GENETIC ANALYSIS OF SOME QUALITATIVE AND QUANTITATIVE TRAITS IN CASTOR (*Ricinus communis* L.)

By
Y. CHANDRA MOHAN

THESIS SUBMITTED TO THE
ACHARYA N.G. RANGA AGRICULTURAL UNIVERSITY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE
AWARD OF THE DEGREE OF

DOCTOR OF PHILOSOPHY (AGRICULTURE)

DEPARTMENT OF GENETICS AND PLANT BREEDING
COLLEGE OF AGRICULTURE
ACHARYA N.G. RANGA AGRICULTURAL UNIVERSITY
RAJENDRANAGAR, HYDERABAD - 500 030

October, 2002

CERTIFICATE

Mr. Y. CHANDRA MOHAN has satisfactorily prosecuted the course of research and that the thesis entitled **"GENETIC ANALYSIS OF SOME QUALITATIVE AND QUANTITATIVE TRAITS IN CASTOR (*Ricinus communis* L.)"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by him for a degree of any university.

Date : -X-2002-
Place : Hyderabad

(Dr. T. NAGESHWAR RAO)
Major Advisor

CERTIFICATE

This is to certify that the thesis entitled "**GENETIC ANALYSIS OF SOME QUALITATIVE AND QUANTITATIVE TRAITS IN CASTOR (*Ricinus communis* L.)**" submitted in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** of the **Acharya N. G. Ranga Agricultural University, Hyderabad**, is a record of the bonafide research work carried out by **Y. CHANDRA MOHAN** under our guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma. The published part has been fully acknowledged. All assistance and help received during the course of the investigation have been duly acknowledged by the author of the thesis.

(Dr. T. NAGESHWAR RAO)
Chairman of the Advisory Committee

Thesis approved by the Student's Advisory Committee

Chairman : **(Dr. T. NAGESHWAR RAO)**
Professor and Head
Department of Genetics and Plant Breeding
College of Agriculture, ANGRAU
Rajendranagar, Hyderabad-500 030.

Co-Chairman: **(Dr. A. VISHNUVARDHAN REDDY)**
Senior Scientist
Plant Breeding
Directorate of Oilseeds Research
Rajendranagar, Hyderabad-500 030

Member : **(Dr. S. CHANDER RAO)**
Scientist (SS)
Plant Pathology
Directorate of Oilseeds Research
Rajendranagar, Hyderabad-500 030

Member : **(Dr. L.M. RAO)**
Professor and Head
Department of Plant Physiology
College of Agriculture, ANGRAU
Rajendranagar, Hyderabad-500 030

Member : **(Dr. B.S. KULKARNI)**
Professor and Head
Department of Statistics and Mathematics
College of Agriculture, ANGRAU
Rajendranagar, Hyderabad-500 030

CONTENTS

LIST OF TABLES

LIST OF PLATES

LIST OF ILLUSTRATIONS

ACKNOWLEDGEMENTS

It is with a feeling of profound etiquette and request towards Dr. T. NAGESHWAR RAO, Professor and Head, Department of Genetics and Plant Breeding, College of Agriculture, Rajendranagar and chairman of advisory committee. I express my heartful gratitude for his valuable guidance, constant encouragement and constructive criticism during the entire course of investigations.

I am greatly beholden beyond words to express my deep sense of gratitude and a great privilege to work under the able and highly exceptional guidance of Dr. A. VISHNUVARDHAN REDDY, Senior Scientist, Directorate of Oilseeds Research Rajendranagar and co-chairman of advisory committee for his scholarly guidance, constant inspiration, affectionate encouragement and constructive criticism imparted me throughout the period of study.

I take immense pleasure in expressing my heartful gratitude and profound sense of indebtness to Dr. S. CHANDER RAO, Scientist, Directorate of Oilseeds Research, Dr. L.M. RAO, Professor and Head, Department of Plant Physiology, Dr. B.S. KULKARNI, Professor and Head, Department of Statistics and Mathematics, College of Agriculture, Rajendranagar, and members of advisory committee for their co-operation and helpful suggestions in over coming hurdles during the course of investigations.

I feel of a great privilege to place on my record with sincere regard and thanks to all the staff of Department of Genetics and Plant Breeding, College of Agriculture, Rajendranagar, whose contribution behind the scene has enabled the successful completion of my investigations.

It is time to surface out my genuflect love and affectionate gratitude to my parents, Sri. Yeshala Satyanarayana and Smt. Jayamma, sisters Veeranjali, Padma, brother-in-laws, Chandramouli, Prabhakar, brothers, Pratap, Ventakesh, sister-in-laws, Uma, Rani who constantly inspired, educated, guided and moulded me to the present position and whose encouragement brings out my best in every one of my endeavours.

Special thanks are also due to Dr. B.P. Sah, Senior Scientist, National Wheat Research Programme, Nepal, for his co-operation, helpful suggestions, timely advice apart from performing various statistical analyses in the study.

My sincere thanks are due to Dr. C. Lavanya, Scientist, Dr. A.R.G. Ranganatha, Senior Scientist, Sri. Balakrishan, Sri. Bhaskar Reddy and various units of Directorate of Oilseeds Research, Rajendranagar for their ready assistance and co-operation.

I affectionately acknowledge the company and valuable help extended by all my seniors, colleagues and junior friends especially MRPC, Madhu, Rampi, Trinath, Anand, Ramgopal, Ravi, Sridhar, Tirumal, Krishna, Anuradha, G.K., Ramana, Saida, Maruthi and Harishan.

I express my thanks to the Government of Andhra Pradesh and Acharya N.G. Ranga Agricultural University for the financial assistance rendered during the present study.

I am also thankful to Raju Graphics for neat and meticulous care in typing of this thesis.

Date : 10.10.92

(Y. CHANDRA MOHAN)

DECLARATION

I, **Y. CHANDRA MOHAN** hereby declare that the thesis entitled **"GENETIC ANALYSIS OF SOME QUALITATIVE AND QUANTITATIVE TRAITS IN CASTOR (*Ricinus communis* L.)"** submitted to the Acharya N.G. Ranga Agricultural University for the degree of **DOCTOR OF PHILOSOPHY IN AGRICULTURE** is the result of original research work done by me. I also declare that any material contained in the thesis has not been published earlier in any manner.

Date : 10.10.2002

(Y. CHANDRA MOHAN)

Place: Hyderabad

Author : **Y. CHANDRA MOHAN**

Title of the thesis: **GENETIC ANALYSIS OF SOME QUALITATIVE AND QUANTITATIVE TRAITS IN CASTOR (*Ricinus communis* L.)**

Degree : **DOCTOR OF PHILOSOPHY**

Faculty : **AGRICULTURE**

Discipline : **GENETICS AND PLANT BREEDING**

Major Advisor : **Dr. T. NAGESHWAR RAO**

University : **ACHARYA N.G. RANGA AGRICULTURAL UNIVERSITY**

Year of submission : **2002**

ABSTRACT

The present investigation was attempted in castor to study the genetics of important morphological characters, to study the inheritance of fusarium wilt resistance, to determine the nature of gene action, to identify best combiners for yield and its components and also to know the magnitude of heterosis and inbreeding depression. The material consisted of four female parents and nine male parents and experiments were conducted objective wise at the College Farm, College of Agriculture, Rajendranagar, Hyderabad and Directorate of Oilseeds Research, Rajendranagar, Hyderabad during *rabi* 2000-01, *kharif* 2001 and *rabi* 2001-02.

Inheritance of morphological traits revealed all the five characters viz., leaf shape (3 flat : 1 cup), stem colour (3 red : 1 green), bloom nature (3 triple : 1 double; 1 triple : 2 partial triple, 1 zero; 1 double : 2 partial double : 1 zero), spininess of capsule (1 spiny : 2 partial spiny : 1 non spiny) and internode nature (3 elongated : 1 condensed) are governed by single gene with complete dominance in some cases and partial dominance for others. Joint segregation studies indicated that the genes governing leaf shape, stem colour, bloom nature and stem colour, bloom nature, spininess of capsule were found to be assorted independently. However, the genes controlling leaf shape and spininess of capsule were found to be linked in repulsion phase with the recombination value of 25.7 per cent. The genes governing the traits, leaf shape and internode nature might involve tight linkage or due to pleiotrophic effect of the gene.

Fusarium wilt resistance is found to be governed by two independent recessive genes involving complementary epistasis.

Analysis of combining ability revealed the existence of significant variation among lines, testers and line x testers for all the characters studied barring oil content in testers. The components of gca and sca variances indicated the predominance of additive gene action for days to 50 per cent flowering, days to maturity, number of nodes, plant height, effective spike length, number of capsules per primary spike and 100-seed weight, while non-additive gene action was predominant for primary spike length, seed yield per plant and oil content. The three lines DCS-5, DCS-27 and SH-72 and the two testers, VP-1 and DPC-9 were identified as good combiners for seed yield per plant. However, the three lines, DCS-5, DCS-9 and DCS-85 and the one tester LRES-17 were found to be best combiners for earliness and related traits apart from oil content.

The *per se* performance of crosses is not correlated with the sca effects in majority of the crosses. The high sca effects of crosses resulted from the parents with either high x high or high x low or low x low gca effects for yield and yield component traits.

The two hybrids viz., LRES-17 x SH-72 and VP-1 x DCS-5 out yielded significantly over the standard check, DCH-177.

The magnitude of inbreeding depression was high under strict selfing than open pollination of F_1 plants. Majority of the crosses exhibited negative values for both heterosis and inbreeding depression for earliness and related traits indicating the predominance of additive gene effects. However for seed yield and primary spike characters both the heterosis and inbreeding depression values were positive inferring the predominance of non-additive gene action. Based on results it is concluded that recommendation of F_2 seed for commercial crop production is not economical. The crosses possessing non-significant inbreeding depression with significant desirable heterosis could be utilized to isolate transgressive segregants in F_2 and subsequent generations.

LIST OF ABBREVIATIONS

%	:	per cent
&	:	and
/	:	per
ANOVA	:	Analysis of variance
B_1	:	backcross generation of parent 1
B_2	:	backcross generation of parent 2
cm	:	centimetre
et al.	:	and others
F_1	:	first filial generation
F_2	:	second filial generation
fig.	:	figure
fsp	:	former species
g	:	gram
gca	:	general combining ability
i.e.	:	that is
kg/ha	:	kilograms per hectare
m	:	metre
No.	:	Number
P_1	:	parent 1
P_2	:	parent 2
sca	:	specific combining ability
SE	:	Standard Error
viz.,	:	namely
vs.	:	versus
χ^2	:	chi-square

CHAPTER I

INTRODUCTION

CHAPTER I

INTRODUCTION

Castor (*Ricinus communis* L.) belongs to the family Euphorbiaceae and according to available literature, it is indigenous to eastern Africa and most probably originated in Ethiopia. The crop is grown for its non-edible oil which is being used in various industries for the manufacturing of lubricants, printing inks, varnishes, plasticizer, cosmetics, fine quality nylon threads etc. It is also being used for medicinal and lighting purposes.

India is the world's principal producer of castor. The other major castor producing countries are Brazil, former USSR, China and Thailand, whilst the main importing countries are the leading industrialized countries viz., USA and Japan. In the year 2000, India exported castor oil worth more than Rs. 1000 crores. In India, castor occupies an area of about 10.77 lakh ha. with a production of 8.67 lakh tonnes. In Andhra Pradesh, it occupies an area of 3.93 lakh ha, with a production of 1.31 lakh tonnes (Damodaram and Hegde, 2002). The productivity levels of castor in Andhra Pradesh are very low (333 kg/ha) compared to average productivity of India (805 kg/ha). However, the productivity of castor in Gujarat is as high as 1393 kg/ha. The reasons for low yields in Andhra Pradesh are; castor is grown as monocrop under rainfed conditions in marginal lands with very low level of management and use of low productive obsolete varieties especially in Telangana region.

With increased production costs of commercial crops like cotton, chillies, castor crop has gained importance as an alternate commercial crop keeping in view of its potential and low input costs especially in Andhra Pradesh, Maharashtra, Karnataka and Madhya Pradesh under rainfed conditions. Hence, there is an increasing need for genetic improvement in castor which is likely to improve the living conditions of poor and marginal farmers in these areas.

In castor, variation exists for all the qualitative characters such as stem pigmentation, waxy coating, leaf shape, spininess of capsules, internode nature etc. Morphological characters have some economic advantages, for instance, varieties with triple bloom nature are more resistant to jassids (Natarajan *et al.*, 1986) and tolerant to drought. Similarly, purple stemmed plants are resistant to castor shoot and capsule borer (Singh *et al.*, 1977). The trait condensed node is correlated with reduced plant height which is a major objective in castor breeding. Further, these traits can also serve as efficient diagnostic characteristic features of varieties, hybrids and their parents. But available literature on genetics of these morphological characters is very meagre. Regarding bloom, castor plants show variation consisting of no bloom (absence of waxy coating on any part of plant), single bloom (presence of waxy coating on stem and petiole only), double bloom (presence of waxy coating on stem, petiole and dorsal side of leaves) and triple bloom (presence of waxy coating on all above ground parts of plant). However, available literature provides information on the inheritance of

bloom by taking only two classes as presence or absence of bloom. To study complete inheritance of bloom nature, observations on the basis of single bloom, double bloom, triple bloom and no bloom are essentially required (Solanki and Joshi, 2001).

In India, among the fungal diseases of castor, wilt caused by *Fusarium oxysporum* fsp. *ricini* is a serious problem causing extensive damage to the crop. As the organism is soil borne, it becomes difficult to control by chemical or physical means, which are uneconomical and there is also a danger of high degree of residual toxicity of the chemicals applied. The use of resistant varieties, provides an ideal solution to the problem of wilt disease as a long term strategy (Prasad and Bhatnagar, 1981). Thus, there is a need to develop fusarium wilt resistant cultivars to combat the disease. Information on the nature of inheritance of fusarium wilt resistance is lacking which is a prerequisite to initiate appropriate breeding programme for the development of wilt resistant varieties on which very little emphasis had been paid so far.

Use of hybrids and high yielding varieties developed elsewhere have very low impact in increasing productivity especially under rainfed conditions. Hence, there is an urgent need to develop early maturing and high yielding varieties and hybrids coupled with disease and insect resistance to enhance castor production and productivity which requires intensive evaluation of germplasm and choosing best parents for hybridization programme. The line x tester mating design (Kempthorne, 1957) helps in

realising the objective to estimate the combining ability of parents and thereby selecting superior parents as well as cross combinations.

Inbreeding depression in general is less in castor, but there are no clear reports to state the extent of inbreeding depression. Moshkin (1986) reported that in order to use inter-line hybrids of castor, it is necessary to clarify, whether the increased yield of seeds is retained during subsequent generation and whether it is possible to use them for sowing the second generation. Hence, it is worthwhile to have complete information on the extent of heterosis in related cross combinations and also to study the extent of inbreeding depression for the possible use of F_2 seed on commercial scale.

In light of the above, the present investigation has been undertaken with the following objectives :

1. To study the inheritance of some morphological characters namely leaf shape, stem colour, bloom nature, spininess of capsule and internode nature.
2. To study the inheritance of fusarium wilt resistance.
3. To study the combining ability of selected genotypes.
4. To assess the magnitude of heterosis and inbreeding depression in selfed and open pollinated conditions.

CHAPTER II

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

A brief review of the relevant literature on for the present investigation is presented here under.

2.1 INHERITANCE OF MORPHOLOGICAL CHARACTERS

Castor has a number of contrasting features for different characters like leaf shape, bloom nature, spininess of capsule, stem pigmentation etc. The morphological traits could be used as genetic markers. Some of the traits have economic advantages for increasing the yields either directly or indirectly. Despite the importance of morphological traits not much work on genetic study has been done. The available information on this aspect is scanty and quite old. A brief review pertaining to the objective is mentioned here under.

Peat (1928) made an extensive study on the inheritance of bloom and reported that in a cross between double bloom and no bloom, the F_2 was double bloom although the bloom was not as heavy as in the parent with double bloom, whereas in F_2, the plants segregated in a dihybrid ratio of 9 double bloom : 3 single bloom : 4 no bloom.

Patwardhan (1931) noted that treble bloom was dominant over double bloom and single bloom over no bloom.

Narain (1952) noticed different classes of bloom in castor as given below:

1. Bloom on the peduncle and capsules only.
2. Very light bloom on the stem, petiole and inflorescence.
3. Single bloom
4. Single bloom plus bloom on the prominent veins of under surface of leaf.
5. Partial double bloom, i.e. bloom on the stem, petiole, peduncle and some portions of under surface of leaf - the margins are left uncovered.
6. Double bloom
7. Partial treble bloom, i.e. double bloom plus bloom on some portions of the upper surface of leaf - the margins remain uncovered.
8. Treble bloom.

Joglekar and Deshmukh (1957) found monogenic inheritance in respect of red stem vs. green stem and blossoming vs. nonblossoming in the cross EC 2848 x EB 16, red stem and blossoming being dominant. They also observed a wide range of segregation with respect to period of maturity.

Zimmerman (1957a) attempted crossing between two no bloom varieties viz., VS. 70 and VS. 121-6 and F_1 was observed to have bloom. The F_2 had 78 plants with bloom and 55 with no bloom, a good fit of a 9:7 ratio which obviously suggest that dominant complementary genes were involved. Crosses of the no bloom varieties with bloom varieties viz., Cimarron and 3/441-9, gave expected bloom in F_1 and a 3:1 segregation for bloom and bloomless in the F_2. He also observed linkage between the gene responsible for bloom and M gene for reddish stem colour.

Zimmerman (1957b) conducted an experiment to determine the mode of inheritance of dwarf internode nature and to find the relationship of dwarf internode to several important agronomic characters in castor bean. It was observed that the dwarf internode nature is monogenic and recessive trait which was inherited independently of node to first raceme, total number of nodes, dehiscence of the capsules and the genes for monoecious and pistillate racemes.

Stein (1959a) reported that recessive gene determines absence of spines on the capsule, number of spines in Ss plants being much lower than in SS. A new allele sf, also results in lack of spines. Number of spines in Ssf plants is however much lower than Ss. In Ssf, spine number varies widely according to age of the plant and raceme position, suggesting that a substance regulating number may be produced in the vegetative parts.

Stein (1959b) reported that anthocyanin production is known to depend upon gene, M. Gene m^g (green) was found to restrict anthocyanin to the young leaves, pistils and hypocotyl, while m^p (pure green) controls absence of anthocyanin from the hypocotyl and all other parts, except the seeds. Gene ag causes the appearance of gland like, multicellular structures, embedded in the epidermis, in which anthocyanin accumulates. This gene therefore acts as an intensifier of red colour. When young m^Pm^Pagag plants are completely green, but at a later stage red "glands" are abundant on the

stems. Gene m^s (strong green) is usually phenotypically similar to m^p but $m^s m^s$agag individuals do not develop red glands.

Narain (1961) studied the inheritance of raceme with bloom, bloomless, light smoky bloom, treble bloom and single bloom characters in castor and found that the raceme with bloom and bloomless characters differ by two factor pairs involving recessive epistatic effect. The difference between full bloom vs. light smoky bloom was found to be monogenic, the bloomless character being dominant over the light smoky bloom character. The bloomy character showed dominance over light smoky bloom and single bloom differed from treble bloom by a single mendelian factor. The factor for treble bloom showed partial dominance over that for single bloom.

Smith (1963) attempted crossing between varieties with spiny capsules and non-spiny capsules and reported that the F_1 plants had sparsely spined capsules. Capsules in the F_2 population were fully spined, sparsely spined, spineless Warty and spineless smooth, and the plants were classified only as spiny or spineless and the pooled population segregated in a 9:7 (spiny : spineless) ratio which gave proof that gene pairs at two loci were responsible for capsule spines.

Anonymous (1968) indicated that differences in stem colour in castor are controlled by one gene pair, red being dominant to green.

Brigham (1968) crossed breeding lines having rough petioles with small spiny protuberances with smooth petioled parents and reported that the

F_1 plants were mainly intermediate in the degree of roughness. Results from further crosses indicated that a single factor is responsible for the inheritance of rough petiole.

Brigham (1973) crossed the mosaic leaf plants with dwarf internode selections in castor and found phenotypically normal plants in the F_1, whilst in the F_2 2006 normal leaf and 621 mosaic leaf plants were observed. The results of backcrosses also confirmed the same as the mosaic leaf character is apparently controlled by a single recessive gene which is designated as ml.

Deokar (1974) crossed the castor lines, V1 and V4 and their F_1 and F_2 generations showed that R_{gst}, controlling stem colour, was independent of the genes controlling other characters.

Bhapkar and Deshmukh (1978) studied the inheritance of ten morphological characters viz., stem colour (1:2:1), midrib colour (1:2:1), leaf colour (1:2:1), inflorescence colour (1:2:1), capsule colour (1:2:1), spininess of capsule (3:1), bloom (4:6:2:4), ground colour of seed (3:1), mottling colour of seed (3:1) and degree of mottling (1:2:1) in a cross V-4 x V-5 of castor. The gene Rst had pleiotropic action on the colour of the stem, midrib, leaf, inflorescence and capsule. A linkage group involving the genes Rst (stem colour), Blm (mottling colour of seed), Wsd (ground colour of seed) and S (spininess of capsule) was also worked out and showed as an independent assortment.

Singh and Yadav (1982) reported that dwarf plant height in castor was governed by a single recessive gene, hence, could be a worth while source for reducing the height of the plant without sacrificing the seed yield.

Anjani (1997) made crosses between four castor genotypes and reported that spininess was partially dominant over non-spininess and dominant over sparse spininess. The three characters showed monogenic inheritance.

Reddy and Sathaiah (1997) studied the inheritance of plant height in castor by crossing 411-J1-44 with T_4 and reported that the F_2 segregation pattern conformed to the ratio 22:20:15:6:1, indicating the involvement of three non allelic genes acting in an additive fashion.

Solanki and Joshi (2001) conducted an experiment to study the inheritance of some morphological traits in castor and revealed that green spike colour epistatic over sulphur white colour and trait being governed by a dominant inhibitory gene and another colour gene (sulphur white). They also observed monogenic nature of inheritance for the other characters viz., nature of internodes, stem colour and presence of bloom. Joint segregation for different pair of traits suggested independent segregation of all the traits studied and no evidence of linkage was detected.

2.2 INHERITANCE OF FUSARIUM WILT RESISTANCE

Castor wilt caused by *Fusarium oxysporum* fsp *ricini* is the most important disease causing extensive damage to the crop. Since, the disease is

primarily soil borne, it is difficult to manage through chemicals. Developing resistant varieties is the only solution to combat the disease. Identification of resistance source and its mode of inheritance is imperative in any breeding programme to develop resistant cultivars / hybrids. A brief review pertaining to inheritance of fusarium wilt resistance in castor and other crops is presented here under.

Castor

Breeding castor for resistance to fusarium wilt was began early in 1957 by Moshkin. It was established that an infectious background during selection and evaluation of the breeding material was important with regard to this characteristic.

At the VNIIMK, initial material of castor with a high resistance to Fusarium has been developed and varieties resistant to this disease have been introduced. The new varieties VNIIMK 360 and Sizaya 7 have good field resistance to Fusarium. These varieties are capable of giving high yields on soil severely infected by Fusarium, whereas the variety control Early hybrid completely perished.

Sviridov (1971) showed that castor hybrids developed on a fusarium background in all circumstances had a much higher resistance to the disease than those obtained on a common background.

Prasad and Bhatnagar (1981) tested 88 castor cultivars in pots by inoculation with *Fusarium oxysporum* fsp. *ricini* and reported that cultivars

279, 882, 413A, 157B, Aruna, M2, NPHyb 1, R63, SA1 and VH 81 had 10 per cent infection or less and 947, Pb1 and Tspior had 15 per cent or less.

Sviridov (1986a) reported that in castor fusarium wilt resistance was governed by a recessive factor.

Sviridov (1986b) reported that resistance to *F. oxysporum* in the interline *Ricinus communis* hybrids studied was controlled by at least 2 loci (Suf1 and Suf2), in some hybrids by the recessive allele suf1 and in others by Suf2 which was epistatic to gene Suf1, with modifiers being present in some cases.

Sviridov (1988) crossed five lines showing resistance to *F. oxysporum* fsp *ricini* with a line homozygous for susceptibility (Suf) genes and observed 2 types of inheritance under artificial infection in the field. In one type, resistance was conditioned by the recessive gene suf1 and in the other type of the interaction of 2 duplicate genes, Suf2 and suf1. When a susceptible line with Suf1 Suf1 suf2 suf2 crossed with resistant L-VN 165 ul.s. (Suf2 Suf2 suf1 suf1), the F_1 hybrids with Suf1 suf1 Suf2 suf2 were resistant.

Podkujchenko (1989) reported that in intraspecific crosses of castor *Fusarium oxysporum* resistance was conditioned by a single gene.

Chattopadhyay *et al.* (1996) studied the host pathogen interaction between *Fusarium oxysporum* and 3 cultivars of *Ricinus communis* and showed that the cultivar 48-1 to be more tolerant to the pathogen and Aruna was found to be susceptible cultivar.

Other crops

Knowles and Houston (1953) reported that fusarium wilt resistance has been found to be due to two complementary genes in flax.

Evminov and Dynnik (1982) reported that F_2 segregation ratios for fusarium wilt resistance in flax varied so widely which indicated that it was controlled by many genes.

Smithson *et al.* (1983) determined the genetic constitutions and wilt (*F.oxysporum* fsp *ciceris*) reaction of 8 cultivars of *Cicer arietinum* and reported that resistance to race 1 appears to be controlled by at least 3 independent loci. Alleles carried at 2 of the loci incompletely recessive to those for early wilting, separately delay wilting and must be present together for complete resistance. An allele carried at a third locus, which is probably dominant to that for early wilting, also delays wilting and confers complete resistance in combination with the recessive alleles at either of the other 2 loci.

Agarwal *et al.* (1991) studied the F_2 segregation ratios from 9 intervarietal crosses involving the linseed wilt resistant cultivars RLC 6 and R552 and 4 susceptible commercial varieties and indicated that resistance to *Fusarium oxysporum* fsp. *lini* is mostly determined by recessive alleles.

Malhotra and Vashistha (1993) evaluated parents, F_1, F_2 and backcross generations between line NT 8, resistant to *F. oxysporum* and 2 susceptible cultivars, HS 101 and Se 17 of tomato for resistance to the pathogen and

14

reported that the F_2 generations segregated in the expected ratio of 3 resistant: 1 susceptible plants. Backcrosses to the susceptible parents gave the expected ratio of 1:1 and backcrosses to the resistant parent gave mostly resistant plants, which indicated the presence of monogenic dominance for resistance in NT 8.

Singh *et al.* (1998) studied the inheritance of fusarium wilt resistance in pigeon pea and showed that resistance to fusarium wilt is dominant over susceptibility and that resistant is under the control of two independent loci.

2.3 COMBINING ABILITY

The concept of combining ability as a measure of gene action was proposed by Sprague and Tatum (1942). They defined the term general combining ability (gca) as the average performance of a line in hybrid combinations and specific combining ability (sca) to designate the deviation of a particular cross from the performance predicted based on the general combining ability of parents involved.

Different methods have been developed for the estimation of general combining ability and specific combining ability effects. The popular methods among them are i) top cross test ii) polycross test iii) diallel mating system and iv) line x tester mating system.

The knowledge of various types of gene action and their relative magnitude controlling the trait is important in deciding proper breeding techniques according to Miller *et al.* (1980), Kempthorne (1957) suggested a

Table 2.1 : Summary of review of literature on nature of gene action governing various characters in castor

Character	Additive	Non-additive	Additive and Non-additive
Days to flowering	Hooks (1968) Patel *et al.* (1984) Pathak and Dangaria (1987) Fatteh *et al.* (1988) Pathak *et al.* (1989) Mehta *et al.* (1991b)	Singh and Srivastava (1982) Manivel *et al.* (1998)	Bhatt *et al.* (1983)
Days to maturity	Patel *et al.* (1984) Pathak and Dangaria (1987) Pathak *et al.* (1989) Mehta *et al.* (1991b)	Kavani *et al.* (2001)	
Plant height	Sindagi (1972) Swarnlata *et al.* (1984) Dangaria *et al.* (1987) Pathak and Dangaria (1987) Fatteh *et al.* (1988) Mehta *et al.* (1991b) Patel *et al.* (1991) Chakrabarty (1997) Ramesh *et al.* (2000)	Manivel *et al.* (1998) Kavani *et al.* (2001)	
Node number	Sindagi (1972) Patel *et al.* (1984) Swarnlata *et al.* (1984) Pathak and Dangaria (1987) Fatteh *et al.* (1988) Mehta *et al.* (1991b) Vindhiyavarman and Ganesan (1995) Chakrabarty (1997) Ramesh *et al.* (2000)	Pathak *et al.* (1989) Manivel *et al.* (1998) Kavani *et al.* (2001)	
Primary spike length	Giriraj *et al.* (1973) Giriraj *et al.* (1974) Swarnlata *et al.* (1984) Dangaria *et al.* (1987) Pathak and Dangaria (1987) Patel *et al.* (1991) Chakrabarty (1997) Mehta (2000)	Sindagi (1972) Singh and Srivastava (1982) Pathak *et al.* (1989) Vindhiyavarman and Ganesan (1995) Ramesh *et al.* (2000) Kavani *et al.* (2001)	Giriraj (1973) Kandasamy *et al.* (1983)
Effective spike length	Dangaria *et al.* (1987) Mehta (2000)	Kandasamy *et al.* (1983) Vindhiyavarman and Ganesan (1995) Kavani *et al.* (2001)	

16

Character	Additive	Non-additive	Additive and Non-additive
Number of capsules per primary spike	Giriraj (1973) Giriraj *et al.* (1973) Giriraj *et al.* (1974) Dangaria *et al.* (1987) Chakrabarty (1997) Mehta (2000)	Bhatt *et al.* (1983) Fattah *et al.* (1988) Pathak *et al.* (1989) Kavani *et al.* (2001)	Swarnlata *et al.* (1984)
Capsule number per plant	Ramaswamy and Madhavamenon (1973) Kandasamy *et al.* (1983)	Singh and Srivastava (1982) Dangaria *et al.* (1987) Vindhiyavarman and Ganesan (1995)	
Racemes per plant	Hooks (1968) Pathak *et al.* (1989) Chakrabarty (1997)	Kandasamy *et al.* (1983) Vindhiyavarman and Ganesan (1995) Ramesh *et al.* (2000) Kavani *et al.* (2001)	
100-seed weight	Giriraj *et al.* (1973) Giriraj *et al.* (1974) Swarnlata *et al.* (1984) Dangaria *et al.* (1987) Fatteh *et al.* (1987) Pathak and Dangaria (1987) Pathak *et al.* (1989) Patel *et al.* (1991) Mehta (2000)	Sindagi (1972) Ramesh *et al.* (2000) Kavani *et al.* (2001)	Giriraj (1973)
Oil content	Giriraj (1973)	Fatteh *et al.* (1987) Dobariya *et al.* (1989) Patel *et al.* (1991) Chakrabarty (1997)	Giriraj (1973) Giriraj *et al.* (1974)
Seed yield	Giriraj *et al.* (1974) Ramaswamy and Madavamenon (1973) Kandasamy *et al.* (1983) Patel *et al.* (1991) Mehta (2000)	Singh and Srivastava (1982) Bhatt *et al.* (1983) Swarnlata *et al.* (1984) Dangaria *et al.* (1987) Pathak and Dangaria (1987) Fatteh *et al.* (1987) Pathak *et al.* (1989) Dobariya *et al.* (1992) Vindhiyavarman and Ganesan (1995) Chakrabarty (1997) Ramesh *et al.* (2000) Kavani *et al.* (2001)	Giriraj (1973) Giriraj *et al.* (1974)

detailed mathematical model for the estimation of gca and sca effects and variances from the crosses involving various combinations.

