GENETIC STUDIES ON INDUCED VIABLE MUTANTS IN RICE
(*Oryza sativa* L.)

By

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THESIS
submitted in partial fulfilment of the requirements
for the degree of
DOCTOR OF PHILOSOPHY
Faculty of Agriculture
Kerala Agricultural University

Department of Plant Breeding
COLLEGE OF AGRICULTURE
Vellayani, Trivandrum

1985

DECLARATION

I hereby declare that this thesis entitled "Genetic studies on induced viable mutants in rice (Oryza sativa L.)" is a bona fide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar titles of any other University or Society.

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Vellayani,
18-3-1985.

CERTIFICATE

Certified that this thesis entitled "Genetic studies on induced viable mutants in rice (*Oryza sativa* L.)" is a record of research work done independently by Sri. P.D. Vijayagopal, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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ACKNOWLEDGEMENTS

The author records his sincere gratitude to Dr. V. Gopinathan Nair, Professor and Head of the Department of Plant Breeding, College of Agriculture, Vellayani for suggesting the problem and for the able supervision, valuable guidance, timely help and constant encouragement in planning and executing the research and for the preparation of this thesis.

The author is indebted to Dr. N. Mohanakumaran, Associate Director (NARP-SR); Dr. V.K. Sasidhar, Professor of Agronomy and Dr. R. Gopimony, Associate Professor of Plant Breeding for going through the manuscript and making useful suggestions. He is also thankful to Dr. R. Subramonia Aiyer, Professor & Head, Department of Soil Science and Agricultural Chemistry as a member of Advisory Committee.

Sincere thanks are due to all his colleagues in the Departments of Agricultural Botany and Plant Breeding for their timely help at the various stages of this investigation.

The author's greatest debts are to his wife Somavalli and children, Biju and Bindu for their understanding and continuous encouragement without which this work would not have been completed.

(P.D. VIJAYAGOPAL)

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

INTRODUCTION

The use of semidwarfs, undoubtedly, is the most brilliant success in the area of rice breeding. The realisation that response to fertilizer application was more a morphological than a physiological phenomenon (Swaminathan, 1966a) led to a wide spread search for genes in cereal crops which decide the ideal plant type. In rice, the plant type concept has materialised after the identification of Dee-geo-woo-gen and the development of Taichung Native-1 in Taiwan. Jennings (1964) viewed the ideal plant type in rice for the tropics as one with erect, short, thick, dark green leaves and short sturdy stem. Many others have also described the ideal plant type suited to the tropics with slight alterations. The plant type concept has thus been changing with the changing requirements and breeding objectives.

The introduction of Taichung Native-1 and IR-8 into India established the plant type concept in the country. The terminology has come to stay in association with nonlodging, short plant stature and short, erect, dark green leaves. It has enabled the genetic destruction of yield barriers in rice and has been responsible for a breakthrough in rice production in many South East Asian countries including India. However, the large scale cultivation of the dwarf varieties raised hopes and fears; hopes for the fact that yields of the order unknown earlier could be realised under proper management and fears on account of their susceptibility to major pests and diseases.

During the past two decades, nearly 150 semidwarf rice varieties of different duration, productivity and grain quality have been released in India for commercial planting. These semidwarf rice varieties, at the present, occupy nearly 30% of the total rice area in the Country. Virtually all of them, including IR-8 and Taichung Native-1, have a common source of dwarfism derived from Dee-geo-woo-gen despite differences in the donor varieties. This simply inherited dwarfing gene not only shortens the culm length; but also brings about several other changes such as stiff straw; short, erect, dark green leaves and increased tillering. It thereby modifies the plant architecture as well as physiological properties. With a single gene dominating large crop areas, there is a potential danger of genetic narrowness. The alarming uniformity created by this narrow genetic base in respect of such an important gene or gene complex foretells genetic vulnerability to many adverse conditions including disease and pest epiphytotics, and poor adaptability to diverse environments. The rice workers have now realised the urgent necessity for widening the genetic base of semidwarfism. In recent years, many projects have been initiated for screening the existing germplasm for dwarfing/semidwarfing genes and for the induction of dwarf mutations.

Induction of mutations by radiations and chemical mutagens has become a quite useful tool in modern plant breeding. Mutation research in rice, from the point of view of its improvement, dates back to 1934. This approach has engaged the attention of a number of scientists particularly in Asian countries where rice forms the staple food. As pointed by Swaminathan (1966b), the rice plant with its essentially secondary polyploid nature, with a partially disomic and partially polysomic genetic constitution, and a strict self-pollinating system, is ideally suited for improvement through mutation breeding. Several workers have established that induced mutants would obviously be of importance in rice breeding through their direct as well as indirect uses. Induced short statured mutants have been reported in rice right from Ichijima in 1934. Semidwarf mutants conforming to the plant type have also been identified by some workers.

The genetics of induced mutants are relatively little investigated up on. The allelic relationship of mutants, both naturally occurring and induced, has been studied by a few workers. Singh et al. (1979) reported that while most of the naturally occurring semidwarf mutants were allelic to Dee-geo-woo-gen, many of the induced semidwarf mutants were nonallelic. Ikehashi and Kikuchi (1982) were of the view that the same locus in the third linkage group was responsible for the semidwarfism which lead to a breakthrough for yield level independently in different regions of the World.

Genetic analysis of semidwarf mutants provides a means to ascertain the allelic relationship of the mutants with Dee-geo-woo-gen. Incorporation of plant type into the well adapted native varieties through the conventional combination breeding not only disturbs the genetic background of these varieties but also perforce retain some of the undesirable effects in spite of efficient selection. Mutagenesis provides an unique method of inducing plant types into the native varieties without disturbing their genetic background.

The present project has been taken up as a part of the nation-wide effort to identify/induce dwarfing genes non-allelic to Dgwg gene to provide a wide genetic base for semi-dwarfism. The investigations aimed at:-

1. the induction of plant type semidwarfs in three native well adapted varieties, viz., Ptb-9, Ptb-28 and Ptb-10 using gamma rays and EMS;
2. the study of the genetic relationship of the induced semi-dwarfs with Dee-geo-woo-gen to identify nonallelic semi-dwarfing genes; and
3. the study of the allelic relationship of the induced mutants.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

At the turn of the century, the enormous potential usefulness of induced mutations for plant breeding has stirred the imagination of geneticists like De Vries, Nilsson Ehle, Muller and Gustafsson. The scope for producing better species of cultivated plants and domesticated animals by the mutation technique was anticipated by them (c.f. Gaul, 1964). The use of X-rays for inducing mutation was suggested by De Vries in 1904 (c.f. Blakesee, 1936), Koernicke in 1905 and Gager in 1908. However, the conclusive proof that ionising radiations induce mutations was presented by Muller (1927) in Drosophila. Reports of Stadler (1928), Gager and Blakeslee (1927) and Goodspeed (1929) indicated the use of ionising radiations for inducing mutations in plants. The historically important findings of this period were followed in the next three to four decades by investigations of a purely experimental nature, such as, the type of mutagens, dosages, M_1 effects, segregation in M_2 and M_3, mutant types and cytological characteristics. These early works did not contribute much to plant improvement. The seventies witnessed the practical utilisation of induced mutations in a wide range of crops (Gregory, 1972).

Even before the discovery of the mutagenic effects of X-rays, the search for chemicals capable of causing mutations began (Auerbach, 1967). Early in the Century, chemical mutagenesis was attempted by Schiemann (1912). Induction of mutations by means of chemical treatments with mustard gas was demonstrated by Auerbach and Robson (1942, 1947) in England and Rapoport (1948) in the USSR. Since then, a number of chemicals possessing mutagenic properties have been identified and their effects studied. The reports on the induction of mutations in higher plants with chemical mutagens are numerous in recent years.

Among the numerous radio-mimetic chemicals now known, the alkylating agents are the most efficient in a wide array of organisms from bacteria to mammals (Auerbach, 1961). Within the alkylating group, monofunctional agents in general and ethyl methane sulphonate in particular appear to be more efficient in several organisms including higher plants (Swaminathan et al., 1962). The mutagenic efficiency of ethyl methane sulphonate was first demonstrated by Heslot et al. (1959) and later by Ehrenberg (1960). Nitrosoguanidine, a comparatively new addition to the series of potential chemical mutagens is reported to induce higher mutation frequency than EMS, NMU and gamma rays (Swaminathan et al., 1970).

A wide range of both physical and chemical mutagens is now available. The relative advantages and disadvantages of the different mutagens have been investigated by many workers. Ehrenberg et al. (1961) and Heiner et al. (1960) showed that some chemicals induced mutations with frequencies two to three times higher than the highest frequencies obtained following radiation treatments. Sato (1966) reported EI and EMS to be more powerful mutagens than radiations in inducing visible mutations in rice. Physical mutagens like X-rays, fast neutrons and gamma rays have been frequently employed in inducing useful mutations in crop plants as compared to chemical mutagens (Swaminathan, 1969b). The available literature on mutation breeding is flooded with works on induced mutation through ionizing radiation. In sexually propagated crops, chemical mutagens yielded very high mutation frequencies and in most cases they were more efficient than ionizing radiations (Kamra and Brunner, 1970). However, it is premature to assess the merits of chemical mutagens on the basis of the number of varieties to which they have given rise, since extensive work with chemical mutagens have begun only in 1960, following the introduction of ethyl methane sulphonate. As such, the choice between the physical and chemical mutagens for induced mutagenesis is only arbitrary. Swaminathan (1969c), however, opined that neutrons among the radiations and ethyl methane sulphonate among the chemicals were generally the mutagens of choice. Nair (1971) ranked the mutagens as gamma rays, EMS, NMU and fast neutrons in terms of the frequency of viable mutations they induced. Based on their efficiency at doses inducing similar biological effects, they were reported to be in the order gamma rays, EMS, fast neutrons and NMU. He, thus, concluded that gamma rays were the best in inducing viable mutations in rice. Thus, both the kinds of mutagens have proven to be of value in induced mutagenesis.

Since the premier works of Yamada (1917) and Nakamura (1918) which indicated increased yields with exposure of seeds to X-rays for short periods, the literature on induced mutations in rice has accumulated tremendously. The progress in mutation research and the practical achievements in crop improvement have been reviewed by many investigators such as (Auerbach, 1961; Gaul, 1961, 1964; Sparrow, 1961; Sparrow et al., 1965; Nilan et al., 1965; 1969; Gustafsson, 1963, 1969; Gustafsson and Gadd, 1966; Heslot, 1965; Nybom and Koch, 1965; Stubbe, 1967; Narayanan and Konzak, 1969; Swaminathan, 1969a and b; Nair, 1971; Escuro et al., 1971; Govindaswami et al., 1972; Carnahan et al., 1975; Chakrabarthi and Sen, 1975; Rutger et al., 1976; Hak and Mun, 1978; Awan and Bari, 1979; Hajra, 1979; Dwivedi et al., 1979; Mikaelsen, 1979; Sreedharan, 1979; Hiraiwa and Tanaka, 1980; Patnaik et al., 1980; Kawai, 1980; Saini and Kumar, 1980; Bakirov, 1980; Awan and Cheema, 1981; Guo, 1981; Mahadevappa et al., 1981; Rutger and Brandon, 1981; Santos, 1981; Ashri, 1982; Lal and Richharia, 1982; Ganashan and Whittington, 1983; Debnath and Mukerjee, 1983; Mese et al., 1984).

Sparrow et al. (1958) listed 31 publications on radio botanical studies in rice for the 60-year period from 1896 to 1955. While Nayar (1965) reviewed most of the mutation works in rice upto 1965, Gustafsson and Gadd (1966) attempted to relate the breeding characteristics and accomplishments to the works which had been done with rice mutations. Mikaelsen (1979) reviewed induction of mutations and their nature, types of useful mutations including those for plant height, changes in flowering and maturation, resistance to diseases and pests, and the use of induced mutations in rice breeding. The available literature on these aspects is so vast that it is out of the scope of the present study to review them. Mutation breeding for resistance has opened up a new and vast field of research. Streams of results of such investigations have been presented in more recent literature. Another aspect of mutation breeding that has attracted the attention of researchers all over the world is the induction of desired plant types.

This review gives greater emphasis to induced mutagenesis in relation to crop breeding.

I. Effects of mutagens in the M_1 generation

The mutagenic sensitivity of plants is usually measured by parameters such as germination, survival, plant growth, fertility and chlorophyll deficient chimeras.

a) Germination

Goud et al. (1967), Siddiq (1967) and Ganashan (1970) reported that germination was not much affected by radiations, though damage occurred afterwards. Germination was not affected even at relatively higher doses of radiations (Nair, 1971). However, considerable delay in germination of seeds at high doses of radiations was reported by Yamagata et al. (1969) and Goud et al. (1967).

On the other hand, germination was greatly reduced by chemical mutagens such as diethyl sulphate (Rao and Ayengar, 1964; Nair, 1971), ethylene imine (Yamagata et al., 1965), ethyl methane sulphonate (Yamagata et al., 1965; Ganashan, 1970; Nair, 1971; Nair, 1976), nitrosomethyl urea (Siddiq, 1967; Siddiq and Swaminathan, 1968; Nair, 1971), methyl methane sulphonate (Nair, 1971) and methyl nitro nitrosoguanidine (Nair, 1971).

b) Survival

The number of seedlings surviving after mutagen treatment has been observed to decrease with increasing doses of mutagens, both physical and chemical (Rao and Ayengar, 1964; Yamagata et al., 1965; Siddiq, 1967; Siddiq and Swaminathan, 1968; Ganashan, 1970). Swaminathan et al. (1970) indicated, based on the data on the percentage of M_1 survival, that the toxicity of NG and NMU was very high, followed by that of gamma rays and EMS. The LD_{50} appeared to be 30 kR with gamma rays and 0.50%, 0.015% and 0.010% with EMS, NMU and NG, respectively.

Even at very low doses, reduction in germination and survival following treatment with NMU, MNNG and MMS was significant. EMS caused least lethality, compared to other chemicals (Nair, 1971). He further reported that in chemical mutagen treatments, M_1 seedlings reaching the fourth leaf stage almost always survived to maturity and indicated the difference between the nature of lethal effects induced by radiations and chemicals. Guo et al. (1983) did not find significant correlation between seedling survival rate in the M_1 and mutation frequency in the M_2.

c) Plant growth

In several radio-biological experiments, seedling injury (measured by the rate of reduction in shoot growth) has been used as a reliable estimate of the damage. Reduction in height of the plants has been more drastic, generally in treatments with radiations than with chemicals (Siddiq, 1967; Singh, 1970). With gamma rays, a linear relationship between the dose and the reduction in shoot growth has been reported. Matsuo et al. (1958), Yamaguchi (1964) and Masima and Kawai (1959) found that seedlings were less variable in height after irradiation with neutrons than with X-rays. Among the chemicals, nitrosomethyl urea was found to be highly effective in reducing the height of seedlings (Singh, 1970). He further reported that the M_1 seedlings recovered in growth rate after 45 days.

Nair (1971) observed greater inhibitory effect of radiations and most of the mutagenic chemicals on the root, in comparison with the effect on the shoot. He further reported that with higher doses of gamma rays and NMU the inhibitory effect on the root was twice as intense as that on the shoot. The height of the M_1 plants decreased progressively with increasing doses of the mutagens. Gamma rays and NMU were more effective in reducing the height of the plants (Nair, 1971). The low variability in height following exposure to fast neutrons than to X-rays, gamma rays and chemical mutagens was explained by him as due to a more uniform effect of fast neutrons on the biological material resulting from their relative insensitivity to the action of modifying factors and absence of secondary physiological effects.

d) Seed fertility

Decreased pollen and seed fertility showed a linear relation with mutagen doses (Beachell, 1957; Chang and Hsieh, 1957; Yamaguchi, 1964; Siddiq, 1967; Singh, 1970 and Awan and Bari, 1979). Bekendam (1961), Henderson (1963) and Yeh and Henderson (1963) indicated a decrease in fertility with increase in dose, upto a certain level beyond which there was, however, a saturation effect. Henderson (1963), Yeh and Henderson (1963), Yamaguchi (1964) and Siddiq (1967) found that neutrons reduced fertility more severely than X-rays and gamma rays. Chemical mutagens such as diethyl sulphate (Rao and Ayengar, 1964; Sato, 1966), ethylene oxide (Sato, 1966), nitrosomethyl urea and ethyl methane sulphonate (Siddiq and Swaminathan, 1968; Nair, 1971), methyl methane sulphonate and methyl nitro nitroso guanidine (Nair, 1971) were reported to induce much less sterility than radiations. Sato (1966) however reported that reduction of M_1 fertility in EMS treatment was to a marked extent comparable to the very low sterility in the case of treatments with ethylene oxide and diethyl sulphate. Guo et al. (1973) observed that M_1 sterility had no correlation with mutation frequency in the M_2.

e) Chimeras

Shastry and Ramiah (1961) and Siddiq (1967) observed chlorophyll deficient sectors on the M_1 plants of rice. Tanaka (1970) recorded such sectors in the haploid plants, following chronic gamma irradiation. Nair (1971) obtained plants with chlorotic streaks after treatment with fast neutrons at a very low frequency; but not in treatments with X-rays or gamma rays. Plants with chlorophyll deficiencies were observed following treatment with chemical mutagens such as ethyl methane sulphonate and nitrosomethyl urea by Siddiq (1967), Singh (1970) and Nair (1971). The frequency of plants with chlorophyll deficient sectors was found to increase progressively with increasing doses of chemical mutagens

(Nair, 1971). Plastid mutations were thought to be responsible for the variegations seen in M_1 generation followed by irradiation (Hsieh, 1959). The possibility of the chimeras being periclinal or having an origin from physiological disorder was indicated by Siddiq (1967). He found them to be non-heritable.

II. Mutations in the M_2 generation

The terminology in literature for characterising the different types of mutations is not uniform. The terms macro- and micromutations were used with various connotations. Gaul (1961) proposed the following phenotypic classification of mutations.

1. Macromutations: Recognizable in a single plant, either transpecific or intraspecific.
2. Micromutations: Recognizable only in a group of plants, either manifest or cryptic.

Macromutations included mutations affecting culm length, growth habit, heading date, spike density, anthocyanin development etc. (Gaul, 1964). It was obvious that such a system of classification presented many difficulties in using the terms macro- and micromutations with any degree of consistency (Swaminathan, 1966b). Swaminathan (1964) proposed the following classification based largely on the screening procedure to be adopted, the extent of pleiotropic or associated effects and the phylogenetic value of the induced mutants.

1. Micromutations - all mutations identifiable and fixable only through the adoption of biometrical procedures.
2. Visible mutations - all mutations identifiable by "eye inspection" or by the use of appropriate screening procedures such as the creation of epiphytotics of diseases. These could be described under two sub groups: (a) lethal and (b) viable.
3. Macromutations - all mutations, though inherited as a single unit, leading to several phenotypic consequences. Such mutations might be the result of the locus involved being a compound one or due to tight linkage or genuine pleiotropy.
4. Systematic mutations - all mutations which either simulated an already existing taxon or necessitated the creation of a new systematic unit, by virtue of the character affected being a key one.

a) Chlorophyll mutations

Gustafsson (1940) classified chlorophyll mutations. This was further extended by Konzak et al. (1968).

i) Frequency

Several workers reported increase in frequency of chlorophyll mutations with increasing doses of mutagens. Chlorophyll mutations were found to increase following X-irradiation

(Kawai and Sato, 1966). At moderate doses of X-rays and gamma rays, the frequency reached a maximum and decreased at higher doses (Matsuo et al., 1958; Miah et al., 1970). Bekendam (1961), Siddiq (1967) and Siddiq and Swaminathan (1968) found an exponential increase in the frequency of chlorophyll mutations with increase in dose of the mutagens. A linear relationship between mutation frequency and dose of X-rays and gamma rays was reported by Yamaguchi and Miah (1964) and Singh (1970). Matsuo et al. (1958), Masima and Kawai (1959) and Yamaguchi (1964) observed an increase in the frequency of mutations with increasing dose of neutron irradiation. Swaminathan et al. (1970) reported high mutation frequency following irradiation. Nair (1971) obtained highest frequencies of chlorophyll mutations with gamma rays. But per unit basis, fast neutrons were more effective than gamma rays. Lal and Richharia (1982) found maximum chlorophyll mutations in T-141 and minimum in Ratna following treatment with gamma rays.

High chlorophyll mutation frequencies were reported with ethylene imines (Yamagata et al., 1965; Kawai and Sato, 1965), diethyl sulphate (Gopal Ayengar et al., 1969), ethyl methane sulphonate (Swaminathan, 1966b; Ismail, 1969; Nair, 1971), nitrosomethyl urea (Swaminathan, 1966b; Siddiq, 1967; Nair, 1971) and methyl nitrosoguanidine (Swaminathan et al., 1968, 1970). Hajra (1979) obtained highest frequency of chlorophyll mutations following treatment with ethyl methane sulphonate for six and seven hours. Guo et al. (1983) found no significant correlation between seedling survival rate in M_1 or frequency of M_1 sterility on the one hand and chlorophyll mutation frequency in the M_2 on the other.

ii) Spectrum

Several investigators reported differences in the spectrum of chlorophyll mutations induced by physical and chemical mutagens. Ethyl methane sulphonate among chemicals and fast neutrons among radiations induced wider spectrum (Swaminathan, 1966b; Swaminathan et al., 1970). *Albinas* predominated the chlorophyll mutation spectrum followed by *viridis* and *xanthas* in treatment with radiations whereas in treatment with chemical mutagens such as ethyl methane sulphonate and diethyl sulphate, *xanthas* and *viridis* were found to increase with a proportionate decrease in *albinas* (Chekandan, 1961; Chao and Chai, 1961; Matsumura and Mabuchi, 1964; Kawai, 1966; Sato, 1966; Basu and Basu, 1969; Nair, 1971). The higher frequency of *albinas* was explained by Swaminathan et al. (1970) as due to the large number of loci governing this phenotype. Kawai and Sato (1965), Siddiq (1967) and Siddiq and Swaminathan (1968) found the spectrum of chlorophyll mutations to be dependent on the mutagen used. Nair (1971) reported that differences in the spectrum of mutations were not significant between doses of either radiations or chemical mutagens.

b) Viable mutations

i) Frequency

Singh (1970) and Nair (1971) reported high frequencies of viable mutations in the mutagen treated materials. Siddiq (1967) observed that the frequencies clearly indicated a saturation effect. According to Kawai (1968), the frequency was higher after irradiation with pile neutrons than with X-rays. Siddiq (1967) opined that at comparable doses of ethyl methane sulphonate and gamma rays, the frequencies of viable mutations were more or less the same whereas Singh (1970) considered ethyl methane sulphonate as the most potent mutagen. Nair (1971) observed that the types of viable mutations induced with the different mutagens did not differ; but their relative frequencies were different. A direct linear relationship between the frequency of viable mutations and dose of gamma rays and fast neutrons was observed by Awan and Bari (1970). Lal and Richharia (1932) reported different frequencies of viable mutations in different varieties.

Siddiq (1967), Siddiq and Swaminathan (1968) reported a wider spectrum of viable mutations after treatment with ethyl methane sulphonate than that obtained with radiations. Singh (1970) also reported similar results after treatment with nitroso methyl urea. Nair (1971) observed high frequencies of mutants with altered duration and grain type following treatments with gamma rays, mutants affecting culm length after treatments with ethyl methane sulphonate and mutants with panicle and spikelet abnormalities following treatments with fast neutrons. He further suggested that the mutation spectrum could be altered through the use of different mutagens.

Large collections of viable mutants were reported by several workers. Kawai (1963) induced more than 1000 types in a single variety by radiation treatment. About 1400 mutant lines with stable visible characters isolated after gamma irradiation of growing plants were assembled by Tanaka (1969). Bekendam (1961) also reported a large number of mutant types. Relatively smaller groups include 473 types induced with ^{32}P by Kawai (1963), 233 types with ^{32}P by Masima and Kawai (1958), 254 types by Huang (1964), 121 types by Marie (1967), 56 types by Swaminathan et al. (1970) and 35 types by Viado et al. (1970). Nair (1971) reported several types of mutants in the M_2 after treatment with both physical and chemical mutagens. Viable mutations after treatment with mutagens, were reported by many workers (Misra et al., 1971; Escuro et al., 1971; Govindaswami et al., 1972; Reddy et al., 1975; Dwivedi et al., 1979; Mallick et al., 1980; Mahadevappa et al., 1981; Ashri, 1982; Ganashan and Whittington, 1983 and Okuno, 1983). Hiraiwa and Tanaka (1980) isolated male sterile mutants following treatment with gamma rays and ethylene imine.

ii) Types of mutations

Swaminathan (1964) proposed a scheme for classification of mutations affecting one or several morphological characters such as (1) macromutations, (2) visible mutations and (3) systematic mutations.

1) Macromutations

Mutations affecting more than one character of the same plant were reported in many investigations. These simultaneous changes were inherited as a single unit of recombination. Erectoides mutants formed one of the major types of macromutations. These were characterised by short stature, stiff straw, broad and dark green leaves, compact ear and small grains. The different types of erectoides mutants differed with respect to characters such as height, stiffness of culm and leaves, number of tillers, compactness of panicles and size of grain (Nair, 1971). Erectoides mutants were reported by Masima and Kawai (1958), Hu et al. (1960), Matsuo and Onozawa (1961), Li et al. (1961, 1962, 1966), Kawai (1968) and Nair (1971). Several macromutants other than erectoides were isolated by Nair (1971), Escuro et al. (1971), Sreerangasamy et al. (1973), Chakrabarthi and Sen (1975), Dwivedi et al. (1979) and Ganashan and Whittington (1983).

2) Visible mutations

Mutations affecting specific plant characters have been induced with a variety of radiations and chemicals.

Culm length

Kawai (1962), Tanaka (1968) and Nair (1971) reported the common occurrence of mutants with reduced height. Semidwarfs and dwarfs have been reported by numerous investigators (Masima and Kawai, 1958; Kawai et al., 1961; Bekendam, 1961; Matsuo and Onozawa, 1961; Hsieh, 1962; Narahari and Bora, 1963; Kawai, 1963; Shastry, 1965; Shastry and Nadhachary, 1965; Swaminathan, 1966b; Siddiq, 1967; Siddiq and Swaminathan, 1968; Ismail, 1969; Singh, 1970; Miah et al., 1970; Ganashan, 1970; Nair, 1971; Misra et al., 1971; Sreerangasamy et al., 1973; Chakrabarthi and Sen, 1975; Govindaswami et al., 1972; Dwivedi et al., 1979; Hajra, 1979; Mahadevappa et al., 1981; Marie, 1981; Ashri, 1982; Ganashan and Whittington, 1983 and Okuno, 1983). A tall mutant was reported by Rutger and Carnahan (1981). Hajra et al. (1982) reported two tall mutants with significantly longer internodes.

Leaf types

Narrow leaf mutants were most frequent as reported by Hsieh (1962), Shastry (1965), Siddiq (1967), Tanaka (1968), Singh (1970) and Swaminathan et al. (1970). Boat leaf mutants have been reported under different names like incurved lamina or rolled leaf by Narahari and Bora (1963), Tanaka (1968), Singh (1970), Swaminathan et al. (1970) and Rutger (1977). Decrease in leaf length was observed by Kawai and Narahari (1971), Nair (1971), Rutger (1977) and Ganashan and Whittington (1983).

Ear types

Tanaka (1968) observed short panicle mutants more frequently than long panicle mutants. He got mutants with lax panicles as frequent as those with compact panicles. Most of the short culm mutants showed reduction in panicle length (Kawai and Narahari, 1971; Ganashan and Whittington, 1983). Govindaswami et al. (1972) reported long panicle mutants. Mutations altering panicle density to yield compact and open types were reported by Singh (1970) and Kawai and Narahari (1971).

Grain types

Mutation affecting grain size, shape, colour, awns, pubescence and breaking were reported by many workers. Kawai (1962) and Ganashan (1970) reported short grain types more frequently than large grain types. Mutants with altered grain size and shape were recorded by Beachell (1957), Bora and Rao (1958), Myakudo et al. (1959), Kawai and Narahari (1971), Mallick et al. (1980) and Okuno (1983). Nair (1971) recorded mutants with small, medium and large grains and others with bold or fine grains. Mutants with less grains of reduced size were reported following irradiation with gamma ray by Ganashan and Whittington (1983). Tawny glume mutants (Hsieh, 1962), mutants with dark brown glumes (Siddiq, 1967) and awned mutants (Soriano, 1961) were also reported. Tip awned mutants were more frequent than fully awned mutants (Siddiq, 1967).

3) Systematic mutations

Shastry (1965) isolated a dwarf in Oryza sativa resembling a wild species O. granulata. Swaminathan (1966b) also obtained a similar type and a mutant in O. glaberrima resembling O. rufipogon. Siddiq and Swaminathan (1968) and Swaminathan et al. (1968) isolated stable mutants affecting the key characters that usually distinguish japonica and and indica varieties. Nair (1971) obtained two mutants resembling O. perennis sub sp. barthii and a third resembling O. sativa var. fatua.

III. Plant height and plant type mutants

The belief that japonica varieties of rice alone were capable of responding well to the application of large doses of fertilizers underwent a remarkable change after the development in Taiwan of Dee-geo-woo-gen, Taichung Native-1 and I-geo-tze, three early maturing, nitrogen responsive, photo-insensitive semidwarf indica varieties. These dwarf indica varieties established that fertilizer response was conditioned more by morphological characters than by physiological ones (Swaminathan, 1966a). That the degree of response to nitrogenous fertilizers was very much dependent on the plant type was suggested by Ramiah (1966). Seetharaman (1969) reported that a variety that yielded well would have erect, short and dark green leaves and that the capacity to yield high was genetically linked with other characteristics of the variety, the sum of which constituted the "plant type". Kumar et al. (1967) believed that the realisation that response to fertilizer application was more a morphological than a physiological phenomenon led to the wide spread search for genes in cereal crops which would help in developing a plant type capable of yielding heavily. From these the plant type concept in rice emerged.

Recent developments in rice breeding have made a significant contribution towards the plant type concept. The plant type concept has, however, been changing with changes in breeding objectives. Tsunoda (1959) found that low nitrogen responders had long, broad, thin, drooping, pale green leaves and tall weak stem. He further observed such a plant type to be far more common in the tropics. Tsunoda (1962) characterised high nitrogen responsive rice plant as one having erect, short, narrow, thick and dark green leaves and short, sturdy stem. Short stature, stiff straw and erect leaves of moderate length which remained green until maturity were considered as the traits for desirable plant type (Beachell and Scott, 1963). Jennings (1964) observed that, although many environmental and cultural factors were associated with low yields in the tropics, the type of the plant capable of more efficient performance under tropical condition was more important. Particular leaf and stem types were necessary for substantial grain yield. Jennings (1964) viewed the ideal plant type for the tropics as one having erect, short, narrow, thick and dark green leaves and short sturdy stem. He conceived that under the conditions of low nitrogen, reduced light and wide spacing, they yielded poor because of insufficient leaf area. Improved cultural practices led to controlled increase in foliage. The need for modification of the plant type was stressed by Beachell and Jennings (1965). Tanaka (1965) found certain morphological characters to be related to high nitrogen response in rice and consequently, Tanaka et al. (196[illegible]) suggested that selection for high yield and nitrogen response could be made indirectly on the basis of the plant type. Beachell (196[illegible]) described the characters for the varietal types for the tropics as follows:

1. Early maturity and insensitivity to day length.
2. Relatively short, upright, narrow, thick, dark green leaves permitting penetration and efficient utilization of sunlight.
3. Short, sturdy culm to reduce lodging at high fertility levels.
4. Resistance to serious pests and diseases.
5. Seed dormancy at the time of harvest.
6. Moderately firm threshability.
7. High grain yield with high milling recovery.

Kumar et al. (1967) regarded plants possessing synchronous tillering, optimum number of wide, upright leaves and thus the capacity for maximum utilization of sunlight and other factors for energy building process, as ideal plant type in barley. According to Seetharaman (1969) the plant type concept was associated with short plant stature with short leaves remaining more or less in an erect alignment with the culm and dark green leaves. He suggested that such a morphological frame work was ideal for efficient functioning from the production point.

Plant types with intermediate stature continued to receive attention for areas of less dependable water control, because varieties with intermediate plant height when planted in such areas gave more stable yields than short statured varieties (Anon., 1976). The physiological advantage for short stature over tall stature was the balance between photosynthesis and respiration. A tall plant tended to have high proportion of non-photosynthetic tissues and more drooping leaves resulting in high respiration and low photosynthesis (Shouich, 1977). Many workers have suggested that plant type in rice is associated with semidwarf or dwarf stature (Jennings, 1964; Beachell and Jennings, 1965; Swaminathan, 1966a; Seetharaman, 1966; Ramiah, 1966; Tanaka, 1963; Reddy and Reddy, 1973; Singh et al., 1979 and Rutger, 1981).

Several investigators have isolated useful mutants in rice. Short statured mutants induced by X-rays were first reported by Ichijima (1934). Ramiah and Rao (1953) obtained short stature mutants with large number of tillers after irradiation with X-rays. Huang and Chang (1958) found that induced mutants affecting culm length were most frequently shorter than the control. Dwarfs with intermediate stature, normal panicle and grain were fairly common in irradiated material (Shah et al., 1961). Moriyama and Futsuhara (1962) and Campos (1962) recorded better yield in mutants in X-irradiated materials. Huang (1964) isolated some mutants characterised by vigorous growth and short stem. [illegible] (19[illegible]) reported mutants in rice useful for breeding because of their lodging resistance, shortened culm, erect, dark green leaves and compact panicle. The mutant rice variety Reimei isolated from Fujiminori, released for commercial cultivation in 1966 in Japan was described by Kawai (1967). A mutant of [illegible]-1 obtained following gamma ray treatment matured seven days earlier and produced more grains of superior quality (Rajagopalan, 1968). Trombay Rice-1 (TR-1) derived from GEB-24 by gamma irradiation was 15 to 20 days earlier in flowering, short-statured and produced larger number of grains (Swaminathan, 1970). Misra et al. (1971) reported several beneficial mutations for culm shortening, high yield, earliness, higher protein content and resistance to pests and diseases, and water logging, after treatment of seeds of two cultivars of *Oryza sativa* and four wild rices (spontaneas) with different chemical mutagens. Many useful mutants with high yield, earliness, short stature, lodging resistance, high harvest index and erect leaves were isolated from the progeny of gamma irradiated seed at dose range of 20 to 35 krad by Escuro et al. (1971). Reddy and Reddy (1971) observed that a semidwarf mutant isolated from HR-47 (Vasumathi) following treatment with diethyl sulphate yielded 20 per cent more than HR-47, matured earlier by 10 days and was lodging resistant. The evolved semidwarf variety could be successfully used directly for commercial cultivation due to its distinct improvement for various agronomic characters. Govindaswami et al. (1972) reported seven promising mutants with short culm, long panicles, high spikelet fertility, superior grain quality and shorter heading time. Improvement in the number of tillers, single plant yield, 1000 grain weight, kernel size and shape, gelatinization temperature and amylose content was also reported. Comparing the yield and other traits, Hu (1973) established that the induced mutants in rice were as good as the short statured varieties evolved through hybridization. Sreerangasamy et al. (1973) isolated early flowering mutants in the rice variety TKM-6, the earliness ranging from seven to fifteen days as compared to control, after gamma ray treatment. Plant type mutants were reported by Reddy and Reddy (1974), Gangadharan et al. (1974), Reddy et al. (1975), Chakrabarthi and Sen (1975), Hajra (1979), Prasad and Sinha (1979), Santos (1981), Rutger (1981), Ashri (1982), Ganashan and Whittington (1983) and Sreerangasamy and Anandakumar (1983).

Carnahan et al. (1975) reported the registration of M_5, a mutant rice variety, for release for commercial cultivation. China mutant, a high yielding short-culm variety was released for cultivation by chemical mutagenesis of the popular tall variety, CH 1039 of Kashmir ([illegible], 1979). [illegible] mutants with tolerance to diseases such as *Pyricularia oryzae*, *Xanthomonas oryzae* and the tungro virus were reported by Mathur (1979). In the improved varieties, [illegible], [illegible] and [illegible], the [illegible] were [illegible] desired by treatment [illegible] in their superior characteristics ([illegible]). [illegible], an early high yielding variety [illegible] ([illegible], [illegible]). In the [illegible] [illegible] ted IR-8, Jhona 349 and [illegible] 73, [illegible] et al. (1981) isolated lines with grains of higher protein content. An instance of improving the native rice well adapted for tidal swamps through induced mutation was described by [illegible] et al. (1981). *Alloria* Lambda and *Alloria* Theta, two short statured mutants with better tillering and yield, were isolated following mutagen treatment of the variety Alloria 11 (Marie, 1981). A mutant with better looking translucent kernels and upright leaves with narrow and appressed blades was obtained from mutagen treated IR-5 (Ashri, 1982). A dwarf mutant obtained by treating H_4 with gamma rays was released for commercial cultivation in Sri Lanka (Ganashan and Whittington, 1983). Three promising dwarf macromutants were identified (Sreerangasamy and Anandakumar, 1983) in the M_2 of TKM-6 treated with chemical mutagens. These photosynthetically efficient mutants were tested for direct use and as parents to provide alternate dwarfing genes.

The induced mutants obviously can play an important role in rice breeding through their direct as well as indirect uses. In Japan, Akihikari derived from the induced mutant, Reimei and Fujihikari derived from another mutant were reported to cover substantial rice area ([illegible], [illegible]). Bakirov ([illegible]) reported that using both chemical and physical mutagens, mutant lines were obtained and that they were used for hybridisation for the improvement of native types. The use of new dwarfing gene sources in breeding programmes in order to avoid the risk of single gene incorporation for dwarfing was stressed by Saini and Kumar (1980). Marie (1981) reported that Thetalam B was selected from the cross between two induced mutants of Allorio II. Thetalam B had stiff straw and reduced plant height of 90 cm against 120 cm for Allorio II and early maturity. The first successful short stature variety released in California was Carlose 76, an induced mutant from Carlose. It was hybridised in turn with other tall varieties to create four short stature varieties (Rutger, 1981). Rutger (1982) discussed the uses of induced mutants in rice improvement in California. He further observed that the incorporation of induced mutants into standard hybridisation programmes was made easy by the close relationship of the mutants and the Californian varieties from which the mutants were evolved. A semidwarf line G 31, with narrow, erect, thick leaves with greater photosynthetic rates, was selected from the F_2 of a cross between an induced mutant of the variety Hatsunishiki and Meitoku-5 (Yamaguchi et al., 1981). Malik (1982) reported stable rice mutants which matured 23 days earlier following gamma irradiation of Basmathi 370. Promising mutants were reported by Kaul and Kumar (1983) in Basmathi 370 and Jhona 349. The possibility of using the induced mutants of [illegible] as parents to provide alternate dwarfing genes was indicated by Sreerangasamy and Anandakumar (1983).

a) Inheritance of plant height and plant type

Since plant height mostly decides the plant type, it is an important agronomic character. It is the association of height with other morphological components such as profuse tillering, upright leaves of appropriate size and sturdiness of stem that confers the ability to the plant to respond to good management. Therefore an understanding of the nature of inheritance of the dwarf plant type could be of considerable plant breeding value.

