DIALLEL ANALYSIS OF SOME QUANTITATIVE CHARACTERS IN DESI COTTON (*Gossypium arboreum* L.)

by

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in
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CERTIFICATE I

This is t cectify that this thesis entitled "Diallel analysisof some quantitative characters in desi cotton, <u>Gosspium</u> <u>arboreum</u> L." submitted for the degree of M.Sc. n the subject of Plant Breeding of the Punjab Agricultual University, is a bona fide research work carried outby Gulzar Singh Chahal under my supervision and that o part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE II

This is to cectify that the thesis entitled "Diallel analysis of some quantitative characters in desi cotton, Gossypium arboreum L." submitted by Gulzar Singh Chahal to the Punjab Agricultural University in partial fulfilment of the requirements for the degree of M.Sc. in the subject of Plant Breeding has been approved by the Student's Advisory Committee after an oral examination on the same, in collaboration with an External Examiner.

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Chapter I

INTRODUCTION

Kapas yield and quality of fibre in cotton (*Gossypium* sp.), as in other crop plants, are complex characters which are polygenically inherited and are greatly influenced by genotype-environment interactions. Increased productivity and superior fibre quality of the cotton varieties are the primary breeding objectives. From experience the breeders know that hybrids between certain parents nick to produce many superior offsprings and that hybrids between other apparantly equally desirable parents produce disappointing progny. Therefore, it is essential to select best combining lines which will give maximum heterosis and large number of desirable recombinants in later generations. Nature and magnitude of genetic variances is also the guiding factor for the choice of suitable parents and for the adoption of appropriate breeding techniques.

Unlike other crops as corn and sorgham; cotton has not enjoyed the use of heterotic breeding. Several cotton workers (Cook, 1909; Turner, 1948; 1953; Stroman, 1961; Marani, 1963; Singh *et al.*, 1964; Hawkins *et al.*, 1965; Lee *et al.*, 1967; Marani, 1968; and Al-Rawi, 1969) have reported heterosis for almost all the agronomic, yield and fibre quality characters, in *Gossypium hirsutum* L. Attempts for its exploitation for economic benefit in cotton have been limited by the difficulty involved in production of hybrid seed on a large scale. The credit for the successful exploitation of this phenomena for the first time in the world goes to Patel (1971) who developed Hybrid-4 (G 67 x Nectariless American) which is very productive and has become very popular in the Gujrat State of India. Here again, it was the availability of cheap labour for producing hybrid seed and highly bushy nature (and hence small quantity of hybrid seed is required per unit area) of the hybrid that made it an economical and feasible proposition.

At present several techniques like top cross and line x tester analysis are available to assess the genetic worth of a set of parents to be used in hybridization programme. The diallel cross technique originally suggested by Schmidt (1919) and later on developed by Jinks and Hayman (1953), Hayman, (1954, 1958, 1960); Jinks (1954); Allard (1956) and Griffing (1956) provides systamatic procedure to determine the genetic architecture of a character under consideration and also about nature of gene action. The potentiality of a particular cross to throw good segregants in advanced generations to aid the selection programme is judged in the F_1 generation itself.

The hirsutum and barbadense species of the genus Gossypium have been extensively studied for determining genetic parameters and nature of gene actions controlling various characters. No such information is available in respect of arboreum sp. The arboreum cottons occupy 45% of the cotton acerage in the Punjab. This investigation was, therefore, undertaken to evaluate arboreum cotton for heterosis, combining ability and nature of gene action.

Chapter II

REVIEW OF LITERATURE

Heterosis in cotton

There is at present, great interest for the possible utilization of heterosis in cotton for increasing production. The phenomena of hybrid vigour in cotton, has doubtlessly been observed since the time of first controlled hybrid studied in this genus. Mell, (1894) published the first known accounts of increase in certain measurements of agronomic and fibre properties in cotton hybrids as compared to the parents which entered the crosses. Cook (1909) was the first man to propose that heterosis found in F_1 plants from crosses of Gossypium hirsutum L. x Gossypium barbadense L. could be used commercially.

Most of the earlier work on this subject involved crosses of Gossypium hirsutum L. and Gossypium barbadense L., more specifically, American Upland and

Egyptian varieties.

Marani (1967) has shown that average magnitude of heterosis for lint yield was 24.5% and 21.6% in intraspecific crosses of Gossypium hirsutum L. and Gossypium barbadense L. respectively, while in their interspecific crosses, heterosis for this character was as high as 72.8 per cent. A considerable advantage, therefore, can be gained by using interspecific cotton hybrids.

Hutchinson, Gadkari and Ansari (1937) expressed the view that hybrid vigour in cotton finds important expression only in interspecific crosses; there being a relative absence of hybrid vigour in intravarietal crosses.

Al-Rawi, (1969) has also reported greater heterosis in interspecific crosses than from intervarietal crosses. Marani (1963) reported that extent of heterosis for yield was higher in interspecific crosses than in intraspecific crosses. In the intraspecific crosses, heterosis was due to increase in boll size and number of bolls produced.

On the other hand Gadkari and Sikka (1952) were of the view that inter hirsutum hybrids may have a greater chance of success in the Punjab as compared with hirsutum x barbadense hybrids.

Roy (1956) found that hybrid vigour in intraspecific crosses was more pronounced in the characters contributing towards yield, while in interspecific crosses it was obvious in vegetative growth characters.

The interspecific hybrids have lower values for lint percentage as a result higher values for seed index, they grow excessively tall and are very late in maturity under northern India conditions.

The genetic differentiation in the cultivated tetraploid species of Gossypium is supposed to be the result of manifold gene substitutions during isolation and subsequent accumulation of modifier complexes due to natural and/or artificial selection pressure (Santhanam, 1951). It follows, therefore, that in interspecific crosses divergent genetic systems are brought together in the F_1 generation.

Utilization of interspecific hybrids for the improvement of cotton production and quality is, by its very nature, a long term project which needs to be tackled from the cytogenetical as well as technological stand points (Joshi, 1960). Singh (1968) has pointed out that interspecific breeding has not been of much success in cotton. He further indicated that the levels of cytogenetic differentiation of different species of cotton are in "awkard" states and interspecific crosses show hybrid breakdown. Use of such hybrids have been proposed for transferring desirable characters among cultivated species.

The two pre-requisites for the successful exploitation of heterosis in cotton are:

1. Choice of suitable parents at varietal or interspecific level which show considerable heterosis when crossed.
2. Cheap method of producing hybrid seed.

Regarding first aspect, several workers have reported that genetic diversity of the parents to be crossed is important.

Ramiah (1944) crossed different ecotypes of *Gossypium arboreum* and reported clear cut heterosis for all characters studied. Balls (1908) working with intervarietal crosses of *G. hirsutum* L. and *G. barbadense* L. reported intensification of certain characters where two botanically dissimilar cottons were crossed.

Roy (1956) also reported the association of hybrid vigour with genetic diversity of parents. The crosses between exotic x local parents exhibited greater heterosis than those between the local parents *inter se*. Somlo (1960) crossed nine improved types of *Gossypium arboreum* L. from *indica* and *bangalense* races. Crosses involving types from different geographical regions exhibited more heterosis, especially in qualitative characters, than those from the same region. Kime and Tilley (1947) has also reported that greater increase in

F_1 heterosis may be expected in crosses involving relatively unrelated lines. So genetic diversity of parents is a 'must' for parents to be crossed.

In addition to genetic diversity, the actual worth of the parents cannot be ignored. Miller and Marani (1963), White and Richmond (1963), Miller et al., (1964) and Marani (1967, 1968) have shown close association between per se performance of strains and their crosses so they can be selected on their per se performance.

Heterotic response of considerable magnitude (usually ranging from 20-60 per cent measured from mid-parent) for yield and its components have been reported. Height of plant is the character usually accepted as better in F_1 than parents between G. barbadense L. and G. hirsatum L. crosses. However, increase in height is important only if it is the result of more internodes rather than their length.

Heterosis has been reported in inter-varietal crosses in G. hirsutum L. and G. barbadense L. by many workers (Kime and Tilley, 1947; Turner, 1948; Jones and Loden, 1951; Turner, 1953; Stroman, 1961; Marani, 1963; White et al., 1964; Ramey, 1963; Singh et al., 1964; Miller and Lee, 1964; Young, 1965; Hawkins et al., 1965; Galal et al., 1966; Lee et al., 1967; Marani, 1967 and 1968;

Pathak, 1968; Al-Rawi, 1969 and Verhalen _et al_., 1971).

Heterosis has also been observed in diploid species i.e. _G_. _arboreum_ L. and _G_. _herbaceum_ L. Hutchinson _et al_., (1938) reported heterosis in staple length, ginning percentage and yield in _G_. _arboreum_ L. In crosses between two high yielding strains, the F_1 outyielded the higher yielding parent by about 20 per cent. Later on Koshal _et al_., (1940) working with same strains of _G_. _arboreum_ L. as used by Hutchinson _et al_., (1938) found heterosis to be significant in fibre length and maturity. Ganesen (1942) using the same three strains found that seed of F_1's were 21-24 per cent heavier than those of the selfed parents. Pandya and Patel (1959) noted marked vigour in F_1 for vegetative growth, high fruiting and less number of bolls in interspecific crosses of _G_. _herbaceum_ L. and _G_. _arboreum_ L. Santhanam (1951) reported heterosis for plant height, yield of seed cotton and lint length in a _G_. _herbaceum_ L. x _G_. _arboreum_ L. cross. The increase in yield to the extent of 158 percentage over the local parent was also recorded in this study. In lint production however, hybrid was intermediate. Bederker (1957) reported heterosis in yield of _kapas_, number of bolls per plant, earliness, boll size, plant height and halo length in _G_. _arboreum_ L. species. Young (1966) has reported heterosis to be of high magnitude in

G. arboreum L. species as compared to *G. hirsutum* L.

For the commercial production of hybrid seed there are three possible ways: (a) natural cross pollination, (b) use of male-sterile lines; and (c) hand pollination. It is apparant that seed production by natural corssing will be limited to areas in which natural crossing is relatively high. There is also a problem to remove homozygotes from the seed-source planting so that only F_1 plants will remain. Male sterility in *Gossypium* has been reported but has not successfully been utilised because of the problem of isolation and maintenance of the sterile lines. Controlled emasculation and pollination by hand is obviously the most certain method of obtaining hybrid seed. However, on account of the high cost involved in hybrid seed production by this method, it would only be limited to areas in which there is an abundance of cheap hand labour. This method has successfully been utilised in the production of Hybrid-4 in Gujrat State by Patel (1971). It was the availability of cheap labour which made it a successful attempt.

Combining ability in cotton

In any crop, a hybrid can be successful only if its performance is far superior than the *per se* performance of its parents including the best local standard if it is not one of them. The lines which produce superior hybrids in combination with others are evantually the most valuable for the breeder.

General combining ability of a line is its average performance in hybrid combinations with other lines. Specific combining ability is the performance of a cross as it does better or worse as compared to the average. Griffing (1956) has shown that total variance in F_1 of diallel cross can be expressed in terms of general (g.c.a.) and specific combining ability (s.c.a.) variances.

$$\text{g.c.a.} = 1/2\ \sigma^2_A + 1/4\ \sigma^2_{AA} + 1/8\ \sigma^2_{AAA} + \ldots\ldots$$

$$\text{s.c.a.} = \sigma^2_D + 1/2\ \sigma^2_{AA} + \sigma^2_{AD} + \sigma^2_{DD} + \ldots\ldots\ldots$$

when F = 1 i.e. completely inbred parents, the

$$\sigma^2_G = 2\sigma^2_g + \sigma^2_s$$

where σ^2_G = total genetic variance,

σ^2_g = variance due to g.c.a. and

σ^2_s = variance due to s.c.a.

Where hybrids can be produced economically specific combining ability is more important but in crops, such as cotton, in which cost of hybrid seed production is very high, general combining ability is more important in developing pure line varieties. Crosses displaying larger amount of additive genetic variance are preferred over those with more heterotic response in this case.

Not much work has been done on combining ability in _desi_ cotton. Soomro _et al_., (1969) and Baluch _et al_., (1969) have published their work in Pakistan and the details are not known. Extensive work has been done in _G. hirsutum_ L. which is reviewed in the following pages:

Kime (1950) did not report any important differences between g.c.a. and s.c.a. for lint yield, bolls per plant, seeds per boll and lint index. Turner (1953) reported s.c.a. to be more important than g.c.a. for yield. Joshi _et al_., (1960) reported that varieties of different origin have higher combining ability effects.

Miller and Marani (1963) and White and Richmond (1963) reported that variances of g.c.a. were larger than variances of s.c.a. and concluded that major portion of genetic variances in base population was additive in nature. The data also indicated that in case of inter-specific crosses, variances of g.c.a. were larger than those of s.c.a. For yield of seed cotton, yield of lint, number of bolls and seed index significant s.c.a. effects were found. But no significant s.c.a. effects were found for boll weight, number of seeds per boll, lint index and lint percentage.

Douglas and Adamson (1966) found significant g.c.a. effects for lint percentage, mean fibre length and fibre strength. Variances for g.c.a. exceeded than s.c.a. for every character measured.

White *et al*. (1964) reported that heterosis in yield might be reasonably accounted for by dominance genes in bolls per plant, boll size or a combination of the two operating with associated genes which exhibit additive effects. Ramey *et al*., (1966) reported substantial amounts of additive genetic variances for the following traits: from interspecific crosses among (*G*. *thurberi*; *G*. *arboreum* and *G*. *hirsutum*), lint percentage, lint index, seed index, weight per boll, fibre strength and seed-cotton yield. Estimates of average degree of dominance obtained were less than unity indicating only partial dominance for genes controlling these traits. Lee *et al*., (1967) reported significantly higher g.c.a. for all characters other than lint yield.

Marani (1967) observed significant g.c.a. effects of *G*. *hirsutum* L. parents for boll weight, lint index, seed index, lint percentage, number of seeds per boll, and plant height. However g.c.a. effects for yield of seed cotton and lint yield were not significant. General combining ability effects in *G*. *barbadense* L. parents were significant only for seed index, number of seeds per boll and mean date of maturity. Effects of g.c.a. were more pronounced than effects of s.c.a. and magnitude of g.c.a. was in most cases in accordance with the performance of parental varieties themselves.

Genetic variances

The resolution of the question whether heterosis is manifested only in F_1 generation or whether transgressive segregants can be isolated in pure lines equal or superior to F_1, depends upon the type of predominant gene action for each character in population under study.

Genetic variances, of interest to the breeder, are:

1. Additive: resulting from additive effects of genes summed over all loci.
2. Dominance: resulting from allelic interactions of all segregating loci.
3. Epistatic: resulting from non-allalic interaction of genes at two or more segregating loci.

By appropriate analysis (Fisher, 1918) the total genetic variance (σ^2_G) can be partitioned into σ^2_A (additive), σ^2_D (dominance) and σ^2_I (epistatic) components. The diallel analysis developed by Jinks and Hayman (1953) is the quickest method of estimating genetic variances using only F_1 generation of the crosses. The technique has extensively been used in cotton recently for studying the nature and magnitude of genetic variances in *G. hirsutum* L. and *G. barbadense* L. The results obtained by various workers have been summarized in table 1. It will be seen that there is predominance of additive gene action for almost all the agronomic and yield characters.

Causes of discrȧpancies may be

1. Varying degree of genotype-environment interaction,
2. Use of fewer and genetically related lines in different studies and
3. Presence of epistatic effects.

Table 1

Nature of gene action for some characters in Upland cotton *G. hirsutum* L.

	Character	Nature of gene action
1.	Number of days from sowing to first flowers	Additive (Marani, 1964) Additive + non-additive (Hooda, 1969)
2.	Plant height	Additive (Marani, 1964) Additive + dominance (White *et al*., 1964)
3.	Number of bolls per plant	Additive (Marani, 1963) Additive + Dominance (White *et al*., 1964) Additive + nonadditive (Hooda, 1969)
4.	Average boll weight	Additive (Marani, 1963; 1967; Hooda, 1969)
5.	Number of seeds per boll	Additive (Marani, 1963; 1967; Hooda, 1969)
6.	Ginning outturn	Additive (Marani, 1963; 1967. Douglas *et al*., 1966)
7.	Seed index	Mostly additive + nonadditive (Hooda, 1969) Additive (Marani, 1963, 1967)
8.	Lint index	Additive (Marani, 1963; 1967; Hooda, 1969)
9.	Average yield per plant	Additive (Marani, 1963; Miller and Marani, 1963) Non-additive (Barnes and Staten, 1961; Lee *et al*., 1967; Hooda, 1969) Additive + partial dominance (White *et al*., 1964)
10.	Halo length	Additive (Douglas and Admson, 1966; Marani, 1968) Additive non-additive (Marani, 1963; Miller and Marani, 1963)

Chapter III

MATERIALS AND METHODS

The studies were conducted during 1970-71 at research area of the Department of Plant Breeding, Punjab Agricultural University, Ludhiana.