Combining ability in castor has been studied by many workers. The review of literature on gene action governing the inheritance of different traits in castor indicates that the characters are governed by either additive or non-additive (dominance and epistatic interactions) or both depending on the breeding material used in the investigation. A brief review of literature on the gene action for different characters in castor is presented in Table 2.1.

2.4 HETEROSIS

The term heterosis was coined by Shull (1914). It refers to the superiority of F_1 hybrid in one or more characters over its parents. The superiority of the F_1 over better parent is heterobeltiosis, where as the term standard heterosis refers to the superiority of F_1 over the standard variety/hybrid grown in the area.

Khan and Rehman (1965) reported that exploitation of heterosis on a commercial scale was shown to be possible in castor crop by using pistillate varieties in combination with suitable monoecious lines possessing high combining ability.

Moshkin (1986) mentioned over the past 15 years, on the basis of female lines at the VNIIMK, four hybrids have been introduced, which significantly exceed the common varieties with regard to productivity. On varietal trail plots, hybrid Krasnodarskii 3 gave the best results which recorded 15-18 % increase in yield over varieties. It was also suggested

Table 2.2 : Summary of review of literature on heterosis for various characters in castor

Character	Positive heterosis	Negative heterosis
Days to flowering		Muhammad *et al.* (1969) Muhammad *et al.* (1970) Hooks *et al.* (1971)
Days to maturity		Khan and Rehman (1965) Gopani *et al.* (1968) Moskin and Voskobojnik (1967)
Plant height	Kabaria and Gopani (1971)	Gopani *et al.* (1968) Muhammad *et al.* (1970) Khan and Rehman (1965)
Number of nodes upto primary spike		Chakrabarty (1997)
Primary spike length	Muhammad *et al.* (1969) Muhammad *et al.* (1970) Kaul *et al.* (1983)	
Effective spike length	Mehta *et al.* (1991a)	
Capsules per primary spike	Khan and Rehman (1965) Gopani *et al.*(1968) Kabaria and Gopani (1971) Kaul *et al.*(1983) Pathak *et al.* (1988) Mehta *et al.* (1991a)	
Capsules per plant	Muhammad *et al.* (1969) Muhammad *et al.* (1970) Saiyed *et al.* (1997)	
Racemes per plant	Muhammad *et al.* (1969) Muhammad *et al.* (1970) Hooks *et al.* (1971) Chakrabarty (1997)	
Branches per plant	Gopani *et al.* (1968) Muhammad *et al.* (1969) Mehta *et al.* (1991a) Saiyed *et al.* (1997)	
100-seed weight	Khan and Rehman (1965) Satyabalan *et al.* (1965) Pathak *et al.* (1988)	

Character	Positive heterosis	Negative heterosis
Oil content	Khan and Rehman (1965) Gopani *et al.* (1968) Hooks *et al.* (1971) Voskobojnik and Moshkin (1977) Saiyd *et al.* (1997)	
Seed yield	Zimmerman and Van Horn (1953) Stein (1958) Ankineedu and Kulkarni (1965) Khan and Rehman (1965) Muhammad *et al.* (1965) Satyabalan *et al.* (1965) Moshkin and Voskobojnik (1967) Gopani *et al.* (1968) Muhammad *et al.* (1969) Muhammad *et al.* (1970) Hooks *et al.*(1971) Kabaria and Gopani (1971) Voskobojnik and Moshkin (1977) Kaul *et al.* (1983) Savy *et al.* (1986) Pathak *et al.* (1988) Mehta *et al.* (1991a) Chakrabarty (1997) Saiyed *et al.* (1997)	

20

replacement of varieties by hybrids is economically beneficial, since the additional expenditures on variety purification and planting crossing plots are recovered by a 25-30 times greater yield.

Heterosis may be positive or negative. In general positive heterosis is desirable for most of the traits, however for some characters namely plant height, days to maturity etc, the negative heterosis is advantage. Brief review regarding the heterosis in castor is presented in Table 2.2.

2.5 INBREEDING DEPRESSION

The most revealing impact of inbreeding is the loss of vigour and physiological efficiency of the organisms, characterized by reduction in size and fecundity, etc. A number of weak and lethal segregants and defectives appear in the population which has undergone inbreeding (generally referred to as selfing). This loss of fitness in the progenies or decline in trait expression with decreased heterozygosity arising from consanguineous mating is known as inbreeding depression or inbreeding decline. Haldane (1948) had aptly summed up his intensive inbreeding experiments as "Inbreeding proved to be disastrous - the enemy of vigour and yield".

Since the maximum decline is reflected in F_2 generation the inbreeding depression can be computed by relative data on F_1 and F_2 for any character.

Galeev (1969) conducted a research in some cross pollinated crops and mentioned that the inbreeding depression in castor is less than that of maize.

21

Podkujchenko (1969) studied about 80 inbreds of castor and collected data on seed yield, earliness, 1000-seed weight and height and showed that little or no reduction had occured after four to seven generations of inbreeding in most cultivars. It was also reported that the maximum reduction in seed yield was in Kubanskaja 2, where it was 75 per cent of the control, while in other cultivars it varied from 80 to 105 per cent.

Kabaria and Gopani (1971) conducted an experiment to compare the performance of F_1 and F_2 generations of Gujarat Castor Hybrid-3 to determine the genetic mechanism governing the expression of heterosis and reported that the heterosis reduced significantly in the F_2 from F_1 by 71.7 and 30.3 per cent respectively for capsule number and seed yield. However, for number of nodes significant increase in F_2 over F_1 was noticed by 17.1 per cent, whereas F_1 reduced by 9.2 per cent over mid parent.

Moshkin (1986) showed that although the yield of seeds in the second generation of inter line hybrids significantly decreases by 9.7 to 9.8 per cent, the yield is on the average, 5 per cent greater than that of the variety control VNIIMK 165. Similar results were found in inter varietal hybrids and it was concluded, since the use of second generation hybrids for sowing does not require additional expenditures, it is economically beneficial.

Pathak *et al.* (1988) showed that seed yield and 100 seed weight had the highest inbreeding depression in castor.

CHAPTER III

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The present investigation was carried out at College Farm, College of Agriculture, Rajendranagar, Hyderabad during *rabi* 2000-2001, *kharif* 2001 and *rabi* 2001-2002. However, the objective to study the mode of inheritance of fusarium wilt resistance was taken at Directorate of Oilseeds Research, Rajendranagar, Hyderabad during *kharif* 2001.

3.1 EXPERIMENTAL MATERIAL

The basic material for conducting the experiments consisted of nine elite monoecious lines and four pistillate lines obtained from Directorate of Oilseeds Research, Rajendranagar, Hyderabad. A total of four experiments were conducted to achieve the objectives.

3.1.1 Inheritance of some morphological characters

Nine parents viz., VP-1, DPC-9, LRES-17, Geeta, DCS-9, DCS-27, SH-72, 48-1 and Co-1 having diverse morphological traits (Table 3.1) were selected for studying the mode of inheritance of certain traits.

Table 3.1: Morphological characteristics of the parents

Parents	Leaf shape	Stem colour	Bloom	Spininess of capsule	Internode nature
Pistillate lines					
VP-1 (Plate 3A)	Cup	Green	Triple	Spiny	Condensed
DPC-9 (Plate 3B)	Flat	Green	Zero	Spiny	Elongated
LRES-17 (Plate 3D)	Cup	Green	Triple	Spiny	Condensed
Geeta (Plate 3C)	Flat	Red	Double	Non Spiny	Elongated
Monoecious lines					
DCS-9 (Plate 4A)	Flat	Red	Double	Spiny	Elongated
DCS-27	Flat	Mahogany	Double	Spiny	Elongated
SH-72 (Plate 4B)	Flat	Green	Double	Spiny	Elongated
48-1 (Plate 4C)	Flat	Red	Double	Non Spiny	Elongated
Co-1 (Plate 4D)	Flat	Green	Zero	Spiny	Elongated

Plate 1: Overall view of the experimental plot

Plate 2: Castor spikes bagged to perform selfing and crossing

Plate 3: **Female parents used in inheritance study of morphological characters**

3A: **VP-1** : Cup leaf, green stem, triple bloom, spiny capsule, condensed internode

3B: **DPC-9** : Flat leaf, green stem, zero bloom, spiny capsule, elongated internal

3C: **Geeta** : Flat leaf, red stem, double bloom, non spiny capsule, elongated internode

3D: **LRES-17** : Cup leaf, green stem, triple bloom, spiny capsule, condensed internode

Plate 4: **Male parents used in inheritance study of morphological characters**

4A: **DCS-9** : Flat leaf, red stem, double bloom, spiny capsule, elongated internode

4B: **SH-72** : Flat leaf, green stem, double bloom, spiny capsule, elongated internode

4C: **48-1** : Flat leaf, red stem, double bloom, non spiny capsule, elongated internode

4D: **Co-1** : Flat leaf, green stem, zero bloom, spiny capsule, elongated internode

4A

4B

4C

4D

3.1.2 Inheritance of fusarium wilt resistance

Wilt resistant castor cultivar, 48-1 and susceptible cultivar, VP-1 were utilized for studying the inheritance of fusarium wilt resistance in castor.

3.1.3 Combining ability studies

Thirteen castor genotypes involving nine monoecious lines and four pistillate testers (Table 3.2) were utilized for combining ability studies.

Table 3.2: Lines and testers involved in combining ability studies

Parent	Entries
Males (lines)	DCS-5, DCS-9, DCS-27, DCS-84, DCS-85, SH-72, 48-1, AVR-1, Co-1
Females (testers)	VP -1, DPC-9, LRES-17, Geeta

These nine lines and four testers were crossed in line x tester fashion to obtain 36 hybrids and were analyzed for combining ability.

3.1.4 Heterosis and inbreeding depression studies

The 36 hybrids developed from nine monoecious lines and four pistillate testers (Table 3.2) were studied to obtain information on heterobeltiosis and standard heterosis over checks, Kranti and DCH-177.

The F_2 population was generated from eight crosses selected based on seed yield of F_1 hybrids two each from four pistillate entries. These eight crosses were observed for inbreeding depression studies.

3.2 METHODS

3.2.1 Inheritance of some morphological characters

The parents mentioned in Table 1 were crossed in different fashions on the basis of their contrasting morphological traits. A total of nine crosses viz., VP-1 x DCS-9, VP-1 x 48-1, VP-1 x DPC-9, VP-1 x Co-1, DPC-9 x SH-72, DPC-9 x 48-1, LRES-17 x Co-1, Geeta x DCS-27 and Geeta x SH-72 were attempted during *rabi* 2000-2001. In *kharif* 2001, all the nine crosses were selfed to produce the F_2 seed and back crossed to either parents (using F_1 as female) to generate B_1 and B_2 families. During *rabi* 2001-2002 all six generations (P_1, P_2, F_1, F_2, B_1 and B_2) were raised to study the inheritance pattern of certain morphological traits.

The crosses studied for mode of inheritance of different characters are presented in the Table 3.3.

Table 3.3 : Crosses studied for mode of inheritance of different characters

Character	Crosses
Leaf shape	VP-1 x DCS-9, VP-1 x 48-1, VP-1 x Co-1, LRES-17 x Co-1
Stem colour	VP-1 x DCS-9, VP-1 x 48-1, DPC-9 x 48-1, Geeta x SH-72, Geeta x DCS-27
Bloom nature	VP-1 x DCS-9, VP-1 x 48-1, VP-1 x Co-1, LRES-17 x Co-1, DPC-9 x SH-72, DPC-9 x 48-1
Spininess of capsule	VP-1 x 48-1, DPC-9 x 48-1, Geeta x DCS-27, Geeta x SH-72
Internode nature	VP-1 x DCS-9, VP-1 x 48-1

In each cross, a population of 15 plants in parents and hybrids, 200 to 300 plants in F_2 and 100 to 200 plants each in B_1 and B_2 generations were studied to

record the segregation pattern for each character. Further, joint segregation was also observed for different character combinations.

3.2.2 Inheritance of fusarium wilt resistance

The hybrid, VP-1 x 48-1 along with its parents VP-1 (susceptible) and 48-1 (resistant) were grown at Directorate of Oilseeds Research, Hyderabad during *rabi* 2000-2001. The resistant parent, 48-1 was grown in pots infected with fusarium inoculum. The F_1 was selfed to get F_2 and also backcrosses were made with both the parents to generate B_1 and B_2 population. In case of 48-1 parent, the plants which showed resistance under pot culture were utilized for collecting pollen for backcrossing. Further, the six generations (P_1, P_2, F_1, F_2, B_1 and B_2) were grown in sick plots during *kharif* 2001 at Directorate of Oilseeds Research, Hyderabad. Five rows each for P_1, P_2 and F_1 and 50 rows for F_2 and 25 rows each for B_1 and B_2 were maintained to record resistant and susceptible reaction. A susceptible check, Aruna and a resistant check, DCS-9 were included at every five test rows. Plants were classified in each population classes as resistant and susceptible based on the plants survived and wilted, respectively. The plants dead at different stages of duration upto 150 days were classified as susceptible.

3.2.3 Combining ability studies

Four pistillate testers (females) were crossed with nine monoecious-lines (males) in a line x tester mating design to obtain 36 hybrids during *rabi* 2000-2001. The 36 crosses along with their parents and two checks viz., DCH-177, Kranti (a total of 51 entries) were grown during *rabi* 2001-2002 in a randomized

block design replicated thrice. The plot size for each entry was two rows of five m length.

3.2.4 Inbreeding depression

Among the 36 crosses obtained from nine lines and four testers, eight crosses were selected based on seed yield of F_1 hybrids, two each from four different pisitillate entries. These eight crosses were selfed to produce the F_2 generation during *kharif*, 2001. Open pollinated seeds were also collected from F_1 plants for comparative study of extent of inbreeding depression under selfed and open pollinated conditions. The F_1 and F_2 generations (both selfed and open pollinated) were evaluated during *rabi* 2001-2002 laid out in a RBD replicated twice. The plot size for each entry was two rows of five m length for F_1s and five rows of five m length for F_2 generation. A random sample of five plants from F_1 and 30 plants from F_2 generation in each replication were utilized to record the observations.

3.2.5 Crossing/selfing programme

Crossing

After complete emergence of spike and before flower opening, selected spikes in both female and male parents were covered with butter paper bags in order to avoid contamination and to collect pollen from selected male parents. When crosses were made between two monoecious parents, the female parents were emasculated by removing male flowers before flower opening. After emergence of stigma in the female parents, pollen collected in petriplates from the desired male parents were applied on to the stigma with the help of small

camel hair brush and spikes were covered with butter paper bags. This procedure of pollination was repeated on every alternate days until all the flowers in spike were open. As the spikes increase in length, the spikes were covered with another butter paper bag one above the other by tearing the top of previous butter paper bag (Plate 2). Mean while, proper care was taken to avoid selfing with the environmentally sensitive interspersed staminate flowers by removing them before opening as and when they appear.

Selfing

For generating F_2 population, the F_1 hybrids were selfed. To achieve selfing, spikes were bagged without emasculation after complete emergence of spike and before flower opening, Further, care was taken to avoid transfer of foreign pollen by tearing off of butter paper bag.

3.2.6 Crop management

Recommended package of practices was adopted to raise a healthy crop. The field was uniformly fertilized at the rate of 80 kg N, 40 kg P_2O_5 and 30 Kg K_2O per hectare. A spacing of 90 x 60 cm was maintained in all the experiments. Irrigations were given as and when required. Necessary prophylactic measures were taken up to safeguard the crop from pests and diseases. Overall view of the experimental plot is shown in Plate 1.

3.3 OBSERVATIONS RECORDED

Observations were recorded on competitive plants of variable number depending on the generation in each replication and the mean values were worked out. However, for the traits viz., days to 50 per cent flowering and days to

maturity the observations were recorded on whole plot basis. The particulars of characters studied are as follows.

3.3.1 Days to 50 per cent flowering

The number of days taken from the sowing to the first flower appearance in 50 per cent of plants in each plot was recorded.

3.3.2 Days to maturity

Number of days taken from sowing date to the date when all the capsules in the primary spike of all the plants in the plot turned to brown and matured was recorded.

3.3.3 Plant height (cm)

From the ground level to the base of the primary spike, the plant height was recorded in centimeters.

3.3.4 Number of nodes

After the emergence of the primary spike, the number of nodes upto primary spike was recorded.

3.3.5 Primary spike length (cm)

The primary spike length was measured in centimeters at the time of harvest.

3.3.6 Effective spike length (cm)

Portion of the primary spike covered with capsules was measured in centimeters at the time of harvest.

3.3.7 Number of capsules per primary spike

The number of matured capsules per primary spike was counted after the harvest.

3.3.8 100-seed weight (g)

One hundred randomly selected dried seeds were weighed (with the help of an electronic top pan balance) and recorded in grams.

3.3.9 Seed yield per plant (g)

Seed yield of single plant (total of three pickings) was recorded in grams after thorough drying and shelling.

3.3.10 Oil content (%)

The seed oil content was determined by Nuclear Magnetic Resonance technique in the laboratory of Directorate of Oilseeds Research, Rajendranagar, Hyderabad and expressed as per cent.

3.4 STATISTICAL PROCEDURES

The data recorded were subjected to the following statistical analysis.

3.4.1 Study of segregation

The data from F_2 and back cross generations for different characters were subjected to chi-square test of goodness of fit. Chi-square was calculated using the formula given below.

$$\chi^2 = \sum \frac{(O-E)^2}{E}$$

Where, O = Observed frequency of a class
E = expected frequency of a class

Significance of χ^2 value was measured by referring to chi-square probability table at (n-1) degrees of freedom, where n represents number of distinct classes.

In cases of joint segregation, whenever the chi-square values were significant the recombination frequencies were worked out from F_2 data using the formula given by Richharia *et al.* (1966).

$$P = \frac{n_1 n_2 n_3 + n_1 n_3 n_4 - 2 n_2 n_3 n_4}{n_1 n_2 n_3 + n_1 n_2 n_4 + n_1 n_3 n_4 + n_2 n_3 n_4}$$

Where,

P = recombination fraction

$n_1 = a_1 + 1$

$n_2 = a_2 + 1$

$n_3 = a_3 + 1$

$n_4 = a_4 + 1$

a_1 = frequency of X_ Y_ phenotypes

a_2 = frequency of X_ yy phenotypes

a_3 = frequency of xx Y_ phenotypes

a_4 = frequency of xx yy phenotypes

assuming X and Y are the genes governing two characters.

From P value, recombination frequency (RF) or cross over value is calculated as follows .

Coupling phase RF = $1-\sqrt{P}$

Repulsion phase RF = $\sqrt{P}$

34

Recombination frequency was also calculated from backcross segregation data with the formula.

$$RF = \frac{\text{No. of recombinants}}{\text{Total progeny}}$$

3.4.2 Analysis of variance

The data were analyzed separately for each character through randomized block design (Panse and Sukhatme, 1961) as given below.

Source	Degrees of freedom	Mean sum of squares	F-value
Replications	(r-1)	M_r	M_r/M_e
Treatments	(t-1)	M_t	M_t/M_e
Error	(r-1) (t-1)	M_e	
Total	(rt-1)		

Where r = Number of replications

t = Number of treatments (genotypes)

M_r, M_t and M_e represent for mean squares due to replications, treatments and error, respectively

3.4.3 Combining ability analysis

Analysis of variance was carried out as per the line x tester model given by Singh and Chaudhary (1985).

ANOVA for line x tester design

Source	Degrees of freedom	Mean sum of squares
Replications	(r-1)	
Genotypes	(n-1)	
Parents	(p-1)	
Crosses	(c-1)	
Parents Vs Crosses	1	
Lines	(l-1)	M_l
Testers	(t-1)	M_t
Lines x Testers	(l-1) (t-1)	$M_{(l \times t)}$
Error	(r-1) (l-1)	M_e

Where,

r = number of replications
n = number of treatments/genotypes
p = number of parents
c = number of crosses
l = number of lines
t = number of testers

The significant difference for each source of variation was verified by applying the 'F' test of Fisher and Yates (1967).

3.4.4 Estimation of combining ability

The analysis of combining ability was based on the method of Kempthorne (1957). The covariances of half sibs and full sibs were used to obtain the estimates of general and specific combining ability and their variances.

Source	Degrees of freedom	Sum of squares	Mean sum of squares	Expected mean squares
Replications	(r-1)	$\frac{X^2_{..k}}{lt} - \frac{X^2_{...}}{ltr}$		
Crosses	(lt-1)	$\frac{X^2_{ij.}}{r} - \frac{X^2_{...}}{ltr}$		
Lines	(l-1)	$\frac{X^2_{i..}}{tr} - \frac{X^2_{...}}{ltr}$	M_1	$\sigma^2 + r[(\text{cov (F.S)} - 2 \text{ cov (H.S)} + t \text{ cov (H.S)}]$
Testers	(t-1)	$\frac{X^2_{j.}}{lt} - \frac{X^2_{...}}{ltr}$	M_2	$\sigma^2 + r[(\text{cov (F.S)} - 2 \text{ cov (H.S)} + mr \text{ cov (H.S)}]$
Lines x Testers	(l-1) (t-1)	SS (crosses) – SS(lines) – SS (testers)	M_3	$\sigma^2 + r[(\text{cov (F.S)} - 2 \text{ cov (H.S)}]$
Error	(r-1) (lt-1)	By difference	M_4	σ^2
Total	(ltr-1)	$X^2_{ijk} - \frac{X^2_{...}}{ltr}$		

Where,

$X...$ = sum of all the ij^{th} hybrid combination over all replications

$X_{i..}$ = sum of i^{th} line over all testers and replications

$X_{.j.}$ = sum of j^{th} tester over all lines and replications

$X_{..k}$ = sum of K^{th} replication

$X_{ij.}$ = sum of ij^{th} hybrid combination over all replications

X_{ijk} = ij^{th} observation in K^{th} replication

From the expected mean sum of squares, covariance of full sibs [cov(FS)] and covariance of half sibs [cov(HS)] were estimated using the formulae given by Dabholkar (1992).

$$\text{cov(HS)} = \frac{M_1 + M_2 - 2M_3}{r(1+t)} \qquad \text{(King } et\ al.\text{, 1961)}$$

$$\text{cov (FS)} = \frac{1}{3r}[\ M_1 + M_2 + M_3 - 3M_4 + r\ \text{cov (HS)}\ (6\text{-}l\text{-}t)]$$

3.4.5 Estimation of variances

After evaluating the cov(HS) and cov(FS) using the above equations, variance due to general combining ability (σ^2 gca) and variance due to specific combining ability (σ^2 sca) were estimated as :

σ^2 gca = cov(HS)

σ^2 sca = cov(FS) – 2 cov(HS)

3.4.6 Estimation of degree of dominance and predictability ratio

Degree of dominance was calculated from the formula given by Baker (1978).

37

$$\text{Degree of dominance} = \sqrt{\frac{\sigma^2_{sca}}{2\sigma^2_{gca}}}$$

Predictability ratio was calculated from the formula.

$$\text{Predictability ratio} = \frac{2\sigma^2_{gca}}{2\sigma^2_{gca} + \sigma^2_{sca}}$$

3.4.7 Estimation of combining ability effects

The additive model used to estimate the gca and sca effects of the ijk^{th} observation was

$$X_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}$$

Where,

μ	=	population mean
g_i	=	gca effect of i^{th} male parent
g_j	=	gca effect of j^{th} female parent
s_{ij}	=	sca effect of ij^{th} combination
e_{ijk}	=	error associated with the observation X_{ijk}
i	=	Number of male parents
j	=	Number of female parents
k	=	Number of replications

The individual effects were estimated as follows

$$\mu = \frac{X...}{ltr}$$

Where,

X... = total of all hybrid combinations over all replications

38

$$\text{gca effect of } i^{th} \text{ line } (g_i) = \frac{X_{i..}}{tr} - \frac{X...}{ltr}$$

Where,

$X_{i..}$ = Total of i^{th} line over all testers and replications

$$\text{gca effect of } j^{th} \text{ tester}(g_j) = \frac{X_{.j.}}{lr} - \frac{X...}{ltr}$$

Where,

$X_{.j.}$ = Total of j^{th} tester over all lines and replications

$$\text{Sca effects of } ij^{th} \text{ cross } (S_{ij}) = \frac{X_{ij.}}{r} - \frac{X_{i..}}{tr} - \frac{X_{.j.}}{lr} + \frac{X...}{ltr}$$

Where,

$X_{ij.}$ = ij^{th} combination total over all replications

3.4.8 Standard errors for combining ability effects

The standard errors (SE) pertaining to gca effects of lines and testers and sca effects of different combinations were calculated as follows.

$$SE\ (g_i) \text{ lines (gca for lines)} = \left[\frac{\text{Error variance}}{rt}\right]^{1/2}$$

$$SE\ (g_i) \text{ testers (gca for testers)} = \left[\frac{\text{Error variance}}{rl}\right]^{1/2}$$

$$SE\ (s_{ij}) \text{ line x tester combination} = \left[\frac{2 \text{ Error variance}}{r}\right]^{1/2}$$

Where,

r = number of replications
l = number of lines
t = number of testers

3.5 ESTIMATION OF HETEROSIS

The deviation of F_1 hybrid from better parent and standard check representing the heterobeltiosis and standard heterosis respectively, were calculated using standard formulae

$$\text{Heterobeltiosis} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

$$\text{Standard heterosis} = \frac{\overline{F_1} - \overline{Check}}{\overline{Check}} \times 100$$

Where,

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

$\overline{BP}$ = mean of the better parent value

$\overline{Check}$ = mean of the standard check

To test the significance of heterosis the following formulae given by Arunachalam (1976) were used.

$$\text{For heterobeltiosis } t_{cal} = \frac{\overline{F_1} - \overline{BP}}{\sqrt{2\,EMS/r}}$$

$$\text{For standard heterosis } t_{cal} = \frac{\overline{F_1} - \overline{Check}}{\sqrt{2\,EMS/r}}$$

Where,

EMS = error mean sum of squares
r = number of replications

The calculated 't' value was compared with 't' table value at the respective error degrees of freedom to test the significance of heterosis.

3.6 ESTIMATION OF INBREEDING DEPRESSION

The inbreeding depression for each character was calculated from the formula used by Miller and Marani (1963)

$$ID = \frac{\overline{F_1} - \overline{F_2}}{F_1} \times 100$$

Where,

ID = inbreeding depression

$\overline{F_1}$ = Mean of F_1 population

$\overline{F_2}$ = Mean of F_2 population

To test the significance of inbreeding depression the following formula was used.

$$t_{cal} = \frac{\overline{F_1} - \overline{F_2}}{\sqrt{\frac{VE_1 + VE_2}{r}}}$$

VE_1 = EMS from F_1 ANOVA

VE_2 = EMS from F_2 ANOVA

r = Number of replications

The calculated 't' value was compared with 't' table value at the respective error degrees of freedom to test the significance of inbreeding depression.

CHAPTER IV

RESULTS

CHAPTER IV

RESULTS

Results of the present investigation on "Genetic analysis of some qualitative and quantitative traits in castor" are presented here under the following headings.

1. Inheritance of certain morphological characters.
2. Inheritance of fusarium wilt resistance
3. Combining ability studies.
4. Heterosis and inbreeding depression

4.1 INHERITANCE OF CERTAIN MORPHOLOGICAL CHARACTERS

An experiment was conducted to study the inheritance of five morphological characters in castor utilizing nine parents (Table 3.1). Crosses were made between the parental lines possessing contrasting morphological traits for the respective characters studied (Table 3.3). The F_1s were selfed to generate F_2, and back crossed to obtain B_1 and B_2 families and were evaluated for segregation of each character separately and in combination with other traits.

4.1.1 Segregation of individual characters

4.1.1.1 Leaf shape

The inheritance of leaf shape was studied in four crosses namely, VP-1 x DCS-9, VP-1 x 48-1, VP-1 x Co-1 and LRES-17 x Co-1 and results

42

are furnished in Table 4.1. The parents, VP-1 and LRES-17 had cup shape leaves, whereas DCS-9 and Co-1 had flat leaves.

In the cross, VP-1 x DCS-9 all the F_1 hybrids expressed flat leaves (Plate 5), while the F_2 population segregated in the ratio of 3 flat : 1 cup leaved plants (Plate 7). The back cross of VP-1 x DCS-9 with cup leaved parent (VP-1) gave a segregation ratio of 1 flat : 1 cup leaved plants. Further, back cross of VP-1 x DCS-9 with flat leaved parent (DCS-9), did not segregate and the entire progeny was with flat leaves.

Similarly in remaining three crosses viz., VP-1 x 48-1 (Plate 6), VP-1 x Co-1 and LRES-17 x Co-1, the F_1 individuals had flat leaves and their F_2 population exhibited a segregation ratio of 3 flat : 1 cup leaved plants. The back crosses of F_1s with respective cup leaved parent segregated at a ratio of 1 flat : 1 cup leaved plants. Further, the entire backcross progenies involving respective flat leaved parent had flat leaves with out any segregation.

4.1.1.2 Stem colour

Inheritance of stem colour was studied in five crosses viz., VP-1 x DCS-9, VP-1 x 48-1, DPC-9 x 48-1, Geeta x SH-72 and Geeta x DCS-27 and results are presented in Table 4.2. The parents, VP-1, DPC-9 and SH-72 had green colour stem, whereas DCS-9, 48-1 and Geeta had red stem and DCS-27 had mahogany colour stem (Plate 8).

The F_1 individuals of cross, VP-1 x DCS-9 had red colour stem (Plate 5), whereas a segregation of 3 red : 1 green stem plants were observed

Table 4.1 Expression of leaf shape (flat vs. cup) in F_1, F_2 and back cross generations in four different crosses of castor

Cross	F_1 phenotype	Generation	Segregation			Expected ratio	χ^2 value	P-range
			Flat	Cup	Total			
Cup x Flat								
VP-1 x DCS-9	Flat	F_2	215	73	288	3:1	0.02	0.95 - 0.90
		B_1 (F_1 x VP-1)	94	78	172	1:1	1.48	0.25 - 0.10
		B_2 (F_1 x DCS-9)	152	-	152	-	-	-
VP-1 x 48-1	Flat	F_2	204	64	268	3:1	0.18	0.75 - 0.50
		B_1 (F_1 x VP-1)	109	90	199	1:1	1.81	0.25 - 0.10
		B_2 (F_1 x 48-1)	159	-	159	-	-	-
VP-1 x Co-1	Flat	F_2	192	64	256	3:1	0.00	> 0.99
		B_1 (F_1 x VP-1)	91	96	187	1:1	0.13	0.75 - 0.50
		B_2 (F_1 x Co-1)	113	-	113	-	-	-
LRES-17 x Co-1	Flat	F_2	193	52	245	3:1	1.86	0.20 - 0.10
		B_1 (F_1 x LRES-17)	81	68	149	1:1	1.13	0.50 – 0.25
		B_2 (F_1 x Co-1)	113	-	113	-	-	-

43

Plate 5: F_1 of cross, VP-1 x DCS-9 showing flat leaf, red stem, triple bloom, spiny capsule and elongated internode

Plate 6: F_1 of cross, VP-1 x 48-1 showing flat leaf, red stem, triple bloom, partial spiny capsule and elongated internode

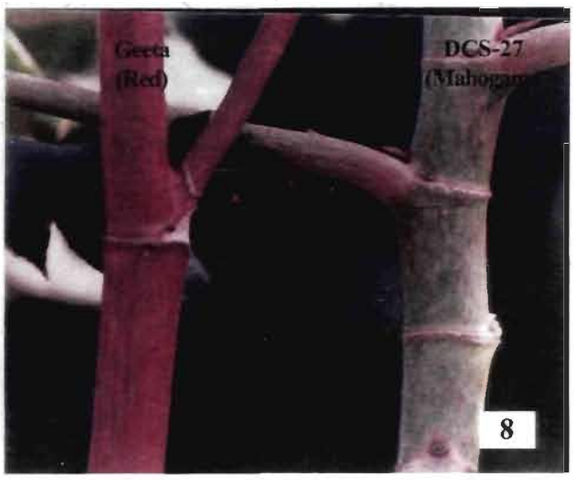
Plate 7: Phenotype of parents, F_1 and F_2 generation for leaf shape in cross, VP-1 x DCS-9

Plate 8: Stem colour of parents, Geeta (red) and DCS-27 (mahogany)

5

6

7



8

Plate 9: F_1 of cross, DPC-9 x SH-72 showing partial double bloom

Plate 10: F_1 of cross, DPC-9 x 48-1 showing partial double bloom

Plate 11: Segregation for bloom nature as double, partial double and zero bloom represented by jassid attack in the F_2 of cross, DPC-9 x 48-1. Zero and partial double bloom plants showed susceptible to jassids.