Much before the exploitation of the Dgwg dwarfing gene, the genetics of dwarfness in spontaneous and induced dwarfs was studied by many workers (Parnell et al., 1922; Akemine, 1925; Kadam, 1937; Nagai and Takahashi, 1952; Butany et al., 1959; Hsieh, 1962). Parnell et al. (1922) recorded that characters like stiff, erect,stem; broad, coarse leaf and erect, compact panicle went together with dwarf habit. Akemine (1925) crossed two dwarfs differing in height and obtained tall F_1 plants. He found 9 tall, 3 first type of dwarf, 3 second type of dwarf and 1 third type of dwarf in the F_2, hence [illegible] non-allelic dwarfism in rice. Among the F_2 segregants, double recessives appearing as double dwarfs as a result of interaction of the genes were also reported. Sugimoto ([illegible]) reported a dwarf in rice which was inherited as [illegible] dominant. In separate crosses such as T 24 x [illegible], shortness and tallness were found to be a simple pair of allelomorphs (Ramiah, 193[illegible]). He further suggested that shortness might be a simple dominant to tallness or tallness might be a simple dominant to shortness. Inheritance of plant stature on the basis of multiple factors was also postulated by him. Five dwarfing genes, d_1, d_2, d_3, d_4 and d_5 were reported, of which d_2 was more frequent (Kadam, 1937). Jodon and Beachell (1943) found double recessives appearing as double dwarfs in the F_2 of crosses between two dwarfs. Butany et al. (1959) opined that the dwarfness in rice was conditioned by the interaction of three recessive genes d_a, d_b and d_c. On this basis, they assumed the genic constitution of the four parents involved in the study as $D_aD_ad_bd_bd_cd_c$, $d_ad_aD_bD_bD_cD_c$, $D_aD_aD_bD_bD_cD_c$ and $D_aD_ad_bd_bD_cD_c$. They further reported that for the expression of the character dwarfism, two of the three recessive genes were required. In _japonica_ rice varieties, twelve dwarfing genes were identified and assigned to seven different linkage groups (Takahashi, 1964). Tallness of Peta was found to be partially dominant to the shortness of I-geo-tze. The presence of modifying genes epistatic to the dwarfing gene has also been reported (Anon., 1964). Chang et al. ([illegible]) reported that a single recessive gene controlled the plant height in rice; but they also envisaged the role of epistatic modifiers in the expression of the character. In a cross between TTJ-15, a tall lodging-susceptible variety and a short stiff-culmed selection, the F_1s were slightly taller than [illegible]-15. The F_2 population showed essentially a bimodal distribution and could readily be divided into a tall group and a short group of plants which showed a satisfactory fit to the 3:1 ratio, indicating a single recessive gene for shortness, probably with a few modifiers controlling the short stature (Anon., 1966a). The mode of inheritance of plant height in CP-SLO appeared to be more complex than in Taiwan's semidwarfs, suggesting a polygenic additive system controlling the character (Anon., 1966b). Several crosses between dwarfs and talls, and semidwarfs and talls were undertaken at the IRRI and the F_2 data indicated that dwarf stature was controlled by a single recessive gene probably with several modifiers and semidwarfism, by genes of polygenic additive nature. The diverse F_2 distribution in the crosses between dwarfs and semidwarfs, among the dwarfs and among the semidwarfs suggested that tallness was generally dominant over short stature; but the dominance was incomplete. A complex of height genes with varying degree of dominance and magnitude of effect was involved in the crosses. The modifiers differed in the direction of effects (Anon., 1968). Suge and Murakami (1968) found the dwarfism of the high yielding variety Tan-ginbozu and the spontaneous mutant from Ginbozu to be controlled by a single recessive gene. The recessive gene was thought to block the conversion of mevalonate to kaurene in the pathway of GA synthesis. The moderately short stature of TN-1 was essentially controlled by a single recessive gene and a few modifiers (Seetharaman and Srivasthava, 1969). The gene suspected as a suppressor recessive gene for height in T-436 which was also of moderately short stature. F_1 of the cross between TN-1 and T-436 was tall and in the F_2, tall, moderately short and extremely short plants were realised in a ratio of 9:6:1. They, therefore, concluded that the parents differed by two pairs of genes.

Dwarfism in rice was reported to be controlled by a single recessive gene by many other workers (Futsuhara, 1968;

Heu et al., 1968; Foster and Rutger, 1978b; Belaya, 1979; Ken, 1979a; Wahiduzzaman and Ahamed, 1980; Ghosh et al., 1981; Gu and Zu, 1981; Kikuchi et al., 1981; Singh and Sharma, 1982; Shinabashi, 1982). But cases of recessive genes controlling tallness were also reported (Ramiah, 1933b; Kadam, 1937; Rutger, 1981). Mitra et al. (1973) explained the pattern of segregation of plant height in F_2 through a 3-gene hypothesis. Sivasubramanian and Madhavamenon (1973) found the plant height to be under the control of dominant additive genes. Foster and Rutger (1978a) reported that the inheritance in plant height could be accounted for by three major genes with additive loci effect with full or partial dominance for tall genes. The same authors found the dwarfism in three other crosses to be controlled by a multiple gene system. Ken (1979a) while assuming that the tallness was largely under dominant monogenic control, the occurrence of transgressive individuals in the F_2 was explained as due to some modifiers controlling semidwarfism. Segregation and recombination among the modifiers resulted in the appearance of transgressive individuals. Wahiduzzaman and Ahamed (1980) found short stature to be recessive to tall and very tall stature, the shortness being controlled by a major allele. Many genes with smaller cumulative effects were also thought to be associated. They further reported that the F_2 frequency curve for tall x very tall was unimodal indicating polygenic inheritance. Ghosh et al. (1981), after studying the segregation pattern involving four dwarfs, concluded that in three dwarfs the dwarfism was determined by a single recessive gene whereas in the other, two recessive genes were involved in the expression of dwarfism. Gu and Zu (1981) were of opinion that two monogenic recessive genes, d_1 and d_2 controlled the dwarf stature. They described the genotypes of the dwarfs as $d_1d_1D_2D_2$ and $D_1D_1d_2d_2$; and the double recessives as $d_1d_1d_2d_2$. A pair of genes with partial dominance controlling culm length was reported by Ken (1979a). The plant height in rice was also reported to be under the control of partially dominant additive genes (Singh et al., 1982). Ganashan and Whittington (1983) reported four different loci with varying degrees of recessiveness controlling short culm. Digenic segregation with complementary gene action was reported by Chauhan and Tandon (1983) in the F_2 of a cross between two tall plants. The result was explained as due to the presence of one major dominant gene each in the tall parent.

b) Genetic analysis of induced plant type mutants

Recent rice breeding history has shown that it is the new plant type, characterised by a dwarf stature and high harvest index, which has led to a major break-through in the yielding ability of the tropical rice varieties. Considerable research has therefore been carried out to induce dwarf and semidwarf types. Genetics of the induced mutants are relatively little investigated. The induced mutants, apart from their direct use for commercial cultivation, can be of indirect use for improving the local strains (Futsuhara et al., 1967; Micke et al., 1972; Reddy and Padma, 1976; Padma and Reddy, 1977; Bakirov, 1980; Sato, 1980; Saini and Kumar, 1980; Rutger, 1981; Yamaguchi et al., 1981; Malik, 1982). A thorough knowledge of the breeding behaviour of the induced mutants is a pre-requisite for directing research aimed at improvement of local strains using these mutants.

Short statured mutants induced by X-rays were first reported by Ichijima (1934) in a japonica cultivar. Several short statured induced mutants were later reported in japonica cultivars (Nishimura and Murakami, 1952). Chang ([illegible]) studied the characteristics of the X-ray induced mutants and their inheritance. Hsieh (1962) obtained intermediate types in the F_2 of the cross between induced mutants and tall types. The short-stiff culm of irradiated [illegible]-2[illegible] dwarf behaved as a monogenic recessive to the tall lodging-susceptible [illegible]-15, probably with a few modifiers controlling the short stature (Anon., 1969). Narahari (1969) found that each of the five X-ray induced dwarfs was governed by a recessive gene for plant height. The semidwarfism in the induced mutants of HR-47 Basumathi was inherited as a simple recessive (Reddy and Reddy, 1971). Each of the five semidwarfs, d_6, d_7, d_8, d_9 and d_{10} obtained following treatment of the local tall rice variety, Tellakattera was controlled by a single recessive gene (Reddy and Padma, 1976; Padma and Reddy, 1977). Rutger et al. (1976) reported that the induced short stature of mutant D_7 was conditioned by a single recessive gene. Narahari (1979) isolated several semidwarf and dwarf mutants in different varieties and found that most of them were single gene recessives. Mohanty and Das (1979) reported that the induced dwarf of the upland variety, Dular was conditioned by a monogenic recessive gene. The F_1s of the cross between the variety Brown gora and its induced dwarf mutant "gora mutant" was tall and in the F_2, talls and dwarfs appeared in a 3:1 ratio (Prasad and Sinha, 1979). Singh et al. (1979) found the dwarfness of the induced Central African Mutant to be a monogenic recessive with equal strength of modifiers of positive and negative effects. Mackill and Rutger (1979) isolated several height mutants in the irradiated cultivar, Carlose and found that semidwarfism in the mutants was conditioned by single recessive genes. Combining different semidwarfing genes into one line, they showed their effects to be cumulative, the double dwarfs being shorter than both the semidwarfs. The dwarfism induced in IR-8 was inherited simply with partial dominance (Mallick et al., 1980). Ghosh et al. (1981) reported that the induced mutant CRM.13-324 was a double recessive dwarf and had nonallelic genes for dwarfism. Another induced mutant JBS.508 mut 47 was reported by the same authors to be semidwarf, possessing a single recessive gene for dwarfism.

Marshall and Murphy (1981) found a single partially recessive gene to be responsible for dwarfism in barley. Polygenic inheritance for plant height in the induced mutants in rice was reported by Marie (1981). Rutger (1981) reported a tall mutant in which the tallness was inherited as a simple recessive. Okuno (1983) observed induction of short culm and simultaneous changes in other characters to be the result of single recessive mutation. He further reported that at least two long culm mutants were under the control of single genes. Four different loci with different degrees of recessiveness controlling culm length was reported by [illegible] and Whittington (1983).

c) Allelism of dwarfing genes

Most of the modern high yielding varieties owe their origin to crosses of semidwarfs like Dee-geo-woo-gen, Taichung Native-1, IR-8 and their derivatives. I-geo-tze, Dee-geo-woo-gen and Taichung Native-1 carry the same allele for semidwarfism (Chang et al., 1965; Anon., 1966; Aquino and Jennings, 1966). This has led to the apparent genetic similarity in improved rice varieties (Mitra et al., [illegible]; Hargrove et al., 1979). Of the various factors for the limited adoption of the high yielding semidwarf varieties in many Asian countries, a high degree of susceptibility to diseases and insect pests, and a narrow choice of quality grades have been found to be more important. The association of these two major drawbacks with most of the high yielding varieties has been attributed to the dwarfing gene of Dee-geo-woo-gen. This genetic vulnerability and genetic suffocation necessitated the broadening of the genetic base. Chang (1976) emphasized the importance of identifying alternate sources of major dwarfing genes. While most of the dwarfs of spontaneous origin had invariably dwarfing genes allelic to Dee-geo-woo-gen, induced mutagenesis appeared to give rise to dwarfing genes different from those found in the naturally occurring dwarfs (Singh et al., 197[illegible]; Ikehashi and Kikuchi, 1982). In a review of the genetic diversity of the semidwarf high yielding varieties in Tamil Nadu, Samuel (1981) observed that all the semidwarf high yielding varieties carried the dwarfing gene of Dgwg and suggested that new sources of semi-dwarfism should be used.

A period of nearly thirty years have passed since the extensive use of the semidwarfing genes. However, the allelic relationship of these genes is being elucidated only in the past few years, giving promising ideas for further improvement of high yielding varieties. Nagao (1951) reported several single gene recessive dwarf types (d). He also indicated that independent genes (d_1, d_2, d_3 ......) were involved in these different types. That all the three nitrogen responsive early maturing semidwarf <u>indicas</u> from

Taiwan viz., TN-1, Dgwg and I-geo-tze carried the same major gene for short stature was proved in their genetic studies at the IRRI (Anon., 1966c, 1969). Variations in the F_2 distribution in the crosses of these varieties with a common parent were described as due to the presence of modifying genes of negative and positive effects (Anon., 1969). Accession 6993, originating from CP-231, exhibited a more complex mode of inheritance for stature indicating the nonallelic nature of the dwarfing genes (Anon., 1966b). At least 14 additional semidwarf varieties or lines of possibly distinct origin were allelic to Dgwg (Li et al., 1966) while several dwarfs nonallelic to Dgwg were also known. From the crosses among the dwarfs and the semidwarfs selected from the world collection at the IRRI, the following varieties could be recognised as having nonallelic gene or genes for short stature (Anon., 1968).

1. Daikoku dwarf and Ai-yeh-lu dwarf
2. Fanny semidwarf
3. Intermediate semidwarf and long-grain semidwarf
4. Accession 6993 and IR-273
5. FF-36, TN-1 and IR-8.

A suppressor gene nonallelic to Dgwg gene controlling plant height was reported by Seetharaman and Srivastava (1969). The Chinese semidwarf Chen-chu-ai had the semidwarfing gene of TN-1, although there might have different modifying genes for height, Cheng-chu-ai-11 and Chi-nan-ai had different genes for semidwarfism (Anon., 1973 and 1976). The induced semidwarfs, KT 20-74, IKB 4-2 and Te 30-21 and Purbachi from China and C 53-39 mutant from Burma had the same dwarfing gene as TN-1. Reddy and Padma (1976) demonstrated that the five induced dwarf mutants, d_6, d_7, d_8, d_9 and d_{10} were nonallelic to Dgwg. These dwarfing genes were also nonallelic to each other (Padma and Reddy, 1977). Narahari (1979) reported some induced mutants allelic to Dgwg. [illegible] and Chang (1978) reported nonallelic genes governing the inheritance of dwarfism in rice. Ling et al. ([illegible]) studied the allelic relationship of the [illegible] and recognised three major groups of genes. Group 1 (comprised of seven dwarfs) was allelic to I-geo-tze and Dee-geo-woo-gen with modifiers of predominantly negative effects, while Group 2 (comprised of four dwarfs) was also allelic to I-geo-tze and Dee-geo-woo-gen; but had a large and equal number of modifiers of positive and negative effects. The induced mutant Central African mutant which constituted Group 3 had a dwarfing gene nonallelic to I-geo-tze and Dee-geo-woo-gen and also nonallelic to the dwarfing gene of the first and second groups. Mackill and Rutger (1979) induced three nonallelic semidwarfing genes (sd_1, sd_2 and sd_4) in the cultivar, Calrose. Saini and Kumar (1980) reported a new source of dwarfing gene identified as a spontaneous mutant in the variety Jhona 349; but the allelic relation of the new source with Dgwg was not reported. The induced mutant Reimei and Jikkoku had dwarfing genes allelic to Dgwg (Ikehashi and Kikuchi, 1980). They further suggested that Hokuriku 100 and Kochihibiki might have different semidwarf genes. Tsai (1980) concluded that the locus for earliness was composed of various gene sites with position effects constituting isoallelic system. Rutger (1981) studied the allelic relationship of six induced mutants and Dgwg. Mahadevappa et al. (1981) reported that the induced [illegible] mutant was nonallelic to Dgwg gene with a system of modifiers with positive effect. A spontaneous semidwarf mutant of [illegible] 64, which showed frequent back mutation to tall lines was reported to be nonallelic to the other semidwarf cultivars ([illegible] and Seshu, 1982). Kinoshita and Shinbashi (1982) in a recent work involving 12 dwarf rice lines with unknown genotypes and 31 lines with single dwarf marker lines showed many dwarfing genes to be nonallelic. Li and [illegible] (1982) found three major recessive nonallelic genes controlling plant height in rice which were absent in the cultivated semidwarf varieties.

d) Pleiotropic action of the dwarfing genes

It is the association of height with other components of a morphological type such as profuse tillering, upright leaves of appropriate size and sturdiness of stem that confers upon the plant the ability to respond to good management.

Dwarf mutants reported in the early literature were generally economically undesirable, often because of reduced size and yield (Jodon and Beachell, 1943; Seetharaman, 1969; Mackill and Rutger, 1979). Pleiotropic effects including changes in leaf shape, size and orientation; seed size, shape, sterility, and panicle characters are a common feature of the semidwarfing genes. Many semidwarfing genes reported have desirable pleiotropic effects; but undesirable effects are also not uncommon.

Parnell et al. (1922) recorded that characters like stiff, erect stem; broad, coarse leaf and erect, compact panicle were inherited together with dwarf habit. Ramiah (1933a) found that besides stature, all the characters of the dwarf plant, its short and compact ear, broad leaves, round shape of grain etc. were transmitted together. Strong association of plant height with flowering duration was also reported (Ramiah, 1933b). Mutations causing reduction in plant height in association with a cluster of other morphological characters like tiller number, flag leaf length, internode number and length as well as panicle and grain characters in different magnitudes were observed by Masima and Kawai (1958), Tanaka (1968), Kawai and Narahari (1971), Reddy and Reddy (1971), Escuro et al. (1971), Dwivedi et al. (1979), Santos (1981) and Okuno (1983). Pleiotropic effect of the semidwarfing genes was also reported by many workers (Beachell and Scott, 1963; Heu et al., 1968; Ganashan, 1971, Hu, 1973; Reddy et al., 1975; Mitra and Mukherji, 1982). Aquino and Jennings (1966) observed desirable pleiotropic effects of dwarf gene on reduced leaf length, erect leaf, growth and strong seedling vigour. A suppressor gene, su-T affecting culm length with pleiotropic effect on panicle expression and leaf characters was reported by Seetharaman (1969) and Seetharaman and Srivastava (1969). Mutants with a reduction in the plant height to the extent of fifty per cent recorded significant and remarkably lower values in peduncle length, extrusion, length and number of grains per panicle ([illegible] et al., 1979). These authors have further observed that the multiple changes in various morpho-physiological characters associated with dwarfism might be due to pleiotropic effects of the major dwarfing gene. Mackill and Rutger (1979) reported a semidwarfing gene, sd_4, that demonstrated pleiotropic effect of small seed size and slightly earlier maturity. They also observed phenotypic dissimilarity among the allelic semi-dwarf mutants due to different pleiotropic effects. The possibility of the existence of different alleles with different agronomic desirability at each particular locus was indicated by the same authors. Awan and Cheema (1981) observed in gamma ray induced semidwarf mutants of Basumathi 370, that reduction in height is associated with reduction in panicle components of yield. Pleiotropic effects of early maturing genes on internode elongation were reported by Yokoo and Okuno (1981). Shinabashi (1982) observed several dwarfing genes having pleiotropic effect on shape and size of grains. Okuno (1983) found that in the induced semidwarf mutants, short culms and simultaneous changes in other characters were controlled by single recessive genes. Most of the short culm mutants reported by Ganashan and Whittington (1983) showed reduction in panicle length, number of grains and grain size; but increase in the number of tillers.

e) <u>Internode length in short culm mutants</u>

The pattern of reduction in the internode l[illegible] semidwarfs and dwarfs was investigated by many workers [illegible], 1972; 1977; [illegible], 1961; [illegible] et al., 1961; [illegible] and Chang, 1965; Joshua et al., 196[illegible]; [illegible] et al., [illegible]; Mallick et al., 1980; [illegible] and [illegible], 1981, 19[illegible]; [illegible], 1981; Okuno, 1983).

Nagao (195[illegible]) found that the reduction in culm [illegible] in the dwarfs was due to the shortened internodes. [illegible] types of dwarfs were characterised by shortened internodes (Nagao, 1951). Kawai et al. (1961) studied the pattern of internode elongation in the induced short culm mutants and observed that there was reduction in the internode length, but not in the number. Shortening of the internode, though brought about reduction in culm length, did not always lead to the stiffness of the culm (Joshua et al., 1969). Kawai and Narahari (1971) recorded that the largest contribution to the reduction of culm length was made by internode 1 and 4 (from top). They, however, found that the lower the position of the internode, the larger was its relative reduction rate. Reddy and Reddy (1971) observed that the panicle bearing 6th internode (from the base) contributed maximum towards shortening of the culm followed by the 5th, 4th, 3rd, 2nd and 1st internodes. Reddy et al. (1975) were of opinion that the reduction in the plant stature of semidwarf and dwarf mutants was mainly due to decrease in the length of specific internodes. They observed that in semidwarfs, the internode-2 (from top) showed the least reduction in length, whereas the internode-4 and the internode-5 showed maximum reduction. In dwarfs, the internode-1 showed the least reduction and the internode-4, the maximum. Rutger et al. (1976) however, found that in the induced semidwarf mutant [illegible]7, length of the upper four internodes was significantly reduced, while the whole length and the length of the fifth internode did not differ significantly. Reduction in the upper four internodes in dwarf induced mutants was also observed by Mallick et al. (1980). Hajra et al. (1992) observed longer internodes in the induced tall mutants.

MATERIALS AND METHODS

MATERIALS AND METHODS

The study was undertaken in the Department of Plant Breeding, College of Agriculture, Vellayani, during the period from 1981 to 1984.

A. MATERIALS

I. Biological materials

Biological materials involved in the study consisted of three tall *indica* rice varieties, viz., Ptb-9, Ptb-10 and Ptb-28, and the dwarf *indica* high yielding variety, Jyothi (Ptb-39). They are presented as figure I. The first three are pure line selections from local varieties and the fourth evolved through hybridization and selection at the Rice Research Station, Pattambi.

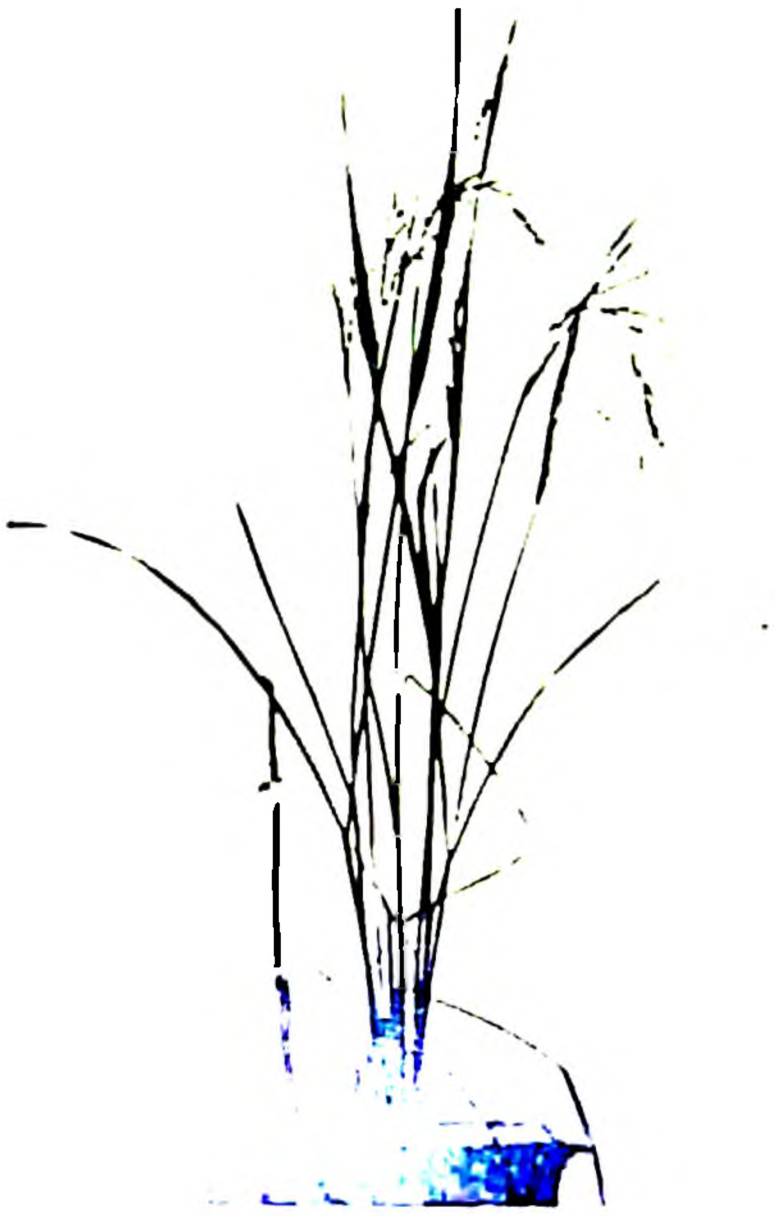
Pure seeds of these varieties were obtained from the Rice Research Station, Pattambi.

Ptb-9 is a medium duration variety (130 days) suitable for the first crop (April-May to July-August). It is one of the popular varieties due to its hardiness. The purple colour of the plant helps in easy weeding operations. It is particularly suited to flooded areas on account of its flood tolerance.

Ptb-10 is a short duration (95 days) cosmopolitan variety and is cultivated all through the year. Its adaptability for cultivation in all the three major crop seasons in the State

Figure I. Varieties

Ptb-9 (x [illegible])



Ptb-10 (x 0.0[illegible])

Ptb-28 (x 0.06)

Jyothi (x 0.07)

has made it popular among the tall indica varieties of the State. Quality of rice is excellent (Sahadevan, 1966). Due to its wider adaptability and other desirable features, this variety formed the base material for evolving a large number of high yielding varieties in the State. Annapurna (TN-1 x Ptb-10), Triveni (TN-1 x Ptb-10) x IR-8), Rohini (Ptb-10 x IR-8), Jyothi (Ptb-10 x IR-8), Aswathi (Ptb-10 x Dee-geo-woo-gen), Sabari (IR-8 x(TN-1 x Ptb-10) and Bharathi (Ptb-10 x IR-8) were evolved with Ptb-10 as the base variety through recombination breeding.

Ptb-28 is an upland (Modan) variety. It is sturdy and can withstand dry sowing and moisture stress conditions during the early stages of growth.

Jyothi (Ptb-39) was chosen as a known source of Dee-geo-woo-gen dwarfing gene for studies on genetic analysis of the induced mutants. It is a semidwarf, high yielding variety evolved through selection following hybridization between Ptb-10 and IR-8. It carries the Dee-geo-woo-gen dwarfing gene contributed by IR-8.

The materials for the study also included:-

i) the M_1 and M_2 generations from Ptb-9, Ptb-10 and Ptb-28.

ii) the M_3 generation of the semidwarf mutants selected in the M_2.

iii) the F_1 and F_2 generations of the crosses between the nine mutants and their respective tall *indica* parents.

iv) the F_1 and F_2 generations of the crosses between the nine mutants and Jyothi.

v) the F_1 and F_2 generations of the crosses between the nine mutants in all possible combinations without reciprocals.

II. Mutagens

Physical as well as chemical mutagens were used for the induction of mutation.

i) Physical mutagen

Gamma irradiation was done using the ^{60}Co source at the Department of Botany, Kerala University, Karyavattom. A wide range of doses from 10 to 45 krad at increments of 5 krad were tried to get maximum incidence of mutations so as to isolate useful viable plant type (dwarf and semidwarf) mutants.

ii) Chemical mutagen

The most effective chemical mutagen, viz., ethyl methane sulphonate ($CH_3SO_2-O-C_2H_5$) at three concentrations, viz., 0.5%, 1.0% and 1.5% was employed for induction of mutations.

B. METHODS

I. Induction and isolation of mutants

i) Selection of seeds

Well filled grains of uniform size were hand picked to obtain samples of the three varieties (Ptb-9, 10, 28) for mutagenic treatment. Seeds were uniformly dried and stabilized for moisture content at 10 to 12 per cent. The viability of the seeds was confirmed through germination tests conducted separately.

ii) Treatment of seeds with gamma rays

Selected seeds from the three varieties were packed in samples of 200 in small polythene covers. The seeds were spread evenly in the covers to ensure uniform exposure to the radiation. The seeds were irradiated through a single exposure. The doses were regulated by adjustment of time.

The procedure for treatment with EMS was based on the recommendations of the third FAO/IAEA research co-ordination meeting on the use of induced mutations in rice breeding (Anon., 1967). Three samples of seeds in each of the varieties, Ptb-9, Ptb-10 and Ptb-28 were pre-soaked in water for 16 hours. At the end of the pre-soaking period, the seeds were drained and pressed between folds of blotting paper to remove the superficial water. 50 ml EMS solutions of the required concentrations were taken in conical flasks and the seeds were dropped into the mutagen solution. The quantity of the mutagen solution was sufficient to cover the seeds completely. The seeds were stirred intermittantly and retained in the mutagen solution for eight hours at a temperature of 28°C. The chemical was then drained off and the seeds were thoroughly washed with distilled water.

A set of seeds soaked in distilled water continuously for 24 hours served as the control for comparative studies.

iii) Handling of materials after mutagen treatment

The seeds after mutagen treatment were handled in the immediate and subsequent generations as per the recommendations of the panel meeting on co-ordination of research on the use of mutations in rice breeding (Anon., 1966d).

iv) M_1 generation

Seeds treated with EMS were sown along with the control immediately after the treatment while the seeds treated with gamma rays were soaked in water for 24 hours before sowing. They were sown in petri dishes lined with wet filter paper in four replications, each containing 50 seeds.

The germinated seeds were transferred to the field nursery in earthen pots from the third day onwards. Each seed was sown flat on the soil surface with the embryo on the side at more or less uniform spacing. Sowing the seeds in earthen pots facilitated easy management. The seedlings were transplanted to the main field when they were 30 days old, in singles at a closer spacing of 20 cm between the rows and 10 cm within the row. The plants were provided with minimum fertility to avoid excessive growth.

The following observations were made in the M_1 generation.

1) Germination

Germinated seeds were counted in the petri dishes from the third day to the seventh day.

2) Survival

The number of surviving plants were estimated, both in the field nursery and in the main field. At the seedling stage, the surviving seedlings were counted on the 30th day. In the main field, the surviving plants were counted at flowering. All plants with green colour were counted as surviving.

3) Plant height

Seedling height was measured on the 30th day at the time of transplanting. Plant height was measured in the main field at flowering. Measurements were taken on 20 plants selected at random from each replication of each treatment.

4) Seed fertility

Seed fertility was estimated by counting the grain and chaff on five ears each, selected from the 20 plants.

5) Abnormalities in seedlings

Counts on abnormalities such as narrow and crinkled leaved seedlings were taken in the nursery.

6) Harvesting M_1 plants

The main and four primary ears were tagged and harvested separately from each plant. Thus a total of five ears were harvested from each of the M_1 plants.

v) M_2 generation

The seeds of the M_1 plants were sown in raised nursery beds of 3.0 x 1.0 x 0.3 m. Seeds from each plant were sown in five separate lines, each line containing seeds from an ear. The following observations were recorded at the seedling stage in the M_2 generation.

1) Chlorophyll mutations

Chlorophyll deficient plants were scored in the nursery from the 10th day onwards after sowing. The ear progenies segregating for chlorophyll mutants were scored to calculate mutation frequency per 100 M_1 plants and per 100 M_1 ears. A maximum of 50 plants from one end in each ear-progeny row was scored to count the total number of mutants and normal seedlings and the mutant frequency per 100 M_2 plants was estimated. In segregating progenies, the mutant and normal seedlings were counted separately. The chlorophyll mutants were classified according to the system suggested by Gustafsson (1940) and expanded by Konzak et al. (1968).

2) Viable mutations

Among the viable mutants, seedlings with reduced height could be readily recognised in the nursery. Such seedlings with reduced height were scored on the 30th day.

Thirty-day old seedlings were transplanted in the main field as ear progeny rows. Single seedlings were planted at a wider spacing of 25 cm between the rows and 20 cm within the rows. All the available seedlings were transplanted from each ear.

Individual plants were observed periodically from the 15th day onwards after transplanting, to identify the mutants which differed from the normal plants phenotypically. From among the mutants identified, plant type semidwarf mutants were located. They were marked and the tall plants around them were removed so that the growth of the mutant might not be affected. The mutants were periodically observed to study their growth pattern. The viable mutants selected were described for their morphological characters. The mutants identified and isolated were harvested separately. Observations on the following characters were made on the mutants.

a) Plant height

Height was measured from the groundto the tip of the flag leaf. The culm length was recorded from the ground level to the neck of the ear.

b) Duration

Number of days upto harvest was recorded.

c) Leaf shape, size, colour and orientation

The upper most leaf below the flag leaf was used for measuring the length and width. Leaf length was measured from the junctura to the tip. Width was recorded at the widest portion of the lamina. Based on the orientation, the leaves were grouped as erect or drooping. Based on the width, the leaves were classified as broad (> 1.1 cm), narrow (0.8 to 1.1 cm) or very narrow (< 0.8 cm). Based on the colour, the leaves were pale green, green or dark green.

d) Tillers and tillering

The mutants were grouped as shy tillering, moderately tillering and heavy tillering based on the number of ear bearing tillers.

e) Plant type

Based on the stand of the plant and nature of the tillers, the plants were grouped as compact with compact tillers, medium with slanting tillers and open with wide open or spreading tillers.

f) Lodging at maturity

Based on the nature of the culm, the plants were weak or strong. The plants were described as lodging or nonlodging based on the tendency to lodge after heading but before maturity.

g) Ear and grain characters

The number of productive tillers were recorded. The length of the ears was measured from the base to the tip. Based on the nature, the ears were compact, medium or open. The mean number of grains per ear was estimated by counting the grains in five ears. Based on exsertion, the ears were either exserted or partially exserted. The size of the grains was determined based on 1000 grain weight.

vi) M_3 generation

M_3 generation was raised from the seeds obtained from the mutants in the M_2 generation to confirm their mutant nature. M_2 plants were harvested separately and the M_3 generation raised under almost identical conditions. The observations recorded in the M_2 were recorded in the M_3 also.

vii) Selection of plant type mutants

Semidwarf plant type mutants with compact tillers, erect dark green leaves and nonlodging habit conforming to the concept of high yielding varieties (Beachell, 1966) were selected from the M_3 generation. These height mutants were described in detail for their morphological characters using the descriptive blank proposed by Ramiah (1938) and Chang and Bardenas (1964) with suitable modifications.

II. Genetic analysis of the mutants

The nine semidwarf mutants selected from the M_3 generation (M_2, M_6 and M_{14} from Ptb-9; M-102, M 107 and M 111 from Ptb-28 and M 202, M 207 and M 210 from Ptb-10) were grown in earthen pots along with the parental varieties and Jyothi. Three sets of seeds in each type were sown at intervals of 10 days to get synchronised flowering to facilitate crossing.

i) Hybridisation

The following crosses were undertaken

1) The nine mutants with their respective tall parents to confirm the genetic nature of the mutants.

2) The nine mutants with Jyothi to study the genic relationship of the mutants with the Dgwg dwarfing gene.

3) Between the nine mutants in all possible (36) combinations without reciprocals to study the genic relationship between them.

Wet cloth method was adopted for emasculation of the spikelets. Hand pollination of the emasculated spikelets was effected at 9.00 AM with the pollen collected from the desired pollen parent. The pollinated panicles were protected by covering with butter paper cover immediately after dusting of the pollen.

ii) F_1 generation

The F_1 generation of the 54 combinations as follows were grown and studied.

1) Mutants with the respective tall parents - 9 Nos.
2) Mutants with Jyothi .. - 9 Nos.
3) Between the mutants .. - 36 Nos.

The four parental varieties and the nine mutants were also grown along with the hybrids for comparison. Data on the following characters were recorded.

Plant height: Identified as tall, semidwarf or dwarf based on the height. Measurements of culm length was also made.

Plant type: Recorded as open, medium or compact.

Internode: The number of internodes and the mean length of the internode for studying the pattern of internode elongation.

Leaf: Nature of orientation, length, width and colour.

Straw: Weak or sturdy, lodging or not.

Ears: Number of ears.

Ear characters: Exserted, partially exserted or enclosed;

compact, semiopen or open; length of ear; number of grain; 1000 grain weight.

Inferences on the genetic nature of each mutants in relation to its parent, the variety Jyothi and the other mutants were drawn tentatively based on the plant type of the hybrid.

iii) F_2 generation

The F_1 of all the 54 cross combinations were selfed and harvested separately. The F_2 was raised on plant progeny basis and scored for height and plant type segregation. The segregating plants were classified as tall (above 110 cm), semidwarf (between 71 to 110 cm) and dwarf (70 cm and below). The chi-square test of goodness of fit was employed.

RESULTS

EXPERIMENTAL RESULTS

I. Induction of mutations

a) Effect of mutagens in the M_1 generation

The effect of gamma rays and EMS on germination of seeds, plant survival, plant height and seed fertility was estimated.

Germination:

Data on the percentage of germination recorded on the 4th and 7th days and the mean period for germination are presented in table 1. Even high doses of gamma rays did not affect the germination of the seeds appreciably while germination decreased progressively with increasing doses of [illegible]. The percentage of germination recorded on the 7th day was more than that recorded on 4th day, especially at the higher doses of the mutagens. Considerable delay in germination was observed at higher doses of both the mutagens as shown by an increase in the mean period of germination. However, there was no difference in varietal response to the mutagens as indicated by the percentage of germination and the mean period for germination.

Survival:

The percentage of survival of the seedlings in the nursery at 30 days and that of the plants in the main field at flowering were recorded and presented in table 2. Gamma rays

Table 1. Effect of gamma rays and EMS on germination of seeds in the M_1

Mutagen and dose	Germination percentage						Mean period for germination					
	Ptb-9		Ptb-10		Ptb-28		in days			as % of control		
	4th day	7th day	4th day	7th day	4th day	7th day	Ptb-9	Ptb-10	Ptb-28	Ptb-9	Ptb-10	Ptb-28
Control	100.0	100.0	100.0	100.0	100.0	100.0	3.0	3.0	3.0	100	100	100
Gamma rays:												
10 krad	96.0	96.0	95.5	96.0	96.0	97.0	3.0	3.1	3.2	100	103	106
15 "	95.0	96.0	94.0	95.0	95.0	97.0	3.2	3.2	3.4	106	100	113
20 "	95.5	95.5	94.5	95.0	93.0	94.0	3.2	3.2	3.5	106	106	116
25 "	90.5	94.0	92.5	94.5	93.5	95.0	3.6	3.6	3.5	120	120	116
30 "	90.0	93.0	90.5	92.5	92.0	94.5	3.6	3.5	3.7	120	116	124
35 "	89.5	93.5	89.5	92.0	89.0	92.5	3.8	3.8	3.9	127	127	130
40 "	87.5	93.0	86.5	92.0	88.0	92.0	3.9	4.0	4.1	130	133	136
45 "	85.5	92.0	84.5	91.5	83.5	91.5	4.1	4.2	4.2	136	139	139
EMS 0.5%	95.0	95.0	93.5	94.5	92.5	93.5	3.1	3.3	3.3	103	109	109
1.0%	84.5	86.0	85.0	88.5	85.5	87.5	3.4	3.4	3.5	113	113	116
1.5%	81.5	83.5	78.5	84.5	79.5	82.5	3.6	3.8	3.9	120	127	130

Table 2. Effect of gamma rays and EMS on survival of plants in the M_1

Mutagen and dose	Survival (percentage of control)					
	at 30 days			at flowering		
	Ptb-9	Ptb-10	Ptb-28	Ptb-9	Ptb-10	Ptb-28
Control	100	100	100	100	100	100
Gamma rays:						
10 krad	100	98	98	100	98	97
15 "	98	98	100	98	99	98
20 "	98	98	99	97	96	96
25 "	98	96	97	96	96	95
30 "	95	96	95	94	94	93
35 "	85	85	86	82	80	78
40 "	69	63	65	52	47	49
45 "	62	61	62	35	37	34
EMS 0.5%	96	95	95	92	90	89
1.0%	90	89	88	82	84	81
1.5%	83	83	82	79	78	76

caused lethality at higher doses with drastic decrease in survival of plants with increasing doses. EMS also proved to be lethal as indicated by decreased survival rates. A further reduction in survival was observed at the advanced stage of growth at higher doses of gamma rays. But such reduction in survival of plants was not noticed in treatment with EMS.

Plant height:

Seedling height on the 30th day at the time of transplanting and plant height at flowering were computed as percentages of the control and presented in table 3. Seedling height was found to decrease with increasing doses of both the mutagens. The magnitude of reduction was greater at the seedling stage than at flowering for the same dose of [illegible]. Comparing the two mutagens, EMS was more effective in reducing the seedling height than gamma rays but these plants partly recovered from injury at later stages of growth.

