# GENETIC STUDIES IN SAFFLOWER
## ( Carthamus tinc torius, L. )

By

**Barhate Khushal Kashinath**

B. Sc. (Agri.) First Class

A Thesis submitted to the

MAHATMA PHULE KRISHI VIDYAPEETH

RAHURI, 413 722 DIST - AHMEDNAGAR,

Maharashtra State. (India.)

in partial fulfilment of the requirements for the degree

of

**MASTER OF SCIENCE ( AGRICULTURE )**

in

**CYTOGENETICS AND PLANT BREEDING**

DEPARTMENT OF BOTANY

POST GRADUATE INSTITUTE,

MAHATMA PHULE KRISHI VIDYAPEETH

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CYTOGENETICS AND PLANT BREEDING

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CANDIDATE'S DECLARATION

I hereby declare that this thesis or part thereof has not been submitted previously by me or any other person for a Degree or Diploma to any other University OR Institution

PLACE : RAHURI

DATED : 17/8/92

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---

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# C E R T I F I C A T E

This is to certify that the thesis entitled, " Genetic studies in safflower ( Carthamus tinctorius, L.)", submitted to Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri in partial fulfilment of the requirement for the degree of MASTER OF SCIENCE (AGRICULTURE) in CYTOGENETICS AND PLANT BREEDING, embodies the result of a piece of bona fide research work carried out by Shri. Khushal K. Barhate under my guidance and supervision and that no part of the thesis has been submitted for any other degree or diploma.

Place : Rahuri

Dated : 17/8/92

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## C E R T I F I C A T E

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Barhate

Place : Rahuri. K.K. Barhate

Dated : 17/8/92

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# ABSTRACT

## GENETIC STUDIES IN SAFFLOWER
## ( *Carthamus tinctorius*, L.)

By

K.K. Barhate
Mahatma Phule Krishi Vidyapeeth
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1992

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| Research Guide | : | Dr.B.N. Narkhede |
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| Major field | : | Cytogenetics and plant breeding. |

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The present investigations entitled " Genetic studies in safflower ( *Carthamus tinctorius*, L.)" were conducted at Central Campus, Mahatma Phule Krishi Vidyapeeth Rahuri, during October, 1990 to March, 1992.

The objectives of the present investigations on safflower were to know the nature of gene action on various characters of safflower and to study the magnitude of heterosis for grain yield, its components and oil content. The parents viz. SSF-3, NS-1021-1, GMU-2375, GMU-2497, N-62-8, JLSF-103, their four $F_1$s, $F_2$s, and four $BC_1$s and $BC_2$s were subjected to genetic analysis so as to generate information on heterosis and estimates of gene effects were determined through generation mean analysis.

Higher magnitude of dominance was observed for the characters viz. primary branches per plant, plant height, days to flowering, seeds per capitulum, oil content, capitula per plant and yield per plant which could be made use by the selection for the characters should be postponed to later generation. Further it indicates that the chances of fixing these traits have a limited scope.

The magnitude of additive gene effects were exhibited higher in diameter of capitulum, two crosses of days to 50 per cent flowering and primary branches per plant suggested that exploitation of these traits in pedigree breeding. It may give rapid improvement by selection if applied within the segregating generation leading to isolation of homozygous lines.

Duplicate type of epistasis was found to be operative in most of the crosses. Significant epistatic gene effects coupled with duplicate epistasis indicated that, through effective selection transgressive segregants could be obtained in subsequent generations.

While considering heterosis&six parameter analysis, non-additive gene actions were operated in most of the crosses, while both additive and non-additive were present for diameter of capitutum & oil content. Simutaneously exploit additive and non-additive gene action reciprocal reccurent selection method maybeused.

High degree of heterosis was observed for the plant height, secondary branches per plant, capitula per plant, diameter of capitulum, seeds per capitulum, yield per capitulum and yield per plant over SP and MP in the combination JLSF-103 x NS-1021-1. Similarly, the combination N-62-8 x GMU-2497 had the highest estimates of heterosis for primary branches per plant and oil content over SP and MP.

The genetic analysis of various aspects revealed that the combinations JLSF-103xNS-1021-1 and N-62-8xGMU-2497 are worth exploiting in further safflower breeding programmes.

Total Pages : 1 to 91

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# Introduction

# 1. INTRODUCTION

Oilseeds play a vital role in the agricultural economy of India from the times immemorial. The improved varieties of oilseeds were selected and bred from germplasm collected in various centres of cultivation ( Knowles, 1955, 1958).

Safflower is mainly grown in India, the U.S.A., Mexico, Ethiopia, Spain, Australia, Portugal and the U.S.S.R. India ranks first in the world in term of area and contributes more than 50 per cent of the world's safflower acreage. However, yield potentials of safflower in India are the lowest in the world. This is because of following reasons.

1) It is mainly grown as a rainfed crop.
2) About 60 per cent area is in drought prone zone.
3) It is grown on marginal and submarginal soils.
4) Inadequate supply of seeds of improved varieties.
5) Lack of use of fertilizers.
6) Minimum use of plant protection measures.
7) Non-adoption of improved technology by cultivators.

Safflower is a minor oilseed crop in India. However, it is an important oilseed crop in Maharashtra and stands second to groundnut so far as area is concerned.

The Maharashtra State stands first in area under safflower in India. About 73 per cent of total area under this crop is in Maharashtra. Out of 8.60 lakh hectares area in India, (FAO, 1990), Maharashtra State has 6.28 lakh hectares (Anonymous, 1990). The annual production (FAO, 1990) of safflower in India was 9.22 million tonnes, out of which Maharashtra State produced 2.55 lakh ~~millions~~ tonnes (Anonymous, 1990). The average yield of this in India was 491 kg/ha, while Maharashtra State had 406 kg/ha.

In the past, it was grown as a source of dye for cloth and food. The leaves of young plants of safflower are also used as a vegetable. In the recent years, safflower is grown mainly for edible oil. Safflower oil is considered to be the best for heart patients as it contains a high degree of polyunsaturated fatty acids.

Safflower is said to be drought tolerent crop because of its strong and deep penetrating tap root

system about 7 feet ( Knowles, 1958). This has facilitated its cultivation in scarcity zone receiving annual precipitation in the range of 300-500 mm.

In any crop, the major scope for enhancing the yield potentiality is improved varieties. The primary aim of any plant breeder is, therefore, to improve both yield and quality by evolving superior cultivars. This may be achieved either by selecting promising types from naturally existing variation or by hybridization.

Yield is a complex metric trait and is governed by a number of quantitative components. Hence, it is necessary to get a clear picture of the genetic architecture involved in the control of yield through the application of principles of biometrical genetics.

Although, a lot of information on the nature of gene actions based on combining ability studies is available, the information regarding gene effects and epistatic interactions based on six parameter model is very limited in safflower. The present investigation was, therefore, undertaken to study the nature of gene actions involved, and magnitude of heterosis. The results of these investigations are presented in this dissertation and discussed for their breeding implications.

Although, the hybrid vigour in safflower at present is not commercially exploited, the performance of $F_1$ hybrids on the basis of heterosis can help in the rejection of the large number of crosses in $F_1$ generation itself.

In designing an efficient breeding programme, the knowledge of relative importance of additive and non-additive gene effects would be useful.

Hence the present investigations were carried out with the following objectives.

1) To know the nature of gene actions involved in the inheritance of various characters in safflower. ( Carthamus tinctorius, L. ).

2) To study the magnitude of heterosis for grain yield, its components and oil content.

The above information is thought to be useful to the safflower workers in their attempts to evolve improved varieties. The material so developed could be advanced to release better variety based on the nature and magnitude of gene action and heterosis determined in the present study.

# Review of Literature

# 2. REVIEW OF LITERATURE

Safflower ( Carthamus tinctorius, L.) was brought into cultivation in the Near East, probably from an ancenstral type that gave rise to all closely related X = 12 diploids. An archeological record of safflower known from Egypt is dated about 1600 B.C. and by the early nineteenth century, it had become one of the most important plant sources of dye stuff but this use was subsequently declined. Safflower is said to be originated from Arabia ( Candolle, 1982). However Vavilov (1951), suggested three centres of origin for cultivated safflower, India on the basis of variability and ancient culture, Afganistan on the basis of variability and proximity of wild species and Ethiopia primarly on the basis of wild safflower species present in that area. In Russia, Kupzow (1932), following detailed study of various collections made in many areas, reached the same conclusion as that of Vavilov. One of the earliest references to safflower in the U.S.A is contained in a research report of the University of California submitted at the beginning of this century (Shinn, 1903 and Conners, 1943). The recent breeding efforts have been much devoted in improving disease resistance and the other breeding aims including the improvement in oil content of seed and lysine content of meal. ( Knowles, 1955).

The present view is an attempt to bring together some of the prominant findings on heterosis and nature of gene action involved in safflower.

Gene action :

Ehdaie and Ghaderi (1978) collected data on yield/plant, heads/plant, seeds/head, seed weight, flowering time and height from six generations of a cross N-10 x Arak 2811, which were planted at Safiabad and Ahraz in Iran. Site effects were significant for all traits except heads/plant. Generation differences were significant for all traits except heads/plant and seeds/head. At safiabad dominance influenced yield/ plant and seeds/head, for other traits and other site, additive and other dominance and significant interallelic interactions were found. Analysis of seed weight showed additive and dominance effects and a significant additive x site interaction.

Kotecha (1979) Observed in the crosses between C. tinctorius and C. palaestinus that gene action was additive for plant height and non additive for days to flowering, days to maturity and days from flowering to maturity.

Channeshappa (1980) studied 4 crosses in the $F_1$, $F_2$ and backcrosses for 11 characters, seed yield was controlled by dominance and dominance x dominance effects, oil content by additive effect, 100 seed weight by additive effects, no. of seeds per head by dominance effect, head diameter by additive and dominance effect and number of secondary branches by additive effect. It is suggested that the best breeding methods for the crop are hybridization and mass selection.

Channeshwarappa et al. (1984) studied 4 diverse parents, 4 $F_1$S amongs them and their $F_2$ and BC progenies. Seed yield/plant was governed by dominance and dominant x dominant gene effects, oil is governed by additive and additive x dominant gene effects. It is concluded that direct selection for oil content is not effective but it could be achieved indirectly through selection for reduced hull content.

Deokar and Patil (1980) studied combining ability effects in a diallel cross involving six cultures viz. B-263 - 2A, 638, IC 11972, 162-2-1, C-11 A and EC-32012 and found that the characters viz. seed weight, plant height, diameter of the capitula, seeds/capitulum, seed yield and capitula/plant were governed by additive and or additive x additive interaction of genes, while number of primary branches were governed by non-additive gene effects.

Makne and Chaudhary (1980) observed combining ability effects in a diallel cross involving five parents viz. N-62-8, Tara, N-7, PVT-74 and No.168. It was reported that the plant height and seed weight were governed by additive gene effects, whereas days to 50 per cent flowering, capitula/plant, weight of seed/capitulum and seed yield/ plant were predominantly governed by non-additive gene effects.

Vijayakumar and Giriraj (1980) reported in a diallel cross involving four indigenous and four exotic parents that both general and specific combining ability variances were significant. The two exotic parents ( Royal and Rio) showed high gca effects, while all the indigenous parents were negative combiners. Indigenous x exotic parent combinations ( S-141 x Royal and A-300 x Rio) showed high specific effects. The study showed that the oil content of presently cultivated varieties is mainly governed by additive gene actions.

Patil (1982) reported additive gene action for diameter of capitulum and oil content.

Ramachandram and Goud (1982 b) observed dominance effect in dwarf x tall, additive effect in medium x tall

combinations predominated for plant height. Dominance as well as non-allelic interactions, particularly dominance x dominance and additive x additive were important for total capitula. Additive, dominance and interaction parameters were important in yield/capitulum. The additive effects and additive x additive interaction in majority of crosses suggested the possible improvement of seed weight by selection. Dominance component was significant in seven crosses for seed number but negative in four of them. Dominance effects followed by interactions and additive component were all found to play significant role in the inheritance of seed yield. Breeding methods which utilize both additive and non-additive gene action such as reciprocal recurrent selection are suggested for improvement of seed yield.

Ramachandram and Goud (1982 a) studied the gene action for seed yield and its principal components in eight intervarietal crosses of safflower. Simple additive dominance model could not explain the inheritance of all the eight characters. The significance of one or more digenic interaction in almost all crosses further confirmed the involvement of epistasis. Additive effects were predominent for diameter of capitulum and primary capitula, while dominance effects formed major fraction

for height of branches, branch length, higher order capitula and seed yield. Higher magnitude of dominance for height of branching, branch length.