Ten varieties of desi cotton, G. arboreum L., viz. 231R, G27, Cocanadas white, H_{420}, 35/5B, M_{2608}, P_{34}, Gaorani-6, NR-5 and C.J.73 were used in producing a set of diallel crosses during kharif 1969-70. These varieties have been maintained through selfing in the past and were thus reasonably homozygous. They were selected in view of their merits based on past performance. The particulars of these varieties are given in brief:

1. 231R:

It is a high yielding variety with tall plant habit. It was recommended for general cultivation in Punjab in 1958. The ginning out-turn is high but fibre length is low. It spins only 6 counts.

2. G27:

This variety was recommended for cultivation in the Punjab in 1969. It is a highly adaptable variety and does well under very adverse as well as favourable conditions. The plant colour is reddish green. Boll number per plant is very high but their size is very small. Lint is short and harsh. It is capable of spinning 6 counts.

3. Cocanadas white:

It is a high yielding strain with high number of bolls of good size per plant. It is inferior in staple length.

4. H_{420} (Hybrid 420):

It was evolved in 1935 from the cross Bani (indicum) x Garo Hill cotton (cernuum) for Vidarbha region of Maharashtra. It has high wilt resistance and ginning outturn. Its lint is very fine and suitable for spinning up to 31 counts.

5. 35/5B:

It is a high yielding strain from Western U.P. Ginning outturn is high. Bolls are small in size. It is inferior in fibre length.

6. M_{2608}:

It is an average yielding strain with very big bolls.

7. P_{34}:

It is a low yielding strain with poor ginning outturn and its chief merit lies in its superior fibre length.

8. Gaorani-6:

It is a selection from indigenous Gaorani (Bani) cottons of Maharashtra State. It was released for general cultivation in 1936 in Nanded area. It is a superior staple cotton and is capable of spinning 26 to 28 counts.

9. NR-5:

It is a reselection from G. arboreum L. race bengalense stock (called Jadi mixture). It has got high ginning outturn and superior fibre length. Yield is, however, low.

10. C.J.73:

It is a single plant selection made at Amreli (Maharashtra) in 1949 from a cross between C.520 x Jarila. It is a superior staple cotton (fibre length 29/32 inch) and is capable of spinning 30 counts.

All possible 45 F_1 crosses, excluding reciprocals, alongwith parents were grown during <u>kharif</u> 1970-71 in randomised block design in four replications. One non-experimental entry was also included in the material to grow 4 tiers each per replication. This entry was, however, excluded from the statistical analysis. There were 10 plants per entry in a replication spaced 1 foot apart in a row. The rows were 2 feet apart. Non-experimental rows were grown on sides. Three seeds were initially sown in each dibble which were subsequently thinned to one plant per hill when the plants had established nicely. Irrigation water was applied when required. Recommended dose of fertilizer was added. The crop was kept weed free by giving hoeings. Data were recorded on five plants selected at random, in a row. Plants on both sides of a gap were not taken.

All 45 crosses and parents were studied for following characters:

1. <u>Plant height</u>

Height of each plant was recorded (in cm) from base to top of the main stem when the plants had attained maximum height and further growth had ceased.

2. <u>Weight of the plant</u>

Average weight (gm) of the selected plants was recorded by cutting them from ground level and weighing them after the final picking was over.

3. Number of bolls per plant

The total number of bolls picked over all the pickings gave the total number of bolls per plant.

4. Boll size (weight of kapas (gm) per boll)

A ten-boll random sample was taken from the 5 plants selected for study from each row. This sample was weighed on a triple beam balance (.2 gm sensitivity) to determine the weight of kapas per boll.

5. Number of seeds per boll

Seed number was counted from ten-boll sample from (4) above and number of seeds per boll was calculated for each entry in each replication.

6. Average yield of kapas per plant

All the selected plants in each progeny were picked and the weight of the sample (under 4) was added to it to give the seed-cotton yield per plant.

7. Lint index

Lint index (weight of lint produced by 100 seeds in gm) was calculated in the following manner:

$$\text{Lint index} = \frac{\text{Seed index x G.O.T.}}{100 - \text{G.O.T.}}$$

8. <u>Seed index</u>

From the sample taken for ginning outturn, all the seeds were counted and weighed in gm on a physical balance, and weight for 100 seeds was calculated therefrom.

9. <u>Ginning out-turn</u>

Ginning out-turn was also determined from the ten-boll <u>kapas</u> sample taken in (4) above. The sample was weighed and ginned. The weight of seed and lint was recorded and ginning out-turn in percentage was worked out as below:

$$\text{Ginning out-turn} = \frac{\text{Wt. of lint}}{\text{Wt. of seed} + \text{Wt. of lint}} \times 100$$

10. <u>Halo length</u>

For this purpose, the standard method of measuring halo length, as recommended by the Director of Technological Laboratory, Matungu, Bombay, was adopted. The observations were recorded on ten seeds picked at random from "sample" taken under (4) above. The fibres on the seeds were divided into two halves by means of a needle. The fibres on the left side were held together by the left hand keeping the pointed end upward. The fibres on right side were combed out into a half - halo by means of a steel comb. The combed halo was placed on the velvet board with its pointed end upwards. The halo length was recorded by means of a celluloid halo measuring disc (small size). The mean of 10 measurements gave the mean halo length (mm) of each progeny in each replication.

Statistical Analysis

Analysis of design was based on the linear model.

$$P_{ijk} = m + g_{ij} + b_k + e_{ijk}$$

where,

P_{ijk} = phenotype of the genotype ij grown in the k th block

m = general population mean

g_{ij} = effect of genotype ij

b_k = effect of k th block

e_{ijk} = environmental effect

Analysis of variance based on this linear model leads to break up of variance into following components:

Source of variance	d.f.	S.S.	Mean of squares
Blocks	(b-1)	$S_b=SB^2/p-(Sx)^2/N$	$M_b=S_b/b-1$
Progenies	(p-1)	$S_p=SP^2/b-(Sx)^2/N$	$M_p=S_p/p-1$
Error	(b-1)(p-1)	S_e=St-Sb-Sp	$M_e=S_e/(b-1)(p-1)$
Total	(bp-1)	$S_t=SX^2-(SX)^2/N$	

Where,

b	=	number of blocks,
p	=	number of progenies,
N	=	total number of observations,
S	=	summation,
B	=	block total,
SX	=	grand total,
S_t	=	total sum of squares,
M_b	=	block mean square,
M_p	=	progeny mean square and
M_e	=	error mean square.

The variances were tested against error variance by usual 'F' test. Progeny variances were tested against M_e for (p-1), (b-1) (p-1) degrees of freedom and block variances were tested against M_e for (b-1), (b-1) (p-1) degrees of freedom at P = 0.05 and P = 0.01.

The standard error of progeny means was equal to $\sqrt{M_e/b}$ and standard error of difference for comparing any two progeny means was $\sqrt{2M_e/b}$. The critical differences were computed by multiplying the standard error of difference with 't' values for (b-1) (p-1) degrees of freedom at P = 0.05 and P = 0.01.

Heterosis and overdominance

Heterosis is the increase of the hybrid over the average of the two parents and its values were mathematically calculated by the following formula:

$$\text{Heterosis} = F_1 - \frac{P_1 + P_2}{2}$$

Where,

F_1 = mean performance of F_1,

P_1 = mean performance of parent number 1 and

P_2 = mean performance of parent number 2.

Standard error of difference for heterotic effects was calculated by the formula

$$\text{S. E. (diff.)} = \sqrt{3M_e/2b}$$

The critical difference was computed by multiplying the standard error of difference with the respective (t) value for error degree of freedom at P = 0.05 and P = 0.01.

Overdominance was calculated as the increase or decrease of a hybrid over the better or poor parents respectively. The standard error of difference for comparing the values of overdominance was calculated as follows:

$$\text{S. E. (diff.)} = \sqrt{2M_e/b}$$

The critical difference was computed as given above for error degree of freedom at P = 0.05 and P =0.01.

Analysis for combining ability

Diallel tables were prepared for those characters which had shown significant differences between progenies. A diallel table was prepared as follows (Page 27) from the values of parents and F_1's averaged over the four blocks:

Where,

$$X_{1.} = X_{11} + X_{12} + \dots + X_{110} \text{ (total of one array)}$$

$$X_{..} = X_{11} + X_{12} \dots + X_{1010} \text{ (total of all progenies)}$$

Diallel table so prepared was analysed for general and specific combining ability, variance components and graphic analysis. The estimates of variance for general and specific combining ability and its effects were computed by Model I (Fixed effect model) and Method 2 (parents plus one set of crosses, no reciprocals) as detailed by Griffing (1956).

The analysis of variance for combining ability was based on the following mathematical model:

$$P_{ijk} = m + g_i + g_j + s_{ij} + e_{ijk}/b$$

Where,

P_{ijk} = phenotype g from cross of ith and jth parent in block k,

m = population mean,

g_i = general combining ability of ith parent,

Diallel table

Parents	1	2	3	4	5	6	7	8	9	10	$X_{i.}$	$X_{i.} + x_{ii}$
1	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}	X_{110}	$X_{1.}$	$X_{1.} + x_{11}$
2		X_{22}	X_{23}	X_{24}	X_{25}	X_{26}	X_{27}	X_{28}	X_{29}	X_{210}	$X_{2.}$	$X_{2.} + x_{22}$
3			X_{33}	X_{34}	X_{35}	X_{36}	X_{37}	X_{38}	X_{39}	X_{310}	$X_{3.}$	$X_{3.} + x_{33}$
4				X_{44}	X_{45}	X_{46}	X_{47}	X_{48}	X_{49}	X_{410}	$X_{4.}$	$X_{4.} + x_{44}$
5					X_{55}	X_{56}	X_{57}	X_{58}	X_{59}	X_{510}	$X_{5.}$	$X_{5.} + x_{55}$
6						X_{66}	X_{67}	X_{68}	X_{69}	X_{610}	$X_{6.}$	$X_{6.} + x_{66}$
7							X_{77}	X_{78}	X_{79}	X_{710}	$X_{7.}$	$X_{7.} + x_{77}$
8								X_{88}	X_{89}	X_{810}	$X_{8.}$	$X_{8.} + x_{88}$
9									X_{99}	X_{910}	$X_{9.}$	$X_{9.} + x_{99}$
10										X_{1010}	$X_{10.}$	$X_{10.} + x_{1010}$

g_j = general combining ability of jth parent,

s_{ij} = specific combining ability of ij, the cross between ith and jth parents,

b = number of blocks and

e_{ijk} = error term for ijk observation.

Analysis of variance table for combining ability

Source of variation	d.f.	Sum of squares	Mean squares	Expectations
g.c.a.	(p-1)	S_g	M_g	$\sigma^2 + (p-2)(1/p-1)\,\Sigma g_i^2$
s.c.a.	$\frac{p(p-1)}{2}$	S_s	M_s	$\sigma^2 + 2/p(p-1)\,\sum_{i}\sum_{j} s_{ij}^2$
Error	m	S_e	M'_e	

Where,

S_g (sum of squares due to g.c.a.) =

$$\frac{1}{p+2}\left(X_{i.} + x_{ii}\right)^2 - 4/p\, X_{..}^2 \,)$$

S_s (sum of squares due to s.c.a.) =

$$\sum_{i \leq j} X_{ij}^2 - \frac{1}{p+2}\left(X_{i.} + x_{ii}\right)^2 + \frac{2X_{..}^2}{(p+1)(p+2)}$$

$M'_e = M_e/b$

m = degrees of freedom for error

<u>Combining ability estimates</u>

Estimates of general and specific combining ability were calculated for only those characters where variances due to g.c.a. or s.c.a. were significant.

General combining ability estimates of parent i

$$(g_i) = \frac{1}{p+2}\,(X_{i.} + x_{ii}) - \frac{2X_{..}}{p}$$

Specific combining ability of the cross i x j (s_{ij}) =

$$X_{ij} - 1/p+2\,(X_{i.} + x_{ii}) + X_{j.} + x_{jj}) + \frac{2X_{..}}{(p+1)\,(p+2)}$$

Where,

$X_{i.}$ = total of array involving ith parent

$X_{j.}$ = total of array involving jth parent

X_{ii} = parental value of the ith parent

X_{jj} = parental value of jth parent

$X_{..}$ = total of all $\frac{p(p+1)}{2}$ items in the diallel table

Standard error to test the significance of general and specific combining ability estimates and the standard error of difference between the two estimates was computed from the following formulae:

$$\text{S.E. for g.c.a. effects} = \sqrt{\frac{(p-1)M'_e}{p(p+2)}}$$

S.E. for s.c.a. effects $= \sqrt{\frac{p^2 + p+2)M'_e}{(p+1)(p+2)}}$

S.E. for difference between two general combining ability effects $= (g_i - g_j) = \sqrt{\frac{2M'_e}{p+2}}$

S.E. for difference between two s.c.a. effects in different arrays $= (s_{ij} - s_{jk}) = \sqrt{\frac{2p\ M'_e}{p+2}}$

Critical differences were estimated by multiplying the corresponding standard error with table value of 't' at error degree of freedom.

Graphical Analysis

The diallel cross technique elaborated by Hayman (1954) was followed for this aspect. The variance - covariance (Vr, Wr) and covariance - covariance (Wr, W') graphs were prepared from the following statistics calculated from the data given in diallel tables for different characters:

V_r = variance of all offsprings in each array,

W_r = covariance of the offspring in each parental array with non-recurrent parent,

W' = covariance of array values with array means and

V_p = variance of parents (diagonal of diallel table).

The regression coefficients of W_r on V_r and W' on W_r were calculated using the following formulae:

$$b \ W_r/V_r = \frac{\text{Sum of products } W_r, V_r}{\text{sum of squares } V_r}$$

$$b' \ W'/W_r = \frac{\text{Sum of products } W_r, W'}{\text{sum of squares } W_r}$$

Where, b and b' denote the regression coefficients of the slope of regression line in V_r, W_r and W_r, W' graphs, respectively. The significance of difference of b from unit slope and b' from 0.50 slope was tested with the use of following formulae:

$$\text{S.E. for b } W_r/V_r = \sqrt{\frac{SS \ W_r - b \times SP \ W_r, V_r}{(p-2) \ S.S. \ V_r}}$$

$$\text{S.E. for b' } W'/W_r = \sqrt{\frac{SS \ W' - b' \times SP \ W', Wr}{(p-2) \ S.S. \ W_r}}$$

From the regression coefficients thus calculated, expected values of W_r and W' were estimated by the following equations:

$$Wr_{ei} = \bar{W}_r - b \ \bar{V}_r + b \ V_{ri}$$

$$W'_{ei} = \bar{W}' - b' \ \bar{W}_r + b' \ W_{ri}$$

where,

Wr_{ei} = expected value of W_r corrosponding to V_{ri}.

W'_{ei} = expected value of W' corresponding to Wr_i.

$\bar{V}_r$, $\bar{W}_r$ and $\bar{W}'$ are means of V_r, W_r, W' values for all arrays respectively. The V_r, W_r graph has the limits, the limiting values of this graph, called parabola limits were computed as follows:

$$W_r^2 = V_r \times V_p \text{ or } \pm W_r = \pm \sqrt{V_r \times V_p}$$

In the V_r, W_r graph the V_r values are taken along the X-axis, while W_r values along Y-axis using same scale on the both axis. The W_r, W' graph was constructed by taking W_r values along X-axis and W' values along Y-axis.

Estimation of Genetic Parameters

Method given by Hayman (1954) has been used which makes use of V_r, W_r, V_p, $V_{\bar{r}}$ (Variance of array means) and E. The genetic parameters D, F, H1, H2 were estimated by using following expressions:

$$D = V_p - E$$

$$F = 2\,V_p - 4\bar{W}_r - 2\,(n-2)\,E/n$$

$$H_1 = V_p - 4\bar{W}_r + 4\bar{V}_r - (3n-2)\,E/n$$

$$H_2 = 4\bar{V}_r - 4\,V_{\bar{r}} - 2E$$

$$h^2 = 4\,(M_{L1} - M_{LO})^2 - 4\,(n-1)\,E/_n{}^2$$

M_{L1} = mean of all F_1's

M_{LO} = mean of parents

Where,

D = component of variation due to additive effects of genes.

H_1 = component of variation due to dominance effect of genes over all segregating loci.

H_2 = component of variation due to non-additive effects corrected for gene distribution

F = covariance of additive and non-additive effects in all the arrays.

E = environmental or non-heritable variation associated with individual means and is calculated from analysis of variance for design of experiment. In this case $E = M'_e$.

h^2 = overall dominance effects of heterozygous loci.

<u>Accuracy of estimates of genetic parameters:</u>

In order to estimate standard errors of these components following equations were used:

S^2 = 1/2 Var $(W_r - V_r)$ and terms of main diagonal of the covariance matrix given by Hayman (1954 pp. 798) were corresponding multipliers.

Var D= $S^2/_n5\ (n^5 + n^4)$

Var F= $S^2/_n5\ (4n^5 + 20n^4 - 16n^3 + 16n^2)$

Var H_1 = $S^2/_n5\ (n^5 + 41\ n^4 - 12n^3 + 4n^2)$

$$\text{Var } H_2 = \frac{s^2}{n^5}(36n^4)$$

$$\text{Var } E = \frac{s^2}{n^5} \quad n^4$$

$$\text{Var } h^2 = \frac{s^2}{n^5}(16n^4 + 16n^2 - 32n + 16)$$

Where,

n = number of parents included in the diallel i.e. ten.

