. Among the treatments, Difenoconazole @ 0.05% was found to be the most effective, as it recorded the lowest disease severity of 69% and significantly highest seed yield of 2693 kg/ha and oil yield of 785 kg/ha, followed by Carbendazim @ 0.1% which recorded disease severity of 70% and the maximum seed yield of 2708 kg/ha and oil yield of 779 kg/ha.

(xii) **Isolation and screening of fungal and bacterial bioagents against *Macrophomina phaseolina* root rot of safflower:** A series of isolations were made out of rhizophere soil infested with root rot fungus *Macrophomina phaseolina*. Among seven isolates assayed for antagonism, three were found to inhibit growth of *Macrophomina phaseolina* in-vitro. Antagonist-coated seeds improved safflower germination along with an increase in radicle length. The vigour index also was significantly higher in them compared to control. This protection from root rot was due to the antagonistic action of *Trichoderma viride*, *Trichoderma harzianum* and *Pseudomonas fluroescens*. *Trichoderma viride* was found to be the best, giving 93% germination, increased radicle length of 11 cm and high vigor index of 1535.

(xiii) **Effect of weather parameters on incidence of *Alternaria leaf* spot:** In early sowing, there was no correlation between *Alternaria* disease and weather parameters. However, during normal and late sowing, the disease was positively correlated with minimum temperature and minimum relative humidity.

(xiv) **Screening of BC_4F_6 selections for wilt resistance:** Out of the 62 entries evaluated in two trials, four entries viz. WR-11-4-6, WR-8-24-12, WR-8-14-10 and WR-4-6-5 recorded < 10% wilt under wilt-sick plot conditions.

ENTOMOLOGY

The main objective of entomology programme was the identification of aphid-tolerant lines and development of efficient control measures for the control of pests. The work done in this discipline is described below :

(i) **Effect of planting time on the incidence of safflower aphids:** Safflower planted later than the recommended planting time (October 1) recorded higher aphid incidence and lower seed yields.

(ii) **Estimation of yield losses due to aphids:** The investigation on estimation of yield losses due to aphids showed that irrespective of fertilizer dosages, unprotected plots suffered nearly 4 times more aphid infestation and 43.85% yield losses compared to their protected counterparts. Yield reduction in fertilized unprotected plots was 48% compared to its fertilized protected counterpart.

(iii) **Chemical control of safflower aphids:** Among the various insecticidal treatments tried for their efficacy against aphids, three sprays of Dimethoate (0.05%) gave the highest monetary returns.

(iv) **Determination of critical crop growth stages for damage due to aphids in safflower:** The study showed that the highest mean yields were obtained from plots receiving Dimethoate 0.05% spray at 15 days' interval with the first spray being applied at 15 days after the first appearance of the aphids.

(v) **Fecundity test for aphid resistance:** Fecundity of aphids was studied by introducing specific number of aphids on a shoot of the test plant and enclosing the shoot in a cellophane paper bag to restrict the aphids to that shoot. The rate of multiplication of the aphids depended upon degree of resistance shown by the plant to aphids. After a high

positive correlation between aphid fecundity under artificial infestation and length of aphid infested portion of a shoot under natural infestation was established, the latter criterion was used more often than the former in screening for aphid resistance, due to greater convenience in its use.

(v) **Aphid-tolerant lines:** Aphid-tolerant lines identified during the course of investigation are : (1) NS 488-1 (2) NS-4 (3) NS-5 (4) NS 269 (5) P. hull 83-1 (6) B-20 (7) NS 1550 (8) NS 1021-1 (9) SSF-3 (10) B-144 (11) PI-77 (12) GMU-178.

USES OF SAFFLOWER OTHER THAN AS AN OILSEED

(I) **Safflower flowers for colour and medicinal uses:**

(i) **Screening of safflower flowers of released cultivars for safflower yellow:** Out of the released safflower cultivars screened for safflower yellow, non-spiny safflower varieties NARI-6 and CO-1 gave the highest amounts of yellow pigment of 30 and 28% respectively. The spiny cultivars contain <10% yellow pigment in their flowers. Therefore, for commercial extraction of colour from safflower flowers, non-spiny varieties like NARI-6 and CO-1 and hybrid NARI-NH-1 should be considered as they not only contain high amounts of pigment in their flowers but give high flower yield and their non-spiny nature makes flower collection relatively easy.

(ii) **Analysis of toxic and nutritive elements in safflower flowers:** An analysis of nutritive and toxic elements in safflower flowers of Indian cultivars was carried out at CFTRI, Mysore in order to assess the suitability of safflower flowers for human consumption. The analysis of toxic elements in the flowers of seven genotypes showed non-spiny cultivars NARI-6 and NARI-NH-1 to have Cd, As and Pb contents within the permissible limit. Flowers of non-spiny cultivars NARI-6 and NARI-NH-1 were found to be rich in protein, total sugars, calcium, iron, magnesium and potassium. Therefore, the flowers are safe for human consumption and are rich in essential components needed for good health.