Ranga Rao (1982 b) recorded the nature of gene action for plant height, number of primary branches, days to first flowering and full maturity in $F_1$ diallel set involving 11 diverse parental lines. Variance component analysis showed a predominance of additive gene effects coupled with incomplete dominance for five out of seven characters. Genes governing all traits except branch number and their angle to main axis showed directional dominance. The distribution of positive and negative alleles in the parental populations was asymmetrical for a majority of the variables. Narrow sense estimates of heritability were high to very high for most of the attributes. There seemed to be considerable scope for effecting desired improvement in a number of characters through the use of conventional selection methods adopted for self pollinated crops.

Narkhede et al. (1984) in 15 crosses observed that the variances due to specific combining ability were large for the characters viz., seed yield/plant, capitula/plant, seed/plant, 100 seed weight, capitula size and hull content indicating predominance of non-additive

gene action. Additive gene action was important for plant height, primary branches per plant.

Ramachandram (1985) reported non-additive gene action in the inheritance of seed yield and capitula/ plant, while additive component predominated in case of seed number, seed weight and proportion of hull. Based on the nature of gene action and available variability in breeding behaviour of the crop, breeding strategies aimed at bringing simultaneous improvement in seed yield and oil content are suggested.

Gupta and Singh (1988) studied data from 10 parents incomplete diallel cross were taken to indicated non-additive gene action for seed oil per cent, seed yield, 100 seed weight and number of bolls per plant in $F_1$ and $F_2$, for number of primary branches in $F_1$. Additive gene action was indicated for plant height in both generations and number of primary branches in $F_2$.

Gupta and Singh (1990) showed, additive dominance and epistatic gene effects for days to flowering and days to maturity.

Heterosis :

Commercial exploitation of hybrid vigour in recent years has led to remarkable increase in yield in

several crops irrespective of their breeding system. Safflower, however, though predominantly a self pollinated crop, is also reported as a cross pollinated crop. Several investigators from various parts of the world have demonstrated the existence of significant heterosis for yield and oil per cent in the crop. Information available on the extent of heterosis in the crop has been cited below.

Smith and Claassen (1963) recorded heterosis for yield with increase of 10 per cent above the highest yielding parent.

Rubis (1969) reported that out of 800 hybrids tested, 30 per cent exceeded the yield of commercial varieties.

Urie and Zimmer (1969) in Six $F_1$ hybrids produced by hand pollination observed 24 per cent higher yields than the highest parent.

Yazdi - Samadi *et al.* (1972) obtained heterosis for yield and for amount of oil/plot in the hybrids studied but no heterosis for oil per cent. Hybrids between Iranian and American varieties were more heterotic than hybrids between American varieties.

In another experiment, two third of hybrids displayed heterosis for yield, one third for oil per cent and two third for amount of oil/plot.

Yazdi - Samadi et al. (1973) while comparing fifteen varieties, inbreds and hybrids derived from the varieties showed that heterosis occurred. in plant height, seed weight and oil content.

Yazdi - Samadi et al. (1975) estimated heterosis for seven traits. The hybrids were significantly superior to their better parents for height, yield, seed weight and oil per cent in first experiment, whereas in second experiment significant heterotic effects were observed for flowering time, height, seed weight and oil per cent.

Karve et al. (1977) noted heterosis in regard to seed yield/plant to the extent of 300per cent over better parent.

Deokar and Patil (1979) in a 6 x 6 diallel cross observed significant heterosis for seed yield/ plant, primary and secondary branches, capitula/plant, capitulum diameter, seed number/capitulum and 1000 seed weight. While the negative heterosis for hulling out turn and no significant heterosis for plant spread. They observed the highest heterotic effects (115.8 per cent)

for the cross 638 x IV-11972 over better parent '638' for seed yield/plant. They further noted that none of the hybrids gave significantly higher yields than the best ( B-263-2A) for all the parents used in the studies but the best combination gave 23.5 per cent increase in yield over the best parent.

Patil (1982) recorded the high degree of heterosis for number of primary branches, capitula per plant, 1000 seed weight, seed yield per plant. The parent EC-42467 was found to be the best combiner for seed yield per plant, while the parent 116-4-2 for oil content. The cross A-No-1 x 122-6-2 had the best specific combination for seed yield and oil content. Additive gene action was observed for diameter of capitulum and oil content.

Ramachandram and Goud (1982 c) estimated heterosis in a 11 x 11 diallel set and observed that overall heterosis was the highest for seed yield(86.6 per cent). It was mostly owing to heterotic effects of total capitula (47.5 per cent) and yield/capitulum (21.2 per cent). Height of branching, days to flowering and oil content showed significantly negative heterosis. The overall heterosis ranged from 4.7 per cent for length of outer involucral bract to 19.9 per cent for spine index. The highest heterosis over better parent and commercial variety

(S-144) for seed yield was 270.1 per cent ( MS-19 x AC-1) and 177.3 per cent (A-1 x G-1157), respectively. Heterosis over commercial variety for oil content was positive but low.

Ranga Rao (1982) in a set of 8 x 8 diallel in 1978 and 10 x 10 diallel in 1979 observed that heterosis was high for yield (55 per cent) and capitulum weight (26 per cent) and moderate for capitulum number (19.5 per cent) and primary branch number/plant (13.5 per cent). Hybrids out yielded their superior parents in 76 crosses and the best adopted control in 28 crosses. The yielding hybrid excelled its superior parent by 119 per cent and the best control by 70 per cent. Heterosis for yield was usually associated with heterosis for number and / or weight of capitula. Hybrids between genetically diverse parents manifested more hybrid vigour than those closly related ones. But no desirable heterotic responce in days to maturity, plant height and oil per cent were detected in crosses that manifested significant positive heterosis for yield. The result suggested tremendous potential of hybrids for raising per hectare yield and oil out turn.

Ranga Rao (1983) recorded that crosses between genetically diverse parents manifested substantial heterosis associated with the large positive specific effects for

yield and its components. The most productive and heterotic hybrids in the material out yielded the best standard check by as much as 42 per cent in experiment 1 and 70 per cent in experiment 2. The studies highlighted the utility of population breeding approach and development of hybrid for attaining rapid and sustained genetic improvement in the yield potential.

Deokar et al. (1984) studied heterosis and heterobeltiosis for different characters among the sixteen cross combinations. A combination B-263- 2 A x JLA - 1259A showed significant and positive heterosis for all the characters except 100 seed weight and hulling per cent, one hybrid for diameter of capitulum and seeds/capitulum, two hybrids each for yield/plant, plant height and primary branches, three hybrids for 100 seed weight and four hybrids for capitula/plant have manifested highly significant and positive heterobeltiosis in characters.

Narkhede et al. (1984) studied heterosis over the mean parental value and over the better parent for yield/plant and 7 yield related characters in 16 Carthamus tinctorius, hybrids derived by crossing 2 female parents with 8 different males. B-262-2A(f) x JLA 125 g(A) (o) showed significant heterosis over the mean parental

value for yield and 5 of the 7 characters studied. Some hybrids showed significant heterosis over the better parent for one or more characters.

Ramachandram and Goud (1984) noted that sca effects and heterosis were highest for seed yield as compared to any other component character. They observed that heterobeltiosis was highest (270.1 per cent) for MS - 40 x A-1.

Narkhede et al. (1986) studied heterosis for yield/plant and 8 related characters was studied in crosses between 3 females and 5 males. Heterosis was significant for all characters but heterosis over the control variety S-4 was greatest for number of seed / capitula. The highest yielding hybrid was Tara x FT-2 which was significantly superior to S-4. Tara x EC-32012 shows high yields and N-7 x BLY - 10220 and N-7 x NS-1016 had high oil content. Most of the parents of these crosses had only poor or avarage general combining ability.

Narkhede and Patil (1987) studied heterosis in 17 crosses of safflower. Overall heterosis was highest for seed yield (157.9 per cent) due to mainly to the heterotic effects of number of capitula/per plant and number of primary and secondary branches/per plant.

The crosses S-4 x JLA-900 and A-1 x JLA 1963 were found useful for further exploitation through selection.

Yadav *et al.* (1987) studied seed yield/plant and 9 related characters in a half-diallel cross of 6 *Carthamus tinctorius*, L. varieties. Heterosis was the greatest for number of capitula/plant, followed by yield and number of secondary branches and was least for oil content. Crosses between parents with low mean values tended to show large heterotic effects for most characters. Heterosis for yield was associated with heterosis for number of capitula.

Malleshappa *et al.* (1989) studied seed yield in the $F_1$ to $F_3$ generations of 2 Indian x Indian and 2 Indian x exotic crosses grown during 1980-82. Midparent heterosis in the $F_1$ was 38.8 and 36.9 % for Indian x Indian crosses and 127 and 182.9 % for Indian x exotic crosses. In $F_3$ respective values were 18.1 and 23.9 % and 21.9 and 42.7 %.

Gupta and Singh (1990) studied 5 parents from a half-diallel cross and their $F_1$, $F_2$ and back cross generations were evaluated for days to flowering (D.F.) and days to maturity (D.M.). Data on heterosis, inbreeding depression and genetic variance were tabulated. Negative heterosis values were greatest in EC- 31367 x local

(-2.28%) for D.F. and in EC-31367 x EC-27249 (-2.29%) for D.M. Additive, dominance and epistatic gene effects were noted.

Pandya et al. (1990) studied the parents and their 50 $F_1$ hybrids from 5 line x 10 tester mating design were evaluated for 8 yield related characters. The testers Annigeri, Bhima, JLSF-88 and NS-1016 were best general combiners for seed yield/plant. The hybrids MS-104 x BSF-9-97, MS-101 x Bhima and MS-101 x Annigeri had mean yield of 720 g/plant and showed 51.5 , 48 and 46.7% heterosis for seed yield, respectively over Bhima.

Judging from the results discussed in the foregoing paragraphs and available evidences, hybrids in safflower seem to offer vast potential as a means of raising per hectare productivity of both seed and oil.

# Material and Methods

# 3. MATERIAL AND METHODS

The present investigation was undertaken to elicit information on the magnitude and nature of gene actions, heterosis for yield and oil per cent in the set of six generations viz. $P_1$ , $P_2$ , $F_1$, $F_2$, $B_1$ and $B_2$, at Central Campus, Mahatma Phule Krishi Vidyapeeth, Rahuri during the year 1990 to 1992.

The material used and statistical procedure followed during the course of present investigation are described hereafter.

## Materials :

The material of present study involved six parents and their four $F_1$S. These were selected on the basis of genetic divergence. These varieties were obtained from the germplasm collection maintained at safflower Research Project, Mahatma Phule Krishi Vidyapeeth, Jalgaon.

## Methods :

Experimental trials were connducted during the rabi seasons of 1990-91 and 1991-92.

## Hybridization Programme :

The seeds of the parents and their four $F_1$s were obtained from safflower Research Project, M.P.K.V.

Pedigree of parents

| Parent | Pedigree |
|---|---|
| JLSF-103 | B-263-2A x JLA-65 |
| N-62-8 | Selection from local |
| SSF-3 | Selection in F 6 generation during 1980-81 Sel.No = 27-7-11-2. |
| GMU 2375 | JLA-404 - PI-665 - NARI Phaltan (Satara) |
| GMU-2497 | JLA-689 |
| NS-1021-1 | This genotype is from Nimbkar phaltan |

Jalgaon and were sown during the rabi season of 1990-91 to obtain the seeds of $F_2$ and backcrosses. The cross seeds were obtained by doing hand emasculation and pollination.

Design and Layout :

The experiment was conducted in a Randomized Block Design with three replications. The experimental material consisting of 22 treatments involving six parents and their four $F_1$s , $F_2$s , $B_1$ and $B_2$ was grown at the Post Graduate Instructional Farm, Department of Botany, M.P.K.V., Rahuri during rabi season of 1991-92.

The row of 15 plants, spaced at 45 cm between rows and 20 cm within row. Two rows of each parents, single row of $F_1$s, 6 rows of $F_1$s and two rows of each $B_1$ and $B_2$ were sown. The border row was planted to avoid the border effect.