Seed fertility:

Data on seed fertility showed significant differences between treatments (Table 4). The percentages of seed fertility decreased with increasing doses of the mutagens. Even-though both the mutagens induced greater fertility reduction at higher doses, the effect was more drastic at higher doses of gamma rays than EMS.

Table 3. Effect of mutagens on seedling and plant height in the M_1

Mutagen and dose	Seedling height at 30 days (% of control)			Plant height at flowering (% of control)		
	Ptb-9	Ptb-10	Ptb-28	Ptb-9	Ptb-10	Ptb-28
Control	100	100	100	100	100	100
Gamma rays:						
10 krad	96	98	100	95	96	98
15 "	92	93	92	95	96	94
20 "	89	90	89	92	94	96
25 "	84	83	83	83	83	84
30 "	81	80	81	85	85	84
35 "	76	72	73	81	79	82
40 "	69	67	67	69	75	79
45 "	65	65	63	68	68	69
EMS 0.5%	85	84	84	92	90	94
1.0%	72	71	72	89	92	91
1.5%	60	62	60	92	90	89

Table 4. Effect of mutagens on seed fertility in the M_1

Mutagen and dose	Ptb-9		Ptb-10		Ptb-28	
	Mean	% of control	Mean	% of control	Mean	% of control
Control	95.5	100	89.5	100	93.0	100
Gamma rays:						
10 krad	72.9	76	75.4	84	73.6	79
15 "	68.6	72	69.3	77	68.0	73
20 "	40.3	42	41.7	47	43.7	47
25 "	35.0	37	29.9	33	35.2	38
30 "	20.3	21	21.0	23	25.8	28
35 "	18.5	19	18.5	20	16.4	18
40 "	15.7	16	16.2	18	16.0	17
45 "	12.2	13	11.8	13	15.4	17
EMS 0.5%	82.1	86	80.3	90	84.5	91
1.0%	78.9	83	77.5	86	78.0	84
1.5%	61.5	64	60.5	68	63.7	68

Abnormalities in seedlings:

Induced abnormalities in seedlings such as narrow and crinkled leaves were more at the higher doses of gamma rays. Such abnormal plants either got eliminated through lethality or recovered at later stages of growth and grew into normal plants.

b) Effect of mutagens in the M_2 generation

Chlorophyll mutations:

The frequency of chlorophyll mutations was estimated per 100 M_1 plants, 100 M_1 ears and 100 M_2 seedlings and the data presented in tables 5 to 7. The frequency increased upto 30 krad in the case of gamma rays. At higher doses (40 and 45 krad) the apparent drop in the frequency could be due to eliminations on account of lethality.

Intensity of colour and differences in the pattern of colour distribution formed the basis for the classification of chlorophyll mutants. The relative percentage of different types of mutants are presented in tables 8 to 10. *Albinas* were most frequent in gamma ray treatments, whereas, *viridis* was predominant in EMS treatments. *Albinas* and most of the *xanthas* perished and did not survive beyond the seedling stage.

Viable mutations:

All mutations affecting the morphology of the different

Table 5. Frequency of chlorophyll mutations in the M_2 (Ptb-9)

Mutagen and dose	Number of M_1 plant progenies		Number of M_1 ear progenies		Number of M_2		Mutation frequency		
	Scored	Segre-gating	Scored	Segre-gating	Seed-lings scored	Chloro-phyll mutants	Per 100 M_1 plants	Per 100 M_1 ears	Per 100 M_2 seed-lings
Control	50	-	150	-	2500	-	-	-	-
Gamma rays:									
10 krad	50	7	232	9	8342	68	14	3.88	0.81
15 "	50	9	243	13	7753	73	18	5.24	0.94
20 "	50	11	212	6	6541	79	22	2.83	1.21
25 "	50	8	185	12	5466	67	16	6.49	1.22
30 "	50	12	182	19	4842	54	24	10.43	1.15
35 "	50	13	143	21	2497	61	26	14.68	2.44
40 "	50	8	148	12	2311	59	16	8.10	2.55
45 "	50	2	164	2	943	7	4	1.21	0.74
DES 0.5%	50	12	217	16	5783	68	24	7.37	1.18
1.0%	50	13	243	22	6348	81	26	9.05	1.28
1.5%	50	17	154	18	3208	49	34	11.67	1.53

Table 6. Frequency of chlorophyll mutations in the M_2 (Ptb-10)

Mutagen and dose	Number of M_1 plant progenies		Number of ear progenies		Number of M_2		Mutation frequency		
	Scored	Segregating	Scored	Segregating	Seedlings scored	Chlorophyll mutants	Per 100 plants	Per 100 M_1 ears	Per 100 M_2 seedlings
Control	50	-	150	-	1500	-	-	-	-
Gamma rays:									
10 krad	50	9	298	12	9243	140	18	4.03	1.51
15 "	50	11	273	21	9005	143	22	7.69	1.59
20 "	50	11	279	23	7939	139	22	8.24	1.75
25 "	50	15	261	31	6837	225	30	11.88	3.30
30 "	50	17	238	33	7302	232	34	13.87	3.18
35 "	50	19	204	27	6518	209	38	13.24	3.21
40 "	50	5	193	9	4326	156	10	4.67	3.61
45 "	50	2	151	5	2377	39	4	3.31	1.64
EMS 0.5%	50	9	287	26	7992	192	18	9.06	2.40
1.0%	50	19	269	47	8407	237	38	17.48	2.82
1.5%	50	17	197	41	6716	189	34	20.81	2.81

Table 7. Frequency of chlorophyll mutations in the M_2 (Ptb-28)

Mutagen and dose	Number of M_1 plant progenies		Number of M_1 ear progenies		Number of M_2		Mutation frequency		
	Scored	Segregating	Scored	Segregating	Seedlings scored	Chlorophyll mutants	Per 100 M_1 plants	Per 100 M_1 ears	Per 100 M_2 seedlings
Control	50	-	150	-	2500	-	-	-	-
Gamma rays:									
10 krad	50	12	284	12	9317	143	24	4.22	1.53
15 "	50	12	236	19	8401	168	24	8.05	1.99
20 "	50	14	243	22	7694	197	28	8.88	2.56
25 "	50	11	223	26	6706	216	22	11.66	3.22
30 "	50	19	242	36	8127	204	38	14.88	2.51
35 "	50	13	194	33	4313	196	36	19.57	4.54
40 "	50	7	202	21	6344	218	14	10.40	3.43
45 "	50	1	146	9	2416	48	2	6.16	1.99
EMS 0.5%	50	10	293	24	8973	213	20	8.19	2.37
1.0%	50	22	275	43	8993	241	24	15.64	2.68
1.5%	50	21	213	39	6811	197	22	18.31	2.89

Table 8. Relative percentage of different types (spectrum) of chlorophyll mutants in the M_2 (Ptb-9)

Mutagen and dose	Total number of mutants	Relative percentage of chlorophyll mutants					
		A	X	V	C	S	Others
Gamma rays:							
10 krad	68	80.8	13.2	4.5	-	1.5	-
15 "	73	80.8	8.2	9.6	1.4	-	-
20 "	79	64.5	10.1	12.7	5.1	5.1	2.5
25 "	67	71.6	4.5	14.9	4.5	4.5	-
30 "	54	66.7	18.5	11.1	-	-	3.7
35 "	61	63.8	11.5	16.4	3.3	1.7	3.3
40 "	59	54.4	13.4	15.2	5.1	3.4	8.5
45 "	7	42.8	57.2	-	-	-	-
EMS 0.5%	68	29.4	10.3	57.4	-	2.9	-
1.0%	81	13.5	14.8	49.4	7.4	3.7	6.2
1.5%	49	30.6	8.2	46.9	6.1	6.1	2.1

A-Albina, X-Xantha, V-Viridis, C-Chlorina, S-Striata

Table 9. Relative percentage of different types (spectrum) of chlorophyll mutants in the M_2 (Ptb-10)

Mutagen and dose	Total number of mutants	Relative percentage of chlorophyll mutants					
			X	V	C	S	Others
Gamma rays:							
10 krad	140	84.3	10.7	4.3	-	0.7	-
15 "	143	65.7	18.2	12.6	3.5	-	-
20 "	139	69.8	12.2	10.8	5.8	1.4	-
25 "	225	60.0	19.7	8.4	6.7	4.0	1.3
30 "	232	65.1	26.7	3.4	2.2	2.6	-
35 "	213	69.9	23.5	3.3	1.4	1.9	-
40 "	156	66.0	15.4	8.3	4.5	4.5	1.3
45 "	39	79.5	5.1	-	7.7	7.7	-
EMS 0.5%	192	24.7	14.6	40.6	8.3	3.6	4.7
1.0%	237	30.8	15.2	47.7	1.7	1.7	2.9
1.5%	189	13.8	15.3	62.4	6.9	1.6	-

A-Albina, X-Xantha, V-Viridis, C-Chlorina, S- Striata

Table 10. Relative percentage of different types (spectrum) of chlorophyll mutants in the M_2 (Ptb-28)

Mutagen and dose	Total number of mutants	Relative percentage of chlorophyll mutants					
		A	X	V	C	S	Others
Gamma rays:							
10 krad	143	72.0	14.7	10.5	-	-	2.8
15 "	163	76.2	7.7	7.7	3.6	2.4	2.4
20 "	197	73.1	11.7	8.1	3.6	2.5	1.0
25 "	216	58.8	17.1	18.6	0.9	2.8	1.8
30 "	204	65.7	13.3	14.2	1.9	1.9	2.5
35 "	196	77.6	11.2	9.7	1.5	-	-
40 "	218	68.3	18.3	10.6	0.5	0.9	0.9
45 "	48	33.3	39.6	18.8	-	-	8.3
EMS 0.5%	213	31.4	18.0	56.8	1.4	0.5	1.9
1.0%	241	31.1	7.5	55.7	3.3	1.2	1.2
1.5%	197	25.1	13.3	55.0	2.1	0.5	3.1

A-Albina, X-Xantha, V-Viridis, C-Chlorina, S-Striata plant parts except chlorophyll deficient types were classed as viable mutations. Such mutations were detected in individual plants in the M_2 generation by visual observation. The induced changes in certain cases affected one or more characters of a plant at the same time.

The viable mutation frequencies estimated separately for the three varieties as mutations per 100 M_1 ears are presented in table 11. The frequencies were found to increase with increasing doses of gamma rays as well as EMS. They did not differ appreciably in the three varieties.

A wide spectrum of mutations affecting various morphological characters such as height, duration, leaf, panicle and grain were identified and isolated. The relative percentages of height, duration and leaf type mutants are given in table 12. The type of mutations induced by the two mutagens did not differ. But differences were observed in the relative frequencies of the different types with predominance of the mutants affecting culm length. Mutants with altered duration were more frequent among the types induced by gamma rays. Dwarfs and semidwarfs among the mutants affecting culm length and late types among the mutants with altered maturity period, were predominant. Mutants with enhanced effects such as tall stature and very long duration were also among the types induced.

Table 11. Frequency of viable mutations in the M_2

Mutagen and dose	Ptb-9			Ptb-10			Ptb-28		
	Number of M_1 ear progenies		Mutation per 100 M_1 ears	Number of M_1 ear progenies		Mutation per 100 M_1 ears	Number of M_1 ear progenies		Mutation per 100 M_1 ears
	Scored	Segregating		Scored	Segregating		Scored	Segregating	
Control	100	-	-	100	-	-	100	-	-
Gamma rays:									
10 krad	100	9	9.0	100	7	7.0	100	8	8.0
15 "	100	17	17.0	100	17	17.0	100	18	18.0
20 "	100	24	24.0	100	22	22.0	98	23	23.7
25 "	98	29	29.6	100	31	31.0	93	26	27.9
30 "	92	27	29.3	91	26	28.6	86	24	27.9
35 "	85	33	38.8	89	35	39.3	84	32	38.1
40 "	63	31	49.2	72	36	50.0	58	30	51.7
45 "	57	23	40.1	51	25	49.0	56	28	50.0
EMS 0.5%	100	8	8.0	100	8	8.0	100	6	6.0
1.0%	100	28	28.0	100	27	27.0	100	28	28.0
1.5%	97	39	40.2	89	36	40.4	96	38	39.6

Table 12. Relative percentage of height, duration and leaf type mutants in the M_2

	Number of mutants		Relative percentage	
	Gamma rays	EMS	Gamma rays	EMS
Height mutants:				
Tall	2	4	33.3	66.7
Semidwarf	22	43	33.8	66.2
Dwarf	9	13	40.9	59.0
Duration mutants:				
Early	6	2	75.0	25.0
Late	8	3	72.7	27.3
Very late	1	-	100.0	-
Leaf type mutants:				
Narrow	3	1	75.0	25.0

Height mutants:

Mutants affecting culm length alone were selected for detailed study. They appeared in three distinct classes.

i) Those which were taller than the parental types (above 140 cm for mutants of Ptb-9, above 135 cm for mutants of Ptb-28 and above 122 cm for mutants of Ptb-10).

ii) Those which could be classified as semidwarfs (71 cm to 110 cm).

iii) Those which were dwarfs (70 cm and below).

Out of the 93 height mutants identified, six were tall, 65 semidwarf and 22 dwarf (Table 13). Fortyone mutants were selected for morphological analysis. Description of these height mutants is given in table 14.

The 41 mutants exhibited variation in height (Figure 11) ranging from 61 cm (Ptb-[illegible] mutant - [illegible]) to 15[illegible] cm (Ptb-28 mutant - M 104). The tall stature was due to an elongation of internodes and not due to an increase in the number of internodes. The semidwarfs also appeared to have the same number of internodes as the parent types. The reduction in height was due to reduced length of the internodes. But in the dwarfs, the number as well as length of the internodes have been reduced. The lower most internode could not be recognised in certain cases due to the drastic reduction in its length. Dwarfs therefore appeared to possess smaller

Table 13. Distribution of viable height mutants - mutagen wise

Muta~~tion~~gen and dose	Tall	Semidwarf	Dwarf
Gamma rays 10 krad	-	-	-
15 "	-	-	-
20 "	-	2	-
25 "	-	3	-
30 "	-	9	2
35 "	2	8	2
40 "	-	-	5
45 "	-	-	-
EMS 0.5%	1	3	-
1.0%	2	24	3
1.5%	1	16	10
Total	6	65	22

Table 14. Description of the height mutants

Sl. No.	Parents/ mutants	Plant height (cm)	Number of inter-nodes	Duration (days)	Plant type	Lodging	Leaf length (cm)	Leaf width (cm)	Leaf orientation	Leaf colour
1	2	3	4	5	6	7	8	9	10	11
1	Ptb-9	138	6	130	open	susceptible	56	0.9	drooping	pale green
2	M 1	92	6	128	compact	resistant	32	1.2	erect	green
3	M 2	94	6	115	compact	resistant	30	1.1	erect	dark green
4	M 3	98	6	132	medium	susceptible	44	1.2	erect	green
5	M 4	103	6	130	compact	resistant	33	1.2	erect	dark green
6	M 5	61	5	78	compact	resistant	14	0.5	erect	dark green
7	M 6	88	6	120	compact	resistant	34	1.4	erect	dark green
8	M 7	95	6	130	medium	susceptible	45	1.2	drooping	green
9	M 8	102	6	132	medium	susceptible	46	1.3	drooping	green
10	M 9	154	6	156	open	susceptible	61	1.2	drooping	pale green
11	M 10	62	5	85	compact	resistant	25	0.6	erect	dark green
12	M 11	91	6	145	open	susceptible	36	1.2	drooping	green
13	M 12	98	6	142	medium	resistant	42	1.1	erect	green
14	M 13	146	6	132	open	susceptible	58	0.9	drooping	pale green
15	M 14	95	6	120	compact	susceptible	34	1.3	erect	dark green
16	M 15	158	6	175	open	susceptible	60	1.2	drooping	pale green
17	Ptb-28	135	6	115	open	susceptible	52	1.1	drooping	pale green
18	M 101	98	6	102	compact	resistant	41	1.1	erect	pale green
19	M 102	93	6	110	compact	resistant	34	1.2	erect	dark green
20	M 103	103	6	102	medium	susceptible	44	1.1	drooping	pale green

(contd.)

Table 14 contd.

1	2	3	4	5	6	7	8	9	10	11
21	M 104	159	6	149	open	susceptible	49	1.0	drooping	pale green
22	M 105	105	6	115	medium	susceptible	48	0.9	erect	pale green
23	M 106	98	6	105	medium	resistant	47	0.9	drooping	pale green
24	M 107	92	6	115	compact	resistant	38	1.2	erect	dark green
25	M 108	93	6	98	medium	resistant	42	1.1	drooping	green
26	M 109	90	6	105	compact	resistant	42	1.2	erect	green
27	M 110	103	6	105	medium	resistant	36	0.9	erect	pale green
28	M 111	95	6	110	compact	resistant	34	1.1	erect	dark green
29	M 112	72	5	85	open	resistant	26	0.7	erect	green
30	M 113	106	6	115	medium	susceptible	41	1.0	drooping	pale green
31	Ptb-10	122	6	92	open	susceptible	48	0.8	drooping	pale green
32	M 201	95	6	92	open	resistant	46	0.9	drooping	pale green
33	M 202	39	6	89	compact	resistant	33	0.9	erect	dark green
34	M 203	98	6	93	compact	resistant	39	1.0	erect	green
35	M 204	39	6	92	medium	susceptible	34	0.9	drooping	pale green
36	M 205	88	6	92	medium	susceptible	35	0.8	erect	green
37	M 206	135	6	105	open	susceptible	49	0.8	drooping	pale green
38	M 207	91	6	93	compact	resistant	30	1.1	erect	dark green
39	M 208	88	6	90	medium	resistant	34	1.1	drooping	pale green
40	M 209	89	6	95	compact	resistant	36	1.1	erect	dark green
41	M 210	91	6	95	compact	resistant	33	1.3	erect	dark green
42	M 211	93	6	95	medium	susceptible	34	1.2	erect	green
43	M 212	98	6	95	medium	susceptible	34	1.1	drooping	green
44	M 213	88	6	93	compact	resistant	34	1.2	erect	green

HEIGHT OF MUTANTS AND VARIETIES

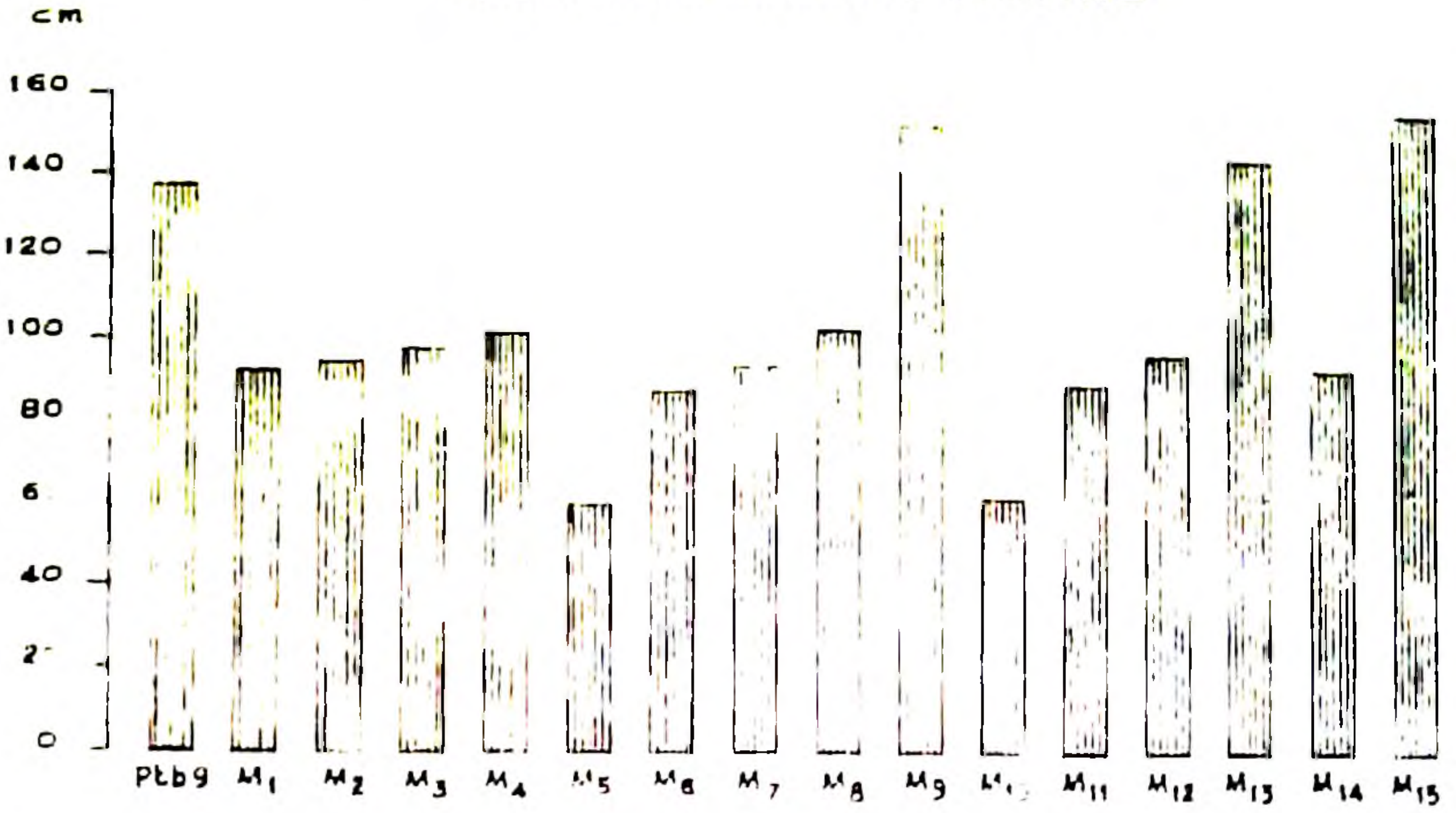


FIG 11-1

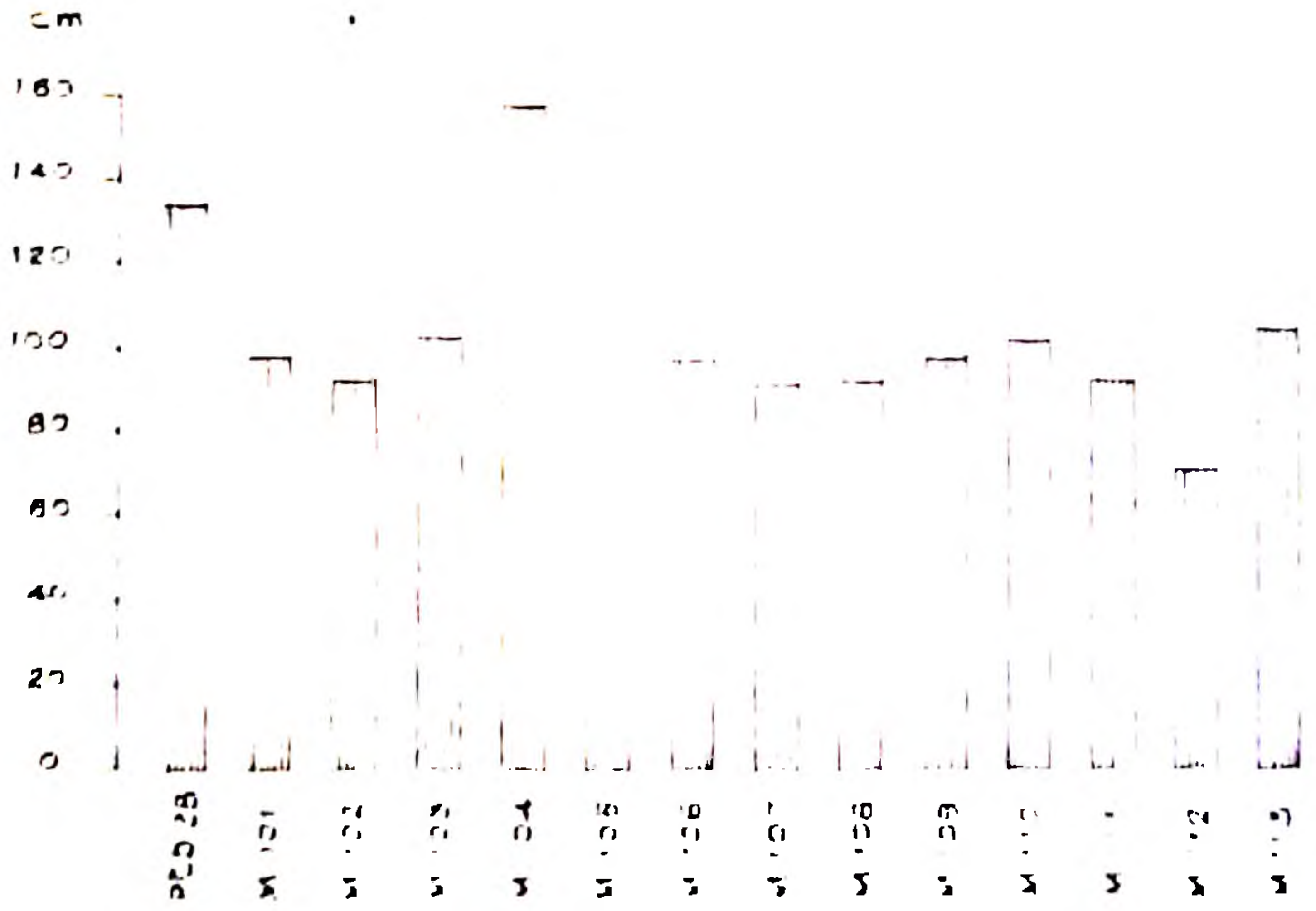


FIG 11-2

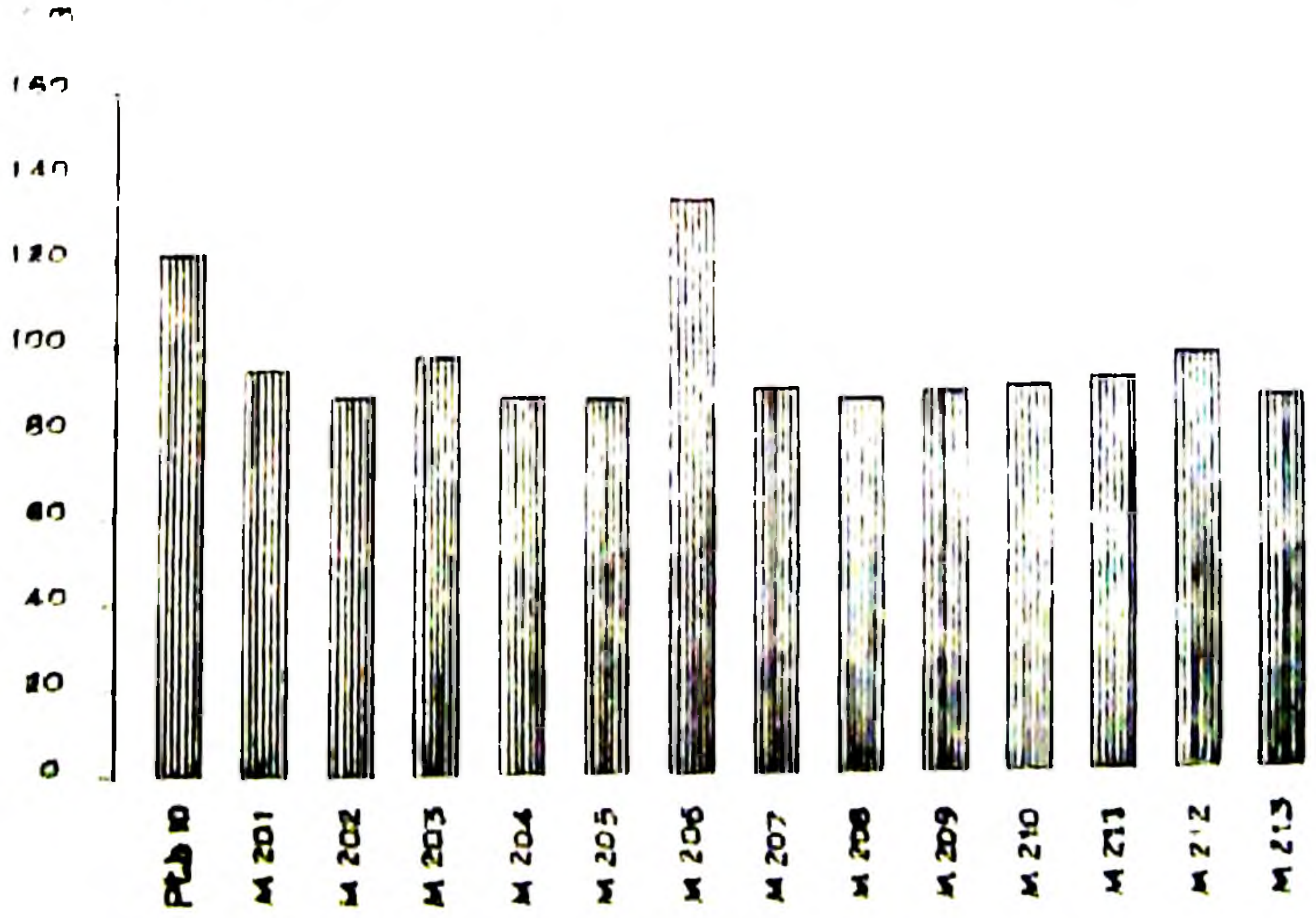


FIG 11-3

number of shortened internodes. Some of the height mutants are presented in figure III.

The duration, i.e., the number of days upto maturity ranged from 78 to 175 days for mutants of Ptb-9, from [illegible] to 105 days for mutants of Ptb-10 and from 85 to 149 days for mutants of Ptb-28 (Table 14). Both early and late mutants appeared. While most of the dwarfs were early maturing, the tall mutants generally showed a tendency for late maturity.

The parent varieties typically had open plant type with open tillers. All the tall mutants exhibited almost the same plant type. Out of the 34 semidwarfs, 16 only had compact plant type. The others were either open or medium open types. The compact types were typically characterized by erect leaves which were either green or dark green. The dwarfs were compact and had very narrow leaves showing grassy appearance.

All the tall plants lodged either at heading or before ripening of the grains. This was due to long and weak culm. Among the semidwarfs, those with compact tillers were invariably resistant to lodging while semidwarfs with open or medium open stand succumbed to lodging sometime after heading before ripening. The short and stout culm of the compact semidwarfs with the tight wrapping of leaf sheath over the culm have contributed to their lodging resistance. The dwarfs were highly nonlodging.

Figure III

Varieties and height mutants

i) Ptb-9 and height mutants

1, 5, 9 and 13-Ptb-9

Others - mutants


1
2
3
4


5
6
7
8


9
10
11
12


13
14
15
16

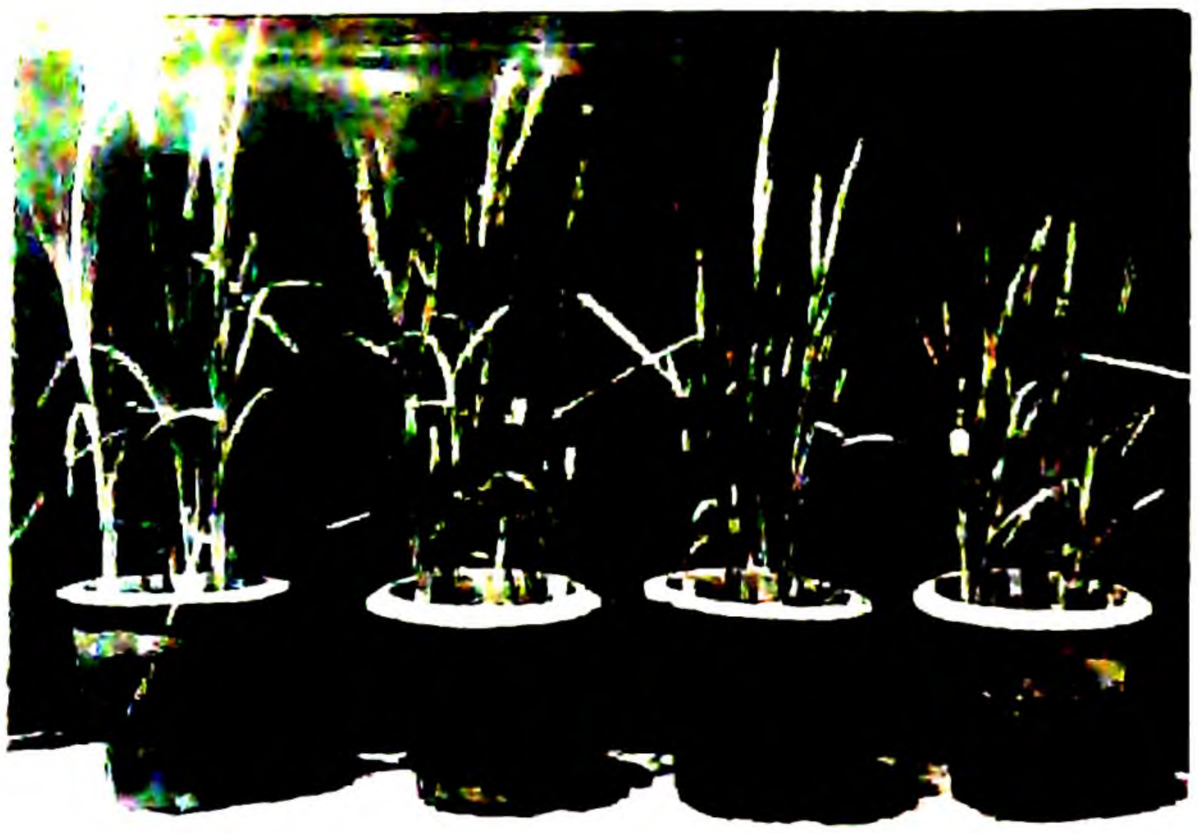
Figure III

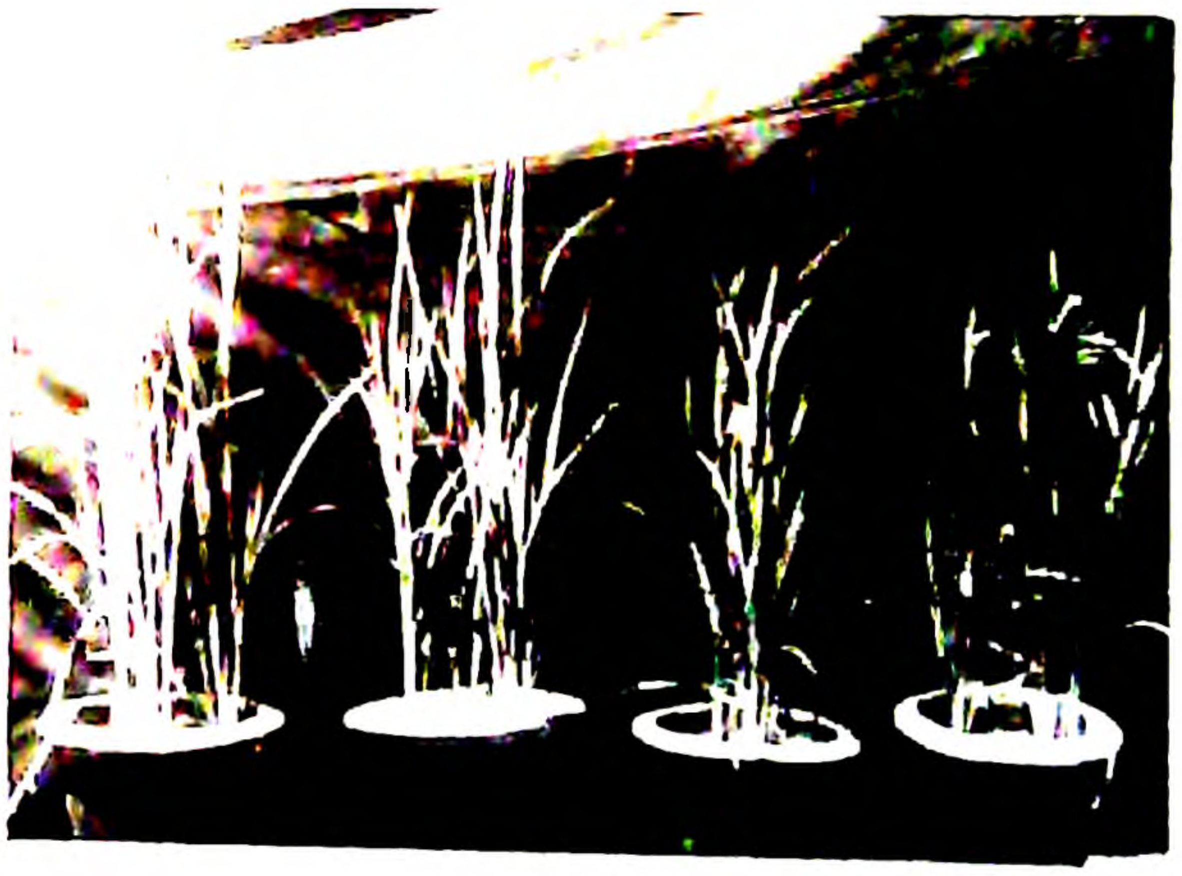
Varieties and height mutants

ii) Ptb-10 and height mutants

1 - Ptb-10

Others - mutants


1
2
3
4


5
6
7
8

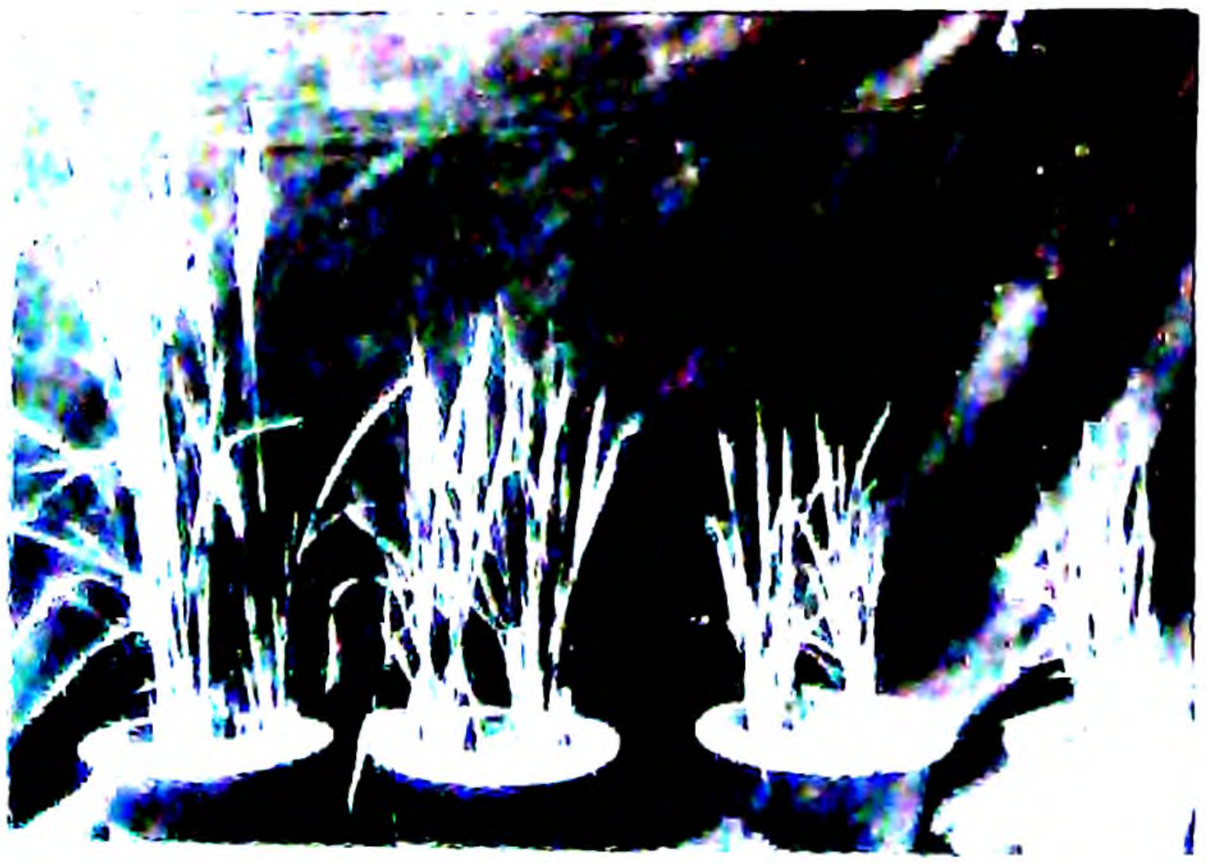

9
10
11
12

Figure III

Varieties and height mutants

ii) Ptb-10 and height mutants

1 - Ptb-10

Others - mutants


1
2
3
4


5
6
7
8


9
10
11
12

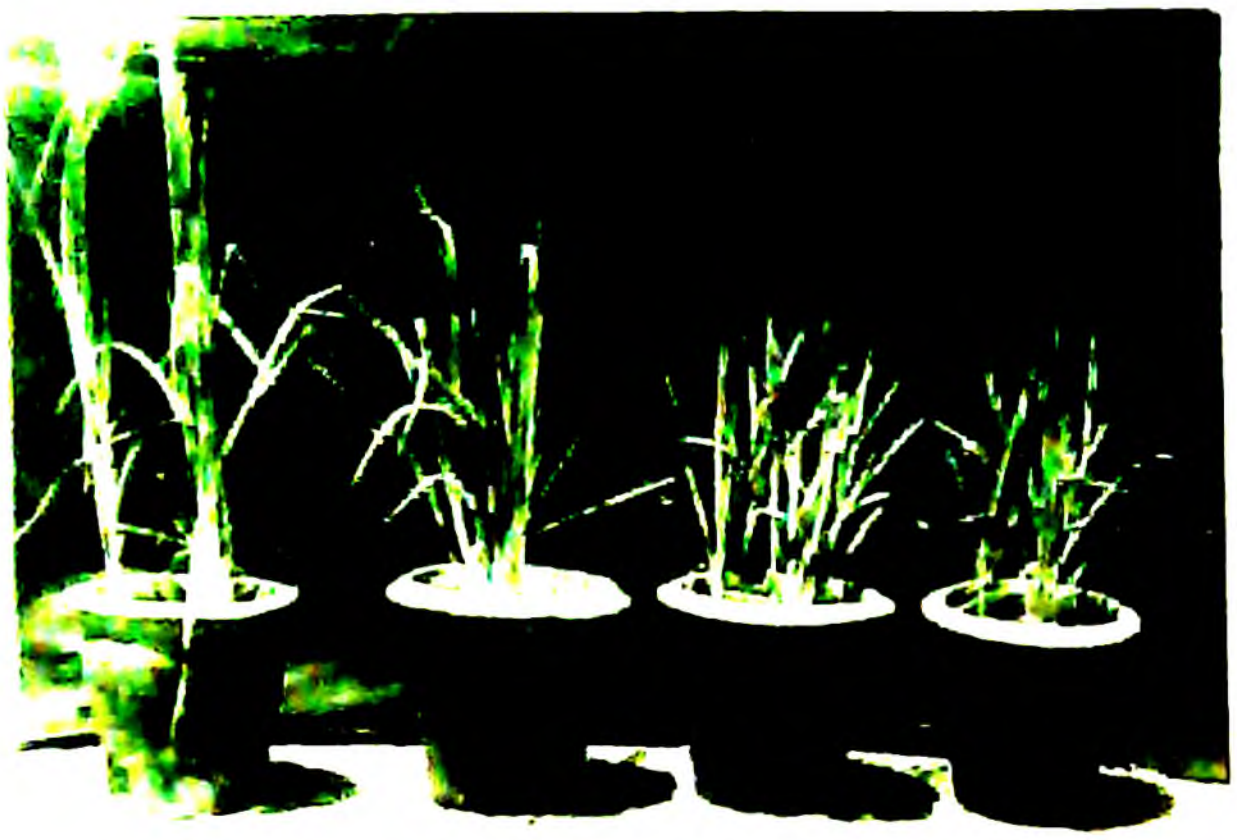
Figure III

Varieties and height mutants

iii) Ptb-28 and height mutants

1 - Ptb-28

Others - mutants


1
2
3
4


5
6
7
8


9
10
11
12

The length of the leaves varied from 14 cm (M 5) to 61 cm (M 9) and breadth (measured at the widest portion) ranged from 0.5 cm (M 5) to 1.4 cm (M 6). Tall mutants appeared to possess long leaves while semidwarfs had short leaves. Dwarf plants invariably had larger number of very narrow and thick leaves. Leaves had an erect orientation in the semidwarfs and dwarfs while they were either curving or drooping in talls. In the tall mutants, the leaves showed early senescence. The dwarfs and semidwarfs had relatively large number of functional leaves at maturity than the parents and the tall mutants. In most of the semidwarfs the flag leaf was functional at maturity. The colour of the leaves ranged from pale green to green in talls and to dark green in many of the semidwarfs and dwarfs.

