105

STUDIES ON INTER-VARIETAL HYBRIDS OF RICE (*Oryza sativa* Linn.) WITH SPECIAL REFERENCE TO HYBRID STERILITY AND HETEROSIS

BY

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THESIS

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CERTIFICATE

This is to certify that the thesis herewith submitted contains the results of bonafide research work carried out by Shri. K. Narayanan Unnithan, under my supervision. No part of the work embodied in this thesis has been submitted earlier for the award of any degree.

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C O N T E N T S

INTRODUCTION

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The species *Oryza sativa* L. is made up of a mass of complex forms showing large variations in morphological as well as physiological characters. Based on hybrid sterility, *O. Sativa* is divided into three geographical races viz; O. *sativa* var. *indica*, *O. sativa* var. *japonica* and *O. sativa* var. *javanica*.

The richness of varietal diversity in the cultivated rice species *O. sativa* and the easy crossability among the varieties have lead to the development of a large number of improved strains through inter-varietal hybridization. Mostly crosses have been limited to types of the same geographical race or sub-species. Varieties with a wide range of adaptability can be evolved only by hybridization and selection. The most important objective in breeding has always been yield, the other requirements being straw strength, response to high fertility, earliness in maturity, less sensitivity to photoperiod and temperature, resistance to major diseases and insect pests and good milling and cooking quality. With such a wide range of objectives it is considered that the choice of parents for any hybridization programme need not be limited to any one of the racial groups. The work on *indica* x *japonica* hybridization has indicated the scope of obtaining suitable varieties with greater response to increased soil fertility. The varying degrees of sterility exhibited in the *indica* x *japonica* hybrids have been explained on genetical, cytological and cytoplasmic grounds.

Though the utilization of heterosis in a self-pollinated crop like rice where each crossed seed is the result of emasculation and pollination of individual spikelet has so far been considered to be of no practical significance (Ramiah 1953), the present trend is to see whether the vigour can be made persistent in the F_2 generation by selecting suitable parents with the least variation for height, flowering duration and grain characters but expressing hybrid vigour (Misra & Shastry 1962). Combination of varieties from the two distantly related groups (viz; indicas and japonicas) might be expected to show considerable hybrid vigour. Heterosis for yield, however, could not be measured, because of the regularly observed seed sterility characteristic of such combinations (Jennings 1966).

As the understanding of the relationship of the different varieties would put the breeding programme on a better footing, a study was undertaken with two varieties each from the indica (Vellayani 1 and Taichung Native 1) and japonica (Tainan 3 and Taichung 65) groups: (i) to assess the relationship of indica and japonica races of rice by morphological and hybrid sterility studies and (ii) to compare the expression of heterosis in different hybrids to facilitate the isolation of superior combinations recording high heterotic vigour for grain and straw yields.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The cultivated rice, *Oryza sativa* L. and its varietal diversity

The species *Oryza sativa* Linn. belongs to the section *Sativa* of the genus *Oryza* of the sub-tribe *Oryzineae* under tribe *Oryzeae* of the family *Gramineae*.

Racial differences in rice as shown by grain size have been recorded by Koernicke as early as 1885. But it remained for Kato *et al.* (1928) and Kato (1930) to establish the concept of two sub-species *japonica* and *indica* on the basis of the morphological and physiological characters as well as the sterility in their hybrids. These two sub-species were considered as the extreme types of a continuous variation by Terao and Mizushima (1939). Oka (1958) based on a study of character association divided the cultivated rice varieties into two groups namely 'Continental' and 'Insular' largely corresponding to *indica* and *japonica* types respectively and sub-divided the 'Insular' group into two minor groups 'Tropical insular' and'Temperate insular' according to their geographical distribution.

The *indicas* have wide distribution and high ranges of variability. In general, they show more rapid germination, lower milling output and more resistance to drought and diseases than *japonicas*, but they are mostly susceptible to 'lodging', poor in high fertility response and have grains with starchy endosperm.

Adapted as they are to the sub-tropical and warm temperature regions, the range of variability in *japonicas* is lesser than in *indicas*. They are characterised by glutinous endosperm, early maturity, response to heavy manuing and non-lodging nature. According to Ramiah (1961) the *indicas* when compared to *japonicas* possess greater number of dominant characters and hence *indicas* could be the original forms from which the *japonicas* were evolved.

Ramiah (1961) has presented the following comparisons of the two sub-species with respect to certain morphological characters.

Combination of characters in *japonica* and *indica* rices

SL.No.	Particulars	Type - A Japonica	Type - B Indica
1	Length of stem	Short	Long
2	Stem habit	Erect	Spreading
3	Number of tillers	Many	Many
4	Hardiness of the plant stem	Hard	Soft
5	Angle formed by the second leaf blade and the stem	Small	Large
6	Length of the second leaf blade	Short	Long
7	Angle formed by the flag leaf and the stem	Medium	Small
8	Length of the flag leaf	Short	Long
9	Width of the flag leaf	Narrow	Narrow

10	Leaf hairs	None	Many
11	Extrusion of the last stem node out of the leaf-sheath	Not extruded	Extruded
12	Number of panicles	Many	Many
13	Length of panicle	Short	Medium
14	Number of panicle branches	Few	Medium
15	Density of panicle	Dense	Medium
16	Weight of panicle	Heavy	Light
17	Type of grain	Short	Narrow
18	Glume hairs	Many	Few
19	Awn	Awnless	Awnless
20	Shattering	Difficult	Easy

Inter-varietal sterility in *O.sativa* L.

The inter-varietal hybrids in *O.sativa* may be broadly grouped into two, namely, inter-racial and intra-racial.

1 Inter-racial

Japonica x *indica*

Extensive studies in hybridization between these two races were made ever since their recognition, mainly with the object of combining the characteristics like high yield, responsiveness to high fertility and non lodging nature of the *japonicas* with the hardiness and adaptability to tropical conditions of *indicas*.

Since the classification of varieties of O.sativa by Kato (1930) into indica and japonica types, the pollen sterility of F_1 hybrids has been regarded as a means for estimating the phylogenetic relationships. The degree of sterility varies widely in different cross combinations ranging from zero to cent per cent.

Kuang and Tu (1949) recorded a mean sterility of 90.66% in indica - japonica hybrids. Brown (1955) found that although meiosis was normal in japonica - indica hybrids, sterility was high. Richharia et al. (1962) recorded a range of 16 to 97% sterility in 26 different indica - japonica hybrids and concluded that sterility could not be used as a criterion while considering the relative affinity between the different varieties and sub-species in the species. In a study of about 300 japonica - indica combinations, Sampath (1964) recorded a spikelet sterility of 60 to 70%. Karunakaran (1964) recorded 63.45% and 88.28% pollen and spikelet sterility respectively in japonica - indica hybrids. On the other hand, Jennings (1966) did not observe large differences in pollen and spikelet fertility in japonica - indica hybrids. An identical mean of 46% for both pollen and spikelet fertility was recorded for all the 363 hybrids, studied.

ii. Intra-racial

Indica x Indica. Members of this race inter-cross readily giving mostly fertile hybrids. However, Oka (1956) reported instances of sterility in these hybrids. Richharia et al. (1962) recorded a range of 0 to 100% sterility in 11 crosses studied by them. Joseph (1962) reported lesser spikelet sterility than pollen sterility in *indica* x *indica* combinations.

Nature of sterility in inter-racial hybrids

The nature of sterility in these hybrids has been explained in terms of genetical, cytological and cytoplasmic factors. The related evidences bearing on the nature of hybrid sterility have been reviewed recently (Henderson 1964, Oka 1964, Sampath 1964 and Shastry 1964.)

Genetical

Hsu (1945) during his investigations found for the first time that the sterility is genic in cause. He studied the F_1, F_2 and F_3 generations of a cross and explained that sterility is mainly due to the lethality of germ cells governed by two factors A & B which act in a complementary manner. The former was assumed to be located in a reduplicated pair of chromosomes and the latter in a non-reduplicated pair. Kuang and Tu (1949) and Kuang (1951) also contended that the lethal effects of genes are the main cause of sterility. Oka (1953 & 1956) arrived at a conclusion from the study of segregating populations of several crosses, that the sterility could be accounted by sets of duplicate genes, in which homozygous recessive combinations lead to abortion of spores or gametes.

Oka (1964) made extensive review of this problem in the light of the experimental results obtained by him and his collaborators, over the period from 1953 to 1962 and characterised the inter-varietal F_1 sterility by the following features:

(1) There is no particular reason for assuming that O. sativa varieties are differentiated in chromosome structure. Differentiation might be mainly due to genic changes.

(2) The inter-varietal F_1 sterility is haplontic or gametophytic, and can be accounted for by assuming sets of duplicate genes which work in the gametes as development maintainers. (Gametic development or G.D. genes). A number of such duplicate genes may be concerned with sterility between distantly related varieties.

(3) The F_1 sterility is accompanied by gametic selection, which results in modification of segregation ratios. It also brings about a restriction on recombination of independent genes.

(4) In the F_2 and later generations of the inter-varietal hybrids, partly sterile or weak segregants are found and from the partly sterile plants true breeding partly sterile lines can be obtained. This sterility is diplontic or sporophytic and is not correlated with F_1 sterility. This phenomenon which may be considered as a partial break-down of hybrids, can also be explained by duplicate genes of sporophytic effect.

(5) The origin of duplicated loci may be accounted for by assuming secondary polyploidy.

Jennings (1966) studied the genetics and consequences of sterility in japonica - indica hybrids and arrived at the following results:

The association between F_1 and F_2 fertility and the presence of many F_2 fertility classes tend to support the hypothesis that sterility in the F_1 and F_2 is caused by common chromosomal and/or genic mechanisms. Recombinants and non-recombinants (parental types) were equally fertile, regardless of the degree of hybrid sterility in the population. There was no deficiency of recombinants resulting from hybrid sterility.

Kihara (1966) suggested that there are small genic differentiation between the two sub-species *indica* and *japonica* which give rise to highly sterile hybrids, though their chromosome behaviour during meiosis is apparently normal. Such differentiation within a genome seems to be not unusual in *Oryza*.

Cytological

Terao and Mizushima (1939), Jones and Longley (1941) and Kuang (1951) contributed to the view that although chromosome pairing in these hybrids was apparently normal at metaphase I, the sterility must be due to small chromosomal differences not detectable at this stage (cryptic structural hybridity). A partial evidence in support of this view was obtained by Cua (1952) who recorded that *japonica* x *indica* allotetraploids are more fertile than the diploid hybrids and form less quadrivalents.

The normal diakinesis and metaphase I with no evidence of translocation or absence of pairing, the occurrence of chromosome bridges without fragments, at anaphase I and telophase I and the occurrence of what appeared to be chromosome loops at pachytene in some hybrids, led Yao *et al.* (1958) to conclude that the partial sterility in inter-varietal hybrids of cultivated rice is probably due primarily to cryptic structural hybridity possibly arising from included inversions.

Mello-Sampayo (1952) found dicentric bridges and acentric fragments at anaphase I in a partially sterile hybrid of a cross between two *japonica* varieties and concluded that the sterility was due to a paracentric inversion. Sampath and Mohanty (1954) found that meiosis in partially sterile hybrids was normal, but bridges with fragments were observed at anaphase I, in 11 of the 85 hybrids studied. These workers assumed that inversions were responsible for the sterility. Henderson *et al.* (1959) suggested that the partial sterility which occur commonly in inter-varietal hybrids is caused by complex inversions of the included type.

Venkataswamy (1957) was the first to indicate that the chromosomal differences between the sub-species were due to translocation. Sampath (1959) supported this view and indicated that the origin of duplication deficiencies in the gametes might account for the sterility in these hybrids.

Shastry and Misra (1961) concluded that *indica* and *japonica* groups were differentiated by a series of small structural differences in their chromosome complements and that the sterility in these hybrids is more related to chromosomal structural hybridity than to genic causes. They also interpreted Oka's G.D. genes as small translocations, where the homologous segments have been located on nonhomologous chromosomes. Henderson (1964) suggested that the hybrid sterility may be as a result of cryptic structural differentiation in chromosomes between the two variety groups. Heish and Oka (1958) observed univalents, stretched chromosomes and anaphase I bridges in pollen mother cells of both semi-sterile F_1 plants and fertile parents. As the frequencies of occurence in the F_1s and their parents were similar they concluded that these phenomena were not indicative of the chromosomal differences between distantly related varieties. Rao (1964) in the analysis of diplotene and anaphase I cells did not get any positive evidence of structural differentiation of chromosomes. The analysis of telophase I indicated high percentage of dyad degeneration.

3 Cytoplasmic

Reciprocal crosses between O. sativa varieties usually show no significant differences in F_1 pollen or spikelet sterility. Sampath and Mohanty (1954) reported semi male sterility in direct and reciprocal crosses. The semi male sterility occurring when japonica was the female parent was attributed to chromosomal abnormalities (inversions). A statistically significant increase in sterility was apparent in the F_1 hybrids of reciprocal cross which the authers interpreted as cytoplasmic effect on pollen development when indica cytoplasm and japonica genes were combined.

Kitamura (1962) made a back-cross experiment between a Philippine variety and a Japanese variety using the latter as the recurrent pollen parent and selected two strains from the BC_3 generations. Crossing the two strains with various Japanese varieties, he found that when the Japanese varieties were used as maternal parent all the F_1s were fertile. But some reciprocal F_1s with a Japanese variety as pollen parent, were partially sterile. It seemed that this was an instance of disharmonious interactions between the cytoplasm of the Philippine variety and certain genes of the Japanese varieties.

Oka (1964) made a back-cross experiment between indica and japonica varieties using the latter as the recurrent pollen parent. Repetition of back-cross until BC_6 did not bring about a remarkable improvement in fertility, but if the partly sterile plants were selfed, the progeny was almost completely fertile. Since a back-cross of the reciprocal combination with recurrent parent as the maternal plant did not restore fertility, the sterility appearing in this experiment could not be attributed to cytoplasmic effect. Rao (1964) also found no major cytoplasmic differences between crosses involving indica and japonica rice varieties. Jennings (1966) found no large reciprocal differences, for either pollen or spikelet fertility. Of the 181 possible comparisons, only 11 were significantly different and in these the differences were generally small. With the exception of some crosses of an *indica* variety with the japonica varieties it was concluded that reciprocal differences in the study did not suggest any cytoplasmic influence on sterility.

Inheritance of quantitative characters in inter-varietal hybrids

Plant height

Monogenic segregation for plant height with tallness as dominant have been reported by Ramiah 1933 b) and Nandi and Ganguli (1941). In some cases the latter authors found tallness to be recessive. A genetic study of the cross peta x I - geo - tze indicated that tallness was partially dominant to shortness and that modifying genes were epistatic to the shortness in genes (Anon.1964). Both parents and hybrids varied considerably in height. Jennings (1966) found that the height of F_1 plants was closer to that of the taller parents, indicating partial dominance for tallness.

Chalam and Venkateswaralu (1965) reported that the inheritance of height in many cases is governed by at least 3 genes designated as T_1, T_2 and T_3 each having differential effect in controlling height.

2 Tillering

Tillering has been shown by Ramiah (1953) to be a polygenic character. Nagai (1959) expressed that when high and low tillering varieties were crossed a transgressive variation was observed in the F_2 with the mean values falling between the parental mean. According to Ghose *et al.*(1960) genes numbering 3 to 4 in some cases and more than 4 in others control tillering.

3. Duration

Ramiah (1933 a) found that short duration is a simple dominant to long duration. In another cross where the parents differed in duration the F_1 was found to be early. He suggested that two genes designated as E_2 and E_3 with a cumulative effect controlled earliness. Sethi et al. (1936) on the other hand found lateness to be a simple dominant over earliness. Chalam and Venkateswarlu (1965) found shorter duration to be simple dominant to long duration. In some cases, however, lateness was found to be dominant and in some other crosses the segregation was polygenic.

Duration expressed in terms of number of days to heading in rice has been demonstrated as being governed by a large number of multiple genes, but the qualifying values of these genes are not the same, Nagai (1959). It has been shown that a pair of genes determine a wide range of difference, besides the basic gene, many more genes may determine minor differences.

Early maturity was controlled by more than one gene with partial dominance (Anon. 1964).

4. Exsertion

In most rice varieties the panicle is long and exserted, while in some it does not emerge from the sheath. Ramiah (1932) recorded that exsertion of panicle is controlled by a large number of genes.

Chalam and Venkateswarlu (1965) are of the opinion that exsertion is governed by at least three genes.

Chang and Bardenas (1965) classified panicle exsertion into broadly four groups.

(i) Exserted: Panicle base is clearly above the flag-leaf sheath.

(ii) Partly exserted: Panicle base appears at the same level as the top of the flag leaf sheath.

(iii) Partly enclosed: Panicle is partly enclosed by the flag-leaf sheath.

(iv) Enclosed: Panicle is entirely enclosed by the flag-leaf sheath.

5 <u>Panicle length</u>

Panicle length in rice is a very variable character and has a definite relationship with yield. Studies made by Bhide (1926) and Ramiah (1930) show that this character is governed by polygenes.