Cultural practices :

Sowing Sowing was done on 2nd Oct, 1991. The sowing was done by dibbling and subsequently thinned to keep single plant per hill after ten days of germination to maintain a uniform plant population. The gap filling was also done ten days after sowing.

| | |
|---|---|
| Fertilizers | The recommended dose of fertilizers i.e. 50 kg: N & 25 Kg of $P_2O_5$ was given to the experimental material. |
| Irrigation | First irrigation was given immidiatly after sowing to assure good germination. Second irrigation i.e.30 days after sowing and third irrigation at the time of flowering. |
| Plant protection | In order to control safflower aphid (Dactynotus carthami, H.R.L.) two sprays of recommended insecticides were given. |
| Weeding | To reduce the competition of weeds with plants a weeding was done. |
| Observations recorded | In each replication, for each entry ten plants of non segregating and twenty plants of segregating generations were selected at random for recording observations of following characters and average were calculated. |

Characters studied :

The details of the twelve characters studied are given below.

1) Days to 50 per cent flowering :

The number of days required to flowering at least 50 per cent of total plants per treatment in each replication was recorded.

2) Days to Maturity

Number of days required to mature at least 50 per cent of total plant population in a particular progany in a replication was recorded.

3) Height at Maturity

Plant height in (cm) measured from ground level to the highest growing point at the time of maturity of the observational plants, was recorded and averages were worked out.

4) Primary branches per plant

Branches arising from main stem were considered as primary branches and those were recorded at the time of harvest.

5) Secondary branches per plant

The number of secondary branches borne on primary branches were recorded at the time of harvest.

ABSTRACT DIGITIZED 25.

6) Capitula per plant

Number of capitula on each observational plant was counted at the time of harvest.

7) Diameter of capitulum (cm)

Diameter of capitulum (cm) of the observational plant was measured and average was worked out.

8) Seeds per capitulum

The number of seeds per main capitulum of the observational plant was counted and average was workdout to have the number of seeds per capitulum.

9) Seed yield per capitulum The weight of total seed obtained from all observational capitulum was recorded in gramme and the averages were calculated.

10) Seed yield per plant (g)

The weight of total seed obtained from all the observational plants was recorded in gramme and the average was calculated.

11) 100 seed weight (g)

This was recorded by taking the weight of 100 seeds in gramme.

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12) Oil content -- The oil content was estimated on NMR (Nuclear magnetic resonance) spectometer, oil seed research project, P.K.V., Akola.

Biometric analysis

Analysis of variance -

The data were collected on randomely selected ten plants per replication from non-segregating generations and twenty plants from segregating generations in each replication for each character. Analysis of variance was carried out by subjecting the mean data separatly for each character and the ANOVA was constructed as follows ( Panse and Sukhatme, 1967).

ANOVA

| Source | D.F | S.S. | M.S.S. | F ratio |
|---|---|---|---|---|
| Replications | (r-1) | RSS | Mr | Mr/E |
| Treatments | (t-1) | TSS | Mt | Mt/E |
| Errors | (r-1)(t-1) | ESS | Me(E) | |

Where,

r = Number of replications

t = Number of treatments.

Joint scaling test :

The Joint scaling test proposed by Cavalli(1952) was applied to test adequacy of additive dominance model.

Estimation of gene effects

To provide information on the nature of gene action governing the traits under study, all the six components of generation means were calculated by following the method outlined by Hayman (1958).

The notations for the various gene effects used in this study were those adopted by Hayman(1958) and they are as under :

| Gene effect | Notation of Hayman (1958) |
|---|---|
| Mean | m |
| Additive | d |
| dominance | h |
| Additive x Additive | i |
| Additive x dominance | j |
| Dominance x dominance | l. |

The estimates of m, d, h, i, j and l were worked out using the following equations suggested by Hayman (1958).

$$m = \bar{F}_2$$

$$d = \bar{B}_1 - \bar{B}_2$$

$$h = \bar{F}_1 + 2\bar{B}_1 - 1/2\,\bar{P}_1 - 1/2\,\bar{P}_2 - 4\bar{F}_2 + 2\bar{B}_2$$

$$i = 2\bar{B}_1 + 2\bar{B}_2 - 4\bar{F}_2$$

$$j = 2\bar{B}_1 - \bar{P}_1 - 2\bar{B}_2 + \bar{P}_2$$

$$l = \bar{P}_1 + \bar{P}_2 + 2\bar{F}_1 + 4\bar{F}_2 - 4\bar{B}_1 - 4\bar{B}_2$$

2) The variances of these estimates of gene effects were obtained as -

$$Vm = V\bar{F}_2$$

$$Vd = V\bar{B}_1 + V\bar{B}_2$$

$$Vh = V\bar{F}_1 + 4\,V\bar{B}_1 + 1/4\,V\bar{P}_1 + 1/4\,V\bar{P}_2 + 16.V\bar{F}_2 + 4\,V\bar{B}_2$$

$$Vi = 4\,V\bar{B}_1 + 4\,V\bar{B}_2 + 16\,V\bar{F}_2$$

$$Vj = 4\,V\bar{B}_1 + V\bar{P}_1 + 4\,V\bar{B}_2 + V\bar{P}_2$$

$$Vl = V\bar{P}_1 + V\bar{P}_2 + 4\,V\bar{F}_1 + 16\,V\bar{F}_2 + 16\,V\bar{B}_1 + 16\,V\bar{B}_2$$

Where,

Vm = Variance of mean

Vd = Variance of d.

Vh = Variance of h.

Vi = Variance of i

Vj = Variance of j

Vl = Variance of l.

$V\bar{P}_1$ = Variance of mean of $P_1$

$V\bar{P}_2$ = Variance of mean of $P_2$

$V\bar{F}_1$ = Variance of mean of $F_1$

$V\bar{F}_2$ = Variance of mean of $F_2$

$V\bar{B}_2$ = Variance of mean of $B_2$

$V\bar{B}_1$ = Variance of mean of $B_1$.

Standard errors

Standard errors of Vm, Vd, Vh, Vi, Vj and Vl were calculated for testing the significance of corresponding estimates as -

S.E. of m $= \sqrt{Vm}$

S.E. of d $= \sqrt{Vd}$

S.E. of h $= \sqrt{Vh}$

S.E. of i $= \sqrt{Vi}$

S.E. of j $= \sqrt{Vj}$

S.E. of l $= \sqrt{Vl}$

Where,

Vm = Variance of m

Vd = Variance of d.

Vh = Variance of h

Vi = Variance of i

Vj = Variance of j

Vl = Variance of l

5) t value for scaling test

It is the ratio of value of scaling test to the S.E. of that scaling test.

$$t(m) = \frac{m}{S.E.(m)}$$

$$t(d) = \frac{d}{S.E.(d)}$$

$$t(h) = \frac{h}{S.E.(h)}$$

$$t(i) = \frac{i}{S.E.(i)}$$

$$t(j) = \frac{j}{S.E.(j)}$$

$$t(l) = \frac{l}{S.E.(l)}$$

Where,

S.E.(m) = Standard error of (m)
S.E.(d) = Standard error of (d)
S.E.(h) = Standard error of (h)
S.E. (i) = Standard error of (i)
S.E.(j) = Standard error of (j)
S.E.(l) = Standard error of(l)

Heterosis

The $F_1$ values were averaged over replications and used in estimating heterosis percentage over their

respective midparent (m.p.) and better parent (B.P.) values by following the method given by Turner (1953) and Hayes et al. (1955).

Estimation of values of $F_1$ over mid parent and better parent.

The values of heterotic effects over mid parents and better parents were calculated for each character by using the following formulae.

$$\text{Per cent heterosis over mid parent} = \frac{\overline{F_1} - \overline{M.P.}}{\overline{M.P.}} \times 100$$

$$\text{Per cent heterosis over better parent} = \frac{\overline{F_1} - \overline{B.P.}}{\overline{B.P.}} \times 100$$

Where,

$\overline{F_1}$ = mean of $F_1$ hybrid.

$\overline{M.P.}$ = Mean of two parents of that particular cross

$\overline{B.P.}$ = Mean of better parent of that particular cross.

Test of significance

Heterosis was tested by least significance difference after 'F' test as follows.

$$\text{L.S.D. for M.P.} = \sqrt{\frac{3me}{2r}} \times \text{t value at 5\% or 1\%}$$

$$\text{L.S.D. for B.P.} = \sqrt{\frac{2me}{r}} \times \text{t value at 5\% or 1\%}$$

Where,

me = Error mean sum of square

r = replications.

# Experimental Results

# 4. EXPERIMENTAL RESULTS

The present investigation of " Genetic analysis of safflower ( Carthamus tinctorious, L.) " was undertaken with a view to analyse the nature of gene action and heterosis for various characters. The experimental material consists of six generations viz. $P_1$, $P_2$, $F_1$, $F_2$ , $B_1$ and $B_2$.

## 4.1 Mean performance of parents, $F_1$S, $B_1$S, $B_2$S and $F_2$S.

### 4.1.1 Days to 50 per cent flowering

From the data presented in Table 1, it will be seen that, the parent NS-1021-1 was the earliest(79.67 days) among all the parents, Whereas the parent GMU-2497 was flowered late (91.67 days). The range of days to 50 per cent flowering in the parents was from 79.67 to 91.67 days.

Amongst the hybrids, JLSF-103 x NS-1021-1 and N-62-8 x GMU-2497 was the earliest and late, respectively. The range of days to 50 per cent flowering in the hybrids was from 75 to 85.67 days.

In the $B_1$s the early flowering was observed in (JLSF-103 x NS-1021-1) x JLSF-103 (74.33 days) and the range was from 74.33 to 85.33 . Amongst $B_2$s, the early flowering was observed in (JLSF 103 x NS-1021-1) x

Table 1 Mean performance of parents, $F_1$s, $F_2$s, $B_1$s and $B_2$s

| | Name of the genotype | Days to 50per cent flowering | Days to maturity | Plant height (cm) | Primary branches per plant |
|---|---|---|---|---|---|
| Parents = | SSF-3 | 82.33 | 111.33 | 65.55 | 14.70 |
| | JLSF-103 | 84.67 | 115.00 | 99.51 | 15.50 |
| | N-62-8 | 89.00 | 133.33 | 93.80 | 15.35 |
| | GMU-2497 | 91.67 | 128.00 | 95.51 | 15.20 |
| | GMU-2375 | 84.67 | 114.67 | 99.51 | 15.20 |
| | NS-1021-1 | 79.67 | 120.00 | 74.78 | 15.00 |
| $F_1$s | JLSF-103 x NS-1021-1 | 75.00 | 113.00 | 93.19 | 16.20 |
| | N-62-8 x GMU-2497 | 85.67 | 122.33 | 108.58 | 19.00 |
| | JLSF-103 x GMU-2497 | 82.67 | 121.00 | 106.12 | 17.85 |
| | SSF-3 x GMU-2375 | 79.33 | 111.33 | 84.43 | 16.50 |
| $F_2$s | F2(JLSF-103 x NS-1021-1) | 81.00 | 111.00 | 90.15 | 15.90 |
| | F2(N-62-8 x GMU-2497) | 90.33 | 118.00 | 93.22 | 17.85 |
| | F2(JLSF-103 x GMU-2497 | 87.33 | 115.33 | 91.00 | 16.75 |
| | F2(SSF-3 x GMU-2375 | 83.00 | 110.33 | 79.18 | 15.33 |
| $B_1$s | (JLSF-103 x NS-1021-1) x JLSF-103 | 74.33 | 111.33 | 105.62 | 16.70 |
| | (N-62-8 x GMU-2497)xN-62-8 | 85.33 | 116.67 | 102.25 | 19.60 |
| | (JLSF-103xGMU-2497)x JLSF-103 | 81.33 | 115.33 | 100.15 | 18.22 |
| | (SSF-3 x GMU-2375) x SSF-3 | 78.67 | 109.00 | 89.22 | 17.00 |
| $B_2$s | (JLSF-103xNS-1021-1)xNS-1021-1 | 80.33 | 112.00 | 99.47 | 16.20 |
| | (N-62-8xGMU-2497)xGMU-2497 | 89.00 | 117.67 | 107.52 | 18.00 |
| | (JLSF-103xGMU-2497)xGMU-2497 | 87.00 | 115.33 | 99.67 | 16.85 |
| | (SSF-3xGMU-2375)x GMU-2375 | 82.67 | 110.33 | 95.33 | 15.85 |