Standard errors were calculated by taking square root of these equations.

Following estimators and ratios were calculated by making use of only significant genetic parameters:

1. $(H_1/D)^{1/2}$ = a weighted measure of average degree of dominance at each locus. Its value, when less than one, indicates that genetic control of the character is largely due to additive gene action though some degree of dominance also exists. Value more than one indicates overdominance.

2. $\bar{u}\bar{v} = H_2/4H_1$ = an estimator of average frequency of negative versus positive alleles at loci exhibiting dominance, and has maximum value of 0.25. Its value, less than 0.25, indicates that positive and negative alleles are not in equal proportions in parents.

Since u + v = 1 and $u - v = \sqrt{1-4\bar{u}\bar{v}}$

the values of u and v can be found out.

3. $W_{ri} + V_{ri}$ = an estimator of order of dominance of parents. Arrays with minimum value are top dominants while with maximum value are top recessives.

4. Prevalence of dominant and recessive genes in all the parents: It is given by sign of F: positive sign indicating dominants to be more prevalent and vice versa.

5. r = correlation coefficient between parental means and their $W_r + V_r$ was calculated by using formula

$$r = \frac{S.P.\ Y_{ri}\ (W_r + V_r)}{\sqrt{SS\ Y_{rs} \times SS\ (W_r + V_r)}}$$

Where,

Y_r = mean of each parent. Positive sign of 'r' indicates that maximum expression of the character is governed by recessive genes while negative sign indicates maximum expression of the character governed by dominant genes.

6. h^2/H_2 = an estimate of number of effective factors operating for a trait and showing some degree of dominance.

<u>Assumptions of a diallel cross</u>

i. diploid segregation,

ii. parents are homozygous,

iii. no reciprocal differences,

iv. independent distribution of genes in parents,

v. independent action of genes and

vi. no multiple allelism.

Their fulfilment and implications have been discussed at the appropriate place in the text.

Chapter IV

EXPERIMENTAL RESULTS

The results obtained for various characters have been presented under the following sub-heads:

A. Analysis of variance,

B. Mean values, heterosis and overdominance and

C. Combining ability analysis, graphic analysis and estimation of genetic parameters.

A. Analysis of variance

The analysis of variance for the design for all the characters studied has been given in Table 2. Variance due to progenies was highly significant for all the characters.

B. Mean values, heterosis and overdominance

The mean values for parents and F_1's along with C.D. values in respect of all the quantitative characters studied have been presented in Appendix I. Heterotic

Table 2

Analysis of variance for design for various characters

Source of variation	d.f.	Mean square									
		Plant height	Plant weight	Number of bolls per plant	Boll size	Number of seeds per boll	Yield of kapas per plant	Lint index	Seed index	Ginning out-turn	Halo length
Blocks	3	9035.49**	7139.48	311.69**	0.17**	37.11**	1128.29**	0.55**	1.94**	0.20	2.93
Progenies	54	1128.55**	8565.01**	191.57**	0.15**	16.25**	463.16**	0.612**	0.92**	26.11**	6.64**
Error	162	420.48	4167.87	57.75	0.03	8.96	157.92	0.119	0.48	8.98	1.32

* Significant at 5% level

** Significant at 1% level

effects, determined as deviations of F_1 means from respective mid-parental values have been given in Table 3. The differences in values of F_1's and those of the respective better parents, if any, have been given in Table 4. These results have been reviewed briefly.

B.1 Plant height

The mean values of parents for plant height ranged from 121.62 cm to 179.15 cm. Gaorani-6 and H_{420} were the tallest parents folåowed by Cocanadas white. M_{2608}, NR-5 and P_{34} had the shortest height. 231R x H_{420} was the tallest hybrid but did not significantly exceed the tallest parent Gaorani-6. It was closely followed by Cocanadas white x Gaorani-6, Cocanadas white x M_{2608}, H_{420} x M_{2608} and 35/5B x Gaorani-6. All of these crosses, except Cocanadas white x Gaorani-6, showed significant heterosis. The highly heterotic hybrids were 231R x M_{2608}, 35/5B x M_{2608}, M_{2608} x NR-5, Cocanadas white x M_{2608}, M_{2608} x P_{34} and 35/5B x NR-5.

The hybrids P_{34} x C.J.73 and H_{420} x NR-5 had the lowest mean values. Overdominance for shortness was found to be significant at 5 per cent level only in the hybrid P_{34} x C.J.73.

B.2 Dry weight (gm) per plant

The parents had high phenotypic variability for

Table 3 Heterotic Effects of Crosses for various characters

	Plant height	Plant weight	Number of bolls/ plant	Boll size	Number of seeds/ boll	Yield of *kapas*/ plant	Lint index	Seed index	Ginning out-turn	Halo length
	1	2	3	4	5	6	7	8	9	10
231R x G_{27}	22.82	53.56	8.87	.39**	-1.00	7.59	.14	1.26**	1.22	.30
231R x C.White	15.94	91.51*	6.75	.13	2.75	12.10	.12	-.27	.82	.20
231R x H_{420}	26.82*	132.06**	15.87**	.01	-2.50	26.98**	.83**	.78	1.85	-.20
231R x 35/5B	14.14	39.57	7.75	-.16	.25	10.88	-.42*	-.42	-2.26*	1.20*
231RxM_{2608}	44.06**	74.88	15.75**	-.08	-1.13	30.36**	.48*	.05	1.96	-.40
231R x P_{34}	28.19*	60.02	9.75*	.49**	4.12*	14.49	.40	.15	3.41**	.60
231R x Gaorani -6	9.50	19.50	7.87	.42**	0.12	10.67	.44*	-.10	1.97	-.20
231R x NR-5	28.33*	64.89	8.87	.64**	- .13	14.45	.05	.40	.52	.20
231R x C.J.73	30.11*	218.15**	18.62**	.05	1.25	28.58**	.06	- .28	1.54	.40
G_{27}xC.White	0.97	-8.30	3.12	.16	0.75	9.78	.15	.56	.79	.10
G_{27}xH_{420}	12.04	61.58	4.50	.05	-1.00	5.92	.15	.49	- .43	-.40
G_{27}x35/5B	18.88	36.88	7.37	.05	0.25	6.97	-.05	.45	- .97	.40
G_{27}xM_{2608}	34.44**	83.98*	18.37**	0	- .63	32.90**	.31	-.26	2.49*	0
G_{27}xP_{34}	0.41	28.64	1.87	.31**	4.12*	1.21	.27	.08	.10	-.60
G_{27}xG.-6	-0.46	-48.74	2.00	.21*	.87	3.36	.62**	.65	3.25**	-.50
G_{27}xNR-5	27.56*	61.98	5.75	.79**	1.37	15.37*	.25	.60	-.34	-.90
G_{27}xC.J.73	-5.66	7.93	0.25	-.14	3.25	-2.90	-.44*	-1.26**	.61	-.60
C.whitexH_{420}	4.74	9.58	0.12	.42**	2.25	4.87	.69**	.59	2.85**	.30

(Table 3 continued)

	1	2	3	4	5	6	7	8	9	10
C.Whitex35/5B	12.58	27.33	3.75	.10	.25	9.70	.04	.13	-.33	.70
C.WhitexM$_{2608}$	41.59**	95.78*	11.50*	.04	-.38	29.54**	.13	.09	1.57	.30
C.WhitexP$_{34}$	18.01	23.06	4.25	.30**	5.62**	9.18	-.68**	-.47	.95	-.70
C.White x G-6	15.57	28.01	4.37	-.29**	3.88*	3.91	.27	.09	2.17*	0
C.White x NR-5	8.19	44.95	13.87**	.11	1.12	21.89**	-.12	-.37	.90	-.10
C.White x C.J.73	21.39	65.86	4.37	.06	1.25	10.19	0	-.40	.40	-.10
H$_{420}$x35/5B	13.04	1.13	4.62	.09	-1.00	6.42	.59**	.89*	- .39	.30
H$_{420}$xM$_{2608}$	33.91**	-17.09	8.87	.16	-.13	18.71*	.58**	.79	1.64	.20
H$_{420}$xP$_{34}$	11.64	-27.91	4.87	.51**	2.62	7.45	.62**	1.48**	-.25	.10
H$_{420}$xG-6	-19.90	-71.56	3.25	.11	3.62*	4.79	.31	-.07	1.23	.40
H$_{420}$xNR-5	-20.68	37.73	0.75	.13	1.12	1.27	.07	.06	1.66	.40
H$_{420}$xC.J.73	-7.30	53.21	4.25	-.02	.25	5.83	-.05	.26	2.25*	-.30
35/5Bx M$_{2608}$	43.62**	129.06**	17.25**	-.12	2.13	33.16**	.16	.48	.07	1.00*
35/5B xP$_{34}$	14.50	86.14*	11.25*	-.01	-.38	14.16	.20	-.11	-2.32*	.60
35/5BxG-6	19.44	38.74	14.12**	-.08	-2.38	19.09*	.43*	.90*	.16	1.10*
35/5B x NR-5	38.48**	71.26	1.62	.17	.62	2.65	-.04	.46	-1.47	.10
35/5B x C.J.73	17.68	36.84	5.87	-.04	-2.00	6.56	.21	.79	-1.87	.30
M$_{2608}$ xP$_{34}$	40.48**	23.96	7.75	.07	1.00	12.81	.27	-.12	2.36*	-.70

	1	2	3	4	5	6	7	8	9	10
M_{2608}xG-6	20.78	-9.69	2.37	-.02	-1.25	6.43	.90**	.62	4.68**	1.10*
M_{2608}xNR-5	42.73**	35.25	11.88*	.13	- .75	23.49**	.60	.61	2.59*	-.40
M_{2608}xC.J.73	24.26	-1.97	4.62	.36**	-.2.88	11.46	-.01	-.37	1.57	-.10
P_{34}x G-6	-8.59	14.90	1.62	.08	1.50	-3.87	.02	.12	.60	0
P_{34}xNR-5	24.26	37.46	9.12*	.28**	2.25	11.35	.17	.32	.83	-1.00*
P_{34}xC.J.73	-30.22*	45.30	1.62	.28**	-.38	-3.37	-.37	-.64	-.78	0
G-6 x NR-5	25.26*	33.01	3.75	-.01	-2.25	4.33	.37	.83*	.15	.30
G-6 x C.J.73	-13.56	-18.37	9.75*	-.01	1.62	12.37	-.13	.13	-1.77	-.90
NR-5xC.J.73	28.96*	78.66*	2.50	.08	.12	3.87	-.06	.36	-1.83	-.30
C.D. 5%	24.61	77.48	9.11	.20	3.58	15.07	.41	.80	2.07	.95
1%	32.27	101.59	11.95	.27	4.70	19.76	.54	1.05	2.72	1.30

C. white = Cocanadas white.
G-6 = Gaorani-6.

Table 4

Mean deviations of the mean of the crosses* from the better (B)/poor (P) parents

Plant height

Cross	Value
231R x M_{2608}	29.00
35/5B x M_{2608}	32.40
35/5B x NR-5	30.30
M_{2608} x P_{34}	31.15
M_{2608} x NR-5	40.08
P_{34} x C.J.73	-28.77
C.D. at 5%	28.40

Plant weight

Cross	Value
231R x C.J.73	208.35
C. white x M_{2608}	91.35
35/5B x M_{2608}	111.25
C.D. 5%	89.47

Number of bolls per plant

Cross	Value
231R x H_{420}	13.25
231R x M_{2608}	14.25
231R x C.J.73	20.25
G27 x M_{2608}	12.50
35/5B x M_{2608}	12.50
M_{2608} x NR-5	10.75
C.D. at 5%	10.52

Boll Size

Cross	Value
231R x G27	0.28
231R x P_{34}	0.26
C. white x H_{420}	0.24
H_{420} x P_{34}	0.37
C.D. at 5%	0.24

Yield of kapas per plant

Cross	Value
231R x H_{420}	22.81
231R x M_{2608}	25.35
231R x C.J.73	26.91
G27 x M_{2608}	22.58
C. white x M_{2608}	18.22
H_{420} x M_{2608}	17.86
35/5B x M_{2608}	24.81
M_{2608} x NR-5	29.61
C.D. at 5%	10.52

Lint index

Cross	Value
H_{420} x M_{2608}	0.53
H_{420} x P_{34}	0.59
M_{2608} x Gaorani-6	0.87
C.D. at 5%	0.47

Seed index

Cross	Value
231R x G27	1.14
C.D. at 5%	0.96

*The values have been given only in respect of hybrids differing significantly from better/poor parents.

this character the mean values for which ranged from 84.37 gm to 224.37 gm. H_{420} was the parent having highest mean weight per plant whereas the lowest value was recorded by NR-5. The hybrids ranged from 110.0 to 330.0 gm in dry weight per plant. Only 231R x C.J. 73 exceeded the parent with highest weight per plant in the material (H_{420}). It was followed by 231R x H_{420} and 35/5B x M_{2608}. Hybrids with low mean weight per plant were H_{420} x C.J.73, G-27 x Gaorani-6, M_{2608} x C.J.73, Gaorani-6 x C.J.73 and G27 x C.J.73, though in no case the weight per plant was significantly lower than the respective low weight parents.

The hybrids which manifested significant degree of heterotic response were 231R x C.J.73, 231R x H_{420}, 35/5B x M_{2608} and Cocanadas white x M_{2608}. Overdominance was recorded in 231R x C.J.73, 35/5B x M_{2608} and Cocanadas white x M_{2608}.

B. 3 <u>Number of bolls per plant</u>

The parents Cocanadas white, G27 and 35/5B had higher number of boåls per plant whereas P_{34}, Gaorani-6 and C.J.73 had the lower number of boåls per plant. The parents ranged from 7-24 in bolls per plant while hybrids were in the range of 10-36 bolls per plant.

G27 x M_{2608} was the only hybrid significantly exceeding the best parent (Cocanadas white) in this material. It was followed, in mean boll value by 35/5B x

M_{2608}, Cocanadas white x NR-5, 231R x C.J.73 and 35/5B x Gaorani-6. High degree of heterosis was observed in 231R x C.J.73, G27 x M_{2608}, 35/5B x M_{2608}, 231R x H_{420} and 231R x M_{2608} hybrids. All these hybrids also recorded significant overdominance. No hybrid had mean value significantly less than the poorest parent in the material for this character.

B. 4 Boll size

M_{2608}, with highest boll weight, had significantly larger bolls than all the parents. P_{34} had the smallest bolls. The weight of kapas per boll in case of hybrids ranged from 1.35 to 2.22 gm of kapas per boll. No hybrid had larger bolls than those of M_{2608}.

Cocanadas white x H_{420}, Cocanadas white x M_{2608}, H_{420} x M_{2608}, 231R x G27 and M_{2608} x NR-5 were the larger boll sized hybrids. Maximum heterosis for this character was recorded by G27 x NR-5 and this was closely followed by 231R x NR-5, H_{420} x P_{34} and 231R x P_{34}. Maximum overdominance was observed in hybrid H_{420} x P_{34} where both the parents had very low boll size. 231R x Cocanadas white, Cocanadas white x M_{2608} and M_{2608} x NR-5 had high mean value per se but manifested low degree of heterosis. Cocanadas white x Gaorani-6 had significant negative heterosis.

B.5 Number of seeds per boll

M_{2608}, C.J.73, Gaorani-6, Cocanadas white and H_{420} recorded the higher number of seeds per boll in order of merit. Range of variability in parents for this character was from 16.25 to 25.25 seeds while in hybrids the number of seeds per boll varied from 16.75 to 24.50. No hybrid was found to exceed the parental extremes in any direction in this material.

Hybrids with higher mean values for seeds per boll were G27 x C.J.73, H_{420} x Gaorani-6, Cocanadas white x P_{34} and Gaorani-6 x C.J.73. Highly heterotic hybrids were Cocanadas white x P_{34}, G27 x P_{34}, 231R x P_{34}, Cocanadas white x Gaorani-6 and H_{420} x Gaorani-6 but in no case, overdominance was found to be significant.

B. 6 Yield of kapas (gm) per plant

Cocanadas white, G27, 35/5B and 231R were the high yielding parents in order of merit. M_{2608} and H_{420} were the poor yielders. The hybrids ranged from 13.15 to 54.70 gm in mean yield of kapas per plant whereas the range for parents was 11.47 to 34.00 gm.

G27 x M_{2608}, the highest yielding hybrid, was significantly better than the best parent (Cocanadas white) in mean yield. This hybrid was followed by 35/5B x M_{2608}, Cocanadas white x M_{2608}, 231R x C.J.73, Cocanadas white x

NR-5, 231R x M_{2608} and 231R x H_{420} in mean yield. All these hybrids were statistically at par with the highest yielding parent. Heterosis for yield of kapas was always associated with heterosis in number of bolls per plant. Negative heterosis was not significant in any case. All the hybrids showing overdominance were those in which one of the parents was a high yielder and the other poor yielder.

B. 7 Lint index

231R had the highest mean value for lint index closely followed by Cocanadas white and G27. H_{420} and Gaorani-6 had the lowest mean values. No hybrid exceeded the best parent (231R) in the material.