9


10


11

Table 4.2 Expression of stem colour (red vs. green/mahogany) in F_1, F_2 and back cross generations in five different crosses of castor

Cross	F_1 phenotype	Generation	Segregation			Expected ratio	χ^2 value	P-range
			Red	**Green**	**Total**			
Green x Red								
VP-1 x DCS-9	Red	F_2	204	84	288	3:1	2.67	0.25 - 0.10
		B_1 (F_1 x VP-1)	85	87	172	1:1	0.02	0.95 - 0.90
		B_2 (F_1 x DCS-9)	152	-	152	-	-	-
VP-1 x 48-1	Red	F_2	193	75	268	3:1	1.27	0.50 - 0.25
		B_1 (F_1 x VP-1)	100	99	199	1:1	0.005	0.95 - 0.90
		B_2 (F_1 x 48-1)	159	-	159	-	-	-
DPC-9 x 48-1	Red	F_2	216	52	268	3:1	6.47	0.025 - 0.01
		B_1 (F_1 x DPC-9)	64	60	124	1:1	0.13	0.75 - 0.50
		B_2 (F_1 x 48-1)	152	-	152	-	-	-
Red x Green								
Geeta x SH-72	Red	F_2	202	81	283	3:1	1.98	0.25 - 0.10
		B_1 (F_1 x Geeta)	110	-	110	-	-	-
		B_2 (F_1 x SH-72)	124	128	252	1:1	0.06	0.90 – 0.75
Red x Mahogany			**Red**	**Mahogany**	**Total**			
Geeta x DCS-27	Red	F_2	169	44	213	3:1	2.14	0.25 - 0.10
		B_1 (F_1 x Geeta)	144	-	144	-	-	-
		B_2 (F_1 x DCS-27)	103	112	215	1:1	0.38	0.75 – 0.50

47

in F_2 generation. The backcross of VP-1 x DCS-9 with parent having green stem (VP-1) gave a segregation ratio of 1 red : 1 green stem plants. However, the backcross of F_1 hybrid with red stemmed parent (DCS-9) yielded plants all with red stems.

Similarly in crosses, VP-1 x 48-1 (Plate 6), DPC-9 x 48-1 (Plate 10) and Geeta x SH-72, all the F_1 hybrids had red stem and their F_2 population segregated at a ratio of 3 red : 1 green stem plants. The backcrosses also corroborated with the F_2 segregation pattern.

However in cross Geeta x DCS-27, the F_1 plants had red stem, whereas the F_2 generation exhibited segregation with a ratio of 3 red : 1 mahogany stem plants. The backcross of F_1 plants with parent having mahogany stem (DCS-27) resulted a progeny segregated at 1 red : 1 mahogany stem plants, while backcross progeny of (Geeta x DCS-27) x Geeta had red stem plants without segregation.

4.1.1.3 Bloom nature

Six crosses namely, VP-1 x DCS-9, VP-1 x 48-1, VP-1 x Co-1, DPC-9 x SH-72, DPC-9 x 48-1 and LRES-17 x Co-1 were studied. The parents, VP-1 and LRES-17 had triple bloom, DCS-9, SH-72 and 48-1 had double bloom and DPC-9 and Co-1 had zero bloom.

In the crosses, involving triple bloom vs. double bloom viz., VP-1 x DCS-9, VP-1 x 48-1, the F_1 plants had triple bloom (Plate 5 & 6), while the F_2 population gave a good fit to 3 triple bloom : 1 double bloom ratio

Table 4.3 Expression of bloom nature (triple vs. double) in F_1, F_2 and back cross generations in two different crosses of castor

Cross	F_1 phenotype	Generation	Segregation			Expected ratio	χ^2 value	P-range
			Triple	Double	Total			
Triple x Double								
VP-1 x DCS-9	Triple	F_2	206	82	288	3:1	1.85	0.20 - 0.10
		B_1 (F_1 x VP-1)	172	-	172	-	-	-
		B_2 (F_1 x DCS-9)	74	78	152	1:1	0.11	0.75 – 0.50
VP-1 x 48-1	Triple	F_2'	198	70	268	3:1	0.17	0.75 - 0.50
		B_1 (F_1 x VP-1)	199	-	199	-	-	-
		B_2 (F_1 x 48-1)	75	84	159	1:1	0.51	0.50 – 0.25

(Table 4.3). Further, backcross of F_1 plants with respective double bloom parent resulted progenies segregated at the ratio of 1 triple bloom : 1 double bloom. However, backcross progenies involving VP-1 (triple bloom) as recurrent parent had all the plants with triple bloom.

In case of crosses involving triple bloom vs. zero bloom viz., VP-1 x Co-1 and LRES-17 x Co-1, the F_1 plants appeared similar to double bloom, but a slight bloom was observed on dorsal surface of leaf (partial triple bloom) (Table 4.4).

The segregation pattern in F_2 generation of both the crosses gave a good fit to the 1 triple bloom : 2 partial triple bloom : 1 zero bloom ratio. Further, backcross progenies of both the crosses involving respective triple bloom parent as recurrent parent had a segregation ratio of 1 triple bloom : 1 partial triple bloom, whereas, backcross of F_1s with Co-1 parent (zero bloom) yielded the progenies with segregation ratio of 1 partial triple : 1 zero bloom.

The F_1 plants of crosses involving zero bloom vs. double bloom viz., DPC-9 x SH-72 (Plate 9) and DPC-9 x 48-1 (Plate 10) had morphology similar to single bloom, but very slight bloom was observed on ventral surface of leaves which were explained as partial double (Table 4.5). The F_2 progeny of both the crosses segregated with the good fit to 1 double bloom : 2 partial double : 1 zero bloom ratio (Plate 11). Further, back crossing of F_1s of both the crosses with zero bloom parent (DPC-9) resulted the progenies segregated in the ratio of 1 partial double : 1 zero bloom, whereas backcross

Table 4.4 Expression of bloom nature (triple vs. zero) in F_1, F_2 and back cross generations in two different crosses of castor

Cross	F_1 phenotype	Generation	Segregation				Expected ratio	χ^2 value	P-range
			Triple	Partial Triple	Zero	Total			
Triple x Zero									
VP-1 x Co-1	Partial Triple	F_2	68	126	62	256	1:2:1	0.34	0.90 - 0.75
		B_1 (F_1 x VP-1)	91	96	-	187	1:1	0.13	0.75 - 0.50
		B_2 (F_1 x Co-1)	-	54	59	113	1:1	0.22	0.75 – 0.50
LRES-17 x Co-1	Partial Triple	F_2	62	124	59	245	1:2:1	0.11	0.95 - 0.90
		B_1 (F_1 x LRES-17)	84	65	-	149	1:1	2.42	0.25 - 0.10
		B_2 (F_1 x Co-1)	-	64	49	113	1:1	1.99	0.25 – 0.10

Table 4.5 Expression of bloom nature (double vs. zero) in F_1, F_2 and back cross generations in two different crosses of castor

Cross	F_1 phenotype	Generation	Segregation				Expected ratio	χ^2 value	P-range
			Double	Partial Double	Zero	Total			
Zero x Double									
DPC-9 x SH-72	Partial Double	F_2	76	151	59	286	1:2:1	4.79	0.10 – 0.05
		B_1 (F_1 x DPC-9)	-	61	49	110	1:1	1.31	0.50 - 0.25
		B_2 (F_1 x SH-72)	106	98	-	204	1:1	0.31	0.75 – 0.50
DPC-9 x 48-1	Partial Double	F_2	64	138	66	268	1:2:1	0.27	0.90 - 0.75
		B_1 (F_1 x DPC-9)	-	61	63	124	1:1	0.03	0.90 – 0.75
		B_2 (F_1 x 48-1)	57	59	-	116	1:1	0.03	0.90 – 0.75

progenies of (DPC-9 x SH-72) x SH-72 and (DPC-9 x 48-1) x 48-1 gave a good fit to 1 double : 1 partial double bloom ratio.

4.1.1.4 Spininess of capsule

Four crosses viz., VP-1 x 48-1, Geeta x DCS-27, Geeta x SH-72 and DPC-9 x 48-1 were studied with a view to record inheritance pattern of spininess of capsule and results are furnished in Table 4.6. The parents, VP-1, DCS-27, SH-72 and DPC-9 had spiny capsules, whereas the parents, 48-1 and Geeta were non spiny.

In the cross, VP-1 x 48-1, the F_1 plants had partial spiny capsules (Plate 12), while the F_2 population exhibited the segregation ratio of 1 spiny : 2 partial spiny : 1 non spiny (Plate 13). Further backcross of VP-1 x 48-1 with spiny parent (VP-1) yielded the progeny segregated with a good fit to 1 spiny: 1 partial spiny ratio, however, the backcross progeny of (VP-1 x 48) x 48-1 segregated at the ratio of 1 partial spiny : 1 non spiny.

Similarly, in rest of the crosses, Geeta x DCS-29, Geeta x SH-72 and DPC-9 x 48-1, the F_1 plants had partial spiny capsules, and their F_2 population segregated at the ratio of 1 spiny : 2 partial spiny : 1 non spiny. Further, the segregation of backcross generations also corroborated with the F_2 segregation pattern in all the three crosses.

4.1.1.5 Internode nature

Inheritance of internode nature (condensed vs. elongated) was studied in two crosses viz., VP-1 x DCS-9 and VP-1 x 48-1 and results are presented

Plate 12: F_1 of cross, VP-1 x 48-1 showing partial spiny capsule

Plate 13: Phenotype of parents, F_1 and F_2 generation for spininess of capsule in cross, VP-1 x 48-1

Plate 14: VP-1 showing condensed internode

Plate 15: Internode nature of parents VP-1 (condensed), 48-1 (elongated) and DCS-9 (elongated)


12


VP-1
(Spiny)
48-1
(Non spiny)
F1
(Partial Spiny)
F2 (1 Spiny : 2 Partial spiny :
1 Non spiny)
13


14


VP-1
(Condensed)
48-1
(Elongated)
DCS-9
(Elongated)
15

Table 4.6 Expression of spininess of capsule (spiny vs. non spiny) in F_1, F_2 and back cross generations in four different crosses of castor

Cross	F_1 phenotype	Generation	Segregation				Expected ratio	χ^2 value	P-range
			Spiny	Partial Spiny	Non Spiny	Total			
Spiny x Non Spiny									
VP-1 x 48-1	Partial Spiny	F_2	61	144	63	268	1:2:1	0.70	0.50 - 0.25
		B_1 (F_1 x VP-1)	95	104	-	199	1:1	0.41	0.75 - 0.50
		B_2 (F_1 x 48-1)	-	78	81	159	1:1	0.06	0.90 – 0.75
DPC-9 x 48-1	Partial Spiny	F_2	68	137	63	268	1:2:1	0.32	0.75 - 0.50
		B_1 (F_1 x DPC-9)	63	61	-	124	1:1	0.03	0.90 – 0.75
		B_2 (F_1 x 48-1)	-	61	55	116	1:1	0.31	0.75 – 0.50
Non Spiny x Spiny									
Geeta x DCS-27	Partial Spiny	F_2	51	114	48	213	1:2:1	1.14	0.50 - 0.25
		B_1 (F_1 x Geeta)	-	81	85	166	1:1	0.10	0.90 - 0.75
		B_2 (F_1 x DCS-27)	110	102	-	215	1:1	0.06	0.90 – 0.75
Geeta x SH-72	Partial Spiny	F_2	66	142	75	283	1:2:1	0.58	0.50 - 0.25
		B_1 (F_1 x Geeta)	-	81	72	153	1:1	0.26	0.75 - 0.50
		B_2 (F_1 x SH-72)	121	131	-	252	1:1	0.40	0.75 – 0.50

in Table 4.7. The parent, VP-1 had condensed internode and the parents, DCS-9 and 48-1 had elongated internode (Plate 14 and 15). The results revealed that the F_1 plants of both the crosses had elongated internodes (Plate 5 and 6), whereas their F_2 progeny exhibited the segregation for internode nature with a good fit to 3 elongated : 1 condensed ratio. Further, the backcross of both the F_1 plants with VP-1 (condensed internode) resulted the progeny segregated at the ratio of 1 elongated: 1 condensed. However, the backcross progenies of (VP-1 x DCS-9) x DCS-9 and (VP-1 x 48-1) x 48-1 did not segregate and had elongated internodes.

4.1.2 Joint segregation for different traits

To study the presence of linkages or pleiotrophy if any among the genes controlling the traits under consideration, joint segregation was recorded for different character combinations and the results are presented here under.

4.1.2.1 Leaf shape, stem colour and bloom nature

Two crosses viz., VP-1 x DCS-9 and VP-1 x 48-1 were studied for joint segregation of leaf shape, stem colour and bloom nature simultaneously and results are presented in Table 4.8. In both the crosses, the F_1 progeny was with flat leaves, red stem and triple bloom (Plate 5 and 6), whereas their F_2 population was segregated with a ratio of 27 : 9 : 9: 3 : 9 : 3: 3: 1 of flat leaf, red stem, triple bloom (FRT) : flat leaf, red stem, double bloom (FRD): cup leaf, red stem, triple bloom (CRT): cup leaf, red stem, double bloom (CRD): flat leaf, green stem, triple bloom (FGT): flat leaf, green stem,

Table 4.7 Expression of internode nature (Condensed vs. Elongated) in F_1, F_2 and back cross generations in two different crosses of castor

Cross	F_1 phenotype	Generation	Segregation			Expected ratio	χ^2 value	P-range
			Elongated	Condensed	Total			
Condensed x Elongated								
VP-1 x DCS-9	Elongated	F_2	215	73	288	3:1	0.02	0.95 - 0.90
		B_1 (F_1 x VP-1)	94	78	172	1:1	1.49	0.25 - 0.10
		B_2 (F_1 x DCS-9)	152	-	152	-	-	-
VP-1 x 48-1	Elongated	F_2	204	64	268	3:1	0.18	0.75 - 0.50
		B_1 (F_1 x VP-1)	109	90	199	1:1	1.81	0.25 - 0.10
		B_2 (F_1 x 48-1)	159	-	159	-	-	-

Table 4.8 Joint segregation for stem colour, leaf shape and bloom nature in F_2 and backcross generations of two crosses in castor

Cross	F_1 phenotype	Generation	Number of plants								χ^2 value	P-range
			Red, Flat, Triple	Red, Flat, Double	Red, Cup, Triple	Red, Cup, Double	Green, Flat, Triple	Green, Flat, Double	Green, Cup, Triple	Green, Cup, Double		
Green, Cup, Triple x Red, Flat, Double												
VP-1 x DCS-9	Red, Flat, Triple	F_2	(O) 113	39	36	16	44	19	13	8	6.90	0.50 - 0.25
			(E) 121.5	40.5	40.5	13.5	40.5	13.5	13.5	4.5		
			Ratio 27:	9:	9:	3:	9:	3:	3:	1		
		B_1 (F_1 x VP-1)	(O) 49	-	36	-	45	-	42	-	2.09	0.75 - 0.50
			(E) 43	-	43	-	43	-	43	-		
			Ratio 1:		1:		1:		1			
		B_2 (F_1 x DCS-9)	(O) 74	78	-	-	-	-	-	-	0.11	0.75 - 0.50
			(E) 76	76	-	-	-	-	-	-		
			Ratio 1:	1								
VP-1 x 48-1	Red, Flat, Triple	F_2	(O) 106	39	34	14	45	14	13	3	2.95	0.90 - 0.75
			(E) 113.0625	37.6875	37.6875	12.5625	37.6875	12.5625	12.5625	4.1875		
			Ratio 27:	9:	9:	3:	9:	3:	3:	1		
		B_1 (F_1 x VP-1)	(O) 62	-	38	-	47	-	52	-	6.05	0.25 – 0.10
			(E) 49.75	-	49.75	-	49.75	-	49.75	-		
			Ratio 1:		1:		1:		1			
		B_2 (F_1 x 48-1)	(O) 75	84	-	-	-	-	-	-	0.51	0.50 – 0.25
			(E) 79.5	79.5	-	-	-	-	-	-		
			Ratio 1:	1								

O = Observed frequency; E = Expected frequency

57

double bloom (FGD) : cup leaf, green stem, triple bloom (CGT): cup leaf, green stem, double bloom (CGD), respectively (Plate 16 and 17). Further, the backcross populations of (VP-1 x DCS-9) x VP-1 and (VP-1 x 48-1) x VP-1 showed a good fit to 1 FRT : 1 CRT : 1 FGT : 1 CGT ratio. However, the backcross progeny of (VP-1 x DCS-9) x DCS-9 and (VP-1 x 48-1) x 48-1 gave the plants segregated at 1 FRT : 1 FRD ratio.

4.1.2.2 Leaf shape and bloom nature

Two more crosses viz., VP-1 x Co-1 and LRES-17 x Co-1 were studied for joint segregation of leaf shape and bloom nature and results are furnished in Table 4.9. The perusal of results showed that F_1 hybrids of both the crosses had flat leaves and partial triple bloom (double bloom with slight bloom on upper surface of leaf). The F_2 progeny of both the crosses segregated at a ratio of 3 flat, triple : 6 flat, partial triple : 3 flat, zero bloom : 1 cup, triple : 2 cup, partial triple : 1 cup, zero bloom (Plate 18). The backcross of F_1s to respective cup leaf, triple bloom parent resulted the progeny segregated for leaf shape and bloom with a good fit to 1:1:1:1 ratio of flat, triple : flat, partial triple : crop, triple : crop, partial triple. Further, backcross progeny involving Co-1 parent (flat, zero bloom) gave a segregation of 1 flat, partial triple : 1 flat zero bloom.

4.1.2.3 Stem colour, bloom nature and spininess of capsule

A cross, DPC-9 x 48-1 was attempted to study the joint segregation of stem colour, bloom nature and spininess of capsule. The F_1 hybrid of the cross had a phenotype with red stem, partial double bloom (single bloom

Plate16A: A recombinant in F_2 generation of cross, VP-1 x DCS-9 showing flat leaf, elongated internode, red stem and triple bloom

Plate 16B: A recombinant in F_2 generation of cross, VP-1 x DCS-9 showing flat leaf, elongated internode, green stem and double bloom

Plate 17A: A recombinant in F_2 generation of cross, VP-1 x 48-1 showing green stem, triple bloom and non spiny capsules

Plate 17B: A recombinant in F_2 generation of cross, VP-1 x 48-1 showing red stem, double bloom and spiny capsules


16A


16B


17A


17B

Plate 18 : A recombinant in F_2 generation of cross, VP-1 x Co-1 showing cup leaf, condensed internode and zero bloom

Plate 19A: A recombinant in F_2 generation of cross, DPC-9 x 48-1 showing red stem, zero bloom and spiny capsule

Plate 19B: A recombinant in F_2 generation of cross, DPC-9 x 48-1 showing red stem, zero bloom and non spiny capsule

Plate 19C: A recombinant in F_2 generation of cross, DPC-9 x 48-1 showing red stem, double bloom and spiny capsule

18

19A

19B

19C

Table 4.9 Joint segregation for leaf shape and bloom nature in F_2 and backcross generations of two crosses in castor

Character	F_1 phenotype	Generation	Number of plants						χ^2 value	P-range
			Flat, Triple	Flat, Partial triple	Flat, Zero	Cup, Triple	Cup, Partial triple	Cup, Zero		
Cup, Triple x Flat, Zero										
VP-1 x Co-1	Flat, Partial triple	F_2	(O) 52	98	42	16	28	20	2.63	0.90 - 0.75
			(E) 48	96	48	16	32	16		
			Ratio 3:	6:	3:	1:	2:	1		
		B_1 (F_1 x VP-1)	(O) 47	44	-	44	52	-	0.91	0.90 - 0.75
			(E) 46.75	46.75	-	46.75	46.75	-		
			Ratio 1:	1:		1:	1			
		B_2 (F_1 x Co-1)	(O) -	54	59	-	-	-	0.22	0.75 – 0.50
			(E) -	56.5	56.5	-	-	-		
			Ratio	1:	1					
LRES-17 x Co-1	Flat, Partial triple	F_2	(O) 44	101	48	18	23	11	4.67	0.50 - 0.25
			(E) 45.9375	91.875	45.9375	15.3125	30.625	15.3125		
			Ratio 3:	6:	3:	1:	2:	1		
		B_1 (F_1 x LRES-17)	(O) 42	35	-	42	30	-	2.76	0.50 - 0.25
			(E) 37.25	37.25	-	37.25	37.25	-		
			Ratio 1:	1:		1:	1			
		B_2 (F_1 x Co-1)	(O) -	64	49	-	-	-	1.31	0.50 – 0.25
			(E) -	56.5	56.5	-	-	-		
			Ratio	1:	1					

O = Observed frequency; E = Expected frequency

61

with slight bloom on lower surface of leaf) and partial spiny capsules. The F_2 progeny of the cross was segregated at a product ratio of (1 spiny : 2 partial spiny : 1 nonspiny) (1 double bloom : 2 partial double : 1 zero bloom) (3 red: 1 green) i.e., 3 : 6 : 3 : 6 : 12 : 6 : 3 : 6 : 3 : 1 : 2 : 1 : 2 : 4 : 2 : 1 : 2 : 1 as shown in Table 4.10 (Plate 19). The back cross of F_1 with DPC-9 parent resulted a progeny segregated with a good fit to 1:1:1:1:1:1:1:1 ratio of red, partial double bloom, spiny : red, partial double bloom, partial spiny : red, zero bloom, spiny : red, zero bloom, partial spiny : green, partial double bloom, spiny : green, partial double bloom, partial spiny: green, zero bloom, spiny : green, zero bloom, partial spiny, respectively. Further, backcross progeny involving 48-1 as recurrent parent, had a segregation with a ratio of 1 red, double bloom, partial spiny : 1 red, double bloom, non spiny : 1 red, partial double bloom, partial spiny : 1 red, partial double bloom, non spiny.

4.1.2.4 Stem colour and spininess of capsule

Three crosses, namely VP-1 x 48-1, Geeta x DCS-27 and Geeta x SH-72 were made to study the joint segregation of stem colour and spininess of capsule and results are presented in Table 4.11. The F_1 plants of all the crosses had red stem and partial spiny capsules. The F_2 population of the crosses segregated at a ratio of 3 red , spiny : 6 red, partial spiny : 3 red, non spiny : 1 green, spiny : 2 green, partial spiny : 1 green, nonspiny. The backcross progenies involving parent with spiny capsules and green stem (VP-1, DCS-27 and SH-72) had the segregation with a good fit to 1:1:1:1 ratio of red, spiny; red, partial spiny : green, spiny : green, partial spiny.

Table 4.10 Joint segregation for stem colour, bloom nature and spininess of capsule in F_2 and back cross generations of a cross in castor

Character	Number of plants								
	F_2			B_1 (F_1 x DPC-9)			B_2 (F_1 x 48-1)		
	Observed	Expected	Ratio	Observed	Expected	Ratio	Observed	Expected	Ratio
Green, Zero, Spiny x Red, Double, Non Spiny Cross DPC-9 x 48-1 F_1 phenotype: Red, Partial double, Partial spiny									
Red, Double, Spiny	12	12.5625	3	-	-		-	-	
Red, Double, Partial Spiny	26	25.125	6	-	-		29	29	1
Red, Double, Non Spiny	10	12.5625	3	-	-		28	29	1
Red, Partial double, Spiny	29	25.125	6	16	15.5	1	-	-	
Red, Partial double, Partial Spiny	57	50.25	12	17	15.5	1	32	29	1
Red, Partial double, Non Spiny	26	25.125	6	-	-		27	29	1
Red, Zero, Spiny	15	12.5625	3	15	15.5	1	-	-	
Red, Zero, Partial Spiny	28	25.125	6	16	15.5	1	-	-	
Red, Zero, Non Spiny	13	12.5625	3	-	-		-	-	
Green, Double, Spiny	3	4.1875	1	-	-		-	-	
Green, Double, Partial Spiny	9	8.375	2	-	-		-	-	
Green, Double, Non Spiny	4	4.1875	1	-	-		-	-	
Green, Partial double, Spiny	6	8.375	2	16	15.5	1	-	-	
Green, Partial double, Partial Spiny	12	16.75	4	12	15.5	1	-	-	
Green, Partial double, Non Spiny	8	18.375	2	-	-		-	-	
Green, Zero, Spiny	3	4.1875	1	16	15.5	1	-	-	
Green, Zero, Partial Spiny	5	8.375	2	16	15.5	1	-	-	
Green, Zero, Non Spiny	2	4.1875	1	-	-		-	-	
χ^2 value	8.2			1.03			0.48		
P- range	0.99 - 0.975			0.995 - 0.99			0.95 - 0.90		

Table 4.11 Joint segregation for stem colour and spininess of the capsule in F_2 and backcross generations of three crosses in castor

Character	F_1 phenotype	Generation	Number of plants						χ^2 value	P-range
			Red, Spiny	Red, Partial Spiny	Red, Non Spiny	Green, Spiny	Green, Partial Spiny	Green, Non Spiny		
Green, Spiny x Red, Non Spiny										
VP-1 x 48-1	Red, Partial Spiny	F_2	(O) 43	108	42	18	36	21	4.32	0.75 – 0.50
			(E) 50.25	100.5	50.25	16.75	33.5	16.75		
			Ratio 3:	6:	3:	1:	2:	1		
		B_1 (F_1 x VP-1)	(O) 46	54	-	49	50	-	0.66	0.90 – 0.75
			(E) 49.75	49.75	-	49.75	49.75	-		
			Ratio 1:	1:		1:	1			
		B_2 (F_1 x 48-1)	(O) -	78	81	-	-	-	0.06	0.90 – 0.75
			(E) -	79.5	79.5	-	-	-		
			Ratio	1:	1					
Red, Non Spiny x Green, Spiny										
Geeta x DCS-27	Red, Partial Spiny	F_2	(O) 40	91	38	11	23	10	3.36	0.75 – 0.50
			(E) 39.9375	79.875	39.9375	13.3125	26.625	13.3125		
			Ratio 3:	6:	3:	1:	2:	1		
		B_1 (F_1 x Geeta)	(O) -	81	85	-	-	-	0.10	0.90 – 0.75
			(E) -	83	83	-	-	-		
			Ratio	1:	1					
		B_2 (F_1 x DCS-27)	(O) - 56	47	-	54	58	-	1.28	0.75 – 0.50
			(E) - 53.75	53.75	-	53.75	53.75	-		
			Ratio 1:	1:		1:	1			
Geeta x SH-72	Red, Partial spiny	F_2	(O) 48	99	55	18	43	20	2.98	0.75 – 0.50
			(E) 53.0625	106.125	53.0625	17.6875	35.375	17.6875		
			Ratio 3:	6:	3:	1:	2:	1		
		B_1 (F_1 x Geeta)	(O) -	81	72	-	-	-	0.26	0.75 – 0.50
			(E) -	76.5	76.5	-	-	-		
			Ratio	1:	1					
		B_2 (F_1 x SH-72)	(O) - 58	66	-	63	65	-	0.60	0.90 – 0.75
			(E) - 63	63	-	63	63	-		
			Ratio 1:	1:		1:	1			

O = Observed frequency; E = Expected frequency

63

64

Further, the backcross of F_1s with respective parent of red, nonspiny characters (48-1 and Geeta) resulted the progenies segregated at a ratio of 1 red, partial spiny : 1 red, nonspiny.

4.1.2.5 Bloom and spininess of capsule

A cross, VP-1 x 48-1 was studied to know the joint segregation of bloom nature and spininess of capsule. The F_1 plants were triple bloom with partial spiny capsules, whereas the F_2 progeny segregated at a phenotypic ratio of 3 triple, spiny; 6 triple, partial spiny : 3 triple, non spiny : 1 double, spiny : 2 double, partial spiny : 1 double, nonspiny (Table 4.12). The backcross of F_1 to VP-1 parent resulted a segregated progeny with a good fit to 1 triple, spiny : 1 triple, partial spiny. Further, back cross progeny involving parent 48-1, had a segregation of 1:1:1:1 of triple, partial spiny : triple, non spiny : double, partial spiny : double, nonspiny.

4.1.2.6 Leaf shape and spininess of capsule

The cross, VP-1 x 48-1 was studied to know the mode of joint segregation of leaf shape and spininess of capsule. The F_1 hybrid had flat leaves with partial spiny capsules. However, the F_2 progeny was not segregated at a ratio of 3 flat, spiny : 6 flat, partial spiny: 3 flat, nonspiny: 1 cup, spiny: 2 cup, partial spiny : 1 cup, nonspiny (Table 4.13). However, backcross progeny involving VP-1 as recurrent parent had not segregated at an expected ratio of 1 flat, spiny : 1 flat, partial spiny : 1 cup, spiny : 1 cup, partial spiny. The back cross progeny involving 48-1 parent, had a segregation with a good fit to 1 flat, partial spiny : 1 flat, nonspiny ratio.