| Name of the cross | Secondary branches per plant | Capitula per plant | Diameter of capitulum (cm) | Seeds per capitulum |
|---|---|---|---|---|
| SSF-3 | 18.20 | 34.90 | 2.41 | 14.80 |
| JLSF-103 | 10.60 | 30.10 | 2.32 | 10.20 |
| N-62-8 | 24.75 | 46.10 | 2.43 | 26.00 |
| GMU-2497 | 14.60 | 29.80 | 1.90 | 9.90 |
| GMU-2375 | 12.42 | 29.92 | 2.21 | 9.92 |
| NS-1021-1 | 9.85 | 26.85 | 1.53 | 6.89 |
| JLSF-103 x NS-1021-1 | 22.65 | 41.85 | 2.12 | 21.80 |
| N-62-8 x GMU-2497 | 30.17 | 51.17 | 2.51 | 32.07 |
| JLSF-103 x GMU-2497 | 18.15 | 38.16 | 2.20 | 17.40 |
| SSF-3 x GMU-2375 | 25.95 | 43.00 | 2.43 | 25.10 |
| F2 (JLSF-103 x NS-1021-1) | 20.25 | 38.15 | 2.01 | 18.15 |
| F2(N-62-8 x GMU-2497) | 27.70 | 47.55 | 2.32 | 27.45 |
| F2 (JLSF-103 x GMU-2497) | 15.37 | 35.12 | 2.00 | 15.12 |
| F2 (SSF-3 x GMU-2375) | 25.52 | 42.85 | 2.11 | 12.85 |
| (JLSF-103 x NS-1021-1) x JLSF-103 | 20.75 | 40.45 | 2.22 | 20.55 |
| N-62-8 x GMU-2497)x N-62-8 | 28.57 | 52.17 | 2.60 | 31.07 |
| (JLSF-103 x GMU-2497) x JLSF-103 | 18.20 | 37.40 | 2.30 | 18.00 |
| (SSF-3 x GMU-2375) x SSF-3 | 26.00 | 45.45 | 2.51 | 23.07 |
| (JLSF-103 x NS-1021-1) x NS-1021-1 | 21.50 | 39.70 | 2.03 | 19.75 |
| (N-62-8 x GMU-2497) x GMU-2497 | 28.45 | 49.45 | 2.30 | 29.45 |
| (SSF-3 x GMU-2375) x GMU-2375 | 26.25 | 43.20 | 2.12 | 23.40 |

| Name of the cross | Yield per capitulum (g) | Yield per plant (g) | 100 seed weight (g) | Oil content (%) |
|---|---|---|---|---|
| SSF-3 | 0.82 | 27.92 | 5.53 | 28.50 |
| JLSF-103 | 0.52 | 18.45 | 5.12 | 29.50 |
| N-62-8 | 1.49 | 28.12 | 5.73 | 30.28 |
| GMU-2497 | 0.46 | 11.10 | 4.50 | 30.49 |
| GMU-2375 | 0.47 | 12.15 | 4.78 | 30.60 |
| NS-1021-1 | 0.28 | 8.95 | 4.11 | 29.29 |
| JLSF-103 x NS-1021-1 | 1.07 | 16.45 | 4.92 | 32.49 |
| N-62-8 x GMU-2497 | 1.81 | 22.72 | 5.66 | 35.42 |
| JLSF-103 x GMU-2497 | 0.90 | 17.13 | 5.21 | 34.12 |
| SSF-3 x GMU-2375 | 1.31 | 19.92 | 5.22 | 39.17 |
| F2 (JLSF-103 x NS-1021-1) | 0.85 | 14.12 | 4.71 | 29.39 |
| F2 (N-62-8 x GMU-2497) | 1.46 | 18.82 | 5.32 | 30.39 |
| F2 (JLSF-103 x GMU-2497) | 0.75 | 14.13 | 4.94 | 30.00 |
| F2 (SSF-3 x GMU-2375) | 0.65 | 17.27 | 5.07 | 30.05 |
| (JLSF-103 x NS-1021-1) x JLSF-103 | 1.03 | 16.98 | 5.00 | 39.39 |
| N-62-8 x GMU-2497 x N-62-8 | 1.71 | 21.27 | 5.51 | 38.44 |
| (JLSF-103 x GMU-2497) x JLSF-103 | 0.94 | 16.13 | 5.20 | 37.12 |
| SSF-3 x GMU-2375) x SSF-3 | 1.22 | 19.72 | 5.29 | 35.05 |
| (JLSF-103 x NS-1021-1) x NS-1021-1 | 0.95 | 15.72 | 4.81 | 29.85 |
| (N-62-8 x GMU-2497) x GMU-2497 | 1.62 | 20.13 | 5.49 | 30.78 |
| (JLSF-103 x GMU-2497) x GMU-2497 | 0.86 | 16.70 | 5.17 | 30.91 |
| (SSF-3 x GMU-2375) x GMU-2375 | 1.19 | 18.60 | 5.08 | 30.59 |

Table 2 Analysis of variance for different quantitative characters in safflower

| Source | DF | Mean sum of squares | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Days to 50 per cent flowering | Days to maturity | Plant height | Primary branches per plant | Secondary branches per plant | Capitulum per plant | Diameter of capitulum | Seeds per capitulum | Yield per capitulum | Yield per plant | 100 seed weight | Oil content |
| Treatment | 22 | 63.87** | 108.98** | 349.50** | 5.40* | 109.24** | 152.67** | 0.17* | 154.46** | 0.53** | 65.01** | 0.44* | 29.55** |
| Error | 44 | 1.31 | 1.35 | 1.34 | 1.38 | 0.53 | 0.44 | 0.06 | 2.13 | 0.003 | 0.69 | 0.20 | 0.15 |

** = Significance for 1%

* = Significance for 5%

NS-1021-1 (80.33 days), late flowering in (N-62-8 x GMU-2497) x GMU 2497 (89.00 days).

Considering $F_1$s, $B_1$s and $B_2$s, crosses involving NS-1021-1 flowered earlier. Amongst $F_2$s, the $F_2$ of (JLSF-103 x NS-1021-1) showed earliness (81.00 days), while the $F_2$ of N-62-8 x GMU-2497 flowered late (90.33 days)

4.1.2 Plant height

In respect of the plant height of the parents, SSF-3 was found to be the dwarfest (65.55 cm) and JLSF-103 and GMU-2375 were the tallest (99.51 cm). A considerable increase in the plant height was observed in $F_1$s. The cross, N-62-8 x GMU-2497 showed maximum height (108.58 cm) followed by the cross (JLSF-103 x GMU-2497) (106.12 cm). None of the hybrids was found to be dwarfer than parental lines. The $B_1$s of JLSF-103 x NS-1021-1 and SSF-3 x GMU-2375 exhibited maximum and minimum plant height, respectively. In $B_1$s plant height ranged from 105.62 to 84.43 cm. In $B_2$, the cross N-62-8 x GMU-2497 was the tallest (107.52 cm) and was ranged from 95.33 to 107.52 cm in cross SSF-3 x GMU-2375.

Considering all $F_1$s, $B_1$s and $B_2$s, the combinations of SSF-3 produced dwarf hybrids. The $F_2$ of SSF-3 x GMU-2375 was the dwarfest among all $F_2$ populations. The $F_2$ of JLSF-103 x GMU-2497 showed maximum height of 99.67 cm.

4.1.3 Days to Maturity

From the data it will be seen that, the parent SSF-3 has matured earlier (111.33 days) among all the parents. The days to maturity ranges from 111.33 to 128.00 days.

Amongst the hybrids, SSF-3 x GMU-2375 and N-62-8 x GMU-2497 was the earliest and late in maturity. respectively. The range of days to maturity was from 111.33 to 122.33 days.

In the $B_1$s, the early maturity was observed in (SSF-3 x GMU-2375) x SSF-3 ( 109.00 days) and the range was 109.00 to 116.67 days in (N-62-8 x GMU-2497) x N-62-8. Amongst $B_2$s, the early maturity was observed in (SSF-3 x GMU-2375) x GMU-2375 (110.33 days) and late in (N-62-8 x GMU-2497) x GMU-2497 (117.67 days).

4.1.4 Primary branches per plant

The parents, GMU-2375 and JLSF-103 had the highest number of primary branches per plant (15.5), while the lowest number was observed in SSF-3 (14.7). Amongst $F_1$s, the combination N-62-8 x GMU-2497 and JLSF-103 x NS-1021-1 had the highest (19.00) and the lowest(16.20)

number of primaries per plant, respectively. A considerable increase in the number of primary per plant was observed in the $B_1$ (19.60) and $B_2$ (18.00) of N-62-8 x GMU-2497, while the $B_1$ of (JLSF-103 x NS-1021-1) x JLSF-103 (16.70) and $B_2$ of (SSF-3 x GMU-2375) x GMU-2375 (15.85) had the lowest number of primary per plant.

Amongst $F_2$s, the number of primary branches was the highest in $F_2$ of N-62-8 x GMU-2497 (17.85), whereas it was the lowest in the $F_2$ of SSF-3 x GMU-2375 (15.33).

4.1.5 Secondary branches per plant

The parent N-62-8 had the highest number of secondaries per plant (24.75) amongst the parental lines, while the lowest number was observed in NS-1021-1. Amongst $F_1$s, the combination N-62-8 x GMU-2497 and JLSF-103 x GMU-2497 had the highest (30.17) and the lowest (18.25) number of secondaries per plant respectively. Number of secondaries per plant was observed in the $B_1$(28.57) and $B_2$(28.45) of N-62-8 x GMU-2497, while $B_1$ and $B_2$ of JLSF-103 x GMU-2497 was the lowest number of secondaries per plant (18.2) and (18.75), respectively.

Amongst $F_2$s, the number of secondaries per plant was the highest in the $F_2$ of N-62-8 x GMU-2497(27.7) Whereas, it was the lowest in the $F_2$ of JLSF-103 x GMU-2497 (15.37). There was considerable decrease in the number of secondaries per plant from $F_1$ to $F_2$ generations of all the crosses.

4.1.6 Capitula per plant

The capitula per plant ranged from 26.85 ( NS-1021-1) to 46.10 (N-62-8). The combination N-62-8 x GMU-2497 produced the maximum number of capitula (51.17) followed by SSF-3 x GMU-2375 (43.00), the lowest was recorded by JLSF-103 x GMU-2497. The $B_1$ and $B_2$ of the cross N-62-8 x GMU-2497 produced maximum number of capitula with the mean values 52.17 and 49.45, respectively. The combinations involving N-62-8 as the parents generally produced more number of capitula.

Amongst $F_2$s, $F_2$ of N-62-8 x GMU-2497 showed high number of capitula per plant (47.55), while the $F_2$ of JLSF-103 x GMU-2497 showed less number of capitula per plant (35.12). There was a decrease in number of capitula per plant from $F_1$ to $F_2$ generations of all crosses.

4.1.7 Diameter of capitulum

A range for the diameter of capitulum was from 2.43 cm (N-62-8) to 1.53 cm (NS-1021) in the parental material. The combination N-62-8 x GMU-2497 had the biggest size of capitulum (2.51 cm), while the lowest diameter of capitulum was noticed in the cross JLSF-103 x NS-1021-1 (2.12 cm). The $B_1$ and $B_2$ of the cross N-62-8 x GMU-2497 recorded the highest diameter of capitulum. While in $B_1$, (JLSF-103 x NS-1021-1) x JLSF-103 had small capitulum size (2.22 cm) and $B_2$ the lowest diameter of capitulum was observed in cross (JLSF-103 x GMU-2497) x JLSF-103 ( 2.01 cm ).

The $F_2$ of N-62-8 x GMU-2497 recorded maximum diameter (2.32 cm) and was the lowest in JLSF-103 x GMU-2497 (2.00 cm). All the $F_2$S had less diameter of capitulum as compared to $F_1$s.

4.1.8 Seeds per capitulum

The seeds per capitulum ranged from 6.89 (NS-1021-1) to 26.00 (N-62-8). The combination N-62-8 x GMU-2497 produced more seed number (32.07) and JLSF-103 x GMU-2497 had less number of seeds per capitulum (17.40). Both the backcrosses of cross N-62-8 x GMU-2497 produced more number of seeds per capitulum i.e 31.07

and 29.45, respectively. While the lowest number of seeds in both backcrosses of JLSF-103 x GMU-2497 (18.00 and 16.55, respectively) were noticed. The $F_2$ of N-62-8 x GMU-2497 recorded more number of seed (27.45), Whereas $F_2$ of SSF-3 x GMU-2375 showed less number of seeds (12.85).