Mohammed and Hanna (1965) indicated the existence of partial dominance for longer length of panicle over shorter one. It was found that the two parents were differentiated by two effective factor pairs. (A - a and B - b). Factor 'A' exhibited a higher degree of partial dominance over 'a'. However, the dominance relation between B and 'b' was not consistent.

6 <u>Grain size and shape</u>

Inheritance studies by Parnel *et al.* (1917) showed normal length of grain to be simple dominant over short length. On the other hand Bhide (1926), Chakravarty (1939) and Majid (1939) reported that grain length is controlled by multiple genes. Studies at the Central Rice Research Institute, Cuttack also show that length of grain is a quantitative character and is governed by 3 genes. According to Ramiah and Parthasarathy (1933) and Mitra and Ganguli (1938) inheritance of the breadth of grain is polygenic. Majid (1939) explained the inheritance of breadth of grain on digenic basis. According to him the thickness of grain is controlled by polygenes. Nagai (1959) reported that the mean size of kernels in the F_1 plant is intermediate between the parents. Jennings (1966) found that the length of F_1 grains was intermediate between parental means.

7 Pollen size and shape

Rao (1964) in a study of inter-racial hybrids of rice, observed that the size of pollen grains varied markedly in different hybrid combinations. He observed three types of pollen grains, normal dark stained fertile ones, abnormal light stained fertile pollen grains and unstained sterile ones. He found no marked variation in the size of sterile pollen grains. Sampath (1964) reported that the pollen from *japonica* x *indica* hybrids varied in size and that the undersized pollen was also viable.

Inheritance of qualitative characters

1 Pigmentation

Parnel *et al.* (1917) reported that the expression of anthocyanin pigment in any part of the plant is governed by two complementary genes. This view was supported by workers from Japan and U.S.A. Hector (1922) reported an association between purple apiculus and colour in (1) leaf sheath, (2) stigma, (3) internode, (4) sterile glumes, (5) lemma and palea, (6) junctura and (7) auricle. This association between the presence of pigment in the different parts of rice plant is not due to linkage but due to pleiotropy. Ramiah (1953) reported that there are other genes which localize the pigmentation in particular organs, besides the basic gene. He also considers that there are genes for intensifying or diluting the pigment and for producing various pigment patterns. According to him two to seven genes are probably involved in the production of different types of pigmentation in the various plant parts such as leaf sheath, internode junctura, auricle, ligule and leaf axil.

In hybrids between green _japonica_ and _indica_ varieties, the production of pigmentation in the leaf sheath, auricle and other plant organs appear to be governed by two complementary genes, one carried by the _indica_ and other by the _japonica_ parent (Anon. 1953).

Ghose _et al._ (1960) reported considerable variation in the intensity of anthocyanin pigment in the leaf sheath. At least four genes (including two basic genes) are involved in the expression of pigment in the leaf sheath. Kadam and D'Cruz (1960) reported that the two basic genes 'A' and 'C' produce colour in the apiculus and both are required along with another specific gene 'LSC' for the development of colour in leaf sheath and stigma.

Venkataswamy (1964) while studying the inheritance of some morphological characters in *japonica* x *indica* crosses obtained the Mendelian ratios for apiculus pigmentation. Misro and Sampath (1964) observed that pigmentation of the apiculus and stigma was dominant over the nonpigmented condition. Jennings (1966) found that coloured apiculus was simple dominant to colourless apiculus in the cross between a colourless *japonica* and coloured *indica* varieties.

2 Hairiness

Nagao *et al.*(1960) found that the pubescence of the leaves is conditioned by two complementary genes and pubescence of glumes by a single incompletely dominant gene. The latter gene also governs pubescence of leaf margins, auricles and panicle branches. Misro and Sampath (1964) studied the inheritance of hairiness on lemma and palea and found hairiness to be a monogenic dominant over glabrousness.

Jennings (1966) reported that F_1 of the cross between Tainan 3 (pubescent in leaves and glumes) and Century Patna 231 (glabrous) was pubescent, and the F_2 segregation suggested monogenic inheritance.

3 Phenol reaction test

Nagai (1959) stated that when the hulls or grains or their aqueous extracts are treated with a dilute solution of phenol and paracresol, the colour reaction exhibited by the oxidation of the substances differs a great deal in varieties. According to him certain varieties of *indica* type possess the power of oxidizing phenolic compounds.

Oka (1953) recorded the 'continental' forms as phenol positive and the insular forms phenol negative. Yamaguchi and Kimura (1958) recorded that most of the Japanese upland varieties studied by them showed positive phenol reaction in contrast to the irrigated rices.

Among eleven varieties tested, Karunakaran (1964) found three Chinese and one *tjerah* types to be phenol positive like the *indica* types. Jennings (1966) reported that the lemmas, paleas and outer glumes of sterile and fertile spikelets of some varieties of rice are stained darkly following soaking for several hours in 1.5% phenol solution. Phenol staining was found to be a simply inherited dominant to no staining.

Heterosis

Jones (1926) was the first to report hybrid vigour in rice for plant height. Juachon (1932) found in certain crosses an increase in vigour for number of earbearing tillers.

Ramiah (1935) from studies over a number of years found that the F_1 showed hybrid vigour for tiller production and earlier flowering and that expression of such vigour varied in hybrids of different combinations. Idsumi (1936) found marked heterosis for plant height, weight of stem, ear length and number of shoots. The morphological differences between Japanese and Indian types bore no relationship to the phenomenon and in fact the degree of heterosis was more marked within Indian types than between Japanese and Indian types.

Kadam (1937) studied five crosses and except in two crosses showing higher F_1 yield than the high yielding parent, evidence of heterosis in other characters was not reported.

Capinpin and Punyasingh (1938) observed marked heterosis in certain crosses for plant height, yield of grain and panicle length. There was no evidence of heterosis in number of culms, grain length, breadth and thickness.

Nagao and Takahashi (1941) found heterosis for panicle weight in a number of inter varietal crosses they studied. Opsomer (1942) found heterosis most marked in grain yield. Capinpin and Amaba (1949) found that the length of F_1 grains in a cross exceeded that of either parent and this they ascribed to heterosis.

Ramiah (1953) recorded that F_1 showed more tillering and early flowering than either parent. Richharia and Misro (1959) reported heterosis in a number of <u>japonica</u> x <u>indica</u> hybrids. Parthasarathy (1960) reported that the F_1 hybrids showed considerable heterosis with regard to plant height and number of ears per plant, but their grain yields were generally inferior to the parents.

Joseph (1962) did not find heterosis to any perceptible degree in the <u>indica</u> x <u>indica</u> combinations while all the <u>japonica</u> x <u>indica</u> combinations studied showed heterosis for productive tillers, plant height and straw yield.

Misro and Shastry (1962) studied heterosis for height, ear bearing tillers and duration in 360 japonica x indica crosses and made the following observations: (1) The manifestation of heterosis in the number of ear-bearing tillers is most conspicuous, height comes next in the order and duration the last. (2) Japonica x indica crosses are in no way inferior to intra-indica crosses with regard to the degree of heterosis.

Namboodiri (1963) studied heterosis in four selected cross combinations. There was clear evidence of vigour only in the height of plant and number of tillers per plant. Hybrid vigour was exhibited only in certain cases. Of the other characters studied there was clear evidence of heterosis in the length of panicle and breadth and thickness of grains. Clear evidence of heterosis is lacking in the case of length of grains. Karunakaran (1964) while studying the heterotic effect of indica x japonica and indica x indica crosses, reported positive heterosis over mid parental value for grain breadth and grain length. Positive heterosis over the higher parent was seen for straw yield, panicle length 1000 grain weight, breadth of grain and grain thickness in the direct crosses and for straw yield, number of tillers, height of plant and panicle length in the reciprocal crosses.

Rao (1965) studied hybrid vigour in crosses involving several varieties and recorded heterosis for productive tillers, number of grains per panicle and straw yield.

Narahari and Pawar (1965) studied 14 indica x japonica hybrids and found majority of the hybrids were superior to indica parent in height, number of grains per plant, panicle density and milling percentage.

Jennings (1966) in a preliminary study of heterosis in normally fertile indica x japonica hybrids, found heterosis for earliness, total tiller production, and grain yield. Plant height in the hybrids showed little or no heterosis and was characterised by a high degree of partial to complete dominance for tallness.

Cytological

Mello-sampayo (1952) in the cytological studies of japonica x indica hybrids reported 24 chromosomes which behaved regularly upto metaphase I. An acentric fragment and a chromatin bridge were observed at anaphase I. The homotypic division was regular but the loss of a fragment is thought to be sufficient to account for the sterility observed. Sampath and Mohanty (1954) observed abnormalities such as laggards, stretched chromosomes and bridges with fragments at anaphase I in hybrids between japonica and indica types. The occurrence of anaphase bridges is ascribed to inversions in japonica parents.

Yao et al. (1958) studied chromosome behaviour in meiosis I in six partially sterile hybrids between varieties of cultivated rice. Diakinesis and metaphase I were normal in these with no evidence of translocation or absence of pairing to account for the sterility. In two of the hybrids chromosome bridges without fragments occurred at anaphase I and telophase I in low but regular frequency. It was concluded that such bridges may be the result of delayed terminalization of chiasmata in pairs of chromosomes which are structurally different at some point.

Hsieh and Oka (1958) found that the F_1 plants and their parents were regular in their chromosome pairing and they did not differ significantly as regards frequency of the rarely occurring univalents of 'stretched' chromosomes at metaphase I and of bridges at anaphase I. Stretched chromosomes may be due to precocious separation of bivalents. The occurrence of such chromosomes and univalents may be indicative of loose pairing of homologues, possibly as a result of formation of an insufficient number of chiasmata per chromosome. The nature of the bridges is unknown, but they could not be inversion bridges in view of of their presence in the parental pureline.

Henderson <u>et al</u>. (1959) made an intensive cytological study of chromosome behaviour at anaphase I in 12 inter-varietal hybrids of cultivated rice. Two types of unusual behaviour were found bridges without fragments and bridges accompanied by acentric fragments. Since bridges without fragments were also found in each of the 3 homozygous varieties in approximately the same frequency as in the hybrids, it was concluded that their behaviour was not abnormal and did not indicate the presence of structural differences in chromosomes. Bridges accompanied by fragments were observed at very low frequencies in 9 of the 12 hybrids indicating the presence of paracentric inversions.

Shastry (1964) reported that normal chromosome pairing at metaphase I and the frequent occurrence of anaphase bridges in *japonica* x *indica* hybrids leads to the hypothesis that there are no restrictions to homology between the chromosomes of *japonica* and *indica* rices and that the differentiation between these subspecies is largely due to gene mutations.

MATERIALS AND METHODS

MATERIALS AND METHODS

A. Materials

Four varieties of rice (*Oryza sativa* L.) representing *japonica* and *indica* types maintained at the Agricultural College & Research Institute, Vellayani were selected for the present study. Details of these varieties are presented in Table I.

Three cross combinations were made using Vellayani 1 as a common parent. The three hybrids fall under the following groups:

Cross No.	Details of crosses made	Group
I	Vellayani 1 x Tainan 3	*indica* x *japonica*
II	Vellayani 1 x Taichung 65	*indica* x *japonica*
III	Vellayani 1 x Taichung Native 1	*indica* x *indica*

B. Methods

1 Hybridization and study of plant characters

The four parental varieties were grown in pots in singles during the season, August to November 1966 for effecting hybridization. The wet cloth method, reported by Chaisang (1961) was employed for emasculation of spikelets for crossing.

The hybrids and their parental varieties were grown in singles in pots, kept side by side in rows. Uniform condition was given to all the pots.

II Morphological description

Morphological description of the F_1 hybrids and parental varieties was made following the schedule of Hutchinson, Ramiah and

Table I

Detailed characteristics of varieties

SL.No.	Particulars	Vellayani 1	Taichung Native 1	Tainan 3	Taichung 65
1	Type	Indica	Taiwanese indica	japonica	japonica
2	Origin	Selection from a mutant type developed by neutron irradiation in Ptb.10 (Evolved at Agricultural College & Research Institute, Vellayani.)	Selection from a cross between Dee-Geo-Woo gen. and Tsai-yuwan-chung.(Taiwan)	Selection from a cross between Kwan Fu 401 x Gj unk 38 (Taiwan)	Selection from a cross between Kameji and shinriki (Taiwan)
3	Habit of plant	Tall	Short	Medium tall	Medium tall
4	Tillers	Few andspreading	Many and compact	Many and compact	Many and compact
5	Panicle exsertion	Well exserted	Exserted	Well exserted	Well exserted
6	Panicle type	Semi-compact partly drooping	Semi-compact drooping	Compact drooping	Compact drooping
7	Lemma palea colour	Green	Green	Green	Green
8	Grain size	Medium	Medium bold	Bold	Bold
9	Grain colour	Straw	Straw	Straw	Straw
10	Awning	Awnless	Awnless	Awnless	Awnless
11	Rice	White	White	White	White
12	Duration	Short (90-100 days)	Medium (120-125 days)	Medium (120-125 days)	Medium (120-125 days)

others (1938). Observations were made from all the available hybrid plants and ten plants in each of the parental varieties, and recorded.

III Phenol reaction test:

A few grains from hybrids of all cross combinations and parental varieties were soaked in 1.5% aqueousphenol solution for six hours, drained and air dried. Hull colour was recorded as unstained (Phenol negative) and stained (phenol positive).

IV Sterility studies:

a Pollen sterility:

Pollen sterility was estimated for the parents and the hybrids using fresh pollen collected at the time of anthesis. The pollens were stained with glycerine acetocarmine (1:1) and the slides kept for a few minutes so as to allow the stain to act on the pollen grains. The slides were examined under the microscope (low power), well stained pollen grains were classed as fertile and others as sterile. Counts were made from 30 microscopic fields selected at random for each plant. The data were tabulated and the percentage of sterility was estimated.

$$\text{Percentage of pollen sterility} = \frac{\text{No.of sterile grains}}{\text{Total number of grains}} \times 100$$

b. Spikelet sterility:

Spikelet sterility was estimated after the earheads attained full maturity. Ten earheads were collected at random from each of the plants and the total number of well filled grains and chaff was recorded separately. The data were tabulated and the percentage of sterility was estimated.

$$\text{Spikelet sterility} = \frac{\text{Number of chaff}}{\text{Total number of spikelets}} \times 100$$

V Quantitative characters:

Observation on inheritance of quantitative characters was made from all the avialable hybrid plants as also the 10 plants in each of the four parental varieties. Characters studied include plant height, productive tillers, flowering duration, exsertion of panicle, length of panicle, number of spikelets per panicle, grain yield per plant, straw yield per plant, 1000 grain weight, length, breadth and thickness of grain and pollen size.

(1) Plant height:

Height was measured to the nearest c.m. from the base of the plant to the tip of the main panicle after the grain had ripened. Mean heights for each cross and their parents were worked out.

(2) Tillering:

The total number of ear-bearing tillers per plant was counted at the time of harvest, the mean number of tillers per plant in both hybrids and parents calculated.

(3) Flowering duration:

Number of days taken from the date of seeding to the emergence of the tip of the first panicle was recorded as the flowering duration.

(4) Exsertion of panicle:

Panicle exsertion was recorded in c.m. from 10 panicles selected at random in each plant. Length of the internode from the tip of the last leaf-sheath to the neck of the panicle was measured and the mean exsertion worked out.

(5) Length of panicle:

Length of 10 panicles selected at random from each plant was measured in cm. and the mean length per plant recorded.

(6) Number of spikelets per panicle:

Total number of spikelets (fertile as well as sterile) was counted from 10 panicles selected at random in each plant and the mean number per panicle was worked out.

(7) Grain and straw yields per plant:

The plants were harvested and seeds collected separately. The yield of grain and straw was recorded in grammes after proper drying and the mean yield per plant was worked out.

(8) 1000 grain weight:

Samples were taken at random from each of the plants and 1000 grains counted and weight recorded in grammes. From this the mean weight was worked out.

(9) Length, breadth and thickness of grain:

30 grains from each plant were selected at random and measured by means of a 'Vernier caliper' graduated in mm. and the mean length, breadth and thickness of grain was recorded for each of the hybrids and the parents.

(10) Pollen size:

Fresh pollen grains were collected at the time of spikelet opening and stained with glycerine - acetocarmine (1:1). The slides were examined under the microscope (high power) and the pollen diameter measured using a standardized ocular micrometer. Diameter of 100 pollen grains selected at random was measured and recorded. The data were tabulated into frequency tables and the mean diameter of the pollen grains was calculated and recorded in microns. (μ)

Mean diameter = Mean $\pm$ Standard error.

VI Heterosis:

Estimation of heterosis for plant height, productive tillers, flowering - duration, panicle exsertion, length of panicle, number of spikelets per panicle grain and straw yield per plant, weight of 1000 grains, length, breadth and thickness of grain and pollen size was made by comparing the F_1 value with the higher parental or the mid-parental value.

VII Statistical analysis:

The total number of plants in each cross and the parents was taken as the number of replication and data analysed adopting the completely randomised design. Data on plant height, number of productive tillers, flowering duration, panicle exsertion, length of panicle, number of spikelets per panicle, grain and straw yield per plant, 1000 grain weight, length, breadth and thickness of grain, pollen size, pollen sterility and spikelet sterility were analysed by the analysis of variance technique.