The tall mutants appeared to be shy tillering (4 or 5 productive tillers) while the semidwarfs were moderately tillering (6 to 12 productive tillers) and dwarfs were profusely tillering (upto 75 productive tillers) as indicated in table 15. While the semidwarfs had a greater proportion of productive tillers to the total tillers, in dwarfs and talls the proportion was narrow. Among the semidwarfs, 14 types exhibited synchronised ripening of ears while the others had both ripened and unripened ears at the time of harvest presumably due to protracted tillering.

Table 15. Ear and grain characters of the height mutants

Sl. No.	Parents/ mutants	Number of ears per plant	Type of ear	Exsertion	Length of ears (cm)	Number of grain per ear	100 grain weight (g)
1	2	3	4	5	6	7	8
1	Ptb-9	6	open	exserted	23.3	79	2.76
2	M 1	7	open	exserted	22.4	98	2.81
3	M 2	9	medium	exserted	33.1	119	2.79
4	M 3	6	medium	partially exserted	21.9	105	2.76
5	M 4	8	open	"	23.2	120	2.78
6	M 5	76	open	exserted	9.5	12	2.19
7	M 6	10	medium	exserted	24.3	141	2.92
8	M 7	8	medium	partially exserted	23.4	117	2.72
9	M 8	8	open	"	21.8	122	2.68
10	M 9	4	open	exserted	20.2	91	2.74
11	M 10	69	open	partially exserted	10.2	14	2.23
12	M 11	6	open	"	20.6	73	2.72
13	M 12	8	medium	"	22.1	114	2.67
14	M 13	5	open	exserted	23.2	89	2.78
15	M 14	12	compact	exserted	23.9	138	2.92
16	M 15	4	open	partially exserted	21.2	83	2.80
17	Ptb-28	4	medium	exserted	24.5	87	2.87
18	M 101	9	open	partially exserted	22.3	126	2.85
19	M 102	8	medium	exserted	25.7	148	2.91

(contd.)

Table 15 contd.

1	2	3	4	5	6	7	8
20	M 103	7	medium	exserted	22.6	94	2.73
21	M 104	5	open	exserted	22.4	128	2.78
22	M 105	8	open	exserted	24.2	103	2.82
23	M 106	7	medium	exserted	24.6	99	2.82
24	M 107	9	medium	exserted	23.3	141	2.98
25	M 108	6	open	partially exserted	24.3	108	2.86
26	M 109	8	medium	exserted	22.8	132	2.79
27	M 110	7	medium	exserted	23.4	119	2.74
28	M 111	12	compact	exserted	25.6	116	2.94
29	M 112	45	medium	exserted	11.2	24	2.22
30	M 113	8	medium	exserted	24.8	127	2.56
31	Ptb-10	5	open	exserted	20.4	72	2.79
32	M 201	5	open	partially exserted	19.8	93	2.63
33	M 202	9	medium	exserted	21.8	94	2.84
34	M 203	9	open	exserted	19.4	86	2.75
35	M 204	8	open	partially exserted	20.1	103	2.74
36	M 205	5	open	"	19.0	108	2.74
37	M 206	5	medium	"	18.9	102	2.81
38	M 207	11	medium	exserted	20.9	98	2.88
39	M 208	8	open	exserted	18.7	121	2.79
40	M 209	6	medium	exserted	20.2	115	2.79
41	M 210	10	compact	exserted	21.9	187	2.92
42	M 211	4	open	exserted	18.3	131	2.79
43	M 212	6	open	partially exserted	17.6	107	2.68
44	M 213	8	medium	exserted	17.5	94	2.79

The number of ears, type of ear exsertion, length of ear, number of grains per ear and weight of 100 grains of the mutants are presented in table 15. The number of ears per plant ranged from 4 in tall types to 76 in dwarf types. The range of variation for ear length was from 9.5 cm in dwarfs to 25.7 cm in semidwarfs. The talls and semidwarfs appeared to possess ears of almost comparable length; but the number of grains per ear was greater in semidwarfs than in the talls indicative of higher grain density in the semidwarfs. The ears of semidwarfs were either completely or partially exserted. The weight of 100 grains ranged from 2.19 to 2.98 g. The shape of the grains varied from almost round to slender elongated.

All the 41 selected mutants were carried forward to the M_3 to confirm their mutant nature. The morphological features of each M_3 progeny were scored. The data did not show any appreciable variation from those in the M_2. The slight differences observed in quantitative estimation might be due to the effect of the season. This was seen in all the types including the parents.

II. Genetic analysis of plant type mutants

Nine morphologically distinct mutants with plant type characters (3 from each variety) were selected for genetic analysis (Figure IV). The detailed morphological description

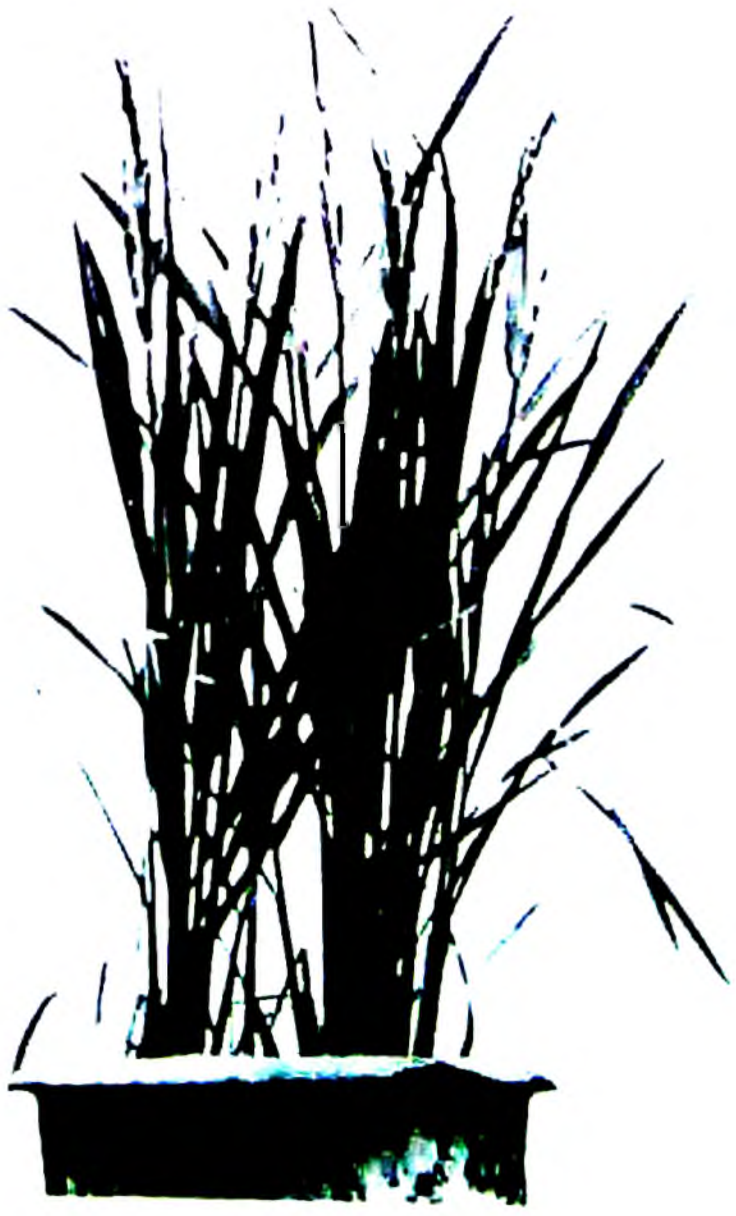
Figure IV

Plant type mutants selected for genetic analysis

M2

M 6

M 14



M 102

M 210

M 207

M 202

M 107

of these plant type mutants and the 4 varieties is given in table 16.

The mutants were semidwarf in stature with short erect leaves (Figure V) oriented at an angle of about 30 degrees to the vertical axis and have short erect flag leaves which remained functional at maturity. In contrast to the open plant habit of the parental types, they exhibited compact habit with moderate number of compact tillers. The leaves were green to dark green in colour as against the pale green leaves of the parents. The proportion of the functional to the dry leaves at maturity was high in most of the selected mutants. Eventhough the panicle length remained unchanged the number of grains per ear was considerably high in some mutants indicating high grain density. The mutants did not show difference in grain size and shape from the parental types. Even at maturity the mutants proved to be resistant to lodging, while the tall parents lodged well before maturity.

All the nine mutants were crossed with their respective parents to confirm their recessive genetic nature. To investigate the allelic relation of the induced dwarfing genes with the Dgwg dwarfing gene, the mutants were crossed with Jyothi, a known carrier of the Dgwg dwarfing gene. With the object of studying the allelic relationship of the dwarfing genes and their mode of inheritance the semidwarf mutants

Table 16. Detailed morphological description of the nine selected plant type mutants, their parents and Jyothi

Description	Ptb-9	M 2	M 6	M 14	Ptb-28	M 102	M 107	M 111	Ptb-10	M 202	M 207	M 210	Jyothi
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Culm:													
a) Diameter (cm)	1.7	1.6	1.5	1.6	1.3	1.5	1.5	1.4	1.3	1.3	1.2	1.5	1.6
b) Length (cm)	96	72	50	72	94	71	70	71	89	68	71	70	72
c) Bearing panicles	5	10	12	14	6	10	12	14	5	12	13	13	11
d) Not bearing panicles	3	3	3	2	4	2	2	3	3	3	2	3	3
e) Strength	weak	strong	strong	strong	weak	strong	strong	strong	weak	strong	strong	strong	strong
Leaf:													
a) Length (cm)	56	30	34	34	50	34	38	34	48	33	30	33	38
b) Width (cm)	1.0	1.1	1.4	1.3	1.1	1.2	1.2	1.1	0.9	0.9	1.1	1.3	1.1
c) Colour	pale green	dark green	dark green	dark green	pale green	dark green	dark green	dark green	pale green	dark green	dark green	dark green	dark green
Flag leaf angle	drooping	erect	horizontal	erect	horizontal	erect	curving	horizontal	drooping	horizontal	curving	erect	erect
Internode:													
a) Number	6	6	6	6	6	6	6	6	6	6	6	6	6
b) Length	16.0	11.9	11.0	12.1	15.6	11.9	11.7	11.9	14.8	11.4	11.8	11.7	11.9
Plant height (cm)	138	94	88	95	135	93	92	95	122	89	91	91	95
Lodging	susceptible	resistant	resistant	resistant	susceptible	resistant	resistant	resistant	susceptible	resistant	resistant	resistant	resistant
Plant type	open	compact	compact	compact	open	compact	compact	compact	open	compact	compact	compact	compact
Panicle:													
a) Type	open	medium	medium	compact	open	medium	medium	compact	open	medium	medium	compact	compact
b) Length (cm)	26	33	24	24	26	26	24	26	22	22	21	22	24
c) Number of grains	68	121	143	132	72	142	146	118	58	96	101	172	126
d) Exsertion	exserted	exserted	exserted	exserted	exserted	exserted	exserted	exserted	exserted	exserted	exserted	exserted	exserted
Spikelet sterility(%)	3.0	3.2	4.0	3.8	4.2	3.0	3.6	4.1	4.3	4.3	4.2	6.2	4.6
Pericarp colour	white	white	white	white	red	red	red	red	red	red	red	red	red
1000 grain weight (g)	27.8	27.9	28.8	28.9	23.2	29.1	28.9	29.5	27.9	28.5	28.7	29.2	28.1
Duration:													
a) Days to flowering	98	91	95	95	87	87	90	88	67	72	72	75	87
b) Days to maturity	130	115	120	120	115	110	115	110	95	89	93	95	107

SELECTED PLANT TYPE MUTANTS AND VARIETIES

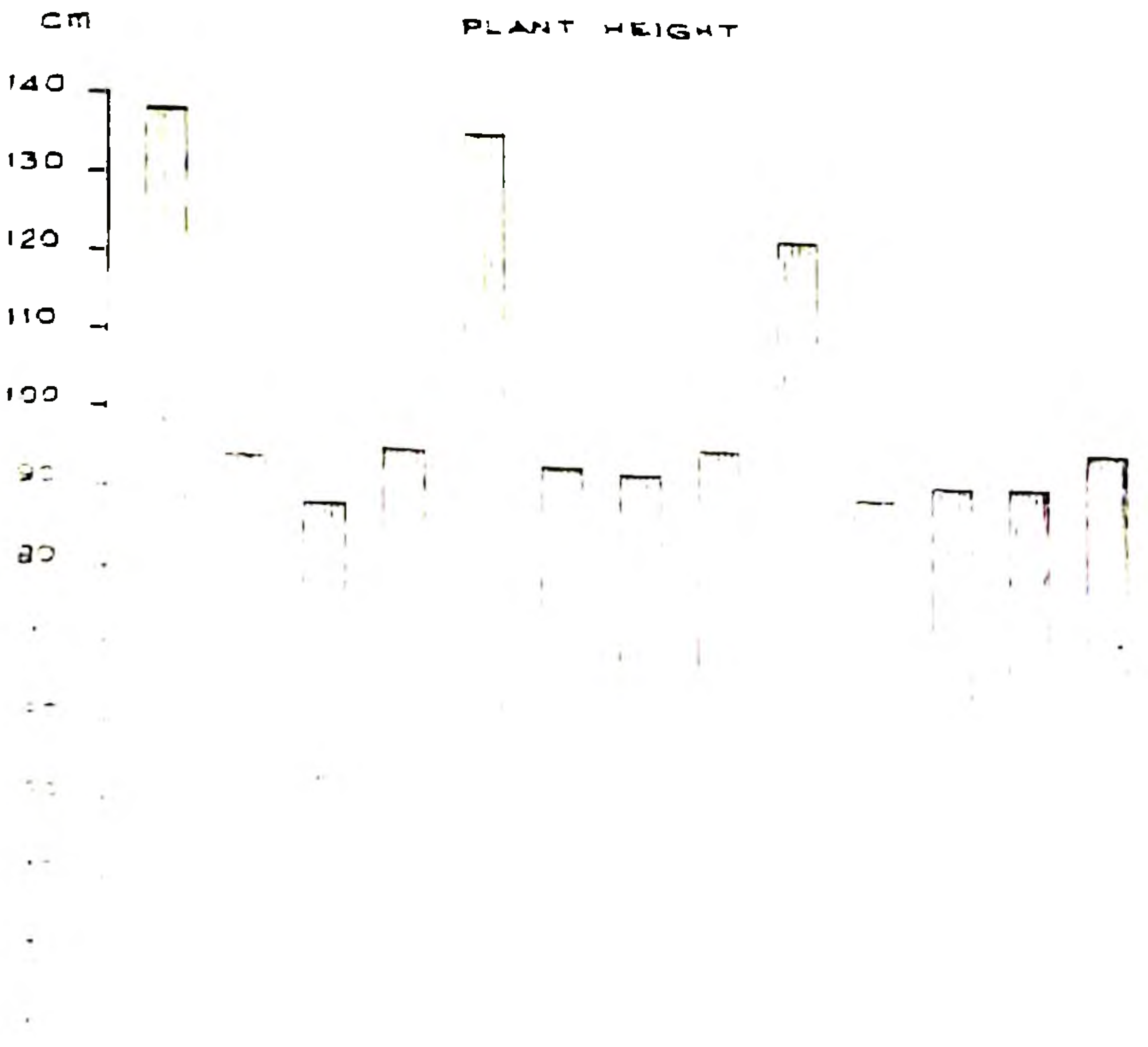


FIG
V-[illegible]

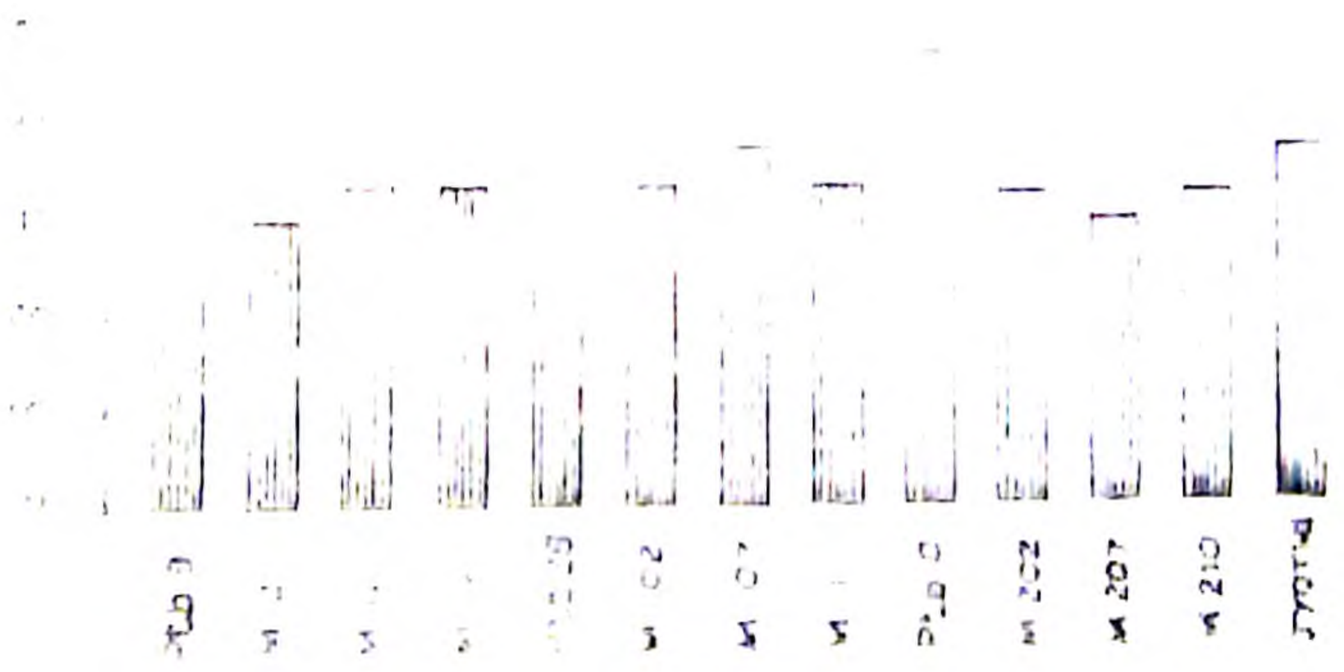


FIG
V-[illegible]

were crossed among themselves in all possible combinations.

a) Crosses with the parents:

i) M 2 x Ptb-9: The M_2 mutant was semidwarf (94 cm) with erect dark green leaves and Ptb-9 was tall (138 cm) with drooping pale green leaves. As shown in table 17, the F_1s were tall with a mean plant height of 141 cm (Figure VII). They had drooping leaves, elongated internodes and open plant habit and were susceptible to lodging. The pale green leaves exhibited early senescence. In the F_2 population, out of 287 plants, 209 had height above 110 cm and 78 fell within the range of 71 cm to 110 cm (Table [illegible]) [illegible] a bimodal distribution. A low frequency in classes of 101 to 110 cm and 111 to 120 cm (Figure VII-1), distinctly separated the two group of tall and semidwarf plants. The modal class observed for the tall plants was 131 to 140 cm and that for semidwarfs was 91 to 100 cm. The frequencies of the plants of the two groups, viz., tall and semidwarf fit to a 3:1 ratio with high probability. The tall segregants exhibited the character of the F_1 plants such as susceptibility to lodging, long drooping leaves, early senescence of leaves and open habit with weak tillers. The semidwarfs in the F_2 population were almost similar to the mutant parent.

ii) M 6 x Ptb-9: The height of F_1 plants ranged from 137 to 145 cm (Table 17) while M 6 had a mean height of 98 cm.

Table 17. Characters of the hybrids and parents in crosses between the mutants and their parents

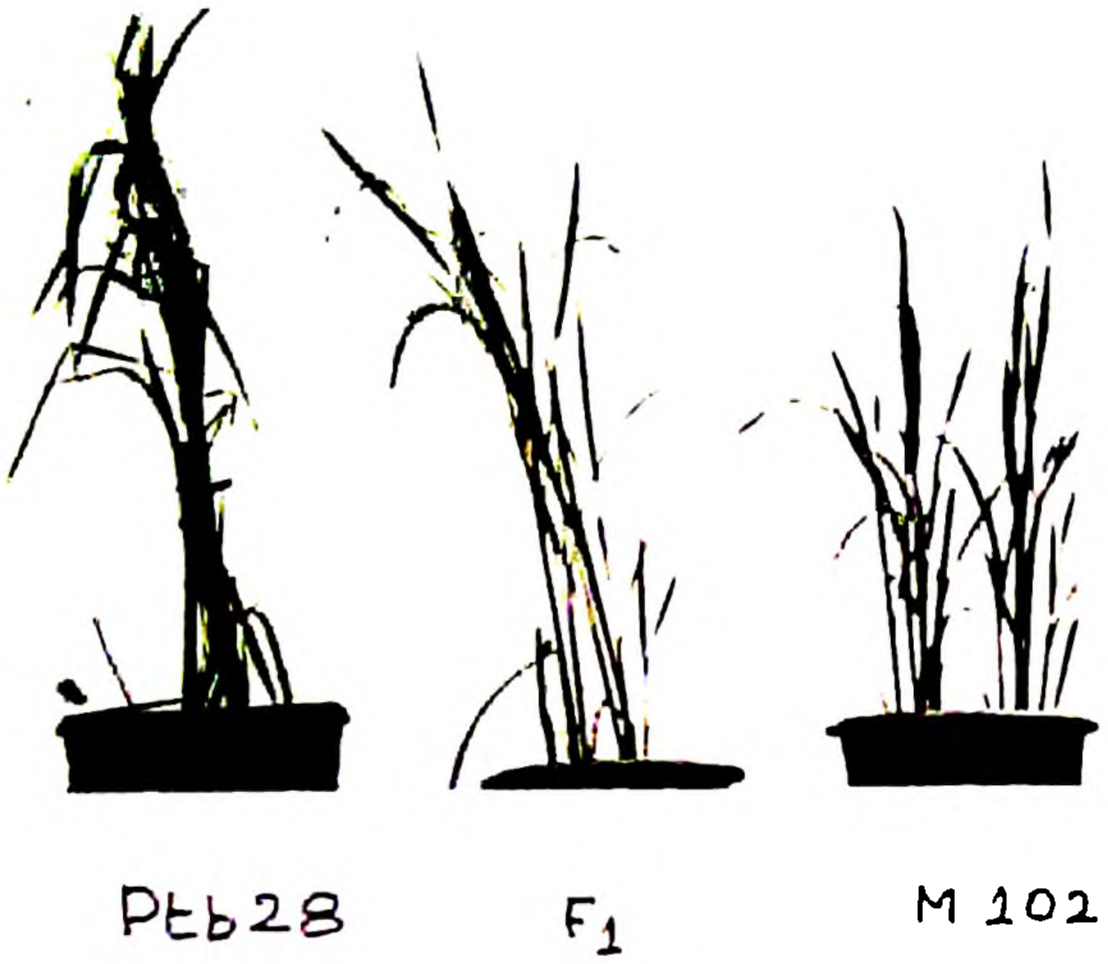
Sl No	Parent/ hybrid	Plant height (cm)		Number of internodes	Duration upto maturity (days)	Length of leaves (cm)	Orientation of leaves	Colour of leaves	Lodging	Plant habit
		Range	Mean							
1	Ptb-9	129-147	138	6	130	56	drooping	pale green	susceptible	open
2	M 2	89-102	94	6	115	30	erect	dark green	resistant	compact
3	M 6	80-93	88	6	120	34	erect	dark green	resistant	compact
4	M 14	85-104	95	6	120	34	erect	dark green	resistant	compact
5	M 2 x Ptb-9	136-145	141	6	123	54	drooping	pale green	susceptible	open
6	M 6 x Ptb-9	137-145	142	6	128	56	drooping	pale green	susceptible	open
7	M 14 x Ptb-9	133-140	136	6	126	54	drooping	pale green	susceptible	open
8	Ptb-28	127-143	135	6	115	52	drooping	pale green	susceptible	open
9	M 102	88-106	93	6	110	34	erect	dark green	resistant	compact
10	M 107	82-102	92	6	115	38	erect	dark green	resistant	compact
11	M 111	87-102	95	6	110	34	erect	dark green	resistant	compact
12	M 102xPtb-28	135-141	138	6	112	52	drooping	pale green	susceptible	open
13	M 107xPtb-28	130-135	132	6	112	52	drooping	pale green	susceptible	open
14	M 111xPtb-28	132-139	136	6	115	54	drooping	pale green	susceptible	open
15	Ptb-10	115-131	122	6	92	48	drooping	pale green	susceptible	open
16	M 202	78-95	89	6	89	33	erect	dark green	resistant	compact
17	M 207	78-99	91	6	93	30	erect	dark green	resistant	compact
18	M 210	76-98	91	6	95	33	erect	dark green	resistant	compact
19	M 202xPtb-10	118-124	120	6	95	48	drooping	pale green	susceptible	open
20	M 207xPtb-10	121-127	124	6	90	54	drooping	pale green	susceptible	open
21	M 210xPtb-10	124-131	128	6	95	53	drooping	pale green	susceptible	open

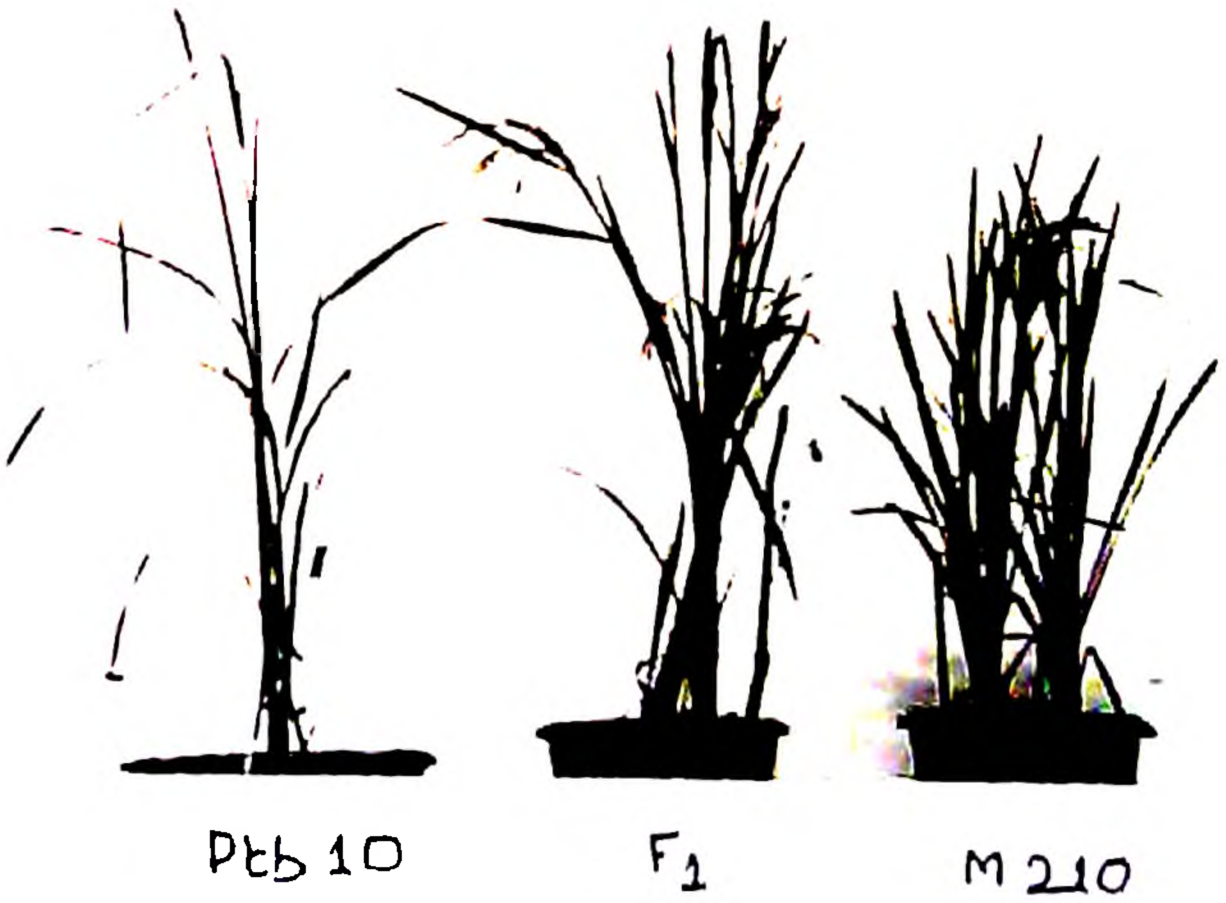
Table 18. Frequency distribution for height in crosses of mutants with their parents in F_2

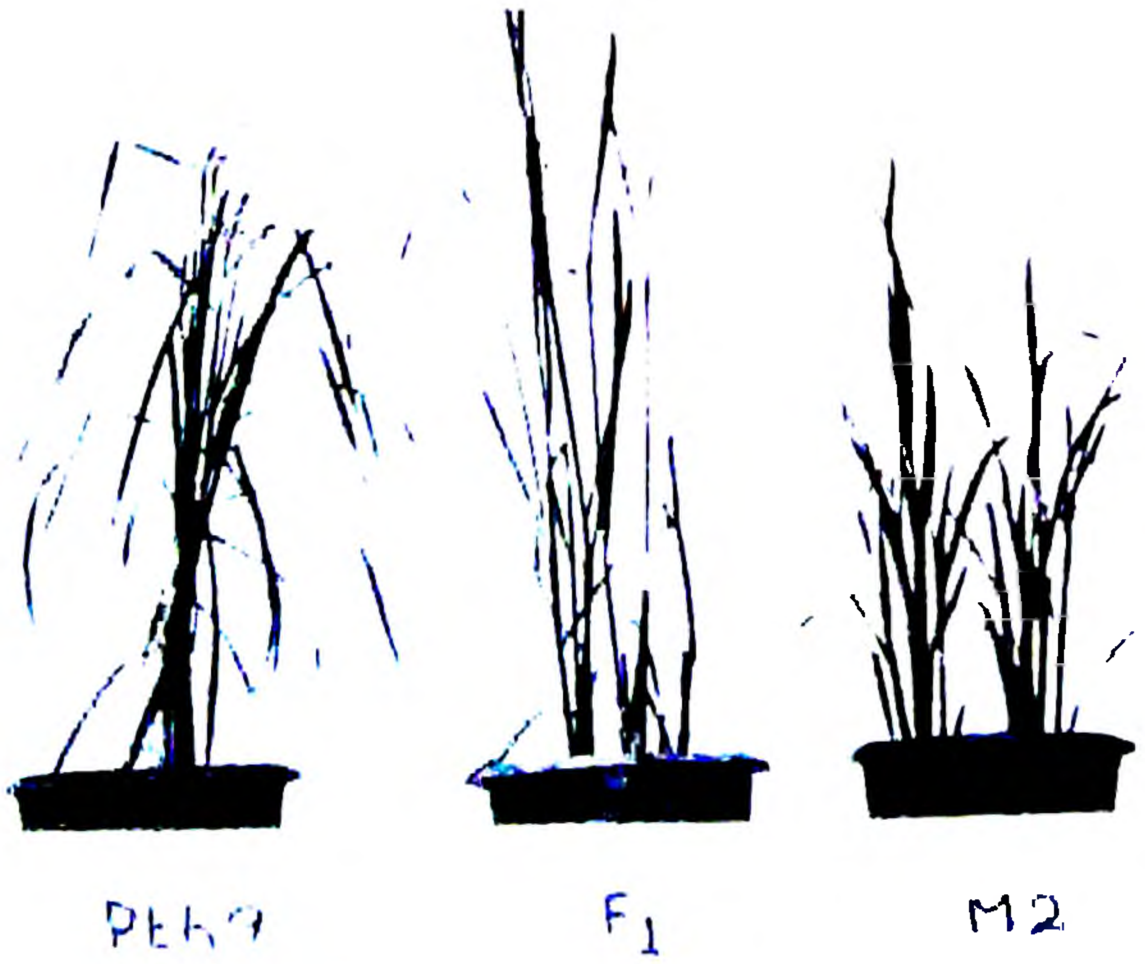
Sl. No.	Parents/crosses	Height classes in cm										Total	Tall	Semi-dwarf	Dwarf	χ^2 (3:1)
		61-70	71-80	81-90	91-100	101-110	111-120	121-130	131-140	141-150	151-160					
1	Ptb-9	-	-	-	-	-	-	5	39	6	-	50	50	-	-	-
2	M 2	-	-	8	35	7	-	-	-	-	-	50	-	50	-	-
3	M 2 x Ptb-9	-	5	26	43	3	3	70	142	64	8	287	209	78	-	0.667
4	M 6	-	6	27	17	-	-	-	-	-	-	50	-	50	-	-
5	M 6 x Ptb-9	-	1	41	50	7	6	90	123	26	5	347	248	99	-	2.209
6	M 14	-	-	6	41	3	-	-	-	-	-	50	-	50	-	-
7	M 14 x Ptb-9	-	1	3	97	4	18	117	134	9	3	386	281	105	-	0.878
8	Ptb-28	-	-	-	-	-	-	14	34	2	-	50	50	-	-	-
9	M 102	-	-	13	29	8	-	-	-	-	-	50	-	50	-	-
10	M 102 x Ptb-28	-	6	36	54	-	5	88	126	27	-	342	246	96	-	1.731
11	M 107	-	-	12	32	6	-	-	-	-	-	50	-	50	-	-
12	M 107 x Ptb-28	4	4	23	44	3	18	49	206	9	11	293	215	78	-	0.452
13	M 111	-	-	3	45	2	-	-	-	-	-	50	-	50	-	-
14	M 111 x Ptb-28	-	3	33	78	1	9	41	194	35	4	388	283	105	-	0.876
15	Ptb-10	-	-	-	-	-	21	26	3	-	-	50	50	-	--	-
16	M 202	-	3	18	29	-	-	-	-	-	-	50	-	50	-	-
17	M 202 x Ptb-10	8	22	38	6	18	64	156	14	2	-	328	254	74	-	1.040
18	M 207	-	2	24	24	-	-	-	-	-	-	50	-	50	-	-
19	M 207 x Ptb-10	9	34	43	7	21	38	148	37	12	-	349	256	93	-	0.651
20	M 210	-	5	17	28	-	-	-	-	-	-	50	-	50	-	-
21	M 210 x Ptb-10	14	31	46	3	23	29	131	48	9	-	334	240	94	-	1.939