Table 4.12 Joint segregation for bloom nature and spininess of the capsule in F_2 and backcross generations of a cross in castor

Cross	F_1 phenotype	Generation	Number of plants						χ^2 value	P-range
			Triple, Spiny	Triple, Partial Spiny	Triple, Non Spiny	Double, Spiny	Double, Partial Spiny	Double, Non Spiny		
Triple, Spiny x Double, Non Spiny VP-1 x 48-1	Triple, Partial Spiny	F_2	(O) 47	106	38	14	45	18	7.99	0.25 – 0.10
			(E) 50.25	100.5	50.25	16.75	33.5	16.75		
			Ratio 3:	6:	3:	1:	2:	1		
		B_1 (F_1 x VP-1)	(O) 95	104					0.41	0.75 – 0.50
			(E) 99.5	99.5						
			Ratio 1:	1						
		B_2 (F_1 x 48-1)	(O) -	37	38	-	41	43	0.57	0.95 – 0.90
			(E) -	39.75	39.75	-	39.75	39.75		
			Ratio	1:	1:		1:	1		

O = Observed frequency; E = Expected frequency

Table 4.13 Joint segregation for leaf shape and spininess of capsule in F_2 and backcross generations of a cross in castor

Cross	F_1 phenotype	Generation	Number of plants						χ^2 value	P-range	RF (%)
			Flat, Spiny	Flat, Partial Spiny	Flat, Non Spiny	Cup, Spiny	Cup, Partial Spiny	Cup, Non Spiny			
Cup, Spiny x Flat, Non Spiny											
VP-1 x 48-1	Flat, Partial Spiny	F_2	(O) 21	123	60	40	21	3	72.18	Significant	25.4
			(E) 50.25	100.5	50.25	16.75	33.5	16.75			
			Ratio 3:	6:	3:	1:	2:	1			
		B_1 (F_1 x VP-1)	(O) 23	86	-	72	18	-	71.01	Significant	25.1
			(E) 49.75	49.75	-	49.75	49.75	-			
			Ratio 1:	1:		1:	1				
		B_2 (F_1 x 48-1)	(O) -	78	81	-	-	-	0.06	0.90 – 0.75	
			(E) -	79.5	79.5	-	-	-			
			Ratio	1:	1						

O = Observed frequency; E = Expected frequency; RF = Recombination frequency

Table 4.14 Joint segregation for leaf shape and internode nature in F_2 and back cross generations of two crosses in castor

Cross	F_1 phenotype	Generation	Number of plants				χ^2 value	P-range	RF (%)
			Flat, Elongated	Flat, Condensed	Cup, Elongated	Cup, Condensed			
Cup, Condensed x Flat, Elongated									
VP-1 x DCS-9	Flat, Elongated	F_2	(O) 215	-	-	73	-	Significant	0
			(E) 162	54	54	18			
			Ratio 9:	3:	3:	1			
		B_1 (F_1 x VP-1)	(O) 94	-	-	78	-	Significant	0
			(E) 43	43	43	43			
			Ratio 1:	1:	1:	1			
		B_2 (F_1 x DCS-9)	(O) 152	-	-	-			
			(E) 152	-	-	-			
			Ratio						
VP-1 x 48-1	Flat, Elongated	F_2	(O) 204	-	-	64	-	Significant	0
			(E) 162	54	54	18			
			Ratio 9:	3:	3:	1			
		B_1 (F_1 x VP-1)	(O) 109	-	-	90	-	Significant	0
			(E) 49.75	49.75	49.75	49.75			
			Ratio 1:	1:	1:	1			
		B_2 (F_1 x 48-1)	(O) 159	-	-	-			
			(E) 159	-	-	-			
			Ratio -						

O = Observed frequency; E = Expected frequency

Further, in B_1 generation, the frequency of plants with flat leave, partial spiny and cup leave, spiny capsules were very high when compared to plants having flat leave, spiny and cup leave, non spiny capsules.

4.1.2.7 Leaf shape and internode nature

Two crosses, namely, VP-1 x DCS-9 and VP-1 x 48-1 were studied to know the inheritance pattern of leaf shape and internode nature together. The F_1 individuals of both the crosses had flat leaves with elongated internodes (Table 4.14). The F_2 progeny of two crosses segregated at 3 flat, elongated : 1 cup, condensed ratio, instead of 9 flat, elongated : 3 flat, condensed : 3 cup, elongated : 1 cup, condensed ratio. Further, backcross progeny involving, VP-1 as recurrent parent had not segregated at a ratio of 1 flat, elongated : 1 flat, condensed : 1 cup, elongated : 1 cup, condensed, however, it was segregated with a good fit to 1:1 of flat, elongated : cup, condensed ratio.

4.2 INHERITANCE OF FUSARIUM WILT RESISTANCE

The cross, VP-1 x 48-1 was attempted to study the mode of inheritance of fusarium wilt. The parent, VP-1 is susceptible, while 48-1 is resistant to wilt. The F_1, F_2 and backcross generations of the cross were evaluated under epiphytotic conditions by growing in sick plots and recorded the disease reaction. The results are presented in Table 4.15.

The F_1 individuals of the cross showed susceptible reaction, while the F_2 population gave a segregation of 266 susceptible and 194 resistant plants. The F_2 ratio confirms with the expected ratio of 9:7. Further, the backcross of F_1 plants with susceptible parent (VP-1) did not segregate and gave all the

Table 4.15 Reaction of F_1, F_2 and back cross generations of a cross to fusarium wilt in castor

Cross	F_1 phenotype	Generation	Segregation			Expected ratio	χ^2 value	P-range
			Susceptible	Resistant	Total			
Susceptible x Resistant								
VP-1 x 48-1	Susceptible	F_2	266	194	460	9:7	0.46	0.50 – 0.25
		B_1 (F_1 x VP-1)	232	-	232	-	-	-
		B_2 (F_1 x 48-1)	53	187	240	1:3	1.09	0.50 – 0.25

plants with susceptible reaction, while backcross progeny of F_1 plants with resistant parent, 48-1 segregated with a good fit to 1 susceptible : 3 resistant plants.

4.3 COMBINING ABILITY STUDIES

4.3.1 Analysis of variance

The results of analysis of variance for ten characters are furnished in Table 4.16. The analysis of variance showed significant differences among the treatments (parents, crosses and checks) for all the characters viz., days to 50 per cent flowering, days to maturity, number of nodes, plant height, primary spike length, effective spike length, number of capsules per primary spike, 100-seed weight, seed yield per plant and oil content. Further analysis of variance for combining ability (Table 4.17) revealed significant differences within parents, crosses, parent vs. cross, lines and line x tester for all the characters studied. However, significant differences were also observed within the testers for all the traits barring oil content.

4.3.2 Mean performance of parents and hybrids

The mean values of parents and crosses for ten characters are furnished in Table 4.18.

4.3.2.1 Days to 50 per cent flowering

The mean values for days to 50 per cent flowering of lines, testers and crosses were recorded as 61.26, 61.08 and 51.14 days, respectively while,

Table 4.16 Analysis of variance (mean squares) for yield and yield component characters in castor

SOURCE	Degrees of freedom	Days to 50% flowering	Days to maturity	Number of nodes	Plant height(cm)	Primary spike length (cm)	Effective spike length (cm)	No. of capsules per primary spike	100 seed weight (g)	Seed yield per plant (g)	Oil content (%)
REPLICATIONS	2	7.78	0.56	0.30	9.02	49.92*	77.37**	5.23	1.98	149.00	0.56
TREATMENTS	50	290.83**	273.90**	15.01**	631.81**	337.29**	229.56**	301.97**	197.77**	9458.70**	18.81**
ERROR	100	8.60	7.71	0.45	15.11	15.05	12.18	21.10	1.15	121.09	0.37
TOTAL	152	101.43	95.18	5.24	217.89	121.51	84.54	113.28	65.85	3193.04	6.44

*, ** Significant at 5% and 1% level, respectively

Table 4.17 Analysis of variance for combining ability of yield and yield component characters in castor

SOURCE	Degrees of freedom	Days to 50% flowering	Days to maturity	Number of nodes	Plant height (cm)	Primary spike length (cm)	Effective spike length (cm)	No. of capsules per primary spike	100-seed weight (g)	Seed yield per plant (g)	Oil content (%)
REPLICATION	2	10.13	0.50	0.25	8.16	49.14*	85.23**	6.84	2.18	104.00	0.44
TREATMENT	48	298.42**	280.12**	15.41**	654.59**	338.74**	237.95**	305.64**	202.93**	9520.83**	18.76**
PARENTS	12	453.47**	455.82**	25.26**	1511.20**	628.57**	480.10**	474.85**	583.88**	5066.20**	19.07**
CROSSES	35	170.83**	154.06**	10.79**	342.33**	245.79**	155.43**	239.37**	78.18**	7908.63**	19.06**
PARENTS vs CROSSES	1	2903.38**	2583.75**	58.77**	1304.19**	114.02**	220.49**	594.90**	9.81**	119403.63**	4.57*
LINES	8	557.36**	403.34**	27.10**	625.74**	391.01**	264.84**	605.82**	254.27**	17902.25**	33.38*
TESTERS	3	218.71**	468.71**	27.21**	1515.09**	886.89**	580.17**	540.99**	143.15**	14850.33**	31.84
LINES X TESTERS	24	36.00**	31.63**	3.31**	101.26**	117.25**	65.87**	79.51**	11.36**	3709.71**	12.69**
ERROR	96	8.82	7.89	0.47	15.73	15.67	11.95	21.84	1.18	121.80	0.38
TOTAL	146	104.05	97.29	5.38	225.66	122.35	87.25	114.94	67.52	3211.65	6.42

*, ** Significant at 5% and 1% level, respectively

72

Table18 Mean performance of parents, crosses and checks for ten characters in castor

	Days to 50% flowering	Days to maturity	Number of nodes	Plant height (cm)	Primary spike length (cm)	Effective spike length (cm)	No. of capsules per primary spike	100-seed weight (g)	Seed yield per plant (g)	Oil Content (%)
Lines										
DCS-5	51.00	106.33	10.73	33.93	27.57	24.33	30.13	22.34	200.53	45.29
DCS-9	45.33	101.00	8.80	36.47	30.93	29.93	34.47	28.57	244.61	46.77
DCS-27	64.67	114.00	11.67	40.87	30.33	28.33	41.00	18.90	157.66	45.22
DCS-84	51.67	115.67	10.47	40.20	41.13	37.60	38.37	29.55	192.23	44.41
DCS-85	51.00	109.00	11.33	39.93	35.07	32.47	27.87	30.85	183.58	49.45
SH-72	71.67	128.00	17.27	83.47	59.13	48.73	65.33	31.85	248.06	46.09
48-1	58.67	121.00	14.87	79.40	50.47	41.93	45.73	28.32	232.63	48.07
AVR-1	63.67	125.00	14.30	56.00	57.07	45.13	46.33	46.82	218.67	49.88
Co-1	93.67	149.67	18.60	75.07	16.13	10.60	20.60	74.42	163.97	48.19
Mean of lines	**61.26**	**118.85**	**13.11**	**53.93**	**38.65**	**33.23**	**38.87**	**34.63**	**204.66**	**47.04**
Testers										
VP-1	65.33	127.33	15.40	35.53	61.47	54.73	49.53	28.83	205.65	51.30
DPC-9	61.33	124.33	12.93	67.00	52.47	44.27	54.53	31.71	276.05	52.27
LRES-17	54.00	114.33	11.53	23.93	54.33	48.27	41.07	28.34	192.26	50.84
GEETA	63.67	125.00	15.47	91.40	53.87	51.73	57.53	29.40	292.76	48.87
Mean of testers	**61.08**	**122.75**	**13.83**	**54.47**	**55.53**	**49.75**	**50.67**	**29.57**	**241.68**	**50.82**
Crosses										
VP-1 X DCS-5	46.00	106.00	10.83	44.13	51.47	50.07	56.73	31.83	355.20	50.13
VP-1 X DCS-9	44.33	102.67	10.20	44.80	45.07	43.87	43.07	33.49	312.53	50.43
VP-1 X DCS-27	48.33	110.67	11.93	57.63	63.53	60.33	70.20	26.11	353.84	44.28
VP-1 X DCS-84	47.00	106.33	10.93	43.80	49.07	46.20	41.37	30.10	306.90	44.50
VP-1 X DCS-85	44.67	107.00	10.00	39.73	46.47	42.53	40.20	33.40	294.73	46.39
VP-1 X SH-72	57.67	112.33	15.17	66.73	71.20	55.33	54.67	33.02	337.80	46.37
VP-1 X 48-1	52.00	112.33	14.60	49.60	54.47	47.67	51.07	31.81	325.14	44.70
VP-1 X AVR-1	53.67	114.67	13.23	44.53	63.73	46.73	39.47	35.10	301.15	49.48
VP-1 X Co-1	69.00	122.67	16.67	54.53	44.27	35.47	52.20	37.90	195.16	47.79
DPC 9 X DCS-5	44.33	102.67	9.47	33.07	39.33	37.67	40.07	35.87	280.05	50.72
DPC 9 X DCS-9	44.67	106.33	10.20	42.73	45.53	42.00	53.27	37.91	337.53	46.98
DPC 9 X DCS-27	51.67	113.33	12.60	54.27	50.07	47.20	69.60	29.63	353.56	47.94
DPC 9 X DCS-84	48.00	113.00	11.00	46.73	49.87	45.33	51.33	37.58	290.81	50.90
DPC 9 X DCS-85	50.00	112.33	10.53	35.87	38.60	35.07	47.27	32.87	251.33	52.64
DPC 9 X SH-72	52.33	114.33	11.07	56.33	43.27	39.80	59.53	35.36	332.11	47.31
DPC 9 X 48-1	50.67	111.00	9.93	52.13	43.40	37.40	47.93	32.69	228.20	50.01
DPC 9 X AVR-1	51.33	110.33	11.73	38.00	39.27	35.47	43.47	40.77	282.25	46.30
DPC 9 X Co-1	63.00	119.00	14.60	44.00	37.47	34.53	50.40	50.22	255.04	46.32
LRES-17 X DCS-5	47.33	105.33	11.07	35.20	44.53	38.93	39.20	29.95	274.03	48.73
LRES-17 X DCS-9	44.00	100.33	9.20	33.20	33.87	32.00	35.40	31.62	215.57	52.08
LRES-17 X DCS-27	47.67	104.33	11.40	39.00	44.13	40.47	49.73	22.90	311.96	46.27
LRES-17 X DCS-84	45.33	101.67	10.50	37.40	35.87	33.87	40.00	29.96	224.88	47.49

Table 18 contd..

	Days to 50% flowering	Days to maturity	Number of nodes	Plant height (cm)	Primary spike length (cm)	Effective spike length (cm)	No. of capsules per primary spike	100-seed weight (g)	Seed yield per plant (g)	Oil content (%)
LRES-17 X DCS-85	44.67	101.00	9.87	35.00	32.00	30.47	36.60	28.84	191.38	50.95
LRES-17 X SH-72	47.67	107.00	11.73	47.87	55.47	48.53	53.53	31.66	360.46	49.47
LRES-17 X 48-1	46.33	104.00	10.80	41.27	48.73	39.60	43.87	32.85	259.56	51.79
LRES-17 X AVR-1	46.67	102.33	9.67	40.27	45.40	33.73	32.33	38.41	303.79	51.08
LRES-17 X Co-1	60.33	120.00	13.53	38.93	38.87	32.67	43.53	40.01	183.71	49.73
GEETA X DCS-5	45.00	105.67	10.93	41.40	38.93	37.33	47.43	29.08	242.82	50.56
GEETA X DCS-9	48.00	111.67	12.73	46.47	47.93	45.47	41.07	33.82	256.43	51.49
GEETA X DCS-27	53.00	116.33	12.47	48.87	36.47	36.00	49.13	25.42	262.95	44.12
GEETA X DCS-84	45.00	108.67	11.67	51.93	46.53	42.80	38.27	32.32	273.27	45.56
GEETA X DCS-85	45.00	108.00	11.13	43.73	41.60	39.20	41.53	32.18	250.04	53.04
GEETA X SH-72	65.00	119.33	14.93	71.27	64.53	56.80	61.33	33.58	347.86	48.68
GEETA X 48-1	55.67	114.67	13.40	67.80	38.27	35.60	39.20	33.06	317.90	48.36
GEETA X AVR-1	62.67	118.67	13.60	68.93	42.13	37.67	40.10	38.89	226.22	50.48
GEETA X Co-1	73.00	134.00	15.20	67.27	38.87	35.33	49.93	42.17	205.64	46.61
Mean of crosses	**51.14**	**110.56**	**11.90**	**47.35**	**45.84**	**41.09**	**47.06**	**33.68**	**280.60**	**48.60**
Grand mean	**53.81**	**113.07**	**12.28**	**49.14**	**45.31**	**40.35**	**45.85**	**33.52**	**263.48**	**48.50**
Checks										
Kranti	47.67	106.67	10.60	43.80	31.07	36.00	36.60	28.08	234.98	45.30
DCH-177	44.67	106.33	10.20	42.73	45.53	42.00	53.27	37.91	337.53	46.98
SE±	2.40	2.27	0.55	3.17	3.17	2.85	3.75	0.87	8.98	0.50
CD (0.05)	4.69	4.44	1.07	6.22	6.21	5.58	7.35	1.71	17.61	0.98
CD (0.01)	6.17	5.84	1.41	8.18	8.16	7.34	9.66	2.25	23.14	1.28

checks kranti and DCH-177 recorded 47.67 and 44.67 days, respectively. The mean values for crosses ranged from 44 days (LRES-17 x DCS-9) to 73 days (Geeta x Co-1). In general, crosses involving LRES-17 tester came to flowering early, while the crosses involving the line, Co-1 were found to be very late flowering.

4.3.2.2 Days to maturity

The mean values for days to maturity were 118.85, 122.75 and 110.56 days for lines, testers and crosses, respectively. The mean values of crosses ranged from 100.33 days (LRES-17 x DCS-9) to 134 days (Geeta x Co-1). Among the checks, kranti recorded 106.67 days to maturity, whereas DCH-177 recorded 106.33 days. Further, it was observed that the crosses of LRES-17 were early maturing, whereas the crosses of Co-1 were late maturing.

4.3.2.3 Number of nodes

The mean values for number of nodes of lines, testers and crosses were recorded as 13.11, 13.83 and 12.28, respectively while, for the checks, the values were 10.60 and 10.20 for kranti and DCH-177, respectively. The mean values of crosses were in the range of 9.2 (LRES-17 x DCS-9) to 16.67 (VP-1 x Co-1). In general, crosses involving LRES-17 tester were with less number of nodes, whereas crosses with Co-1 line had more number of nodes.

4.3.2.4 Plant height (cm)

The mean plant heights were 53.93 cm, 54.47 cm and 47.35 cm for lines, testers and crosses, respectively. The mean values of crosses ranged from 33.07 cm (DPC-9 x DCS-5) to 71.27 cm (Geeta x SH-72). The crosses involving LRES-17 tester were dwarf, whereas crosses involving SH-72 line had more plant height. Among the checks, kranti recorded 43.80 cm, while DCH-177 had 42.73 cm plant height.

4.3.2.5 Primary spike length (cm)

The mean lengths of primary spikes were recorded as 38.65 cm, 55.53 cm and 45.84 cm for lines, testers and crosses, respectively. Among the lines, SH-72 (59.13 cm) and among the testers, VP-1 (61.47 cm) recorded maximum primary spike lengths. However, the primary spike lengths of crosses were in the range of 32.0 cm (LRES-17 x DCS-85) to 71.2 cm (VP-1 x SH-72). Further, primary spike lengths of checks were 31.07 cm for kranti and 45.53 cm for DCH-177.

4.3.2.6 Effective spike length (cm)

The testers recorded greater average effective spike length (49.75 cm) in comparison to the lines (33.23 cm) and crosses (41.09 cm). Further, the line, SH-72 (48.73 cm) and the tester, VP-1 (54.73 cm) recorded maximum effective spike lengths. However, among the crosses, it was in the range of

30.47 cm (LRES-17 x DCS-85) to 60.33 cm (VP-1 x DCS-27). For standard checks, the effective spike length was 36.07 cm in kranti and 42.00 cm in DCH-177.

4.3.2.7 Number of capsules per primary spike

The higher mean number of capsules per primary spike was observed in testers (50.67) compared to lines (38.87) and crosses (47.06). The line, SH-72 and the tester, Geeta (57.53) had maximum number of capsules per primary spike. Further, among the crosses, it was in the range of 32.33 (LRES-17 x AVR-1) to 70.2 (VP-1 x DCS-27). In kranti, the mean number of capsules per primary spike was 36.60, whereas in DCH-177, it was 53.27.

4.3.2.8 100-seed weight (g)

The average 100-seed weights were 34.63 g, 29.57 g and 33.68 g for lines, testers and crosses, respectively while the values were 28.08 g and 37.91 g for kranti and DCH-177, respectively. Among the crosses, the values were in the range of 22.90 g (LRES-17 x DCS-27) to 50.22 g (DPC-9 x Co-1) for the trait. In general, the crosses involving the line, DCS-27 were with lower values of 100-seed weight, while crosses with Co-1 line had higher values of 100-seed weight.

4.3.2.9 Seed yield per plant (g)

The crosses recorded greater mean seed yield per plant (280.6 g), when compared to lines (204.66 g) and testers (241.68 g). Further, the parents,

SII-72 (248.06 g) and Geeta (292.76 g) recorded maximum values of mean seed yield per plant among lines and testers, respectively. However, the values were ranged from 183.71 g (LRES-17 x Co-1) to 360.46 g (LRES-17 x SII-72) among the crosses for the trait. The checks, kranti and DCH-177 recorded mean seed yield of 234.98 g and 337.53 g, respectively.

4.3.2.10 Oil content (%)

The testers recorded higher average oil content (50.82 %) in comparison to the lines (47.04 %) and crosses (48.60 %). Further, the line, AVR-1 (49.88 %) and the tester, DPC-9 (52.27 %) recorded maximum oil content. However, among the crosses oil content ranged from 44.12 per cent (Geeta x DCS-27) to 53.04 per cent (Geeta x DCS-85). In kranti, the oil content was recorded as 45.30 per cent, whereas in DCH-177 it was 48.50 per cent. In general, the crosses involving DCS-27 line exhibited low values of oil content.

4.3.3 Variances and Degree of dominance

The components of gca and sca variance and degree of dominance are presented in Table 4.19. The perusal of results revealed that the variances due to gca were higher in magnitude when compared to variances due to sca for all the traits studied except primary spike length, seed yield per plant and oil content. Further, the degree of dominance values were near to one for primary spike length, seed yield per plant and oil content, while for rest of the traits it was far less than one.

Table 19 Variance components of gca, sca and degree of dominance for ten characters in Castor

Character	Gca variance (σ^2_{gca})	Sca variance (σ^2_{sca})	$\sigma^2_{gca}/\sigma^2_{sca}$	Degree of dominance	Predictability ratio
1. Days to 50% flowering	18.05	9.07	1.99	0.50	0.80
2. Days to maturity	20.74	7.91	2.62	0.44	0.84
3. Number of nodes	1.22	0.95	1.28	0.62	0.72
4. Plant height	49.70	28.51	1.74	0.53	0.78
5. Primary spike length	26.75	33.88	0.79	0.80	0.61
6. Effective spike length	19.98	10.65	1.88	0.52	0.79
7. Number of capsules per primary spike	25.33	19.21	1.32	0.62	0.73
8. 100-seed weight	9.61	3.38	2.84	0.42	0.85
9. Seed yield per plant	649.57	1195.96	0.54	0.96	0.52
10. Oil content	1.02	4.11	0.25	1.42	0.33

4.3.4 Combining ability analysis

The general combining ability effects (gca) of lines and testers and specific combining ability effects (sca) of crosses for different characters are presented in Table 4.20 and 4.21 respectively.

4.3.4.1 Days to 50 per cent flowering

The gca effects of the lines ranged from -5.89 (DCS-9) to 15.19 (Co-1) for days to 50 per cent flowering. Three lines viz., DCS-9, DCS-5 and DCS-85 recorded significant negative gca effects, whereas three lines, viz., Co-1, SH-72 and AVR-1 had significant positive gca effects. Among the testers, LRES-17 recorded significant negative gca effect (-3.36), whereas Geeta had significant positive gca effect (3.56).

For the trait, the sca effects ranged from -4.90 (Geeta x DCS-84) to 5.77 (Geeta x SH-72). Among the 36 crosses studied, four crosses exhibited significant positive sca effects, while five crosses exhibited significant negative sca effects for the trait.

4.3.4.2 Days to maturity

The gca effects among the lines ranged from -5.64 (DCS-5) to 13.36 (Co-1) for days to maturity. Further four lines, viz., DCS-5, DCS-9, DCS-85 and DCS-84 exhibited significant negative gca effects, while two lines viz., Co-1 and SH-72 exhibited significant positive gca effects. Among the testers,

Table 4.20 General combining ability effects of parents for ten characters in castor

	Parents	Days to 50% flowering	Days to maturity	Number of nodes	Plant height (cm)	Primary spike length (cm)	Effective spike length (cm)	No. of capsules per primary spike	100-seed weight (g)	Seed yield per plant (g)	Oil content (%)
	Lines										
1	DCS-5	-5.47 **	-5.64 **	-1.33 **	-8.90 **	-2.27 *	-0.09	-1.20	-1.99 **	7.42 *	1.43 **
2	DCS-9	-5.89 **	-5.31 **	-1.32 **	-5.55 **	-2.74 *	-0.25	-3.86 **	0.53	-0.09	1.64 **
3	DCS-27	-0.97	0.61	0.20	2.60 *	2.71 *	4.91 **	12.61 **	-7.66 **	39.97 **	-2.95 **
4	DCS-84	-4.81 **	-3.14 **	-0.88 **	-2.38 *	-0.51	0.96	-4.31 **	-1.19 **	-6.64 *	-1.49 **
5	DCS-85	-5.06 **	-3.47 **	-1.52 **	-8.76 **	-6.17 **	-4.27 **	-5.66 **	-1.85 **	-33.74 **	2.15 **
6	SH-72	4.53 **	2.69 **	1.32 **	13.20 **	12.78 **	9.03 **	10.21 **	-0.27	63.95 **	-0.65 **
7	48-1	0.03	-0.06	0.28	5.35 **	0.38	-1.02	-1.54	-1.07 **	2.09	0.11
8	AVR-1	2.44 **	0.94	0.15	0.59	1.79	-2.69 **	-8.21 **	4.61 **	-2.25	0.73 **
9	Co-1	15.19 **	13.36 **	3.10 **	3.84 **	-5.97 **	-6.59 **	1.96	8.90 **	-70.72 **	-0.99 **
	SE±	0.86	0.81	0.20	1.14	1.14	1.00	1.35	0.31	3.19	0.18
	CD (0.05)	1.68	1.59	0.39	2.24	2.24	1.96	2.64	0.61	6.24	0.35
	CD (0.01)	2.21	2.09	0.51	2.95	2.94	2.57	3.48	0.81	8.21	0.46
	Testers										
1	VP-1	0.27	-0.04	0.71 **	2.15 **	8.52 **	6.49 **	2.83 **	-1.15 **	28.56 **	-1.48 **
2	DPC-9	-0.47	0.81	-0.67 **	-2.55 **	-2.86 **	-1.70 *	4.37 **	3.31 **	9.49 **	0.19
3	LRES-17	-3.36 **	-5.44 **	-1.04 **	-8.66 **	-3.74 **	-4.39 **	-5.48 **	-1.88 **	-22.24 **	1.13 **
4	GEETA	3.56 **	4.67 **	0.99 **	9.06 **	-1.92 *	-0.40	-1.72	-0.29	-15.81 **	0.16
	SE±	0.57	0.54	0.13	0.76	0.76	0.67	0.90	0.21	2.12	0.12
	CD (0.05)	1.12	1.06	0.26	1.50	1.49	1.30	1.76	0.41	4.16	0.23
	CD (0.01)	1.47	1.39	0.34	1.97	1.96	1.71	2.32	0.54	5.47	0.31

*, ** Significant at 5% and 1% level, respectively

Table 4.21 Specific combining ability effects for ten characters in 36 crosses of castor

	Cross	Days to 50% flowering	Days to maturity	Number of nodes	Plant height (cm)	Primary spike length (cm)	Effective spike length (cm)	No. of capsules per primary spike	100 seed weight (g)	Seed yield per plant (g)	Oil content (%)
1	VP-1 X DCS-5	0.06	1.12	-0.46	3.53	-0.62	2.58	8.05 **	1.3 *	38.62 **	1.58 **
2	VP-1 X DCS-9	-1.19	-2.55	-1.10 **	0.85	-6.56 **	-3.46	-2.96	0.43	3.46	1.67 **
3	VP-1 X DCS-27	-2.10	-0.46	-0.88 *	5.54 *	6.46 **	7.84 **	7.70 **	1.24 *	4.71	0.11
4	VP-1 X DCS-84	0.40	-1.05	-0.81 *	-3.32	-4.79 *	-2.34	-4.20	-1.24 *	4.38	-1.13 **
5	VP-1 X DCS-85	-1.69	-0.05	-1.10 **	-1.00	-1.72	-0.77	-4.03	2.73 **	19.30 **	-2.88 **
6	VP-1 X SH-72	1.73	-0.88	1.23 **	4.03	4.06	-1.27	-5.43 *	0.77	-35.31 **	-0.11
7	VP-1 X 48-1	0.56	1.87	1.70 **	-5.25 *	-0.27	1.11	2.72	0.35	13.89 *	-2.53 **
8	VP-1 X AVR-1	-0.19	3.20 *	0.46	-5.55 *	7.58 **	1.84	-2.20	-2.04 **	-5.76	1.63 **
9	VP-1 X Co-1	2.40	-1.21	0.95 *	1.20	-4.12	-5.52 **	0.35	-3.53 **	-43.28 **	1.66 **
10	DPC-9 X DCS-5	-0.86	-3.06	-0.44	-2.83	-1.37	-1.63	-10.16 **	0.87	-17.47 **	0.50
11	DPC-9 X DCS-9	-0.11	0.27	0.28	3.49	5.29 *	2.87	5.69 *	0.39	47.53 **	-3.45 **
12	DPC-9 X DCS-27	1.97	1.35	1.17 **	6.88 **	4.38	2.90	5.56 *	0.31	23.49 **	2.10 **
13	DPC-9 X DCS-84	2.14	4.77 **	0.64	4.32	7.39 **	4.99 *	4.22	1.78 **	7.35	3.60 **
14	DPC-9 X DCS-85	4.39 *	4.44 **	0.82 *	-0.16	1.79	-0.05	1.49	-2.27 **	-5.03	1.70 **
15	DPC-9 X SH-72	-2.86	0.27	-1.49 **	-1.66	-12.49 **	-8.61 **	-2.11	-1.36 *	-21.94 **	-0.83 *
16	DPC-9 X 48-1	-0.03	-0.31	-1.58 **	1.99	0.04	-0.96	-1.96	-3.22 **	-63.99 **	1.10 **
17	DPC-9 X AVR-1	-1.78	-1.98	0.34	-7.38 **	-5.51 *	-1.23	0.25	-0.83	-5.60	-3.22 **
18	DPC-9 X Co-1	-2.86	-5.73 **	0.27	-4.63 *	0.46	1.74	-2.99	4.33 **	35.66 **	-1.48 **
19	LRES-17 X DCS-5	5.03 **	5.86 **	1.53 **	5.41 *	4.71 *	2.32	-1.18	0.14	8.24	-2.44 **
20	LRES-17 X DCS-9	2.11	0.53	-0.34	0.06	-5.49 *	-4.44 *	-2.32	-0.71	-42.71 **	0.71 *
21	LRES-17 X DCS-27	0.86	-1.39	0.34	-2.28	-0.67	-1.14	-4.45	-1.24 *	13.62 *	-0.51
22	LRES-17 X DCS-84	2.36	-0.31	0.52	1.10	-5.72 *	-3.79	2.74	-0.65	-26.85 **	-0.75 *
23	LRES-17 X DCS-85	1.94	-0.64	0.52	5.08 *	-3.92	-1.96	0.68	-1.10	-33.26 **	-0.93 **

*, ** Significant at 5% and 1% level, respectively

Table 4.2 1 contd..