Hybrids 231R x G27, 231R x H_{420}, 231R x Cocanadas white and Cocanadas white x H_{420} had the high mean lint index values. Maximum heterosis in this character was recorded by M_{2608} x Gaorani-6. Significant heterosis for low lint index was observed only in Cocanadas white x P_{34} hybrid. Overdominance was observed in M_{2608} x Gaorani-6, H_{420} x P_{34} and H_{420} x M_{2608}.

B.8 Seed index

The parent M_{2608} had the highest while H_{420} and G27 had the low mean values for seed index.

Hybrids 231R x G27, H_{420} x P_{34} and M_{2608} x

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Gaorani-6 exceeded the parent with highest mean seed index (M_{2608}) in the material. H_{420} x P_{34} had maximum heterosis closely followed by 231R x G27, 35/5B x Gaorani-6 and H_{420} x 35/5B. Negative heterosis was recorded by G27 x C.J.73 hybrid. Only 231R x G27 had significant over-dominance for higher seed index.

B.9 Ginning out-turn

231R, Cocanadas white and G27 had high ginning outturn values among the parents. Parent M_{2608} had the lowest ginning outturn value but not significantly different from Gaorani-6 and P_{34}, the other low ginning outturn parents. Range of variability for this character in parents was 28.07 to 38.22 whereas in hybrids it was from 28.55 to 38.17. No hybrid exceeded the parental limits significantly. Heterosis for this character was observed in six hybrids out of which, M_{2608} x Gaorani-6 recorded highest value for heterosis. All the heterotic hybrids involved combinations of parents with good x poor per se performance. Negative heterosis was observed in 231R x 35/5B and 35/5B x P_{34}. Overdominance was not significant for any of the hybrids.

B. 10 Halo length

The parent C.J.73 had the highest mean halo length.

P_{34} and Gaorani-6 were at par with C.J.73 in halo length though all other parents were significantly inferior than the latter. 231R had the lowest mean value for halo length closely followed by Cocanadas white, G27 and 35/5B.

All the hybrids involving C.J.73 had high mean halo length - though hybrids M_{2608} x Gaorani-6 and H_{420} x Gaorani-6 were also having high mean halo length. All the 45 hybrids were below the best parent (C.J.73) in mean halo length. Heterosis was recorded in 231R x 35/5B, M_{2608} x Gaorani-6 and 35/5B x Gaorani-6 hybrids. Hybrid P_{34} x NR-5 recorded negative heterosis. Overdominance was not observed in any hybrid.

C. Combining ability analysis, graphic analysis and <u>estimates of genetic parameters</u>

Analysis of variance for combining ability in respect of the quantitave characters has been given in Table 5. Variances due to general combining ability were significant for all the characters studied. Variances due to specific combining ability were also significant for all the characters except for number of seeds per boll, ginning outturn and halo length. The general magnitude of variance due to general combining ability was higher than for specific combining ability for all the characters except for number of bolls per plant, boll size and lint index. Estimates of general

Table 5

Analysis of variance for combining ability for various characters

Source of variation	d.f.	Mean square									
		Plant height	Plant weight	Number of bolls per plant	Boll size	Number of seeds per boll	Yield of _kapas_ per plant	Lint index	Seed index	Ginning out-turn	Halo length
g.c.a.	9	529.25**	2321.12*	150.44**	0.108**	10.49**	290.70**	0.538**	.295**	30.74**	8.87**
s.c.a.	45	232.88**	2105.25**	792.20**	0.242**	2.78	80.81**	0.760**	.220**	1.74	0.23
Error	162	105.12	1044.47	14.44	0.008	2.24	39.48	0.297	.121	2.25	0.33

* Significant at 5% level of significance

** Significant at 1% level of significance combining ability effects of the parents have been given in Table 6 and those for specific combining ability in Table 7.

The mean estimates of variance for D, H_1, H_2, F, E and h^2 components along with their standard errors have been given in Table 8. Ratios of components, correlation of Wr + Vr with Yr (Parents), values of h^2/H_2, order of dominance of parents and order of parents for mean performance have been given in Table 9. Wr + Vr values for each array for all the characters have been presented in Table 10.

The overall examination of genetic situation in terms of additive and non-additive effects is possible with the help of Vr, Wr, and W', Wr graphs. The interpretations of these graphs and implications of combining ability estimates and genetic parameters have been presented in the following pages, separately for each character.

C. 1 Plant height

231R, Gaorani-6, NR-5, Cocanadas white and H_{420} were good general combiners for greater height. While C.J.73 and P_{34} were good combiners for short height. Cocanadas white x C.J.73 was the only combination manifesting significant specific effect for greater height whereas P_{34} x C.J.73 and H_{420} x NR-5 were significant in the other direction.

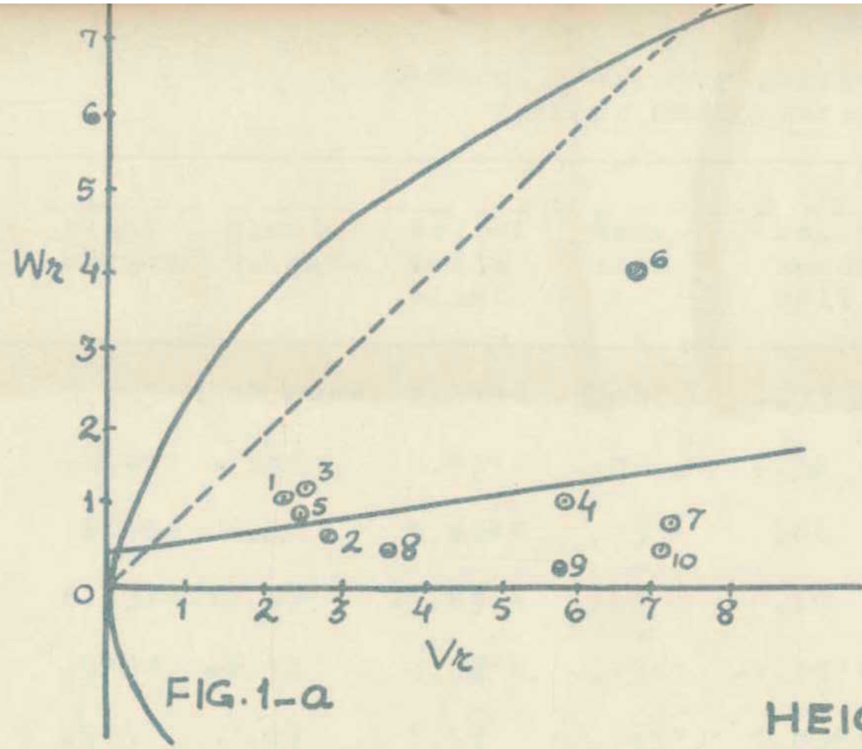

FIG. 1-a

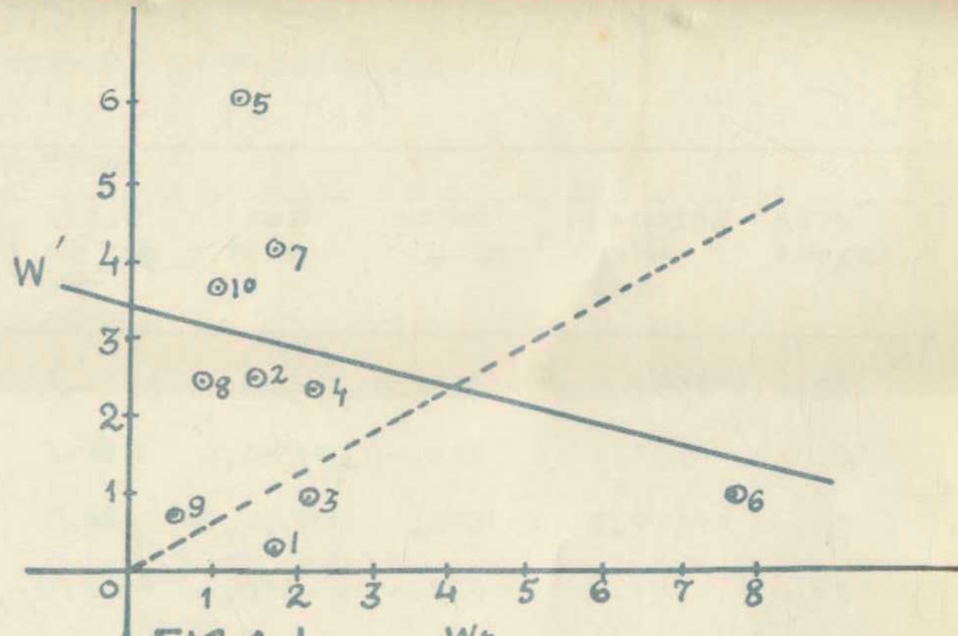

FIG. 1-b

HEIGHT IN CM.

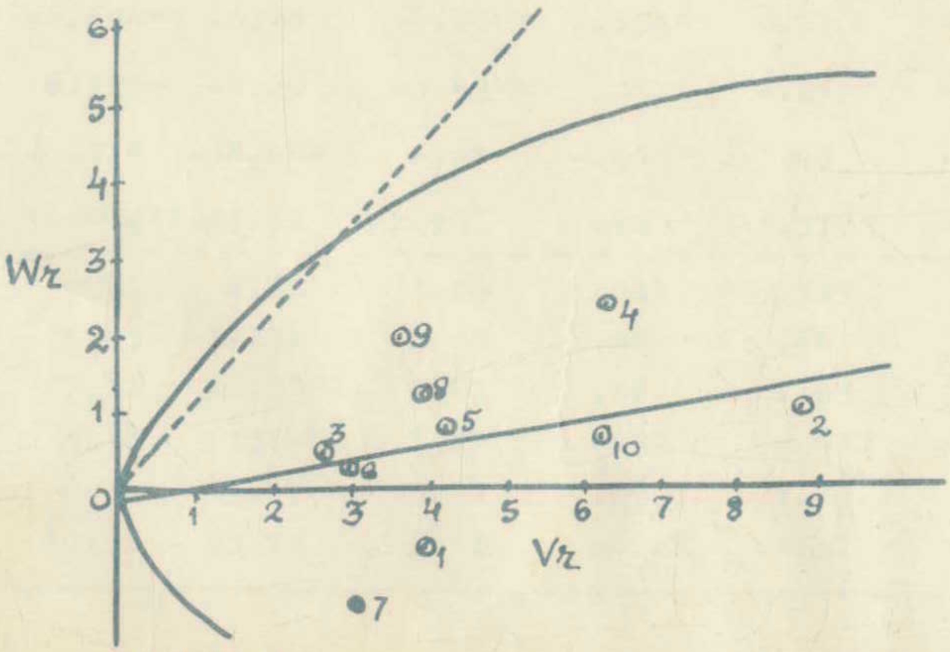

FIG. 7-a

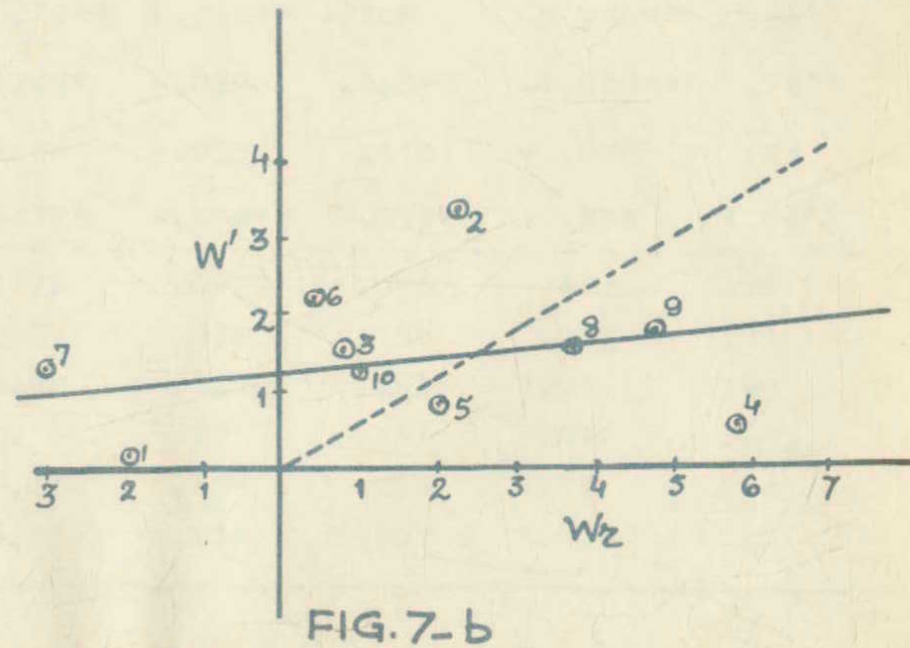

FIG. 7-b

SEED INDEX

Table 6

General combining ability effects of parents for various characters

	CHARACTERS									
	Plant height	Plant weight	No. of bolls / plant	Boll size	No. of seeds/ boll	Yield of *kapas* per plant	Lint index	Seed index	Ginning out-turn	Halo length
231R	7.233**	24.69**	2.69**	.04	-.73	4.49**	.426**	.001	2.967**	-.98**
G_{27}	-2.951	-1.46	3.57**	-.04	-.38	3.48*	.097*	-.052	1.132**	-1.00**
C. White	6.18*	6.87	3.69**	.13**	.64	6.94**	.273**	.050	1.977**	-.93**
H_{420}	6.131*	17.60*	-3.85**	-.01	.10	-5.78**	-.056	-.153	.174	-.13
35/5B	.970*	-6.32	4.23**	-.13**	-1.55**	3.99*	-.115*	.036	-.844*	-.28
M_{2608}	.914	7.09	1.55	.16**	1.40**	3.08	-.037	.246**	-1.358**	.10
P_{34}	-8.694**	-6.46	-4.80**	-.13**	-.71	-6.49**	-.262**	-.108	-1.750**	.56**
G-6	6.527*	-8.29	-3.43**	.01	-.21	-4.09*	-.083	.228*	-1.826**	.71**
NR-5	6.27*	-18.04*	-.68	-.01	.08	-1.46	-.035	.110	- .004	.25
C.J.73	-10.042**	-15.69	-2.95**	.02	1.37**	-4.17*	-.208**	-.259**	- .470	1.68**
S.E.(eff.)	2.81	8.85	1.04	.024	.409	1.72	.0477	.095	.411	.16
C.D. 5%	5.50	17.34	2.03	.05	.801	3.37	.092	.186	.805	.31
1%	7.22	22.34	2.67	.06	1.05	4.42	.120	.244	1.05	.40
S.E.(diff.)	4.18	13.20	1.55	.035	.611	2.56	.07	.141	.612	.235
C.D.5%	8.20	25.87	3.04	.068	1.20	5.01	.137	.276	1.19	.46
1%	10.75	33.92	3.98	.089	1.57	6.57	.179	.362	1.57	.60

Table 7

Specific combining ability estimates of the hybrids for different characters

Hybrids	CHARACTERS						
	Plant height	Plant weight	Number of bolls per plant	Boll size	Yield of <u>kapas</u> per plant	Lint index	Seed index
1	2	3	4	5	6	7	8
231 R x G_{27}	+ 6.22	- 7.26	+ 0.99	+ 0.25**	+ 1.40	+ 0.40*	+ 1.08**
231 R x C. White	- 2.99	+ 25.03	- 1.13	+ 0.03	+ 3.80	- 0.04	- 0.24
231 R x H_{420}	+ 15.86	+ 91.04**	+ 8.41*	- 0.14	+ 20.95**	+ 0.43**	+ 0.36
231 R x 35/5B	- 10.05	- 35.96	- 1.92	- 0.19*	+ 2.57	- 0.56**	- 0.70*
231 R x M_{2608}	+ 9.55	+ 3.75	+ 4.02	- 0.09	+ 14.61*	+ 0.11	- 0.09
231 R x P_{34}	+ 12.61	+ 0.90	+ 1.87	+ 0.32**	+ 10.03	+ 0.27	+ 0.11
231 R x G-16	- 1.86	- 15.94	+ 0.24	- 0.10	+ 6.41	+ 0.09	- 0.34
231 R x NR-5	+ 4.06	- 10.49	+ 0.49	- 0.01	+ 7.13	- 0.14	+ 0.15
231 R x C.J.73	+ 17.33	+149.27**	+ 10.77**	+ 0.08	+ 23.42**	+ 0.04	- 0.14
G_{27} x C. White	- 8.81	- 35.72	- 0.76	+ 0.02	+ 1.81	+ 0.05	+ 0.50
G_{27} x H_{420}	+ 9.24	+ 59.63*	+ 1.04	- 0.13	+ 0.21	- 0.19	- 0.02
G_{27} x 35/5B	+ 4.45	+ 0.41	+ 1.70	- 0.01	- 1.02	- 0.12	+ 0.09
G_{27} x M_{2608}	+ 9.09	+ 51.90	+ 10.64**	- 0.05	+ 17.48**	0	- 0.48
G_{27} x P_{34}	- 6.01	+ 6.78	- 2.01	+ 0.11	- 2.93	+ 0.17	- 0.05