VIII Cytological studies:

Panicles of the proper stage from all the cross combinations and parents were fixed between 9.30 and 10 A.M. in Farmer's fluid (1:3 acetic alcohol) to which a drop of ferric chloride was added, and the materials kept in the fixative over night, washed in rectified spirit and stored in 70% alcohol. With a view to finding out the abnormalities, if any, present in the chromosome behaviour during meiosis resulting in the partial sterility in F_1s, attention was concentrated on stages of the first division such as diakinesis, metaphase-I and anaphase-I. Temporary slides with 1% acetocarmine were prepared, gently warmed over falme, and the cells flattened, placing the slides in folds of filter paper by applying modest pressure. The slides were examined with the help of an Olympus microscope of 97 x oil immersion objective and 10 x and 15 x oculars.

EXPERIMENTAL RESULTS

RESULTS

Hybridization:

A total number of sixtytwo hybrid seeds were obtained in the three cross-combinations as detailed below:

Indica x *japonica*

I	(a) Vellayani 1 x Tainan 3	11	21
	(b) do (reciprocal)	10	
II	(a) Vellayani 1 x Taichung 65	3	11
	(b) do (reciprocal)	8	

Indica x *indica*

III	(a) Vellayani 1 x Taichung Native 1	21	30
	(b) do (reciprocal)	9	
		Total	62

A. Quantitative characters:

Data on quantitative characters such as plant height, productive tillers, flowering duration, panicle exsertion, length of panicle, number of spikelets per panicle, grain yield, straw yield, 1000 grain weight, length, breadth and thickness of grain and pollen size in respect of the parents and hybrids are presented in Tables II to XIV. Analysis of variance tables are given in Appendix.

(i) Plant height:

Of the three cross - combinations studied the hybrid was on par with the superior parent Vellayani 1 in cross numbers I and II for plant height whereas in the other cross (Cross No. III) the hybrid was intermediate between the parents. Mean plant height for parents and hybrids are presented as Table II (Plates I to VI and Fig.2).

(ii) Productive tillers:

Significant increase in tiller production was recorded by the hybrid in the cross between Vellayani 1 and Taichung 65 (Cross No. II). Eventhough Cross No. I and III recorded more number of tillers, they were not statistically significant when compared with the high parental value. (Vide Table III and Fig.3).

(iii) Flowering duration:

The F_1 plants were earlier in flowering than both the parents in all the three cross combinations (Vide Table IV and Fig.1)

(iv) Panicle exsertion:

In cross Nos. I & II the hybrids showed well exserted panicles like their parents. In cross No.III, where only one of the parents (Vellayani 1) had well exserted panicle, the hybrid showed well exserted nature with a mean exsertion of 1.28 cm (Vide Table V & Fig.6).

(v) Length of panicle:

Hybrids of Cross No. 1 produced longer panicles whereas in

Table II

Mean Height of Plant in cm

Crosses	I		II		III	
Sl. No.	Parent/ hybrid	Height	Parent/ hybrid	Height	Parent/ hybrid	Height
1	Vellayani 1	131.00	Vellayani 1	131.00	Vellayani 1	131.00
2	F_1	133.48	F_1	125.09	F_1	111.70
3	Tainan 3	113.30	Taichung 65	101.40	Taichung Native 1	85.50
	C.D. (0.05) 1,2 & 2, 3	= 4.03	C.D. (.05) 1, 2 & 2, 3	= 6.96	C.D. (.05) 1, 2 & 2, 3	= 4.24
	C.D. (.05) 1, 3	= 4.66	C.D. (.05) 1,3	= 7.13	C.D. (.05) 1, 3	= 5.21

TABLE III

Mean number of productive tillers

Sl. No.	Parent/ hybrid	No.of tillers	Parent/ hybrid	No. of tillers	Parent/ hybrid	No. of tillers
1	Vellayani 1	41.20	Vellayani 1	41.20	Vellayani 1	41.20
2	F_1	55.24	F_1	69.36	F_1	69.90
3	Tainan 3	48.00	Taichung 65	40.00	Taichung Native 1	61.60
	C.D. (.05) 1, 2 & 2, 3	= 11.14	C.D. (.05) 1, 2 & 2, 3	= 20.60	C.D. (.05) 1, 2 & 2, 3	= 15.30
	C.D. (.05) 1, 3	= 12.97	C.D. (.05) 1, 3	= 21.50	C.D. (.05) 1, 3	= 18.75

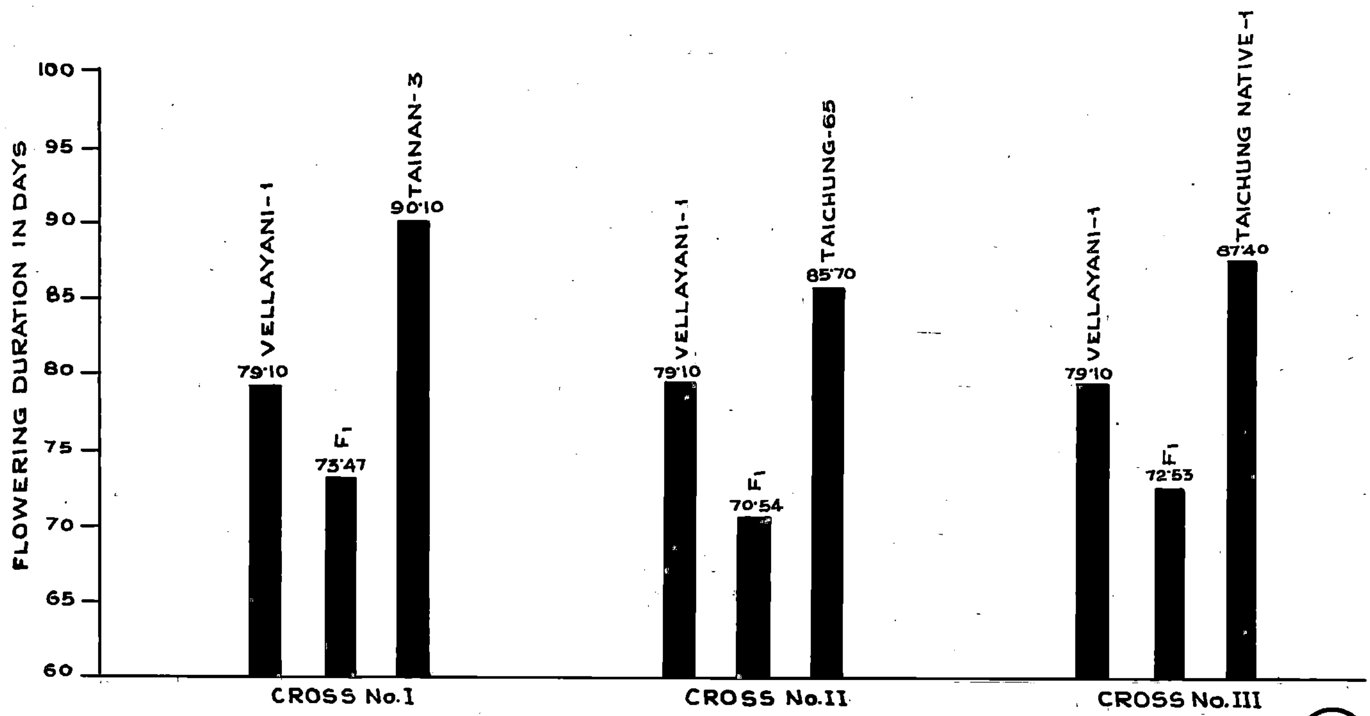
FLOWERING DURATION IN DAYS
100
95
90
85
80
75
70
65
60
VELLAYANI-1
79·10
F1
73·47
TAINAN-3
90·10
VELLAYANI-1
79·10
F1
70·54
TAICHUNG-65
85·70
VELLAYANI-1
79·10
F1
72·53
TAICHUNG NATIVE-1
87·40
CROSS No. I
CROSS No. II
CROSS No. III

FIG. 1

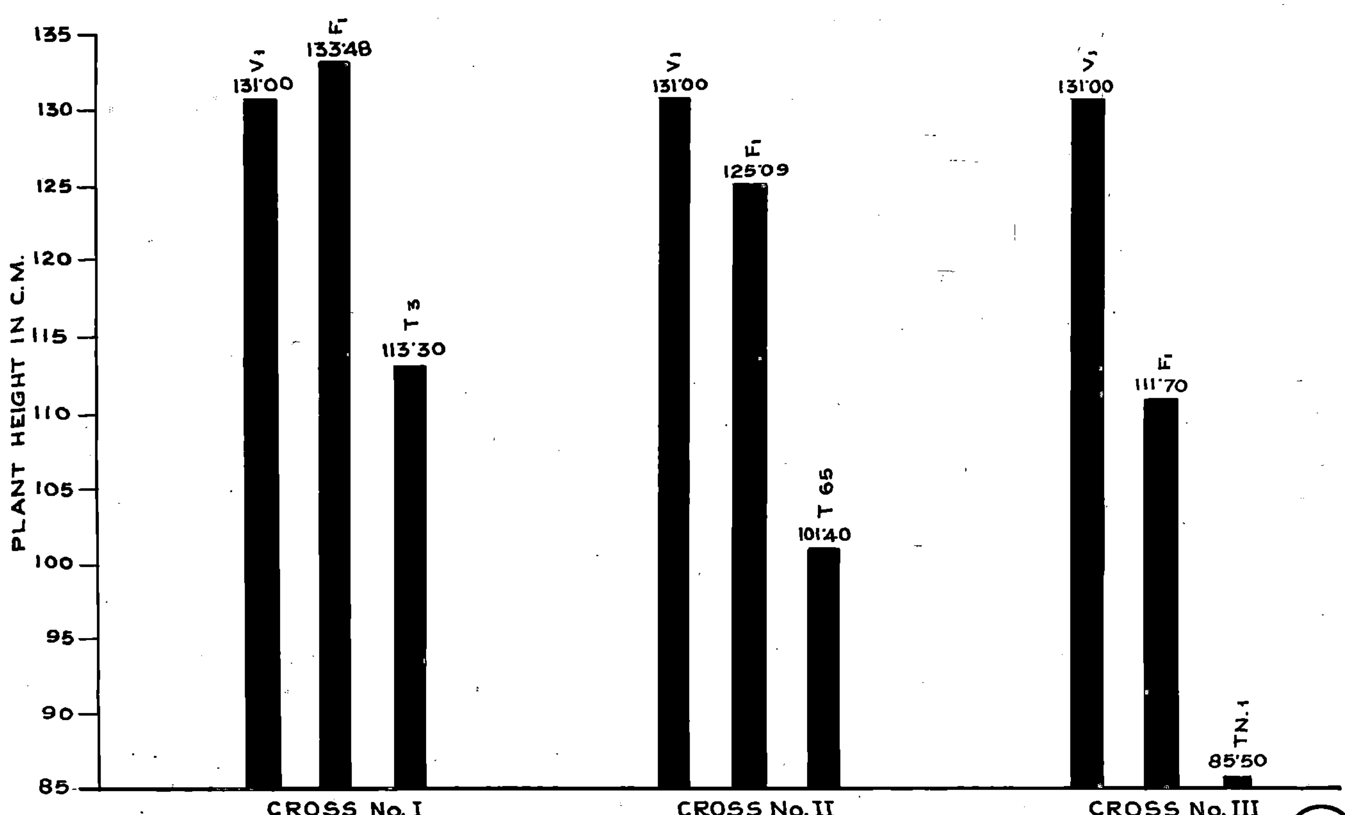
PLANT HEIGHT IN C.M.
135
130
125
120
115
110
105
100
95
90
85
V1
131·00
F1
133·48
T3
113·30
V1
131·00
F1
125·09
T 65
101·40
V1
131·00
F1
111·70
TN.1
85·50
CROSS No. I
CROSS No. II
CROSS No. III

FIG. 2

Table IV

Mean flowering duration in days

Sl. No.	Parent/ hybrid	Flowering duration.	Parent/ hybrid	Flowering duration	Parent/ hybrid	Flowering duration
1	Vellayani 1	79.10	Vellayani 1	79.10	Vellayani 1	79.10
2	F_1	73.47	F_1	70.54	F_1	72.53
3	Tainan 3	90.10	Taichung 65	85.70	Taichung Native 1	87.40
	C.D. (.05) 1, 2 & 2,3	= 2.23	C.D. (.05) 1,2 & 2, 3	= 3.00	C.D. (.05) 1, 2 & 2,3	= 3.33
	C.D (.05) 1,3	= 2.25	C.D. (.05) 1,3	= 3.07	C.D. (.05) 1,3	= 4.08

Table V

Mean panicle exsertion in cm

Sl. No.	Parent/ hybrid	Exsertion	Parent/ hybrid	Exsertion	Parent/ hybrid	Exsertion
1	Vellayani 1	4.56	Vellayani 1	4.56	Vellayani 1	4.56
2	F_1	6.52	F_1	6.49	F_1	1.28
3	Tainan 3	7.09	Taichung 65	8.51	Taichung Native 1	0.12
	C.D. (.05) 1, 2 & 2, 3	= 1.26	C.D.(.05) 1,2 & 2, 3	= 2.00	C.D. (.05) 1, 2 & 2, 3	= 0.58
	C.D. (.05) 1,3	= 1.48	C.D. (.05) 1,3	= 2.21	C.D. (.05) 1,3	= 0.70