	Cross	Days to 50% flowering	Days to maturity	No. of nodes up to primary spike	Plant height (cm)	Primary spike length (cm)	Effective spike length (cm)	No. of capsules per primary spike	100 seed weight (g)	Seed yield per plant (g)	Oil content (%)
24	LRES-17 X SH-72	-4.64 **	-0.81	-0.45	-4.02	0.59	2.81	1.75	0.13	38.14 **	0.38
25	LRES-17 X 48-1	-1.47	-1.06	-0.34	-2.77	6.26 **	3.92 *	3.83	2.13 **	-0.91	1.94 **
26	LRES-17 X AVR-1	-3.56 *	-3.72 *	-1.35 **	1.00	1.51	-0.28	-1.03	1.99 **	47.67 **	0.61
27	LRES-17 X Co-1	-2.64	1.53	-0.43	-3.59	2.74	2.56	0.00	-0.69	-3.94	0.99 **
28	GEETA x DCS-5	-4.23	-3.92 *	-0.63	-6.11 **	-2.71	-3.27	3.30	-2.31 **	-29.39 **	0.36
29	GEETA x DCS-9	-0.81	1.75	1.16 **	-4.40	6.75 **	5.03 *	-0.41	-0.11	-8.27	1.08 **
30	GEETA x DCS-27	-0.73	0.50	-0.63	-10.14 **	-10.16 **	-9.60 **	-8.81 **	-0.31	-41.82 **	-1.7 **
31	GEETA x DCS-84	-4.90 **	-3.42 *	-0.35	-2.10	3.12	1.15	-2.75	0.12	15.12 *	-1.72 **
32	GEETA x DCS-85	-4.65 **	-3.75 *	-0.24	-3.91	3.85	2.78	1.86	0.64	18.99 **	2.12 **
33	GEETA x SH-72	5.77 **	1.42	0.72	1.65	7.84 **	7.08 **	5.79 *	0.46	19.12 **	0.56
34	GEETA x 48-1	0.94	-0.50	0.22	6.04 **	-6.03 **	-4.07 *	-4.59	0.74	51.01 **	-0.52
35	GEETA x AVR-1	5.52 **	2.50	0.55	11.94 **	-3.58	-0.34	2.98	0.88	-36.32 **	0.98 **
36	GEETA x Co-1	3.10	5.42 **	-0.79 *	7.02 **	0.92	1.23	2.64	-0.11	11.56	-1.17 **
	SE±	1.71	1.62	0.39	2.29	2.29	2.00	2.70	0.63	6.37	0.36
	CD (0.05)	3.36	3.18	0.77	4.49	4.48	3.91	5.29	1.23	12.49	0.7
	CD (0.01)	4.42	4.18	1.02	5.90	5.89	5.14	6.95	1.61	16.41	0.92

*, ** Significant at 5% and 1% level, respectively

LRES-17 alone recorded significant negative gca effect (-5.44), whereas Geeta alone exhibited significant positive gca effect (4.67) for the trait.

The sca effects for days to maturity ranged from -5.73 (DPC-9 x Co-1) to 5.86 (LRES-17 x DCS-5). Out of 36 crosses, five crosses each exhibited significant negative and significant positive sca effects.

4.3.4.3 Number of nodes

The gca effects for the number of nodes ranged from -1.52 (DCS-85) to 3.1 (Co-1) among the lines and from -1.04 (LRES-17) to 0.99 (Geeta) among the testers. Three lines viz., DCS-85, DCS-5 and DCS-9 and two testers viz., LRES-17 and DPC-9 exhibited significant negative gca effects, while two lines viz., Co-1 and SH-72 and two testers viz., Geeta and VP-1 exhibited significant positive gca effects.

For this trait, sca effects were in the range of -1.58 (DPC-9 x 48-1) to 1.7 (VP-1 x 48-1). Further, among 36 crosses, eight crosses showed significant negative sca effects, whereas seven crosses showed significant positive sca effects for number of nodes.

4.3.4.4 Plant height

The gca effects for plant height ranged from -8.9 (DCS-5) to 13.2 (SH-72) among the lines, while for testers, they ranged between -8.66 (LRES-17) to 9.06 (Geeta). Further, the lines, DCS-5, DCS-85, DCS-9 and DCS-84 and the testers, LRES-17 and DPC-9 exhibited significant negative

gca effects, while the lines SH-72, 48-1, Co-1 and DCS-27 and the testers, Geeta and VP-1 exhibited significant positive gca effects for the trait.

The sca effects of the crosses ranged from -10.14 (Geeta x DCS-27) to 11.94 (Geeta x AVR-1) for plant height. Among the crosses, six crosses showed significant negative sca effects, while seven crosses showed significant positive sca effects.

4.3.4.5 Primary spike length

The gca effects ranged from -6.17 (DCS-85) to 12.78 (SH-72) among the lines, and from -3.74 (LRES-17) to 8.52 (VP-1) among testers for primary spike length. The lines, SH-72 and DCS-27 and the testers, VP-1 exhibited significant positive gca effects, while the lines DCS-85, Co-1, DCS-9 and DCS-5 and the testers, LRES-17, DPC-9 and Geeta exhibited significant negative gca effects.

The sca effects for primary spike length ranged from -12.49 (DPC-9 x SH-72) to 7.84 (Geeta x SH-72). Further, out of 36 crosses, eight crosses each recorded significant positive and significant negative sca effects for the trait.

4.3.4.6 Effective spike length

The gca effects for effective spike length were in the range of -6.59 (Co-1) to 9.03 (SH-72) among lines and -4.39 (LRES-17) to 6.49 (VP-1) among testers. The lines, SH-72 and DCS-27 and the tester, VP-1 exhibited significant positive gca effects, while the lines Co-1, DCS-84 and AVR-1

and the testers, LRES-17 and DPC-9 exhibited significant negative gca effects for the trait.

The sca effects for the trait ranged from -9.6 (Geeta x DCS-27) to 7.84 (VP-1 x DCS-27). Among the crosses, five crosses each recorded significant positive and significant negative sca effects.

4.3.4.7 Number of capsules per primary spike

For number of capsules per primary spike, the gca effects ranged from -8.21 (AVR-1) to 12.61 (DCS-27) among lines and -5.48 (LRES-17) to 4.37 (DPC-9) among testers. Two lines viz., DCS-27 and SH-72 and two testers viz., DPC-9 and VP-1 recorded significant positive gca effects, whereas four lines viz., AVR-1, DCS-85, DCS-84 and DCS-9 and a tester, LRES-17 recorded significant negative gca effects for the trait.

The sca effects for the trait ranged from -10.16 (DPC-9 x DCS-5) to 8.05 (VP-1 x DCS-5), while five and three crosses exhibited significant positive and significant negative sca effects, respectively.

4.3.4.8 100-seed weight

The gca effects for 100-seed weight ranged from -7.66 (DCS-27) to 8.90 (Co-1) in lines and -1.88 (LRES-17) to 3.31 (DPC-9) in testers. Further, two lines, Co-1 and AVR-1 and a tester, DPC-9 recorded significant positive gca effects, while five lines viz., DCS-27, DCS-5, DCS-85, DCS-84 and 48-1 and two testers viz., LRES-17 and VP-1 recorded significant negative gca effects for the trait.

For 100-seed weight, the sca effects were in the range of -3.53 (VP-1 x Co-1) to 4.33 (DPC-9 x Co-1). However, among crosses, seven crosses exhibited significant positive sca effects and eight crosses had significant negative sca effects for the trait.

4.3.4.9 Seed yield per plant

For seed yield per plant, the gca effects ranged from -70.72 (Co-1) to 63.95 (SH-72) among lines, whereas among testers, it was from -22.24 (LRES-17) to 28.56 (VP-1). Three lines viz., SH-72, DCS-27 and DCS-5 and two testers viz., VP-1 and DPC-9 exhibited significant positive gca effects, while three lines viz., Co-1, DCS-85 and DCS-84 and two testers viz., LRES-17 and Geeta exhibited significant negative gca effects for the trait.

However, the sca effects for seed yield per plant ranged from -63.98 (DPC-9 x 48-1) to 51.01 (Geeta x 48-1). Further, out of 36 crosses, 13 crosses recorded significant positive sca effects, while 11 crosses exhibited significant negative sca effects.

4.3.4.10 Oil content

The gca effects for oil content ranged from -2.95 (DCS-27) to 2.15 (DCS-85) among lines, whereas it was from -1.48 (VP-1) to 1.13 (LRES-17) among testers. Four lines viz., DCS-85, DCS-9, DCS-5 and AVR-1 and a tester, LRES-17 exhibited significant positive gca effects, while four lines viz., DCS-27, DCS-84, Co-1 and SH-72 and a tester, VP-1 recorded significant negative gca effects for the trait.

The sca effects of oil content ranged from -3.45 (DPC-9 x DCS-9) to 3.6 (DPC-9 x DCS-84). However, among 36 crosses, 14 crosses exhibited significant positive sca effects, whereas 13 crosses exhibited significant negative sca effects for the trait.

4.4 HETEROSIS AND INBREEDING DEPRESSION

4.4.1 Heterosis

Heterosis was measured in all the 36 crosses for 10 characters studied and expressed as per cent of heterosis over the better parent (Heterobeltiosis) and per cent of heterosis over standard checks viz., Kranti and DCH-177 (Standard heterosis) and the results are presented in Table 4.22.

4.4.1.1 Days to 50 per cent flowering

For the character, days to 50 per cent flowering heterobeltiosis was in the range of -25.26 per cent (VP-1 x DCS-27) to 14.66 per cent (Geeta x Co-1). Out of 36 crosses, 22 crosses recorded significant negative heterobeltiosis, whereas two crosses recorded significant positive heterobeltiosis. However, the range of standard heterosis was from -7.69 per cent (LRES-17 x DCS-9) to 53.15 per cent (Geeta x Co-1) over Kranti, while it was from -1.5 per cent (LRES-17 x DCS-9) to 63.42 per cent (Geeta x Co-1) over DCH-177. Further, out of 36 crosses none of the crosses exhibited significant negative standard heterosis over any of the two checks.

4.4.1.2 Days to maturity

Heterobeltiosis was ranged from -11.78 per cent (VP-1 x SH-72) to 10.56 per cent (Geeta x DCS-9) for days to maturity. Among 36 crosses,

Table 4.22: Heterobeltiosis and standard heterosis for yield and other characters in 36 crosses of castor

	Crosses	Days to 50% flowering			Day to maturity		
		Heterobeltiosis	Standard heterosis		Heterobeltiosis	Standard heterosis	
			Kranti	DCH 177		Kranti	DCH 177
1	VP-1 X DCS-5	-9.80 *	-3.50	2.98	-0.31	-0.62	-0.31
2	VP-1 X DCS-9	-2.21	-6.99	-0.76	1.65	-3.75	-3.45
3	VP-1 X DCS-27	-25.26 **	1.40	8.19	-2.92	3.75	4.08
4	VP-1 X DCS-84	-9.03 *	-1.40	5.22	-8.07 **	-0.31	0.00
5	VP-1 X DCS-85	-12.42 **	-6.29	0.00	-1.83	0.31	0.63
6	VP-1 X SH-72	-11.73 **	20.98 **	29.10 **	-11.78 **	5.31 *	5.64 **
7	VP-1 X 48-1	-11.36 **	9.09	16.41 *	-7.16 **	5.31 *	5.64 **
8	VP-1 X AVR-1	-15.71 **	12.59 *	20.15 **	-8.27 **	7.50 **	7.84 **
9	VP-1 X Co-1	5.61	44.76 **	54.47 **	-3.66 *	15.00 **	15.36 **
10	DPC-9 X DCS-5	-13.07 **	-6.99	-0.76	-3.45	-3.75	-3.45
11	DPC-9 X DCS-9	-1.47	-6.29	0.00	5.28 *	-0.31	0.00
12	DPC-9 X DCS-27	-15.76 **	8.39	15.67 *	-0.58	6.25 **	6.58 **
13	DPC-9 X DCS-84	-7.10	0.70	7.45	-2.31	5.94 **	6.27 **
14	DPC-9 X DCS-85	-1.96	4.90	11.93 *	3.06	5.31 *	5.64 **
15	DPC-9 X SH-72	-14.67 **	9.79	17.15 **	-8.04 **	7.19 **	7.52 **
16	DPC-9 X 48-1	-13.64 **	6.29	13.43 *	-8.26 **	4.06	4.39 *
17	DPC-9 X AVR-1	-16.30 **	7.69	14.91 *	-7.26 **	3.44	3.76
18	DPC-9 X Co-1	2.72	32.17 **	41.03 **	-4.29 *	11.56 **	11.91 **
19	LRES-17 X DCS-5	-7.19	-0.70	5.95	-0.94	-1.25	-0.94
20	LRES-17 X DCS-9	-2.94	-7.69	-1.50	-0.66	-5.94 **	-5.64 **
21	LRES-17 X DCS-27	-11.73 **	0.00	6.72	-8.48 **	-2.19	-1.88
22	LRES-17 X DCS-84	-12.26 **	-4.90	1.48	-11.08 **	-4.69 *	-4.39 *
23	LRES-17 X DCS-85	-12.42 **	-6.29	0.00	-7.34 **	-5.31 *	-5.02 *
24	LRES-17 X SH-72	-11.73 **	0.00	6.72	-6.41 **	0.31	0.63
25	LRES-17 X 48-1	-14.20 **	-2.80	3.72	-9.04 **	-2.50	-2.19
26	LRES-17 X AVR-1	-13.58 **	-2.10	4.48	-10.50 **	-4.06	-3.76
27	LRES-17 X Co-1	11.73 **	26.57 **	35.06 **	4.96 *	12.50 **	12.85 **
28	GEETA X DCS-5	-11.76 *	-5.59	0.74	-0.63	-0.94	-0.63
29	GEETA X DCS-9	5.88	0.70	7.45	10.56 **	4.69 *	5.02 *
30	GEETA X DCS-27	-16.75 **	11.19 *	18.65 **	2.05	9.06 **	9.40 **
31	GEETA X DCS-84	-12.90 **	-5.59	0.74	-6.05 **	1.88	2.19
32	GEETA X DCS-85	-11.76 **	-5.59	0.74	-0.92	1.25	1.57
33	GEETA X SH-72	2.09	36.36 **	45.51 **	-4.53 *	11.88 **	12.23 **
34	GEETA X 48-1	-5.11	16.78 **	24.63 **	-5.23 *	7.50 **	7.84 **
35	GEETA X AVR-1	-1.57	31.47 **	40.30 **	-5.07 *	11.25 **	11.60 **
36	GEETA X Co-1	14.66 **	53.15 **	63.42 **	7.20 **	25.63 **	26.02 **

*, ** Significant at 5% and 1% level, respectively

Table 4.22 contd..

	Crosses	Number of nodes			Plant height		
		Heterobeltiosis	Standard heterosis		Heterobeltiosis	Standard heterosis	
			Kranti	DCH 177		Kranti	DCH 177
1	VP-1 X DCS-5	0.93	2.20	6.18	30.06 **	0.76	3.28
2	VP-1 X DCS-9	15.91 *	-3.77	0.00	26.08 **	2.28	4.84
3	VP-1 X DCS-27	2.29	12.58 *	16.96 **	62.20 **	31.58 **	34.87 **
4	VP-1 X DCS-84	4.46	3.14	7.16	23.26 *	0.00	2.50
5	VP-1 X DCS-85	-11.76 *	-5.66	-1.96	11.82	-9.28	-7.02
6	VP-1 X SH-72	-1.52	43.08 **	48.73 **	87.80 **	52.36 **	56.17 **
7	VP-1 X 48-1	-1.79	37.74 **	43.14 **	39.59 **	13.24	16.08 *
8	VP-1 X AVR-1	-7.46	24.84 **	29.71 **	25.33 **	1.67	4.21
9	VP-1 X Co-1	8.23 *	57.23 **	63.43 **	53.47 **	24.51 **	27.62 **
10	DPC-9 X DCS-5	-11.80 *	-10.69 *	-7.16	-2.55	-24.51 **	-22.61 **
11	DPC-9 X DCS-9	15.91 *	-3.77	0.00	17.18 *	-2.44	0.00
12	DPC-9 X DCS-27	8.00	18.87 **	23.53 **	32.79 **	23.90 **	27.01 **
13	DPC-9 X DCS-84	5.10	3.77	7.84	16.25 *	6.70	9.36
14	DPC-9 X DCS-85	-7.06	-0.63	3.24	-10.18	-18.11 *	-16.05 *
15	DPC-9 X SH-72	-14.43 **	4.40	8.53	-15.92 **	28.61 **	31.83 **
16	DPC-9 X 48-1	-23.20 **	-6.29	-2.65	-22.19 **	19.03 **	22.00 **
17	DPC-9 X AVR-1	-9.28 *	10.69 *	15.00 **	-32.14 **	-13.24	-11.07
18	DPC-9 X Co-1	12.89 *	37.74 **	43.14 **	-34.33 **	0.46	2.97
19	LRES-17 X DCS-5	3.11	4.40	8.53	3.73	-19.63 **	-17.62 *
20	LRES-17 X DCS-9	4.55	-13.21 *	-9.80 *	38.72 **	-24.20 **	-22.30 **
21	LRES-17 X DCS-27	-1.10	7.55	11.76 *	62.95 **	-10.96	-8.73
22	LRES-17 X DCS-84	0.32	-0.94	2.94	66.27 **	-14.61 *	-12.47
23	LRES-17 X DCS-85	-12.94 **	-6.92	-3.24	46.24 **	-20.09 **	-18.09 **
24	LRES-17 X SH-72	1.73	10.69 *	15.00 **	100.00 **	9.28	12.03
25	LRES-17 X 48-1	-6.36	1.89	5.88	72.42 **	-5.78	-3.42
26	LRES-17 X AVR-1	-16.18 **	-8.81	-5.20	68.25 **	-8.07	-5.76
27	LRES-17 X Co-1	17.34 **	27.67 **	32.65 **	62.67 **	-11.11	-8.89
28	GEETA X DCS-5	1.86	3.14	7.16	22.00 *	-5.48	-3.11
29	GEETA X DCS-9	44.70 **	20.13 **	24.80 **	27.42 **	6.09	8.75
30	GEETA X DCS-27	6.86	17.61 **	22.25 **	19.58 *	11.57	14.37
31	GEETA X DCS-84	11.46 *	10.06	14.41 **	29.19 **	18.57 *	21.53 **
32	GEETA X DCS-85	-1.76	5.03	9.12 *	9.52	-0.15	2.34
33	GEETA X SH-72	-3.45	40.88 **	46.37 **	-14.62 **	62.71 **	66.79 **
34	GEETA X 48-1	-9.87 **	26.42 **	31.37 **	-14.61 **	54.79 **	58.67 **
35	GEETA X AVR-1	-4.90	28.30 **	33.33 **	23.10 **	57.38 **	61.32 **
36	GEETA X Co-1	-1.72	43.40 **	49.02 **	-10.39 *	53.58 **	57.43 **

*, ** Significant at 5% and 1% level, respectively

Table 4.22 contd..

	Crosses	Primary spike length			Effective spike length		
		Heterobeltiosis	Standard heterosis		Heterobeltiosis	Standard heterosis	
			Kranti	DCH 177		Kranti	DCH 177
1	VP-1 X DCS-5	-16.27 **	65.67 **	13.05	-8.53	39.07 **	19.21 **
2	VP-1 X DCS-9	-26.68 **	45.06 **	-1.01	-19.85 **	21.85 **	4.45
3	VP-1 X DCS-27	3.36	104.51 **	39.53 **	10.23 *	67.59 **	43.64 **
4	VP-1 X DCS-84	-20.17 **	57.94 **	7.78	-15.59 **	28.33 **	10.00
5	VP-1 X DCS-85	-24.40 **	49.57 **	2.06	-22.29 **	18.15 *	1.26
6	VP-1 X SH-72	20.41 **	129.18 **	56.38 **	1.10	53.70 **	31.74 **
7	VP-1 X 48-1	-11.39 *	75.32 **	19.64 **	-12.91 *	32.41 **	13.50 *
8	VP-1 X AVR-1	3.69	105.15 **	39.97 **	-14.62 **	29.81 **	11.26
9	VP-1 X Co-1	-27.98 **	42.49 **	-2.77	-35.20 **	-1.48	-15.55 *
10	DPC-9 X DCS-5	-25.03 **	26.61 **	-13.62	-14.91 *	4.63	-10.31
11	DPC-9 X DCS-9	-13.21 *	46.57 **	0.00	-5.12	16.67 *	0.00
12	DPC-9 X DCS-27	-4.57	61.16 **	9.97	6.63	31.11 **	12.38
13	DPC-9 X DCS-84	-4.96	60.52 **	9.53	2.41	25.93 **	7.93
14	DPC-9 X DCS-85	-26.43 **	24.25 *	-15.22 *	-20.78 **	-2.59	-16.50 *
15	DPC-9 X SH-72	-26.83 **	39.27 **	-4.96	-18.33 **	10.56	-5.24
16	DPC-9 X 48-1	-17.28 **	39.70 **	-4.68	-15.51 *	3.89	-10.95
17	DPC-9 X AVR-1	-31.19 **	26.39 **	-13.75	-21.42 **	-1.48	-15.55 *
18	DPC-9 X Co-1	-28.59 **	20.60 *	-17.70 *	-21.99 **	-4.07	-17.79 *
19	LRES-17 X DCS-5	-18.04 **	43.35 **	-2.20	-19.34 **	8.15	-7.31
20	LRES-17 X DCS-9	-37.67 **	9.01	-25.61 **	-33.70 **	-11.11	-23.81 **
21	LRES-17 X DCS-27	-18.77 **	42.06 **	-3.07	-16.16 **	12.41	-3.64
22	LRES-17 X DCS-84	-33.99 **	15.45	-21.22 **	-29.83 **	-5.93	-19.36 **
23	LRES-17 X DCS-85	-41.10 **	3.00	-29.72 **	-36.88 **	-15.37	-27.45 **
24	LRES-17 X SH-72	-6.20	78.54 **	21.83 **	-0.41	34.81 **	15.55 *
25	LRES-17 X 48-1	-10.31	56.87 **	7.03	-17.96 **	10.00	-5.71
26	LRES-17 X AVR-1	-20.44 **	46.14 **	-0.29	-30.11 **	-6.30	-19.69 **
27	LRES-17 X Co-1	-28.47 **	25.11 *	-14.63 *	-32.32 **	-9.26	-22.21 **
28	GEETA X DCS-5	-27.72 **	25.32 *	-14.50	-27.84 **	3.70	-11.12
29	GEETA X DCS-9	-11.01	54.29 **	5.27	-12.11 *	26.30 **	8.26
30	GEETA X DCS-27	-32.30 **	17.38	-19.90 *	-30.41 **	0.00	-14.29
31	GEETA X DCS-84	-13.61 *	49.79 **	2.20	-17.27 **	18.89 *	1.90
32	GEETA X DCS-85	-22.77 **	33.91 **	-8.63	-24.23 **	8.89	-6.67
33	GEETA X SH-72	9.13	107.73 **	41.73 **	9.79	57.78 **	35.24 **
34	GEETA X 48-1	-28.96 **	23.18 *	-15.95 *	-31.19 **	-1.11	-15.24 *
35	GEETA X AVR-1	-26.17 **	35.62 **	-7.47	-27.19 **	4.63	-10.31
36	GEETA X Co-1	-27.85 **	25.11 *	-14.63 *	-31.70 **	-1.85	-15.88 *

*, ** Significant at 5% and 1% level, respectively

Table 4.22 contd..

	Crosses	Number of capsules per primary spike			100-seed weight		
		Heterobeltiosis	Standard heterosis		Heterobeltiosis	Standard heterosis	
			Kranti	DCH 177		Kranti	DCH 177
1	VP-1 X DCS-5	14.54	55.01 **	6.50	10.40 **	13.35 **	-16.04 **
2	VP-1 X DCS-9	-13.06	17.67	-19.15 **	16.16 **	19.26 **	-11.66 **
3	VP-1 X DCS-27	71.22 **	91.80 **	31.78 **	-9.46 **	-7.04 *	-31.13 **
4	VP-1 X DCS-84	-16.49 *	13.02	-22.34 **	1.84	7.17 *	-20.60 **
5	VP-1 X DCS-85	-18.84 *	9.84	-24.54 **	8.29 **	18.94 **	-11.90 **
6	VP-1 X SH-72	-16.33 **	49.36 **	2.63	3.68	17.59 **	-12.90 **
7	VP-1 X 48-1	3.10	39.53 **	-4.13	10.32 **	13.27 **	-16.09 **
8	VP-1 X AVR-1	-20.32 **	7.83	-25.91 **	-25.04 **	24.99 **	-7.41 **
9	VP-1 X Co-1	5.38	42.62 **	-2.01	-49.08 **	34.94 **	-0.03
10	DPC-9 X DCS-5	-26.53 **	9.47	-24.78 **	13.11 **	27.73 **	-5.38 *
11	DPC-9 X DCS-9	-2.32	45.54 **	0.00	19.54 **	34.99 **	0.00
12	DPC-9 X DCS-27	69.76 **	90.16 **	30.66 **	-6.56 *	5.52	-21.84 **
13	DPC-9 X DCS-84	-5.87	40.26 **	-3.64	18.49 **	33.80 **	-0.87
14	DPC-9 X DCS-85	-13.33	29.14 **	-11.26	3.66	17.06 **	-13.29 **
15	DPC-9 X SH-72	-8.88	62.66 **	11.75	11.02 **	25.91 **	-6.73 **
16	DPC-9 X 48-1	-12.10	30.97 **	-10.02	3.09	16.42 **	-13.77 **
17	DPC-9 X AVR-1	-20.29 **	18.76	-18.40 **	-12.92 **	45.19 **	7.54 **
18	DPC-9 X Co-1	-7.58	37.70 **	-5.39	-32.52 **	78.82 **	32.47 **
19	LRES-17 X DCS-5	-4.55	7.10	-26.41 **	5.68	6.64 *	-21.00 **
20	LRES-17 X DCS-9	-13.80	-3.28	-33.55 **	10.65 **	12.58 **	-16.59 **
21	LRES-17 X DCS-27	21.30 *	35.88 **	-6.65	-19.20 **	-18.47 **	-39.59 **
22	LRES-17 X DCS-84	-2.60	9.29	-24.91 **	1.38	6.68 *	-20.97 **
23	LRES-17 X DCS-85	-10.88	0.00	-31.29 **	-6.49 *	2.71	-23.93 **
24	LRES-17 X SH-72	-18.06 **	46.27 **	-0.49	-0.61	12.72 **	-16.49 **
25	LRES-17 X 48-1	-4.08	19.85	-17.65 *	15.94 **	16.99 **	-13.35 **
26	LRES-17 X AVR-1	-30.32 **	-11.66	-39.31 **	-17.98 **	36.76 **	1.32
27	LRES-17 X Co-1	6.01	18.94	-18.28 **	-46.24 **	42.46 **	5.54 *
28	GEETA X DCS-5	-17.56 **	29.60 **	-10.96	-1.08	3.56	-23.29 **
29	GEETA X DCS-9	-28.62 **	12.20	-22.90 **	15.02 **	20.42 **	-10.79 **
30	GEETA X DCS-27	-14.60 *	34.24 **	-7.77	-13.55 **	-9.50 **	-32.95 **
31	GEETA X DCS-84	-33.49 **	4.55	-28.16 **	9.35 **	15.07 **	-14.75 **
32	GEETA X DCS-85	-27.81 **	13.48	-22.04 **	4.33	14.60 **	-15.11 **
33	GEETA X SH-72	-6.12	67.58 **	15.13 *	5.43 *	19.57 **	-11.42 **
34	GEETA X 48-1	-31.87 **	7.10	-26.41 **	12.45 **	17.72 **	-12.79 **
35	GEETA X AVR-1	-30.30 **	9.56	-24.72 **	-16.95 **	38.47 **	2.59
36	GEETA X Co-1	-13.21 *	36.43 **	-6.27	-43.33 **	50.17 **	11.24 **

*, ** Significant at 5% and 1% level, respectively

Table 4.22contd..

	Crosses	Seed yield per plant			Oil content		
		Heterobeltiosis	Standard heterosis		Heterobeltiosis	Standard heterosis	
			Kranti	DCH 177		Kranti	DCH 177
1	VP-1 X DCS-5	72.72 **	51.16 **	5.24 *	-2.27 *	10.67 **	6.70 **
2	VP-1 X DCS-9	27.77 **	33.00 **	-7.41 **	-1.69	11.33 **	7.34 **
3	VP-1 X DCS-27	72.06 **	50.58 **	4.83	-13.67 **	-2.24 *	-5.75 **
4	VP-1 X DCS-84	49.43 **	30.61 **	-9.07 **	-13.25 **	-1.76	-5.28 **
5	VP-1 X DCS-85	43.32 **	25.43 **	-12.68 **	-9.56 **	2.42 *	-1.26
6	VP-1 X SH-72	36.18 **	43.76 **	0.08	-9.61 **	2.36 *	-1.30
7	VP-1 X 48-1	39.77 **	38.37 **	-3.67	-12.85 **	-1.31	-4.85 **
8	VP-1 X AVR-1	37.27 **	28.16 **	-10.78 **	-3.54 **	9.24 **	5.32 **
9	VP-1 X Co-1	-5.10	-16.95 **	-42.18 **	-6.84 **	5.50 **	1.72
10	DPC-9 X DCS-5	1.45	19.18 **	-17.03 **	-2.96 **	11.97 **	7.96 **
11	DPC-9 X DCS-9	22.27 **	43.64 **	0.00	-10.11 **	3.72 **	0.00
12	DPC-9 X DCS-27	28.08 **	50.46 **	4.75	-8.28 **	5.84 **	2.04 *
13	DPC-9 X DCS-84	5.35	23.76 **	-13.84 **	-2.62 **	12.36 **	8.34 **
14	DPC-9 X DCS-85	-8.96 **	6.96	-25.54 **	0.71	16.21 **	12.05 **
15	DPC-9 X SH-72	20.31 **	41.33 **	-1.61	-9.48 **	4.44 **	0.70
16	DPC-9 X 48-1	-17.34 **	-2.89	-32.39 **	-4.32 **	10.40 **	6.45 **
17	DPC-9 X AVR-1	2.24	20.12 **	-16.38 **	-11.41 **	2.22 *	-1.45
18	DPC-9 X Co-1	-7.61 *	8.54 *	-24.44 **	-11.38 **	2.25 *	-1.40
19	LRES-17 X DCS-5	36.65 **	16.62 **	-18.81 **	-4.16 **	7.57 **	3.72 **
20	LRES-17 X DCS-9	-11.87 **	-8.26 *	-36.13 **	2.44 **	14.98 **	10.86 **
21	LRES-17 X DCS-27	62.26 **	32.76 **	-7.58 **	-8.99 **	2.16	-1.51
22	LRES-17 X DCS-84	16.97 **	-4.30	-33.37 **	-6.59 **	4.85 **	1.09
23	LRES-17 X DCS-85	-0.46	-18.56 **	-43.30 **	0.22	12.49 **	8.45 **
24	LRES-17 X SH-72	45.31 **	53.40 **	6.79 *	-2.71 **	9.21 **	5.30 **
25	LRES-17 X 48-1	11.57 **	10.46 **	-23.10 **	1.86	14.33 **	10.24 **
26	LRES-17 X AVR-1	38.93 **	29.28 **	-10.00 **	0.47	12.77 **	8.73 **
27	LRES-17 X Co-1	-4.44	-21.82 **	-45.57 **	-2.18 **	9.79 **	5.85 **
28	GEETA X DCS-5	-17.06 **	3.34	-28.06 **	3.46 **	11.63 **	7.62 **
29	GEETA X DCS-9	-12.41 **	9.13 *	-24.03 **	5.35 **	13.67 **	9.60 **
30	GEETA X DCS-27	-10.18 **	11.90 **	-22.10 **	-9.73 **	-2.61 *	-6.09 **
31	GEETA X DCS-84	-6.66 *	16.30 **	-19.04 **	-6.78 **	0.58	-3.02 *
32	GEETA X DCS-85	-14.59 **	6.41	-25.92 **	7.26 **	17.09 **	12.90 **
33	GEETA X SH-72	18.82 **	48.04 **	-3.06	-0.40	7.46 **	3.62 **
34	GEETA X 48-1	8.59 **	35.29 **	-5.82 *	-1.05	6.76 **	2.94 *
35	GEETA X AVR-1	-22.73 **	-3.73	-32.98 **	1.20	11.44 **	7.45 **
36	GEETA X Co-1	-29.76 **	-12.49 **	-39.08 **	-4.63 **	2.90 **	-0.79

*, ** Significant at 5% and 1% level, respectively

19 crosses exhibited significant negative heterobeltiosis, whereas four crosses exhibited significant positive heterobeltiosis. However, for the trait range of standard heterosis was from -5.94 per cent (LRES-17 x DCS-9) to 25.63 per cent (Geeta x Co-1) over check Kranti, while it was from -5.64 per cent (LRES-17 x DCS-9) to 26.02 per cent (Geeta x Co-1) over check, DCH-177. Further, out of 36 crosses, three crosses exhibited significant negative heterosis over two checks, whereas 16 and 17 crosses exhibited significant positive heterosis over checks, Kranti and DCH-177 respectively.