4.1.9 Yield per capitulum

In the parental lines, yield per capitulum ranged from 0.28 g (NS-1021-1) to 1.49 g (N-62-8) The highest seed yield per capitulum (1.81 g) was obtained in the combination N-62-8 x GMU-2497. Amongst the $B_1$s, the $B_1$ of (N-62-8 x GMU-2497) x N-62-8 had the highest yield of 1.71 g, whereas amongst the $B_2$S, the $B_2$ of (N-62-8 x GMU-2497) x GMU-2497 gave the highest yield of 1.62 g per capitulum. The back crosses of JLSF-103 x GMU-2497 with its both the parents were the low yielders (0.94 g and 0.86 g, respectively).

The $F_2$ of N-62-8 x GMU-2497 showed maximum yield per capitulum (1.46 g), Whereas $F_2$ of SSF-3 x GMU-2375 (0.65 g) had lower level of grain yield per capitulum. A significant decrease in the yield level from $F_1$ to $F_2$ was observed in all the crosses. In general, the combinations involving N-62-8 as one of the parent showed high yields.

4.1.10 Yield per plant

In yield per plant for the parental lines ranged from 8.92 g (NS-1021-1) to 28.12 g( N-62-8). The highest grain yield per plant (22.72 g) was obtained in the combination N-62-8 x GMU-2497. Amongst the $B_1$s, the $B_1$ of (N-62-8 x GMU-2497) x N-62-8 gave the highest yield of (21.27 g), whereas amongst $B_2$s, the $B_2$ of (N-62-8 x GMU-2497) x GMU-2497 gave the highest yield of (20.13 g). In the $B_1$ of (JLSF-103 x GMU-2497) x JLSF-103 was low yilder (16.13 g) and in $B_2$ of (JLSF-103 x NS-1021-1) x NS-1021-1 was low yielder (15.72 g).

The $F_2$ of N-62-8 x GMU-2497 showed maximum yield per plant (18.82 g). While the $F_2$s of JLSF-103 x NS-1021-1 (16.45 g) had lower level of yield per plant. There was significant decrease in the level of yield from $F_1$ to $F_2$ in all crosses.

4.1.11 100 seed weight

Amongst the parental material, N-62-8 recorded the highest 100 grain weight (5.73 g) and the lowest 100 grain weight (4.11 g) by NS-1021-1. In the hybrids, it ranged from 5.78 g (N-62-8x GMU-2497) to 5.21 g (JLSF-103 x NS-1021-1). The maximum 100 grain weight

was observed in the $B_1$ and $B_2$ of the cross N-62-8 x GMU-2497 ... 5.51 g and 5.49 g, respectively. Both in $B_1$ and $B_2$ generations the lowest yield was observed in the cross (JLSF-103 x NS-1021-1).

The $F_2$ of N-62-8 x GMU-2497 had the highest (5.32 g), while the lowest (4.71 g) in $F_2$ of JLSF-103 x NS-1021-1.

The combinations involving the parental line N-62-8 had higher seed weight in different generations and also in $F_1$.

4.1.12 Oil content

Amongst the parental material, oil content was from 28.5% (SSF-3) to 30.28% (N-62-8), Whereas, it ranged from 32.49% (JLSF-103 x NS-1021-1) to 39.17% (SSF-3 x GMU-2375) in hybrids. In $B_1$ and $B_2$, maximum oil contents were 38.44% and 30.78%, respectively in the cross (N-62-8 x GMU-2497) and lower in cross JLSF-103 x NS-1021-1 (30.39% and 29.85% respectively).

The $F_2$ of N-62-8 x GMU-2497 with the highest oil content (30.39%) ... and the lowest in cross JLSF-103 x NS-1021-1 ( 29.85%).

Table 3 Estimation of genetic parameters on epistatic model for 12 quantitative characters in safflower.

| Character and cross | $\chi^2$ for Joint scaling test | m | d | h | i | j | l |
|---|---|---|---|---|---|---|---|
| Days to 50 per cent flowering | | | | | | | |
| 1) JLSF-103 x NS-1021-1 | -1.76** | 145.42** | -12.68** | 8.21** | -5.88** | -12.85** | -20.27** |
| 2) N-62-8 x GMU-2497 | -1269.58** | 269.64** | - 3.05** | -5.76** | -5.88** | - 1.48 | 2.38** |
| 3) JLSF-103 x GMU-2497 | -340.17** | 260.68** | -16.92** | -10.21** | -4.60** | - 2.26** | 6.19** |
| 4) SSF-3 x GMU-2375 | -540.47** | 143.84** | - 2.90** | - 3.70** | -8.45** | - 1.94 | 2.32** |
| Days to maturity | | | | | | | |
| 1) JLSF-103 x NS-1021-1 | -3751.13** | 344.26** | 0.00 | - 0.24 | 0.00 | 7.64** | 7.32** |
| 2) N-62-8 x GMU-2497 | 68.33** | 125.47** | - 1.50 | -1.41* | -1.01 | 0.35 | 2.62** |
| 3) JLSF-103 x GMU-2497 | 422.22** | 96.10** | - 0.80 | 0.22* | 0.63 | 1.06 | 1.49** |
| 4) SSF-3 x GMU-2375 | - 262.26** | 163.05** | - 1.06 | -2.55** | -0.93 | - 3.51** | 3.49** |
| Plant height | | | | | | | |
| 1) JLSF-103 x NS-1021-1 | - 225.03** | 181.75** | 6.43** | 19.74** | 17.78** | - 6.097** | 21.96** |
| 2) N-62-8 x GMU-2497 | 170.80** | 81.13** | - 3.99** | 11.28** | 8.80** | - 2.84** | - 8.28** |
| 3 JLSF-103 x GMU-2497 | 13.28** | 87.08** | 0.38 | 8.95** | 7.32** | - 1.19 | - 4.16** |
| 4) SSF-3 x GMU-2375 | -3563.60** | 113.76** | -15.46** | 19.46** | 18.05** | 7.19** | -14.98** |
| Primary branches/per plant | | | | | | | |
| 1) JLSF-103 x NS-1021-1 | 35.49** | 33.40** | 0.76 | 1.21 | 0.95 | 0.39 | - 5.45** |
| 2) N-62-8 x GMU-2497 | -2471.11** | 17.85** | 2.25** | 1.69 | 0.90 | 1.26 | - 1.86 |
| 3) JLSF-103 x GMU-2497 | 330.67** | 26.04** | 2.12** | 1.84 | 1.08 | 1.07 | - 1.65 |
| 4) SSF-3 x GMU-2375 | 10.55** | 51.1** | 1.95 | -13.72** | 2.60** | 1.89 | - 1.94 |

| Character and cross | $\chi^2$ for joint scaling test | m | d | h | i | j | l |
|---|---|---|---|---|---|---|---|
| Secondary branches/per plant | | | | | | | |
| 1) JLSF-103 x NS-1021-1 | 495.41** | 924.65** | -5.96** | 12.81** | 3.58** | 2.49** | -5.56** |
| 2) '-62-8 x GMU-2497 | 18.38** | 251.81** | 0.159 | 2.39** | 0.67 | -1.96** | -4.20** |
| 3) JLSF-103 x GMU-2497 | 246.98** | 20.38** | -0.85 | 6.34** | 4.52** | 1.71 | -6.26** |
| 4) SSF-3 x GMU-2375 | 24.87** | 67.19** | 0.39 | 6.24** | 1.77 | -2.87** | -7.40** |
| Capitula /per plant | | | | | | | |
| 1) JLSF-103 x NS-1021-1 | 2013.43** | 33.52** | 1.68 | 4.60** | 1.66 | -1.90 | -5.57** |
| 2) N-62 x GMU-2497 | -201.42** | 100.10** | 6.49** | 11.31** | 6.27** | -10.65** | -12.73** |
| 3) JLSF-103 x GMU-2497 | 96.79** | 156.66** | 2.85** | 13.81** | 6.61** | 1.96* | -11.68** |
| 4) SSF-103 x GMU-2375 | 895.37** | 118.04** | 3.36** | 8.26** | 2.98** | -0.33 | -10.46** |
| Diameter of capitutum | | | | | | | |
| 1) JLSF-103 x NS-1021-1 | -8694.48** | 21.26** | 0.46 | 1.58 | 1.16 | -1.68 | - 1.72 |
| 2) N-62-8 x GMU-2497 | -1151.39** | 77.33** | 2.38** | 2.21* | 1.86 | 0.13 | - 1.05 |
| 3) JLSF-103 x GMU-2497 | 608.43** | 26.49** | 2.82** | 1.55 | 1.69 | 0.31 | - 0.42 |
| 4) SSF-3 x GMU-2375 | 72.17** | 15.62** | 2.78** | 2.01* | 1.96* | 1.36 | - 0.78 |
| Seeds/per capitutum | | | | | | | |
| 1) JLSF-103 x NS-1021-1 | -1133.7** | 29.90** | 0.87 | 6.62** | 2.63** | -0.87 | - 5.75** |
| 2) '-62-8 x GMU-2497 | 45.63** | 132.60** | 1.63 | 11.55** | 5.22** | -6.24** | - 7.77** |
| 3) JLSF-103 x GMU-2497 | -26.52** | 39.47** | 5.06** | 6.57** | 2.82** | -1.51 | - 9.14** |
| 4) SSF-3 x GMU-2375 | -1766.42** | 45.24** | -0.61 | 19.36** | 15.16** | -2.49** | -10.85** |

| Character and cross | $X^2$ for Joint scaling test | m | d | h | i | j | l |
|---|---|---|---|---|---|---|---|
| Yield/per capitutum | | | | | | | |
| 1) JLSF-103 x NS-1021-1 | -1374.37** | 74.56** | 3.80** | 25.84** | 12.72** | 1.53 | -28.99** |
| 2) N-62-8 x GMU-2497 | 874.32** | 128.06** | 2.92** | 23.27** | 11.37** | -113.44** | -23.75** |
| 3) JLSF-103 x GMU-2497 | 17.84** | 26.04** | 3.84** | 8.13** | 4.89** | 1.90 | - 9.72** |
| 4) SSF-3 x GMU-2375 | 153.79** | 1.986** | 1.58 | 0.18 | -0.31 | -7.25** | - 0.36 |
| Yield/per plant | | | | | | | |
| 1) JLSF-103 x NS-1021-1 | 16776 .54** | 45.40** | 1.52 | 5.39** | 4.28** | -3.52** | - 3.75** |
| 2) N-62-8 x GMU-2497 | 99573 .8** | 24.22** | 2.74** | 2.93** | 2.33* | -11.44** | - 1.97* |
| 3) JLSF-103 x GMU-2497 | 7.64** | 26.86** | 4.19** | 5.25** | 4.30** | - 3.39** | - 4.62** |
| 4) SSF-3 x GMU-2375 | 166.34** | 73.48** | 1.34 | 3.75** | 3.96** | - 6.85** | - 1.18 |
| 100 seed weight | | | | | | | |
| 1) JLSF-103 x NS-1021-1 | 34059.63** | 80.37** | 0.48 | 1.44 | 0.95 | - 0.34 | - 0.62 |
| 2) N-62-8 x GMU-2497 | -120.40** | 73.58** | 0.08 | 1.39 | 0.68 | - 1.13 | - 0.93 |
| 3) JLSF-103 x GMU-2497 | -228.42** | 13.87** | 0.10 | 0.85 | 0.63 | - 0.89 | - 1.90 |
| 4) SSF-3 x GMU-2375 | 14756.05** | 10.16** | 1.41 | 0.25 | 0.22 | - 0.79 | - 0.20 |
| Oil content | | | | | | | |
| 1) JLSF-103 x NS-1021-1 | 2305.05** | 114.35** | 1.65 | 4.88** | 2.39** | 1.24 | 0.21 |
| 2) N-62-8 x GMU-2497 | 67169.75** | 237.42** | 17.93** | 21.76** | 16.96** | 18.12** | -22.73** |
| 3) JLSF-103 x GMU-2497 | -46123.35** | 101.01** | 21.05** | -14.08** | 12.12** | 21.63** | -13.94** |
| 4) SSF-3 x GMU-2375 | 69293.54** | 52.75** | 8.92** | 8.08** | 4.45** | 10.38** | - 1.50 |

Gene effects :

The data of joint scaling tests are presented in Table 3 . Joint scaling test was significant for most of the characters studied, indicating the presence of non-additive gene actions.