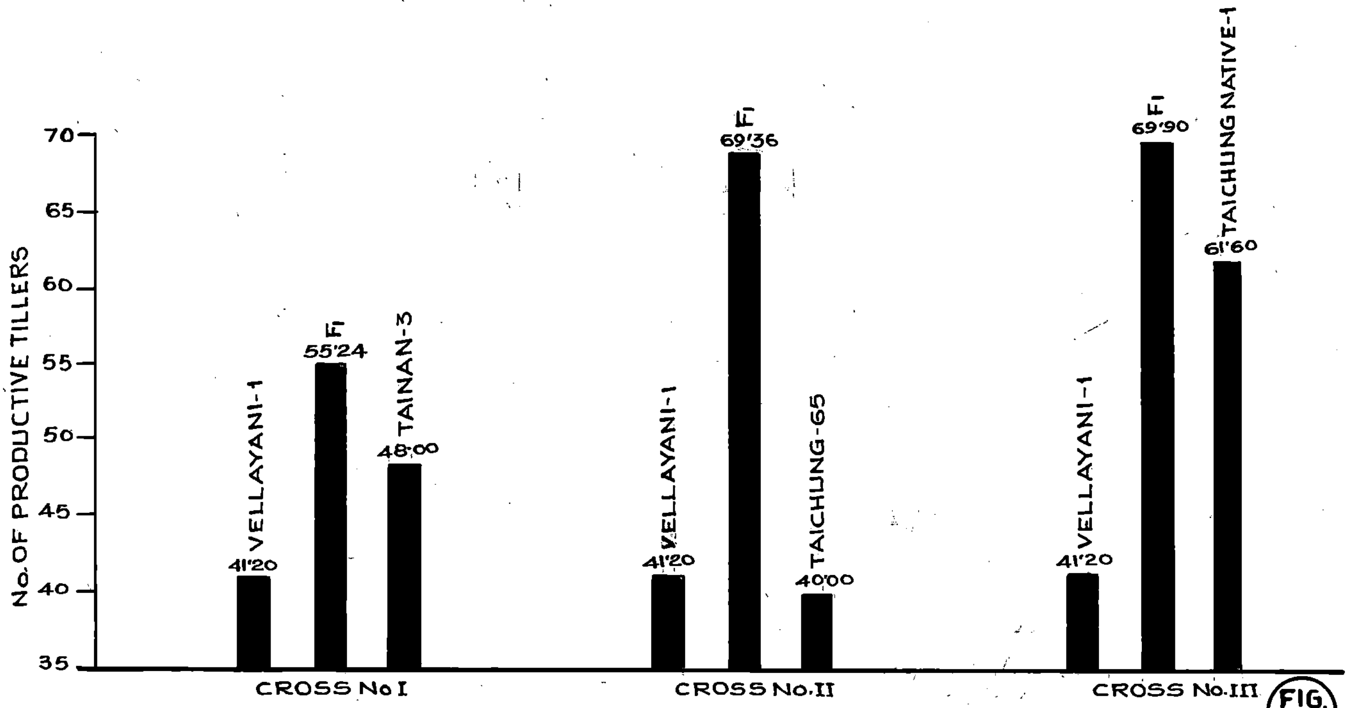

FIG. 3

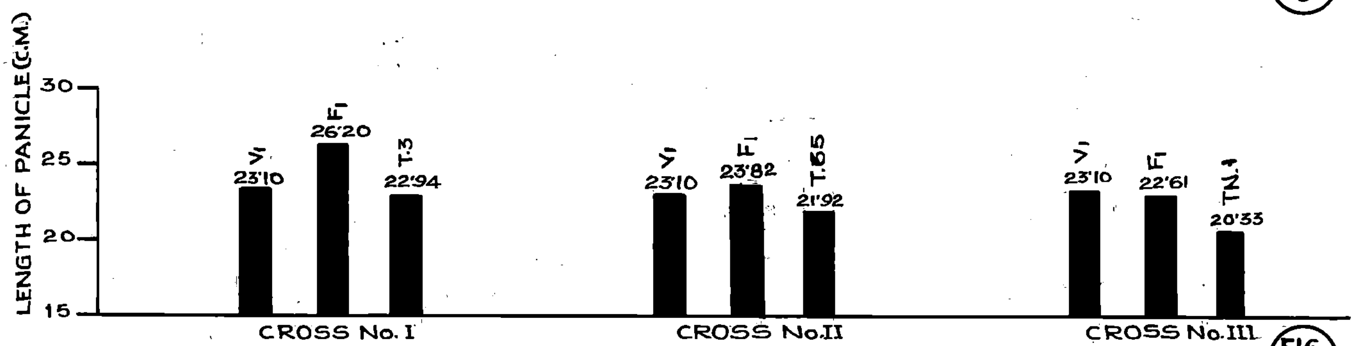

FIG. 4

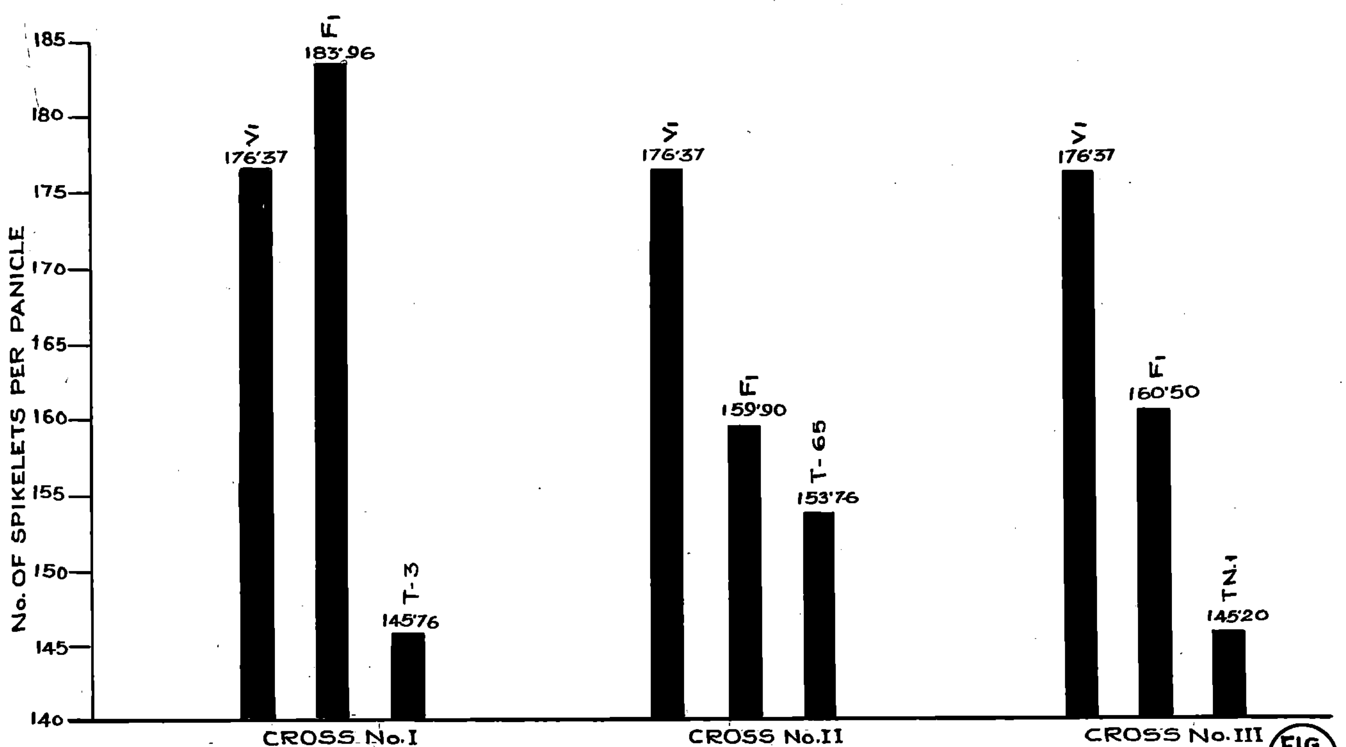

FIG. 5

Cross Nos. II & III the panicle length was on par with that of the superior parent (Vide Table VI, Plates VII to IX and Fig.4).

(vi) Number of spikelets per panicle:

In cross number 1 the hybrid was on par with the superior parent (Vellayani 1) whereas in the other two crosses the hybrids were on a par with the parents having lower value. (Vide table VII & Fig.5).

(vii) Grain yield:

All the three cross combinations recorded a decrease in grain yield per plant which could be attributed to high spikelet sterility (vide Table VIII & Fig.8).

(viii) Straw yield:

Highly significant increase in straw yield was recorded by hybrids in cross Nos. I & III. The increase in straw yield in the hybrid of cross No. II was not statistically significant. (Vide TableIX & Fig.9).

(ix) Thousand grain weight:

Significantly higher increase for thousand grain weight of hybrids over the parents was recorded in all the three cross combinations studied (Vide Table X & Fig. 10).

(x) Length of grain:

There was marked increase in grain length in the hybrids over the parents in all the three cross-combinations. (Vide Table XI & Fig.11).

(xi) Breadth of grain:

All the 3 hybrids showed significantly higher breadth of grain over the parents. (Vide Table XII & Fig. 11).

Table VI

Mean length of panicle in cm

Sl. No.	Parent/ hybrid	Length of panicle	Parent/ hybrid	Length of panicle	Parent/ hybrid	Length of panicle
1	Vellayani 1	23.10	Vellayani 1	23.10	Vellayani 1	23.10
2	F_1	26.20	F_1	23.82	F_1	22.61
3	Tainan 3	22.94	Taichung 65	21.92	Taichung Native 1	20.33
	C.D. (.05) 1, 2 & 2, 3	= 1.29	C.D.(.05) 1, 2 & 2, 3	= 1.31	C.D. (.05) 1, 2 & 2, 3	= 1.06
	C.D. (.05) 1,3	= 1.52	C.D. (.05) 1,3	= 1.35	C.D. (.05) 1,3	= 1.32

Table VII

Mean number of spikelets for panicle

Sl. No.	Parent/ hybrid	No. of spikelets	Parent/ hybrid	No. of spikelet	Parent/ hybrid	No. of spikelets
1	Vellayani 1	176.37	Vellayani 1	176.37	Vellayani 1	176.37
2	F_1	183.96	F_1	159.50	F_1	160.50
3	Tainan 3	145.76	Taichung 65	153.76	Taichung Native 1	145.94
	C.D. (.05) 1, 2 & 2, 3	= 15.60	C.D. (.05) 1, 2 & 2, 3	= 16.58	C.D. (.05) 1, 2 & 2, 3	= 14.67
	C.D. (.05) 1, 3	= 18.00	C.D. (.05) 1,3	= 17.00	C.D. (.05) 1,3	= 17.89

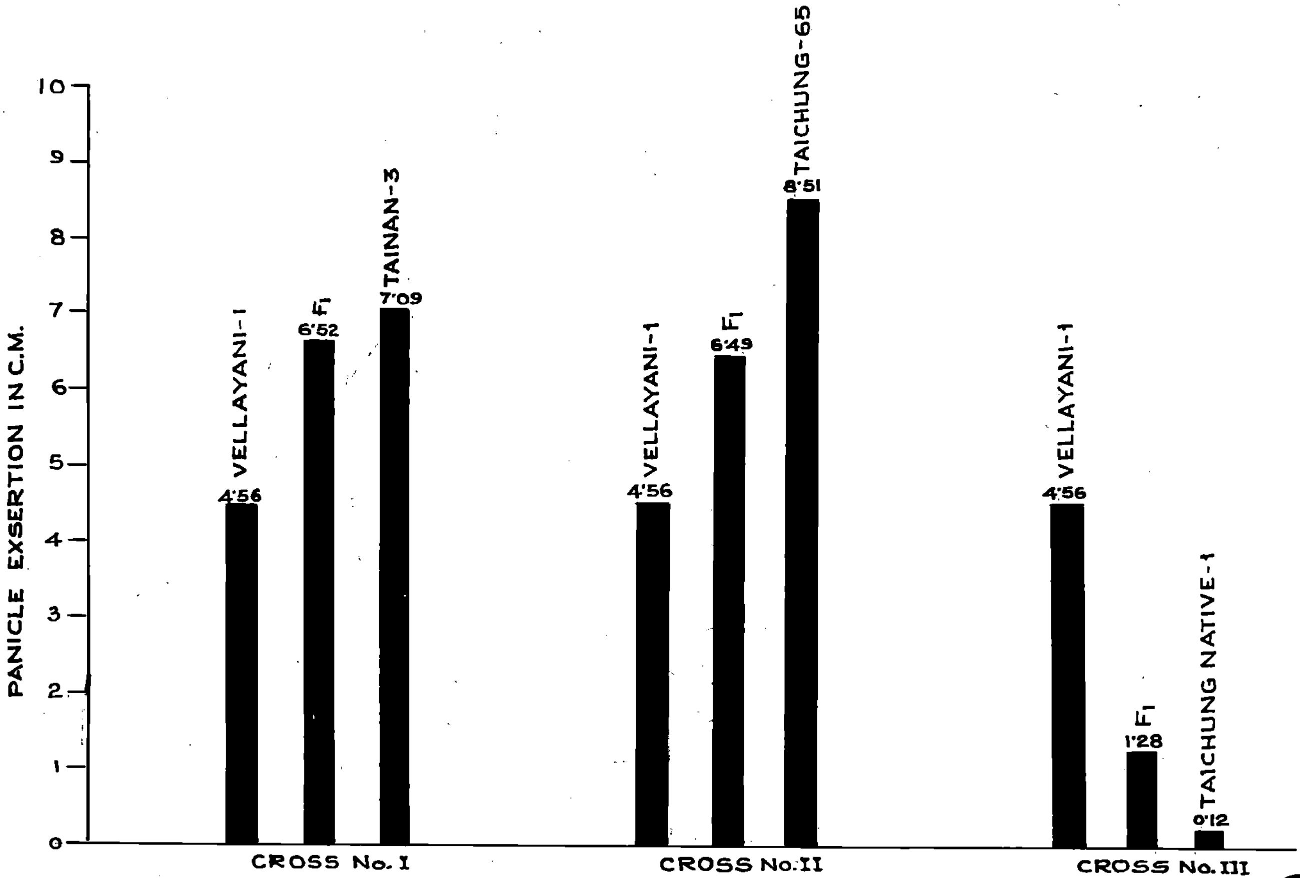
PANICLE EXSERTION IN C.M.
VELLAYANI-1
4'56
F1
6'52
TAINAN-3
7'09
VELLAYANI-1
4'56
F1
6'49
TAICHUNG-65
8'51
VELLAYANI-1
4'56
F1
1'28
TAICHUNG NATIVE-1
0'12
CROSS No. I
CROSS No. II
CROSS No. III

FIG. 6

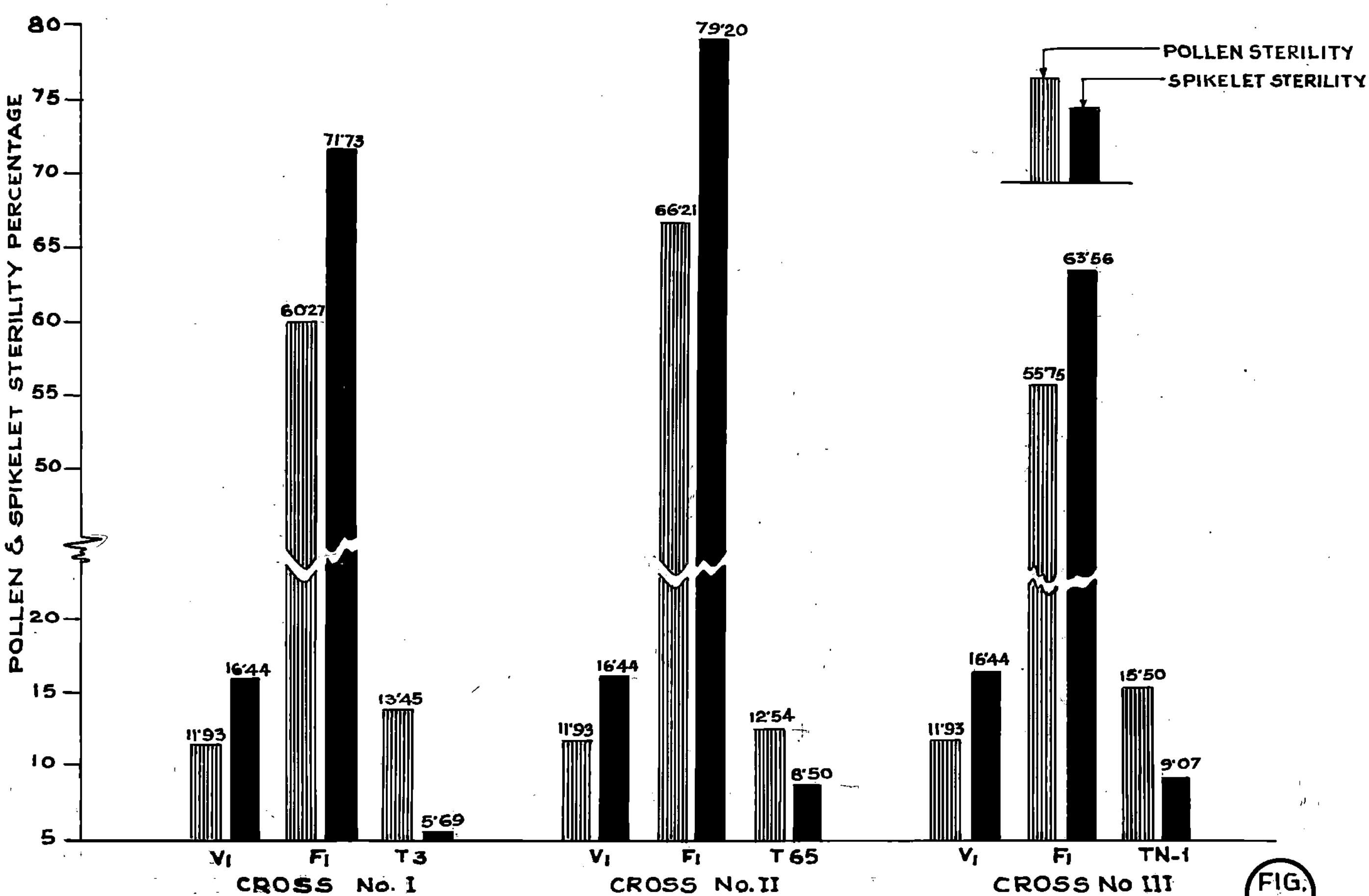
POLLEN & SPIKELET STERILITY PERCENTAGE
POLLEN STERILITY
SPIKELET STERILITY
11'93
16'44
60'27
71'73
13'45
5'69
11'93
16'44
66'21
79'20
12'54
8'50
11'93
16'44
55'75
63'56
15'50
9'07
V1
F1
T3
V1
F1
T 65
V1
F1
TN-1
CROSS No. I
CROSS No. II
CROSS No III

FIG. 7

Table VIII

Grain yield per plant in grammes

Sl. No.	Parent/ hybrid	Grain yield	Parent/ hybrid	Grain yield	Parent/ hybrid	Grain yield
1	Vellayani 1	87.00	Vellayani 1	87.00	Vellayani 1	87.00
2	F_1	62.05	F_1	62.82	F_1	74.90
3	Tainan 3	88.50	Taichung 65	79.25	Taichung Native 1	88.40

C.D. (.05) 1, 2 & 2, 3 = 7.70	C.D. (.05) 1, 2 & 2, 3 = 4.30	C.D. (.05) 1, 2, & 2,3 = 8.04
C.D. (.05) 1, 3 = 9.12	C.D. (.05) 1,3 = 4.50	C.D. (.05) 1,3 =10.05

Table IX

Straw yield in grammes

Sl. No.	Parent/ hybrid	Straw yield	Parent/ hybrid	Straw yield	Parent/ hybrid	Straw yield
1	Vellayani 1	91.00	Vellayani 1	91.00	Vellayani 1	91.00
2	F_1	141.95	F_1	114.00	F_1	141.00
3	Tainan 3	98.10	Taichung 65	77.00	Taichung Native 1	99.50

C.D.(.05) 1, 2 & 2, 3 = 14.79	Not significant	C.D. (.05) 1, 2 & 2, 3 = 15.48
C.D. (.05) 1, 3 = 18.05		C.D. (.05) 1, 3 = 19.10