	2	3	4	5	6	7	8
G_{27} x G-6	- 2.66	- 45.12	- 1.63	+ 0.16*	- 0.59	+ 0.33*	+ 0.32
G_{27} x NR-5	+ 12.44	+ 25.66	+ 1.37	+ 0.12	+ 8.38	+ 0.12	+ 0.27
G_{27} x C.J.73	- 9.29	- 13.96	- 3.61	- 0.15*	- 7.74	+ 0.40*	- 1.20**
G.White x H_{420}	- 0.39	- 17.88	- 3.37	+ 0.26**	- 3.29	+ 0.43**	+ 0.31
C.white x 35/5B	- 4.18	-15.42	- 1.92	+ 0.06	- 0.76	+ 0.03	- 0.01
C. white x M_{2608}	+ 13.90	+ 57.63	+ 3.77	+ 0.02	+ 11.65*	- 0.09	+ 0.09
C. white x P_{34}	+ 17.63	- 4.87	+ 3.37	+ 0.11	+ 2.58	- 0.34*	+ 0.38
C. White x G-6	+ 11.04	+ 25.50	+ 0.74	- 0.33**	- 2.50	+ 0.06	- 0.02
C. White x NR-5	- 8.50	+ 2.56	+ 9.49**	- 0.03	+ 11.45*	- 0.18	+ 0.48
C. White x C.J.73	+ 23.76*	+ 29.96	+ 0.52	+ 0.08	+ 2.10	+ 0.12	+ 0.18
H_{420} x 35/5B	+ 3.75	- 15.95	- 0.63	+ 0.02	- 1.76	+ 0.35*	+ 0.31
H_{420} x M_{2608}	+ 13.20	- 29.78	+ 1.56	+ 0.10	+ 3.08	+ 0.11	+ 0.35
H_{420} x P_{34}	+ 18.20	- 30.37	+ 1.41	+ 0.29**	+ 3.11	+ 0.37*	+ 2.93**
H_{420} x G-6	- 17.46	- 48.55	+ 0.04	+ 0.05	+ 0.65	- 0.14	- 0.62*
H_{420} x NR-5	- 30.33**	+ 20.70	- 0.94	- 0.05	- 5.93	+ 0.22	- 0.50
H_{420} x C.J. 73	+ 2.04	- 63.64*	+ 0.81	- 0.03	+ 0.80	- 0.17	+ 0.09
35/5B x M_{2608}	+ 11.23	+ 80.83**	+ 7.73*	- 0.06	+ 15.26**	- 0.04	+ 0.18
35/5B x P_{34}	+ 1.09	+ 47.43	+ 5.58	- 0.10	+ 7.55	- 0.20	+ 0.05
35/5B x G-6	+ 10.25	+ 25.50	+ 8.70*	- 0.10	+ 12.67*	+ 0.24	+ 0.49
35/5B x NR-5	+ 16.37	+ 18.09	- 4.55	+ 0.11	- 6.82	- 0.06	+ 0.04

1	2	3	4	5	6	7	8
35/5B x C.J. 73	+ 7.00	- 9.84	+ 0.23	+ 0.07	- 0.76	+ 0.35*	+ 0.76*
M_{2608} x P_{34}	+ 16.15	- 8.62	+ 0.02	- 0.01	- 1.26	+ 0.05	- 0.19
M_{2608} x G-6	+ 0.68	- 0.79	- 5.11	+ 0.06	- 7.43	+ 0.48**	+ 0.35
M_{2608} x NR-5	+ 9.61	- 11.79	+ 3.64	+ 0.09	+ 6.58	+ 0.34*	+ 0.03
M_{2608} x C.J. 73	+ 2.73	- 42.52	- 3.09	- 0.24**	- 3.29	- 0.09	- 0.26
P_{34} x G-6	- 9.76	+ 18.01	- 2.01	- 0.01	- 6.44	- 0.18	- 0.07
P_{34} x NR-5	+ 10.16	+ 0.63	+ 4.74	+ 0.08	+ 5.72	+ 0.13	+ 0.14
P_{34} x C.J. 73	- 32.81**	+ 14.97	- 2.23	- 0.32**	- 6.84	- 0.24	- 0.43
G-6 x NR-5	+ 15.39	+ 21.66	- 0.38	- 0.07	- 1.10	+ 0.13	+ 0.45
G-6 x C.J.73	- 11.94	- 23.19	+ 6.14	+ 0.10	+ 9.09	- 0.20	+ 0.14
NR-5 x C-J.73	+ 17.66	+ 33.87	- 1.86	+ 0.08	- 2.45	+ 0.03	+ 0.36
S.E. (Effect.)	9.45	29.76	3.50	.08	5.78	.16	.32
C.D. at 5%	18.52	58.32	6.86	.15	11.33	.31	.62
1%	24.28	76.48	8.96	.20	14.85	.41	.82

C.White = Cocanadas White G-6 = Gaorani-6

Table 9

Ratio of components, order of dominance of parents and order of parents based on their mean performance

Characters	$(H_1/D)^{1/2}$	$\bar{u}\ \bar{v}$	u:v	$\frac{h^2}{H_2}$	Correlation of Wr+Vr and Yr(Parent)	Order of dominance of parents dominant → recessive	Order of parents based on their mean performance High → low
Plant height	1.73	0.17	78:22	-	-0.51	5 3 2 8 1 9 4 10 7 6	8 4 3 1 2 7 5 10 9 6
Plant weight	3.12	0.21	70:30	-	-0.21	5 9 3 6 1 7 10 2 8 4	4 8 3 2 6 7 1 5 10 9
Number of bolls/plant	1.65	0.23	64:36	3.02	-0.39	5 1 3 4 2 10 7 8 9 6	3 2 5 9 1 6 10 8 4 7
Boll size	1.24	0.18	76:24	0.21	-0.38	3 1 9 8 5 6 2 4 10 7	6 3 10 8 1 9 5 4 2 7
No. of seeds/ boll	1.28	0.21	70:30	0.42	-0.26	5 9 6 3 10 1 2 4 7 8	6 10 8 4 3 9 2 1 5 7
Yield of <u>kapas</u> per plant	-	0.20	72:28	2.59	-0.56	1 3 5 4 7 8 2 10 9 6	3 2 5 1 8 9 10 7 4 6
L i n t Index	1.23	0.16	67:33	1.36	0.29	5 9 3 6 1 7 10 2 8 4	1 3 2 10 9 5 6 7 8 4
Seed index	-	0.25	50:50	0.22	- 066	7 3 6 1 5 8 9 10 4 2	6 3 8 1 10 7 9 5 2 4
Ginning out-turn	0.50	0.14	87:13	1.09	-0.74	2 1 3 9 5 6 4 10 8 7	1 3 2 5 9 10 4 7 8 6
Halo length	-	0.23	64:36	-	0.81	2 3 5 9 8 10 7 6 1 4	10 7 8 9 6 4 5 2 3 1

Table 10

Wr + Vr Values

	Plant height	Plant weight	Number of bolls per plant	Boll size	Number of seeds per boll	Yield of kapas per plant	Lint index	Seed index	Ginning out-turn	Halo length
231 R	168.24	5156.28	32.23	.031	4.50	48.18	.190	.160	5.16	3.01
G_{27}	182.81	2144.46	52.43	.048	5.69	109.33	.246	.516	4.16	1.55
C. White	168.94	1160.96	35.10	.027	4.32	54.55	.155	.136	5.54	2.15
H_{420}	355.25	3588.43	43.96	.064	7.27	95.82	.348	.448	11.25	3.30
35/5B	165.72	1979.84	25.31	.039	2.43	66.21	.064	.240	7.00	2.29
M_{2608}	566.54	2159.90	120.96	.045	4.13	328.74	.175	.138	9.08	2.74
P_{34}	416.88	281.97	58.26	.089	7.64	105.98	.185	.081	13.28	2.65
G-6	204.61	606.98	63.72	.033	8.15	109.29	.267	.264	13.19	2.38
NR-5	302.69	1568.18	63.82	.033	2.52	145.66	.080	.277	6.47	2.29
C.J.73	390.33	3653.08	54.14	.068	4.47	128.25	.210	.330	13.09	2.48

Maximum value represents top recessive variety.
Minimum value represents top dominant variety.

On the Vr, Wr graph (Fig. 1-a), very poor regression was observed which indicated high genotype-environment interaction. There was not greater diversity among the parents. Parent M_{2608} was the top recessive. Overall partial dominance was observed. On the W', Wr graph the regression coefficient was (Fig. 1-b) negative ($b' = .125 \pm .215$) but not significant. This confirmed the presence of higher order genotype x environment interactions or environmental influence on the plant height.

Estimation of degree of dominance was not considered worthwhile because of the presence of higher order genic interactions. The relative gene frequency was calculated for this character as the failure of assumptions is unimportant for this purpose (Hayman, 1954). $\bar{u}\bar{v} = .17$ indicated asymmetrical distribution of positive and negative allels whereas positive F value indicated dominant genes to be more prevalent among the parents.

C. 2 Weight per plant

231R and H_{420} were good general combiners for higher plant weight whereas NR-5 was good combiner for low plant weight. 231R x C.J.73, 231R x H_{420} and 35/5B x M_{2608} were good specific combinations for high plant weight. For low plant weight, H_{420} x C.J.73 (good x average combiner) combination was the best.

Graphs were not drawn for this character since both regression coefficients (b = -.021 ± .360 and b' = -.282 ± .099) were negative indicating that higher order non-allelic interactions or environmental influences were involved. Ratio of positive to negative allels was 70:30.

C. 3 Number of bolls per plant:

35/5B, Cocanadas white, G27 and 231R were good general combiners for greater number of bolls per plant. P_{34}, H_{420} and Gaorani-6 were poor combiners for this character. 231R x C.J.73, G27 x M_{2608}, Cocanadas white x NR-5 and 35/5B x Gaorani-6 were good specific combinations for higher number of bolls per plant. All involved good x average combiners.

Overdominance was indicated since the regression line intersected the Wr - asix below the origin (Fig.2-a). The regression slope (b = .721 ± .130) was not significantly different from unity indicating additive gene action. All the array points occupied positions below the expected regression line. Parent M_{2608} had maximum concentration of recessive allels and was widely different from the rest of the parents. The regression coefficient (Fig.2-b) of W' on Wr (b' = .486 ± .109) was not significantly different from 0.5. Majority of the points fell above the theoretical regression line on this graph giving an indication of some complementary type of gene action.

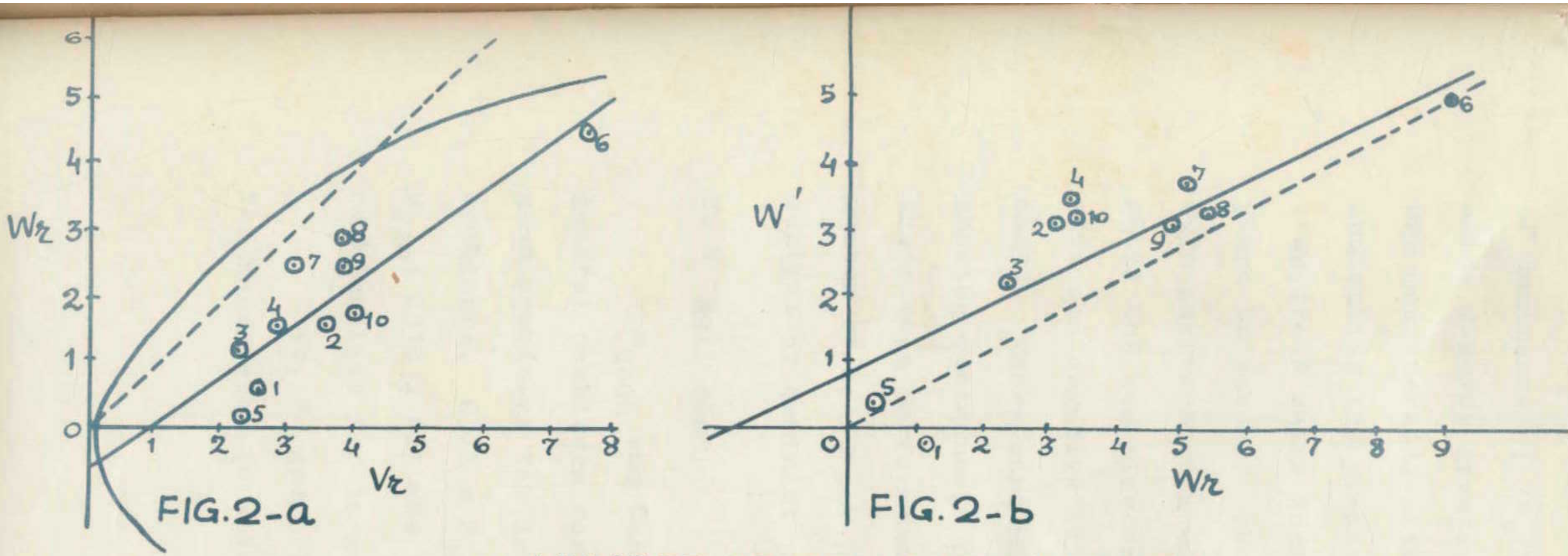

FIG. 2-a FIG. 2-b

NUMBER OF BOLLS PER PLANT

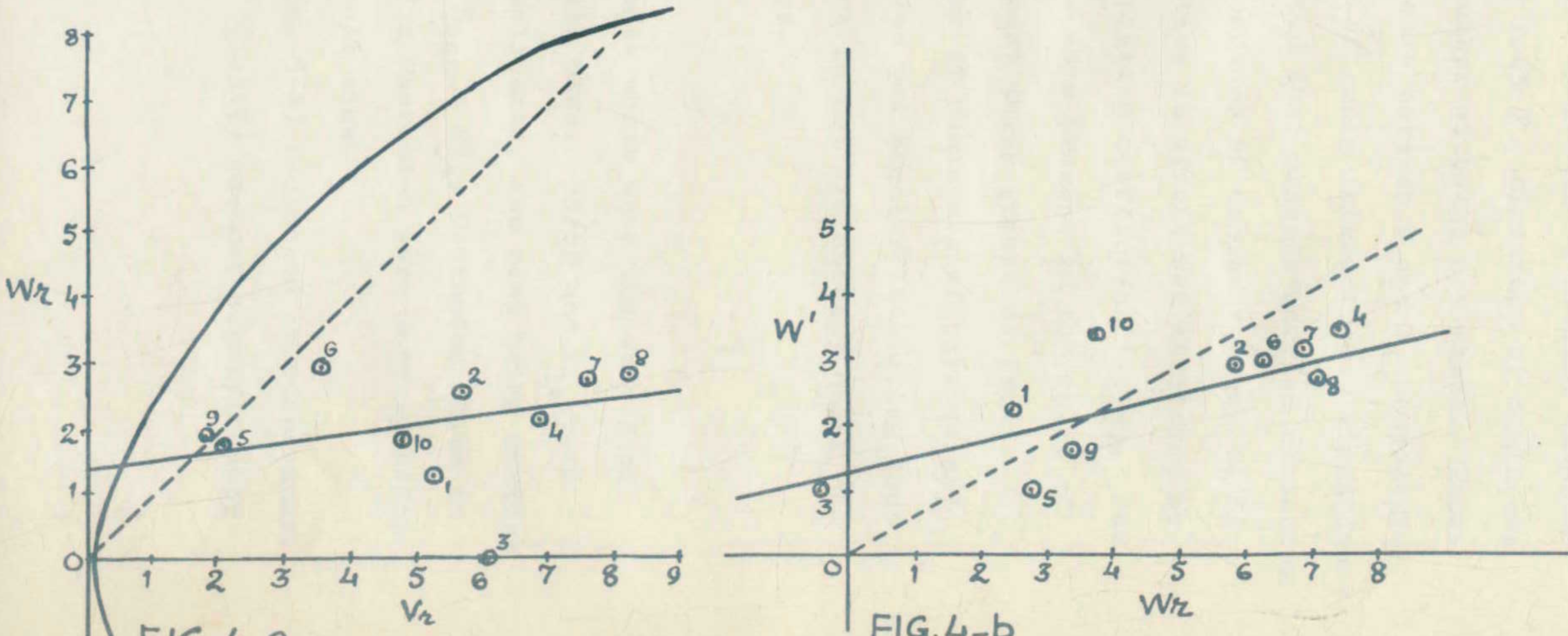

FIG. 4-a FIG. 4-b

NUMBER OF SEEDS PER BOLL

Overdominance was indicated by overall measure of dominance ($\sqrt{H_1/D} = 1.65$), direction of dominance being towards greater number of bolls per plant. There was considerable difference between D and H_1 components indicating the presence of genic interaction. Significant negative F value indicated that parents carried recessive genes in excess. The tendency of dominant genes to be more positive than negative in effect was indicated by small but negative correlation coefficient (-.39). Positive and negative allels were present in the ratio of 64:36. There were at least three groups of genes showing dominance. Order of dominance of parents and their mean performance was not similar indicating that number of bolls per plant is not exclusively under the control of dominant genes.

C. 4 <u>Boll size</u>

M_{2608} and Cocanadas white were the only good general combiners for boll size. 35/5B and P_{34} were good combiners for low boll size, the rest being average combiners. 231R x P_{34}, H_{420} x P_{34}, Cocanadas white x H_{420}; 231R x G27 and G27 x Gaorani-6 were good specific combinations for large boll size.