The estimates of various gene effects studied for 12 characters are presented in Table 3 .

The parameter $\hat{m}$ was significant in all the combinations of almost all the characters studied.

Days to 50 per cent flowering

As regards the gene effects additive (d) and dominance (h) gene effects were important in all the combinations.

The epistatic gene effects ( i,j, and l) were found to be significant in all combinations excdpt in N-62-8 x GMU-2497 and SGF-3 x GMU - 2375 combinations which did not show the additive x dominance (j) interaction. The combination, JLSF-103 x NS-1021-1 exhibited maximum interaction effects and possessed the highest dominance x dominance gene effects. The dominance gene effects were negative and significant

in all combinations except in the JLSF-103 x NS-1021-1, while dominance x dominance gene interaction was positive and significant in all combination except JLSF-103 x NS-1021-1, which indicated predominance of duplicate type of interaction.

Days to maturity

The only combination SSF-3 x GMU-2375 exhibited the negative significant dominance gene effect, which was non-significant in rest of the crosses. Similarly, additive gene effect was non-significant in all the combinations.

The additive x dominance gene interaction was found to be significant in the combinations of JLSF-103 x NS-1021-1 and SSF-3 x GMU-2375. Whereas dominance x dominance gene interaction was significant in the three combinations. The parameter (h) was significant and negative and the (l) was significant and positive in the combination SSF-3 x GMU-2375 which was an indication of duplicate type of interaction.

Plant height

The estimates of additive (d) and dominance (h) gene effects were significant in all the combinations except in JLSF-103 x GMU-2497, for additive

gene effects. The dominant gene effect were higher than additive gene effects in all the combinations.

The interaction effects (i, j and l) were found to be significant in all the combinations except additive x dominance gene effect in the cross, JLSF-103 x GMU-2497. The relative magnitude of additive x additive was more followed by dominance x dominance effect. The parameter (h) was positive and significant, while the (l) was negative and significant in all the combinations indicating the predominance of duplicate type of interaction.

Primary branches per plant

The additive gene effect was significant in N-62-8 x GMU-2497 and JLSF-103 x GMU-2497 combinations. The dominance (h) gene effect was significant only in the combination SSF-3 x GMU-2375 only.

Similarly, the interactions additive x additive (i), dominance x dominance (l) were only significant in the combinations SSF-3 x GMU-2375 and JLSF-103 x NS-1021-1, respectively.

Secondary branches per plant

The estimates of dominance gene effect were significant in all the combinations. The additive gene effects were significant in only one combination i.e JLSF-103 x NS-1021-1. Out of the epistatic gene effects (i, j and l), additive x additive (i) was significant in combinations JLSF-103 x NS-1021-1 and JLSF-103 x GMU-2497, additive x dominance (j) was non-significant in the combination, JLSF-103 x GMU-2497 only and dominance x dominance (l) gene effects were significant in all the combinations.

Capitula per plant

The estimates of dominant gene effect were significant in all the combinations. The additive gene effect was non-significant in only one combination, JLSF-103 x NS-1021-1.

The interaction, additive x additive was non-significant only in one combination i.e JLSF-103 x NS-1021-1. While the additive x dominance (j) effects were significant in the combinations N-62-8 x GMU-2497, ~~was~~ JLSF-103 x GMU-2497 and JLSF-103 x GMU-2497. The interactions dominance x dominance (l) were significant in all the combinations. The relative contribution of

dominance was more than additive effects. The dominance gene effects were significant and positive, while dominance x dominance gene interaction was significant and negative in all combinations, indicating that there was predominance of duplicate type of gene action in the combinations.

Diameter of capitulum

Additive gene effects were significant in all the combinations exept JLSF-103 x NS-1021-1. The dominance gene effects were significant in the combinations N-62-8 x GMU-2497 and SSF-3 x GMU-2375. The epistatic gene effects (i, j and l) were found to be non-significant in all the combinations except additive x additive (i) was significant in the combination SSF-3 x GMU-2375.

Seeds per capitulum

The estimate of dominance gene effect was significant in all the combinations. The additive gene effect was significant in only one combination i.e JLSF-103 x GMU-2497.

The epistatic gene effects (i, j and l) were found to be significant in all the combinations except 'j' in the combinations JLSF-103 x NS-1021-1 and JLSF-103 x GMU - 2497.

The magnitude of dominance effect was relatively more. The dominance gene effects were significant and positive, while dominance x dominance gene interaction was significant and negative in all the combinations indicating the predominance of duplicate type of gene action.

Yield per capitulum

The estimates of additive and dominance gene effects were significant in all the combination except SSF-3 x GMU-2375. The combination JLSF-103 x NS-1021-1 exhibited the highest magnitude of additive and dominance gene effects. Dominance gene effects were more than additive effects.

The epistatic gene effects showed that, the additive x additive (i) and dominance x dominance (l) effects were significant in all combinations except SSF-3 x GMU-2375. The additive x dominance (j) interaction were significant in the combinations N-62-8 x GMU-2497 and SSF-3 x GMU-2375. The parameter (h) was positive, while (l) was negative and significant in all the combinations except SSF-3 x GMU-2375 exhibiting prependerence duplicate type of gene action.

Yield per plant

The estimates of additive and dominance gene effects were significant in all the combinations except additive effects in the combinations JLSF-103 x NS-1021-1 and SSF-3 x GMU-2375. The magnitude of dominance effects were comparatively more than additive effects.

The epistatic gene effects showed that all the interactions (i, j and l) were significant for all the crosses except dominance x dominance (l) in the combination SSF-3 x GMU-2375. The additive x dominance(j) gene effect was the highest. The parameters, 'h' and 'l' were significant with positive and negative direction, respectively in all combinations except SSF-3 x GMU-2375, indicating the predominance of duplicate type of interaction.

100 seed weight

As regards the gene effects, both additive (d) and dominance (h), were non-significant in all the combinations. The interactions were also non-significant.

Oil content

The estimates of additive and dominance gene effedts were significant in all the combinations except additive effect in the combination, JLSF-103 x NS-1021-1.

The epistatic gene effects showed that additive x additive (i) effects were significant in all combinations. Dominance x dominance effects were significant in the two combinations, N-62-8 x GMU-2497 and JLSF-103 x GMU-2497. The interaction, additive x dominance (j) were significant in all the combinations, except JLSF-103 x NS-1021-1. The estimates of dominance (h) effect were significant and positive and dominance x dominance (l) were significant and negative in the two combinations, N-62-8 x GMU-2497 and JLSF-103 x GMU-2497, indicating that the predominance of duplicate type of interaction.

Heterosis

The mean performance of parents, $F_1$s is given in Table 4 and the estimate of heterosis calculated over the mid-parent and better parent.

Days to 50 per cent flowering

The range of heterobeltiosis was from -2.36 to -5.86 per cent and heterosis was from -4.99 to -8.72 per cent. The highly significant heterosis and heterobeltiosis was observed in the cross JLSF-103 x NS-1021-1, indicating the possibility of developing hybrids with earliness. The avarage heterosis and heterobeltiosis

Table 4 Heterosis for 12 quantitative characters in safflower.

| Character and cross | Heterosis % over M.P. | Heterosis % over B.P. |
|---|---|---|
| **Days to 50 per cent flowering** | | |
| 1) JLSF-103 x NS-1021-1 | -8.72** | -5.86** |
| 2) N-62-8 x GMU-2497 | -5.16** | -3.84** |
| 3) JLSF-103 x GMU-2497 | -6.23** | -2.36** |
| 4) SSF-3 x GMU-2375 | -4.99** | -3.64** |
| **Days for maturity** | | |
| 1) JLSF-103 x NS-1021-1 | -3.82** | -1.73** |
| 2) N-62-8 x GMU-2497 | -6.37** | -4.42** |
| 3) JLSF-103 x GMU-2497 | -0.41 | 0.00 |
| 4. SSF-3 x GMU-2375 | -1.47 | 0.00 |
| **Plant height** | | |
| 1) JLSF-103 x NS-1021-1 | +6.93** | -6.35** |
| 2) N-62-8 x GMU-2497 | 14.71** | 13.68** |
| 3) JLSF-103 x GMU-2497 | 8.82** | 6.64** |
| 4) SSF-3 x GMU-2375 | 2.30** | -15.15** |
| **Primary branches per plant** | | |
| 1) JLSF-103 x NS-1021-1 | 6.22 | 4.51 |
| 2) N-62-8 x GMU-2497 | 24.38** | 23.37** |
| 3) JLSF-103 x GMU-2497 | 16.28** | 15.16** |
| 4) SSF-3 x GMU-2375 | 9.27 | 6.45 |

| Character and cross | Heterosis over | |
|---|---|---|
| | M.P. | B.P. |
| Secondary branches per plant | | |
| 1) JLSF-103 x NS-1021-1 | 121.91** | 113.67** |
| 2) N-62-8 x GMU-2497 | 53.34** | 21.89** |
| 3) JLSF-103 x GMU-2497 | 44.84** | 25.00** |
| 4) SSF-3 x GMU-2375 | 69.49** | 42.58** |
| Capitula per plant | | |
| 1) JLSF-103 x NS-1021-1 | 46.97** | 39.03** |
| 2) N-62-8 x GMU-2497 | 34.83** | 9.33** |
| 3) JLSF-103 x GMU-2497 | 27.41** | 26.77** |
| 4) SSF-3 x GMU-2375 | 32.67** | 23.20** |
| Diameter of capitulum | | |
| 1) JLSF-103 x NS-1021-1 | 10.12 | -8.62 |
| 2) N-62-8 x GMU-2497 | 15.93 | 3.29 |
| 3) JLSF-103 x GMU-2497 | 4.26 | -5.17 |
| 4) SSF-3 x GMU-2375 | 5.19 | 0.08 |
| Seeds per capitulum | | |
| 1) JLSF-103 x NS-1021-1 | 155.11** | 113.72** |
| 2) N-62-8 x GMU-2497 | 78.66** | 23.31** |
| 3) JLSF-103 x GMU-2497 | 79.10** | 76.47** |
| 4) SSF-3 x GMU-2375 | 103.07** | 69.59** |

| Character and cross | Meterosis over | |
|---|---|---|
| | M.P. | B.P. |
| Yield per capitulum | | |
| 1) JLSF-103 x NS-1021-1 | 167.5** | 105.76** |
| 2) N-62-8 x GMU-2497 | 85.64** | 21.47** |
| 3) JLSF-103 x GMU-2497 | 83.67** | 73.07** |
| 4) SSF-3 x GMU-2375 | 103.10** | 59.75** |
| Yield per plant | | |
| 1) JLSF-103 x NS-1021-1 | 20.20** | +10.84** |
| 2) N-62-8 x GMU-2497 | 15.85** | -19.20** |
| 3) JLSF-103 x GMU-2497 | 15.93** | - 7.15** |
| 4) SSF-3 x GMU-2375 | - 0.05 | -28.65** |
| 100 seed weight | | |
| 1) JLSF-103 x NS-1021-1 | 14.07** | 2.73** |
| 2) N-62-8 x GMU-2497 | 12.89** | + 0.87** |
| 3) JLSF-103 x GMU-2497 | 8.31 | 1.75 |
| 4) SSF-3 x GMU-2375 | 1.21 | -5.60 |
| Oil content | | |
| 1) JLSF-103 x NS-1021-1 | 10.52** | 10.13** |
| 2) N-62-8 x GMU-2497 | 16.57** | 16.16** |
| 3) JLSF-103 x GMU-2497 | 13.75** | 11.9** |
| 4) SSF-3 x GMU-2375 | 32.55** | 28.0** |

* = Significant at 5% level

** = Significant at 1% level.

was -6.28 and -3.90 per cent, respectively. There was significant negative heterosis for this character.

Days to maturity

The value of heterosis and heterobeltiosis was found to be significantly negative for this trait. The range of heterosis was from -0.41 to -6.37 per cent and the range of heterobeltiosis was from 0.00 to -4.42 per cent. Significant heterobeltiosis was observed in only one cross, N-62-8 x GMU-2497, and the heterosis was significant in the crosses, JLSF-103 x NS-1021-1 and N-62-8 x GMU-2497. The average heterosis was -3.02 per cent, while heterobeltiosis was -1.54 per cent.