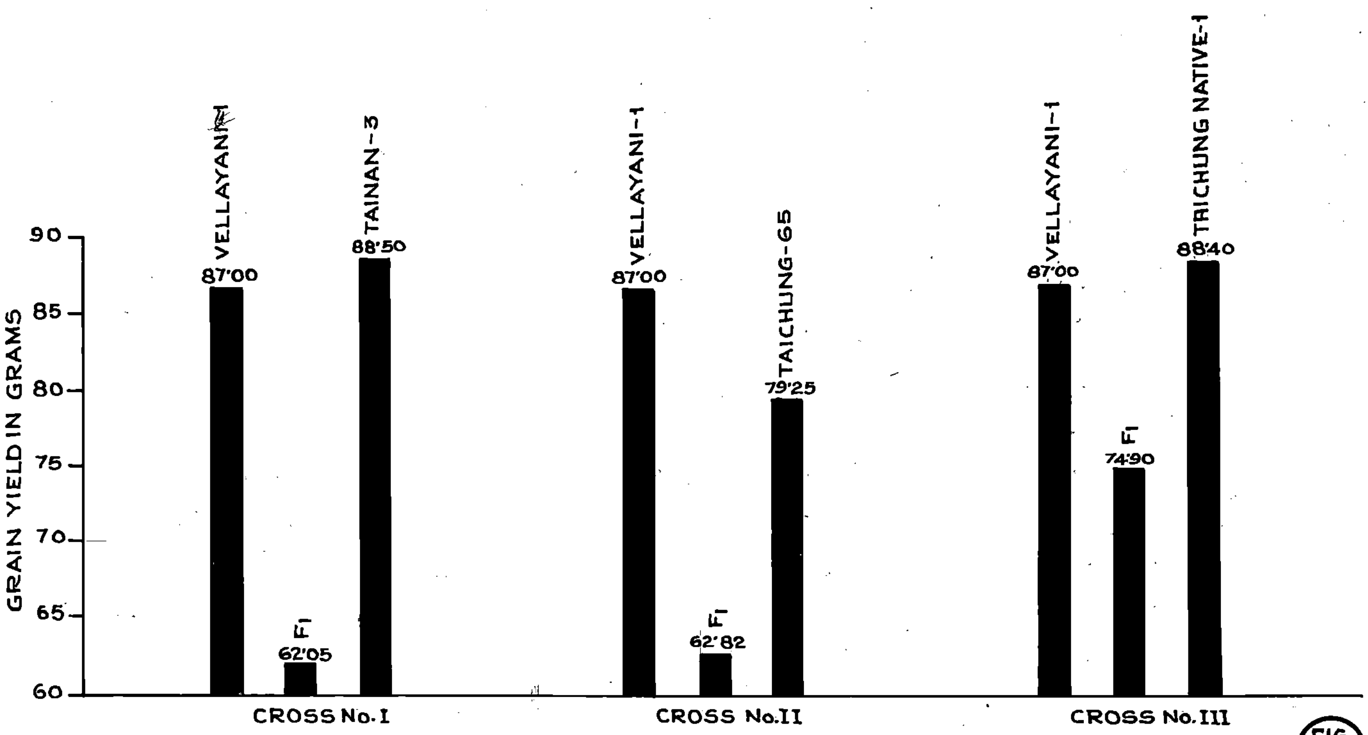
GRAIN YIELD IN GRAMS
90
85
80
75
70
65
60
VELLAYANI-1
87'00
F1
62'05
TAINAN-3
88'50
VELLAYANI-1
87'00
F1
62'82
TAICHUNG-65
79'25
VELLAYANI-1
87'00
F1
74'90
TRICHUNG NATIVE-1
88'40
CROSS No. I
CROSS No. II
CROSS No. III

FIG. 8

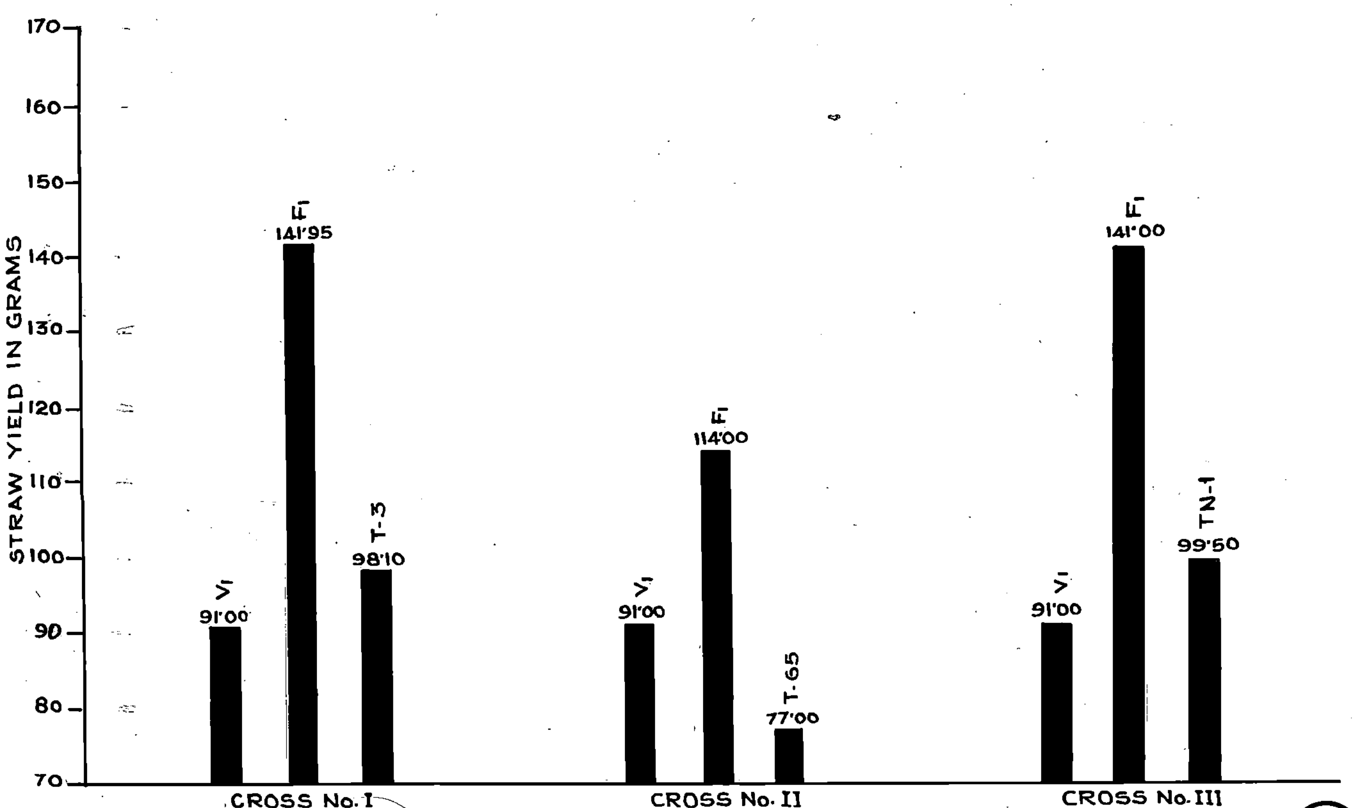
STRAW YIELD IN GRAMS
170
160
150
140
130
120
110
100
90
80
70
V1
91'00
F1
141'95
T-3
98'10
V1
91'00
F1
114'00
T-65
77'00
V1
91'00
F1
141'00
TN-1
99'50
CROSS No. I
CROSS No. II
CROSS No. III

FIG. 9

Table X

Thousand grain weight in grammes

Sl. No.	Parent/ hybrid	1000 grain weight	Parent/ hybrid	1000 grain weight	Parent/ hybrid	1000 grain weight
1	Vellayani 1	19.22	Vellayani 1	19.22	Vellayani 1	19.22
2	F_1	24.77	F_1	24.81	F_1	23.43
3	Tainan 3	21.76	Taichung 65	21.40	Taichung Native 1	21.21

C.D. (.05) 1, 2 & 2, 3	= 0.69	C.D. (.05) 1, 2 & 2, 3	= 0.74	C.D. (.05) 1, 2 & 2, 3	= 0.66
C.D. (.05) 1, 3	= 0.77	C.D. (.05) 1,3	= 0.76	C.D. (.05) 1, 3	= 0.82

Table XI

Grain length in mm

Sl. No.	Parent/ hybrid	Grain length	Parent/ hybrid	Grain length	Parent/ hybrid	Grain length
1	Vellayani 1	7.29	Vellayani 1	7.29	Vellayani 1	7.29
2	F_1	7.47	F_1	7.60	F_1	7.54
3	Tainan 3	6.41	Taichung 65	6.65	Taichung Native 1	7.28

C.D. (.05) 1, 2 & 2, 3	= 0.99	C.D. (.05) 1, 2 & 2, 3	= .102	C.D. (.05) 1, 2 & 2, 3	= 0.86
C.D. (.05) 1, 3	= .115	C.D. (.05) 1, 3	= .106	C.D. (.05) 1, 3	= .110

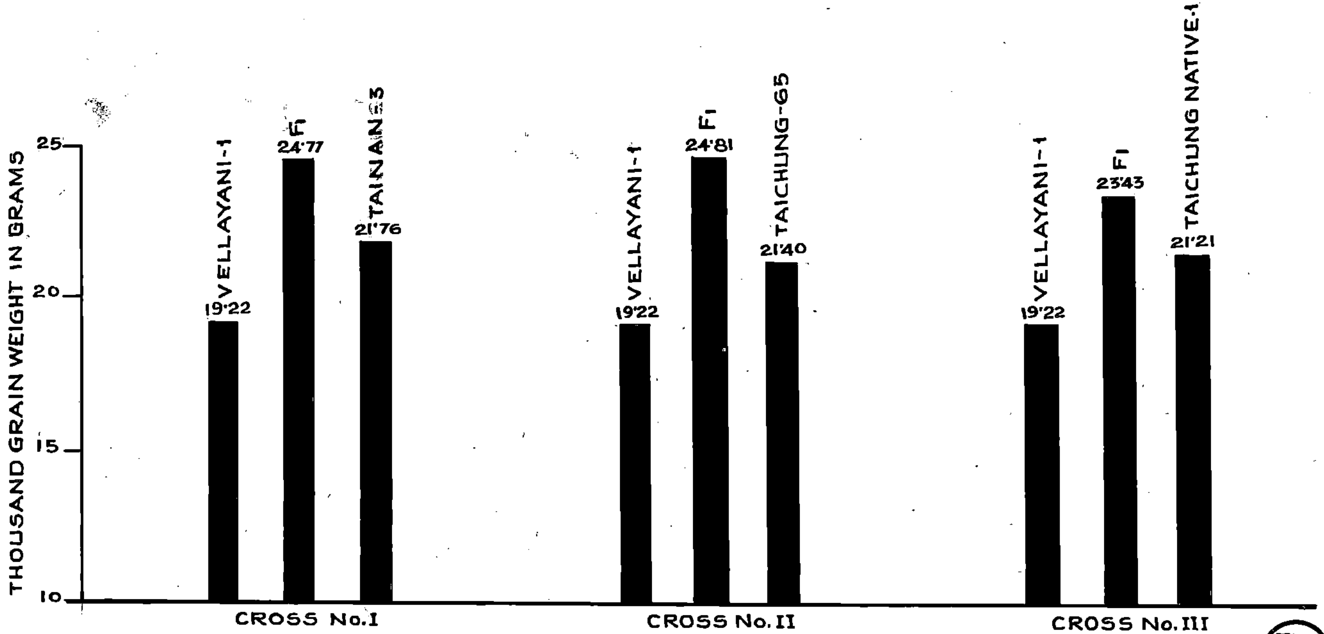
THOUSAND GRAIN WEIGHT IN GRAMS
25
20
15
10
VELLAYANI-1
19·22
F1
24·77
TAINAN-3
21·76
VELLAYANI-1
19·22
F1
24·81
TAICHUNG-65
21·40
VELLAYANI-1
19·22
F1
23·43
TAICHUNG NATIVE-1
21·21
CROSS No. I
CROSS No. II
CROSS No. III

FIG. 10

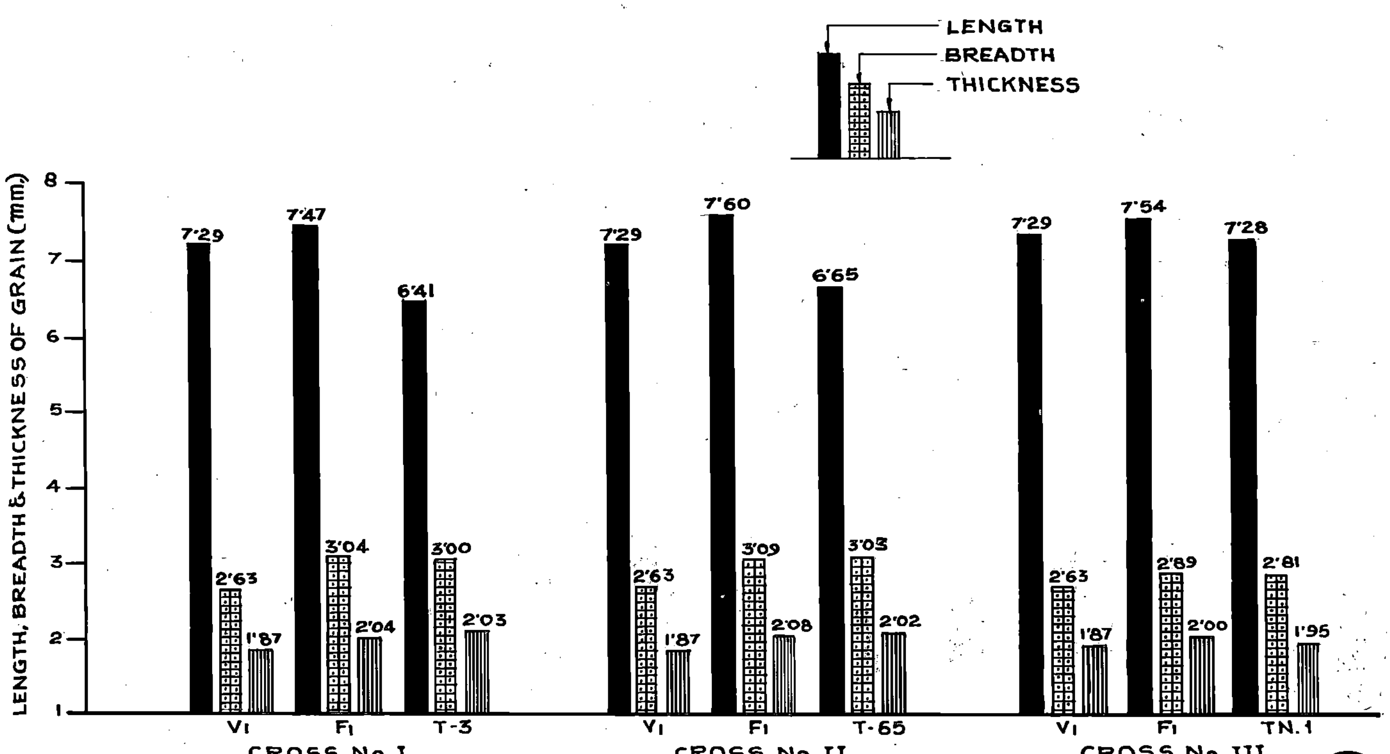
LENGTH
BREADTH
THICKNESS
LENGTH, BREADTH & THICKNESS OF GRAIN (mm)
8
7
6
5
4
3
2
1
7·29
2·63
1·87
7·47
3·04
2·04
6·41
3·00
2·03
7·29
2·63
1·87
7·60
3·09
2·08
6·65
3·03
2·02
7·29
2·63
1·87
7·54
2·89
2·00
7·28
2·81
1·95
V1
F1
T-3
V1
F1
T-65
V1
F1
TN.1
CROSS No. I
CROSS No. II
CROSS No. III

FIG. 11

Table XII

Breadth of grain in mm

Sl. No.	Parent/ hybrid	Grain breadth	Parent/ hybrid	Grain breadth	Parent/ hybrids	Grain breadth
1	Vellayani 1	2.63	Vellayani 1	2.63	Vellayani 1	2.63
2	F_1	3.04	F_1	3.09	F_1	2.89
3	Tainan 3	3.00	Taichung 65	3.03	Taichung Native 1	2.81
	C.D. (.05) 1, 2 & 2, 3	= .03	C.D. (.05) 1, 2 & 2, 3	= .043	C.D. (.05) 1, 2 & 2, 3	= .02
	C. D. (.05) 1, 3	= .05	C.D. (.05) 1, 3	= .054	C.D. (.05) 1, 3	= .03

Table XIII

Thickness of grain

Sl. No.	Parent/ hybrid	Thickness	Parent/ hybrid	Thickness	Parent/ hybrid	Thickness
1	Vellayani 1	1.87	Vellayani 1	1.87	Vellayani 1	1.87
2	F_1	2.04	F_1	2.08	F_1	2.00
3	Tainan 3	2.03	Taichung 65	2.02	Taichung Native 1	1.95
	C.D. (.05) 1, 2 & 2, 3	= .025	C.D. (.05) 1, 2 & 2, 3	= .023	C. D. (.05) 1, 2 & 2, 3	= .026
	C.D. (.05) 1, 3	= .029	C. D. (.05) 1, 3	= .024	C. D. (.05) 1, 3	= .032

(xii) Thickness of grain:

A significant increase in the thickness of grain in the hybrid was recorded in cross Nos. II & III over the higher parental values. Eventhough a slight increase was recorded in Cross No.I it did not show statistical significance. (Vide Table XIII, Fig. 11).