Vr, Wr graph (Fig. 3-g) indicated overdominance. The regression ($b = 1.07 \pm .317$) was not significantly

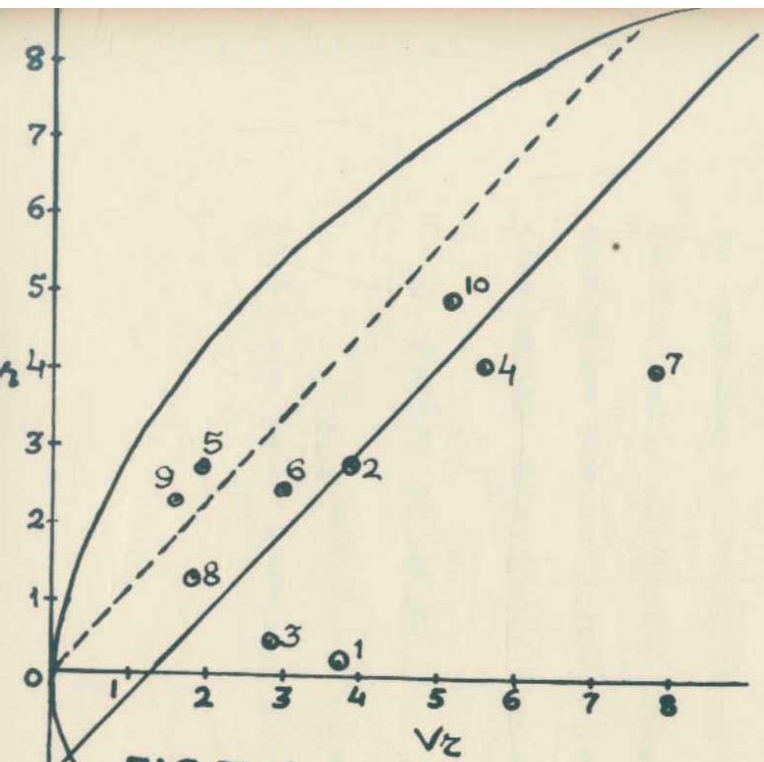

FIG. 3-a

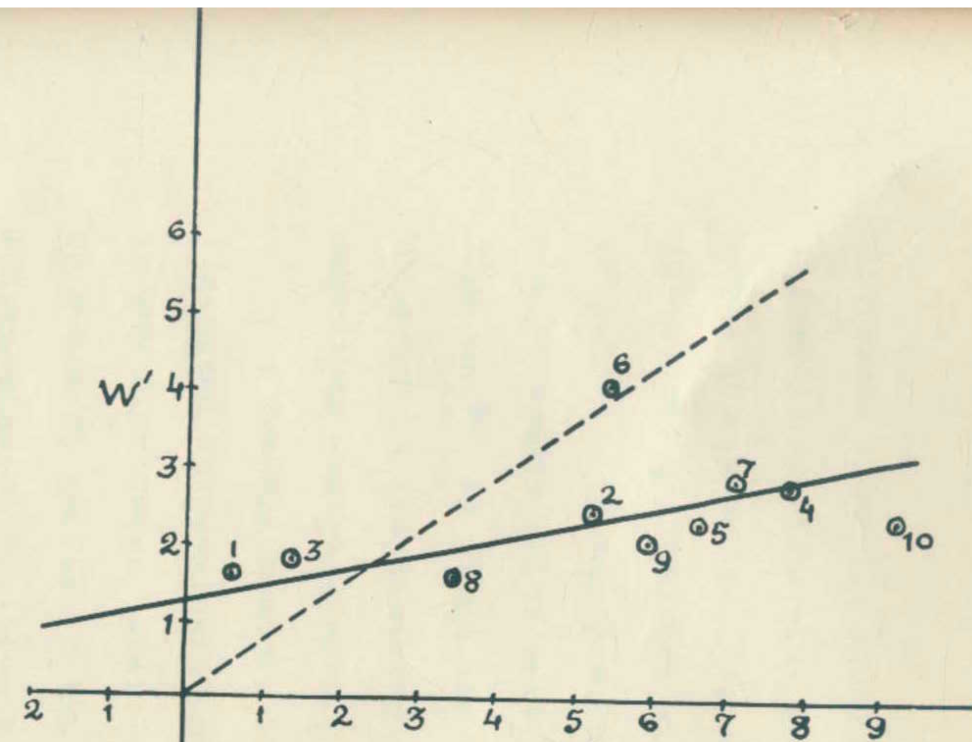

FIG. 3-b

BOLL SIZE

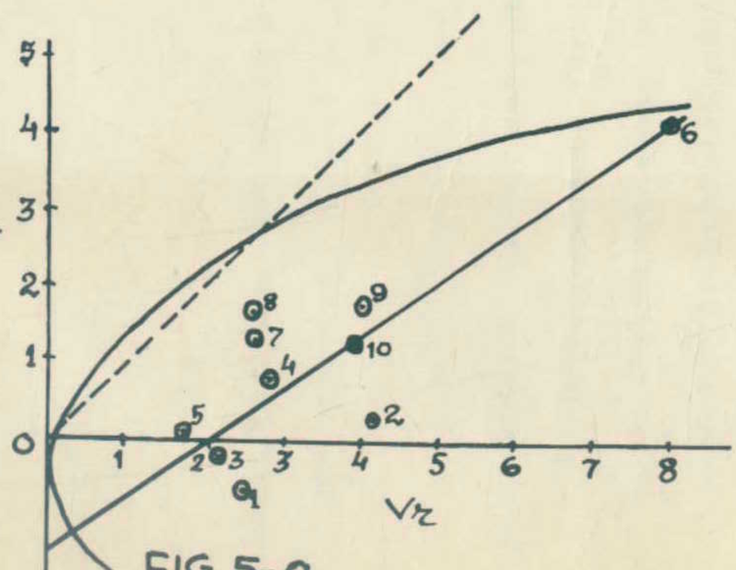

FIG. 5-a

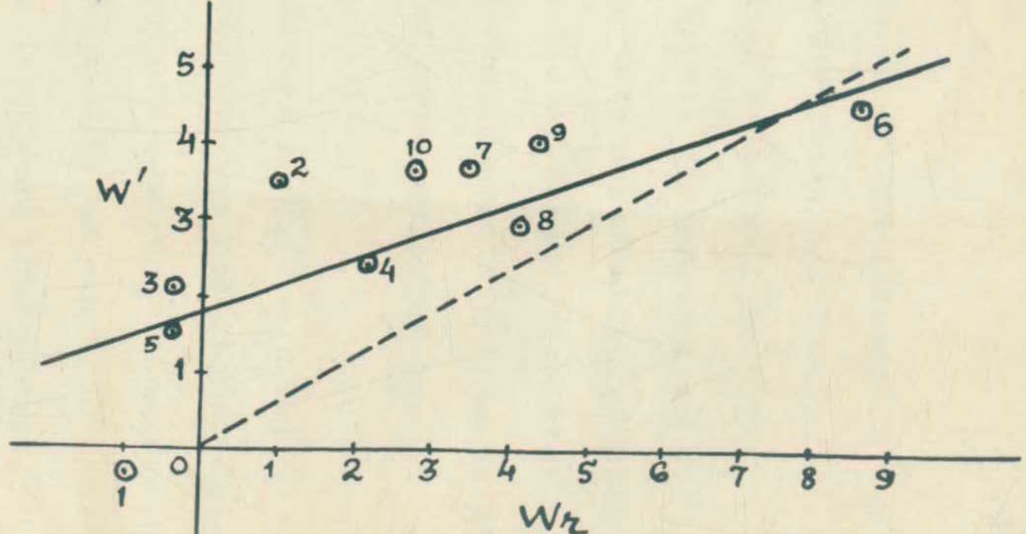

FIG. 5-b

YIELD OF *KAPAS* PER PLANT

different from one showing absence of non-allelic interactions. No wide genetic diversity was indicated among the parents. Regression of W' on Wr was (b' = .239 ± .131) not significantly different from 0.5 (Fig. 3-b). Since some array points especially for 231R and Cocanadas white were below the expected regression line on Vr, Wr graph and above the theoretical line on W', Wr graph, a complementry type of gene action of low magnitude was suggested.

Overall measure of dominance ($\sqrt{H_1/D}$ = 1.24) indicated overdominance but direction was not significant to any direction. Small differences between estimates of D and H_1 indicated the low magnitude of genic interactions. Positive F value indicated that parents carried dominant genes in excess. Small but negative value of correlation of (Wr + Vr) and Yr indicated greater positive effects of dominant genes as compared to negative effects. Positive and negative allels were in the ratio of 76:24. Number of factors showing dominance was very low (0.21). Top dominant parent (Cocanadas white) was the second best in mean performance.

C. 5 <u>Number of seeds per boll</u>

M_{2608} and C.J.73 were good general combiners and 35/5B was poor combiner for this character, the rest being the average combiners. No significant specific combination was observed.

On the Vr, Wr graph, the regression line (Fig.4-a) intersected the Wr-axis above the origin, showing partial dominance. The regressive coefficient (b = .150 ± .165) deviated significantly from unity indicating presence of high non-allelic interactions. Since most of the points were below the regression line on both the graphs, a duplicate type of gene action was suggested in addition to that of complementary type. Genetic diversity among the parents for seeds per boll was present. Regression of W' on Wr (b' = .179 ± .105) was significantly different from 0.5 (Fig. 4-b) suggesting the presence of non-allelic interaction. Presence of partial dominance was also confirmed.

The value for $(H_1/D)^{1/2}$ suggested overdominance which seems to have been inflated by genic interactions since partial dominance only was observed from the graphic analysis. Low numbers of seeds per boll was in the direction of dominance. Since H_1 was significant, non-significant F value indicated symmetrical distribution of dominant and recessive genes among the parents. The ratio of positive to negative genes in the parents was 70:30. Absence of any strong correlation value (-.26) may be explained that the dominant genes have larger effect in positive direction than vice versa. This might have resulted in under estimation of h^2/H_2 which was only (0.42). The order of the parents listed on the basis of magnitude of dominance and mean performance was not similar.

C. 6 Yield of kapas per plant

Cocanadas white was the best general combiner for kapas yield followed by 231R, 35/5B and G27 in order. P_{34}, H_{420} and C.J.73 were the poor combiners. 231R x C.J.73, 231R x H_{420}, G27 x M_{2608}, 35/5B x M_{2608} and 231R x M_{2608} were the best combinations.

The regression line intersected the Wr axis (Fig. 5-a) below the origin indicating overdominance. However, the regression slope was significantly deviating from unity (b = .5653 ± .1391) indicating the presence of non-allelic interactions. Some of the points fell below the theoratical regression line (b = 1.0). Genotype-environment interaction was present in this character since the regression line does not meet the limiting parabala. Parent M_{2608} had the maximum frequency of recessive allels and was widely different from other parents which had maximum concentration of dominant allels for this character. On the W', Wr graph (Fig. 5-b) regression line did not differ significantly from slope of 0.5. Overdominance was confirmed by some points falling in third quadrent. Array points below the regression line on the Wr, Vr, graph were above the theoretical line of regression on W', Wr graph showing complementary type of gene interaction.

Average degree of dominance calculated by $(H_1/D)^{1/2}$ was not worked since D was non-significant. However, H_1 value indicated dominance to be important in the inheritance of yield. Non-significant F values indicated the symmetrical distribution of dominant and recessive allels in the parents while asymmetry of positive and negative alleles was indicated by $\bar{u}\bar{v}$ value of 0.20. Small value of correlation of Wr + Vr and Yr (-.56) indicated that some of the genes showed dominance in a positive direction for yield (high yield) while some acted in the negative direction. Order of dominance of parents and their mean performance was not similar. At least 3 genes were showing phenomena of dominance.

C. 7 Lint index

231R, Cocanadas white and G27 were good combiners for high lint index. P_{34}, C.J.73 and 35/5B were good general combiners for low lint index. M_{2608} x Gaorani-6, 231R x H_{420}, Cocanadas white x H_{420} and 231R x G27 were good specific combinations for high lint index. 231R x

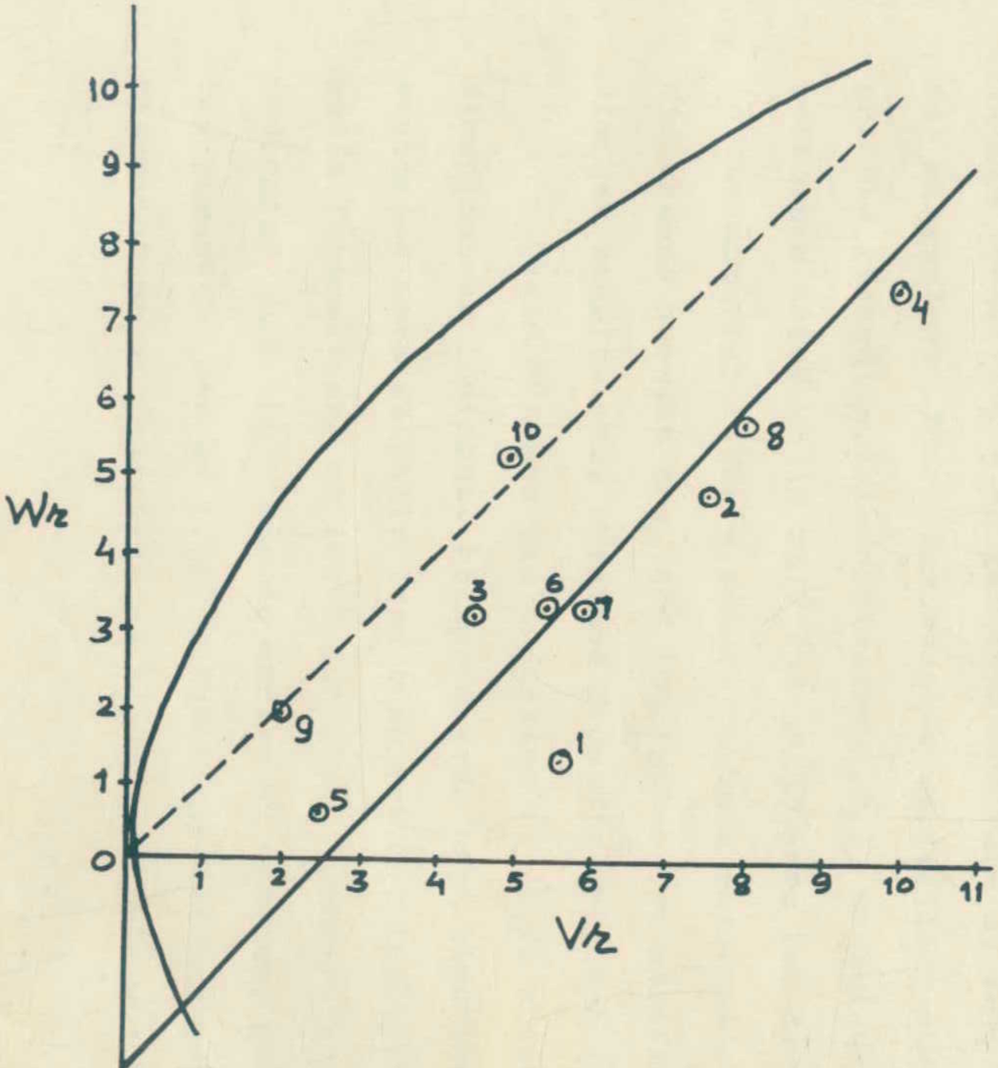

FIG. 6-a

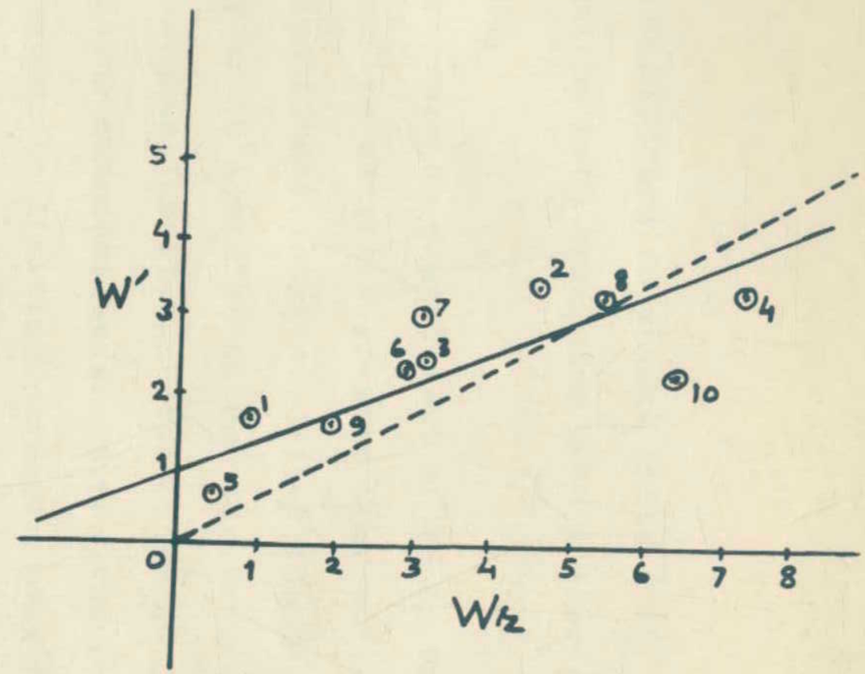

FIG. 6-b

LINT INDEX

35/5B, G27 x C.J.73 and Cocanadas white x P_{34} were the poor combinations both involving good x poor general combiners.