Plant height

The range of heterosis and heterobeltiosis was as 2.30 to 14.74 and -15.15 to 13.68 per cent, respectively. Heterosis and heterobeltiosis were found to be significant except in two crosses in which negative heterobeltiosis was observed. The average heterosis and heterobeltiosis was 8.19 and 0.29 per cent, respectively.

Primary branches per plant

Only two crosses showed a positive heterosis and heterobeltiosis. The range of heterosis was from

6.22 to 24.38 per cent and heterobeltiosis was from 4.51 to 23.37 per cent. The high magnitude of heterosis and heterobeltiosis was observed in the cross N-62-8 x GMU-2497. The average heterosis and heterobeltiosis was 14.04 and 12.38 per cent, respectively.

Secondary branches per plant

All the four crosses, exhibited positive heterosis and heterobeltiosis. The range of heterosis was from 44.84 to 121.91 per cent and heterobeltiosis was from 21.89 to 113.67 per cent. The cross JLSF-103 x NS-1021-1 showed higher magnitude of heterosis and heterobeltiosis. The average heterosis and heterobeltiosis was 72.39 and 50.79 per cent, respectively.

Capitula per plant

The value of heterosis and heterobeltiosis was found to be positively significant in all the four crosses. The values of heterosis and heterobeltiosis were high in the cross JLSF-103 x NS-1021-1. The range of heterosis and heterobeltiosis was from 27.41 to 46.97 and 9.33 to 39.03 per cent, respectively. The average heterosis for this attribute was 35.47 and 24.59 per cent for heterobeltiosis.

Diameter of capitulum

The range of heterosis was from 4.26 to 18.93 per cent and heterobeltiosis was from -8.62 to 3.29 per cent. The heterosis was positively non significant, while heterobeltiosis for all crosses showed negatively non significant.

The average heterosis and heterobeltiosis was 8.81 and 4.29 per cent, respectively.

Seeds per capitulum

The range of heterosis and heterobeltiosis for this trait was from 78.66 to 155.11 and 23.24 to 113.72 per cent, respectively. Highest degree of heterosis and heterobeltiosis was observed in the cross JLSF-103 x NS-1021-1. The magnitude of heterosis for this cha racter was comparatively high. The average heterosis and heterobeltiosis were 103.99 and 70.78 per cent, respectively.

Yield per capitulum

Highly significant increase in the grain yield per capitulum heterosis and heterobeltiosis was observed in all the hybrids, the maximum being in the combination JLSF-103 x NS-1021-1 and minimum in N-62-8 x GMU-2497.

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The range of heterosis was from 83.67 to 167.5 per cent while heterobeltiosis was from 21.47 to 105.76 per cent. The average heterosis was 109.97 per cent, while heterobeltiosis was 65.02 per cent.

Yield per plant

The range of heterosis was from -0.05 to 20.20 per cent and heterobeltiosis was from -7.15 to -28.65 per cent. Negative non-significant heterosis was observed in cross SSF-3 x GMU-2375.

Negative significant heterobeltiosis was observed in all the crosses. The average heterosis and heterobeltiosis was 13.02 and -16.46 per cent, respectively.

100 seed weight

Heterosis for this trait was significantly positive, while heterobeltiosis was significantly negative except in the cross JLSF-103 x GMU-2497. The range of heterosis was from 1.21 to 14.07 per cent, while heterobeltiosis was from -5.60 to 1.73 per cent. Average heterosis was 9.12 per cent, while heterobeltiosis was 2.74 per cent, which indicated the possibility of increasing yield by increasing 100 grain weight.

Oil content

Heterosis and heterobeltiosis was significant in all the crosses. The range of heterosis and heterobeltiosis was from 13.75 to 32.56 and 10.14 to 28.01 per cent, respectively. The average heterosis and heterobeltiosis was 18.35 and 16.55 per cent, respectively. The cross SSF-3 x GMU-2375, showed higher magnitude of heterosis and heterobeltiosis for this trait.

# Discussion

# DISCUSSION

The estimation of different types of gene effcts and/or their contribution to heterosis is an important step in exploiting hybrid vigour commercially. The present study, was therefore, undertaken to estimate the gene effects and heterosis.

Yield is a complex character being determined by several contributing traits. To bring about substantial improvement in the yield, the knowledge of its genetic control is a must for the breeder to decide an appropriate breeding methodology. Therefore, an attempt has been made in the present investigation to estimate gene effects and heterosis, that would enlighten the breeder about the genetic potentiality of population under study.

In the model to estimate genetic parameters and various gene actions, used in the present study certain assumptions are made. 1) No multiple allelism 2) Linkage absent 3) Lethal gene absent 4) Constant variability for all genotypes and (5) Enviormental effect additive with the genotypic values.

## ANOVA as a whole

The analysis of variance of different progenies (Table 2) showed highly significant differences for all the characters, indicating a high degree of variability

among genetic stocks of safflower ( Carthamus tinctorius,L.) selected for these studies.

While examining the overall performance of different populations, parents, $F_1$s , $B_1$s, $B_2$s and $F_2$s (Table 1 ), it was revealed that, among the parents, N-62-8 was higher for secondary branches per plant, capitula per plant, diameter of capitulum, seed per capitulum, yield per capitulum, yield/plant and 100 seed weight. Although the parent NS-1021-1 was the earliest, had less oil content. The parent GMU-2375 was higher for plant height, primary branches per plant and oil content.

Among the crosses, N-62-8 x GMU-2497, stood first for plant height, primary branches per plant, secondary branches per plant, capitula per plant, diameter of capitulum, seeds per capitulum, yield per capitulum and yield/plant. The cross, JLSF-103 x NS-1021-1 was the earliest among all the crosses. The hybrid, SSF-3, x GMU-2375 had more amount of oil content among all the hybrids.

Among the $F_2$ progenies, N-62-8 x GMU-2497 was the highest yielder with the highest number of primary branches per plant, secondery branches, capitula per plant, diameter of capitulum, seeds per capitulum, yield

per capitulum and 100 seed weight. The $F_2$ of a cross, JLSF-103 x NS-1021-1 was the earliest and the cross SSF-3 x GMU-2375 was the dwarfest.

The earliest $B_1$s and $B_2$s of the cross, JLSF-103 x NS-1021-1. The cross, N-62-8 x GMU-2497 yielded the highest among all the backcrosses and had the highest number of primaries, secondaries, capitulum, seeds per capitulum, diameter of capitulum yield per capitulum, 100 seed weight and oil content. The backcrosses of SSF-3 x GMU-2375 were the dwarfest among all the crosses.

A conclusion can therefore be drown that, the parent N-62-8 appeared to be the best for yield and yield components, While, NS-1021-1 for earliness and parent SSF-3 was for dwarfness.

Scaling test and gene actions

The significant values of joint scaling tests given in the chapter 4 indicated that, interactions might have been involved in the expression of the characters studied. This was confirmed by significant estimates of i, j and l obtained by fitting a six parameters model.

Days to 50 per cent flowering

The estimates of six parameter showed that in the cross, JLSF-103 x NS-1021-1 and JLSF-103 x GMU-2497, additive, dominance and epistatic interactions played a significant role in expression of this trait, while additive, additive x additive and dominance x dominance gene actions played a predominant role in the crosses N-62-8 x GMU-2497 and SSF-3 x GMU-2375. Dominance and dominance x dominance gene effects were of greater in magnitude than other effects. Duplicate gene actions were observed in all the crosses. Edhaie and Ghaderi (1978) and Gupta and Singh (1990) reported that, additive, dominance and interactions governed this trait. While Kotecha (1979); Makne and Chaudhary (1980) observed non-additive gene action, while Ranga Rao (1982,b) reported that, additive gene effect was important for this trait.

Days to maturity

The estimates of six parameters revealed the highly significant dominance, additive x dominance and dominance x dominance gene effects in the cross SSF-3 x GMU-2375 and additive x dominance, dominance x dominance and dominance x dominance in the crosses

JLSF-103 x NS-1021-1 and N-62-8 x GMU-2497, respectively. Duplicate gene action was observed in the cross SSF-3 x GMU-2375.

Kotecha (1979) observed that, the days to maturity was controlled by non-additive gene action., While, Ranga Rao (1982,b) reported that, additive gene action governing this trait. Gupta and Singh (1990) showed, additive, dominance and epistatic gene effect for this character.

Plant height

In the crosses, JLSF-103 x NS-1021-1, N-62-8 x GMU-2497 and SSF-3 x GMU-2375 additive, dominance and epistatic interactions played a significant role in expression of this trait, while dominance, additive x additive and dominance x dominance played predominant role in the cross JLSF-103 x GMU-2497. Dominance and dominance x dominance gene effects were of greater magnitude. Duplicate gene actions were observed in all the crosses. The gene action observed in the present study is inconformity of the reports of Ehdaie and Ghaderi (1978), However, additive gene effect mainly governing this trait was reported by Kotecha (1979),

Makne and Chaudhary (1980), Ramachandram and Goud (1982,b) Ranga Rao (1982,b), Narkhede et al. (1984), Gupta and Singh (1988). While additive and additive x additive effects were reported by Deokar and Patil (1980). Ramachandram and Goud (1982,d) reported that, dominance gene action governed this character.

Primary branches per plant

Significant additive gene effects were present in the crosses N-62-8 x GMU-2497 and JLSF-103 x GMU-2497, While dominance x dominance and dominance, additive x additive gene effects played predominant role in the crosses JLSF-103 x NS-1021-1 and SSF-3 x GMU-2375, respectively. Similar gene action is reported by Deokar and Patil (1980), While, Narkhede et al. (1984) and Ranga Rao (1982,b) and Gupta and Singh (1988) observed that, additive gene effects were more important.

Secondary branches per plant

Dominance, additive x dominance and dominance x dominance gene effects were prevalent in the cross N-62-8 x GMU-2497 and SSF-3 x GMU-2375, Whereas dominance, additive x additive and dominance x dominance gene effects were present in the cross JLSF-103 x GMU-2497. All effects were present in the cross JLSF-103 x NS-1021-1. Duplicate gene actions were observed in all the crosses. Whereas,

Channeshappa (1980) reported that predominance of additive gene effect for this trait.

Capitula per plant

Significant additive, dominance and epistatic gene effects were present in the crosses N-62-8 x GMU-2497 and JLSF-103 x GMU-2497. While additive and dominance x dominance was predominant in the cross JLSF-103 x NS-1021-1. Additive, dominance, additive x additive and dominance x dominance gene effects were important in expression of this trait in the cross SSF-3 x GMU-2375. Duplicate type of gene interactions were present in all the crosses. Edhaie and Ghaderi (1978) found that, additive, dominance gene actions were responsible for this trait, While Deokar and Patil (1980) reported, additive and additive x additive gene effects for this trait. 'The additive gene effects for this trait. The additive gene effects were reported by Ramachandram and Goud (1982,d). However, importance of non-additive gene effects was reported by Makne and Chaudhary (1980), Narkhede et al. (1984), and Ramachandram (1985) and Gupta and Singh (1988).

Diameter of capitulum

Additive, dominance and additive gene effects were found for this trait in the crosses N-62-8 x GMU-2497 and JLSF-103 x GMU-2497, respectively, while

additive, dominance and additive x additive gene effects present in the cross SSF-3 x GMU-2375. However, Deokar and Patil (1980), Patil (1982) and Ramachandram and Goud (1982,d) reported an additive gene action for diameter of capitulum. Channeshappa (1980) reported that, additive and dominance was important for this trait. Narkhede et al. (1984), however, reported that non-additive gene action was governed this trait. Ramachandram and Goud (1982 d), however, reported additive gene action for this trait.

Seeds per capitulum

Doininance and epistatic gene effects were present in the crosses, N-62-8 x GMU-2497 and SSF-3 x GMU-2375, while, dominance, i, l and additive dominance li and l were significant in the crosses, JLSF-103 x NS-1021-1 and JLSF-103 x GMU-2497, respectively. However, the of h and l were high. Duplicate type of gene interactions were present in all the crosses. Channeshappa (1980) and Ramachandram & Goud (1982,b) stressed the importance of dominance gene effects for seeds per capitutum. Predominance of additive gene effects were reported by Deokar and Patil (1980) and Ramachandram (1985). Narkhede et al. (1984) however, observed that, non-additive gene action was governing this trait.

Yield per capitulum

All gene effects were significant in the cross, N-62-8 x GMU-2497 while in the crosses, JLSF-103 x NS-1021-1 and JLSF-103 x GMU-2497 it was observed that additive, dominance and epistatic gene effects except additive x dominance gene effect were present. Additive x dominance gene effect was prevailing in the cross SSF-3 x GMU-2375. . Dominance and dominance x dominance gene effects had higher magnitude. Duplicate gene interaction present in all crosses except SSF-3 x GMU-2375.