(xiii) Pollen size:

Pollen grain of the hybrids were smaller in size in all the three cross combinations studied (Vide Table XIV). Fertile pollen grains in the hybrids showed considerable variation in size. The range of variability for mean pollen diameter was 36.14 to 44.00 microns for Cross No. I, 35.77 to 43.91 microns for Cross No. II and 37.20 to 43.20 microns for Cross No. III. In the parental varieties the pollen diameter ranged from 40.96 to 43.58 microns for Vellayani 1, 40.52 to 43.01 microns for Tainan 3, 40.52 to 43.43 microns for Taichung 65, and 39.14 to 41.65 microns for Taichung native 1.

B. Qualitative characters:

A comparative study of qualitative characters in the parental varieties and their hybrids is presented as Table XVII.

(i) Pigmentation:

In cross No. III both the parents were devoid of pigmentation in the leafsheath, whereas in the hybrid the leaf sheath was light purple pigmented.

Table XIV

Mean diameter of pollen grain in microns

Sl. No.	Parent/ hybrid	Mean diameter	Parent/ hybrid	Mean diameter	Parent/ hybrid	Mean diameter
1	Vellayani 1	42.96	Vellayani 1	42.96	Vellayani 1	42.96
2	F_1	39.16	F_1	40.11	F_1	38.79
3	Tainan 3	41.13	Taichung 65	41.89	Taichung Native 1	40.78

C.D. (.05) 1, 2 & 2, 3 = 1.22	C.D. (.05) 1, 2 & 2, 3 = 1.68	C.D. (.05) 1, 2 & 2, 3 = 1.48
C.D. (.05) 1, 3 = 1.42	C.D. (.05) 1, 3 = 1.74	C.D. (.05) 1,3 = 1.73

Table XV

Pollen sterility percentage

Sl. No.	Parent/ hybrid	Pollen sterility	Parent/ hybrid	Pollen sterility	Parent/ hybrid	Pollen sterility
1	Vellayani 1	11.93	Vellayani 1	11.93	Vellayani 1	11.93
2	F_1	60.27	F_1	66.21	F_1	55.75
3	Tainan 3	13.45	Taichung 65	12.54	Taichung Native 1	15.50

C.D. (.05) 1, 2 & 2, 3 = 5.06	C.D. (.05) 1, 2 & 2, 3 = 4.03	C. D. (.05) 1, 2 & 2, 3 = 5.43
C.D. (.05) 1, 3 = 6.16	C.D. (.05) 1, 3 = 4.46	C.D. (.05) 1, 3 = 6.83

TABLE XVI

Spikelet sterility percentage

Sl. No.	Parent/ hybrid	Spikelet sterility	Parent/ hybrid	Spikelet sterility	Parent/ hybrid	Spikelet sterility
1	Vellayani 1	16.44	Vellayani 1	16.44	Vellayani 1	16.44
2	F_1	71.73	F_1	79.20	F_1	63.56
3	Tainan 3	5.69	Taichung 65	8.50	Taichung Native 1	9.07
	C.D.(.05) 1, 2 & 2, 3	= 3.64	C.D. (.05) 1, 2 & 2, 3	= 5.12	C.D. (.05) 1, 2 & 2, 3	= 3.62
	C.D. (.05) 1, 3	= 3.75	C.D. (.05) 1, 3	= 5.32	C. D. (.05) 1, 3	= 4.42

In Cross No.II the hybrid had light purple apiculus though only one of the parents (Taichung 65) possessed this trait.

(ii) Leaf hairiness:

In Crosses I & II where the parents differed in this character the hybrids showed hairiness on the leaves.

(iii) Tillering habit:

Compact tillering habit was found to be dominant over spreading in all the three crosses studied.

(iv) Nature of panicle:

Semi-compact nature of panicle was found to be dominant over compact nature in Cross Nos. I & II.

(v) Spikelet hairiness:

Spikelet hairiness was found to be dominant over non-hairy as seen in Cross Nos. I & II.

(vi) Grain shape:

Grains were found to be medium bold in hybrids of cross Nos. I & II whereas the *japonica* parents had obovate grains suggesting that the medium bold condition is dominant over obovate nature.

(vii) Phenol reaction:

Of the four parents and three hybrids tested, the two *japonica* parents alone were found to be phenol negative (unstained). All the three

Table XVII

Qualitative characters - Parents and hybrids

Cross No.	Parent/ hybrid	Pigmentation		Leaf hairiness	Tillering habit	Nature of panicle	Spikelet hairiness	Grain shape/ size	Phenol reaction
		Leaf sheath	Apiculus						
I	a) Vellayani 1	Green	Green	Hairy	Spreading	Semi compact	Non-hairy	Medium	Changes to black (Phenol positive)
	b) F_1	,,	,,	do	Compact	do	Hairy	Medium bold	do
	c) Tainan 3	,,	,,	Smooth	Compact	Compact	do	Obovate	No change (Phenol negative)
II	a) Vellayani 1	Green	Green	Hairy	Spreading	Semi compact	Non hairy	Medium	Phenol positive
	b) F_1	,,	Purple	do	Compact	do	Hairy	Medium bold	do
	c) Taichung 65	,,	do	Smooth	do	Compact	do	Obovate	Phenol negative
III	a) Vellayani 1	Green	Green	Hairy	Spreading	Semi compact	Non hairy	Medium	Phenol positive
	b) F_1	Light purple	,,	do	Compact	do	do	Medium bold	do
	c) Taichung Native 1	Green	,,	do	Compact	do	do	Medium bold	do

hybrids were phenol positive (stained black) like their indica parents (Vide Plates X to XII)

C. Heterosis:

The degree of positive and negative heterosis for different characters was calculated by taking the higher and lower parental values respectively as the basis. The values are tabulated and presented in Table XVIII.

(i) Productive tillers:

Marked heterosis was recorded in Cross No. II for the number of productive tillers whereas in the other two crosses the hybrids did not differ from the better parent, statistically.

(ii) Length of panicle:

Hybrids in Cross No. I recorded positive heterosis whereas in Cross Nos. II & III the hybrids were on par with the better parents.

(iii) Number of spikelets per panicle:

Cross No. I showed positive heterosis whereas in Cross Nos. II & III the hybrids did not differ from the parents for the number of spikelets per panicle.

(iv) Straw yield:

Marked positive heterosis was recorded for straw yield in cross Nos. I & III whereas in cross No. II heterosis was not significant.

Table XVIII

Degree of heterosis for different characters

Cross No.	Cross	Percentage increase over higher parental value: Productive tillers	Length of panicle	No. of spikelet per panicle	Straw yield	1000 grain weight	Grain size: Length	Breadth	Thickness	% increase over lower parental value: Flowering duration	Pollen size
I	Vellayani 1 x Tainan 3	-	+ 13.42	+ 4.34	+ 44.67	+ 13.56	+2.47	+1.33	-	-7.12	-5.03
II	Vellayani 1 x Taichung 65	+68.35	-	-	-	+ 15.93	+4.25	+1.98	+2.97	-10.82	-4.04
III	Vellayani 1 x Taichung Native 1	-	-	-	+ 41.70	+ 10.47	+3.43	+2.54	+2.51	- 8.92	-4.88

(v) 1000 grain weight:

Positive heterosis was recorded in the hybrids of all the three cross combinations studied for thousand grain weight.

(vi) Length of grain:

Marked positive heterosis for length of grain was recorded in the hybrids of all the three crosses studied.

(vii) Breadth of grain:

The hybrids of all the three cross combinations showed positive heterosis for the breadth of grain.

(viii) Thickness of grain:

Hybrids of cross Nos. II & III recorded marked heterosis for the thickness of grain whereas in the hybrid of Cross No. I heterosis was not significant.

(ix) Flowering duration:

Hybrids in all the three cross combinations were earlier than the early parent and showed negative heterosis for flowering duration.

(x) Pollen size:

Negative heterosis was recorded in the hybrids of all the three cross combinations for pollen size.

D. (1) Hybrid sterility:

Data on pollen and spikelet sterility are tabulated and presented as Tables XV and XVI respectively (Fig.7).

a. Pollen sterility:

The range of pollen sterility observed in the hybrids of the three cross combinations was from 55.75 to 66.21 per cent whereas in the parental varieties the range was as low as 11.93 to 15.50 per cent. No reciprocal difference in pollen sterility was observed in any of the crosses studied.

(i) *Indica* x *japonica*:

The two hybrids Vellayani 1 x Tainan 3 and Vellayani 1 x Taichung 65 recorded 60.27 and 66.21 per cent pollen sterility respectively. The sterility percentage in the parental varieties Vellayani 1, Tainan 3 and Taichung 65, were 11.93, 13.45 and 12.54 respectively.

(ii) *Indica* x *indica*:

The only hybrid (Vellayani 1 x Taichung Native 1) studied under this group showed 55.75 per cent sterility, whereas their parents recorded 11.93 and 15.50 per cent sterility respectively.

Pollen sterility was comparatively more in the two *indica* x *japonica* hybrids than in the *indica* x *indica* hybrid.

b. Spikelet sterility:

Spikelet sterility in the hybrids of the three crosses ranged from 63.56 to 79.20 per cent whereas the range in parental varieties was 5.69 to 16.44 per cent. No reciprocal difference was observed in any of the crosses (Plates XII to XV).

(i) Indica x japonica:

The two crosses Vellayani 1 x Tainan 3 and Vellayani 1 x Taichung 65 showed 71.93 and 79.20 per cent spikelet sterility respectively as against 5.69, 8.50 and 16.44 recorded by the parents Tainan 3, Taichung 65 and Vellayani 1 respectively.

(ii) Indica x indica:

The crosses between Vellayani 1 and Taichung Native 1 recorded 63.56 per cent spikelet sterility as compared to 16.44 and 9.07 per cent respectively shown by their parents.

Spikelet sterility was comparatively more in the two indica x japonica hybrids than in the indica x indica hybrid. It was also found that the hybrids of all the three cross combinations studied, recorded greater percentage of spikelet sterility than pollen sterility.

2. Meiotic studies:

Pollen mother cells of the hybrids of all the three cross combinations were studied to detect meiotic abnormalities. Attention was mainly concentrated on stages such as diakinesis, metaphase I and anaphase I.

Twelve bivalents could be clearly traced in metaphase I in all the hybrids and parental varieties. Separation of Chromosomes in anaphase I was also normal. There was no evidence to suggest meiotic abnormality in these hybrids.

DISCUSSION

DISCUSSION

The present study was made using four rice varieties of which two belong to the *japonica* race (Tainan 3 and Taichung 65) and the other two are *indica* types (Taichung Native 1 and Vellayani 1). Crosses were made using Vellayani 1 as the common parent and the three hybrid combinations were studied along with the four parental varieties. The results obtained are interpreted and presented below.

A. Quantitative characters:

(i) Plant height:

In cross Nos. I and II the tall plant habit of Vellayani 1 was found to be dominant over the medium tall habit of Tainan 3 and Taichung 65. This observation of the dominance of tallness is supported by similar reports by Ramiah (1933 b) and Nandi and Ganguli (1941). However, in the cross with Taichung Native 1 the tall stature of Vellayani 1 showed only incomplete dominance as reported by Jennings (1966).

(ii) Productive tillers:

In all the three crosses studied the mean number of productive tillers per plant in the hybrid was either the same as or more than the high tillering parent. This apparently suggests that the high tillering capacity is inherited as a dominant character. Higher productive tillers in the F_1 hybrids was reported by Ramiah (1953), Parthasarathy (1960), Misro & Shastry (1962) and Jennings (1966).

(iii) Flowering duration:

With respect to duration expressed in terms of number of days to flowering the hybrids in all the three crosses were found to be earlier than the respective parental varieties. The early flowering habit of inter-varietal hybrids in rice was previously reported by Ramiah (1933 a) and Jennings (1966).

(iv) Panicle exsertion:

The well exserted nature of panicle was found to be incompletely dominant over exserted nature as seen in Cross No. III.

(v) Length of panicle:

In all the three crosses the hybrids produced panicles as long as or longer than the better parent, thereby suggesting that the long panicle condition is a dominant character. This observation is comparable to the report made by Mohammed and Hanna (1965) that longer length of panicle shows partial dominance over shorter one.

(vi) Number of spikelets per panicle:

In cross No. I the hybrid was on par with the superior parent (Vellayani 1) for the number of spikelets per panicle. In Crosses II & III also the mean values of the hybrids were higher than the lower parental values, though the increase was not statistically significant. Increase in number of spikelets in rice hybrids was reported by Rao (1965) and Narahari & Pawar (1965).

(vii) Grain and straw yield:

In inter-varietal hybrids of rice where there is marked spikelet sterility, a reduction in grain yield is normally expected. The inferior grain yield of rice hybrids was reported by Parthasarathy (1960). On the other hand, Jennings (1966) reported that normally fertile hybrids showed higher grain yield. The decrease in grain yield per plant recorded by the hybrids of all the three crosses studied could also be attributed to high spikelet sterility. However, the degree of decrease was not proportional to the extent of spikelet sterility; the reduction in number of grains being to some extent compensated by the increase in grain size.

In two out of three crosses (Crosses I and III) the hybrids gave significantly higher straw yields than the better parent whereas in Cross No.II the increased straw yield of the hybrid was not statistically significant. The higher straw yield could be sonsidered to be due to greater vigour in plant growth and high tillering capacity in the hybrids. Joseph (1962), Karunakaran (1964) and Rao (1965) recorded increased straw yield in rice hybrids.

(viii) Grain size and 1000 grain weight:

Grain size in the hybrid was found to be significantly larger in all the three crosses. This increase in the grain size was through an increase in grain measurements in all the three dimensions (length, breadth and thickness). This observation is not in agreement with the reports of Nagai (1959) that the mean size of kernels in the F_1 is intermediate between the parents. Jennings (1966) reported that the length of F_1 grain was intermediate between the parental mean. It is quite reasonable to assume that the reduction in the number of fertile grains in the panicle might have lead to the development of bigger grains. The hybrids were also found to be superior with respect to 1000 grain weight. This increase in grain weight is most probably due to the increase in grain size.

(ix) Pollen size:

Pollen size was represented as the mean diameter of a pollen grain. The hybrids of all the three crosses produced smaller sized fertile pollen. In all the hybrids fertile pollen grains were found to show considerable variation in size. The range of variability for mean pollen diameter was much more in the hybrids than that in the respective parental varieties. This observation is in confirmity with the report of Sampath (1964) that the pollen from japonica x indica hybrids varied in size. It was also observed that variability in the two japonica x indica hybrids (Crosses I & II) was more than in the indica x indica hybrids (Cross No.III). Such variability in size of pollen grains in the inter-varietal rice hybrids was recorded by Rao (1964).

B. Inheritance of qualitative characters:

(i) Pigmentation:

The dominant nature of anthocyanin pigmentation of plant parts is indicated in the cross between Vellayani 1 and Taichung 65 (Cross No.II) wherein the hybrid and one of the parents (Taichung 65) are pigmented in the apiculus. Apiculus pigmentation was thus found to be completely dominant over the non-pigmented condition. This is in confirmity with the findings of Misro & Sampath (1964) and Jennings (1966).

In the hybrid of cross between Vellayani 1 and Taichung Native 1 anthocyanin pigmentation was found in the leaf sheath whereas both the parents did not show any sign of pigmentation. The development of pigmentation in the hybrid can be the result of complementary interaction between genes in the two parents. This observation is in agreement with other reports on the existence of complementary genes governing anthocyanin pigmentation in leaf sheath, auricle and other plant parts (Anon.1953).

(ii) Hairiness of leaf and grain:

Hairiness of leaves in Vellayani 1 was found to be dominant over the smooth nature in two crosses studied. Dominance of hairiness over glabrousness was reported by Jennings (1966). Hairiness of grains of the *japonica* varieties (Tainan 3 and Taichung 65) was found to be dominant over the non-hairy condition of Vellayani 1. This is comparable to the reports made by Nagao et al. (1960), Misro & Sampath (1964) and Jennings (1966) that hairiness in glumes is dominant over glabrousness.

(iii) Phenol reaction:

Among the parental varieties the *japonica* types (Tainan 3 and Taichung 65) were phenol negative whereas the *indica* types (Vellayani 1 and Taichung Native 1) were phenol positive. This favours the view of Oka (1953) that the 'Continental' forms (*indica types*) are phenol positive and the 'insular' forms (*japonica* types) are phenol negative. It was found that in crosses between phenol positive and phenol negative types (Crosses I & II) the hybrids were phenol positive thereby suggesting that the phenol positive reaction of *indica* varieties is dominant over phenol negative reaction of the *japonica* varieties. This observation is in confirmity with the report of Jennings (1966) that phenol staining is a simply inherited dominant to nonstaining.

C. Heterosis:

In all the crosses the hybrids showed positive heterosis for characters such as 1000 grain weight and length and breadth of grains. Heterosis for characters such as number of productive tillers, length of panicle, number of spikelets per panicle, grain thickness and straw yield was shown by some of the crosses. With respect to straw yield the heterotic effect was marked in the hybrids of Cross I and III giving 44.67 and 41.70 per cent increase respectively over the better parents. Heterosis for different plant characters was reported by several workers on rice - Ramiah (1935, 53), Namboodiri (1963) and Jennings (1966) for tiller production, Capinpin & Punyasingh (1938) for panicle length, Capinpin and Amaba (1949) for grain length, Parthasarathy (1960) and Misro & Shastry (1962) for number of ear heads per plant and Namboodiri (1963) for length of panicle and breadth and thickness of grain. Karunakaran (1964) recorded heterosis in intervarietal hybrids of rice for several characters such as straw yield, panicle length, 1000 grain weight, breadth of grain, thickness of grain and number of tillers per plant. Rao (1965) recorded heterosis for productive tillers, number of grains per panicle and straw yield. On the contrary Capinpin & Punyasingh (1938) did not find heterosis for grain characters such as length, breadth and thickness.