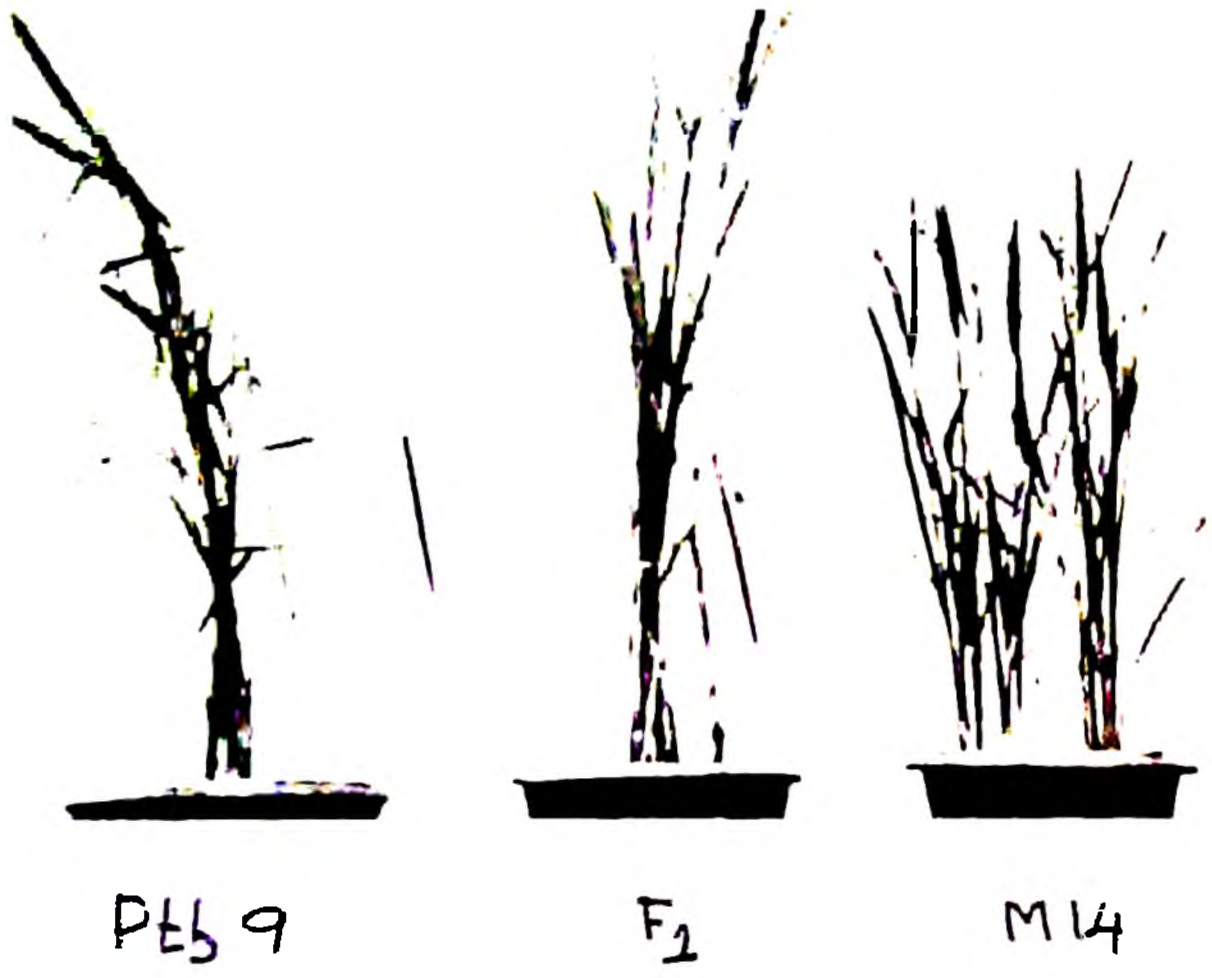
Figure VI

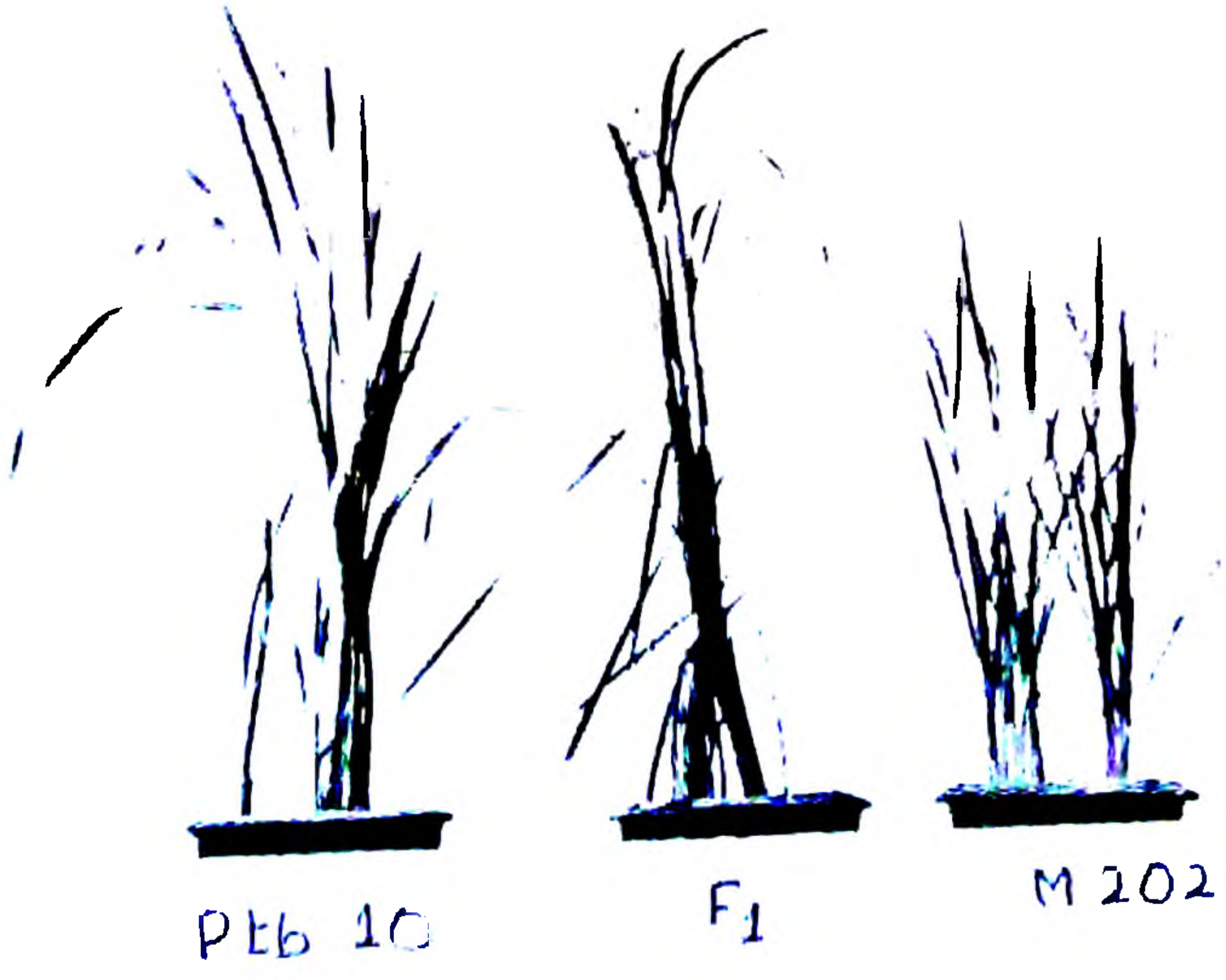
F_1s of mutants x varieties


Ptb28
F_1
M 102


Ptb 10
F_1
M 210


Ptb9
F_1
M2


Ptb 9
F_1
M 14


Ptb 10
F_1
M 202

FREQUENCY DISTRIBUTION (MUTANTS X VARIETIES)

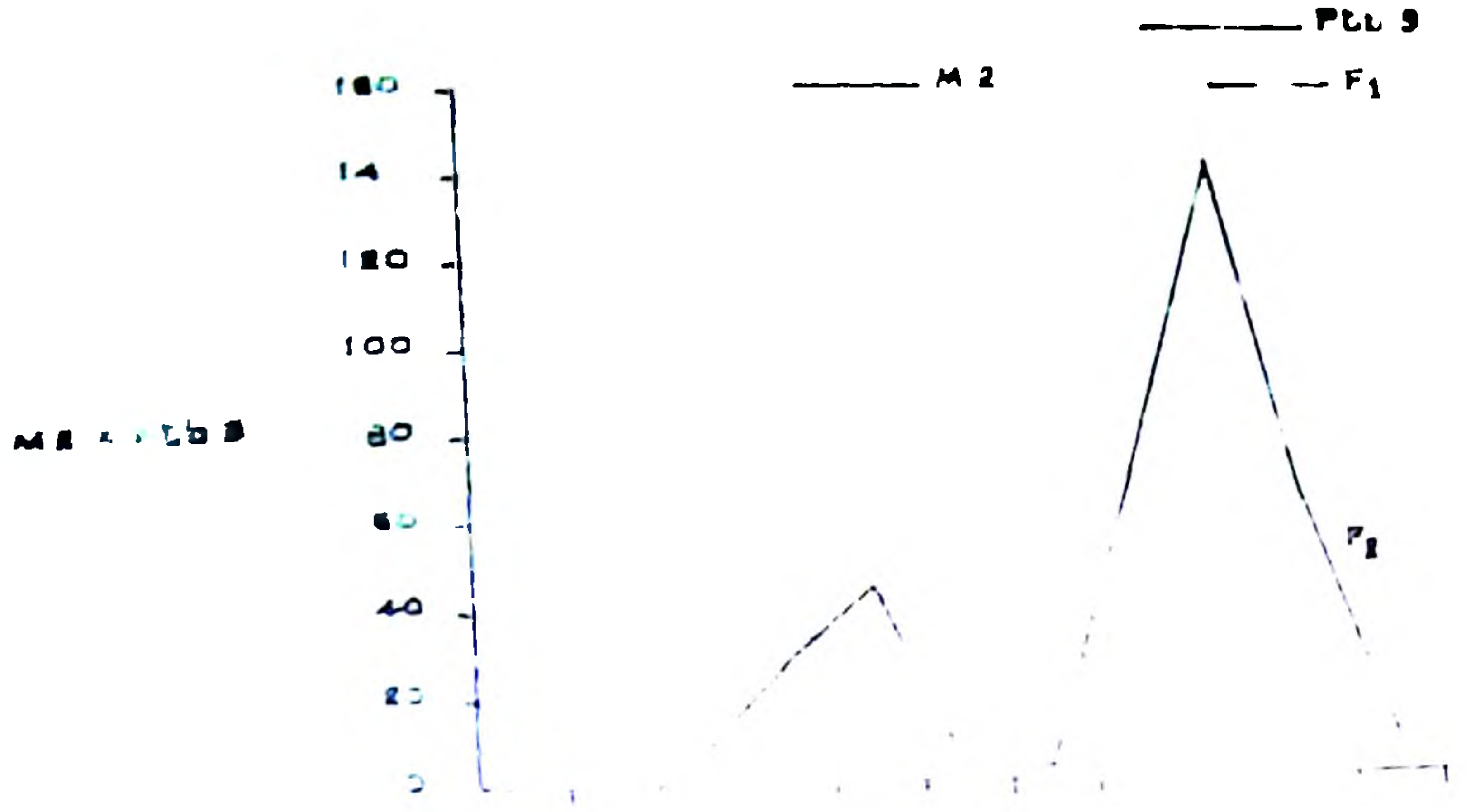


FIG VII-1

FIG VII-2

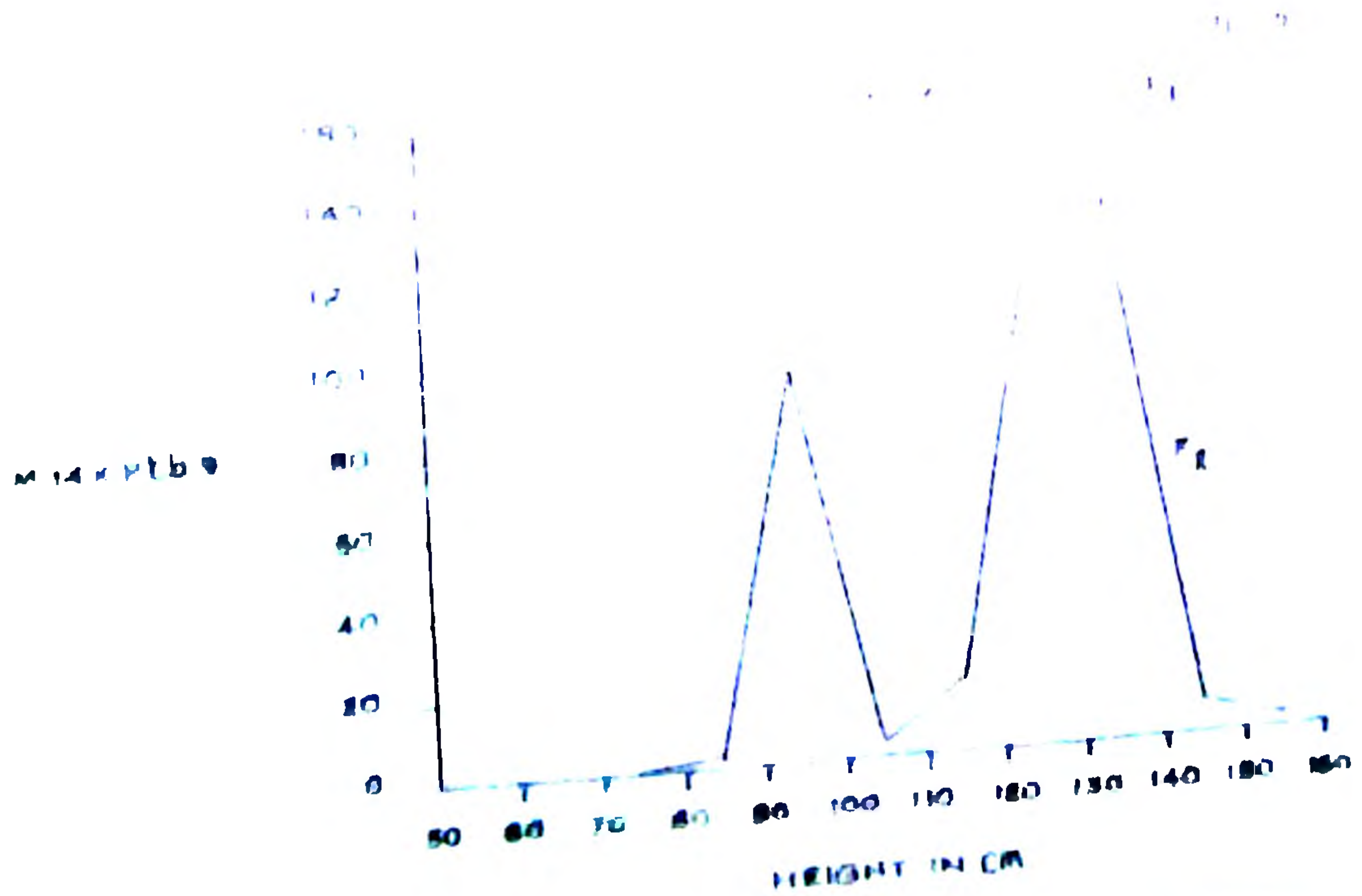


FIG VII-3

The F_1 plants resembled the tall parent in appearance with open habit, weak stand, elongated internodes and culm, long drooping pale green leaves and lodging susceptibility. Both tall and semidwarf plants appeared in F_2 population. Among 347 F_2 plants, 99 had plant height ranging from 71 to 110 cm and 248 from 111 to 160 cm (Figure VII-2, Table 18). This segregation pattern gave a good fit for a 3 tall:1 semidwarf ratio when tested with χ^2 test of goodness of fit. The tall F_2 plants with their long culm, weak stand, open habit, shy tillering and long drooping pale green leaves resembled the F_1 plants and the tall parent. They succumbed to lodging at or after heading. The semidwarfs resisted lodging and exhibited compact plant habit, erect and dark green leaves. The culm was short and stout with reduced internodal length.

iii) M 14 x Ptb-9: As given in table 17, the F_1 plants ranged in height from 133 to 140 cm. The mutant parent was semidwarf (75 cm) and Ptb-9 was tall (133 cm). The F_1 plants were similar to the tall parents and exhibited the open plant habit, long drooping leaves in contrast to the compact habit and erect leaves of the semidwarf mutant parent. The plants were found to lodge immediately after heading. The F_2 progeny indicated a bimodal distribution for plant height with 105 semidwarf plants with height ranging from 71 to 110 cm and 281 tall plants from 111 to 160 cm (Table 18, Figure VII-3).

The χ^2 test of goodness of fit revealed that the 3 tall:1 semidwarf model would be a good fit with high probability. The open habit, long culm, elongated internodes, drooping long leaves and lodging susceptibility made the tall F_2 plants resemble the F_1 plant while the semidwarfs appeared distinct with erect leaves, compact habit and nonlodging nature.

iv) M 102 x Ptb-28: The mean height of M 102 was 93 cm and that of Ptb-28 was 135 cm. The range of variation of height in F_1 was from 135 to 141 cm and is recorded in table 17. The plants in the F_1 generation were characterised by elongated internodes and long culm, long drooping leaves and susceptibility to lodging. They appeared almost similar to the tall parent. In the F_2 generation, out of 342 plants, 246 were tall (above 110 cm) and 96 semidwarf (between 71 and 100 cm). Plants in the 101 to 110 cm class were almost absent (Figure VII-4, Table 18) clearly indicating two distinct groups of tall and semidwarf plants in F_2. A 3:1 model gave a good fit to the observed frequencies of talls and semidwarfs with high probability. The talls were similar to the F_1s and the tall parent with long culm, elongated internodes, long and drooping leaves and open habit. They lodged after heading. The semidwarfs had erect leaves and were resistant to lodging with short and stout stem.

v) M 107 x Ptb-28: While M 107 was semidwarf (92 cm) the F_1 plants were tall with a range for plant height from 130 to

FREQUENCY DISTRIBUTION (MUTANTS x VARIETIES)

M 102 x ptb 28

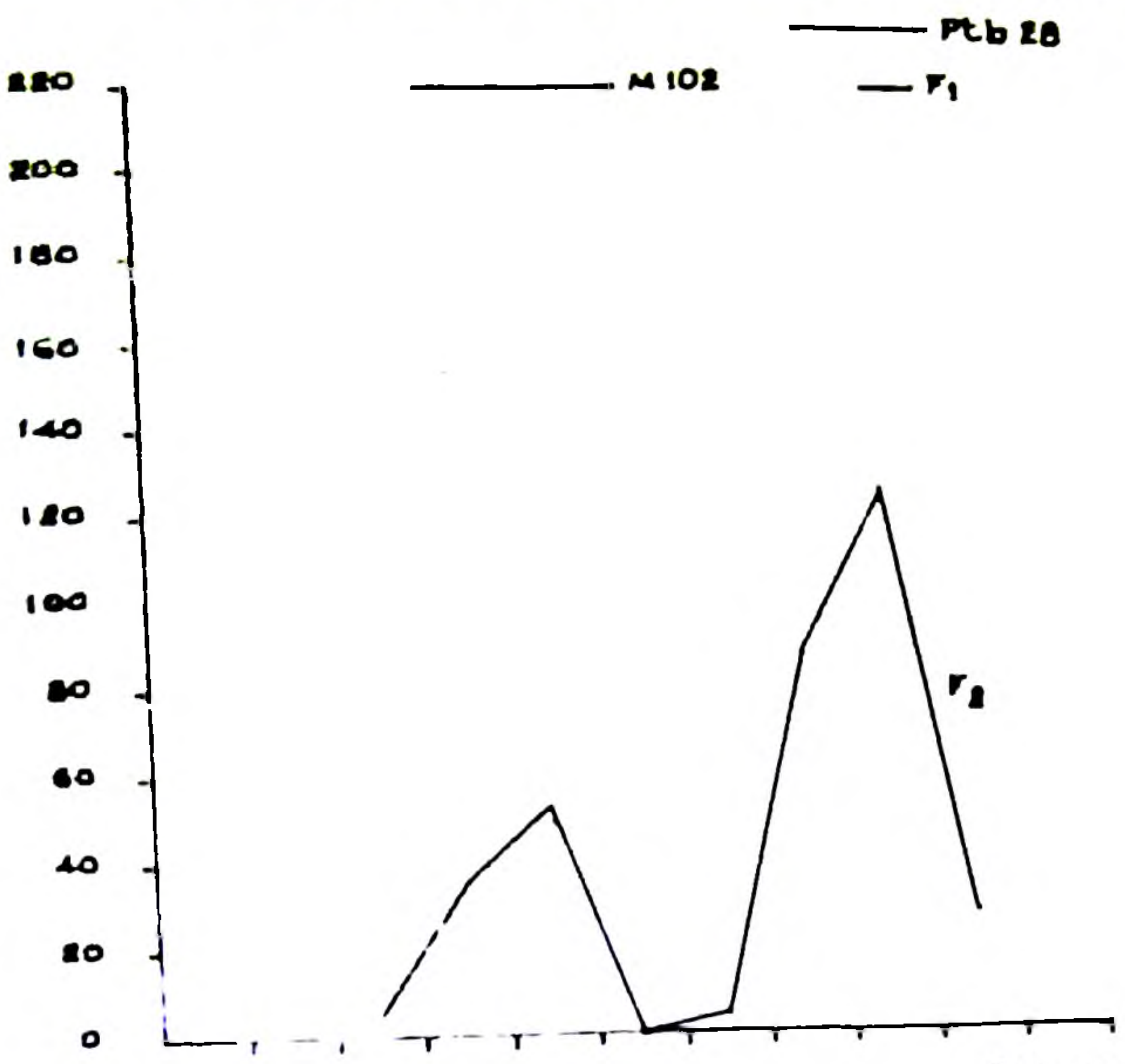


FIG VII-4

M 107 x ptb 28

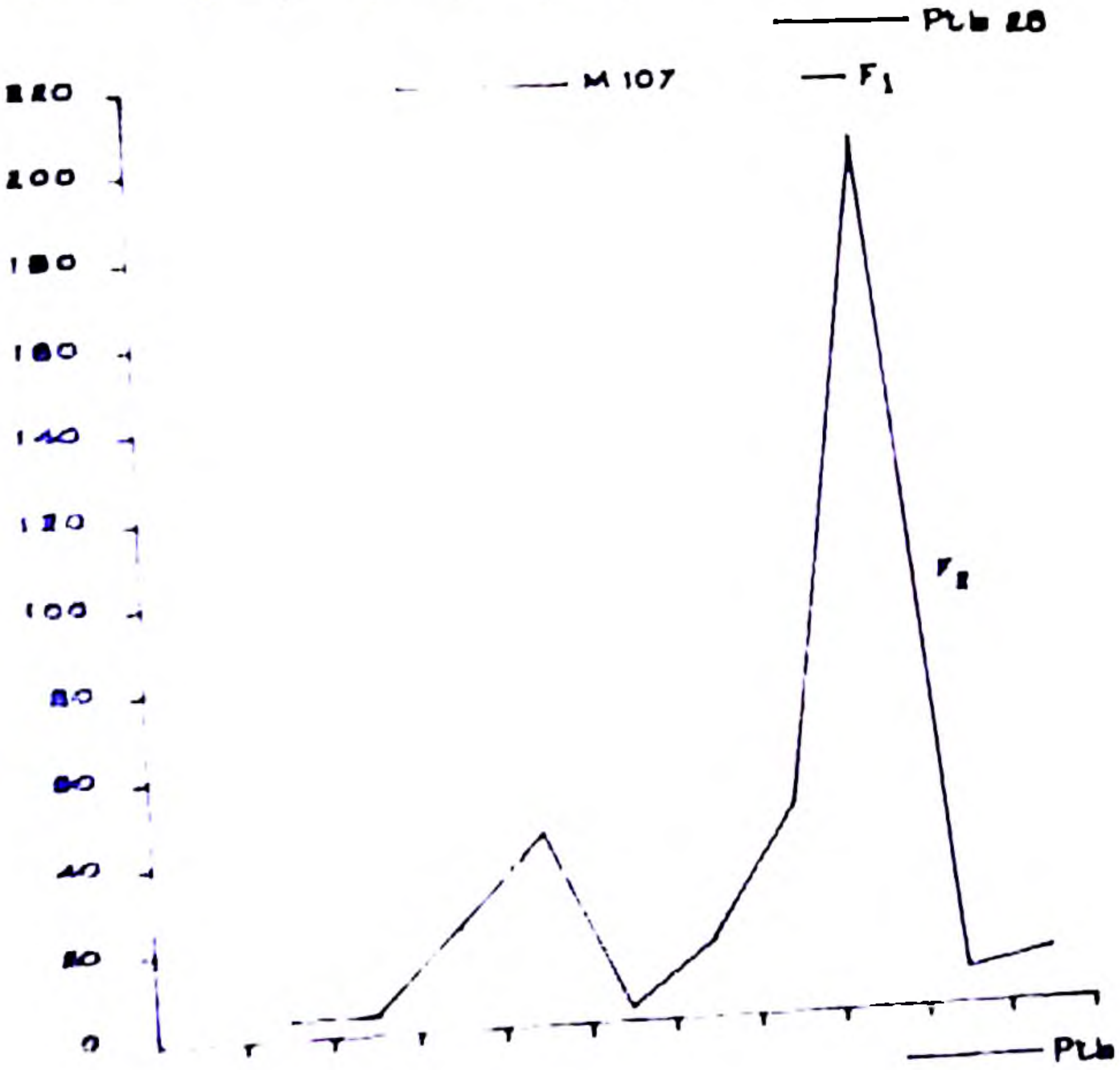


FIG VII-5

M 111 x ptb 28

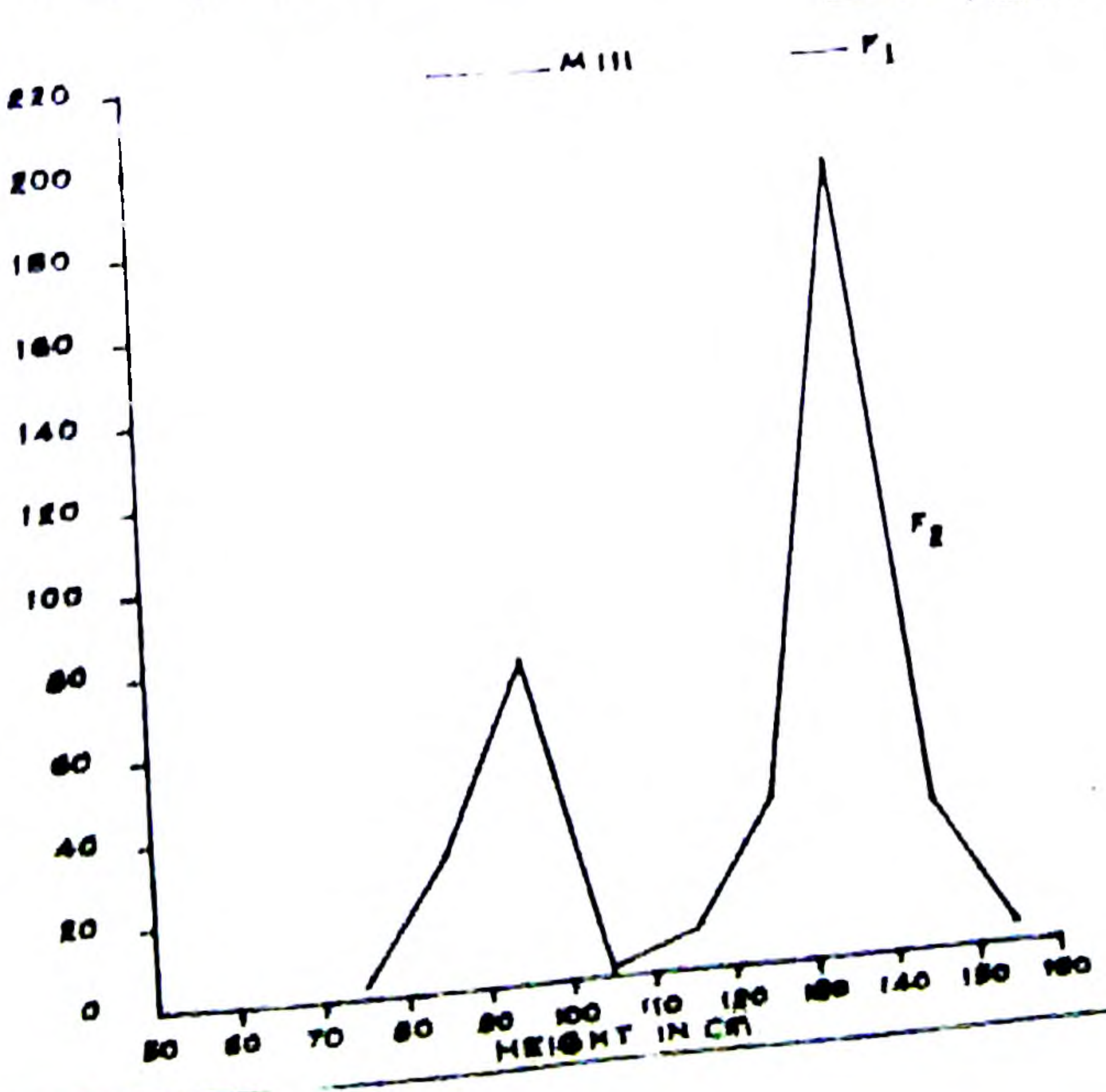


FIG VII-6

135 cm (Table 17). The F_1 plants were characterised by long culm, elongated internodes, leaves which were drooping and open plant habit. As in the case of the tall parent, the F_1 plants were susceptible to lodging. In the F_2, plant height ranged from 61 to 160 cm with two modal classes of 91 to 100 cm and 131 to 140 cm (Table 18). The relatively low frequency of plants between the two modal classes distinctly divided the F_2 population into two groups viz., tall and semidwarf (Figure VII-5). Phenotypically, the tall plants could be distinguished from the plants of the other group with their open habit, susceptibility to lodging and leaf characters. The leaves were long and drooping and were pale green while the semidwarf plants resembled the mutant parent in appearance, size, colour and orientation of the leaves. Out of the total of 283 F_2 plants, 213 were tall and 70 semidwarf. The segregation pattern gave a good fit to the expected model of 3 tall:1 semidwarf.

vi) M 111 x Ptb-28: M 111 was semidwarf with a mean height of 95 cm. The F_1 plants like Ptb-28 were tall, ranging from 132 to 139 cm in height (Table 17). In plant and leaf characters the F_1s resembled the tall parent. Due to the long culm resulting from elongated internodes they lodged before maturity. Plant height varied from 71 to 160 cm could be divided into talls and semidwarfs (Figure VII-6). Among the 388 F_2 segregants, 283 had height above 110 cm and 105 fell between 71 to 80 cm to 101 to 110 cm classes (Table 18). The test of goodness of fit indicated that the segregation for plant height gave a satisfactory fit for the 3 tall:1 semi-dwarf model. The tall plants had a close similarity with the F_1s and the tall parent, Ptb-28. The leaves were long and drooping with pale green colour, the tillers were open and the plants were susceptible to lodging. The semidwarfs resembled the mutant parent M 111 in almost all characters.

vii) M 202 x Ptb-10: While M 202 and Ptb-10 had mean heights of 83 cm and 122 cm respectively the height of F_1 plants ranged from 113 to 124 cm (Table 17). Unlike the semidwarf parent, the F_1s had leaves which were pale green and drooping with early senescence. The culm appeared to be long with elongated internodes. Ptb-10 and F_1 plants appeared to be similar. Table 18 reveals that the F_2 distribution for plant height showed variation from 61 to 70 cm class to 140 to 150 cm class with two modal classes of 81 to 90 cm and 121 to 130 cm. Assuming the limit between the tall and the semi-dwarf as 100 cm, the entire F_2 population could be grouped into talls and semidwarfs. Within the semidwarfs, the variation was unimodal and continuous suggesting that all plants within the range of 61 to 100 cm could be considered as a single group (Figure VII-7). Thus out of 328 F_2 plants observed, 254 were tall and 74 were semidwarf indicating a 3:1 segregation ratio. The χ^2 test of goodness of fit confirmed

(MUTANTS X VARIETIES)

M 202 x pt.b 10

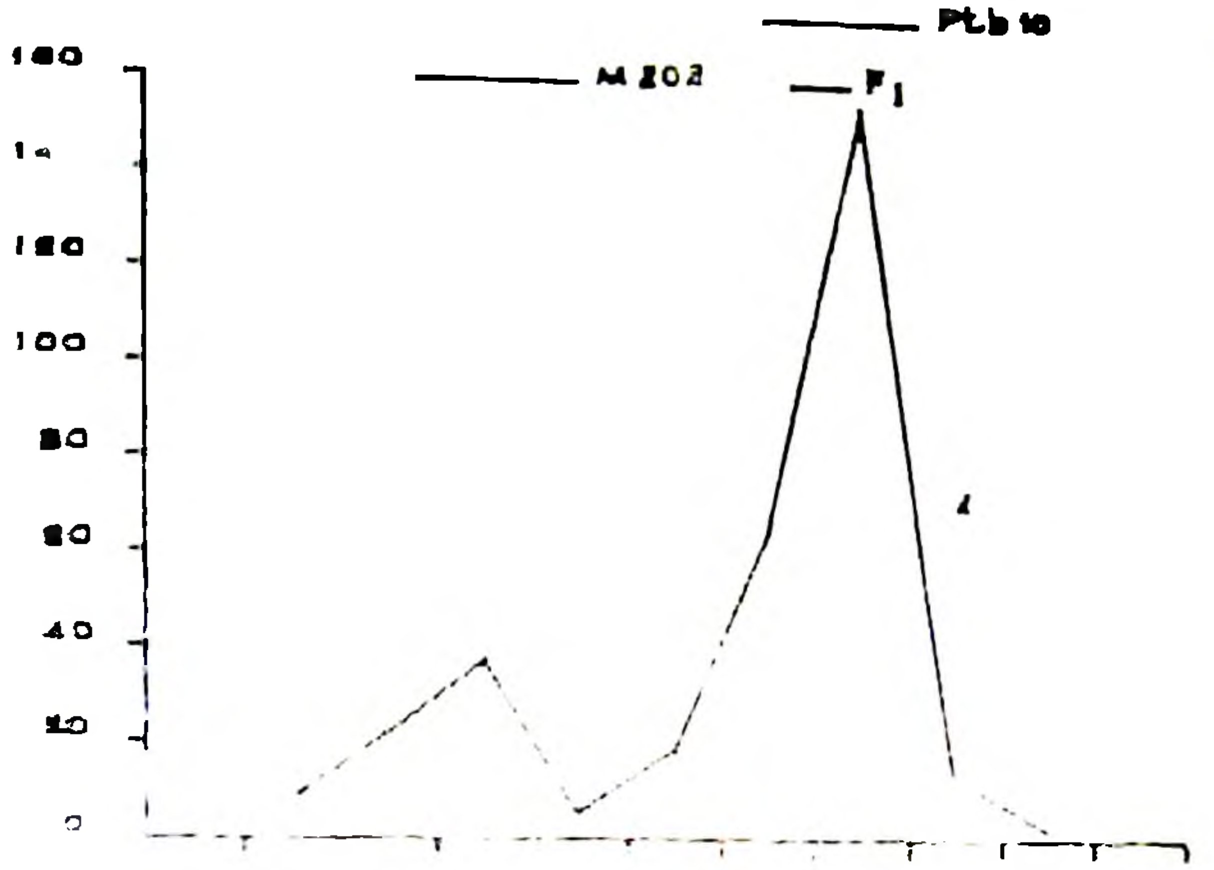


FIG VII-7

M 207 x pt.b 10

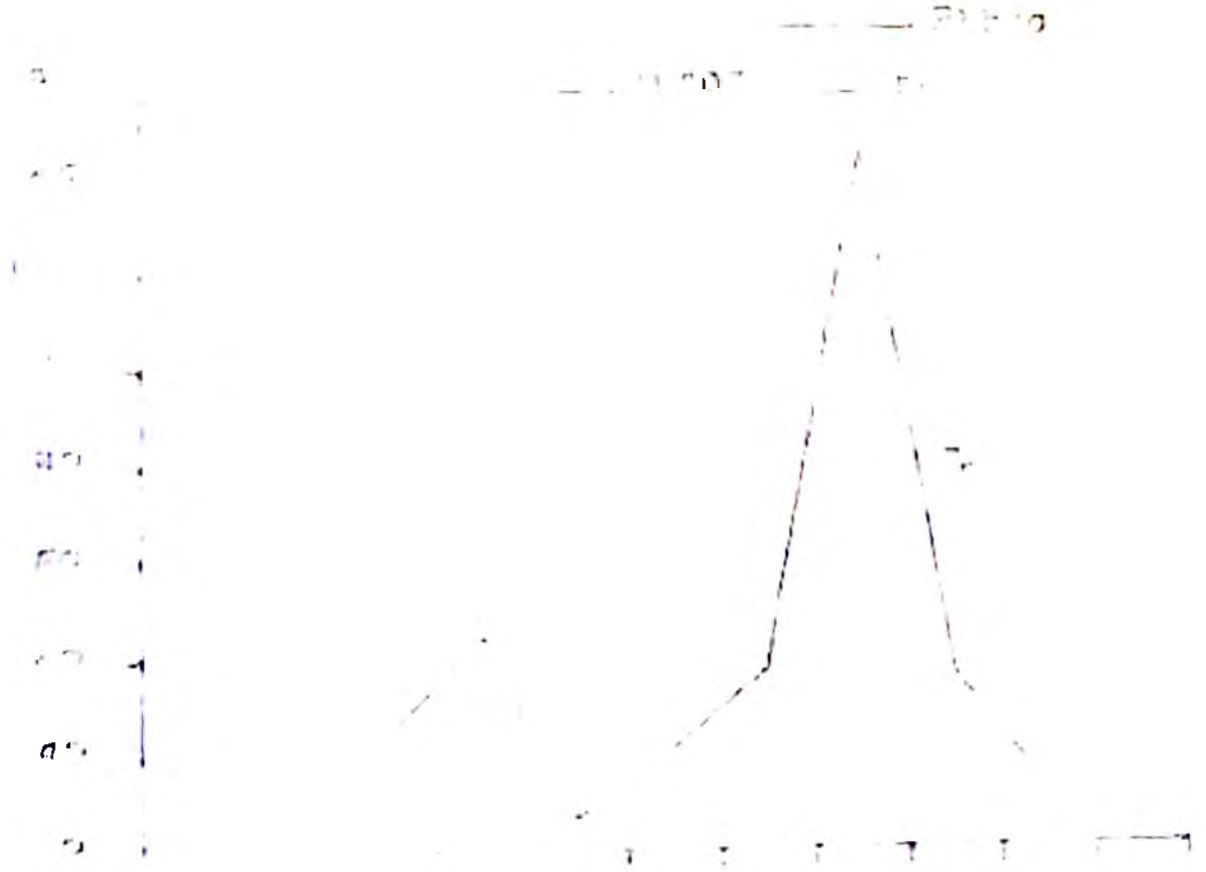


FIG VII-8

M 210 x pt.b 10

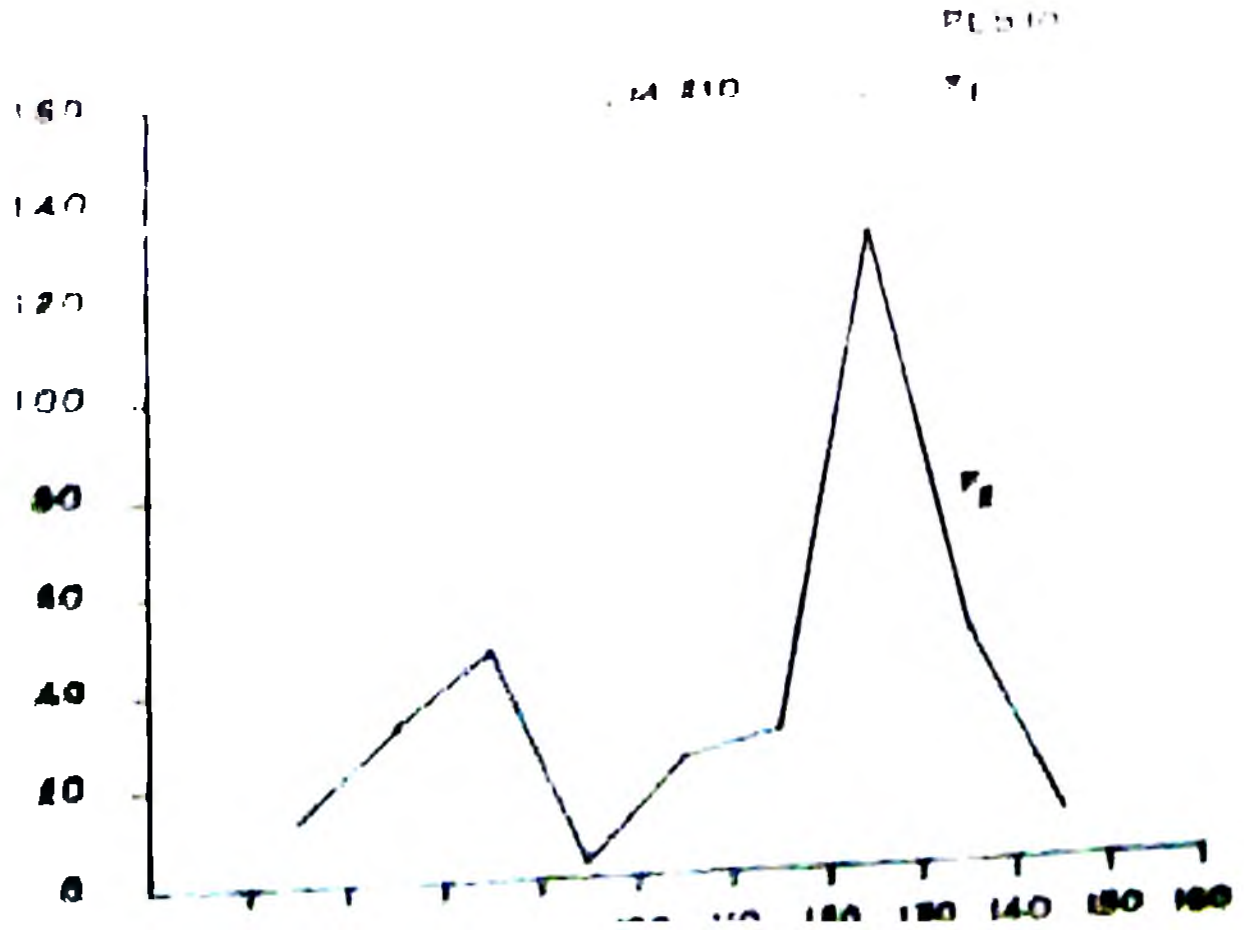


FIG VII-9

this assumption. The tall plants in the F_2 to a great extent looked like the F_1s and the semidwarfs, the mutant parent.