(iii) **Assessment and acceptance of flower extract as food colourant:** A simple and easy to use method of colour

extraction from safflower flowers was devised. The colour concentration of 4.5% was standardized and used for colouring different food items. The quantity of 4.5% concentration required for colouring different food products was: 5 ml for 250 g raw material of *Jilebi*, 0.5 ml for 100 g ice cream, 0.2 ml for 100 g of *shrikhand*, 8 ml for 100 g cake, 5 ml for 1200 g of *burfi* and 3 ml for 1200 g *pedha*.

(iv) **Development of safflower herbal tea:** After testing different combinations, safflower flower powder (0.3 g) + lemongrass (0.1 g) + cardamom (0.08 g) in 100 ml of water was found to give excellent taste, aroma and colour. From the research carried out mainly in China extract of safflower flowers can be used to cure various chronic disease like hypertension, arthritis, spondylosis, coronary artery diseases and sterility in men and women. This should help to popularize safflower flowers for human consumption and in commercializing safflower flowers to give additional income to the farmers.

Safflower petal packets

(v) **Studies on eco-friendliness of safflower colour:** The eco-friendliness test of safflower colour for toxic elements and

pesticide residues was carried out at IIT, Kanpur. It revealed that the amounts of Cu, Co and Cr each were 0.01 ppm and Zn and Cd were 0.02 ppm each. Ni amount in dye was 0.9 ppm however no traces of Pb, As and Hg were found in the dye. The colour was also found to be free from the pesticide residues of BHC, DDT, Methyl parathion, Endosulfan, Malathion, DDE, DDD, 2,4-D, 2,4,5-T, Aldrin, Dieldrin, 12 Ethion, Dimethoate, Formaldehyde and all the 22 banned Amines. Thus the colour was found to be safe and eco-friendly in nature.

(vi) **Efficacy and safety of safflower herbal tea when given as an add-on therapy in patients suffering from mild hypertension:** A clinical trial to study efficacy and safety of safflower tea in controlling hypertension was carried out in association with T. N. Medical College and BYL Nair Charitable Hospital, Mumbai. The results of the clinical study revealed that the addition of safflower herbal tea to the ongoing anti-hypertension monotherapy, successfully reduced the blood pressure in patients of mild hypertension. It was noted that in safflower-treated group, the percentage decrease in blood pressure was more between day 0 and day 15 as compared to that between day 15 and day 30. However, safflower tea did not show significant effect on lipid profile parameters.

(vii) **Development of safflower petal collector:** A knapsack-type simple, suction mechanism-based battery-operated petal collector was developed for flower collection from a spiny crop of safflower. The testing of battery-operated petal collector showed that on an average a person could

collect 400-500 g of flowers/day (6 hours/day) which was nearly twice as much as that collected by hand from a crop of spiny safflower.

Battery-operated safflower petal collector

(II) **Young safflower as a leafy vegetable:** Safflower plants at an early stage of growth are used as potherb and salad locally in and around the area of its production in India. Safflower leaves are a rich source of fiber, minerals, vitamins and antioxidants. Therefore, in order to popularize safflower as a leafy vegetable it is crucial to create awareness on diet-related health benefits from this crop. Promotion of safflower as a leafy vegetable will benefit the consumers in securing nutrition and will also help safflower growers to enhance their income significantly. The aim of this study was to assess the potential of safflower cultivars/genotypes for fresh vegetable yield, nutritional qualities and monetary returns in different seasons.

In order to generate the desired information 15 safflower cultivars/genotypes were assessed for their fresh vegetable yield

and quality parameters of safflower leaves under winter, summer and monsoon conditions during 2014-15. The results showed that the average fresh vegetable yield of safflower at 30-35 DAS was the maximum (7008 kg/ha) in monsoon 2015- grown crop followed by the crops grown in winter 2014-15 (3960 kg/ha) and summer 2015 (3313 kg/ha). This indicated that apart from regular winter, safflower as a vegetable crop can also be produced in both summer and monsoon seasons, thus making it possible to have a round the year supply to the consumers. The nutritive analysis of safflower leaves in comparison to fenugreek and spinach (the two popular leafy vegetables in the market) showed that safflower leaves are as nutritious as them.

The high returns in a short period of 30 days coupled with its high nutritional quality as a leafy vegetable should be publicized. This will enhance the requirement for safflower as a vegetable which can be easily fulfilled from the regular safflower grown as an oilseed during winter season as the excess plants are removed at 30-35 days after sowing. The removed plants can be marketed as a leafy vegetable to obtain additional income instead of using as a fodder for animals. The lower 3-4 leaves of each plant may also be detached during the rosette stage (30-40 DAS) without any adverse effect on the productivity of the crop as an oilseed. Thus the income obtained from the sale of thinned plants and removal of the lower 3-4 leaves/plant at 30-40 DAS can meet the entire cost of cultivation of the crop in advance. This can also support all future input needs of the crop. The income likely to be generated from the seeds and flowers would be net earnings in the hands of the farmer. However, in order to realize this it is important to promote safflower as a nutritious leafy vegetable among the public.

Safflower crop ready for harvest as a leafy vegetable

For more details, contact Dr. Nandini Nimbkar (President, NARI) at nnimbkar@gmail.com / nariphaltan@gmail.com

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Nimbkar Agricultural Research Institute
Lonand Road, Phaltan, Maharashtra
www.nariphaltan.org
nariphaltan@gmail.com