4.4.1.3 Number of nodes

The character exhibited heterobeltiosis ranging from -23.2 per cent (DPC-9 x 48-1) to 44.7 per cent (Geeta x DCS-9). Among the crosses, eight crosses recorded significant negative heterobeltiosis and seven crosses recorded significant positive heterobeltiosis. However, the range of heterosis over check, Kranti was -13.21 per cent (LRES-17 x DCS-9) to 57.23 per cent (VP-1 x Co-1), while it was from -9.8 per cent (LRES-17 x DCS-9) to 63.43 per cent (VP-1 x Co-1) over check, DCH-177. Further, significant negative heterosis was exhibited in two crosses over Kranti and single cross over DCH-177, while significant positive heterosis was observed in 16 crosses over check, Kranti and 19 crosses over check, DCH-177 for the trait.

4.4.1.4 Plant height

The heterobeltiosis for plant height ranged from -34.33 per cent (DPC-9 x Co-1) to 100 per cent (LRES-17 x SH-72). Seven and 24 crosses respectively recorded significant negative and significant positive heterosis

over their respective better parents. The range of heterosis over check, Kranti was from -24.51 per cent (DPC-9 x DCS-5) to 62.71 per cent (Geeta x SH-72), while it was -22.61 per cent (DPC-9 x DCS-5) to 66.79 per cent (Geeta x SH-72) over DCH-177. Further significant negative heterosis was observed in six crosses over Kranti and seven crosses over DCH-177, while significant positive heterosis was observed in 11 crosses over Kranti and 12 crosses over DCH-177.

4.4.1.5 Primary spike length

For this character, the range of heterobeltiosis was from -41.10 per cent (LRES-17 x DCS-85) to 20.41 per cent (VP-1 x SH-72). Out of 36 crosses, only one cross exhibited significant positive heterobeltiosis, whereas 27 crosses exhibited significant negative heterobeltiosis. The range of heterosis for primary spike length was 3.00 per cent (LRES-17 x DCS-85) to 129.18 per cent (VP-1 x SH-72) over Kranti, while it was -29.72 per cent (LRES-17 x DCS-85) to 56.38 per cent (VP-1 x SH-72) over DCH-177. Further, 32 crosses over Kranti and six crosses over DCH-177 recorded significant positive heterosis, while nine crosses recorded significant negative heterosis over DCH-177.

4.4.1.6 Effective spike length

Among the crosses, heterobeltiosis for effective spike length ranged from -36.88 per cent (LRES-17 x DCS-85) to 10.23 per cent (VP-1 x DCS-27). Further, significant positive heterobeltiosis was recorded in one cross, whereas 27 crosses recorded significant negative heterobeltiosis. The

heterosis for the trait ranged from -15.37 per cent (LRES-17 x DCS-85) to 67.59 per cent (VP-1 x DCS-27) over Kranti and -25.08 per cent (LRES-17 x DCS-85) to 48.36 per cent (VP-1 x DCS-27) over standard hybrid, DCH-177. Out of 36 crosses, significant positive heterosis was recorded in 15 crosses over Kranti and six crosses over DCH-177, while 11 crosses showed significant negative heterosis over check, DCH-177. However none of the crosses showed significant negative heterosis over check, Kranti.

4.4.1.7 Number of capsules per primary spike

The range of heterobeltiosis for the trait ranged from -33.49 per cent (Geeta x DCS-84) to 71.22 per cent (VP-1 x DCS-27). Three crosses exhibited significant positive heterobeltiosis, while 16 crosses exhibited significant negative heterobeltiosis. The range of heterosis over Kranti was -11.66 per cent (LRES-17 x AVR-1) to 91.8 per cent (VP-1 x DCS-27), while it was -39.31 per cent (LRES-17 x AVR-1) to 31.78 per cent (VP-1 x DCS-27) over DCH-177. Further, 18 and three crosses exhibited significant positive heterosis over Kranti and DCH-177, respectively, while 18 crosses recorded significant negative heterosis over DCH-177 for the trait. However, none of the crosses exhibited significant negative heterosis over check, Kranti.

4.4.1.8 100-seed weight

The heterobeltiosis for 100-seed weight ranged from -49.08 per cent (VP-1 x Co-1) to 19.54 per cent (DPC-9 x DCS-9). Among 36 crosses, 14 crosses recorded significant positive heterobeltiosis and 13 crosses recorded

significant negative heterobeltiosis. However, the heterosis ranged from 18.47 per cent (LRES-17 x DCS-27) to 32.6 per cent (DPC-9 x Co-1) over Kranti and -39.59 per cent (LRES-17 x DCS-27) to 32.47 per cent (DPC-9 x Co-1) over DCH-177. Further, 30 and four crosses recorded significant positive heterosis, while three and 27 crosses recorded significant negative heterosis over checks, Kranti and DCH-177, respectively.

4.4.1.9 Seed yield per plant

The character, seed yield per plant had heterobeltiosis ranging from -29.76 per cent (Geeta x Co-1) to 72.06 per cent (VP-1 x DCS-27). Among the crosses, 19 crosses recorded significant positive heterobeltiosis and 11 crosses recorded significant negative heterobeltiosis. The heterosis ranged from -21.82 per cent (LRES-17 x Co-1) to 53.4 per cent (LRES-17 x SH-72) over Kranti and -44.46 per cent (LRES-17 x Co-1) to 8.97 per cent (LRES-17 x SH-72) over DCH-177. Further, 25 crosses over Kranti and two crosses over DCH-177 recorded significant positive heterosis, while five crosses over Kranti and 27 crosses over DCH-177 recorded significant negative heterosis.

4.4.1.10 Oil content

Heterobeltiosis for oil content ranged from -13.67 per cent (VP-1 x DCS-27) to 7.26 per cent (Geeta x DCS-85). Among the crosses, four crosses exhibited significant positive heterobeltiosis and 24 crosses had significant negative heterobeltiosis. However, the heterosis ranged from -2.61 per cent (Geeta x DCS-27) to 17.09 per cent (Geeta x DCS-85) over Kranti and

-6.09 per cent (Geeta x DCS-27) to 12.90 per cent (Geeta x DCS-85) over DCH-177. Further, significant positive heterosis was recorded in 30 crosses over Kranti and 21 crosses over DCH-177, while two and five crosses recorded significant negative heterosis over Kranti and DCH-177, respectively.

4.4.2 Inbreeding depression

An experiment was attempted to observe the extent of inbreeding depression for different characters in eight crosses, selected based on seed yield of F_1 hybrids to each from four pistillate lines. For this purpose, two populations such as one from F_1 plants selfed seed (F_2 selfed) and another from F_1 plants open pollinated seed (F_2 open pollinated) were raised along with F_1 hybrids. Further, inbreeding depression was calculated from above two populations separately for different characters and results are presented in Table 4.23 along with the values of mid parental heterosis for comparison. The results were explained in detail here under.

4.4.2.1 Days to 50 per cent flowering

For days to 50 per cent flowering all the eight crosses showed negative heterosis and negative inbreeding depression. The cross, VP-1 x DCS-27 exhibited highest significant negative inbreeding depression (-48.28 %, -30.35 %) under selfed and open pollinated F_2 population, which also had highest significant negative heterosis (-25.64 %). However, the cross, VP-1 x DCS-5 recorded non-significant inbreeding depression with highly significant negative heterosis for the trait. Among the eight crosses,

Table 4.23: Heterosis in F_1 and inbreeding depression in F2 of eight selected crosses for ten characters in castor

Cross	Days to 50% flowering			Days to maturity			Number of nodes			Plant height			Primary spike length		
	Heterosis	Inbreeding depression		Heterosis	Inbreeding depression		Heterosis	Inbreeding depression		Heterosis	Inbreeding depression		Heterosis	Inbreeding depression	
		Selfed	Open pollinated		Selfed	Open pollinated		Selfed	Open pollinated		Selfed	Open pollinated		Selfed	Open pollinated
VP-1 x DCS-5	-20.92 **	-3.62	-0.72	-9.27**	-6.29*	-5.66**	-17.09**	-27.39**	-15.39**	27.06**	0.15	2.95	15.61*	14.12	7.51
VP-1 x DCS-27	-25.64 **	-48.28**	-30.35**	-8.29**	-14.76**	-9.34**	-11.82**	-34.08**	-15.08**	50.87**	2.26	9.43	38.42**	11.12	12.17
DPC-9 x DCS-9	-16.25 **	-5.97	-14.18**	-5.62**	-3.76	-8.15**	-6.13	-13.73**	-3.92	-17.40**	-3.51	-9.13	9.19	3.81	-0.15
DPC-9 x DCS-27	-17.99 **	-18.71**	-13.55**	-4.90**	-1.18	1.18	2.44	-5.02	-3.44	0.62	34.34**	24.14 **	20.93**	50.47**	21.77 **
LRES-17 x DCS-27	-19.66 **	-9.79*	-13.29**	-11.69**	-13.74**	-11.50**	-1.72	-13.45**	-7.02*	20.37*	-21.71*	-10.68	4.25	8.99	8.38
LRES-17 x SH-72	-24.14 **	-11.89**	-2.10	-5.67**	-11.53**	-8.41**	-18.52**	-24.72**	-26.99**	-10.86*	-33.08**	-19.85 **	-2.23	16.77*	9.37
Geeta x SH-72	-3.94*	-8.72**	-3.08	-5.67**	-3.91	-0.56	-8.76**	-3.58	2.23	-18.49**	-19.93**	-6.45	14.22**	20.56**	3.15
Geeta x 48-1	-8.99 **	-1.20	-3.59	-6.78**	-4.07	-4.36*	-8.62**	-5.47	-7.96**	-20.61**	-3.44	-1.72	-26.65**	-3.83	1.31

*, ** Significant at 5% and 1% level, respectively

Table 4.23 contd..

Cross	Effective spike length			Number of capsules per primary spike			100 seed weight			Seed yield per plant			Oil content		
	Heterosis	Inbreeding depression		Heterosis	Inbreeding depression		Heterosis	Inbreeding depression		Heterosis	Inbreeding depression		Heterosis	Inbreeding depression	
		Selfed	Open pollinated		Selfed	Open pollinated		Selfed	Open pollinated		Selfed	Open pollinated		Selfed	Open pollinated
VP-1 x DCS-5	26.64 **	20.11 **	15.71*	42.43**	4.64	4.82	24.41**	8.95**	5.08	74.90**	22.33**	18.43**	3.80**	-1.31	5.90**
VP-1 x DCS-27	45.26 **	18.23 **	13.15*	55.08**	28.96**	23.41**	9.39**	4.42	-5.21	94.79**	29.27**	22.31**	-8.24**	-1.12	-6.86**
DPC-9 x DCS-9	13.21 *	2.30	5.32	19.70**	4.57	0.69	25.77**	1.75	0.69	29.66**	26.74**	14.54**	-5.09**	-0.77	-1.97
DPC-9 x DCS-27	30.03 **	52.54 **	21.75**	45.71**	50.91**	18.25**	17.10**	16.99**	8.62*	63.04**	43.14**	21.32**	-1.65	6.25**	0.50
LRES-17 x DCS-27	5.66	7.33	6.67	21.20**	13.40	9.99	-3.06	3.39	-5.70	78.31**	44.18**	31.98**	-3.66**	3.31**	-2.67*
LRES-17 x SH-72	0.07	24.18**	11.61	0.63	30.64**	12.08	5.19*	3.75	1.07	63.73**	26.48**	17.07**	2.06*	4.58**	6.19**
Geeta x SH-72	13.07 **	20.36 **	0.47	-0.16	5.38	4.24	9.65**	12.87**	3.21	28.64**	27.61**	17.33**	2.52**	4.22**	4.53**
Geeta x 48-1	-23.99 **	2.25	10.30	-24.08**	-13.09	-4.76	14.56**	-3.98	0.54	21.01**	4.28	14.70**	-0.23	-0.74	3.91**

*, ** Significant at 5% and 1% level, respectively

significant negative inbreeding depression was observed in five crosses in selfed F_2 and four crosses in open pollinated F_2 population.

4.4.2.2 Days to maturity

All the eight crosses exhibited significant negative heterosis and negative values of inbreeding depression for days to maturity under both selfed and open pollinated F_2 population, barring the cross, DPC-9 x DCS-27 which exhibited non-significant positive inbreeding depression under open pollinated F_2 generation.

Highest significant negative inbreeding depression was observed in cross, VP-1 x DCS-27 (-14.76 %) followed by LRES-17 x DCS-27 (-13.74 %), LRES-17 x SH-72 (-11.53 %) and VP-1 x DCS-5 (-6.29 %) under F_2 selfed condition. The crosses, Geeta x 48-1, Geeta x SH-72 and DPC-9 x DCS-9 showed non-significant inbreeding depression in selfed F_2 population. However, the cross, Geeta x SH-72 recorded non-significant inbreeding depressions under open pollinated F_2 generation also.

4.4.2.3 Number of nodes

For number of nodes the magnitude of inbreeding depression was high in selfed than open pollinated F_2 population for all the crosses except LRES-17 x SH-72 and Geeta x 48-1. All the eight crosses recorded negative heterosis and negative inbreeding depression values except Geeta x SH-72 which had positive inbreeding depression in open pollinated F_2 population. The cross, VP-1 x DCS-27 exhibited highest significant negative inbreeding depression (-34.08 %) followed by VP-1 x DCS-5 (-27.39) and LRES-17 x

SH-72 (-24.72 %) in selfed F_2 population. These crosses also had significant negative heterosis. However, the cross, DPC-9 x DCS-27 exhibited non-significant values for inbreeding depression and heterosis for number of nodes.

4.4.2.4 Plant height

Among eight crosses, three crosses under F_2 selfed and one cross under F_2 open pollinated condition exhibited significant negative inbreeding depression for plant height. Only cross, DPC-9 x DCS-27 showed significant positive inbreeding depression (34.34 and 24.14 %) in both selfed F_2 and open pollinated F_2 population, though it had non-significant heterosis (0.62 %). The crosses, VP-1 x DCS-5, VP-1 x DCS-27, DPC-9 x DCS-9 and Geeta x 48-1 showed non-significant inbreeding depression, while former three crosses had significant positive heterosis and the latter cross had significant negative heterosis.

4.4.2.5 Primary spike length

For primary spike length, the magnitude of inbreeding depression was high in selfed F_2 than open pollinated F_2 population except for VP-1 x DCS-27 cross. The cross, DPC-9 x DCS-27 exhibited highest significant positive inbreeding depression under both F_2 selfed and F_2 open pollinated condition and also had significant positive heterosis. However, the crosses, LRES-17 x SH-72 and Geeta x SH-72 showed significant positive inbreeding depression in selfed F_2 population. Further, the crosses, VP-1 x DCS-5 and

VP-1 x DCS-27 recorded non-significant inbreeding depression though they had significant positive heterosis for primary spike length.

4.4.2.6 Effective spike length

The values of inbreeding depression were positive for all the crosses and their magnitude was high in selfed F_2 than open pollinated F_2 population for effective spike length. The cross, DPC-9 x DCS-27 recorded highest significant positive inbreeding depression (52.5 %) followed by LRES-17 x SH-72 (24.18 %), Geeta x SH-72 (20.36 %), VP-1 x DCS-5 (20.11 %) and VP-1 x DCS-27 (18.23 %) in selfed F_2 population. However, all these crosses had significant positive heterosis except LRES-17 x SH-72. The cross, DPC-9 x DCS-9 showed non-significant inbreeding depression though it had significant positive heterosis. Further, the crosses, LRES-17 x DCS-27 and Geeta x 48-1 also recorded non-significant inbreeding depression but the former cross had non-significant heterosis, while the latter had significant negative heterosis.

4.4.2.7 Number of capsules per primary spike

The magnitude of inbreeding depression was high in F_2 selfed than F_2 open pollinated condition for number of capsules per primary spike barring the cross, VP-1 x DCS-5. The crosses, DPC-9 x DCS-27 and VP-1 x DCS-7 recorded significant positive inbreeding depression in both selfed F_2 and open pollinated F_2 population and were also exhibited significant positive heterosis. However, the crosses, VP-1 x DCS-5, DPC-9 x DCS-9 and LRES-17 x DCS-27 exhibited non-significant inbreeding depression, though

they recorded significant positive heterosis for the trait. Further, the crosses, Geeta x 48-1 recorded non-significant negative inbreeding depression and significant negative heterosis.

4.4.2.8 100-seed weight

For 100-seed weight the values of inbreeding depression were high in selfed F_2 than open pollinated F_2 generation for all the crosses except LRES-17 x DCS-27. The cross, DPC-9 x DCS-27 recorded highest significant positive inbreeding depression under both F_2 selfed and F_2 open pollinated condition, while the crosses, Geeta x SH-72 and VP-1 x DCS-5 recorded significant positive inbreeding depression in selfed F_2 population only. However, the crosses, DPC-9 x DCS-9, Geeta x 48-1, VP-1 x DCS-27 and LRES-17 x SH-72 showed non-significant inbreeding depression though they had significant positive heterosis for 100-seed weight.

4.4.2.9 Seed yield per plant

For seed yield per plant all the crosses recorded significant positive heterosis and significant positive inbreeding depression in both selfed and open pollinated population of F_2 barring Geeta x 48-1 cross, which had non-significant inbreeding depression under F_2 selfed condition. The magnitude of inbreeding depression was high under F_2 selfed than F_2 open pollinated condition for all the crosses, except for the cross, Geeta x 48-1. The crosses, LRES-17 x DCS-27 and DPC-9 x DCS-27 exhibited highest significant positive inbreeding depression, whereas the crosses, VP-1 x DCS-5 and VP-1

x DCS-27 had moderate inbreeding depression values, though they reported highest heterosis.

4.4.2.10 Oil content

For oil content four crosses each under F_2 selfed and F_2 open pollinated condition exhibited significant positive inbreeding depression. However, negative significant inbreeding depression was observed in crosses VP-1 x DCS-27 and LRES-17 x DCS-27 in open pollinated F_2 population, which reported significant negative heterosis. The only cross, VP-1 x DCS-5 exhibited non-significant negative inbreeding depression in selfed F_2 population, though it had significant positive heterosis.

CHAPTER V

DISCUSSION

CHAPTER V

DISCUSSION

Castor (*Ricinus communis* L.) is an important crop grown for its non-edible oil which has an everlasting demand in various industries. However, its average yield levels are relatively low in India, more particularly in Andhra Pradesh, owing to lack of proper crop management and susceptibility to pests and diseases. Castor is being grown as monocrop under rainfed conditions in marginal lands of Telangana region of Andhra Pradesh. Developing the varieties / hybrids adoptable to such conditions by manipulating the genetic architecture of plant might be rewarding in increasing the yields of the crop.

In castor, large variation exists for most of the qualitative characters such as leaf shape, stem colour, bloom nature, spininess of capsule and internode nature which have several economic features. Despite its importance, available literature on genetics of these traits is very meagre. Studying the mode of inheritance of these important morphological traits in newly developed material is imperative for improving the existing varieties \ hybrids.

Castor wilt caused by *Fusarium oxysporum* fsp. *ricini* is the most important disease causing extensive damage to the crop. Further, it is very difficult to control the disease, since it is primarily soil borne. Development of resistant varieties is the only feasible solution for combating the disease.

Breeding efforts were initiated early in 1957 by Moshkin for developing resistance to fusarium wilt in castor. Despite the efforts, fusarium wilt disease is still a menace to castor growing farmers. Hence, identification of resistance source and its mode of inheritance is imperative to develop cultivars / hybrids resistant to fusarium wilt.

Castor crop improvement programme aimed at evolving high yielding, dwarf, early maturity hybrids / varieties can be carried out effectively, only if information on combining ability of the parents to be used is available. The concept of combining ability gained importance in plant breeding as it provides the means of understanding the nature of gene action for developing suitable breeding procedures and selecting the parental lines for further breeding programme.

In addition to enhance the yield potential of hybrids, it is necessary to reshuffle the genes by crossing and to study the heterotic effects of F_1 and its maintenance in F_2 and subsequent generations. Information on the extent of inbreeding depression apart from the level of heterosis provides basis for estimating the nature and magnitude of gene action which aids in selecting the breeding procedure to be followed for further improvement of the traits. If the farmer prefer to go for cultivation of their home grown F_2 seed of F_1 hybrids, the information on loss in seed yield due to inbreeding is prerequisite. Galeev (1969) conducted research in some cross pollinated crops and stated that inbreeding depression is less in castor to maize. But

very little information is available on the magnitude of inbreeding depression in castor and the possible utilization of F_2 seed on commercial scale.

Keeping in view of the above points, the present study was planned with the title of "Genetic analysis of some qualitative and quantitative traits in castor" and the results of the study are discussed experiment wise here under.

5.1 INHERITANCE OF CERTAIN MORPHOLOGICAL CHARACTERS

Five important morphological characters were studied to know their genetic behaviour utilizing nine parents. Crosses were made between the parental lines possessing contrasting morphological traits for the respective characters under study. The results of the study are discussed here under.

5.1.1 Segregation of individual characters

Inheritance of leaf shape was studied in four crosses involving parents with flat and cup shape leaves. The F_1 plants of all the crosses expressed flat leaf showing its dominant nature and in F_2 population segregated in 3:1 ratio for flat and cup shape leaved plants (Table 4.1) indicating monogenic dominant gene control for the leaf shape. The results are further conformed with segregation ratio of backcrosses. Pokhriyal *et al.* (1964) also reported that cuppish leaf shape in *Brassica juncea* is recessive to normal leaf and is governed by two pairs of recessive factors. Brigham (1973) found that mosaic leaf character is controlled by a single recessive gene in castor.

Four crosses were studied to know the inheritance of stem colour i.e. red vs. green. The results (Table 4.2) showed that red stem was dominant over green stem as it is expressed in F_1 generation and the colour of the stem is controlled by a single dominant gene as it showed a 3 red : 1 green plants in F_2. The results are also corroborated with backcross segregation ratios. Further one cross (Geeta x DCS-27) was studied involving parents with red and mahogany stem. The expression of F_1 and F_2 plants inferred that red is dominant over mahogany and is also a monogenic trait. These results are in conformity with the earlier workers, Joglekar and Deshmukh (1957), Anonymous (1968), Reenen (1976) and Solanki and Joshi (2001), who reported that the red colour stem is monogenic and dominant. However, Bhapkar and Deshmukh (1978) reported that red stem colour is partially dominant over green with pink colour as partial double.

A total of six crosses were studied to understand the mode of inheritance of bloom nature in castor. Two crosses viz., VP-1 x DCS-9 and VP-1 x 48-1, where the parent VP-1 was triple bloom and DCS-9 and 48-1 were double bloom, gave the F_1 individuals with triple bloom showing its dominant nature. The F_2 population was segregated at a ratio of 3 triple : 1 double bloom, implying that the character is governed by single gene and triple bloom is dominant over double (Table 4.3). These results are further conformed by the segregation pattern of backcross generations. However, in two crosses (VP-1 x Co-1 and LRES-17 x Co-1) involving parents with triple and zero bloom, the F_1 plants were similar to double bloom with partial

bloom on upper surface of leaf which were explained as partial triple bloom. The F_2 generation was segregated in 1:2:1 ratio of triple, partial triple and zero bloom, respectively (Table 4.4) inferring that triple bloom is partially dominant over zero bloom and is governed by single gene. It was also conformed with the segregation ratio of backcross generations. Further, in crosses, viz., DPC-9 x SH-72 and DPC-9 x 48-1, where DPC-9 was zero bloom and SH-72 and 48-1 were double bloom, the F_1 plants were similar to single bloom with partial bloom on lower surface of leaf and were explained as partial double bloom. The F_2 segregation conforms with the expected ratio of 1 : 2 : 1 of double, partial double and zero bloom, respectively (Table 4.5), suggesting that the double bloom is partially dominant over zero bloom and is also of monogenic control. These results are similar to the reports of Zimmerman (1957a), Narain (1961) and Solanki and Joshi (2001) revealing that bloom nature is monogenically dominant over zero bloom. However, Peat (1928) observed the F_2 ratio of 9 : 3 : 4 (recessive epistasis) of double, single, zero bloom, respectively for the cross involving parents with double and zero bloom, while Zimmerman (1957a) observed the F_2 ratio of 9 bloom : 7 no bloom (complementary epistasis) for the cross involving two no bloom varieties. The findings of Bhapker and Deshmukh (1978) revealed that bloom nature in governed by one partial dominant gene and one modifier gene, so that it gave a F_2 ratio of 4 : 6 : 2 : 4 of triple, double, single and no bloom, respectively. However, White (1918), Harland (1920) and Harland (1928) reported that there was either complete or partial dominance of bloom in F_1.

Inheritance of spininess of capsule was studied in four crosses involving parents with spiny and non-spiny capsules (Table 4.6). All the F_1s were with partial spiny capsules and in F_2 it showed a segregation ratio of 1 spiny : 2 partial spiny : 1 non spiny. It clearly indicates the partial dominance of spininess over non spiny with partial spiny as intermediate class and is also controlled by single gene. These results are also conformed with the segregation of backcross generations. Similarly, Smith (1963) and Anjani (1997) reported that spininess was partially dominant over nonspiny. In contrary, Bhapker and Deshmukh (1978) showed that spininess was monogenically dominant over nonspiny.

Two crosses viz., VP-1 x DCS-9 and VP-1 x 48-1 were studied to understand the mode of inheritance of internode nature in castor, where VP-1 was with condensed and DCS-9 and 48-1 were with elongated internodes (Table 4.7). All the F_1s had elongated internode showing dominance of elongated internode and the F_2 showed a segregation of 3 elongated : 1 condensed internode indicating a monogenic dominant gene control of internode nature which were further confirmed by the segregation pattern in the backcross progenies. These results were in conformity with the earlier reports of Zimmerman (1957b) and Solanki and Joshi (2001).

5.1.2 Joint segregation

Segregation of more than one character together was considered to know the presence/absence of linkages/pleiotrophy of different genes controlling different traits and the results are discussed here under.

Two crosses viz., VP-1 x DCS-9 and VP-1 x 48-1 were studied for joint segregation of leaf shape, stem colour and bloom nature (Table 4.8). The segregation pattern of F_2 and backcross populations revealed that all these three characters have assorted independent of each other and found no evidence of linkage. Solanki and Joshi (2001) also reported that in castor stem colour and bloom nature were segregating independent of each other. However, Harland (1922) and Zimmerman (1957b) reported the gene M (Mahogany stem) was linked with the gene B (Bloom) with a cross over a value of 8.3 per cent. Further two crosses, VP-1 x Co-1 and LRES-17 x Co-1 were studied for joint segregation of leaf shape and bloom nature (Table 4.9) and observed the independent segregation for these two traits.

The cross, DPC-9 x 48-1 was attempted to study segregation of stem colour, bloom nature and spininess of capsule together (Table 4.10). The chi-square values were observed as non-significant with the expected ratios for F_2 and backcross generations implying that all the three traits are segregating independently and found no evidence of linkage. Further three crosses viz., VP-1 x 48-1, Geeta x DCS-27 and Geeta x SH-72 were studied to know the joint segregation of stem colour and spininess of capsule and results (Table 4.11) revealed the absence of linkage among the genes controlling the two traits. However, joint segregation for bloom nature and spininess of capsule was studied in a cross, VP-1 x 48-1 (Table 4.12) and it was observed that the two traits were segregated independently with each other and found no evidence of linkage.

Joint segregation for leaf shape and spininess of capsule was studied in a cross, VP-1 x 48-1 (Table 4.13). Since the chi-square value was significant for F_2 and B_1 [(VP-1 x 48-1) x (VP-1)] generations, it was suggested that the two traits were not segregating independently with each other and found the evidence of linkage between the genes controlling leaf shape and spininess of capsule. The frequency of parental types and recombinant types in B_1 generation (Fig.1) clearly indicates that the gene for flat leaf (dominant) and gene for nonspiny (recessive) are linked, which are in repulsion phase. Further, the two traits observed a recombination frequency of 25.44 per cent in F_2 and 25.9 per cent in B_1 generation, inferring that the two genes are located on the same chromosome with the average distance of 25.7 map units.

Two crosses, viz., VP-1 x DCS-9 and VP-1 x 48-1 were studied to know the joint segregation of leaf shape and internode nature (Table 4.14). It was observed that the recombinants were absent in both F_2 and backcross generation of two crosses implying that the two traits might be controlled by pleiotrophic gene or might be involving tight linkage.

5.2 INHERITANCE OF FUSARIUM WILT RESISTANCE

The inheritance of fusarium wilt resistance was studied utilizing a susceptible line, VP-1 and a resistant line, 48-1. The parent, VP-1 was crossed with 48-1 and the resultant F_1 was selfed as well as backcrossed to both the parents to obtain F_2, B_1 and B_2 generations. The F_1 and segregating generations were grown in sick plots and observed the disease reaction

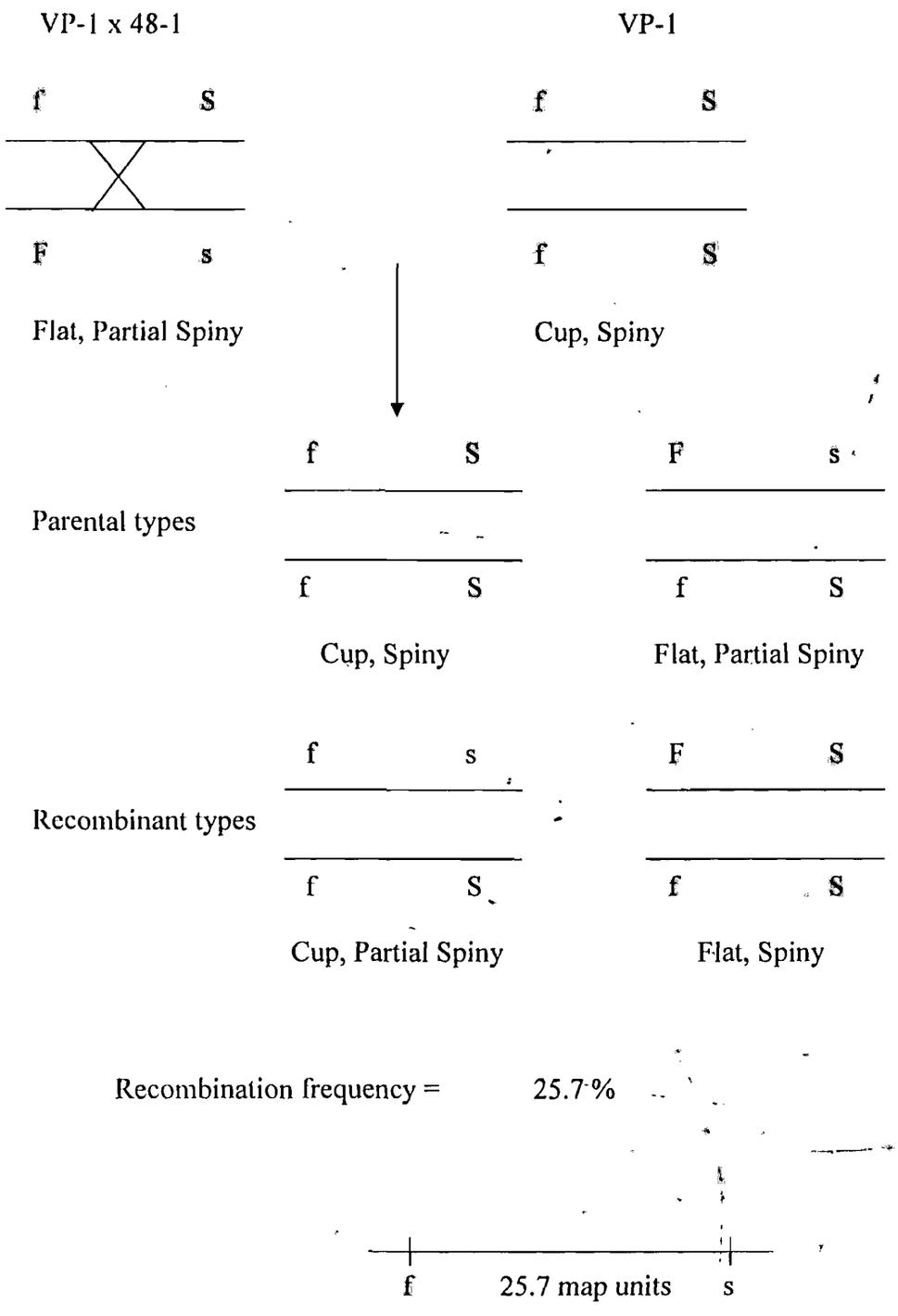


Fig. 1 : Diagramatic representation of parental and recombinant types in the backcross of (VP-1 x 48-1) x VP-1 for leaf shape and spininess of the capsule

(Table 4.15). The F_1 individuals showed susceptible reaction indicating that the susceptibility is dominant over resistance. While, the F_2 population confirmed with the segregation ratio of 9 susceptible : 7 resistant, indicating that the resistance is governed by two independent recessive genes involving complementary epistasis. The results are also corroborated with the segregation ratios of backcrosses. Similarly, Knowles and Houston (1953) reported that fusarium wilt in flax was governed by two complementary genes. However, Sviridov (1986a) reported that in castor fusarium wilt resistance was governed by a recessive factor.