viii) M 207 x Ptb-10: The mean plant heights of M 207, Ptb-10 and the F_1 plants were 91 cm, 122 cm and 120 cm respectively (Table 17). While M 207 had erect leaves and compact habit, the F_1s like the tall parent, Ptb-10, had long drooping leaves and open habit. F_1s were also characterised by elongated internodes and susceptibility to lodging as the tall parent. Unlike the F_1, the F_2 progeny showed great variation in plant height and associated characters. Plants ranged in height from 61 to 150 cm (Table 18). If the plants above 100 cm are considered as tall plants, the F_2 consisted of 256 talls and 33 semidwarfs (Figure 11-B). This segregation ratio gave a satisfactory fit to 3:1 model. The talls in the F_2, appeared to resemble the F_1s and the tall parent whereas the semidwarfs with their compact habit short and sturdy culm and erect dark green leaves looked like the mutant parent.

ix) M 210 x Ptb-10: The F_1 plants appeared to be tall like the tall parent, Ptb-10. The mean height of F_1s was 128 cm while that of M 210 was 91 cm (Table 17). The F_1 plants had long and drooping leaves, elongated internodes and open habit which made them lodge before maturity. The F_2 segregated for stature and the associated characters. The segregating plants ranged in height from 61 to 70 cm class to 140 to 150 cm class. The frequency of the semidwarf plants was maximum in the 81 to 90 cm class and that of the tall plants was maximum in the 121 to 130 cm class. A clear break in the distribution curve was observed at the 91 to 100 cm class with the minimum number of individuals (Figure VII-9; Table 18). Plants falling between 61 to 70 cm class and 91 to 100 cm class were considered as semidwarfs and the rest as talls. Other associated characters such as long and drooping leaves, open plant habit and susceptibility to lodging were also taken into consideration for the grouping of the plants. Out of 334 plants, 240 were tall and 94 semidwarfs. This indicated that the plants segregated 3 tall:1 semidwarf.

b) Crosses with Jyothi

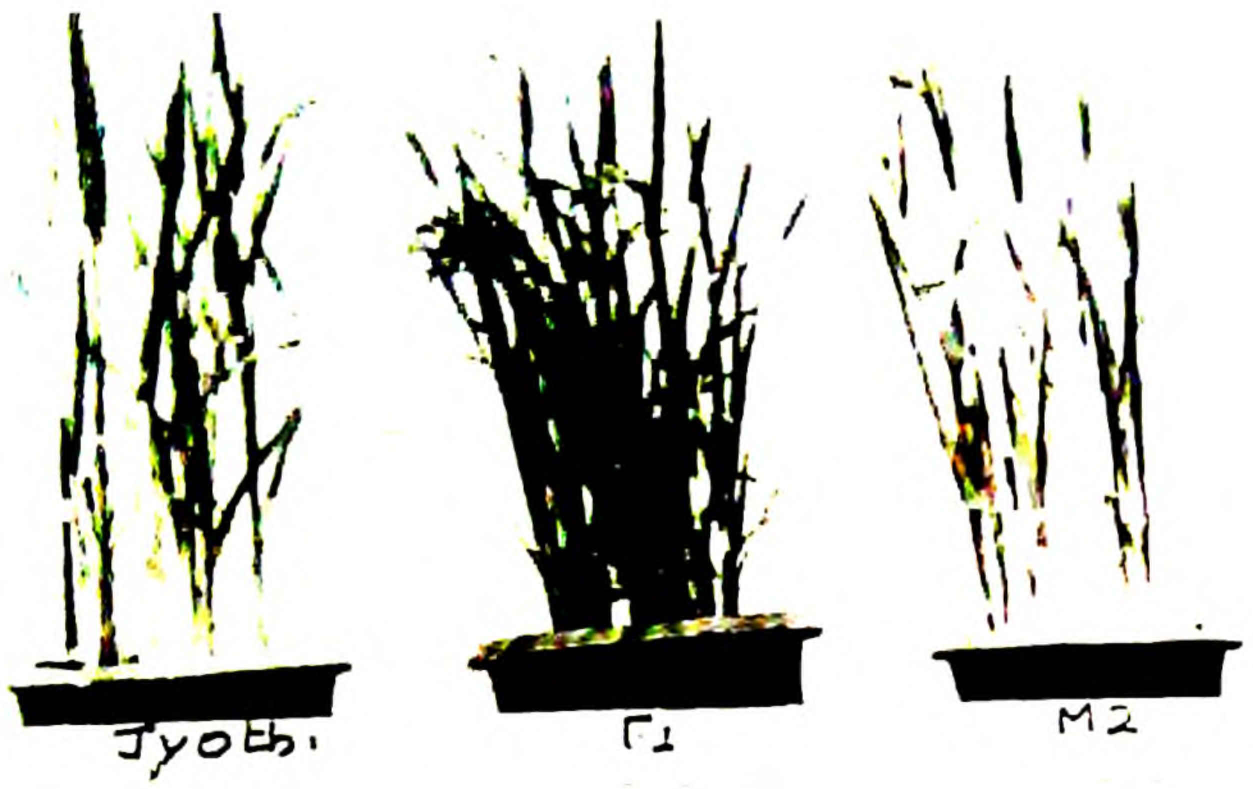
1) Jyothi x M 2: Jyothi, a known carrier of dgwg dwarfing gene, had a mean height of 95 cm indicating its semidwarf nature. They had erect dark green leaves which showed late senescence. The semidwarf nature was due to the shortened internodes and not due to reduction in the number of internodes since both the tall and Jyothi plants had almost the same number of internodes. The M 2 mutant was also semidwarf (94 cm) with the associated leaf and culm characters. The height of F_1 plants ranged from 95 to 103 cm with a mean of 101 cm suggesting semidwarf nature (Table 19). The plants were also characterised by erect short dark green leaves, compact habit and lodging resistance (Figure VIII). In F_2,

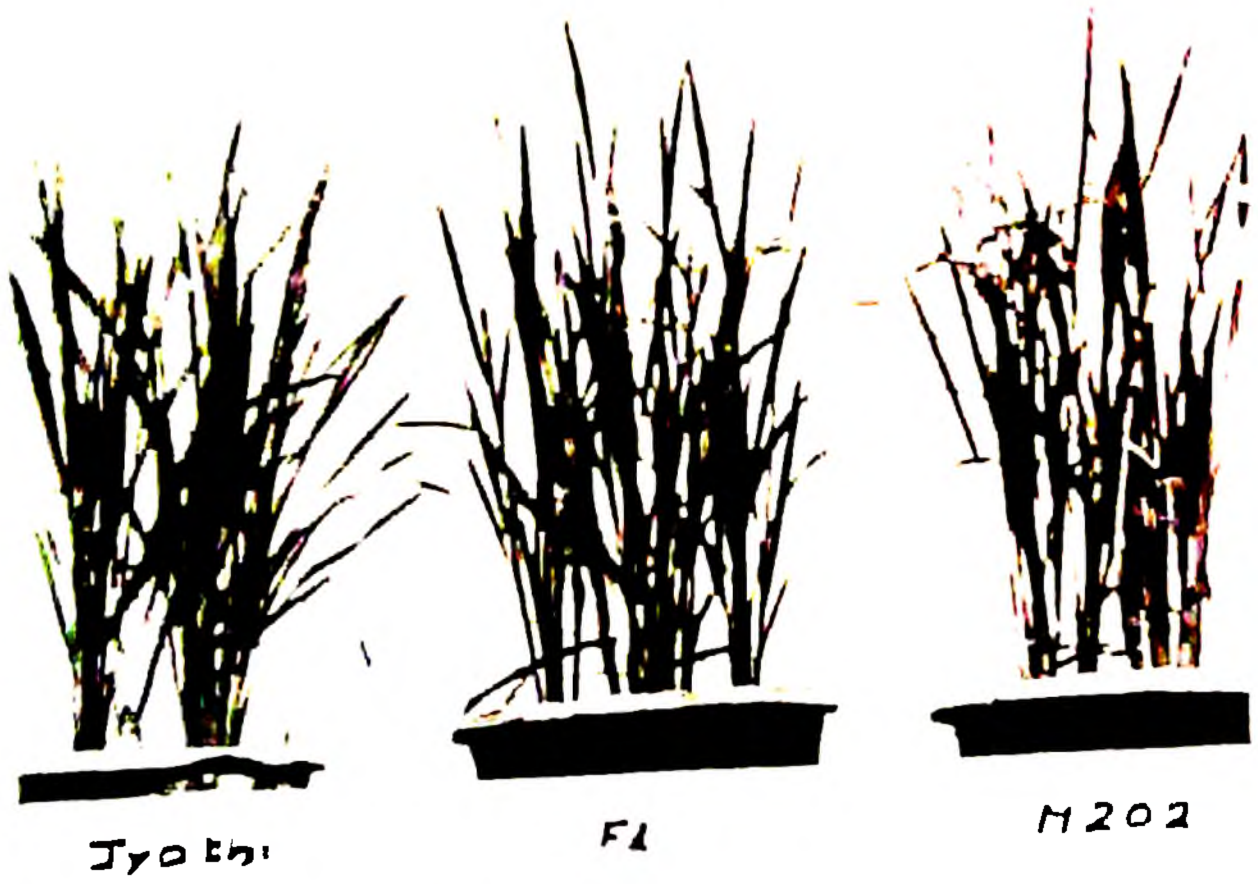
Table 19. Characters of the hybrids and parents in crosses between mutants and Jyothi

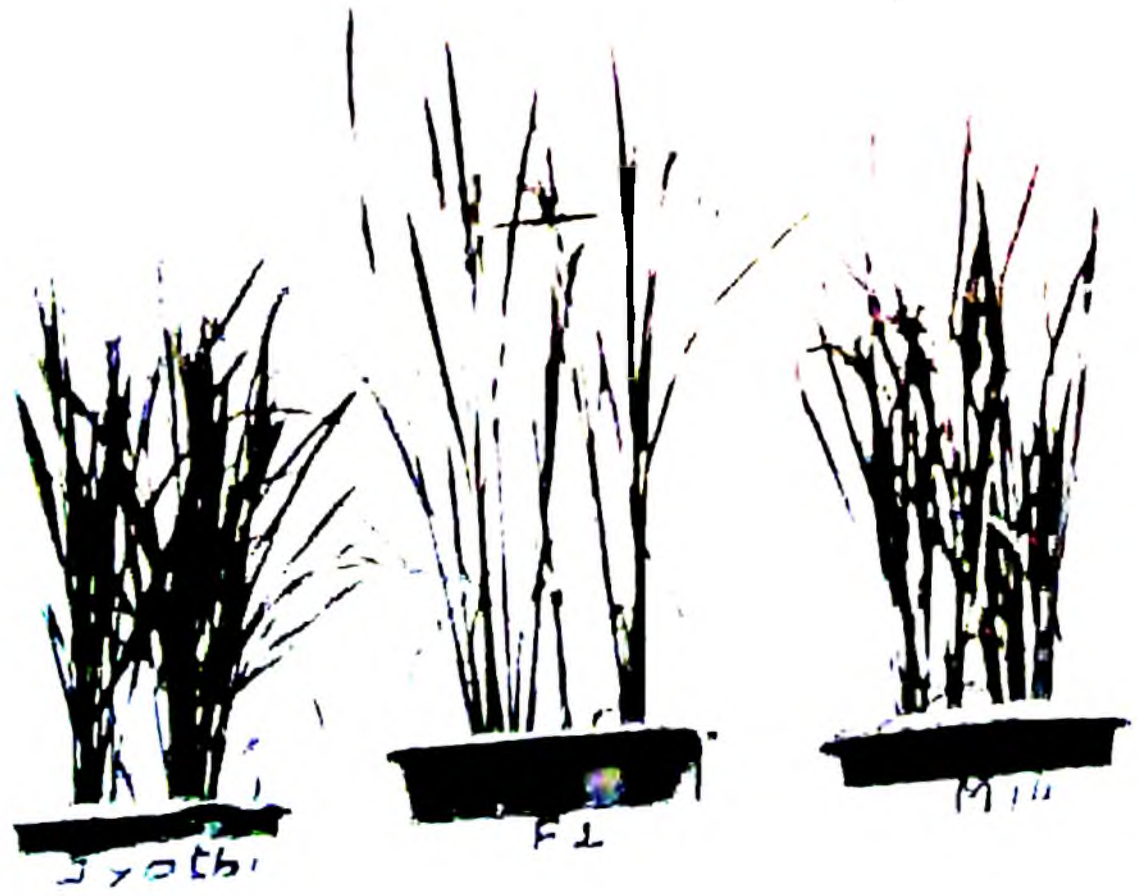
Sl. No.	Parent/hybrid	Plant height (cm)		Number of internodes	Duration (days)	Leaf length (cm)	Leaf orientation	Leaf colour	Lodging	Plant habit
		Range	Mean							
1	Jyothi	84-104	95	6	110	36	erect	dark green	resistant	compact
2	M 2	89-102	94	6	115	30	erect	dark green	resistant	compact
3	Jyothi x M 2	95-103	101	6	108	30	erect	dark green	resistant	compact
4	M 6	80-93	88	6	120	34	erect	dark green	resistant	compact
5	Jyothi x M 6	122-130	126	6	105	53	drooping	pale green	susceptible	open
6	M 14	85-104	95	5	120	34	erect	dark green	resistant	compact
7	Jyothi x M 14	124-133	129	6	108	52	drooping	pale green	susceptible	open
8	M 102	83-106	93	6	110	34	erect	dark green	resistant	compact
9	Jyothi x M 102	135-139	137	6	110	49	drooping	pale green	susceptible	open
10	M 107	82-102	92	6	115	38	erect	dark green	resistant	compact
11	Jyothi x M 107	130-134	132	6	110	51	drooping	pale green	susceptible	open
12	M 111	87-102	95	6	110	34	erect	dark green	resistant	compact
13	Jyothi x M 111	94-101	98	6	110	35	erect	dark green	resistant	compact
14	M 202	78-95	89	6	89	33	erect	dark green	resistant	compact
15	Jyothi x M 202	89-96	93	6	98	34	erect	dark green	resistant	compact
16	M 207	78-99	91	6	93	30	erect	dark green	resistant	compact
17	Jyothi x M 207	122-128	125	6	98	53	drooping	pale green	susceptible	open
18	M 210	76-98	91	6	95	33	erect	dark green	resistant	compact
19	Jyothi x M 210	124-129	126	6	101	50	drooping	pale green	susceptible	open

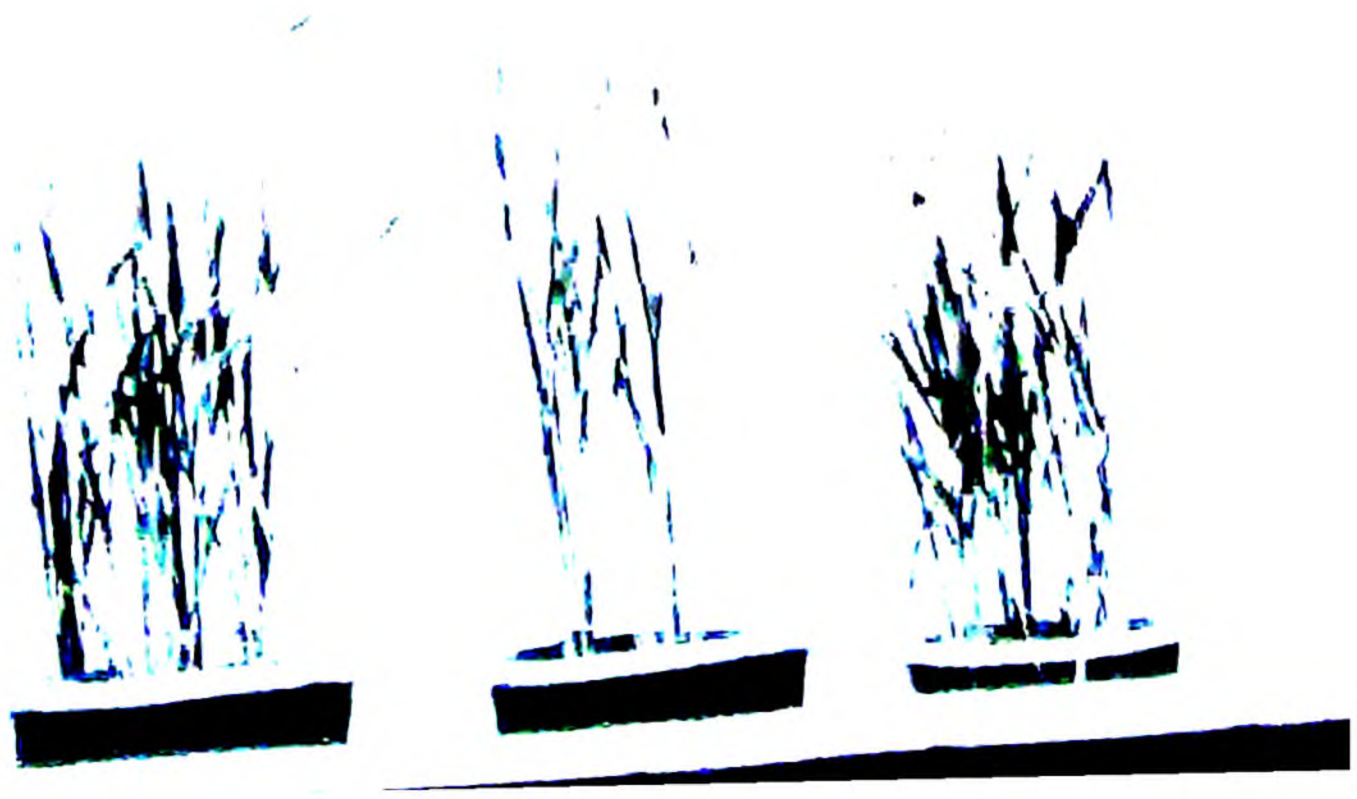
Figure VIII

F_1s of mutants x Jyothi


Jyothi
F1
M2


Jyothi
F1
M202


Jyothi
F1
M11



plant height ranged from 71 to 80 cm class to 101 to 110 cm class (Table 20). The distribution pattern suggested that all the 218 F_2 plants were semidwarfs (Figure IX-1). In appearance they were indistinguishable from the parents.

ii) Jyothi x M 6: Both Jyothi and M 6 were semidwarfs with the characteristic leaf and culm characters. The leaves were dark green, short and erect and the culm was short and stout. In contrast to the parents, the F_1s were tall (126 cm) with long culm as a result of elongated internodes (Table 19). The plants exhibited open habit and lodged after heading. The leaves were long, pale green and drooping. In the F_2, a total number of 381 plants were studied. Unlike in the F_1, the plant height in the F_2 ranged from 71 to 80 cm class to 141 to 150 cm class with two modal classes of 91 to 100 cm and 121 to 130 cm. The relatively low frequency of the plants in between these two modal classes divided the frequency distribution into two distinct groups (Figure IX-2; Table 20). Considering 110 cm as the upper limit of plant height for semidwarfs, the F_2 population consisted of 205 talls and 176 semidwarfs. The F_2 population showed good fit to a 9:7 model with high probability. The talls were invariably characterised by large and drooping leaves and lodging habit.

iii) Jyothi x M 14: While both the parents were semidwarf, the F_1 plants were tall with a mean height of [illegible] cm

Table 20. Frequency distribution for height in crosses between mutants and Jyothi in F_2

Sl. No.	Parents/crosses	Height classes in cm											Total	Tall	Semidwarf	Dwarf	χ^2 (9:7/ 9:6:1)
		51-60	61-70	71-80	81-90	91-100	101-110	111-120	121-130	131-140	141-150	151-160					
1	Jyothi	-	-	-	15	23	12	-	-	-	-	-	50	-	50	-	-
2	M 2	-	-	-	8	35	7	-	-	-	-	-	50	-	50	-	-
3	Jyothi x M 2	-	-	1	94	107	6	-	-	-	-	-	218	-	218	-	-
4	M 6	-	-	6	27	17	-	-	-	-	-	-	50	-	50	-	-
5	Jyothi x M 6	-	-	13	56	98	9	11	123	62	9	-	381	205	176	-	0.864
6	M 14	-	-	-	6	41	3	-	-	-	-	-	50	-	50	-	-
7	Jyothi x M 14	5	17	6	47	66	13	18	116	56	17	4	365	211	132	22	0.401
8	M 102	-	-	-	13	29	8	-	-	-	-	-	50	-	50	-	-
9	Jyothi x M 102	5	13	4	38	79	15	21	95	40	11	6	327	173	136	18	2.232
10	M 107	-	-	-	12	32	6	-	-	-	-	-	50	-	50	-	-
11	Jyothi x M 107	-	-	16	41	84	12	19	97	67	23	-	359	206	153	-	0.181
12	M 111	-	-	-	3	45	2	-	-	-	-	-	50	-	50	-	-
13	Jyothi x M 111	-	-	8	105	118	15	-	-	-	-	-	246	-	246	-	-
14	M 202	-	-	3	18	29	-	-	-	-	-	-	50	-	50	-	-
15	Jyothi x M 202	-	2	9	80	106	11	-	-	-	-	-	208	--	208	-	-
16	M 207	-	-	2	24	24	-	-	-	-	-	-	50	-	50	-	-
17	Jyothi x M 207	4	23	10	28	95	14	12	122	56	3	-	367	193	147	27	2.103
18	M 210	-	-	5	17	28	-	-	-	-	-	-	50	-	50	-	-
19	Jyothi x M 210	-	-	5	51	116	7	19	91	98	10	-	394	218	176	-	0.256

FREQUENCY DISTRIBUTION (MUTANTS x JYOTHI)

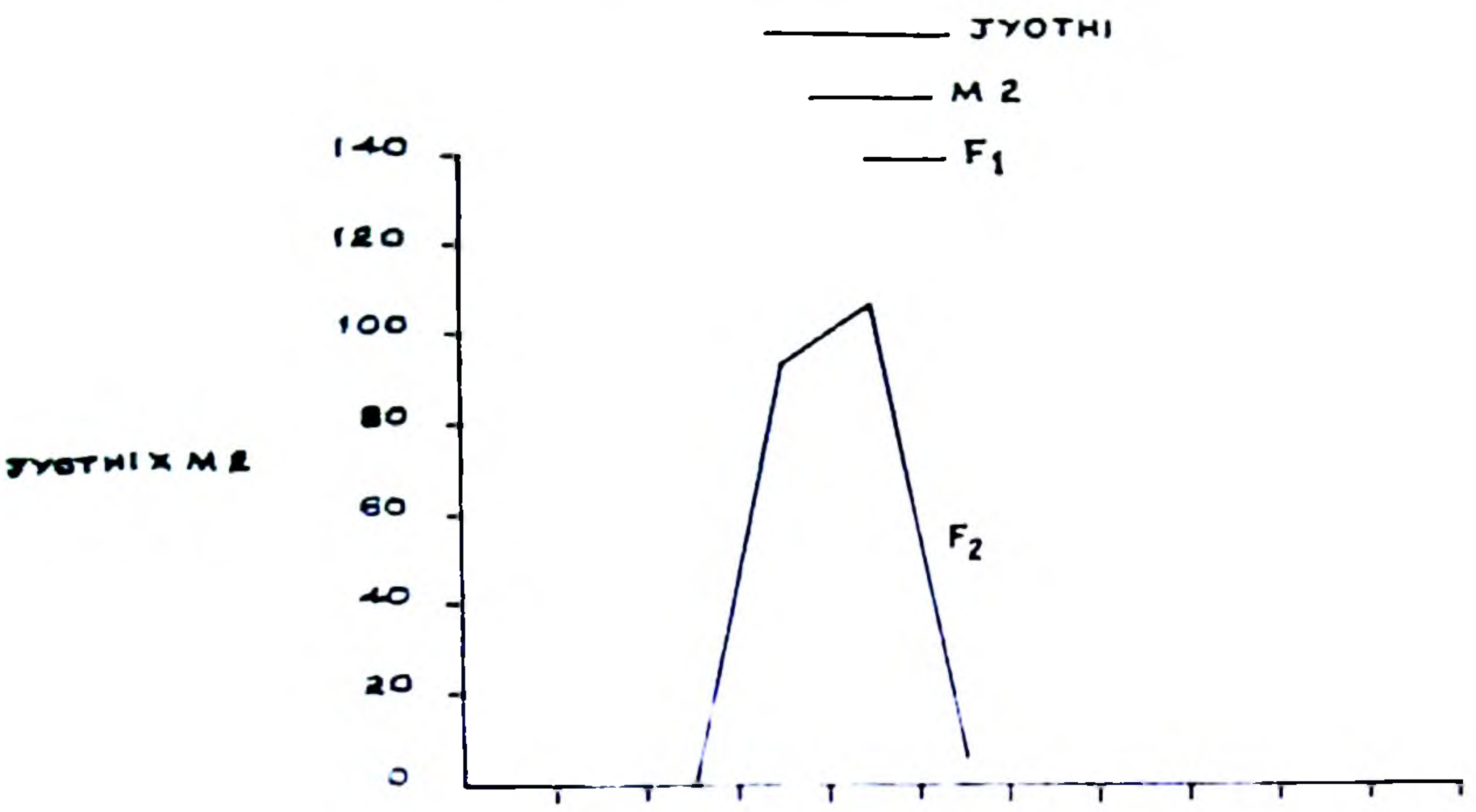


FIG IX-1

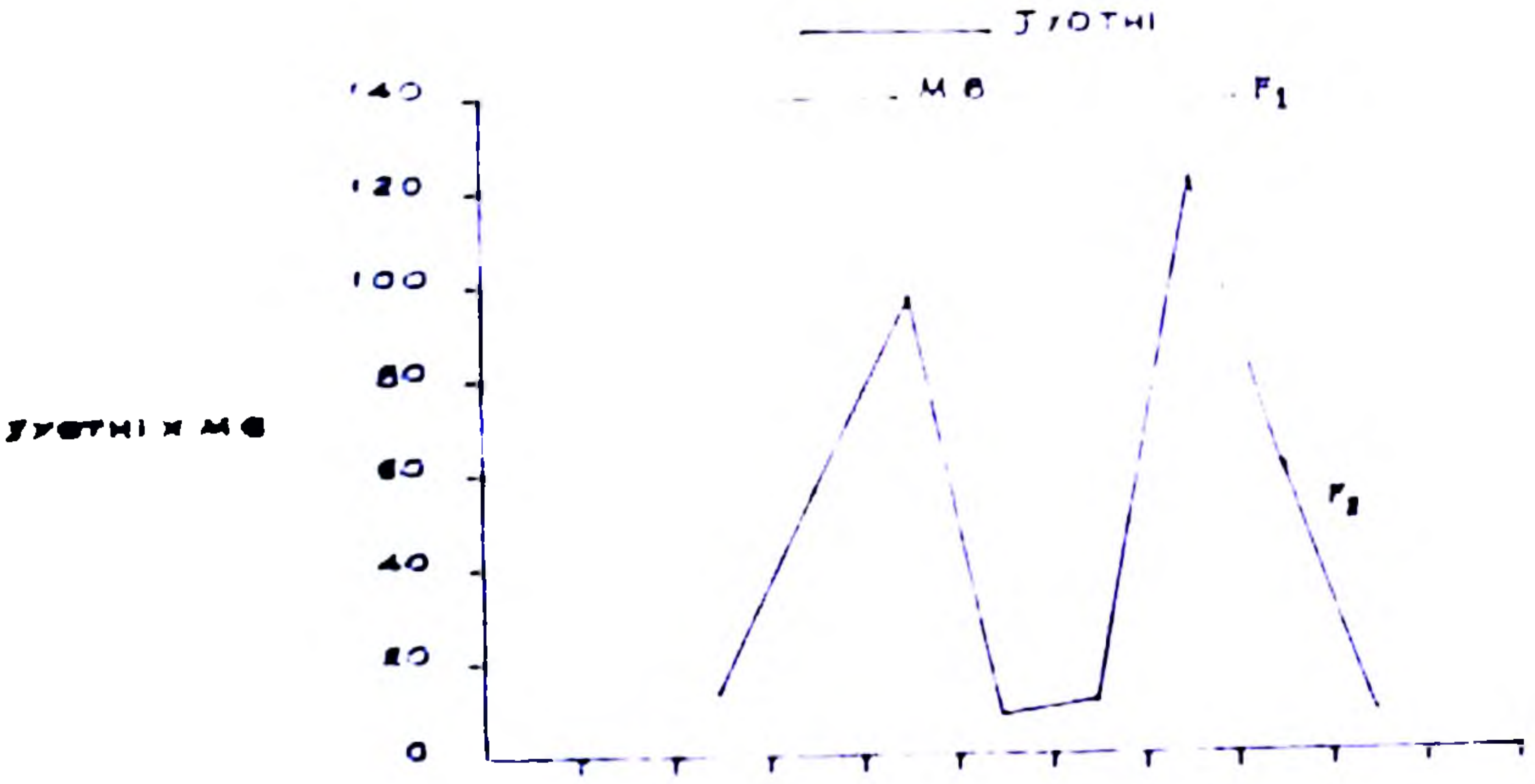


FIG IX-2

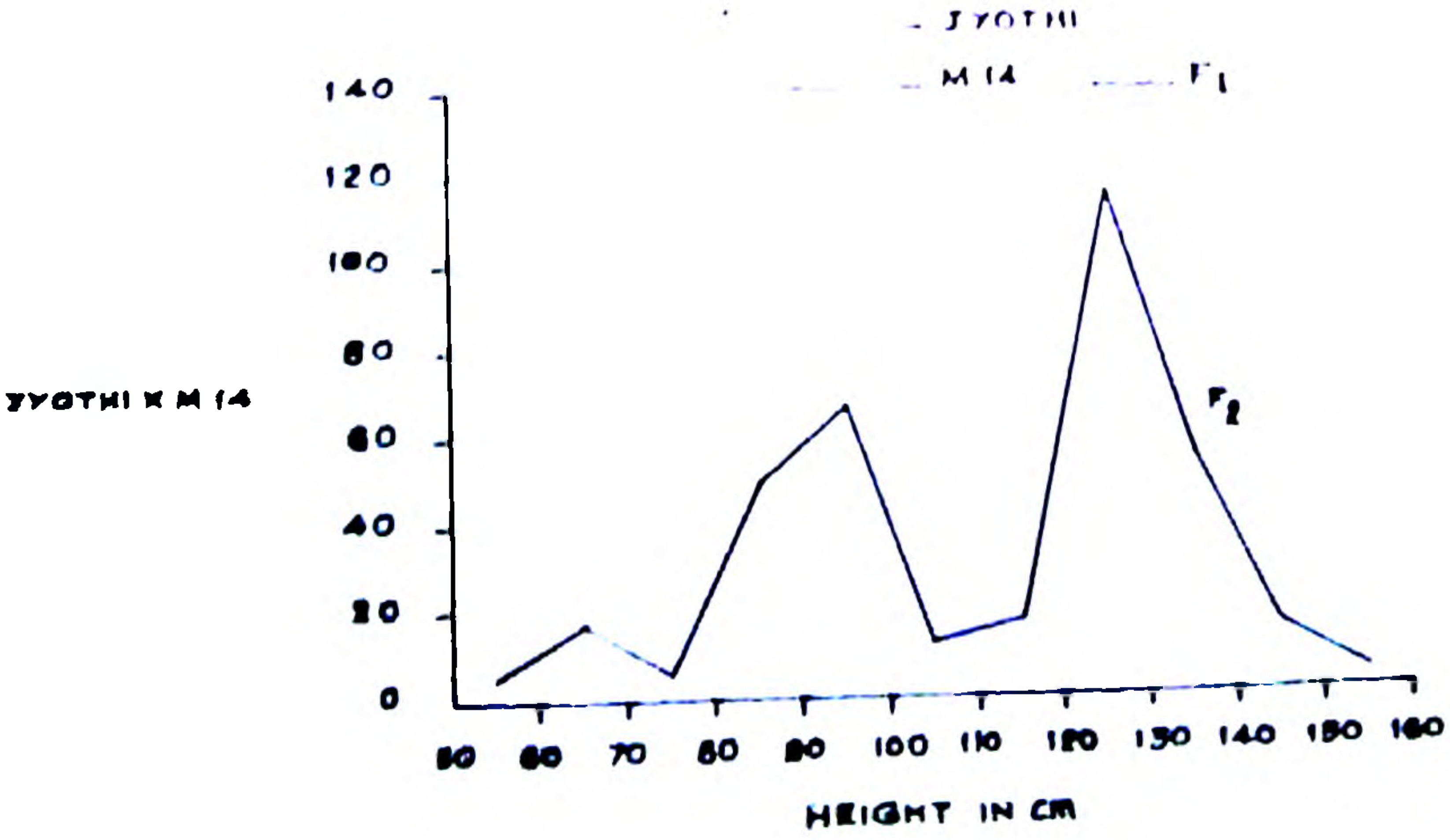


FIG IX-3

(Table 19). They were characterised by large narrow and drooping leaves, long culm and open habit. The long culm was the result of the elongation of internodes and not due to increase in the number of internodes since the internode number of both the semidwarf parents and the F_1s was almost the same. The elongated internodes made the plants succumb to lodging at the time of heading. In the F_2, plant height varied from 51 to 60 cm class to 151 to 160 cm class (Table 20). The distribution also indicated 3 modes (Figure IX-3). Assuming plants below 70 cm as dwarfs the F_2 population could be considered to have segregated for talls, semidwarfs and dwarfs. Thus out of 365 F_2 plants, 211 were tall, 132 semidwarf and 22 dwarf. This segregation pattern showed a good fit to a 9:6:1 model. The 9:3:3:1 model was not used because of the difficulty in distinguishing between the two types of semidwarfs. The dwarfs could be distinguished from the semidwarfs primarily because of the reduced culm length. It was noted that the highly reduced culm length in dwarfs was due to the reduction in number as well as length of the internodes. The dwarfs were also characterised by very short thick dark green erect leaves and often by large number of tillers. They had compact plant habit and were nonlodging.

iv) Jyothi x M 102: While both Jyothi and M 102 were semidwarf in stature, the F_1s were tall (137 cm) with long and drooping leaves (Table 19). The tall culm appeared to be due to the elongation of internodes rather than an increase in the number of internodes. Plant height showed great variation in the F_2 generation. It ranged from 51 to 60 cm class for the shortest to 151 to 160 cm class for the tallest plants (Table 20). The arbitrary limit of 70 cm between dwarfs and semidwarfs and 110 cm between semidwarfs and talls divided the distribution into three groups (Figure IX-4). The F_2 population consisted of 173 talls, 136 semidwarfs and 18 dwarfs. The talls had long drooping leaves and resembled the F_1s. They lodged before ripening of the grains. All the semidwarfs were similar in height and resembled the parents. It was difficult to further group them into the two parental types. The dwarf plants formed a distinct group with their very short stature; small, erect, thick and very dark green leaves and compact habit. The pattern of elongation of internodes revealed that while talls and semidwarfs had almost the same number of distinguishable internodes, the dwarfs had a lower number. The reduction in culm length in dwarfs, therefore, appeared to be due to a reduction in number as well as length of internodes. The observed frequencies of talls, semidwarfs and dwarfs showed good fit to a 9:6:1 model. Here again, as in the case the cross Jyothi x M 14, the 9:3:3:1 model could not be used because of the difficulty in distinguishing the two types of semidwarfs.

v) Jyothi x M 107: Data presented in table 19 indicate that the F_1 plants were tall unlike the parents which were