The regression coefficient of Wr on Vr (b=1.085 ± 0.638) which was slightly greater than unity (Fig.6-a), though not significant, suggested that the gene action was primarily of an additive nature for this character. However, the regression line shifted towards right of origin indicating overdominance. Since the regression line did not meet the limiting parabola away from the origin the presence of genotype-environment interaction was suggested. There was greater variability among the parents regarding this character. H_{420} contained more recessive alleles while 231R and 35/5B were top dominants in the material. There seemed to be a major gene difference between H_{420} and the latter two strains. Similar results were obtained from W', Wr graph (Fig.6-b).

Overdominance was indicated ($\sqrt{H_1/D}$ = 1.23), direction of dominance being towards high lint index. D estimates were slightly less than for H_1, indicating genic interactions of low magnitude. Positive F value indicated that there was an excess of dominant genes in the parents. Low $\hat{u}\bar{v}$ (.16) value indicated asymmetrical distribution of positive and negative allels which were in ratio of 67:33. Small correlation between (Wr + Vr) and Yr (.29) indicated that dominants were both positive and negative. At least two genes were showing phenomena of dominance for this trait.

C. 8 Seed index

M_{2608} and Gaorani-6 were only two parents showing good general combining ability for high seed index, whereas C.J.73 was the poor combiner. $H_{420} \times P_{34}$, 231R x G27 and 35/5B, x C.J.73 were good specific combinations.

Overdominance of low order (Fig. 7-a) was indicated on the Wr, Vr graph. The regression coefficient was significantly different from unity indicating the presence of higher order genic and environmental interactions. Scatter of array points along the line suggested low genetic diversity among the parents. The regression of W' on Wr (b' = .0674 ± .0309) was very low (Fig. 7-b) which might be due to epistasy and environmental variations.

Estimate of D was not significant and, therefore, degree of dominance was not calculated. H_1 was significant but non-significant F value indicated that dominant and recessive genes were equally distributed among the parents. The $\bar{u}\bar{v}$ value (.25) indicated symmetrical distribution of positive and negative genes. Small correlation coefficient of (Wr + Vr) and Yr (-.66) indicated that dominant genes were mostly positive in effect though they had negative effects also. There was at least one gene showing dominance and mean direction of dominance was towards high seed index. Top recessive and second best for recessiveness had lowest mean performance indicating recessiveness to be complete. This observation was supported by small value of correlation of (Wr + Vr) and Yr.

C. 9 Ginning outturn

231R, Cocanadas white and G27 were good combiners for high ginning outturn while Gaorani-6, P_{34}, 35/5B and M_{2608} were poor general combiners for this character. No specific combination was found to be significant.

The regression line on Vr, Wr graph (Fig. 8-a) shifted towards left of origin showing partial dominance. The regression coefficient (b = .724 ± .124) was not significantly different from unity suggesting primarily additive type of gene action in the control of this character. P_{34}, Gaorani-6, C.J.73 and H_{420} carried most of the recessive allels. G27 and 231R had the maximum number of dominant genes among the lines under study since they were located nearest to the origin on W' and Wr graph (Fig. 8-b). The absence of non-allelic interactions was suggested as the b' value did not differ significantly from 0.5 (b' = .684 ± .152). All the points

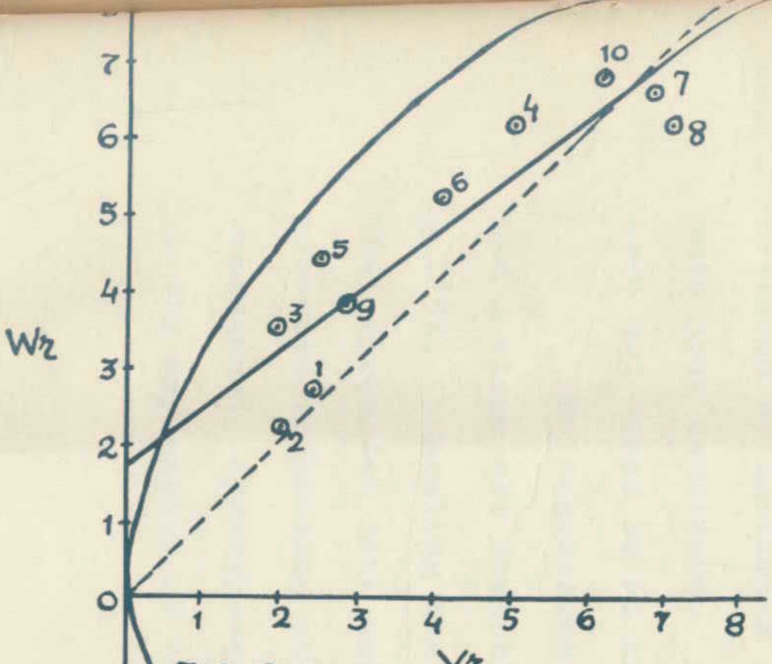

FIG. 8-a

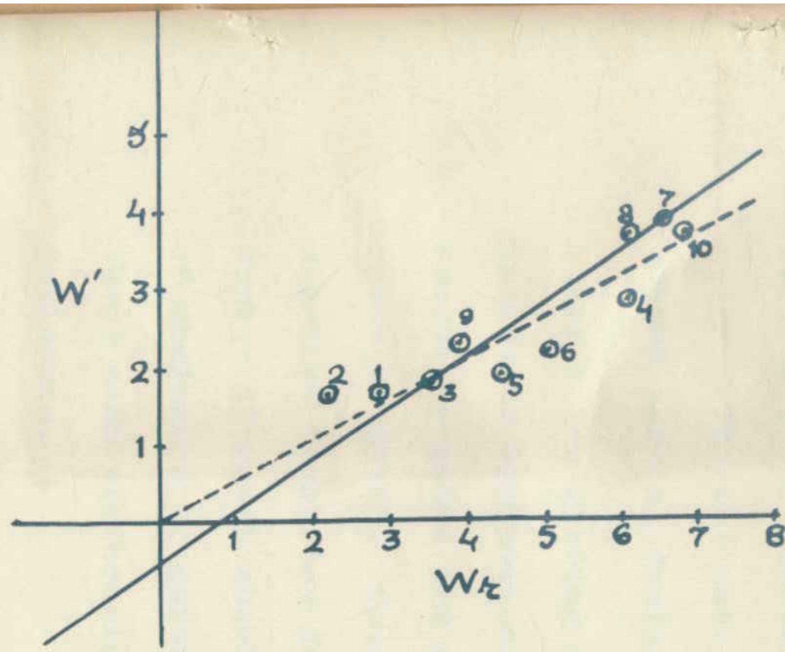

FIG. 8-b

GINNING OUT-TURN

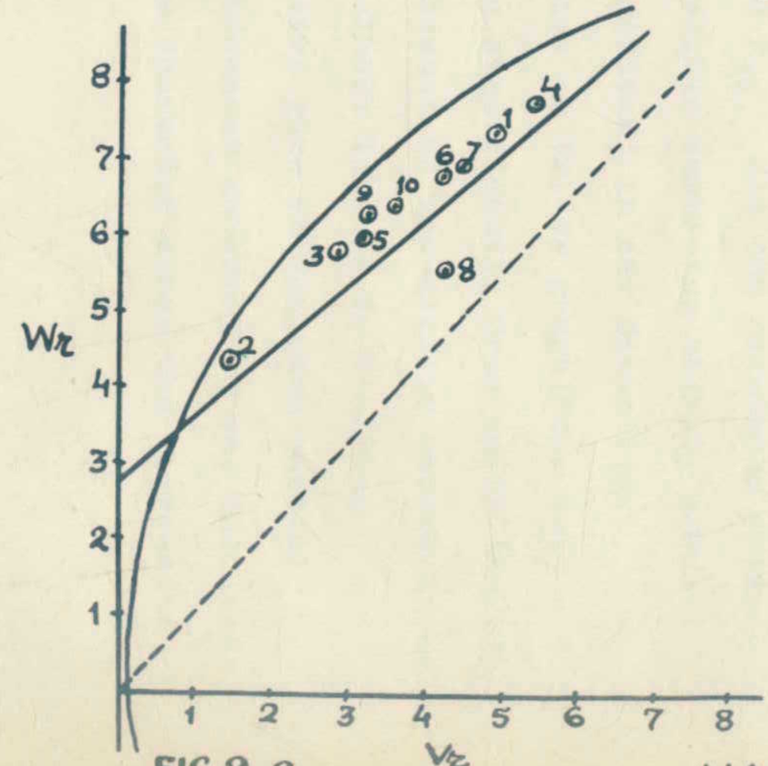

FIG. 9-a

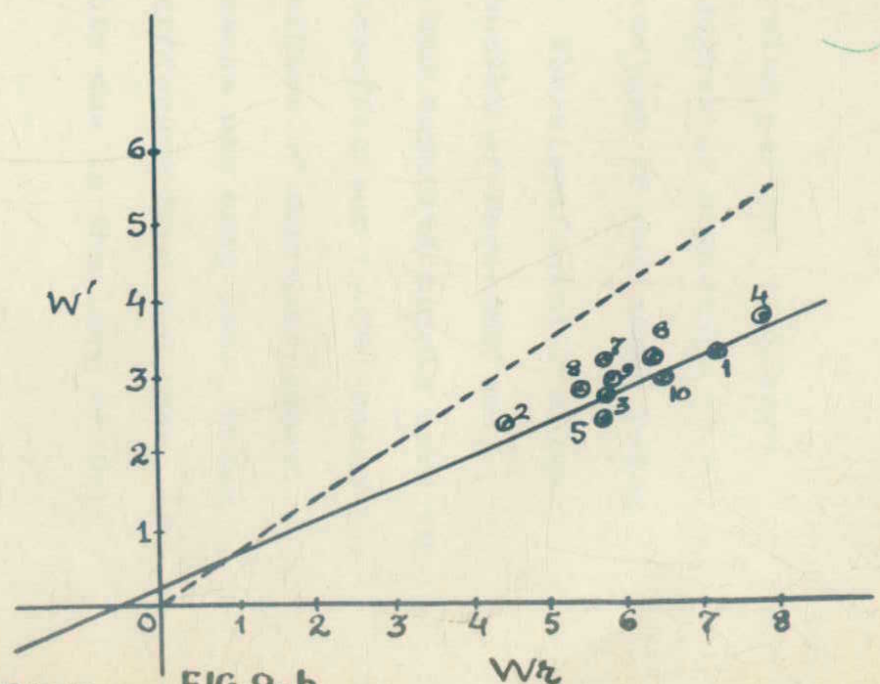

FIG. 9-b

HALO LENGTH

fell in first quadrent confirming partial dominance.

The estimate of the degree of dominance (0.5) showed partial dominance, direction of dominance being towards low ginning outturn. Non-significant F value indicated symmetrical distribution of dominant and recessive genes but positive and negative allels were in ratio of 87:13. Correlation coefficient (-.74) being negative indicated positive effect of dominant genes. Number of genes showing dominance was only one. Order of dominance of parents was different from the order of their mean performance probably due to the lack of full dominance.

C. 10 Halo length

C.J.73 was good general combiner for halo length followed by Gaorani-6 and P_{34}. All the remaining parents were poor combiners. Specific combining ability effects were not found to be significant in any direction.

The regression line on Vr, Wr graph(Fig. 9-a) had a slope not deviating significantly from unity (b=.774 ± .152) indicating the absence of non-allelic interactions. The regression line was almost tangent to limiting parabola indicating additive gene action with partial dominance. Genotype-environment interaction was involved in the expression of this character since the regression line did not touch the limiting parabola away from the origin. Parent H_{420} carried maximum concentration of recessive allels while G27 had most of the dominant genes, rest of the parents being inbetween these two. Regression of W' on Wr (b' = .416 ± .178) (Fig. 9-b) indicated absence of non-allelic interactions. All array points fell in the first quadrent indicating partial dominance. Fairly uniform scatter of array points along the regression line in both the graphs indicated high degree of homozygosity to be present in the parents with regard to this character.

The non-significant H_1 value suggested only additive gene system and, therefore, dominance ratio was not calculated. Non-significant F value suggested the absence of genes showing dominance. This was also suggested by low value of h^2/H_2. Lack of unidirectional dominance might be responsible for such low values since partial dominance was detected from the graph. Positive and negative allels were present in the ratio of 63:37. High positive correlation value between (Wr + Vr) and Yr (.81) indicated that most of the dominant genes had negative effect on halo length.

Chapter V

DISCUSSION

Information on the nature of genetic variation between varieties of Gossypium arboreum L. is completely lacking. As such it is not possible to select suitable varieties which should be hybridized to give the expected progress in a breeding programme. The present study was, therefore, undertaken to investigate the nature of genetic differences which control yield and its component in a set of diallel crosses. The set of assumptions of a diallel analysis were largely fulfilled in the present study. The parents utilized in the investigation have been maintained, in the past, through selfing and were thus homozygous. G. arboreum L. is a diploid species and the reciprocal differences have been reported to be not present. The effect of linkage and multiple allelism could not be detected in the presence of genic interaction, which have been explained wherever detected by the graphs.

Heterosis:

The results of this study have revealed the presence of heterosis in F_1 in the ten characters viz. plant height, weight of the plant, yield of kapas per plant, number of bolls per plant, boll size, number of seeds per boll, ginning out-turn, halo length, lint index and seed index, suggesting gene interactions to be important for these characters. Over dominance was observed in all the characters except number of seeds per boll, ginning outturn and halo length.

Heterosis for yield of seed cotton ranged from 15.00 to 33.16 gm as deviations of the F_1 mean from the mean of their parents. Highest degree of manifestation of heterosis, among all the characters, was observed for yield of seed cotton especially in hybrids G_{27} x M_{2608}, 35/5B x M2608 and Cocanadas white x M_{2608}, all involving good x poor yielding parents. The variety M_{2608} combined its largest boll size with the varieties having highest number of bolls per plant in these highly heterotic hybrids. As regards boll, size, low x low combinations were heterotic whereas no such response was observed in the crosses of high x high boll size parents. This clearly indicated accumulation of dominant favourable genes, of course, showing interactions, since the overdominance was also present in low x low boll size combinations. The absence of heterosis in high x high boll size combinations did not indicate the presence or absence of any type of gene interaction since heterosis might be absent due to the internal cancellation of components of heterosis (Jinks *et al*., 1958).

The heterotic effects in yield were generally associated with heterotic effects in number of bolls per plant. There was no relationship between the performance of a variety and the extent of heterosis in its hybrids indicating non additive genetic variances for yield. All heterotic combinations for yield invovled good x poor or good x average yield parents. This suggested the manifestation of heterosis only in those hybrids where the extent of divergence among the parents was quite marked. William and Gilbert (1960) working on *Lycopercum esculantum* species had also generalised that heterosis is expressed in hybrids between poorer genotypes in the inbreedirg species.

Heterosis, in boll size has been accounted for by the presence of heterosis either in number of seeds per boll and seed index or a combination of the two. In mean halo length, however, only three out of the 45 F_1 hybrids showed significant heterosis. All good x good combination gave good hybrids while poor x poor resulted in hybrids with low mean halo length, suggesting that *per se* performance of varieties could be a good index to predict the performance of a hybrid in halo length. The most superior hybrid for halo length, P_{34} x C.J.73 was very poor in yield of <u>kapas</u> per plant.

<u>Combining ability</u>

The objective of the combining ability analysis was to compare general and specific combining ability differences when the parents themselves were used as testers. The differences in general combining ability are related to additive genetic variance (plus interaction components) whereas differences in specific combining ability are attributable to non-additive genetic variance (dominance variance and epistatic variance involving dominance), Falconar (19 61). The differences in the type of variances were, therefore, used to determine the nature of gene action.

The variance for general combining ability was significant for all these characters. The comparison of general and specific combining ability variances (Table 4) suggested that additive genetic variance was more important than non-additive genetic variance in all the characters studied except number of bolls per plant, boll size and lint index. The variety Cocanadas white was the best combiner for yield, which could be associated with its high combining ability for number of bolls per plant, high ginning outturn, high lint index and large boll size. 231 R was also a good combiner for yield and number of bolls per plant but was a poor combiner for boll size. It had the highest general combining ability value for lint index and ginning out-turn, but it was poor combiner for halo length. 35/5B was the good combiner of bolls and yield but poor combiner in boll size, probably due to low combining ability for number of seeds per boll. G_{27}, a good general combiner for yield was also good combiner for number of bolls, ginning out turn and lint index but it was a poor combiner for halo length. The high combiners for yield generally had also maximum concentration of dominant genes for yield and number of bolls per plant. So their high combining ability might be due to possession of dominant genes for these characters.