5.3 COMBINING ABILITY STUDIES

The experiment was undertaken to gather information on the combining ability of few elite castor lines. These lines were involved in a line x tester mating design which is one of the powerful tools available to determine both general and specific combining ability effects of parents and cross combinations respectively and the results of the present study are discussed in this chapter under suitable sub-headings.

5.3.1 Analysis of variance and mean

The success of any breeding programme depends upon the knowledge and utilization of the genetic variability available among the parents and its progeny for the characters of interest. Analysis of variance (Table 4.17) revealed significant differences among genotypes, parents and hybrids for all the traits studied, indicating the existence of sufficient variability for effecting selection. The average performance of hybrids was different from

that of parents as evident from the significance of parents vs. crosses source of variation for all the characters. Further, significant differences were also observed among lines, testers and line x tester for all the traits except for oil content in testers, suggesting sufficient amount of variability in the material. A comparison of five best cross combinations for various characters is presented in Table 4.24. The hybrids in general were early maturing, dwarf and high yielding compared to the parents. The crosses, involving the tester, LRES-17 and the lines, DCS-9 and DCS-5 were early maturing, while crosses involving Co-1 parent were late maturing. Further the crosses of DCS-27 and SH-72 had long spikes. However, the crosses with DCS-27 had low 100-seed weight, while with Co-1 had higher values of 100-seed weight.

5.3.2 Combining ability analysis

The main objective of this part of study was to identify parents with better potential to transmit desirable characteristics to the progeny and identify the better specific crosses for seed yield and yield components. The analysis of quantitative inheritance was also an equally important objective to gain knowledge regarding the nature and magnitude of gene action, which has prime bearing concerning choice of most appropriate and efficient breeding procedures.

The average performance of hybrids was different from that of parents as evident from the significance of parent vs. cross source of variation for all the traits. This indicated the importance of non-additive genetic variation as well as heterosis in the material investigated. Further, the mean sum of squares attributed

Table 4.24 Performance of five superior crosses for each of the ten characters in castor

Cross	Per se performance	sca effect	P_1		P_2		Heterobeltiosis	Heterosis	
			Per se performance	gca effect	Per se performance	gca effect		Kranti	DCH-177
Days to 50% flowering									
LRES-17 x DCS-9	44.00	2.11	54.00	-3.36 **	45.33	-5.89 **	-2.94	-7.69	-1.50
VP-1 x DCS-9	44.33	-1.19	65.33	0.27	45.33	-5.89 **	-2.21	-6.99	-0.76
DPC-9 x DCS-5	44.33	-0.86	61.33	-0.47	51.00	-5.47 **	-13.07 **	-6.99	-0.76
VP-1 x DCS-85	44.67	-1.69	65.33	0.27	51.00	-5.06 **	-12.42 **	-6.29	0
DPC-9 x DCS-9	44.67	-0.11	61.33	-0.47	45.33	-5.89 **	-1.47	-6.29	0
Days to maturity									
LRES-17 x DCS-5	100.33	5.86 **	114.33	-5.44 **	106.33	-5.64 **	-0.94	-1.25	-5.64 **
LRES-17 x DCS-85	101.00	-0.64	114.33	-5.44 **	109.00	-3.47 **	-7.34 **	-5.31 *	-5.02 *
LRES-17 x DCS-84	101.67	-0.31	114.33	-5.44 **	115.67	-3.14 **	-11.08 **	-4.69 *	-4.39 *
VP-1 x DCS-9	102.67	-2.55	127.33	-0.04	101.00	-5.31 **	1.65	-3.75	-3.45
DPC-9 x DCS-5	102.67	-3.06	124.33	0.81	106.33	-5.64 **	-3.45	-3.75	-3.45
Number of nodes									
LRES-17 x DCS-9	9.20	-0.34	11.53	-1.04 **	8.80	-1.32 **	4.55	-13.21 *	-9.80 **
DPC-9 x DCS-5	9.47	-0.44	12.93	-0.67 **	10.73	-1.33 **	-11.80 **	-10.69 *	-7.16
LRES-17 x AVR-1	9.67	-1.35 **	11.53	-1.04 **	14.30	0.15	-16.18 **	-8.81	-5.20
LRES-17 x DCS-85	9.87	0.52	11.53	-1.04 **	11.33	-1.52 **	-12.94 **	-6.92	-3.24
DPC-9 x 48-1	9.93	-1.58 **	12.93	-0.67 **	14.87	0.28	-23.20 **	-6.29	-2.65
Plant height									
DPC-9 x DCS-5	33.07	-2.83	67.00	-2.55 **	33.93	-8.90 **	-2.55	-24.51 **	-22.61 **
LRES-17 x DCS-9	33.20	0.06	23.93	-8.66 **	36.47	-5.55 **	38.72 **	-24.20 **	-22.30 **
LRES-17 x DCS-85	35.00	5.08 **	23.93	-8.66 **	39.93	-8.76 **	46.24 **	-20.09 **	-18.09 **
LRES-17 x DCS-5	35.20	5.41 **	23.93	-8.66 **	33.93	-8.90 **	3.73	-19.63 **	-17.62 *
DPC-9 x DCS-85	35.87	-0.61	67.00	-2.55 **	39.93	-8.76 **	-10.18	-18.11 *	-16.05 *
Primary spike length									
VP-1 x SH-72	71.20	4.06	61.47	8.52 **	59.13	12.78 **	-20.41 **	129.18 **	56.38 **
Geeta x SH-72	64.53	7.84	53.87	-1.92 **	59.13	12.78 **	9.13	107.73 **	41.73 **
VP-1 x AVR-1	63.73	7.58 **	61.47	8.52 **	57.07	1.79	3.69	105.15 **	39.97 **
VP-1 x DCS-27	63.53	6.46 **	61.47	8.52 **	30.33	2.71	3.36	104.51 **	39.53 **
LRES-17 x SH-72	55.47	0.59	54.33	-3.74 **	59.13	12.78 **	-6.20	78.54 **	21.83 **

*, ** Significant at 5% and 1% level, respectively

Table 4.24 contd..

Cross	Per se performance	sca effect	P_1		P_2		Heterobeltiosis	Heterosis	
			Per se performance	gca effect	Per se performance	gca effect		Kranti	DCH-177
Effective spike length									
VP-1 x DCS-27	60.33	7.84 **	54.73	6.49 **	28.33	4.91 **	10.23	67.59 **	43.64 **
Geeta x SH-72	56.80	7.08 **	51.73	-0.40	48.73	9.03 **	9.79	57.78 **	35.24 **
VP-1 x SH-72	55.33	-1.27	54.73	6.49 **	49.73	9.03 **	1.10	53.70 **	31.74 **
VP-1 x DCS-5	50.07	2.58	54.73	6.49 **	24.33	-0.09	-8.53	39.07 **	19.21 **
LRES-17 x SH-72	48.53	2.81	48.27	-4.39 **	49.73	9.03 **	-0.41	34.81 **	15.55 *
Number of capsules per primary spike									
VP-1 x DCS-27	70.20	7.70 **	49.53	2.83 **	41.00	12.61 **	71.22 **	91.80 **	31.78 **
DPC-9 x DCS-27	69.60	5.56 *	54.53	4.37 **	41.00	12.61 **	69.76 **	90.16 **	30.66 **
Geeta x SH-72	61.33	5.79 *	57.53	-1.72	65.33	10.21 **	-6.12	67.58 **	15.13 *
DPC-9 x SH-72	59.53	-2.11	54.53	4.37 **	65.33	10.21 **	-8.88	62.66 **	11.75
VP-1 x DCS-5	56.73	8.05 **	49.53	2.83 **	30.13	-1.20	14.54	55.01 **	6.50
100-seed weight									
DPC-9 x Co-1	50.22	4.33 **	31.71	3.31 **	74.42	8.90 **	-32.52 **	78.82 **	32.47 **
Geeta x Co-1	42.17	-0.11	29.40	-0.29	74.42	8.90 **	-43.33 **	50.17 **	11.24 **
DPC-9 x AVR-1	40.77	-0.83	31.71	3.31 **	46.82	4.61 **	-12.92 **	45.19 **	7.54 **
LRES-17 x Co-1	40.01	-0.69	28.34	-1.88 **	74.42	8.90 **	-46.24 **	42.46 **	5.54 *
Geeta x AVR-1	38.89	0.88	29.40	-0.29	46.82	4.61 **	-16.95 **	38.47 **	2.59
Seed yield per plant									
LRES-17 x SH-72	360.46	38.14 **	192.26	-22.24 **	248.06	63.95 **	45.31 **	53.40 **	6.79 *
VP-1 x DCS-5	355.20	38.62 **	205.65	28.56 **	200.53	7.42 *	72.72 **	51.16 **	5.24 *
VP-1 x DCS-27	353.84	4.71	205.65	28.56 **	157.66	39.97 **	72.06 **	50.58 **	4.83
DPC-9 x DCS-27	353.56	23.49 **	276.05	9.49 **	157.66	39.97 **	28.08 **	50.46 **	4.75
Geeta x SH-72	347.86	19.12 **	292.76	-15.81 **	248.06	63.95 **	18.82 **	48.04 **	3.06
Oil content									
Geeta x DCS-85	53.04	2.12 **	48.87	0.16	49.45	2.15 **	7.26 **	17.09 **	12.90 **
DPC-9 x DCS-85	52.64	1.70 **	52.27	0.19	49.45	2.15 **	0.71	16.21 **	12.05 **
LRES-17 x DCS-9	52.08	0.71 *	50.84	1.13 **	46.77	1.64 **	2.44 **	14.98 **	10.86 **
LRES-17 x 48-1	51.79	1.94 **	50.84	1.13 **	48.07	0.11	1.86	14.33 **	10.24 **
Geeta x DCS-9	51.49	1.08 **	48.87	0.16	46.77	1.64 **	5.35 **	13.67 **	9.60 **

*, ** Significant at 5% and 1% level, respectively

to the male and female parents of the hybrids which provide a measure of their general combining ability and the interaction between male and female parents which provide a measure of specific combining ability (Rojas, 1951) were significant for all the traits except for oil content in testers, indicating the importance of both additive and non-additive gene effects for the traits.

Estimates of the relative contribution of general and specific combining ability within the genetic variability present in a population are of interest to plant breeders as breeding methods to be adopted differ appreciably depending upon the type of gene action. The estimates of components of variance (Table 4.19) and the degree of dominance indicated the predominance of additive gene action for days to 50 per cent flowering, days to maturity, number of nodes, plant height, effective spike length, number of capsules per primary spike and 100-seed weight. It implied that improvement in these traits is possible through selection in segregating generations. However, for primary spike length, seed yield per plant and oil content magnitude of sca variances were higher than gca variances indicating the preponderance of non-additive gene action. The presence of marked non-additive gene action suggests the possibility of improvement through hybridization with respect to primary spike length, seed yield per plant and oil content. Similarly, earlier workers reported predominance of additive gene action for days to 50 per cent flowering, days to maturity, number of nodes, plant height, effective spike length, number of capsules per primary spike and 100-seed weight, whereas predominance of non-additive gene action for primary spike length, seed yield per plant and oil content (Table 2.1).

The results of gca effects (Table 4.20) revealed that the lines, SH-72 and DCS-27 and the tester, VP-1 were found to be good combiners for seed yield per plant, number of capsules per primary spike, effective spike length and primary spike length, while the lines, DCS-85, Co-1 and DCS-84 and the tester, LRES-17 were found to be poor combiners for these traits. Similarly, Manivel and Hussain (1997) reported that VP-1 was good combiner for seed yield and primary spike length. For number of capsules per primary spike, the tester, DPC-9 recorded highest significant positive gca effect. The lines, Co-1 and AVR-1 and the tester, DPC-9 contributed maximum desirable alleles for 100-seed weight as evidenced by recording high significant gca effects and high *per se* performance. For oil content, the lines, DCS-85, DCS-9, DCS-5, AVR-1 and the tester, LRES-17 were identified as good combiners, since they exhibited significant positive gca effects. In contrary, the lines, DCS-27, DCS-84, Co-1 and SH-72 and the tester, VP-1 were found to be poor combiners for oil content.

Since, earliness and dwarf nature is desirable, parents with negative gca effects for days to 50 per cent flowering, days to maturity, number of nodes, plant height were considered as best combiners. The lines, DCS-9, DCS-5, DCS-85 and DCS-84, the tester, LRES-17 were found to be good combiners, for days to 50 per cent flowering, days to maturity, number of nodes and plant height, hence these lines can be included as one of the parents in crossing programme to develop genotypes with early maturity. Similarly, Manivel *et al.* (1998) identified LRES-17 as a good combiner for

earliness. However, the lines, Co-1, SH-72 and the tester, Geeta were identified as poor combiners for earliness and related traits.

It was observed that *per se* performance of parents for majority of the traits, in general, was related to their gca effects. Thus, if a trait is unidirectionally controlled by a set of alleles and additive effects are important, the choice of parents based on *per se* performance may be effective. These results are akin to the earlier reports of Sudhakar *et al.* (1995) and Mehta (2000). Further, parents which exhibited significant gca effects for seed yield per plant, also possessed high significant gca effects for some of the yield components.

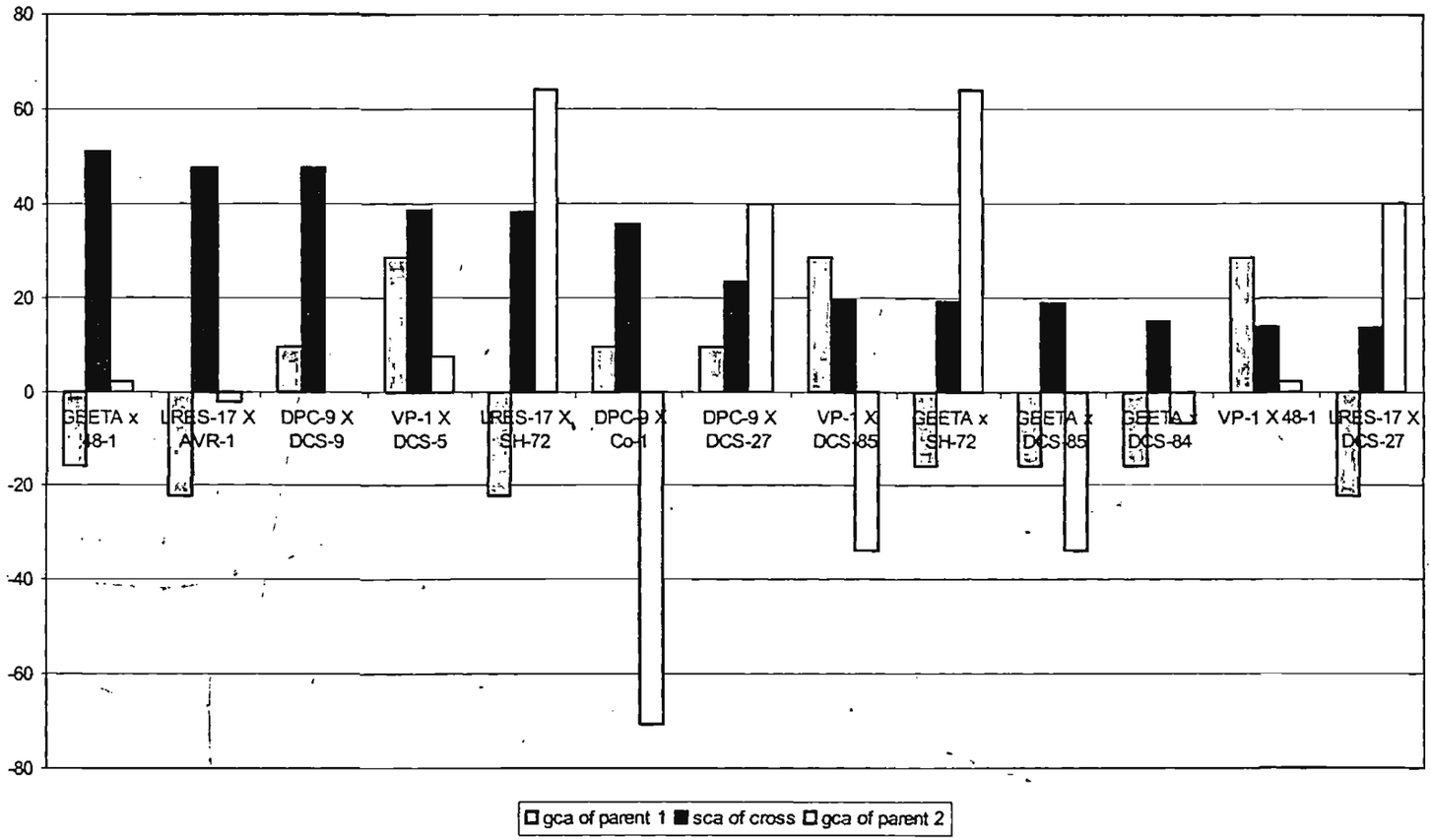
The study of sca effects (Table 4.21) revealed significant and desirable effects in several hybrids for days to 50 per cent flowering (5), days to maturity (5), number of nodes (8), plant height (6), primary spike length (8), effective spike length (5), number of capsules per primary spike (5), 100-seed weight (7), seed yield per plant (13) and oil content (14).

The crosses exhibiting significant desirable sca effects for different characters involve parents with either high x high or high x low or low x low gca effects, indicating the predominance of additive, non-additive and complimentary gene action in the respective crosses. Hence, it could be suggested that information on gca effects should be supplemented by sca effects and *per se* performance of crosses for identifying the transgressive segregants. These results are in confirmity with Mehta (2000).

In majority of the crosses with significant sca effects involved the parents having one good and one poor combiner for all the characters indicating the significance of non-additive gene action in governing the traits. It is in conformity with the results of Singh and Srivastava (1982) and Fatteh *et al.* (1988) suggested that most of the superior combinations have involved at least one good general combiner and thus combining ability of a parent might be considered as a reliable guide in the prediction of the yield potential of a cross. In general, selection is rapid if gca effects of the parents and sca effects of the crosses are in same direction.

For seed yield per plant, out of 13 crosses having significant positive sca effects, 7 crosses (54 %) had parents with high x low gca effects, while 3 crosses (23 %) each had parents with high x high and low x low gca effects (Fig.2). In the present study it was observed that majority of the higher sca effects involved both or at least one good combiner indicating additive x additive or additive x dominance type of gene action. A comparison of mean performance of hybrids and their sca effects (Table 4.24) revealed that high *per se* performance of crosses was not always related with their higher sca effects in majority of the traits. Therefore, *per se* performance should be given preference over sca effects while choosing best cross combinations, since sca effects are merely a measure of deviation of F_1 performance from prediction based on parental gca effects. These results are akin to the reports of Manivel *et al.* (1998) and Mehta (2000).

Fig 2 Graph showing gca and sca effects of crosses having significant positive sca effects for seed yield per plant



Among the 14 crosses, which exhibited significant positive sca effect for oil content, 7 crosses (50 %) had parents with high x high gca effects, while 6 crosses (43 %) had high x low gca effects. However, single cross (7 %) involved the parents with low x low gca effects (Fig.3). It is also suggested that majority of the superior crosses resulted from the parents among which at least one parent had high gca effect for oil content indicating the predominance of non-additive gene action.

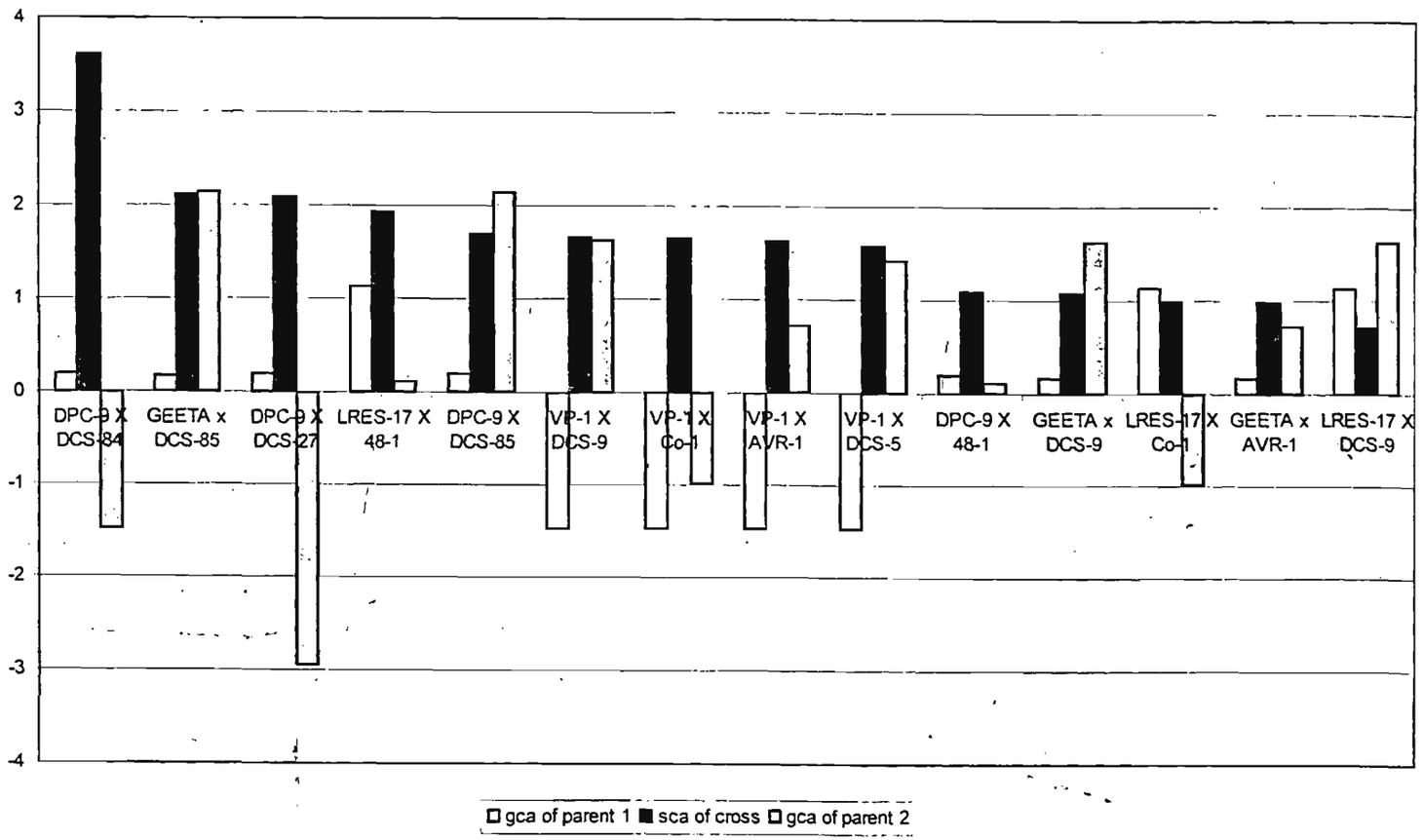
Since, the degree of dominance for seed yield and oil content are near to unity and superior crosses involving the parents with good gca effects, it is recommended that the crosses having desirable sca effects could be handled through recurrent or reciprocal recurrent selection for the improvement of yield and oil content. Further, the crosses exhibited high *per se* performance and substantial heterosis over better check could be exploited through heterosis breeding.

5.4 HETEROSIS AND INBREEDING DEPRESSION

5.4.1 Heterosis

Commercial exploitation of heterosis in crop plants is regarded, a major breakthrough in the realm of plant breeding. Heterosis breeding had led to considerable yield improvement in several crops (Rai, 1979). A substantial degree of heterosis for yield and related traits over better parent and standard checks have been reported in castor hybrids (Stein, 1958; Muhammad *et al.*, 1965; Hooks *et al.*, 1971; Chakrabarty, 1997).

Fig 3 Graph showing gca and sca effects of crosses having significant positive sca effects for oil content



The aim of heterosis analysis in the present study was to identify the best combination of parents resulting in high degree of useful heterosis. The existence of overall heterosis was evident by the significance of parent vs. cross in the analysis of variance (Table 4.17) for all the characters under study. Higher levels of heterosis in desired direction was observed in several crosses for various traits (Table 4.25). Majority of the crosses recorded significant and negative heterobeltiosis for days to 50 per cent flowering (22), days to maturity (19), number of nodes (8), and plant height (7). Similarly, negative heterosis was reported by earlier workers for days to 50 per cent flowering (Muhammad *et al.*, 1969; Muhammad *et al.*, 1970; Hooks *et al.*, 1971), days to maturity (Khan and Rehman, 1965; Moshkin and Voskobojnik, 1967; Gopani *et al.*, 1968; Muhammad *et al.*, 1970), plant height (Khan and Rehman, 1965; Gopani *et al.*, 1968; Muhammad *et al.*, 1970), number of nodes (Chakrabarty, 1997). However, none of the crosses exhibited significant negative heterosis over the checks, Kranti and DCH-177 for days to 50 per cent flowering, while 3 crosses each for days to maturity, 2 and 8 crosses for node number, 6 and 5 crosses for plant height exhibited significant negative heterosis over Kranti and DCH-177, respectively.

Considerable number of crosses recorded significant positive standard heterosis for primary spike length (32 over Kranti and 9 over DCH-177), effective spike length (15 over Kranti and 8 over DCH-177), number of capsules per primary spike (18 over Kranti and 3 over DCH-177), seed yield per plant (25 over Kranti and 4 over DCH-177) and oil content (30 over

Table 4.25: Number of crosses with significant desirable heterosis for ten characters in castor

Character	Number of hybrids with significant heterosis in the desired direction over		
	Better parent	Kranti	DCH-177
1. Days to 50% flowering	22	0	0
2. Days to maturity	19	3	3
3. Number of nodes	8	2	8
4. Plant height	7	6	5
5. Primary spike length	1	32	9
6. Effective spike length	1	15	8
7. Number of capsules per primary spike	3	18	3
8. 100-seed weight	14	30	4
9. Seed yield per plant	19	25	2
10. Oil content	6	30	22

Kranti and 22 over DCH-177). Similarly positive heterosis was also reported earlier by several researchers in castor, for primary spike length (Muhammad *et al.*, 1969, Muhammad *et al.*, 1970; Kaul *et al.*, 1983), effective spike length (Mehta *et al.*, 1991a), number of capsules per primary spike (Khan and Rehman, 1965; Gopani *et al.*, 1968; Kabaria and Gopani, 1971; Kaul *et al.*, 1983; Pathak *et al.*, 1988; Mehta *et al.*, 1991a), 100-seed weight (Khan and Rehman, 1965; Satyabalan *et al.*, 1965; Pathak *et al.*, 1988), seed yield (Stein, 1958; Ankineedu and Kulkarni, 1965; Khan and Rehman, 1965; Muhammad *et al.*, 1965; Satyabalan *et al.*, 1965; Moshkin and Voskobojnik, 1967; Gopani *et al.*, 1968; Muhammad *et al.*, 1969; Muhammad *et al.*, 1970; Hooks *et al.*, 1971; Kabaria and Gopani, 1971; Voskobojnik and Moshkin, 1977; Kaul *et al.*, 1983; Savy *et al.*, 1986; Pathak *et al.*, 1988; Mehta *et al.*, 1991a; Chakrabarty, 1997; Saiyed *et al.*, 1997) and oil content (Khan and Rehman, 1965; Gopani *et al.*, 1968; Hooks *et al.*, 1971; Voskobojnik and Moshkin, 1977; Saiyed *et al.*, 1997).

A comparison of five best cross combinations for various characters is presented in Table 4.24. The overall results of heterobeltiosis, standard heterosis indicated that the parents involved in the crossing programme should have at least one with high *per se* performance. Similar results were also ascribed from specific combining ability studies. High sca resulted either due to high x high or high x low gca effects of parents. The degree of dominance values indicated that complete dominance might be the cause of heterosis for seed yield for plant, whereas over-dominance for oil content.

The main reason ascribed is diversified parents involved in the cross combinations or uncommon gene(s) for trait(s) in the parents for the observed level of heterosis. Breeder can exploit non-additive gene action through heterosis breeding programme for the desirable crosses involving high x low gca effects of parents, whereas, since, heterosis obtained from high x high gca effects is of fixable type, pedigree method of breeding can be practiced for improvement of the respective trait(s).

Based on the *per se* performance of hybrids and extent of heterosis, two hybrids, namely, LRES-17 x SH-72 and VP-1 x DCS-5 were selected which out yielded significantly over the better check, DCH-177 and could be exploited through heterosis breeding programme. Further, the crosses also exhibited non-significant heterosis over short duration check, DCH-177 for earliness and its related traits (days to 50 % flowering, days to maturity, number of nodes, plant height) except, LRES-17 x SH-72 for number of nodes. Hence, such crosses could also be handled further to derive high yielding and short duration castor genotypes.

5.4.2 Inbreeding depression

An attempt was made to study the extent of inbreeding depression in both selfed and open pollinated populations for ten characters in eight selected crosses in the second filial generation and results (Table 4.23) are discussed here under.

For days to 50 per cent flowering, days to maturity, number of nodes and plant height majority of the crosses exhibited significant negative inbreeding depression, indicating the higher values in F_2 than the F_1 generation. In contrary, positive inbreeding depression is desirable for the earliness and related traits to obtain desirable segregants in F_2 and subsequent generations. However, the heterosis values were negative and significant in majority of the crosses for these traits. Further, the crosses exhibiting higher negative heterosis also exhibited higher values of negative inbreeding depression, suggesting the predominance of additive gene effects.

The crosses, VP-1 x DCS-5 and Geeta x 48-1 for days to 50 per cent flowering, Geeta x 48-1, Geeta x SH-72, DPC-9 x DCS-9 and DPC-9 x DCS-27 for days to maturity, Geeta x SH-72 and Geeta x 48-1 for number of nodes and Geeta x 48-1 and DPC-9 x DCS-9 for plant height exhibited non-significant inbreeding depression in selfed population apart from exhibiting significant negative heterosis for the respective traits indicating the fixing of additive gene effects, which would result in the appearance of transgressive segregants in the F_2 and subsequent generations. Hence, such crosses could be handled for isolating desirable segregants with earliness and dwarf nature. However, the cross, LRES-17 x DCS-27 showed significant positive heterosis in F_1 and significant negative inbreeding depression in selfed F_2 population for plant height suggesting the predominance of both additive and non-additive gene action.