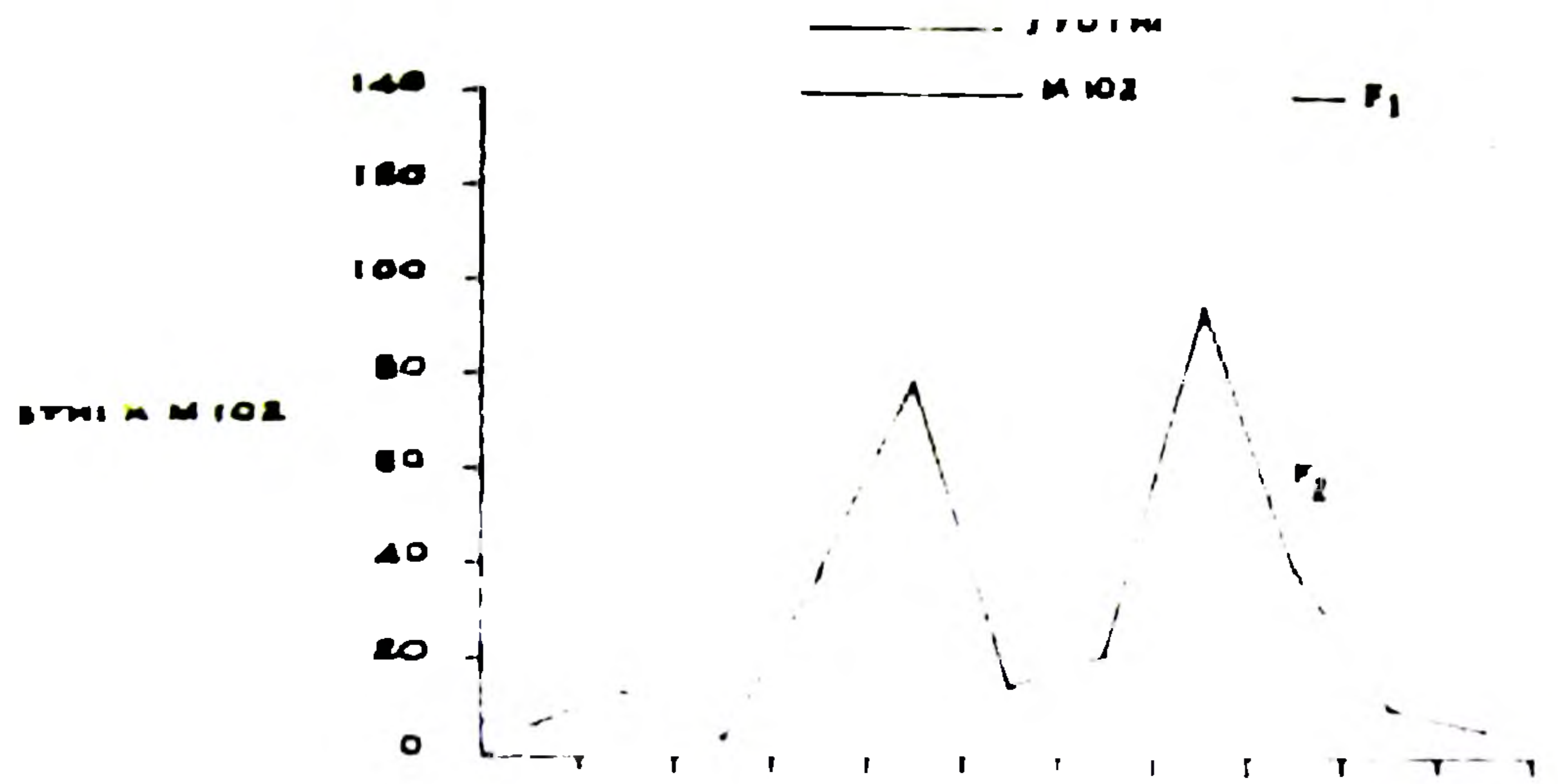


FIG IX-4

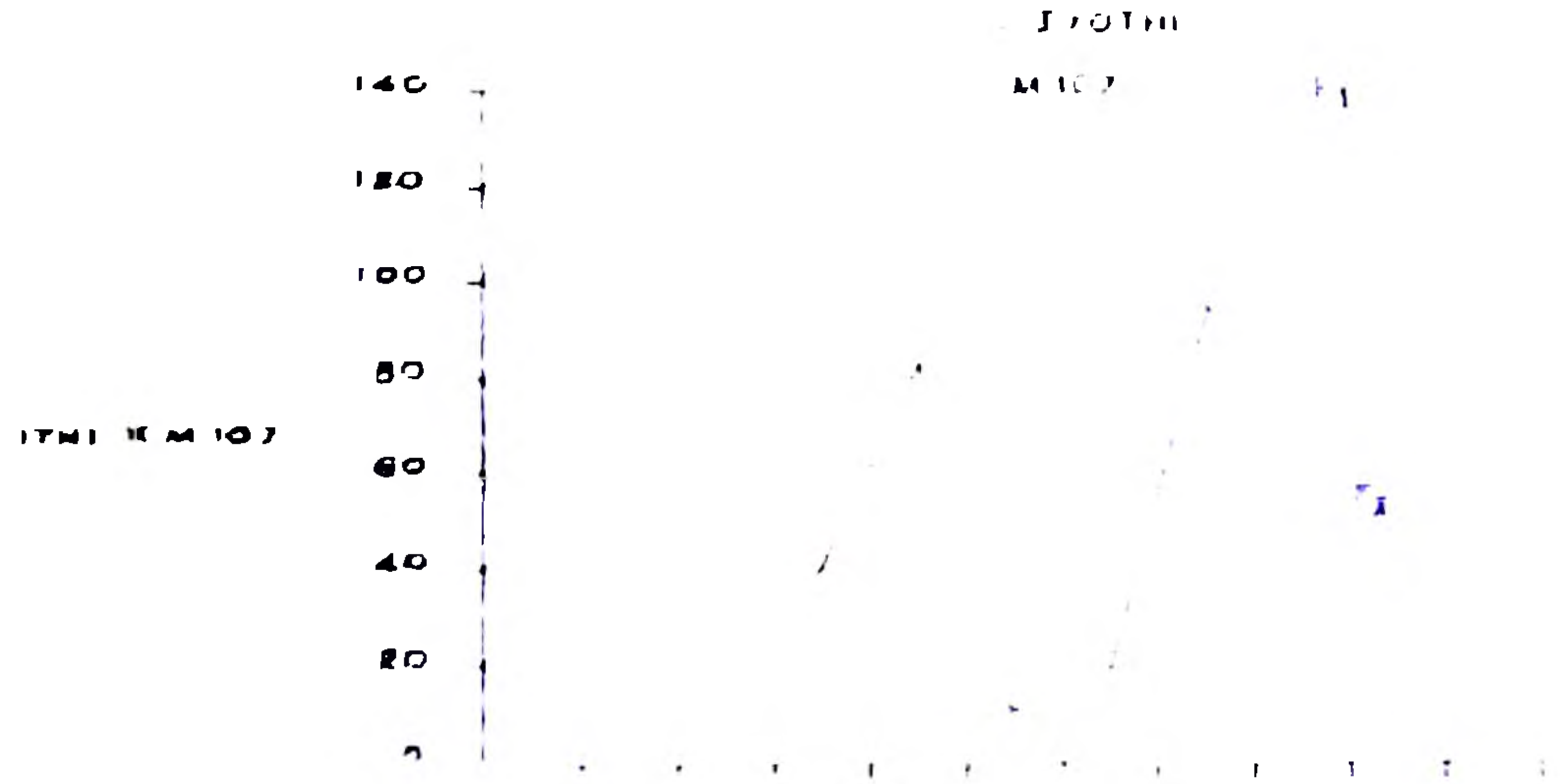


FIG IX-5

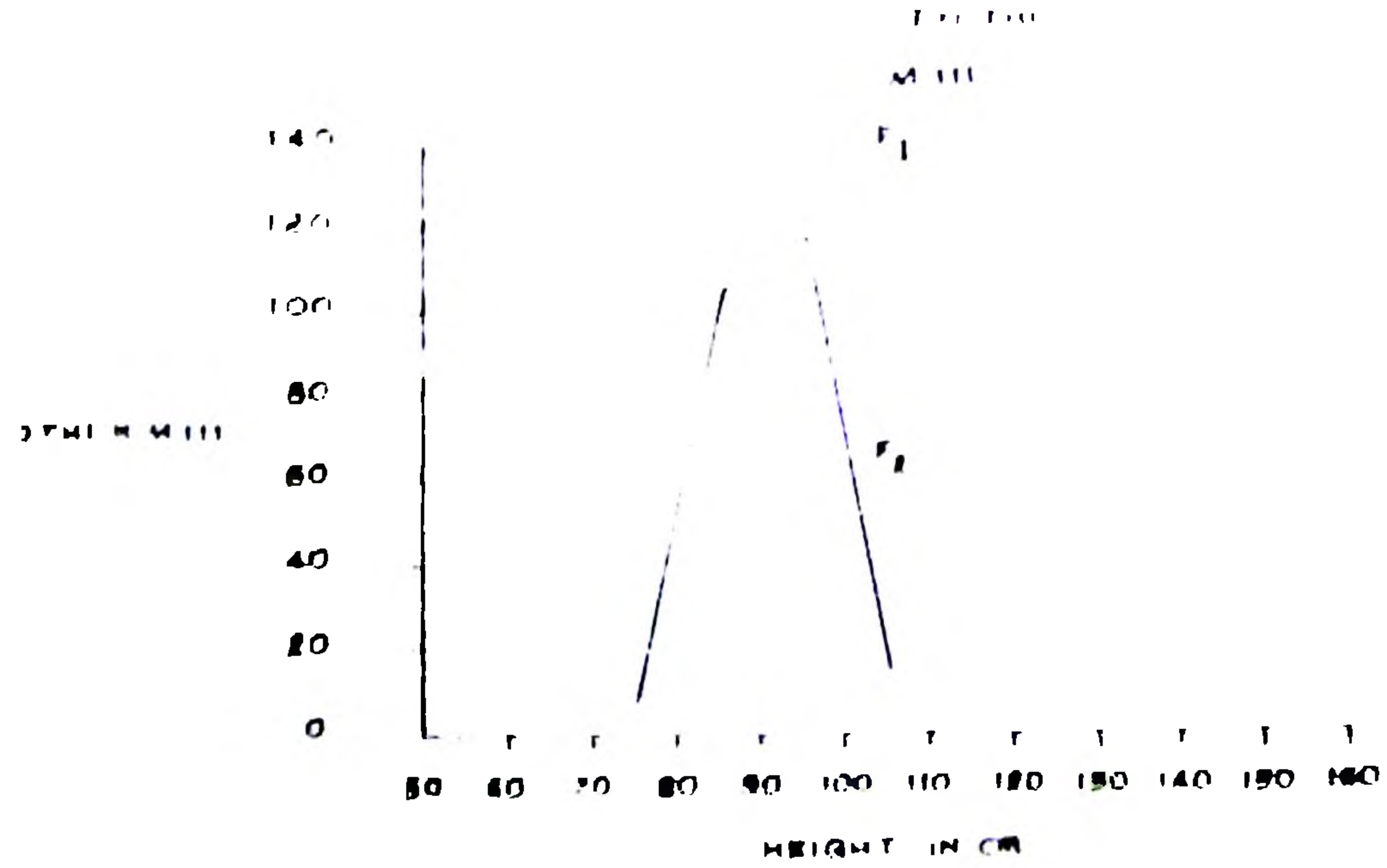


FIG IX-6

semidwarf. There were distinct differences in the orientation, length, colour and in the stage of senescence of leaves in the parental and F_1 generations. While both Jyothi and M 107 had short, erect and dark green leaves, the F_1s possessed long pale green nearly drooping leaves. The compact habit did not appear to have been inherited by the tall F_1 plants. While the range of variation for plant height was from 130 to 134 cm in the F_1, it was from 71 to 80 cm class to 141 to 150 cm class in the F_2 (Table 20). None of the classes were shorter than 70 cm. Based on the F_2 distribution for plant height (Figure IX-5) the population was grouped into talls and semidwarfs. A further grouping of semidwarfs was difficult because of their uniformity. The talls and semidwarfs could be further distinguished by their plant habit and leaf characters. The talls lodged after heading while the semidwarfs were nonlodging. Out of the [illegible] F_2 plants, [illegible] were talls and 153 semidwarfs showing an approximate segregation ratio of 9:7. The test of goodness of fit also confirmed this assumption.

vi) Jyothi x M 111: The F_1s were similar to the parental plants in stature being semidwarfs. The height range was from 94 to 101 cm with the mean height of 98 cm (Table 19). The culm and leaf characters also closely resembled those of the parents. In the F_2 generation, all the plants appeared to be semidwarf with a very narrow range of variation (Table 20).

No plant with height more than 110 cm or less than 70 cm could be recovered in the F_2 (Figure IX-6). Almost all plants had compact habit, erect dark green leaves and lodging resistance. It was therefore assumed that there was no segregation for plant height and associated characters in the F_2.

vii) Jyothi x M 202: As in the cross Jyothi x M 111, the F_1 plants were semidwarfs and were indistinguishable from the parental types. Plant height in the F_1 ranged from 89 to 96 cm (Table 19). They exhibited compact habit and lodging resistance and possessed short erect dark green leaves. The narrow range of variation for plant height in the F_2 (Table 20) and unimodal distribution suggested absence of segregation for the character (Figure IX-7). All the F_2s could be considered as semidwarfs. Further, all the plants had uniform compact plant habit and short, erect dark green leaves which further confirmed the assumption.

viii) Jyothi x M 207: As against the semidwarf stature of Jyothi and M 207, the F_1s were tall. The plants ranged from 122 to 128 cm in height (Table 19). They were characterised by long, pale green and drooping leaves; long and weak culm and open habit. Elongation of internodes contributed to the increased culm length. Almost all the F_1 plants succumbed to lodging after heading. The F_2 distribution for plant height showed great variation and ranged from 51 to 60 cm

FREQUENCY DISTRIBUTION (MUTANTS X JYOTHI)

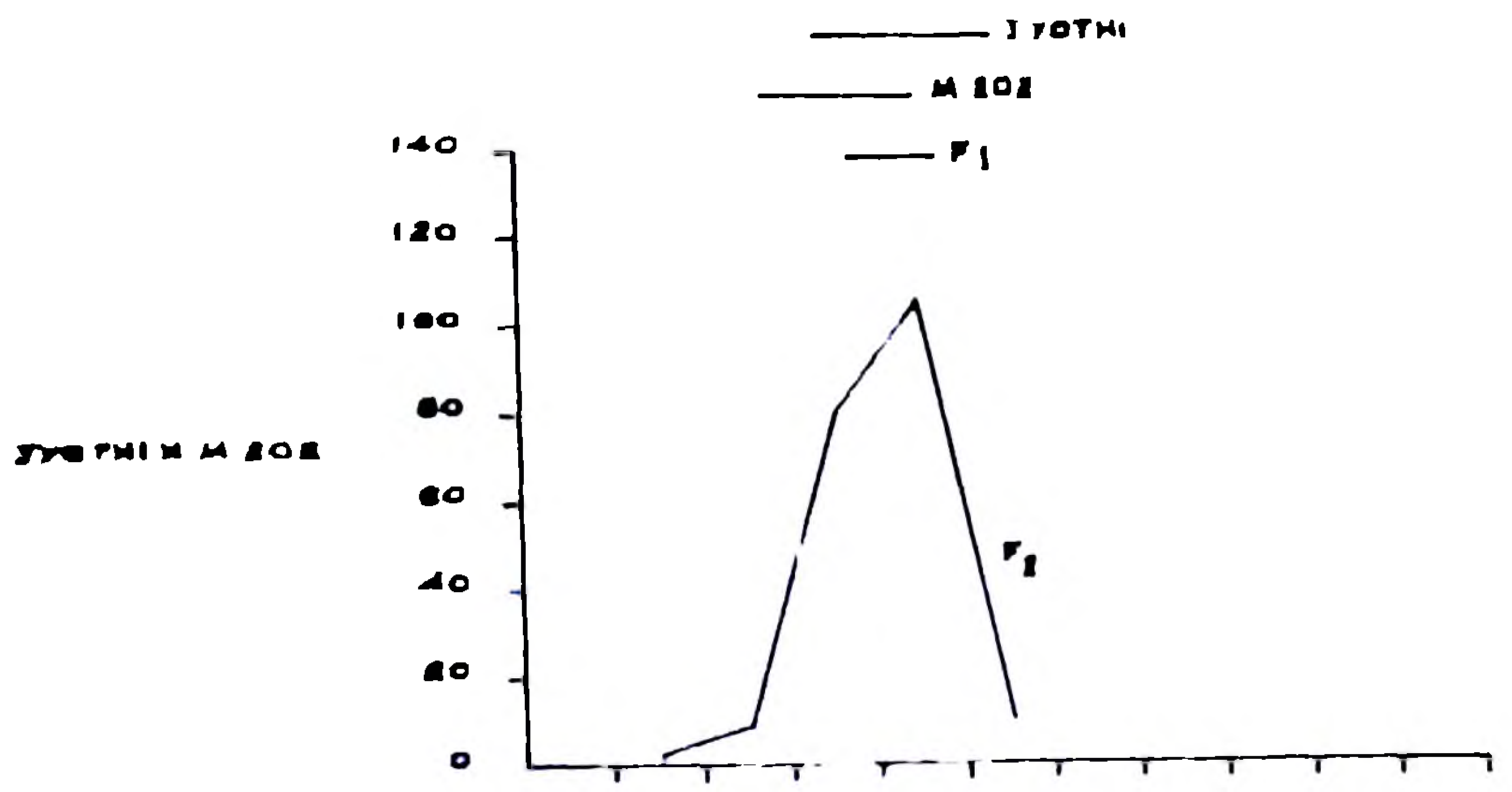


FIG IX-7

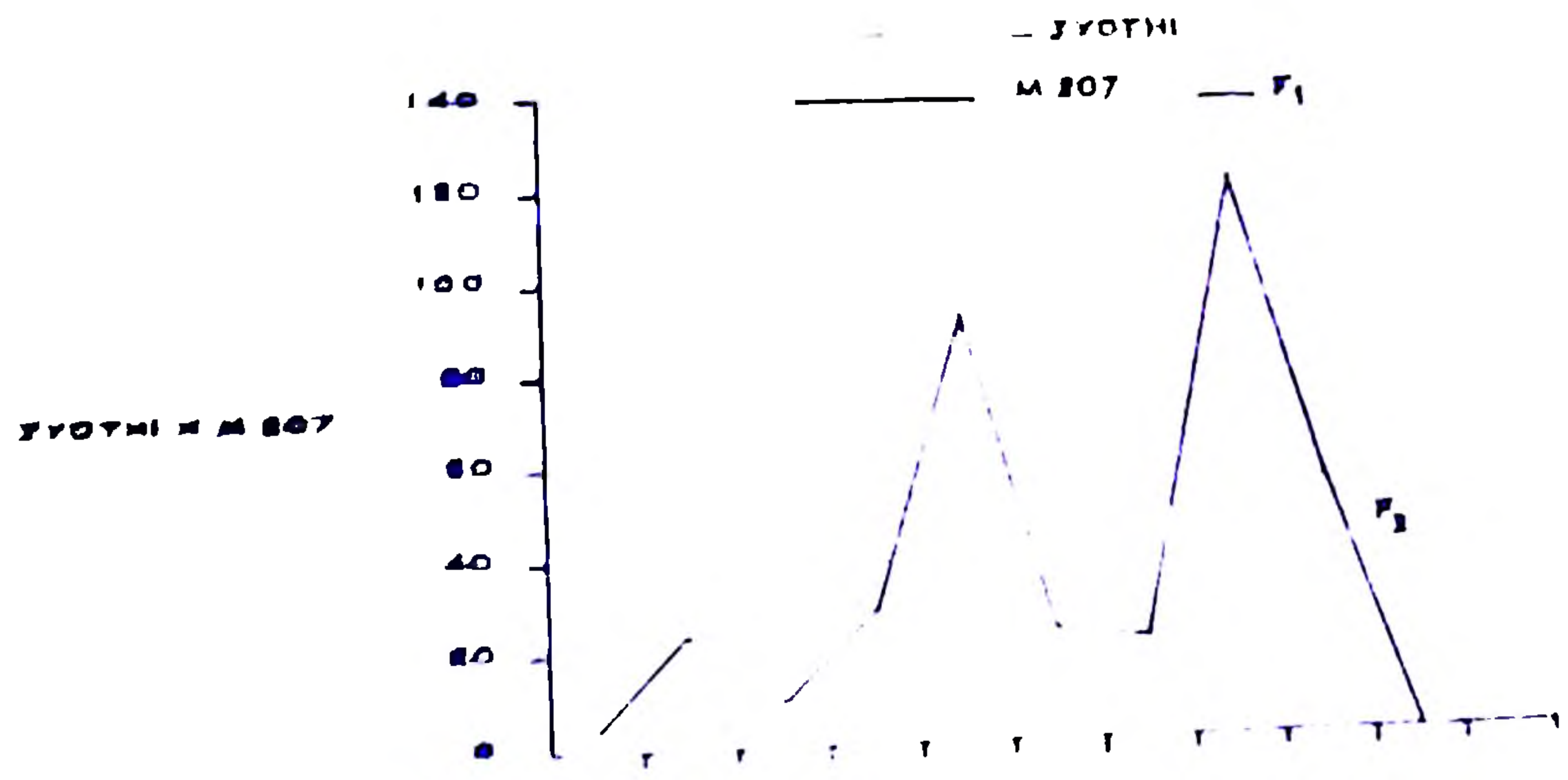


FIG IX-8

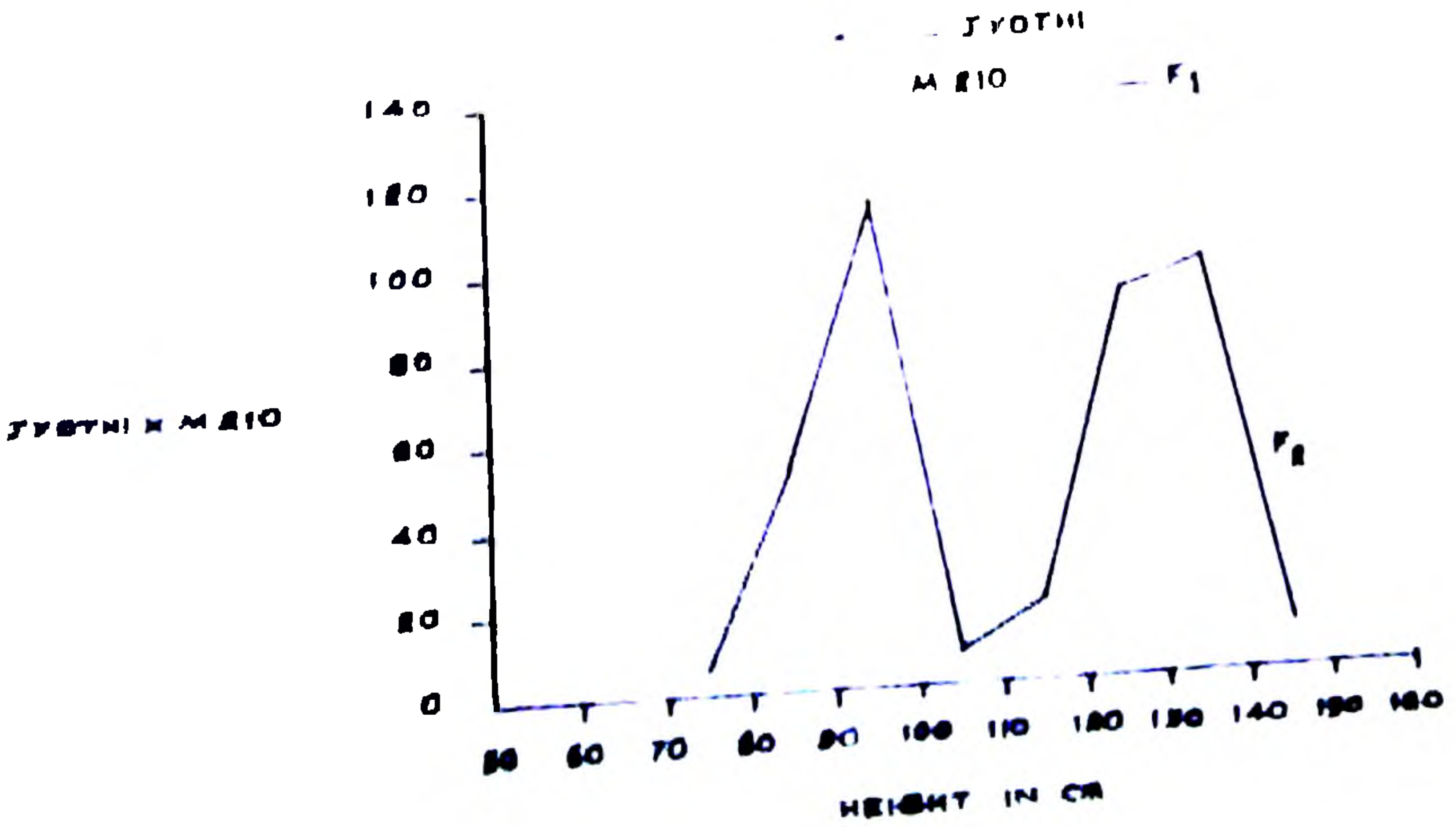


FIG IX-9

class to 141 to 150 cm class (Table 20). The distribution was also characterised by 3 modes the modal classes being 61 to 70 cm, 81 to 90 cm and 121 to 130 cm (Figure IX-8). The pattern of segregation indicated the presence of tall, semidwarf and dwarf plants. Considering the plants below 70 cm as dwarfs, those falling between 71 to 110 cm as semi-dwarfs and those above 110 cm as talls, the F_2 population could be considered to consist of 193 talls, 147 semidwarf and 27 dwarfs. Analysis of the observed frequencies showed satisfactory fit to 9:6:1 ratio. As in the crosses Jyothi x M 14 and Jyothi x M 102, 9:3:3:1 model could not be used because of the difficulty in further classifying the semi-dwarfs due to similarity in appearance. The talls had characteristic long drooping leaves and open plant habit while the dwarfs had very short stem and thick dark green erect leaves. The short culms of the dwarfs appeared to possess a lower number of shortened internodes than in the semidwarfs and talls.

ix) Jyothi x M 210: While both the parents were semi-dwarf, the F_1 plants were tall, the mean plant height being 125 cm. The range of variation and the mean height of the F_1s are presented in table 19. The long culm was the result of the elongation of the internodes rather than an increase in the number of internodes. Unlike the semidwarfs, the talls possessed long leaves which were either curving or drooping and exhibited open habit leading to lodging before grain ripening. The F_2 plant height was characterised by bimodal distribution ranging from 71 to 80 cm class to 141 to 150 cm class (Figure IX-9). The modal classes were 91 to 100 cm and 131 to 140 cm. The relatively low frequency in the class 101 to 110 cm virtually divided the distribution into two distinct groups, viz., talls and semidwarfs. None of the plants could be recognised as having height less than 70 cm. Thus among the 394 F_2 plants studied, 218 were talls and 176 were semidwarfs (Table 20). The chi-square analysis indicated satisfactory fit to 9:7 ratio. The talls resembled the F_1s while the semidwarfs looked like the parents.

c) Crosses between the mutants

i) M 2 x M 6: Both M 2 and M 6 were the induced mutants of Ptb-9. M 2 (94 cm) was slightly taller than M 6 ([illegible] cm); but M 6 took 5 to 10 days more to complete flowering. Unlike the mutants, the F_1 plants were tall, the height ranging from 134 to 141 cm with a mean of 139 cm (Table 21). The F_1s resembled Ptb-9, with long drooping pale green leaves, open plant habit and susceptibility to lodging (Figure [illegible]). The pattern of elongation of the internodes showed that the increase in culm length was the result of increased internode length and not due to increase in the number of internodes. In the F_2 generation, plant height ranged from the 71 to 80 cm class to 151 to 160 cm class. Distribution of F_2 was a bimodal

Table 21. Characters of the hybrids and parents in crosses between the mutants

Sl. No.	Parents/hybrids	Plant height (cm) Range	Plant height (cm) Mean	Number of inter-nodes	Duration (days)	Leaf length (cm)	Leaf orientation	Leaf colour	Lodging	Plant habit
1	2	3	4	5	6	7	8	9	10	11
1	M 2	89-102	94	6	115	30	erect	dark green	resistant	compact
2	M 6	80-93	88	6	120	34	erect	dark green	resistant	compact
3	M 14	85-104	95	6	120	34	erect	dark green	resistant	compact
4	M 102	83-106	93	6	110	34	erect	dark green	resistant	compact
5	M 107	82-102	92	6	115	38	erect	dark green	resistant	compact
6	M 111	87-102	95	6	110	34	erect	dark green	resistant	compact
7	M 202	73-95	89	6	89	33	erect	dark green	resistant	compact
8	M 207	73-99	91	6	93	30	erect	dark green	resistant	compact
9	M 210	76-98	91	6	95	33	erect	dark green	resistant	compact
10	M 2 x M 6	134-141	139	6	123	53	drooping	pale green	susceptible	open
11	M 2 x M 14	133-139	136	6	130	53	drooping	pale green	susceptible	open
12	M 2 x M 102	131-140	135	6	120	55	drooping	pale green	susceptible	open
13	M 2 x M 107	128-134	131	6	120	56	drooping	pale green	susceptible	open
14	M 2 x M 111	98-109	103	6	115	34	erect	dark green	resistant	compact
15	M 2 x M 202	69-101	98	6	98	32	erect	dark green	resistant	compact
16	M 2 x M 207	124-130	128	6	105	56	drooping	pale green	susceptible	open
17	M 2 x M 210	126-133	131	6	105	56	drooping	pale green	susceptible	open
18	M 6 x M 14	137-142	139	6	130	56	drooping	pale green	susceptible	open
19	M 6 x M 102	129-134	132	6	115	54	drooping	pale green	susceptible	open
20	M 6 x M 107	95-101	97	6	95	32	erect	dark green	resistant	compact

(contd.)

Table 21 contd.

1	2	3	4	5	6	7	8	9	10	11
21	M 6 x M 111	126-132	129	6	110	56	drooping	pale green	susceptible	open
22	M 6 x M 202	122-130	126	6	102	51	drooping	pale green	susceptible	open
23	M 6 x M 207	124-130	127	6	115	52	drooping	pale green	susceptible	open
24	M 6 x M 210	94-98	96	6	105	32	erect	dark green	resistant	compact
25	M 14 x M 102	125-132	129	6	126	54	drooping	pale green	susceptible	open
26	M 14 x M 107	130-137	134	6	115	51	drooping	pale green	susceptible	open
27	M 14 x M 111	130-136	133	6	115	54	drooping	pale green	susceptible	open
28	M 14 x M 202	121-127	124	6	93	50	drooping	green	susceptible	open
29	M 14 x M 207	121-130	126	6	101	51	drooping	pale green	susceptible	open
30	M 14 x M 210	127-132	129	6	105	43	drooping	pale green	susceptible	open
31	M 102 x M 107	135-139	136	6	115	54	drooping	pale green	susceptible	open
32	M 102 x M 111	130-139	135	6	115	54	drooping	pale green	susceptible	open
33	M 102 x M 202	125-130	128	6	102	51	drooping	pale green	susceptible	open
34	M 102 x M 207	95-100	98	6	95	34	erect	dark green	resistant	compact
35	M 102 x M 210	125-134	129	6	102	49	drooping	pale green	susceptible	open
36	M 107 x M 111	132-140	137	6	115	54	drooping	pale green	susceptible	open
37	M 107 x M 202	124-130	126	6	110	43	drooping	green	susceptible	open
38	M 107 x M 207	126-133	130	6	103	54	drooping	pale green	susceptible	open
39	M 107 x M 210	88-96	92	6	95	33	erect	dark green	resistant	compact
40	M 111 x M 202	86-94	90	6	95	34	erect	dark green	resistant	compact
41	M 111 x M 207	125-130	128	6	98	48	drooping	pale green	susceptible	open
42	M 111 x M 210	127-133	130	6	98	49	drooping	pale green	susceptible	open
43	M 202 x M 207	121-128	125	6	93	48	drooping	pale green	susceptible	open
44	M 202 x M 210	118-124	122	6	90	48	drooping	pale green	susceptible	open
45	M 207 x M 210	121-125	123	6	95	51	drooping	pale green	susceptible	open

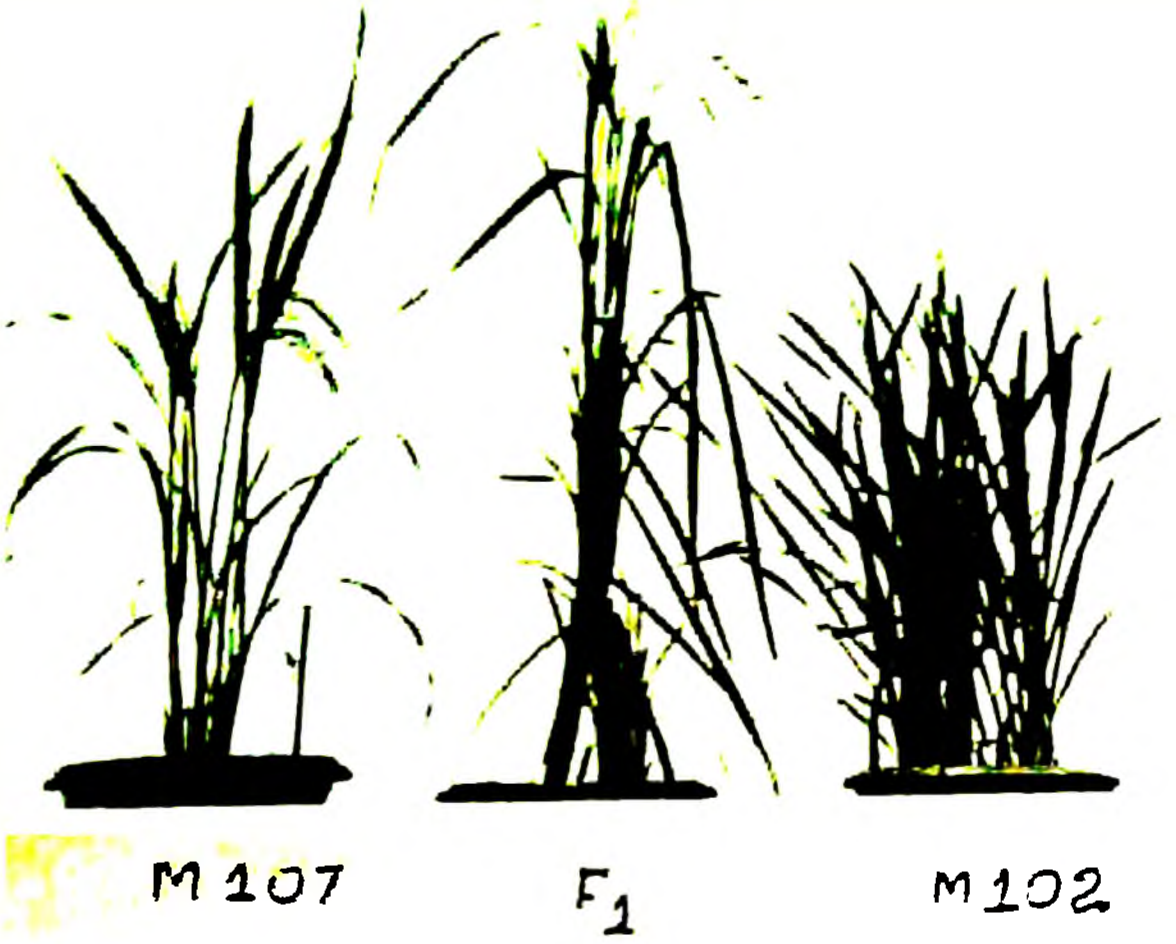
Figure X

F_1s of mutants x mutants

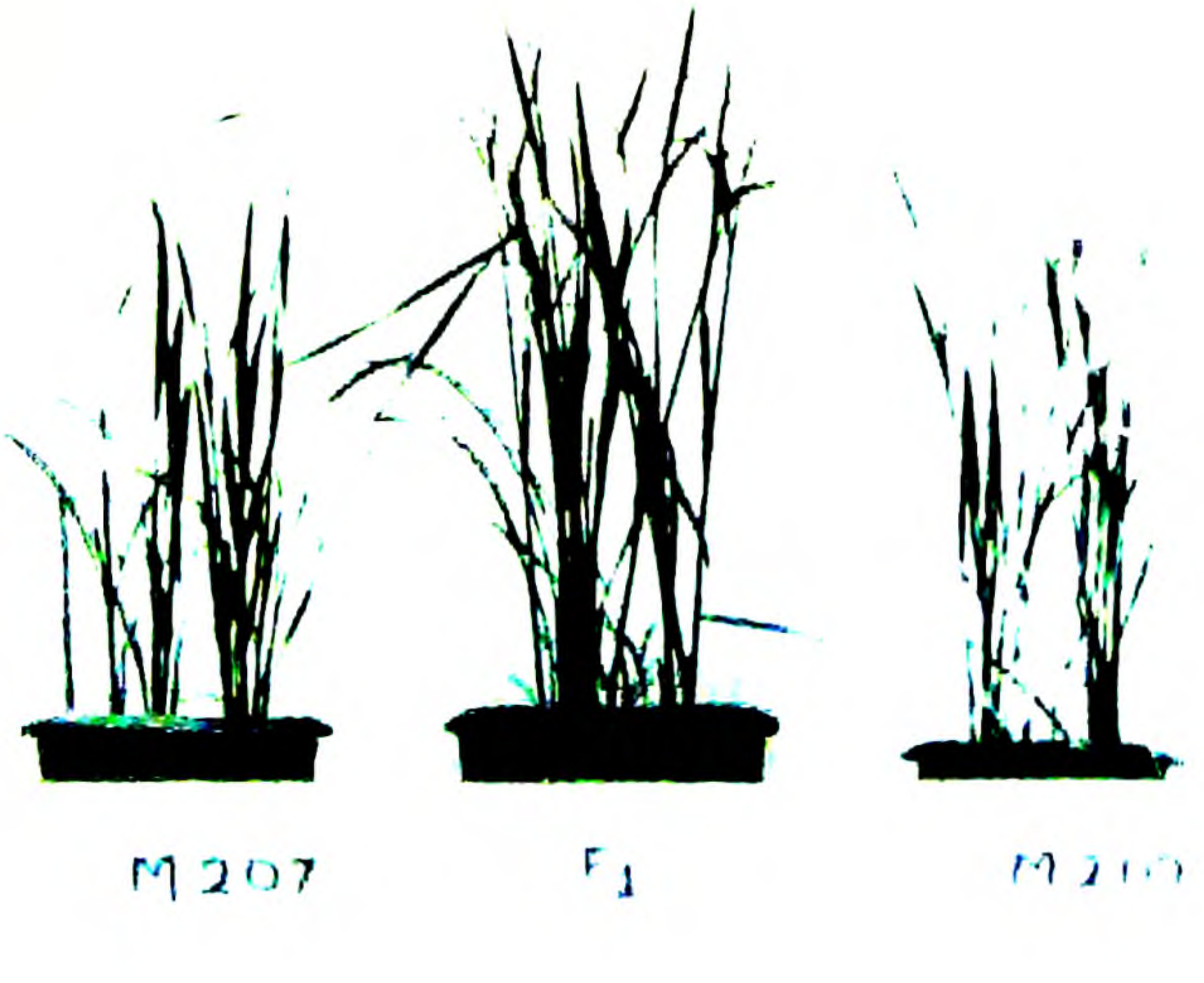

M2
F1
M6


M.
F1
M111


M14
F1
M2..7


M 107
F1
M 102


M 102
F1
M 202


M 207
F1
M 201

with the modal classes of 91 to 100 cm and 131 to 140 cm and classes with relatively lower number of plants in between (Figure XI-1, Table 22). The low frequency of plants observed in 101 to 110 and 111 to 120 classes distinctly separated, the tall and semidwarf plants. But none of the plants were below 70 cm. Out of the 368 F_2s studied, 204 were talls and 164 semidwarfs. The segregation fitted with high probability to the ratio, 9:7. The tall plants looked like the F_1s and Ptb-9 exactly while the semidwarfs resembled the mutant parents. A further grouping of semidwarfs however, was not possible.

ii) M 2 x M 14: While both M 2 and M 14 were semidwarfs with compact habit, erect dark green leaves and stout culm with lodging resistance, the F_1s were weak with long culm and narrow long leaves which were pale green. They showed open habit and susceptibility to lodging. F_1s ranged from 133 to 139 cm in height (Table 21). The elongation of internodes led to the long culm which made the plants weak and susceptible to lodging. The range of variation for height was much more in F_2 than in the F_1. Height ranged from the 51 to 60 cm class to 151 to 160 cm class. Three modal classes were observed in the distribution curve (Figure XI-2). Distinct segregation for three different height groups was indicated by the low frequency of plants in 71 to 80 cm class compared with the modal classes and the absence of plants in the

FREQUENCY DISTRIBUTION (CROSSES BETWEEN MUTANTS)