The variety M_{2608} was an average combiner for yield and number of bolls but it was the best combiner for boll size, seed index and number of seeds per boll. C.J.73 was a good combiner for number of seeds per boll and also for halo **length** but it was a poor combiner for yield, number of bolls per plant and plant height. It should prove to be a good donar for long lint.

The large similarities in the ranking of parents for general combining ability especially for yield and number of bolls per plant, and their ranking based on parental performance *per se* suggested that additive genetic variance was important in these characters. The *per se* performance of the parents has also been reported to be useful in making the choice of parents for hybridization in *G. hirsutum* L. and *G. barbadense* L. species also (Miller and Marani, 1963; Marani, 1967 and 1968; White and Richmond, 1963; and Al-Rawi and Kohel, 1970).

P_{34}, H_{420}, C.J.73 and Gaorani-6, which were poor combiners for yield were also poor combiners for its component characters. The varieties G_{27}, Cocanadas white and 231R are evidently useful parents for yield, since all these have positive general combining ability for each of the component characters. The Cross G_{27}x Cocandas white (high x high combiners) was good in yield and number of bolls per plant (no significant specific combining ability effects in this cross) and is, therefore, likely to throw good segregants for number of bolls and yield of *kapas* in later generations. The hybrid of Cocanadas white and M_{2608} parents with good general combining ability effects for boll size, and in the absence of any specific combining ability effects for this character in this cross, is also expected to retain its high mean performance for boll size in later generations.

The magnitude of variance due to specific combining ability for yield was less than for general combining ability In component characters, however, specific combining ability variances were high than those for general combining ability.

This indicated that non additive genetic variance was more important for yield components. Specific combinations of good x poor (231R x H_{420} and 231R x C.J.73) and good x average (G_{27} x M_{2608}) combiners for yield had high specific combining ability effects and were top ranking also. These had also high specific combining ability effects for number of bolls but not for boll size. 231 R x P_{34}, H_{420} x P_{34} and Cocanadas white x H_{420} were good specific combinations for boll size. These results revealed that both additive as well as non additive gene interactions are important in determining boll size.

In seed index only three hybrids, all involving average x average (231 R x G_{27}) and average x low (H_{420} x P_{34} and 35/5B x C.J.73) combining parents were found to be good specific combinations. This indicated that non-additive genetic variance was important for high seed index.

Ginning outturn, halo length and number of seeds per boll were the characters with non-significant specific combining ability variances. This indicated that genetic control was largely of additive nature for these three characters. The preponderance of additive genetic variance and general absence of heterosis suggests that significant advancement in these traits can be made in segregating populations by using simple selection procedures which would increase the frequency of desirable additive genes.

Graphic analysis

The variance-covariance and covariance-covariance graphs give useful information which can be hepful in breeding programmes. Parents can be classified on the basis of their allelic contents. This analysis also demonstrates whether any of the varieties used as parents contains the possible complete complement of dominant or recessive alleles. Information obtained by combining ability and graphic analysis is comparable most of the times. According to Tandon (1970) combining ability analysis is more important when non-allelic interactions are high and dominance is low.

In the two components of yield viz. number of bolls per plant and boll size additive gene action was detected. Non-allelic genic interactions in these characters were not large enough to be detected in the graphs. In yield, which is a compound and dependant character, these interactions were high. Overdominance was suggested for number of bolls, boll size, yield of kapas, lint index and seed index. No attempt was made to investigate whether this overdominance is due to int-rallelic interactions or inter-allelic interactions. Parents taken from the extremes of graphs showing maximum genetic diversity also gave maximum heterosis for yield and its components. The parent M_{2608} carried more than an average share of recessive genes but not the complete set of recessive genes, for yield and number of bolls per plant. G_{27} and M_{2608} had an equal concentration of dominant and recessive genes for boll size but possibly M_{2608} had more favourable dominant genes as compared to G_{27}. So all these favourable genes for boll size have accumulated in hybrid G_{27} x M_{2608} purely in additive manner, though slight interactions could not be overruled.

Additive gene action was indicated in the control of ginning outturn, halo length and lint index. Genic interactions probably of non-allelic type, were indicated in the inheritance of seed index and number of seeds per boll. P_{34} Gaorani-6 and C.J.73 had more recessive genes for ginning out-turn while G_{27} and 231R had more dominant genes. G_{27} was also top dominant for halo length and H_{420} was top recessive for this character. In lint index, H_{420} had more recessives while 35/5B and 231R were top dominants. Since none of the parents had complete set of dominant or recessive allels for any character their concentration in one parent, through breeding, could be helpful for improving yield, number of bolls per plant and boll size where dominance plays important role.

The fact that graphical analysis is less informative in cases where higher genic and environmental interactions are involved, was also seen in case of plant height and dry plant weight. In both these characters, graphs did not give any useful information and were, therefore, considered not to be important.

Genetic analysis and its implications:

The relative contribution of additive and non-additive components of genetic variances, no doubt, can be assessed from graphs but they can best be compared from their direct estimates. Various ratios of genetic components give more clear genetic relationship among parents as compared to graphical analysis.

The results from the estimates of g.c.a. and s.c.a. components of variance, graphical analysis and from the genetic parameters have revealed that non-additive gene interactions are important in all the characters except ginning outturn and halo length. The material studied carried greater proportion of favourable genes for yield and its components. Order of dominance of parents and their mean performance was not similar for any of the yield components. In the light of the small correlation values obtained for Wr + Vr and Yr in bolls per plant and boll size, it seems that there were dominant genes with both positive and negative effects even though those with positive effect were more numerous than with negative effects or at least mean number of dominance was towards positive side.

In determining boll size, the dominance plays important role but the number of genes showing dominance might be underestimated due to the absence of unidirectional dominance. Both graphic analysis and estimates of relative frequency of genes showing dominance indicated the possibility of improvement in bollsize by accumulation of favourable genes even in top ranking varieties viz. M2608 and Cocanadas white.

The non-allelic interactions and/or the dispersion of favorable dominant alleles might have resulted in observed overdominance for yield and its components. Since dominant loci play an appreciable role in the control of yield and its components, trangressive segregants for yield due to accumulation of more favourable dominant genes than in either of the parents can be isolated from hybrids involving 231R and G27 with M2608. Since both dominants and recessives act towards the high expression of yield and its components selection is needed to increase frequency of both types of favourable alleles. The identification of better genotypes involving favourable dominants might be easily and quickly achieved but so far as recessives are concerned there are less chances of getting the best allelic concentration by selection as some of the desirable recessive alleles would be concealed in heterozygous form. The control of ginning outturn and halo length was largely additive and thus improvement in these characters is possible through selection after hybridization.

The previous work on G. hirsutum L. indicates that mostly additive type of gene action is involved in the control of boll size and lint index (Marani 1963; and 1967, Hooda, 1969). This study with G. arboreum L. genotypes, has revealed that dominance is more important than additive gene action for these traits. In ginning out-turn, halo length and number of seeds per boll, the conclusions are similar to the results reported in G. hirsutum L. by Marani, 1963 and 1967, Douglas et al. 1966, Verhalen and Murray, 1966; and Marani, 1968. Additive type of gene action is important for these traits in both of the species. Additive components are reported to be more important than non-additive for yield in G. hirsutum L. species whereas the situation has been found to be just the reverse in G. arboreum L. Young (1966) also reported that the magnitude of heterosis as well as inbreeding depression were of high order in arboreum species than in hirsutum.

High yield is not the only goal in cotton but the search for an isolate with yield of its more productive parent or even more, along with good attributes of other parents like halo length and ginning outturn etc. is desirable. The present material offers the possibilities of isolating lines with good yield and halo length after hybridizing suitably chosen parents. Selection should be directed to increase the frequency of favourable genes with additive effects. This procedure will be more effective for the improvement of halo length, ginning outturn and number of seeds per boll. After the major portion of favourable genes with additive effects have been fixed, breeding procedures which can utilize the non-additive genetic variance might prove profitable.

Chapter VI

SUMMARY

Information on the nature of gene action for yield and its component characters in G. arboreum L. species is altogether lacking. Therefore, a diallel cross set of ten varieties was attempted during kharif 1969 to obtain information on (a) the extent of heterosis (b) general combining ability and specific combining ability estimates and (c) nature and magnitude of genetic parameters. The parents and their 45 hybrids (excluding reciprocals) were grown in a randomised block design with four replications in the research area of the Department of Plant Breeding, Punjab Agricultural University, Ludhiana, during kharif 1970. Data were recorded in respect of plant height, dry plant weight, number of bolls per plant, boll size, number of seeds per boll, yield of kapas per plant, lint index, seed index, ginning outturn and halo length.

1. The analysis of variance for all the ten characters showed significant differences between progenies. Heterosis was observed in all the characters but its highest manifestation was recorded in number of bolls per plant and kapas yield. Three hybrids viz. G_{27} x M_{2608}, Cocanadas white x M_{2608} and 35/5B x M_{2608} significantly outyielded the locally recommended variety G_{27}. Ginning outturn, halo length and number of seeds per boll manifested moderate heterosis.

2. Overdominance was observed in all the characters excepting ginning outturn, halo length and number of seeds per boll. No relationship between the performance of a variety and the extent of heterosis in its crosses was observed.

3. Variances due to general combining ability were significant for all the characters whereas for specific combining ability, variances were not significant for number of seeds, per boll, ginning outturn and halo length. Cocanadas white, 231R, 35/5B and G_{27} were good general combiners for yield of kapas and number of bolls per plant. M_{2608} and Cocanadas white were good general combiners for boll size. General combining ability of the parents was associated with their *per se* performance.

4. Graphic analysis indicated overdominance for number of bolls, boll size, yield of kapas, lint index and seed index. Partial dominance was seen for plant height, ginning outturn, halo length and number of seeds per boll. Non-allelic interactions were involved in the inheritance of plant height, dry plant weight, number of seedsper boll, yield of kapas and seed index. No single parent carried all the possible dominant or recessive alleles in these parents for any of the characters. Chances of improvement, therefore, were indicated by accumulating genes showing phenomena of dominance for these characters.

5. The estimates of genetic parameters have revealed that non-additive genetic variance was important in the inheritance of all these characters except halo length. Additive genetic variance was of major importance for ginning outturn also. The distribution of favourable and unfavourable genes in the parents was asymmetrical for all the characters except in seed index. This asymmetry was usually more marked where the dominant gene action was more important.

6. The implications of the nature of gene action and scope of improvement in various characters has been discussed.

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* Original not seen

Appendix I

Mean performance of parents and their crosses

	Plant height	Plant weight	Number of bolls/ plant	Boll size	Number of seeds per plant	Yield of kapas per plant	Lint index	Seed index	Ginning out turn	Halo length
	1	2	3	4	5	6	7	8	9	10
1. 231 R	151.75	121.65	13.75	1.79	19.00	21.49	3.36	5.44	38.22	17.5
2. G-27	149.70	147.47	23.50	1.57	19.00	32.12	2.82	5.17	35.22	18.2
3. Gocanadas White	163.30	151.97	23.75	1.96	20.50	34.10	3.33	5.81	36.41	17.9
4. B_{420}	177.15	224.37	9.50	1.60	20.50	13.17	2.20	4.52	32.56	19.3
5. 35/5B	144.07	107.50	21.25	1.60	19.00	28.18	2.59	5.18	33.75	18.5
6. M_{2608}	121.62	143.12	11.75	2.22	25.25	11.47	2.30	5.88	28.07	19.9
7. P_{34}	140.27	136.45	6.75	1.32	16.25	14.89	2.27	5.35	29.88	21.2
8. Gaorani-6	179.15	183.75	10.00	1.89	20.75	20.08	2.24	5.63	28.42	21.2
9. NR-5	127.72	84.37	14.00	1.63	20.25	19.23	2.66	5.18	33.70	20.8
10.C.J.73	143.16	102.05	10.50	1.93	23.50	18.14	2.66	5.42	32.92	23.5
1x2	173.55	188.12	27.50	2.07	18.00	34.04	3.73	6.58	37.99	18.2
1 x 3	173.47	228.32	25.50	2.02	22.50	39.89	3.47	5.36	38.17	17.9
1 x 4	192.27	305.07	27.50	1.70	17.25	44.31	3.61	5.76	37.24	18.2
1 x 5	162.05	154.15	25.25	1.53	19.25	35.72	2.56	4.89	33.73	19.2
1 x 6	180.75	207.27	28.50	1.93	21.00	46.84	3.31	5.71	35.11	18.3

	1	2	3	4	5	6	7	8	9	10
1 x 7	174.20	189.07	20.00	2.05	21.75	32.68	3.24	5.55	37.46	20.3
1 x 8	184.95	172.20	19.75	1.76	20.00	31.46	3.24	5.44	35.29	19.2
1 x 9	169.07	167.90	22.75	1.85	19.50	34.81	3.06	5.71	35.44	19.4
1 x 10	177.57	330.00	30.75	1.91	22.50	48.40	3.07	5.15	37.11	20.9
2 x 3	157.47	141.42	26.75	1.93	20.50	42.89	3.23	6.05	35.11	18.2
2 x 4	175.47	247.50	21.00	1.64	18.75	28.56	2.66	5.33	33.51	18.4
2 x 5	165.77	164.37	29.75	1.64	19.25	32.12	2.67	5.63	33.57	18.8
2 x 6	170.10	229.27	36.00	1.89	21.50	54.70	2.87	5.27	34.19	19.1
2 x 7	145.40	170.60	17.00	1.76	21.75	24.72	2.82	5.34	32.90	19.1
2 x 8	163.97	116.87	18.75	1.94	20.75	29.46	3.15	6.05	35.12	19.2
2 x 9	166.2	177.90	24.50	1.89	21.00	41.05	2.99	5.78	34.17	18.6
2 x 10	140.77	140.62	17.25	1.61	24.50	22.23	2.30	4.04	34.73	20.3
3 x 4	174.97	178.32	26.75	2.20	22.75	28.51	3.46	5.76	37.37	18.9
3 x 5	166.27	157.07	26.25	1.88	20.50	40.84	3.00	5.63	34.79	18.9
3 x 6	184.05	243.32	29.25	2.13	22.50	52.32	2.95	5.94	33.85	19.2
3 x 7	169.80	167.27	19.50	1.94	24.00	33.68	2.48	5.11	34.13	18.9
3 x 8	186.80	195.87	21.25	1.63	16.75	31.00	3.06	5.81	34.62	19.6
3 x9	153.70	163.12	32.75	1.91	22.50	47.57	2.87	5.13	35.95	19.3
3 x 10	174.62	192.87	21.50	2.01	23.25	35.52	2.99	5.22	35.15	20.6

	1	2	3	4	5	6	7	8	9	10
4 x 5	173.65	167.07	20.00	1.69	18.75	27.10	2.99	5.74	32.77	19.2
4x 6	183.30	166.65	19.50	2.07	22.75	31.03	2.83	5.99	31.96	19.8
4 x 7	170.35	152.50	13.00	1.97	21.00	21.48	2.86	6.42	30.97	20.4
4 x 8	158.25	132.50	13.00	1.86	24.25	21.42	2.53	5.01	31.72	21.7
4 x 9	131.75	192.00	12.50	1.75	21.50	17.47	2.50	4.91	34.79	20.5
4 x 10	152.85	110.00	14.25	1.75	21.75	21.49	2.38	5.23	34.94	21.1
5 x 6	176.47	254.37	33.75	1.79	20.00	52.99	2.61	6.01	30.98	20.2
5 x 7	156.67	208.12	25.25	1.45	17.25	35.70	2.23	5.16	29.50	20.5
5 x 8	181.05	184.37	29.75	1.67	17.50	43.22	2.85	6.31	31.25	20.10
5 x 9	174.05	167.20	19.25	1.79	20.25	26.36	2.59	5.64	32.26	19.8
5 x 10	160.80	141.62	21.75	1.73	19.25	29.72	2.84	6.09	31.87	21.3
6 x 7	171.42	163.75	17.00	1.84	21.75	25.99	2.56	5.50	31.34	19.9
6 x 8	171.17	153.75	13.25	2.04	21.75	22.21	3.17	6.38	32.93	21.7
6 x 9	167.40	149.00	24.75	2.06	22.00	38.84	3.08	6.14	33.48	20.00
6 x 10	156.65	120.62	15.75	1.72	21.50	26.27	2.47	5.28	32.07	21.6
7 x 8	151.12	175.00	10.00	1.69	20.00	13.62	2.28	5.61	28.55	21.2
7 x 9	158.25	147.87	19.50	1.76	20.50	28.41	2.64	5.59	32.12	20.0

	1	2	3	4	5	6	7	8	9	10
7 x 10	11.50	164.55	10.25	1.35	19.50	13.15	2.10	4.75	30.62	22.4
8 x 9	[illegible]	167.07	15.75	1.75	19.75	23.99	2.82	6.24	31.21	20.3
8 x 10	[illegible]	124.57	20.00	1.90	23.75	31.48	2.32	5.66	28.90	21.5
9 x 10	164.4[illegible]	171.87	14.75	1.86	22.00	22.56	2.60	5.66	31.48	21.7
C.D. at 5%	21.47	89.93	10.58	0.24	4.18	17.49	.965	0.47	4.18	1.60
1%	28.34	118.69	13.96	0.33	5.51	23.09	1.27	0.62	5.51	2.11

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