Yield per plant

Dominance and epistatic gene effects were highly significant in all the crosses except dominance x dominance in the cross SSF-3 x GMU-2375, however, additive gene effects were present in the crosses, N-62-8 x GMU-2497 and JLSF-103 x GMU-2497. The magnitude of additive x dominance was higher than other epistatic components. Duplicates gene action was also observed in all the crosses except SSF-3 x GMU-2375. Ehdaie and Ghaderi (1978), Ramachandram and Goud (1982,d) Channeshappa (1980) and [illegible] reported that, the yield per plant was mainly controlled by dominance gene effects. Additive and additive x additive gene effects were prevailing for

this trait, as reported by Deokar and Patil (1980). However, Ramachandram and Goud (1982 b) reported that, additive, dominance were present for this trait. However, Narkhede et al. (1984), Channeshwarappa (1984) Ramachandram (1985) and Gupta Singh (1988), reported that yield per plant was governed by non-additive gene action.

100 seed weight

None of the gene actions was present in all the crosses.

Additive gene actions governed by this trait were observed by Deokar and Patil (1980), Makne and Chaudhary (1980), Ramchandram and Goud (1982 b), Channeshappa (1980), Ramachandram (1985), while non additive gene effects were predominant were reported by Narkhede et al. (1984) and Gupta and Singh (1988).

Oil content

The result revealed the presence of dominance and additive x additive gene effects governing this trait in the cross, JLSF-103 x NS-1021-1, while all the types of gene effects except dominance x dominance in the cross SSF-3 x GMU-2375 were present in remaining crosses. Duplicate gene interactions were present in the crosses N-62-8 x GMU-2497 and JLSF-103 x GMU-2497.

Vijayakumar and Giriraj (1980), Channeshwarappa (1984) and Patil (1982) observed that oil content was governed by additive gene effects, while Gupta and Singh (1988) reported non-additive gene action governing this trait.

Heterosis

The results of heterosis for different characters, revealed that consistently higher amount of positive heterosis was present for plant height, primary branches per plant, secondary branches per plant, capitula per plant, seeds per capitulum, yield per capitulum, diameter of capitulum, yield per plant, 100 seed weight and oil content. This suggests that the positive heterosis in these characters had relatively more influence for heterosis in yield. All the crosses exhibited negative heterosis and heterobeltiosis for days to 50 per cent flowering and days for maturity.

For days to 50 per cent flowering all the combinations exhibited significant negative heterosis. As earliness is regarded as beneficial, the above combinations for earliness heterosis and heterobeltiosis posses considerable promise for exploiting this trait

in safflower breeding programme. These findings are in conformity with those reported by Yazdi-Samadi et al. (1973) Narkhede et al. (1986) noted the significant heterotic effect for flowering time, however, Ramachandram and Goud (1982) and Gupta and Singh reported the negative heterosis.

In respect of days for maturity, only one combination (N-62-8 x GMU-2497) showed the significant negative heterosis and heterobeltiosis and In the combination JLSF-103 x NS-1021-1, there was only significant negative heterosis and another combinations did not show any heterotic effects. Yazdi-Samadi et al. (1973) noticed the heterotic effect for maturity while, Ranga Rao (1982) noticed that there was no desirable heterotic responce for maturity,. However, Gupta and Singh (1990) reported that, there was negative heterosis governed this trait.

For plant height, all the combinations showed significant positive heterosis, however, the combinations, JLSF-103 x NS-1021-1 and SSF-3 x GMU-2375 exhibited significant negative heterobeltiosis, while other two combinations showed significant positive heterobeltiosis. It clearly indicated that there was dominance gene action predominent over mid parents, while for better parent two combinations showed dominance

gene action and remaining two showed additive gene action. The positive heterosis for plant height was also reported by Yazdi-Samadi et al. (1973, 1975), Deokar et al. (1984) Narkhede et al. (1986), While negative heterosis reported by Ramachandram and Goud (1982, c). However, Ranga Rao (1982a) reported that there was no desirable heterotic effect.

Only two combinations expressed highly significant positive heterosis and heterobeltiosis for number of primary branches indicating the dominance. Maximum positive heterosis was shown by the combination N-62-8 x GMU-2497. Number of primary branches is one of the important components contributing to yield in this crop, all these parents could be used in the improvement of this character.

These findings are in agreement with those observed by Deokar and Patil (1979), Ranga Rao (1982a), Deokar et al. (1984) and Narkhede and Patil (1987).

For number of secondary branches per plant, all the combinations showed highly significant positive heterosis and heterobeltiosis showing dominance. Especially the combination JLSF-103 x NS-1021-1 expressed very high heterosis which could be exploited in development of hybrids, positive and significant heterosis was

previously observed by Deokar and Patil (1979), Narkhede et al. (1987) and Yadav et al. (1987).

For the number of capitula per plant, all the four combinations exhibited highly significant positive heterosis as well as heterobeltiosis. The combination, JLSF-103 x NS-1021-1, showed maximum positive heterosis and heterobeltiosis. However, the per se performance of other combinations was also high, which the parents could be used in other breeding programme. Positive and significant heterosis was previously observed by Deokar and Patil (1979), Ramachandram and Goud (1982, c), Ranga Rao (1982), Deokar et al. (1984). Narkhede et al. (1987) and Yadav et al. (1987).

In respect of diameter of capitulum, all the combinations expressed non significant positive heterosis. All combinations showed non significant negative heterobeltiosis.

The combination N-62-8 x GMU-2497 showed maximum heterosis (15.93%) and helterobeltiosis (3.29%). Both the parents seemed to contribute substantially to this trait and could find place in the breeding programme of hybrids. But the previous studies of Deokar and Patil (1979) and Deokar et al. (1984) reported that, this trait showed positive significant heterosis.

All the combinations exhibited highly significant positive heterosis for seeds per capitulum. Although maximum heterosis was expressed by the combination JLSF-103 x NS-1021-1 (155.11%). Similar results were also reported by Deokar and Patil (1979) Deokar et al. (1984). Narkhede et al. (1986).

For yield per capitulum, all the combinations showed significant heterosis and heterobeltiosis. The combination JLSF-103 x NS-1021-1 showed maximum heterosis (167.5%) and heterobeltiosis (105.76%). The positive heterosis for this character was reported by Ramachandram and Goud (1982,c).

In respect of yield per plant, significant positive heterosis was observed in all combinations except SSF-3 x GMU-2375 and significant negative heterobeltiosis was observed in all the combinations. The parent, NS-1021-1 having the lowest mean yield gave the highest significant positive heterosis, indicating that, high yielding hybrids may not necessarily be from high yielding parents, thus, yield performance per se should not be the only criteria for identification of parents. However, the divergence of parents contributed to heterosis.

The heterosis for seed yield was mostly associated with the heterosis for the number of primary and secondary branches and number of capitula per plant. The expression of heterosis for other yield components like 100 seed weight, diameter of capitulum, seeds per capitulum did not seem to have a direct bearing on heterosis for yield though yield is an end product of the multiple interaction of yield components. The heterotic effects for this character were also observed in previous studies conducted by Smith and Claassen (1963), Rubis (1969), Urie and Zimmer (1969), Yazdi-Samadi et al. (1972 and 1975), Karve et al. (1977), Ramachandram and Goud (1982, c), Ranga Rao (1982, and 1983), Deokar et al. (1984), Narkhede et al. (1984) and Ramachandram and Goud (1984), Narkhede & Patil (1987 ) Yadav et al. (1987), Malleshappa et al. (1989) and Pandya et al. (1990).

For 100 seed weight, only two combinations showed significant positive heterosis, but only one combination exhibited significant negative heterobeltiosis. In the previous studies, Yazdi-Samadi et al. (1973) (1975) Karve et al. (1977) and Deokar and Patil (1979) noticed positive heterosis. While, there was no heterotic effect for seed weight was reported by Deokar et al. (1984).

All the combinations exhibited highly significant positive heterosis and heterobeltiosis for oil content. Although, maximum heterosis was observed in the combination

SSF-3 x GUM-2375.

These findings are in conformity with those reported by Yazdi-Samadi et al. (1973, 1975) and Yadav et al. (1987), however, negative heterosis was reported by Ramachandram and Goud (1982, c) and no desirable heterosis by Yazdi-samadi et al. (1972) and Ranga Rao (1982). Safflower being a often cross pollinted crop, the hybrid vigour for this crop can be exploited. However, selection on the basis of transgressive type of segregation in the succeeding generations can bring about improvement.

Study of heterosis and estimates of six parameters indicated that the characters, days to 50 per cent flowering, days to maturity, plant height, primary and secondary branches per plant, capitulum per plant, seeds per capitulum, yield per capitulum, yield per plant would be controlled by the non-additive gene action whereas the presence of both additive and non-additive gene actions would be responsible for the expression of the characters, diameter of capitulum and oil content.

Thus, the improvement of seed yield depends on the utilization of additive and non-additive gene action. The extent of heterosis was high for seed yield

in case of JLSF-103 x NS-1021-1 indicated the possible use of hybrid vigour. In the absence of usable male sterility system to produce hybrids, breeding method such as reciprocal reccurent selection which simultaneously exploit additive and non additive gene action are expected to break the constraints to achieve higher yields in safflower.

# Summary and Conclusions

# SUMMARY AND CONCLUSION

The knowledge of gene action is essential to plan appropriate breeding programmes. The relative magnitude of gene effects and heterosis are the helpful ingredients to judge the genetic potential of the crosses. With this view, the present investigation was undertaken. Six generations viz. $P_1$, $P_2$, $F_1$, $F_2$, $BC_1$ and $BC_2$ of four crosses of safflower (Carthamus tinctorius L.) were studied to know the genetic architecture involved in the control of yield and yield contributing characters.

The parents viz. SSF-3, NS-1021-1, GMU-2375, GMU-2497, N-62-8 and JLSF-103 and four of each $F_1$, $F_2$, $B_1$ and $BC_2$ were subjected to genetic analysis.

The studies were conducted by laying out replicated trial in R.B.D. in the Post Graduate Instructional Farm of Mahatma Phule Krishi Vidyapeeth, Rahuri during the year 1991-92.

Gene effects :

The magnitude of additive gene effects were exhibited higher than dominance gene effects in diameter of capitutum except JLSF-103 x NS-1021-1, in days to 50 per cent flowering except N-62-8 x GMU-2497 and

SSF-3 x GMU-2375, Primary branches per plant in N-62-8 x GMU-2497 and JLSF-103 x GMU-2497 and 100 seed weight in the combination SSF-3 x GMU-2375. These results suggested that, these combination could be exploited in early generations through selection. Selection may be applied within the segregating generations leading to isolation of homozygous line with increase in mean values.

The predominance of dominant gene effects was observed in the control of the characters like oil content, yield per plant, secondary branches per plant, capitula per plant, secondary branches per plant, ~~capitulum per plant~~, seeds per capitulum, plant height days to maturity except JLSF-103 x GMU-2497 and N-62-8 x GMU-2497. The selection for these characters should be post-poned to later generations. Further, it indicates that the chances of fixing the particular trait have a limited scope.

Epistatic interactions were predominant for most of all characters except 100 seed weight, wherein dominance x dominance gene interactions were of higher magnitude as compared to other gene effects. Duplicate epistasis was observed for most of the characters,

significant epistatic gene effects coupled with duplicate epistasis indicated that, through effective selection, transgressive segregants could be obtained in subsequent generations.

Heterosis

The significantly negative heterosis and heterobeltiosis for days to 50 per cent flowering and days to maturity was observed and was desirable. Highly positive and significant heterosis and heterobeltiosis for plant height, primary branches per plant, secondary branches per plant, capitula per plant, ~~diameter of capitulum~~, seeds per capitulum, yield per capitulum, yield per plant and oil content was observed. For these characters ~~simple~~ recurrent selection in segregating generations on the basis of heterosis estimate would be of more important. The combination JLSF-103 x NS-1021-1 showed a consistenly high magnitude of positive heterosis for yield and yield contributing characters except primary branches per plant, plant height, oil content, days to 50 per cent flowering and maturity days. The parents viz. JLSF-103 and NS-1021-1 could be utilized in the hybridization programme for developing new hybrid combinations.

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