Hybrids in all the three crosses were earlier in flowering than the early parent and produced pollen grains of smaller size than both the parents, thereby suggesting negative heterosis for flowering duration and pollen size. The earlier flowering habit of the hybrids of the inter-varietal crosses in rice was reported by several workers like Ramiah (1935, 53) and Jennings (1966).

D. Sterility:

All the three hybrids were found to be partially sterile and percentage of spikelet sterility was always more than the percentage of pollen sterility. This is in agreement with the report of Karunakaran (1964) that spikelet sterility was more than pollen sterility in *japonica* x *indica* hybrids, but does not agree with that of Jennings (1966) who did not observe large differences in pollen and spikelet fertility. The higher spikelet sterility can be possibly due to degeneration of zygotes in addition to ovule sterility.

The degree of pollen and spikelet sterility varied slightly in the hybrids of the three crosses. Such variations in hybrid sterility were recorded by several workers like Richharia *et al.* (1962) and Sampath (1963). It was also found that the degree of both pollen and spikelet sterility was more in the two *japonica* x *indica* hybrids (Crosses I & II) than in the *indica* x *indica* hybrid (Cross III).

No reciprocal difference was observed in either pollen or spikelet sterility in any of the crosses studied which is in confirmity with the findings of Jennings (1966) that there is no large reciprocal differences for either pollen or spikelet fertility.

The inter-varietal hybrids studied did not provide any indication for cytological abnormalities during meiosis. Metaphase I was normal with 12 bivalents and anaphase I separation also was apparently normal. These observations are in agreement with the findings of Terao & Mizushima (1939), Jones & Longly (1941), Kuang (1951), Sampath & Mohanty (1954) and Kihara (1966).

The absence of meiotic abnormalities in stages later than diakinesis eliminates the possibility of large chromosome abnormalities to be the cause of partial sterility in these intervarietal hybrids. It appears reasonable to suggest that partial sterility might be either due to genic causes or due to cryptic structural hybridity. The possibility of ~~of~~ cytoplasmic factors contributing to sterility is eliminated due to the lack of reciprocal differences in the degree of sterility.

SUMMARY

SUMMARY AND CONCLUSION

The present study involves the inter-varietal hybridization between two *indica* (Vellayani 1 and Taichung Native 1) and two *japonica* (Tainan 3 and Taichung 65) varieties of rice using Vellayani 1 as the common parent and investigations of quantitative and qualitative characters, hybrid sterility and heterosis of the F1 generation in the three cross combinations.

1. Among the quantitative characters studied, plant height, high tillering habit, earliness in flowering, panicle exsertion and long panicle nature were found to be dominant in the hybrids.

2. The nature of anthocyanin pigmentation in the apiculus was found to be dominant.

In one of the three crosses the possible interaction of complementary genes governing pigmentation in the leaf sheath was indicated.

Hairiness of leaves as well as grains was found to be dominant in the hybrids.

The "Phenol positive" reaction of the *indica* varieties was found to be dominant over "phenol negative" reaction of the *japonicas*.

3. The hybrids showed decrease in grain yield and increase in straw yield. The decrease in grain yield was due to the high spikelet sterility. However, the degree of decrease in grain yield was not proportional to the extent of spikelet sterility, the reduction in

number of grains being to some extent compensated by the increase in grain size and weight.

4. Uniform positive heterosis in all the three crosses studied was obtained for 1000 grain weight and length and breadth of grains. All the three crosses showed negative heterosis for flowering duration and pollen size. Heterosis for other characters such as number of productive tillers, length of panicle, number of spikelets per panicle, grain thickness and straw yield was shown only by some of the crosses.

Among the three cross-combinations studied Velleyani 1 x Tainan 3 exhibited positive heterosis for most of the important yield attributes viz., panicle length, number of spikelets per panicle, straw yield, 1000 grain weight and length and breadth of grains, combined with marked earliness for flowering. Though this hybrid did not show an increased yield due to high percentage of spikelet sterility high yielding fertile segregants from this cross in later generations could be expected.

5. All the three crosses exhibited pollen and spikelet sterility to a marked extent, spikelet sterility always being more than pollen sterility. The _indica_ x _japonica_ crosses invariably recorded higher percentage of pollen and spikelet sterility.

The sterility in the inter-varietal hybrids in the present study could not be attributed to any major cytological abnormalities.

Hence, it appears reasonable to suggest that partial sterility may be either due to genic causes or due to cryptic structural hybridity. The possibility of cytoplasmic factors contributing to sterility is eliminated due to the lack of reciprocal differences in the degree of sterility.

LITERATURE CITED

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Anonymous 1953 Ann. Rep. C.R.R.I. Cuttack, 1949-1953

________ 1964 Ann. Rep. Internat. Rice Research Institute., 22-26.

Bhide, R.K. 1926 Inheritance and correlation of certain characters in rice crosses. Poona Agri. Coll. Mag., 18: 78-85 (Quoted by Ramiah, 1953).

Brown, F.B. 1955 Rice hybridization in Malaya. News Lett. FAO. Internat. Rice Comm. 15: 6-11.

Capinpin, J.M. and Punyasingh, K. 1938 A study of varietal crosses and hybrid vigour in rice. Philipp. Agrst. 27: 255-77.

________ and Amaba, R.M. 1949 Morphology and heredity of caryopsis characters in Inangel rice. Philipp. Agrst., 33: 51-62.

Chakravarthy, S.C. 1938 Rept. Rice Res. Sta., Chinsurah (Bengal), 1938-1939 (Quoted by Ghosh et al. 1960)

Chaisang, K 1961 Studies on anthesis, pollination and hybridization techniques in rice (O. sativa Linn.) Dessertation approved for M.Sc.(Ag.) degree of Madras University (Unpub.)

Chalam, G.V. and Venkateswarlu, J 1965 Agr. Botany in India I: 82-179. Asia publishing house, Calcutta.

Chang, T.T. and Bardenas, E.A. 1965 The morphological and varietal characteristic of the rice plant. Internat. Rice. Res. Instt., Tech. Bullt. 4: 20.

Chang, T.T. 1963 Present knowledge of rice genetics and cytogenetics Internat. Rice. Res. Instt. Tech. Bullt. I.

Cua, L.D. 1952 Artificial polyploidy in the Oryzeae III. Cytogenetical studies on intra and inter subspecies tetraploid hybrids in Oryza sativa L. Rep. Kihara. Inst. Biol. Res., 2: 42 - 53. P.B.A. 24: Abst. No.347.

Ghose, R.L.M., Ghatge, M.B. and Subrahmanyan, V. 1960 Rice in India. I.C.A.R. New Delhi.

Hector, C.P. 1922 Correlation of colour characters in rice. Mem. Agri. Ind. Bot. Sur. 11: 153-83. (Quoted by Ramiah, 1953)

Heish, S.C. and Oka, H.I 1958 Cytological studies of sterility in hybrids between distantly related varieties of rice; O. sativa L. Jap. J. Genet., 33: 73-80.

Henderson, M.T. 1964 Cytogenetics studies Louisiana Agrl. Expt. Station on the nature of hybrids sterility in O. sativa. Proc. Symp. Rice Genet. Cytogenet. 1963: 147-153. Elsevier, Amsterdam.

Yeh, B.P. and Exner, B. 1959 Further evidence of structural differentiation in the chromosomes as a cause of sterility in inter-varietal hybrids of rice, Oryza sativa L. Cytologia, 24: (4): 415-422 (Quoted by Chang, 1963)

Hsu, K.J. 1945 On sterility resulting from crossing of different types of rice. Indian. J. Genet., 5: 51-57.

Hutchinson, J.B. Ramiah, K., and others. 1938 The description of crop plant characters and their ranges in variation, II. Variability in rice Ind. J. Agric. Sci., 8: 592-616.

Idsumi, Y	1936	Investigations in heterosis in rice plants. P.B.A. 7: Abst., 1265.
Jennings, P.R.	1966	Evaluation of partial sterility in indica x japonica rice hybrids. Internat. Rice. Res. Instt. Tech. Bullt. 5 Losbanos, Philippines.
Jones, J.W.	1926	Hybrid vigour in rice - J. Amer. Soc. Agron., 18: 423-28.
________ and Longley, A.F.	1941	sterility and aberrant chromosome number in Caloro and other varieties of rice. J. Agri.Res., 62: 381-401. (Quoted by Ramiah 1953).
Joseph, C.A.	1962	Studies on certain hybrids in the genous Oryza, Dissertation approved for M.Sc.(Ag.) degree of Madras University (Unpub.)
Juachon, P.B.	1932	Inbreeding experiment with Hambas rice variety. P.B.A.3: Abst. 83.
Kadam, B.S.	1937	Heterosis in rice, Ind. J. agri. Sci., 7: 118-26.
________ and D' Cruz, R.	1960	Genic analysis in rice - III. Inheritance of some characters in two clustered varieties of rice. Ind. J. Gent. Plant Breeding 20: 79-83.
Karunakaran, K.	1964	Studies in some varieties and Inter-racial hybrids of Oryza sativa Linn. Dissertation approved for M.Sc.(Ag.) degree of Madras University.
Kato, S.	1930	On the affinity of cultivated varieties of rice plant, Oryza sativa L. J. Dep. Agri. Kyushu Imp. Univ. 2:241-76.

Kato, S., Osaka, H.K. and Hara, S.	1928	On the affinity of rice varieties as shown by fertility of hybrid plants. Rep. Bull. Sci. Fak. Terkutt., Kyushu. Imp. Univ. Japan 3: 131-147.
Kihara, H.	1966	Genone analysis in the genus Oryza News. lett. FAO. Internat. Rice Comm. 15: I
Kitamura, E.	1962	Studies on cytoplasmic sterility in hybrids between distantly related varieties. I. The ferility of direct and reciprocal F_1 hybrids between breeding lines from hybrids between Philippine and Japanese rices, on the one hand and Japanese rices on the other. Jap.J. Breed. 12: 81-84 (Quoted by Karunakaran, 1964)
Koernicke	1885	Cited by Morinaga 1954.
Kuang, H.H	1951	Study on rice cytology and genetics as well as breeding work in China. Agron. J., 43: 387-397.
________ and Tu, D.S.	1949	Studies on rice cytology and genetics as well as breeding work in China. Agron. J., 41: 195-199.
Majid, S.	1939	Ann. Rept. Deep water Rice Res. Sta., Habibganj, Assam, 1938-1939 (Quoted by Ghosh et al. 1960)
Mello-Sampayo, T.	1952	An inversion occurring in an F_1 hybrid between two strains of Oryza sativa L. Genetica iberica 4: 43:46. (Quoted by Shastry and Misra, 1961)
Misro, B and Sampath, S.	1964	Tech. Report (1964) C.R.R.I (Unpublished)

Misro, B., and Shastry, S.V.S. 1962 Observations on inter-racial (japonica x indica) crosses of rice (Oryza sativa L.) I Heterosis. Proc. Bihar Acad. Agri. Sc. VIII & IX: 42-54.

Mitra, S.K., and Ganfuli, P.M. 1938 Inheritance of size and shape of grain in rice. Proc. 25th Indian Sci.Congr. (Abst.) 13 (Quoted by Ghose et al.1960)

Mohommed,A.H., and Hanna, A.S. 1965 Inheritance of quantitative characters in rice; II inheritance of panicle length. Canad. J. Genet. Cyt. (1965) P.B.A. 36: 2

Morinaga, T. 1954 Classification of rice varieties on the basis of affinity. Jap. J. Breed. 4: 1-14.

Nagai, I. 1959 Japonica rice: Its Breeding and Culture. Yokendo Ltd., Tokyo.

Nagao,S. and Takahashi 1941 Studies on hybridization of rice, II Heterosis in the crosses between the strains of Hokkaido, considered from the stand point of strain phylogeny P.B.A. 21: Abst. 353.

Takahashi and Kinoshita, T. 1960 Genetical studies on rice plant,XXV. Inheritance of 3 morphological characters pubescence of leaves and floral glumes and deformation of empty glumes. J. Fac. Agri. Hokkaido Univ. 1960:51:299-314. (P.B.A. 31)

Namboodiri, K.M.N 1963 Hybrid vigour in rice Rice News Teller, 11: 4: 92-96.

Nandi, H.K. and Ganguli, P.M. 1941 Inheritance of height of plants in Soil paddy. Proc. 29th Indian Sci. Congr. Abst. 34 (Agriculture) (Quoted by Ghoshi et al. 1960)

Narahari, P. and Pawar, M.S.	1965	Inter-racial hybrids of *indica* x *japonica* rices and their performance in advanced generation. *Ind. J. agric. Sci.* (965): *35*:259-71 *P.B.A. 36*: Abst.
Oka, H.I.	1963	Variation of various characters and character combinations among rice varieties. *Jap. J. Breed.*, *3*: 33-43.
————	1956	Complementary dominant lethal genes in rice *Ann. Rep. Nat. Inst. Genet.* Japan., No. *7*: 37-38.
————	1958	Inter-varietal variation and classification of cultivated rice. *Indian. J. Genet.*, *18*: 79-89.
————	1964	Consideration on the genetic basis of inter-varietal sterility in *Oryza sativa* *Proc. Symp. Rice Genet.*, *Cytogenet.* 1963 158-174. Elsevier, Amsterdam.
Opsomer, J.E.	1942	Contribution to the study of heterosis in rice *P.B.A. 17*: Abst., 717.
Parnel, F.R., Rengaswamy Ayyangar, G.N, and Ramiah, K.	1917	Inheritance of characters in rice I *Mem. Dept. Agri. Inst. Bot. Scr.*, *9*:75-105.
Parthasarathy, N.	1960	Final report on the International rice hybridization project. *News. Lett. FAO. Internat. Rice Comm.* *9*: 12-23.
Ramiah, K.	1930	The inheritance of characters in rice Part III. *Mem. Dept. Agric. Ind. Bot. Ser.* *18*: 211-17.
————	1932	*Madras Agri. Sta. Rept.* (1931-32)

Ramiah, K.	1933 a	Inheritance of flowering duration. Indian J. Agri. Sci., 3: 377-410
________	1933 b	Inheritance of height of plant in rice. Indian J.Agri.Sci., 3: 411-432.
________	1935	Rice genetics Proc. Assoc. Econ. Biol. Coimbatore., 3: 51-61. (Quoted by Ghosh et al. 1960)
________	1953	Rice Breeding and Genetics I.C.A.R. New Delhi, Monograph No. 19.
________	1961	Rice Genetics. Foundation lecture delivered at the Post Graduate Training Centre (Unpublished), Coimbatore
________ and Parthasarathy, N.	1933	Inheritance of grain length in rice (Oryza sativa L.) Indian J. Agri.Sci. 3: 808-819.
Rao, G.M.	1964	Studies on sterility in inter-racial hybrids of rice (Oryza sativa L.) Andhra agric. J. 11: (6): 256-71.
________	1965	Studies on hybrid vigour in inter-racial hybrids of rice (Oryza sativa Linn.) Andhra agric. J. 7 (1): 1-12.
Richharia, R.H. and Misro, B.	1959	The japonica - indica hybridization project in rice. An attempt for increased rice production. J. Biol. Sci., 2: 35-47.
Misro, B. and Rao, R.K.	1962	Sterility in rice hybrids and its significance. Euphytica, 11: 137-142.
Sampath, S.	1959	Effect of semi sterility in breeding from indica x japonica hybrid. Rice News. Teller. 7: 16-17.
________	1964	Significance of hybrid sterility in rice, Proc. Symp. Rice Genet. cytogenet. 1963: 175-188. Elsevier, Amsterdam.

Sampath, S., and Mohanty, H.K.	1954	Cytology of semi sterile rice hybrids. Curr. Sci., 23: 182-183.
______ and Seetharaman, R.	1962	The formation of geographical races in the cultivated rice, Oryza sativa Rice News Teller, 10: 17-19.
Sethi, R.L., Sethi, B.L., and Mehta, T.R.	1936	Inheritance of earliness in United provinces rices. Indian J. Agri.Sci. 6:1246-1274.
Shastry, S.V.S.	1964	Is sterility genic in japonica - indica rice hybrids? proc. Symp. Rice Genet. Cytogenet. 1963: 154-157. Elsevier, Amsterdam.
Shastry, S.V.S., and Misra, R.N.	1961	Pachytene analysis in Oryza II Sterility japonica - indica rice hybrids. Chromosoma (Berl.) 12: 248-271.
Terao, T, and Mizushima, U.	1939	Some considerations on the classification of Oryza sativa L. Jap. J. Bot. 10: 213-258.
Venkataswamy, T.	1957	Genetical and cytological studies of sterility in inter-racial hybrids of rice (Oryza sativa L.) unpublished thesis I.A.R.I.
______	1964	Inheritance of certain morphological characters in relation to hybrid sterility in inter-racial crosses of rice (Oryza sativa L.) Andhra agric. J. 11: 5: 161-72.
Yao, S.Y., Henderson, M.T. and Jodon, N.E.	1958	Cryptic structural hybridity as a probably cause of sterility in inter-varietal hybrids of rice Oryza sativa L. Cytologia, 23: 46-55.
Yamaguchi, H.S., and Kimura, H.S.	1958	On inter-varietal variation in some characters of the kinds of upland rice commonly grown in Japan. Jap.J. Breed., 7: 241-46.