For the traits viz., primary spike length, effective spike length, number of capsules per primary spike, in general, the magnitude of inbreeding depression was high in selfed compared to open pollinated population, indicating that the inbreeding depression would be high under strict inbreeding than in open pollinated F_1 individuals. Further, the crosses showing higher heterotic effects consequently expressed the higher values of inbreeding depression in most of the cases, inferring the predominant role of non-additive gene action. However, the cross, Geeta x 48-1 exhibited non-significant inbreeding depression and significant negative heterosis for primary spike length, effective spike length and number of capsules per primary spike. The crosses, VP-1 x DCS-5 and VP-1 x DCS-27 for primary spike length, DPC-9 x DCS-9 for effective spike length and VP-1 x DCS-5, DPC-9 x DCS-9 and LRES-17 x DCS-27 for number of capsules per primary spike exhibited desirable non-significant inbreeding depression, though they had significant positive heterosis. It suggests the possibility of fixing of additive gene effects for the traits in these crosses. The genetic theory of evolution of genes (Fasoulas, 1981) also appears to be fitting well, as the dominant genes represent the most desirable conditions in the evolution of gene actions, where all heterotic effects are constantly converted through recombination into additive and fixable effects and thereby leading to stability of hybrid vigour in F_2, showing absence of any inbreeding depression. Such crosses could be used to produce biparental progenies to get segregants superior to better parent, which may be handled through pedigree method of breeding.

These results are akin to the reports of Hirve and Tiwari (1991) who mentioned inbreeding depression was absent in Indian mustard.

For 100-seed weight also the magnitude of inbreeding depression was high in selfed F_2 than open pollinated F_2 population barring the crosses which involve, DCS-27 as male parent. Since, the 100-seed weight of DCS-27 parent was least (Table 4.18), open pollination of the hybrids of DCS-27 had negative inbreeding depression. The crosses exhibiting significant positive inbreeding depression viz., DPC-9 x DCS-27, VP-1 x DCS-5, Geeta x SH-72 were also recorded significant positive heterotic effects indicating the presence of dominance and over dominance for 100-seed weight, wherein heterosis breeding could be rewarding for improvement of the trait. Similarly, Pathak *et al.* (1988) reported high inbreeding depression for 100-seed weight in castor. However, the crosses, DPC-9 x DCS-9, VP-1 x DCS-27, LRES-17 x SH-72 and Geeta x 48-1 recorded non-significant inbreeding depression in selfed F_2 population though they had significant positive heterosis indicating the predominance of fixable gene effects. Hence, it could be possible to isolate desirable transgressive segregants in the F_2 and subsequent generations which could be handled through pedigree method of breeding to develop suitable varieties with high test weight.

Similarly for seed yield per plant the magnitude of inbreeding depression was high under selfed F_2 compared to open pollinated F_2 population. It suggests that the inbreeding depression was high under strict

selfing than the open pollination of F_1 hybrids. Among eight crosses, studied seven crosses had significant positive values for both inbreeding depression and heterosis, indicating the predominance of non-additive gene components in governing seed yield. These results were also confirmed with the values of degree of dominance. Similar results were reported by Pathak *et al.* (1988) in castor and Singh and Rai (1995) in Indian mustard. Therefore, the desirable best crosses can be utilised in the breeding programme and rapid progress can be achieved by family selection following intermating in subsequent generations for the improvement of seed yield. However, the cross, Geeta x 48-1 exhibited non-significant inbreeding depression in selfed F_2 condition besides expressing positive heterosis. It indicates the predominance of additive type of gene action. These results are akin to the reports of Yazdi-Samadi *et al.* (1975) who reported negligible inbreeding depression in safflower. Hence, the cross could be used to produce biparental progenies and evaluate subsequently to get superior segregates which might be handled through pedigree method of breeding.

For oil content, two crosses viz., LRES-17 x SH-72 and Geeta x SH-72 exhibited significant positive inbreeding depression and also had significant positive heterosis suggesting the preponderance of non-fixable gene effects. The cross LRES-17 x DCS-27 recorded significant positive inbreeding depression in selfed F_2 population and significant negative heterosis in F_1 suggesting the presence of epistatic interactions in governing the trait. However, the cross, VP-1 x DCS-5 exhibited non-significant

negative inbreeding depression, though it had significant positive heterosis inferring the predominance of fixable gene effects. Hence, it could be possible to isolate desirable transgressive segregants from such cross in F_2 and subsequent generation, which might be handled through pedigree method of breeding for improving oil content.

For the utilisation of F_2 seed for commercial crop production, it is essential to have low inbreeding depression for seed yield and also they should be uniform in height and maturity duration. However, the F_2 population of the crosses involving LRES-17 as female parent showed large variation in plant height and days to maturity, while the crosses with VP-1 showed large variation in plant height. Further, most of the crosses studied exhibited high magnitude of inbreeding depression for seed yield per plant barring the cross, Geeta x 48-1. It was also found that the decrease in seed yield was several folds high when compared to hybrid seed cost. Hence, based on the results it could be suggested that it is not worthwhile to recommend F_2 seed for commercial crop production. However, the crosses involving DPC-9 as female parent whose height and maturity parameters were relatively on par with majority of good male combiners, the F_2 seed could be suggested for sowing, if the cross is highly heterotic with no inbreeding depression.

CHAPTER VI

SUMMARY

CHAPTER VI

SUMMARY

The present study in castor was undertaken to understand the genetics of certain important morphological characters and their associations, to know the mode of inheritance of fusarium wilt resistance, to obtain information on the nature of combining ability and gene effects of parents and also to study the extent of heterosis and inbreeding depression in selected crosses.

Experiments were conducted objective wise and salient findings emerged there from have been summarised below.

1. Inheritance of certain morphological characters

Nine crosses were made between the parental lines possessing contrasting features of morphological characters for one or more of the five traits studied viz., leaf shape (cup vs. flat), stem colour (red vs. green), bloom nature (triple vs. double; triple vs. zero; zero vs. double), spininess of capsule (spiny vs. nonspiny) and internode nature (condensed vs. elongated). The F_1, F_2 and backcross generations for each of the nine crosses were evaluated for the expression of respective morphological traits studied.

Results revealed that the leaf shape is controlled by single gene and flat shape being dominant over cup shape. Similarly the stem colour is monogenically controlled with red colour being dominant over green. The crosses involving triple bloom and double bloom parents revealed that triple bloom is dominant over double bloom and is under single gene control. However, the crosses

between triple bloom and zero bloom parent showed that triple bloom is partially dominant over zero bloom and is of monogenic control, whereas the crosses between zero bloom and double bloom parent revealed the partial dominant nature of double bloom over zero bloom and is also controlled by single gene. Studies on genetics of spininess of capsule showed that spininess is partially dominant over nonspiny with partial spiny as intermediate class and is of monogenic control. In case of internode nature elongated internode is dominant over condensed nature and is controlled by single gene.

Joint segregation studies in different crosses for leaf shape, stem colour, bloom nature and stem colour, bloom nature, spininess of capsule revealed that the genes governing the traits are assorting independently and found no evidence of linkage. However, the genes governing traits viz., leaf shape and spininess of capsule were found to involve linkage with cross over value of 25.7 per cent. The allele for cup shape leaf (recessive) is linked with the allele for spiny capsule (dominant) and vice-versa i.e., in repulsion phase. Due to absence of recombinants it is concluded that the traits, cup shape leaf and condensed nature of internodes might involve tight linkage or due to pleiotrophic effect of the gene.

2. Inheritance of fusarium wilt resistance

The cross, VP-1x 48-1 involving a susceptible parent (VP-1) and a resistant parent (48-1) was attempted and further handled to produce F_2, B_1, B_2 generations. F_1 hybrids and segregating generations were screened in wilt sick plot and observed for the disease reaction. The expression of F_1 individuals and the segregation of F_2 and back cross populations revealed that resistance to wilt is

controlled by two genes involving complimentary epitasis and resistance is recessive over susceptibility.

3. Combining ability studies

Nine males and four females were crossed in line x tester fashion to obtain 36 F_1 hybrids. The parents and crosses were evaluated for ten quantitative characters and data were subjected to combining ability analysis.

The analysis of variance for combining ability revealed significant differences among lines, testers, line x testers for all the traits except for oil content in testers, indicating the presence of ample variation for effecting selection. In general the hybrids were early maturing, dwarf and high yielding compared to their parents. The estimates of components of variance and degree of dominance indicated the predominance of additive gene action for days to 50 per cent flowering, days to maturity, number of nodes, plant height, effective spike length, number of capsules per primary spike and 100-seed weight. However, the traits, primary spike length, seed yield per plant and oil content were found to be governed predominantly by non-additive gene action.

Among the parents, LRES-17, DCS-5, DCS-9 and DCS-85 were found to be good combiners for early maturity and dwarfness apart from oil content, while the parents, VP-1, DPC-9, DCS-5, DCS-27 and SH-72 were adjudged as the best general combiners for seed yield per plant. It could be suggested that the female lines possessing good combining ability for seed yield could be crossed to the best combining male parents for earliness and related traits or vice versa in order to obtain desirable segregants.

Of the 36 hybrids studied, four hybrids, namely DPC-9 x DCS-9, VP-1 x DCS-5, DPC-9 x DCS-27 and Geeta x SH-72 had high significant sca effects for seed yield and for one or more yield component characters viz., primary spike length, effective spike length, number of capsules for primary spike and 100-seed weight. The crosses exhibiting significant desirable sca effects for different characters involve parents with either high x high or high x low or low x low gca effects. In general, majority of the crosses with significant sca effects involved parents having one good and one poor combiner for all the characters indicating the significance of non-additive gene action in governing the traits.

4. Heterosis and inbreeding depression

The existence of overall heterosis was evident by the significance of parent vs. cross in the analysis of variance of all the characters studied. Two hybrids viz., LRES-17 x SH-72 and VP-1 x DCS-5 significantly out yielded the better check, DCH-177 and could be exploited through heterosis breeding programme following proper testing.

Inbreeding depression studies indicated that in general the magnitude of inbreeding depression was high in selfed population compared to open pollinated population of F_2. It suggests that the level of depression is high under strict selfing than open pollination of F_1 hybrids. In majority of the crosses both heterosis and inbreeding depression were negative and significant for days to 50 per cent flowering, days to maturity, number of nodes and plant height indicating predominance of additive gene effects in governing the traits. However, for seed yield per plant, 100-seed weight, number of capsules per primary spike, effective

spike length, primary spike length and oil content, majority of crosses exhibited significant positive values for both heterosis and inbreeding depression indicating the predominance of non-additive gene effects. Further, desirable non-significant inbreeding depression and significant positive heterosis were observed in VP-1 x DCS-5 and VP-1 x DCS-27 for primary spike length, DPC-9 x DCS-9 for effective spike length and VP-1 x DCS-5, DPC-9 x DCS-9 and LRES-17 x DCS-27 for number of capsules per primary spike. Hence, it could be possible to isolate desirable trangressive segregants in the F_2 and subsequent generations which could be handled through pedigree method of breeding to develop suitable varieties. For seed yield per plant none of the crosses exhibited non-significant inbreeding depression except the cross, Geeta x 48-1. In contrary it is essential to have low inbreeding depression for seed yield apart from having uniform plant height and maturity duration for the possible utilisation of F_2 seed for commercial crop production. However, the F_2 population of the cross involving LRES-17 parent showed large variation in plant height and maturity duration, whereas the crosses of VP-1 showed wide array of recombinants, for plant height. Further, since the reduction in seed yield from F_1 to F_2 is several times higher than hybrid seed cost, it is suggested that recommendation of F_2 seed for sowing is not economical.

CONCLUSIONS

The genetic study of certain morphological characters in castor indicated that each of the five characters viz., leaf shape, stem color, internode nature, bloom nature and spininess of capsules are governed by single gene, where. the former three characters had complete dominance reaction, whereas latter two characters expressed partial dominance. The bloom nature is controlled by single gene possessing multiple alleles with dominance or partial dominance reaction in the order of triple bloom, double bloom, zero bloom.

The genes governing the traits leaf shape, stem colour, bloom nature and stem colour, bloom nature, spininess of capsules are assorting independent of each other and found no evidence of linkage. Hence the characters can be transferred easily to the desired parents depending upon their significance. The genes controlling leaf shape and spininess of capsules were found to be linked with the cross over value of 25.7 per cent, whereas the traits, leaf shape and internode nature might be involved tight linkage or due to pleitrophic effect of the gene. The progeny of large F_2 population grown in isolation is needed to study further to confirm the results regarding tight linkage or pleitrophy.

Fusarium wilt resistance in governed by two independent recessive genes involving complementary epistasis. Back cross method can be utilized to transfer the recessive genes controlling fusarium wilt resistance.

The predominance of non-additive gene effects for seed yield and oil content can be exploited through heterosis breeding. Reciprocal recurrent

selection procedure is also useful to utilize additive and non-additive gene action for population improvement.

The magnitude of inbreeding depression was high under strict selfing than open pollination of F_1 plants. It is not economical to recommend F_2 seed for commercial crop production. The crosses possessing non-significant inbreeding depression with significant desirable heterosis can be utilized to isolate transgressive segregants in F_2 and subsequent generations.

LITERATURE CITED

LITERATURE CITED

Agarwal S K, Narware H R and Sahu R H 1991 Inheritance of fusarium wilt resistance in linseed. Journal of Oilseeds Research 8(2) : 231-233.

Anjani K 1997 Inheritance of spininess of capsule in castor (*Ricinus communis* L.). Crop Improvement 24(1) : 113-114.

Ankineedu G and Kulkarni L G 1965 Studies in the exploitation of hybrid vigour with monoecious lines in castor. Indian Oilseeds Journal 9 : 206-208.

* Anonymous 1968 Annual report of the institute for Agricultural Research, Samaru, 1966-67 Ahmadu Bello University, Zaria, N. Nigeria. Plant Breeding Abstracts 40 : 2296.

Arunachalam V 1976 The utility of covariances of combining ability in plant breeding. Theoretical and Applied Genetics 47 : 303-306.

Baker R J 1978 Issues in diallel analysis. Crop Science 18 : 533-536.

Bhapkar D G and Deshmukh R B 1978 Inheritance of some morphological characters in castor (*Ricinus communis* L.). Journal of Maharastra Agricultural Universities 3(3) : 193-196.

Bhatt D, Reddy T P and Deepika B 1983 Combining ability for flowering, capsule number and yield in castor. Indian Journal of Agricultural Sciences 53(10) : 873-875.

* Brigham R D 1973 Mosaic leaf, a new genetic character in castor (*Ricinus communis* L.). Plant Breeding Abstracts 44 : 7967.

* Brigham R D 1968 Inheritance of the rough petiole character in dwarf internode castor, *Ricinus communis* L. Plant Breeding Abstracts 41 : 1522.

Chakrabarty S K 1997 Combining ability and heterosis studies in castor (*Ricinus communis* L.). Journal of Oilseeds Research 14(2) : 182-188.

Chattopadhyay C, Raoof M A and Appaji S 1996 Studies on wilt complex of castor bean plant (*Ricinus communis* L.) observations on interaction between host and some associated organisms. Journal of Research, APAU 24(1-2) : 9-13.

Dabholkar A R 1992 Elements of biometrical genetics. Concept Publishing Company, New Delhi p. 201.

Damodaram T and Hegde D M 2002 Oilseeds situation. A statistical compendium. Directorate of Oilseeds Research, Hyderabad.

Dangaria G J, Dobaria K L, Fatteh V G and Patel V J 1987 Heterosis and combining ability analysis in castor. Journal of Oilseeds Research 4(1) : 46-53.

Deokar A B 1974 A linkage group in castor. Research Journal of Mahatma Phule Agricultural University 5(1) : 1-5.

Dobariya K L, Dangariya C J and Patel V J 1992 Combining ability analysis in a castor diallel. Journal of Maharastra Agricultural Universities 17(2) : 235-238.

Dobariya K L, Patel I D, Patel P S and Patel V J 1989 Combining ability and genetic architecture of oil content in castor (*Ricinus communis* L.). Journal of Oilseeds Research 6(1) : 92-96.

* Evminov V N and Dynnik V P 1982 Inheritance of resistance to fusarium wilt in flax hybrids. Len-i-konoplya 5 : 33-34.

* Fasoulas A 1981 Principles and methods of plant breeding. Aristotelian University, Thessaloniki, Greek.

Fatteh U G, Dangaria C J, Dobariya K L and Patel V J 1987 Combining ability for seed characters in castor. Journal of Oilseeds Research 4 : 54-58.

Fatteh U G, Dangaria C J, Dobariya K L and Patel V J 1988 Combining ability by line x tester analysis in castor (*Ricinus communis*). Indian Journal of Agricultural Sciences 58(1) : 7-10.

Fisher K A and Yates F 1967 Statistical tables for biological, agricultural and medical research. Longman Group Limited, London.

* Galeev G S 1969 Some results of research studies with cross pollinated plants. Plant Breeding Abstracts 41 : 4627.

Giriraj K 1973 Diallel analysis of five quantitative characters in castor. Mysore Journal of Agricultural Sciences 7(2) : 343-344.

Giriraj K, Mensinkai S W and Sindagi S S 1973 Combining ability of some quantitative characters in 6 x 6 diallel crosses of castor. Indian Journal of Agricultural Sciences 43(3) : 319-322.

Giriraj K, Mensinkai S W and Sindagi S S 1974 Components of genetic variation for yield and its attributes in 6 x 6 diallel crosses of castor. Indian Journal of Agricultural Sciences 44(3) : 132-136.

Gopani D D, Kabaria M M and Patel R H 1968 Study of hybrid vigour in castor. Indian Journal of Agricultural Sciences 38 : 520-527.

Haldane J B S 1948 The number of genotypes which can be formed with a given number of genes. Genetics 49 : 117-119.

Harland S C 1920 Inheritance in *Ricinus communis* L. Journal of Genetics 10 : 207-218.

Harland S C 1922 Inheritance in *Ricinus communis* L. Part II. Journal of Genetics 12 : 251-253.

* Harland S C 1928 The genetics of *Ricinus communis* L. Bibligr. Genet. 4 : 171-177.

Hirve C D and Tiwari A S 1991 Heterosis and inbreeding depression in Indian mustard. Indian Journal of Genetics and Plant Breeding 51(2) : 190-193.

* Hooks J A 1968 Estimates of general and specific combining ability, heterosis and heritability of eight agronomic traits in castor beans. Dissertation Abstracts 28 : Order No. 67-15, 822; p. 2228B.

Hooks J A, Willams J H and Gardner C O 1971 Estimates of heterosis from a diallel cross of inbred lines of castor, *Ricinus communis* L. Crop Science 11 : 651-655.

Joglekar R G and Deshmukh N Y 1957 A short note on inheritance in castor. Nagpur Agricultural College Magazine 31 : 18-19.

Kabaria M M and Gopani D D 1971 Note on heterosis and F_2 performance in castor. Indian Journal of Agricultural Sciences 41(3) : 271.

Kandasamy M, Palanisamy S, Dorairaj M S and Dorairaj M S 1983 Combining ability in *Ricinus communis* L. Madras Agricultural Journal 70(11) : 755-757.

Kaul S L, Prasad M V R and Swarnalata K 1983 Genetic basis of yield heterosis in castor. Precongress Scientific meeting on genetics and improvement of heterotic systems. 15-16.

Kavani R H, Golakia P R and Dhaduk H L 2001 Combining ability analysis in castor (*Ricinus communis* L.) Journal of Oilseeds Research 18(1) : 24-27.

Kempthrone O 1957 An introduction to genetic statistics. John Wiley and Sons Incorporated, New York.

Khan S A and Rehman A 1965 Hybrid seed production in castor *Ricinus communis* L. Pakistan Journal of Agricultural Research 3(2-3) : 73-79.

* King J G, Quinby J R, Stephens J C, Kramer N W and Lahr K A 1961 An evaluation of parents of grain sorghum hybrids. Bull. Texas Agric. Exp. Stn. M.P., 510.

* Knowles P F and Houston B R 1953 Inheritance of resistance to fusarium wilt in flax. Abstracts of the annual meetings of the American Society of Agronomy, Dallas, Texas pp: 91-92.

Malhotra S K and Vashistha R N 1993 Resistance studies in tomato against race 1 of fusarium wilt (*Fusarium oxysporum* f sp. *lycopersici*). Crop Research 6(1) : 183-185.

Manivel P and Hussain H S J 1997 Genotype x environment interaction for combining ability estimates in castor (*Ricinus communis* L.). Journal of Oilseeds Research 14(1) : 31-35.

Manivel P, Hussain H S J and Raveendran T S 1998 Combining ability for earliness traits over environments in castor. Madras Agricultural Journal 85(3-4) : 157-160.

Mehta D R 2000 Combining ability analysis for yield and its component characters in castor (*Ricinus communis* L.) Indian Journal of Agricultural Research 34(3) : 200-202.

Metha D R, Vashi P S and Kakadia M U 1991a Hybrid vigour in castor. Gujarat Agricultural University Research Journal 17(1) : 16-22.

Mehta D R, Vashi P S and Kakadia M U 1991b Combining ability for earliness and its related traits in castor (*Ricinus communis* L.). Gujarat Agricultural University Research Journal 17(1) : 23-26.

Miller J F, Hammond J J and Roath W W 1980 Comparison of inbred vs. single cross testers and estimates of genetic effects in sunflower. Crop Science 20 : 703-706.

Miller P A and Marani A 1963 Heterosis and combining ability in diallel crosses of upland cotton. *Gossypium hirsutum* L. Crop Science 3 : 441-444.

Moshkin V A 1986 Castor. Oxonian Press Pvt. Ltd., New Delhi.

Moshkin V A and Voskobojnik L K 1967 The method of interline hybridization in castor oil plant breeding. Bulletin on Science and Technology Information of Oil Plants 1(7) : 40-42.

Muhammad S V, Chandrasekharan N R, Navakodi and Shetty B K 1965 Preliminary studies on the general combining ability of certain inbred types of castor. Madras Agricultural Journal 52 : 452 (Abstract)

Muhammad S V, Srinivasulu N, Navakodi K, Ramaswamy N M, Sivaram M R, Kandaswamy M and Dorairaj M S 1970 Hybrid vigour in *Ricinus communis* L. II. General combining ability of certain exotic and indigenous inbreds with TMV-1. Madras Agricultural Journal 57 : 578-584.

Muhammad S V, Srinivasulu, Dorairaj M S, Navakodi K, Ramaswamy N M and Sivaram M R 1969 Hybrid vigour in *Ricinus communis* L. I. General combining ability between certain Egyptian inbreds and TMV-1. Madras Agricultural Journal 56 : 244-251.

Narain A 1952 Bloom character in castor oil plant (*Ricinus communis* L.). Current Science 21 : 166-167.

Narain A 1961 Inheritance of bloom in castor. Indian Journal of Genetics and Plant Breeding 21(2) : 136-141.

Natarajan C, Palinisamy G A, Muthaiah A R and Palanisamy S 1986 TMV-5 a new high yielding castor for Tamilnadu. Madras Agricultural Journal 73(3): 121-124.

Panse V G and Sukhatme P V 1961 Statistical methods of agricultural research workers. Indian Council of Agricultural Research, New Delhi.

Patel I D, Dangaria C J, Fatteh U G and Patel V J 1984 Combining ability for earliness and its related traits in castor. Indian Journal of Agricultural Sciences 54(8) : 625-629.

Patel P S, Patel D R and Patel I D 1991 Variability studies on yield components in castor (*Ricinus communis* L.). Gujarat Agricultural University Research Journal 17(1) : 116-118.

Pathak H C and Dangaria C J 1987 Combining ability for yield and its components in castor. Indian Journal of Agricultural Sciences 57(1) : 13-16.

Pathak H C, Dixit S K and Patel P G 1988 Gene effects and heterosis in castor (*Ricinus communis* L.) Indian Journal of Agricultural Sciences 58(6) : 476-478.

Pathak H C, Dixit S K and Patel P G 1989 Line x Tester analysis for seed yield and its components in castor (*Ricinus communis* L.). Indian Journal of Genetics and Plant Breeding 49(1) : 125-129.

Patwardhan G B 1931 Preliminary note on the inheritance of characters in castor. Journal of Indian Botanical Society 10 : 100-109.

Peat J E 1928 Genetic studies in *Ricinus communis* L. Journal of Genetics 19 : 373-389.

* Podkujchenko G V 1969 Production of inbred lines of castor oil plant and their investigation. Plant Breeding Abstracts 40 : 1397.

* Podkujchenko G V 1989 Donors of resistance to fusarium in castor oil plant. Nauchno Tekhnicheskii Byulleten' Vsesoyuznogo Nauchno Issledovatel's kogo Instituta Maslichnykh Kul'turl No. 1 : 24-26.

Pokhriyal S C, Vijay Kumar and Mangath K S 1964 Inheritance studies in *Brassica juncea* coss. Indian Oilseeds Journal 8 : 293-296.

Prasad N and Bhatnagar A 1981 Evaluation of resistant varieties of castor against castor wilt pathogen. Indian Journal of Mycology and Plant Pathology 11(1): 137-138.

Rai B 1979 Heterosis breeding, Agro-biological publications, New Delhi.

Ramaswamy N M and Madhavamenon P 1973 Genetic analysis of yield components in *Ricinus communis* L. Madras Agricultural Journal 60(9-12) : 1491-1498.

Ramesh T, Venkateswarlu O, Durgaprasad M M K and Sankaraiah M 2000 Estimation of genetic parameters in castor. Journal of Oilseeds Research 17(2) : 234-238.

Reddy T P and Sathaiah V 1997 Inheritance of plant height in castor (*Ricinus communis* L.). Advances in Plant Sciences 10(1) : 245-247.

* Reenen H A V 1976 Castor (*Ricinus communis* L.) in the northern states of Nigeria. Plant Breeding Abstracts 47 : 8714.

Richharia R H, Ghosh A K, Prakasa Rao S V S and Misro B 1966 Formulae for the estimation of linkage from F_2 data. Central Rice Research Institute, Cuttack, India, Bulletin No. 5.

* Rojas B A 1951 Analysis of group of experiments on combining ability in corn. M.Sc. Thesis, IOWA State University of Science and Technology, USA.

Saiyed M P, Shukla P T and Dhameliya H R 1997 Heterosis for yield and yield components in castor (*Ricinus communis* L.) over environments. Gujarat Agricultural University Research Journal 23(1) : 22-27.

Satyabalan K, Ponnaiaya B W X and Raman V S 1965 Studies on hybrid vigour in castor. Indian Oilseeds Journal 9 : 283-289.

* Savy F A, Bangatto N V, Aloisi S J, Sordi G De, Campana M P and Abramides E 1986 Castor breeding ix. Performance of progenies and cultivars in Sao Paulo State. Revista-de-Agricultura, Piracicaba, Brazil 61(1) : 35-45.

* Shull G H 1914 Beginnings of the heterosis concept. Iowa State University Press pp. 14-48.

* Sindagi S S 1972 Combining ability of some *Ricinus communis* L. Genetica Polonica 13(1) : 75-82.

Singh A and Srivastava A N 1982 Note on line x tester analysis in castor. Indian Journal of Agricultural Sciences 52(9) : 610-612.

Singh H and Yadav A K 1982 Genetic analysis of plant height in castor (*Ricinus communis* L.). Haryana Agricultural University Journal of Research 12(3) : 467-470.

Singh H V, Yadava T P and Singh R 1977 Screening of castor varieties against castor shoot and capsule borer (*Dichocrosis punctiferalis guen* Lepidoptera : Pyralidae). Haryana Agricultural University Journal of Research 7(3) : 128-132.

Singh I P, Vishwa D, Chaudhary R G and Dhar V 1998 Inheritance of resistance to fusarium wilt in Pigeonpea. Indian Journal of Agricultural Sciences 68(11) : 729-731.

Singh P K and Rai B 1995 Study of inbreeding depression from F_1 to F_3 generation in some intervarietal crosses of Indian rapeseed *Brassica compestris* L. Prain. Indian Journal of Genetics and Plant Breeding 55(2) : 208-213.

Singh R K and Chaudhary B D 1985 Biometrical methods in quantitative genetic analysis. Kalyani Publishers, New Delhi.

Smith J D 1963 Inheritance of capsule spines on castor beans (*Ricinus communis* L.) Crop Science 3 : 278-279.

Smithson J B, Kumar J and Singh H 1983 Inheritance of resistance to fusarium wilt in chickpea. International chickpea Newsletter 9 : 21-22.

Solanki S S and Joshi P 2001 Inheritance study of some morphological traits in castor (*Ricinus communis* L.). Indian Journal of Genetics and Plant Breeding 61(2) : 136-139.

Sprague G F and Tatum L A 1942 General versus specific combining ability in single crosses of corn. Journal of American Society of Agronomy 34 : 923-932.

* Stein H 1958 An analysis of a case of hybrid vigour in the castor bean plant. Plant Breeding Abstracts 29 : 2382.

* Stein H 1959a Spininess in *Ricinus*, a character determined by a mobile morphogenetic factor. Plant Breeding Abstracts 30 : 1863.

* Stein H 1959b Colour inheritance in *Ricinus*. Plant Breeding Abstracts 30 : 1864.

Sudhakar D, Khan W M A and Ganesan K 1995 Combining ability in castor, *Ricinus communis*. Madras Agricultural Journal 82(2) : 155-156.

* Sviridov A A 1971 The role of soil infection in obtaining fusarium resistant *Ricinus* hybrids. Plant Breeding Abstracts 44 : 8874.

* Sviridov A A 1986a Genetic structure of varietal populations of castor in respect of resistance to fusarium. Nauchno Tekhnicheskii Byulleten' Vsesoyuznogo Nauchno Issledovatel's kogo Instituta Maslichnykh Kul'tur 111(94) : 3-7.

Sviridov A A 1986b Inheritance of resistance to fusarium in castor following interline crossing. Nauchno Tekhnicheskii Byulleten' Vsesoyuznogo Nauchno Issledovatel's kogo Instituta Maslichnykh Kul'tur 90 : 13-16.

Sviridov A A 1988 Inheritance of resistance to fusarium in castor bean. Genetica, USSR, 24(5) : 908-913.

Swarnlata, Prasad M V R and Rana B S 1984 Inheritance of yield and its components in castor. Indian Journal of Genetics and Plant Breeding 44(3) : 538-543.

Vindhiyavarman P and Ganesan K 1995 The combining ability in castor. Madras Agricultural Journal 82(9-10) : 545-547.

* Voskobojnik L K and Moshkin V A 1977 Heterosis in castor oil plant. Vestinik Sejskokhozyajstvennoj Nauki 5 : 93-99.

* White O E 1918 Inheritance studies on castor beans. Brooklyn. Bot. Garden Mem. 1 : 518-521.

Yazdi-Samadi B, Sarafi A and Zali A A 1975 Heterosis and inbreeding depression estimates in safflower. Crop Science 15 : 81-83.

Zimmerman L H 1957a Complementary genes for bloom in *Ricinus communis* L. Journal of Heredity 48 : 242-243.

Zimmerman L H 1957b A relationship of dwarf internode gene to several important agronomic characters in castor beans. Agronomy Journal 49 : 251-254.

* Zimmerman L H and Van Horn D L 1953 Performance of castor inbred lines and their hybrid combinations with Nebraska -145-4. Plant Breeding Abstracts 24 : 943.

---

* Original not seen

The literature cited are presented as per the guidelines for thesis presentation of Acharya N.G. Ranga Agricultural University.