Appendix

Analysis of variance table

(a) Plant height

Crosses	I		II		III	
Source	df	Variance	df	Variance	df	Variance
Treatment	2	1440.33**	2	2470.90**	2	5247.90**
Error	38	26.77	28	60.61	47	33.63

Analysis of variance table

(b) Productive tillers

Cross	I		II		III	
Source	df	Variance	df	Variance	df	Variance
Treatments	2	695.29**	2	2939.34**	2	3093.90**
Error	38	208.82	28	554.72	47	435.21

Analysis of variance table

(c) Flowering duration

Cross	I		II		III	
Source	df	Variance	df	Variance	df	Variance
Treatments	2	936.33**	2	607.55**	2	861.31**
Error	38	8.71	28	11.21	47	20.82

** F ratio .. Significant at 1% level

Analysis of variance table

(d) Panicle exsertion

Cross	I		II		III	
Source	df	Variance	df	Variance	df	Variance
Treatments	2	18.54**	2	39.01**	2	55.54**
Error	38	2.69	28	5.89	47	0.63

Analysis of variance table

(e) Length of panicle

Cross	I		II		III	
Source	df	Variance	df	Variance	df	Variance
Treatments	2	52.07**	2	9.50**	2	23.96**
Error	38	2.84	28	2.18	47	2.18

Analysis of variance table

(f) No. of spikelets per panicle

Cross	I		II		III	
Source	df	Variance	df	Variance	df	Variance
Treatments	2	50.27**	2	1387.95**	2	2597.90
Error	38	4.01	28	346.28	47	403.50

** F ratio corresponding to this is significant at 1% level

Analysis of variance table

(g) Grain yield per plant

Cross	I		II		III	
Source	df	Variance	df	Variance	df	Variance
Treatment	2	3389.25**	2	161.34**	2	987.95**
Error	38	10.50	28	24.92	47	125.95

Analysis of variance table

(h) Straw yield per plant

Cross	I		II		III	
Source	df	Variance	df	Variance	df	Variance
Treatments	2	11575.57**	2	3683.55	2	12739.00
Error	38	402.42	28	1463.64	47	454.94

Analysis of variance table

(i) 1000 grain weight

Cross	I		II		III	
Source	df	Variance	df	Variance	df	Variance
Treatments	2	110.01**	2	83.70**	2	72.17**
Error	38	0.78	28	16.28	47	0.84

** F ratio corresponding to this is significant at 1% level

Analysis of variance table

(j) Grain length

Cross	I		II		III	
Source	df	Variance	df	Variance	df	Variance
Treatments	2	3.89	2	2.40^{**}	2	0.24^{**}
Error	36	0.016	28	0.014	47	0.015

Analysis of variance table

(k) Grain breadth

Cross	I		II		III	
Source	df	Variance	df	Variance	df	Variance
Treatments	2	0.5900^{**}	2	0.6250^{**}	2	0.2500^{**}
Error	36	0.0026	28	0.0025	47	0.0117

Analysis of variance table

(l) Grain thickness

Cross	I		II		III	
Source	df	Variance	df	Variance	df	Variance
Treatments	2	0.11^{**}	2	0.1200^{**}	2	0.0550^{**}
Error	36	0.001	28	0.0007	47	0.0013

F ratio corresponding to this is significant at 1% level

Analysis of variance table

(m) Pollen size

Cross	I		II		III	
Source	df	Variance	df	Variance	df	Variance
Treatments	2	51.11**	2	21.71**	2	60.63**
Error	38	2.46	28	3.69	47	3.94

Analysis of variance table

(n) Pollen sterility

Cross	I		II		III	
Source	df	Variance	df	Variance	df	Variance
Treatments	2	11601.42**	2	10337.26**	2	10637.44**
Error	38	46.49	28	23.83	47	58.15

Analysis of variance table

(o) Spikelet sterility

Cross	I		II		III	
Source	df	Variance	df	Variance	df	Variance
Treatments	2	18952.06	2	15959.00	2	15624.60**
Error	38	17.09	28	33.51	47	24.51

** F ratio corresponding to this is significant at 1% level.

PLATE I

Photograph of hybrid Vallayani 1 x Tainan 3 with parents

(Cross No. I)

PLATE II

Photograph of hybrid Tainan 3 x Vellayani 1 with parents

(Receprocal cross)

PLATE I

PLATE II

PLATE III

Photograph of hybrid Vellayani 1 x Taichung 65 with parents

(Cross No. II)

PLATE IV

Photograph of hybrid Taichung 65 x Vellayani 1 with parents

(Reciprocal Cross)

PLATE III

PLATE IV

PLATE V

Photograph of hybrid Vellayani 1 X Taichung Native 1 with parents

(Cross No. III)

PLATE VI

Photograph of hybrid Taichung Native 1 x Vellayani 1 with parents

(Reciprocal cross)

PLATE V

PLATE VII

Photograph showing the length of panicles in parents and hybrid in cross between Tainan3x Vellayani 1 (Cross No.I)

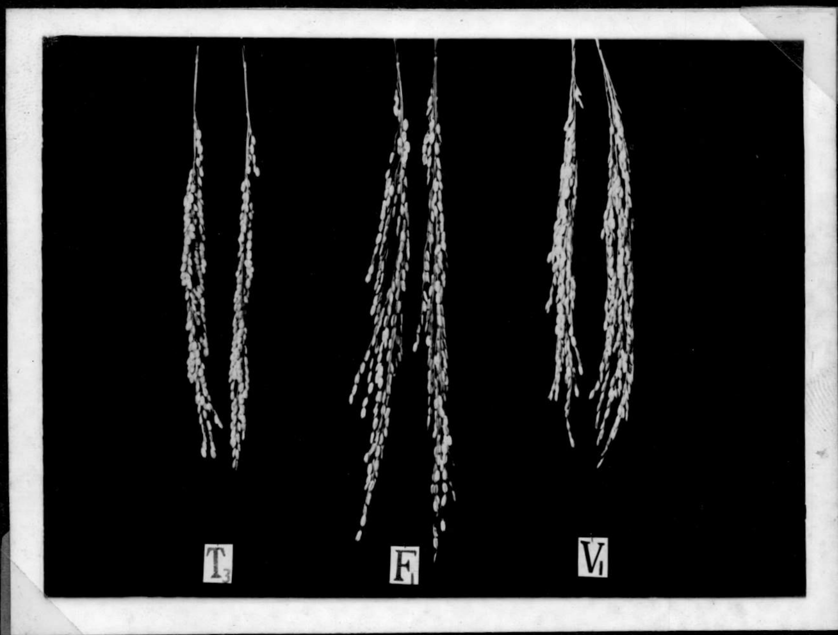

PLATE VII

PLATE VIII

Photograph showing length of panicles in parents and hybrid in cross between Taichung 65 x Vellayani 1 (Cross No.II)

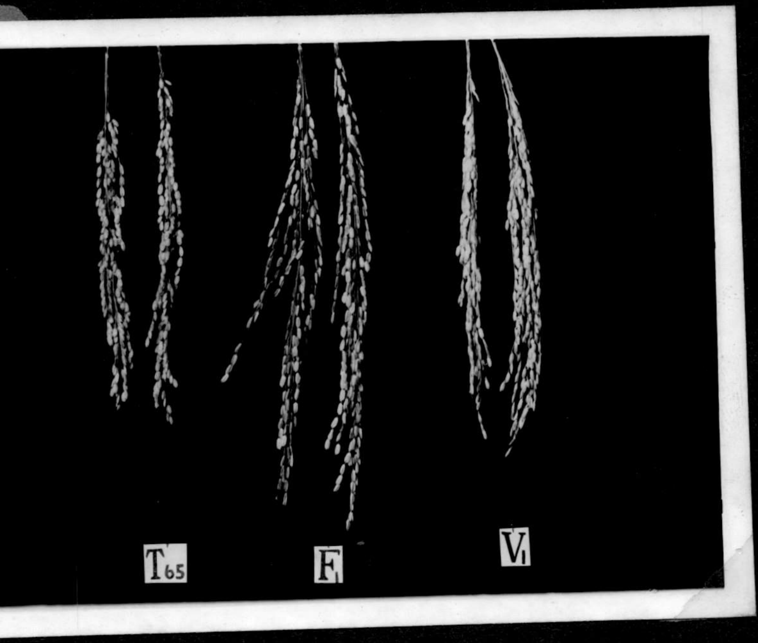

PLATE VIII

PLATE IX

Photograph showing length of panicles in parents and hybrid in cross between Taichung Native 1 x Vellayani 1 (Cross No.III)

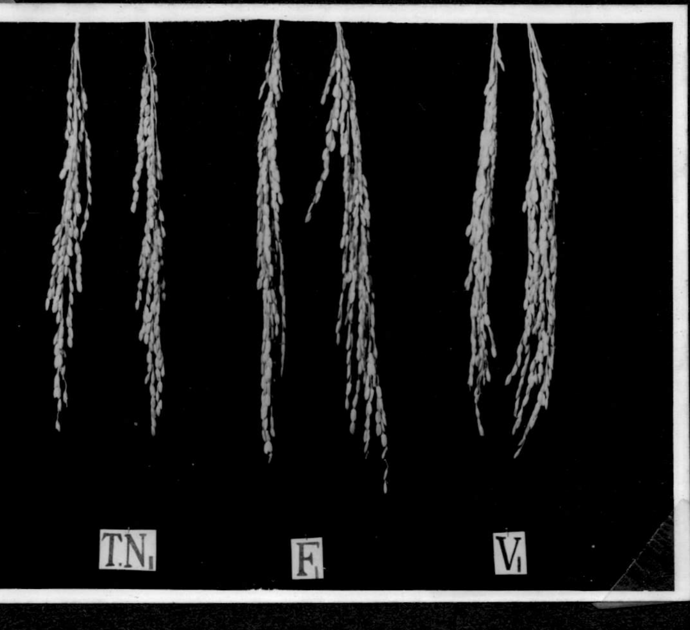

PLATE IX

Phenol reaction of the different parents and hybrids studied. Note the positive reaction (Colour change) in _indica_ varieties and the hybrids and the negative reaction (no colour change) in _japonica_ varieties.

PLATE X

Vellayani 1 x Tainan 3
(Cross No. 1)

PLATE XI

Vellayani 1 x Taichung 65
(Cross No.II)

PLATE XII

Vellayani 1 x Taichung Native 1
(Cross No. III)

1. Direct cross
2. Reciprocal cross

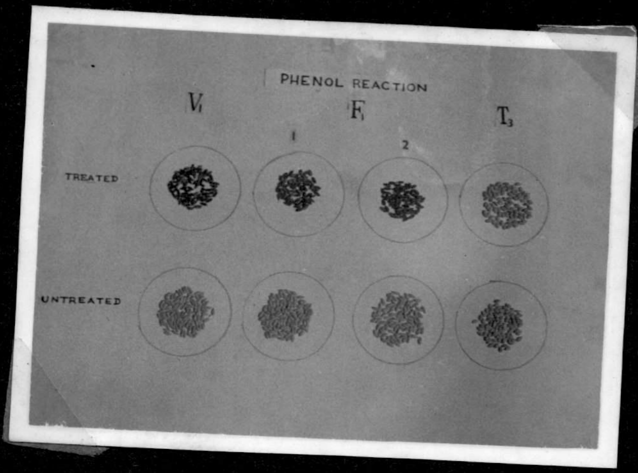

PLATE X

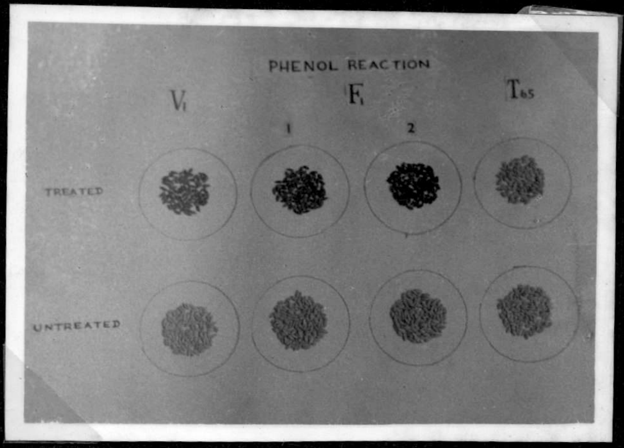

PLATE XI

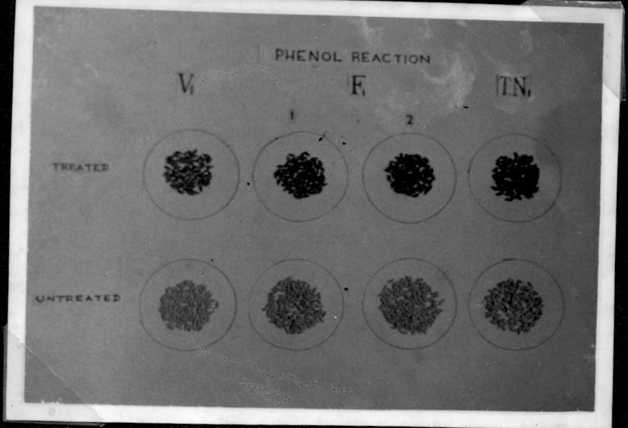

PLATE XII

Colour photograph of panicles of parents and hybrids showing the range of spikelet sterility.

PLATE XIII

Vellayani 1 x Tainan 3
(Cross No. I)

PLATE XIV

Vellayani 1 x Taichung 65
(Cross No. II)

PLATE XV

Vellayani 1 x Taichung Native 1
(Cross No. III)

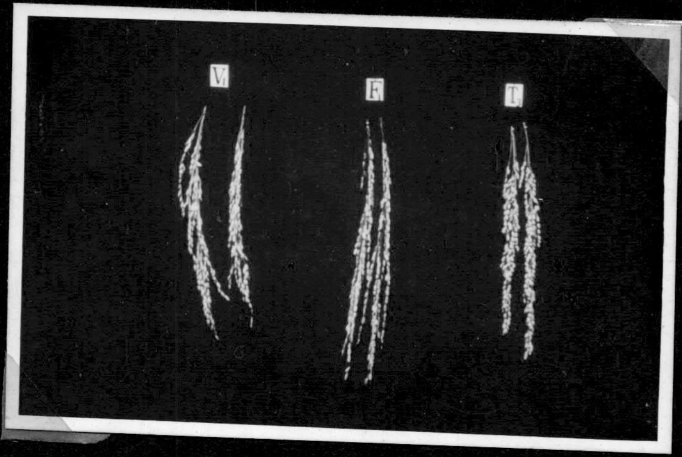

PLATE XIII

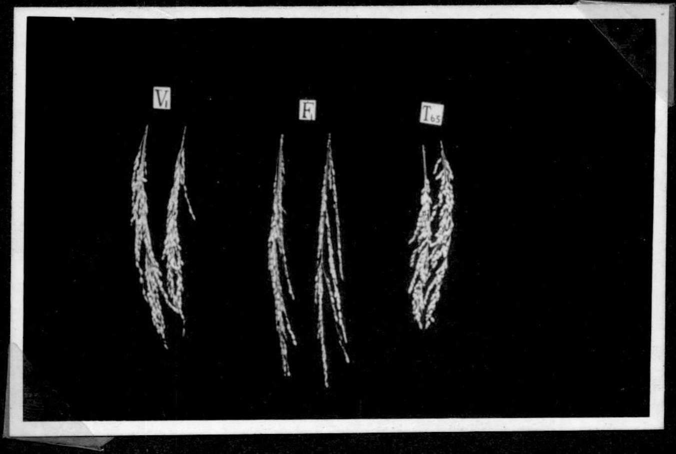

PLATE XIV

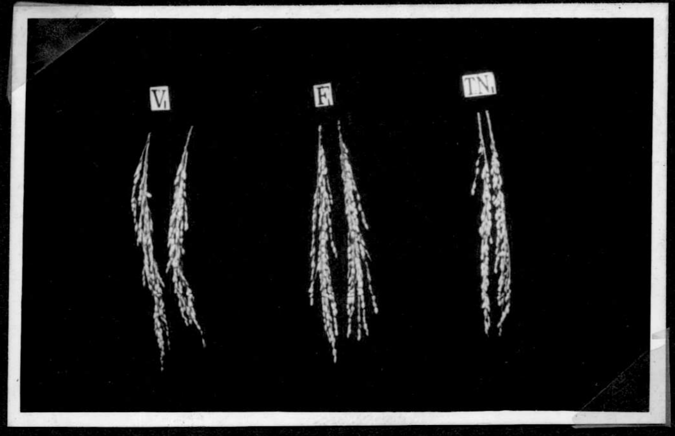

PLATE XV