M2 x M6

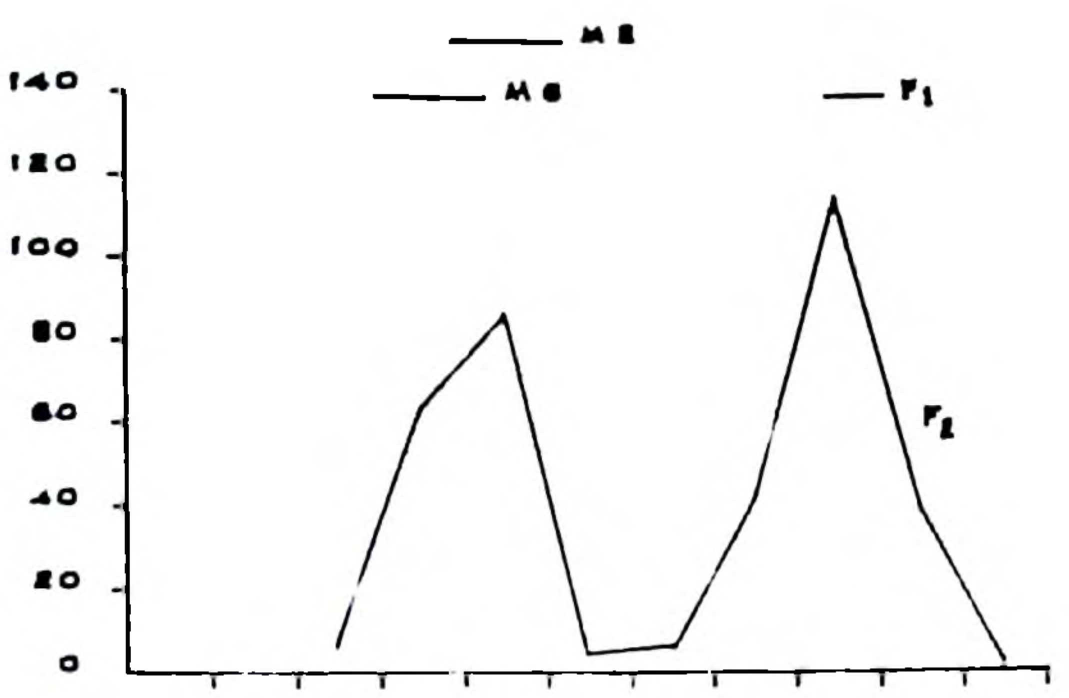


Fig XI-1

M2 x M14

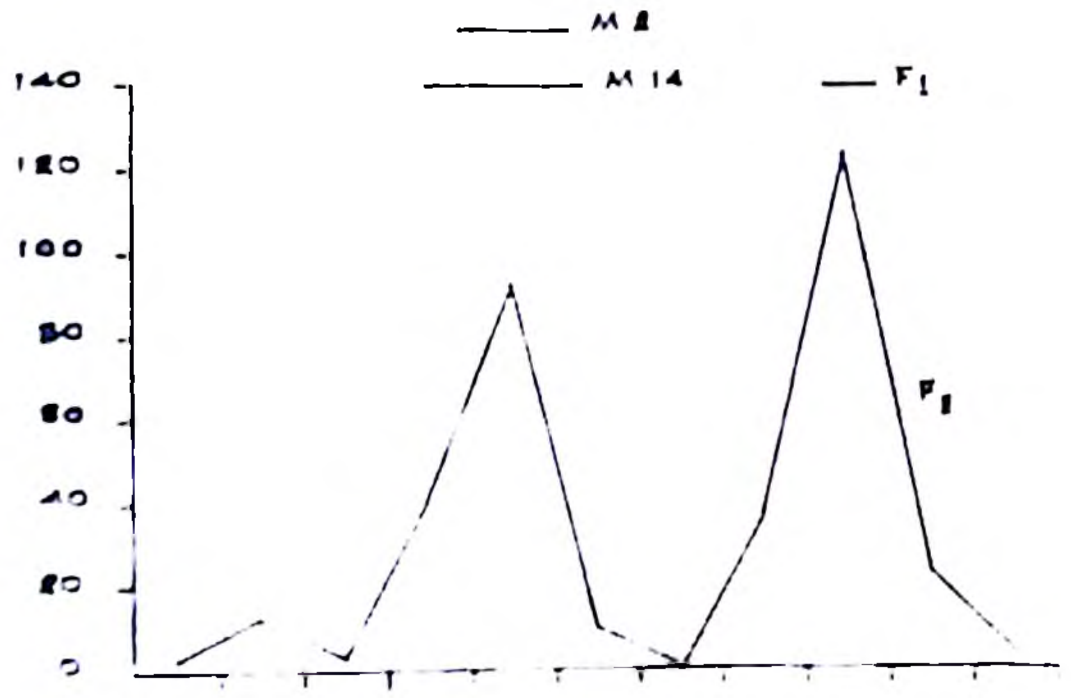


Fig XI-2

M2 x M102

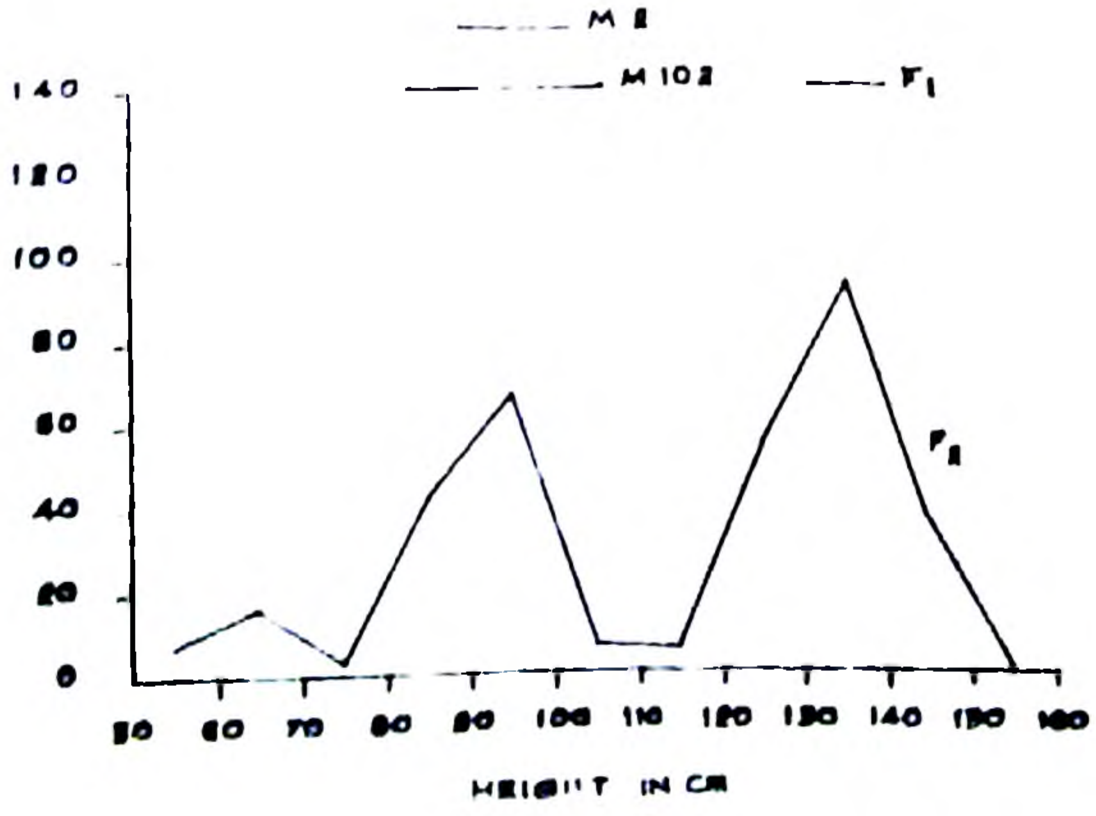


Fig XI-3

Table 22. Frequency distribution for height in crosses between mutants in F_2

Sl. No.	Parents/crosses	Height classes in cm											Total	Tall	Semi-dwarf	Dwarf	χ^2 (9:7/ 9:6:1)
		51-60	61-70	71-80	81-90	91-100	101-110	111-120	121-130	131-140	141-150	151-160					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	M 2	-	-	-	8	35	7	-	-	-	-	-	50	-	50	-	-
2	M 6	-	-	6	27	17	-	-	-	-	-	-	50	-	50	-	-
3	M 14	-	-	-	6	41	3	-	-	-	-	-	50	-	50	-	-
4	M 102	-	-	-	13	29	8	-	-	-	-	-	50	-	50	-	-
5	M 107	-	-	-	12	32	6	-	-	-	-	-	50	-	50	-	-
6	M 111	-	-	-	3	45	2	-	-	-	-	-	50	-	50	-	-
7	M 202	-	-	3	18	29	-	-	-	-	-	-	50	-	50	-	-
8	M 207	-	-	2	24	24	-	-	-	-	-	-	50	-	50	-	-
9	M 210	-	-	5	17	28	-	-	-	-	-	-	50	-	50	-	-
10	M 2 x M 6	-	-	7	65	87	5	7	41	115	39	2	368	204	164	-	0.099
11	M 2 x M 14	2	12	3	39	93	11	-	36	123	24	4	347	187	146	14	4.379
12	M 2 x M 102	8	16	2	41	66	7	6	54	92	38	1	331	191	116	24	1.079
13	M 2 x M 107	-	-	-	19	126	-	5	38	120	11	-	319	174	145	-	0.319
14	M 2 x M 111	-	-	8	81	158	12	-	-	-	-	-	259	-	259	-	-
15	M 2 x M 202	-	-	2	85	118	6	-	-	-	-	-	211	-	211	-	-
16	M 2 x M 207	7	9	4	34	77	-	6	73	106	16	2	334	203	115	16	3.187
17	M 2 x M 210	-	-	-	49	84	8	-	68	73	9	3	294	153	141	-	1.988
18	M 6 x M 14	-	-	13	62	69	6	9	60	94	13	-	325	176	149	-	0.613
19	M 6 x M 102	-	-	9	47	91	2	9	49	117	17	6	347	198	149	-	0.105
20	M 6 x M 107	-	-	6	70	147	18	-	-	-	-	-	241	-	241	-	-
21	M 6 x M 111	-	-	-	59	83	[illegible]	4	81	83	13	4	343	185	158	-	0.759
22	M 6 x M 202	-	-	24	106	53	2	33	113	62	3	-	396	211	185	-	1.478

(contd.)

Table 22 contd.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
23	M 6 x M 207	-	-	17	67	82	8	5	109	86	9	-	383	209	174	-	0.381
24	M 6 x M 210	-	-	-	93	111	9	-	-	-	-	-	234	-	234	-	-
25	M 14 x M 102	4	12	1	38	64	4	17	103	59	5	2	309	186	107	16	2.306
26	M 14 x M 107	-	-	15	63	72	17	10	134	54	1	-	366	199	167	-	0.544
27	M 14 x M 111	2	11	6	43	51	9	6	59	54	18	7	266	144	109	13	2.191
28	M 14 x M 202	8	9	5	54	77	7	9	84	93	9	-	355	195	143	17	2.013
29	M 14 x M 207	5	13	2	51	93	2	4	108	67	3	-	348	182	148	18	4.219
30	M 14 x M 210	-	-	8	70	78	5	5	102	104	9	-	381	220	160	-	0.384
31	M 102 x M 107	-	-	3	52	113	6	7	57	123	5	3	369	193	174	-	1.862
32	M 102 x M 111	3	19	1	63	74	6	4	94	102	10	8	384	218	144	22	0.186
33	M 102 x M 202	12	12	4	71	32	7	4	88	93	-	-	323	185	114	24	1.313
34	M 102 x M 207	-	-	2	89	115	11	-	-	-	-	-	218	-	218	-	-
35	M 102 x M 210	-	-	9	71	66	1	3	72	78	3	4	306	160	146	-	1.912
36	M 107 x M 111	-	-	2	55	90	6	2	63	93	4	6	321	168	153	-	2.141
37	M 107 x M 202	-	-	8	86	53	3	14	72	69	6	-	311	161	150	-	2.561
38	M 107 x M 207	-	-	3	68	67	7	2	103	91	4	1	346	201	145	-	0.577
39	M 107 x M 210	-	-	9	74	98	16	-	-	-	-	-	197	-	197	-	-
40	M 111 x M 202	-	-	4	101	106	7	-	-	-	-	-	218	-	218	-	-
41	M 111 x M 207	8	11	3	49	84	5	6	117	82	8	3	376	216	141	19	0.772
42	M 111 x M 210	-	-	7	73	71	8	11	70	76	7	7	330	171	159	-	3.150
43	M 202 x M 207	7	17	8	53	64	6	8	98	61	13	-	327	172	131	24	2.303
44	M 202 x M 210	-	-	12	46	78	4	12	99	53	2	-	306	166	140	-	0.478
45	M 207 x M 210	-	-	11	66	56	14	10	81	72	8	-	318	171	147	-	0.818

111 to 120 cm class. Thus the F_2 consisted of 187 talls, 146 semidwarfs and 14 dwarfs. The F_2 frequency distribution is presented in table 22. The frequencies of the segregating plants gave a satisfactory fit to a 9:6:1 model. Further grouping of semidwarfs was difficult eventhough the semidwarfs exhibited slight variations. The talls resembled the F_1s and Ptb-9 while the semidwarfs were similar to the mutant parents. While talls had characteristic leaves and plant habit, the semidwarfs had short erect leaves and compact habit. The dwarfs formed a very distinct group with compact habit, more numerous tillers, very short culm and short, erect, thick and dark green leaves. The lower internodes were so much shortened that they were unrecognisable with the result that the culm of dwarfs appeared to have a lower number of internodes.

iii) M 2 x M 102: The mean height of M 2 was 94 cm and that for M 102 was 93 cm. The range of height in F_1 was 131 to 140 cm with a mean of 135 cm as recorded in table 21. F_1 appeared tall with characteristic long drooping leaves, weak long culm and open habit. The long culm carried elongated internodes. The F_1s invariably lodged immediately after heading. A very wide range of variation in plant height was observed in the F_2. The shortest plants were grouped under the class 51 to 60 cm and the tallest plant was in the class 151 to 160 cm. F_2 distribution for height revealed 3 modal classes, viz., 61 to 70 cm, 91 to 100 cm and 131 to 140 cm (Figure XI-3). Relatively low frequency of plants in classes between these modal classes distinctly separated the population into three groups. Out of 331 F_2 plants, 191 were talls, 116 were semidwarfs and 24 were dwarfs (Table 22). The frequencies of segregating plants showed good fit for the 9:6:1 model when tested statistically. The talls were similar in appearance to the F_1s and lodged before maturity. The semidwarfs with their short culm, erect short leaves and compact habit resisted lodging. The dwarfs typically had very short culm and very short but thick and dark green leaves which were upright. Many of them had large number of tillers with small panicles. Observations on internode elongation pattern indicated that dwarfs either had very shortened unrecognisable lower internodes or had reduced number of internodes while both talls and semidwarfs had almost equal number of internodes even though of different lengths.

iv) M 2 x M 107: While M 2 and M 107 were semidwarfs (94 cm and 92 cm respectively) the F_1s were tall with a mean height of 131 cm (Table 21). They had long drooping leaves with open habit. As against the semidwarf parents, F_1s lodged after heading before ripening. In the F_2 generation, plants ranged in height from 81 to 90 cm class to 141 to 150 cm class. Bimodal distribution was observed for plant height with two modal classuof 91 to 100 cm and 131 to 140 cm (Figure XI-4,

FREQUENCY DISTRIBUTION (CROSSES BETWEEN MUTANTS)

M 2 × M 107

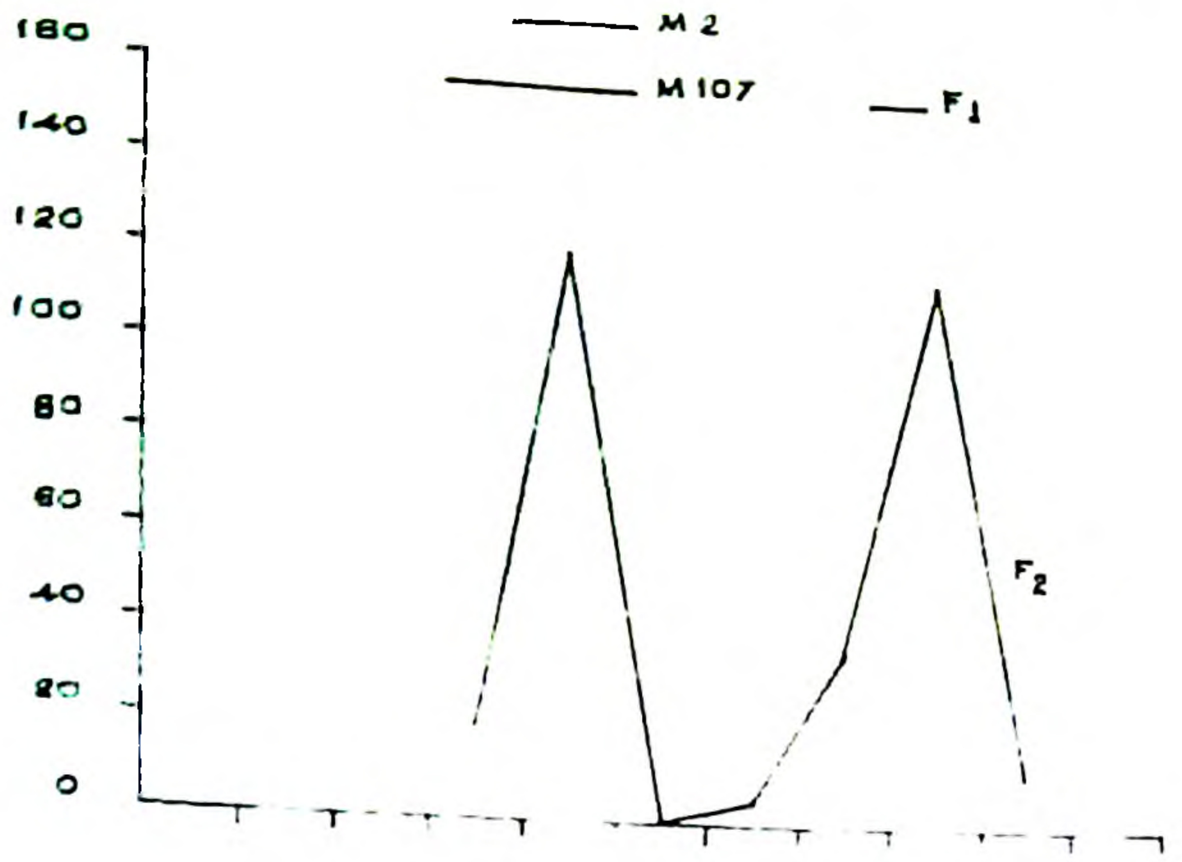


FIG XI-4

M 2 × M 111

FIG XI-5

M 2 × M 202

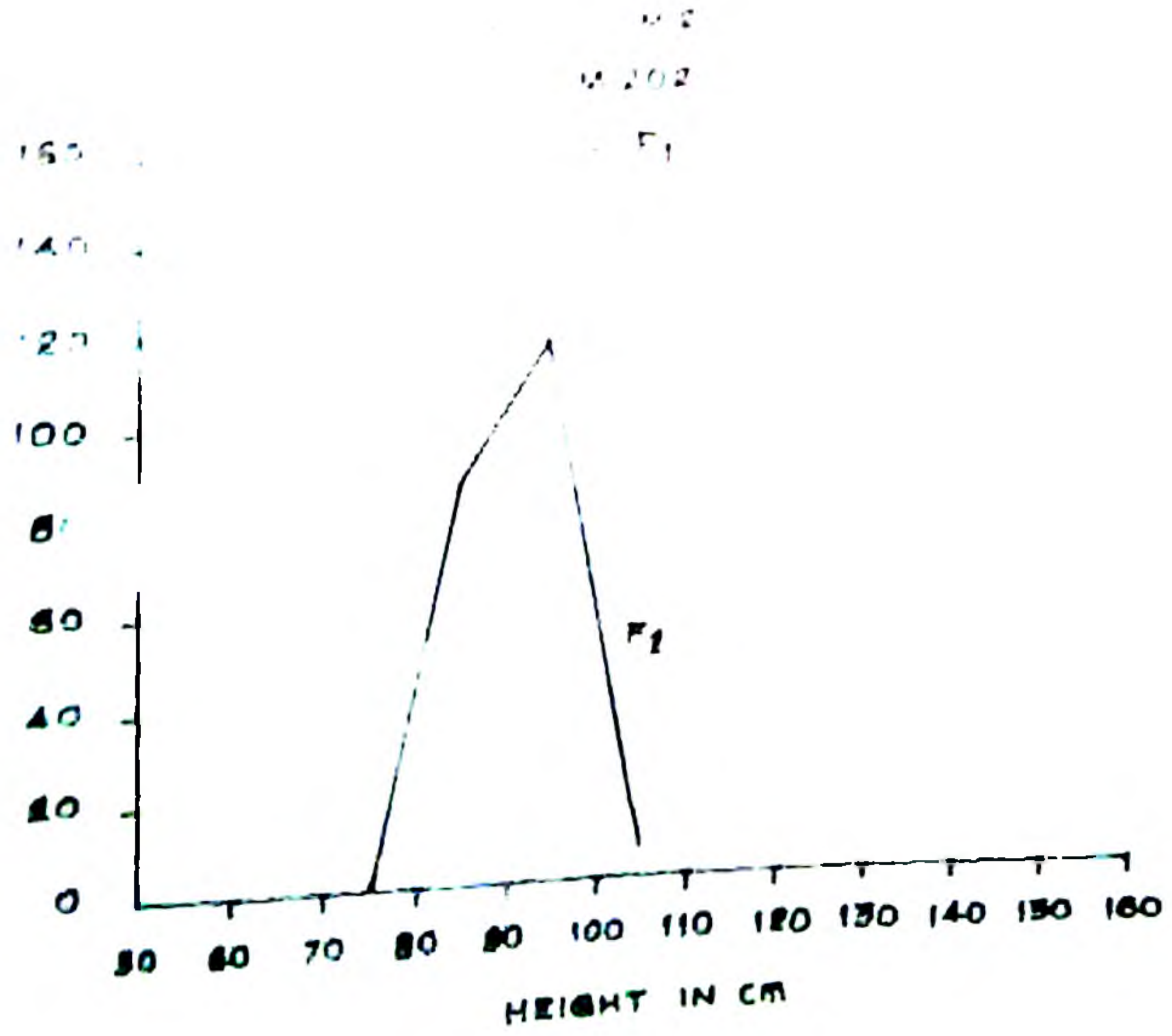


FIG XI-6

Table 22). Absence of plants in the 101 to 110 cm class and the low frequency of plants in the 111 to 120 cm class separated the two groups of tall and semidwarf plants. No plant could be recognised as having height below 70 cm. The tall plants were associated with the characteristic long pale green drooping leaves, long culm with elongated internodes and open habit. They more or less resembled the F_1 plants. Eventhough the semidwarfs showed variation they could not be further grouped. They possessed erect dark green leaves and compact habit. The short and stout stem made them resistant to lodging. Out of 319 F_2 plants scored, 174 were talls and 145 semidwarfs. Frequencies of plants segregating above and below the height class of 101 to 110 cm fitted a 9:7 ratio with high probability.

v) [illegible] x [illegible] 111: Like the mutant parents, the F_1s were semidwarfs. They ranged from 98 to 109 cm with a mean value of 103 cm (Table 21). The F_1s looked like the parents in the orientation of leaves, size of leaves, plant habit and lodging nature (Figure X). They had short erect leaves which remained green even at the ripening of the grains, exhibited compact habit and were resistant to lodging. Even though the F_2 showed more variation for height than the F_1, all the plants could be grouped as semidwarfs since none of them fell below 70 cm and above 110 cm (Figure XI-5, Table 22). In appearance, orientation of leaves and in plant habit the

F_2s resembled the F_1 plants and their mutant parents. The culm was short and stout with shortened internodes and the plants were nonlodging.

vi) M 2 x M 202: The mean plant height in the F_1 generation was 98 cm (Table 21) suggesting semidwarf stature as in the case of their parents. The characteristic features of the semidwarfs, viz., erect short dark green leaves, compact habit, short and stout culm with shortened internodes and nonlodging nature, were observed in the F_1 plants. While the F_1s ranged from 95 to 101 cm for plant height, the F_2 plants ranged from 71 to [illegible] cm class to 101 to 110 cm class (Figure XI-6, Table 22). All the F_2 plants were more or less like the F_1 plants in appearance. In the pattern of internode elongation also they exhibited close similarity with F_1s and the parents. None of the F_2 plants lodged.

vii) M 2 x M 207: While both the mutants, M 2 ([illegible] cm) and M 207 ([illegible] cm) were semidwarf in stature, the F_1s were tall, the mean height being 128 cm (Table 21). Unlike the parents, the F_1s had long pale green leaves which were drooping, exhibited open plant habit, and had weak long culms. The long culm was the result of elongation of internodes. The lodging habit of the plants could be attributed to the long weak culms due to elongation of internodes. Unlike the F_1, where the range of plant height was very limited, the F_2 showed wide range of variation for plant height. Plants could be grouped from 51 to 60 cm class to 151 to 160 cm class (Table 22). The F_2 curve showed 3 modal classes, viz., 61 to 70 cm, 91 to 100 cm and 131 to 140 cm. There was no plant in the class 101 to 110 cm. Similarly, in the class 71 to 80 there was low frequency of plants. These divided the distribution curve into three (Figure XI-7). Thus in the F_2, 203 talls, 115 semidwarfs and 16 dwarfs were recognised. Apart from the stature, other characters associated with the different height groups were helpful in grouping the plants. The talls exhibited open habit with long culm and long drooping leaves, while the semidwarfs had short culm and short erect leaves. The semidwarfs were nonlodging whereas the talls lodged. The dwarfs had very short culm and very short, upright, thick and dark green leaves. The observed frequencies of the height groups showed a good fit to 9:6:1 ratio with high probability. The semidwarfs exhibited variability, but it was difficult to further divide them into groups and therefore the model 9:3:3:1 was not used for testing the goodness of fit.

viii) M 2 x M 210: The F_1 plants had elongated culm and tall stature unlike the mutant parents which were semidwarf. The tall plants were characterised by pale green long drooping leaves which showed early senescence (Table 21). They had open plant habit and exhibited susceptibility to lodging. The open plant habit and exhibited susceptibility to lodging. The open plant habit and exhibited susceptibility to lodging.

FREQUENCY DISTRIBUTION (CROSSES BETWEEN MUTANTS)

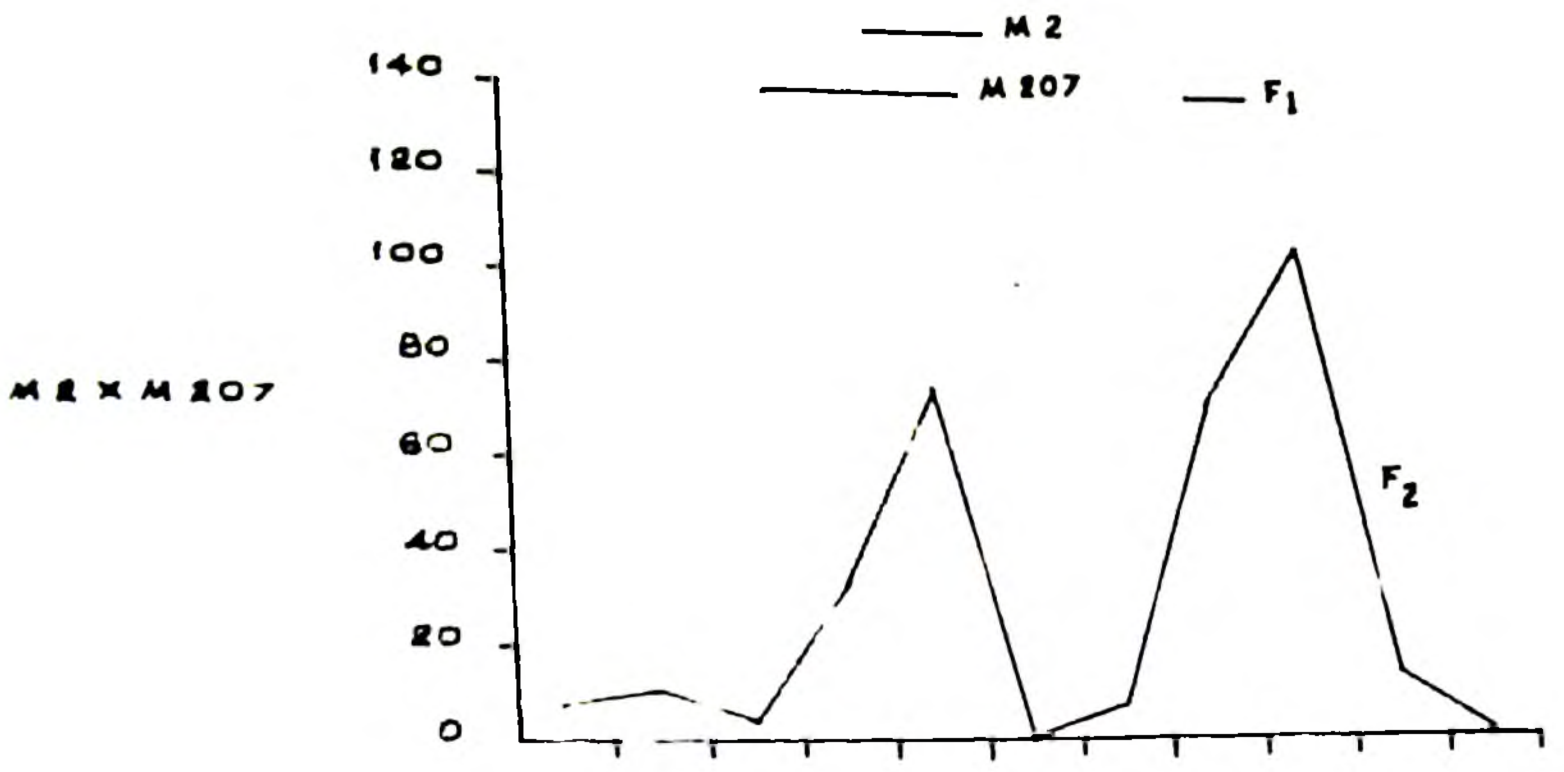


FIG. XI-7

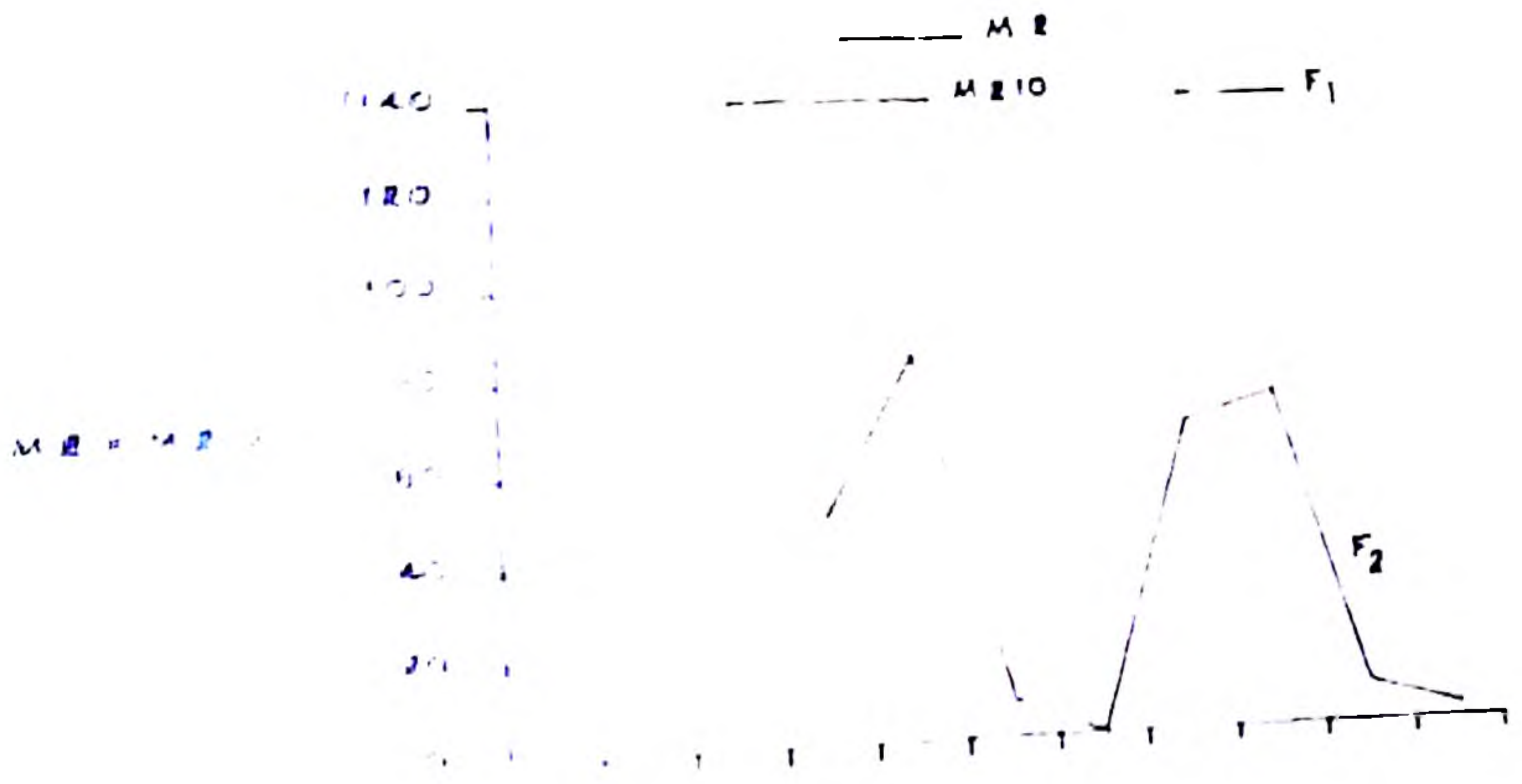


FIG. XI-8

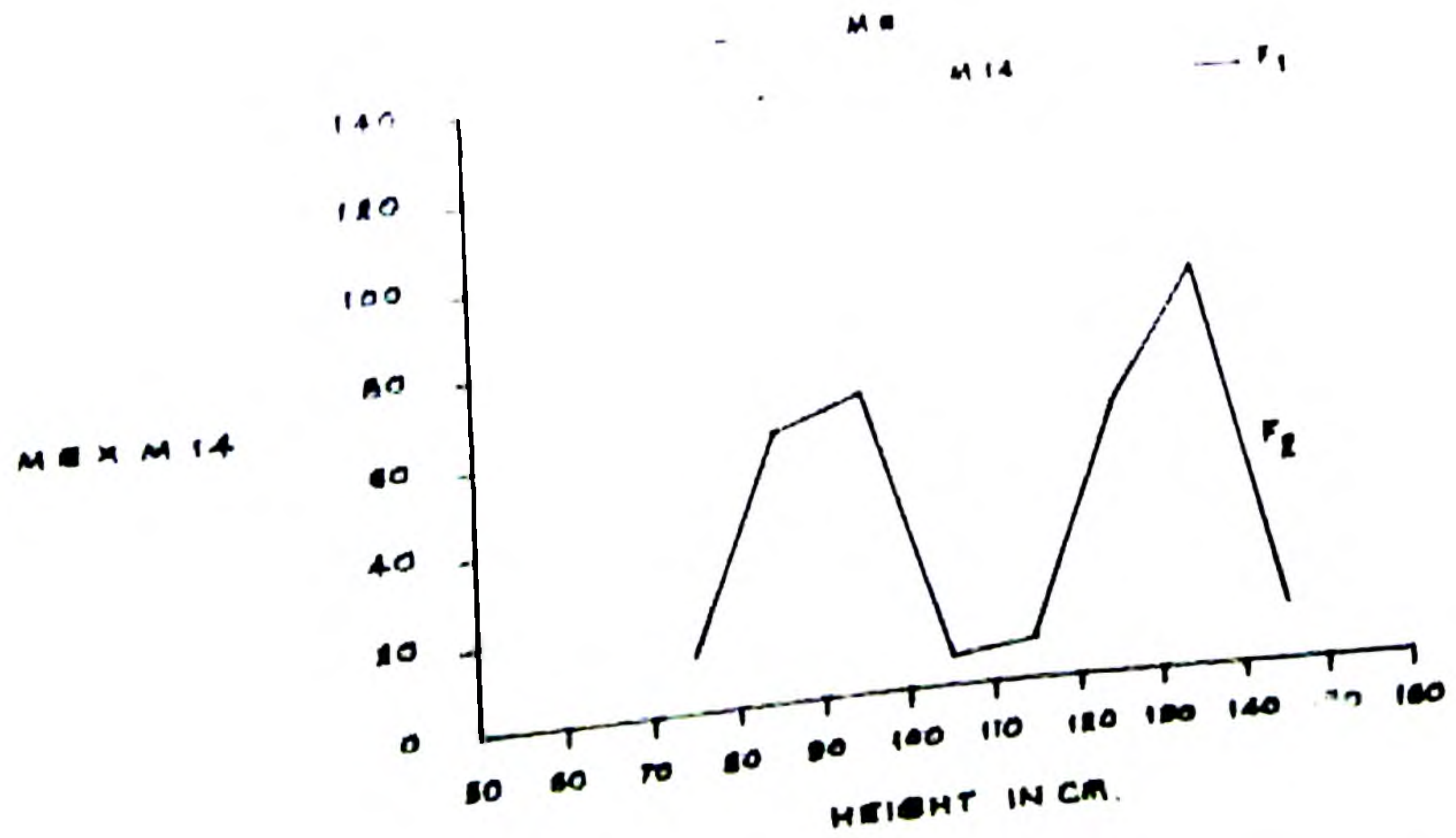


FIG. XI-9

internodes. Bimodal distribution was observed in the F_2 with the maximum frequencies in the two modal classes of 91 to 100 cm and 131 to 140 cm (Figure XI-3). The absence of plants in the 111 to 120 cm class separated the two groups of talls and semidwarfs. Out of 294 F_2 plants 153 were tall and 141 semidwarf (Table 22). The talls were characteristically weak with long culm and long drooping leaves and showed open habit and lodging. Thus, they resembled the F_1s. But the semidwarfs had compact habit, and erect short leaves and were nonlodging. The χ^2 test of goodness of fit revealed that the observed frequencies of talls and semidwarfs fitted well to a 9:7 model.

ix) [illegible] 6 x [illegible] 14: Both [illegible] 6 and [illegible] 14 were mutants of Ptb-9 and were semidwarf with mean height [illegible] cm and [illegible] cm, respectively. Unlike the mutants the F_1 plants were tall, the mean height being [illegible] cm with a range of [illegible] to [illegible] cm. The F_1 plants more or less resembled Ptb-9. The leaves were long with drooping nature and showed early senescence unlike the leaves of the mutants which were erect and showed very late senescence. The tall F_1s exhibited open habit and weak stand. The study of internodes indicated that the long culm was the result of elongated internodes which contributed to the susceptibility to lodging. While the range of variation for plant height was very narrow in the F_1, the F_2 plants exhibited wide variation in height. The shortest plants fell in the class 71 to 80 cm and the tallest in the class 141 to 150 cm. The F_2 distribution for plant height showed two modal classes of 91 to 100 cm and 131 to 140 cm with relatively low frequencies in between which divided the distribution into two groups of talls and semidwarfs (Figure XI-9). Virtually none of the plants could be considered as dwarf. The F_2 progeny included 176 talls and 149 semidwarfs. The segregation of talls and semidwarfs showed good fit to 9:7 ratio, when tested using chi-square test of goodness of fit. The tall plants in the F_2 were more or less similar to the F_1 plants and Ptb-9 and the semidwarfs resembled the mutant parents.

x) M 6 x M 102: Unlike the mutants, the F_1s showed elongation of internodes resulting in long culm. The plants were tall and weak with open habit. The leaves were long pale green and drooping and showed early senescence. While the semidwarf parents were nonlodging, the F_1s lodged after heading. Height varied from 120 to 134 cm with a mean of 132 cm. The range of variation for plant height in the F_2 generation was much greater. Some of the shorter plants had height of 71 to 80 cm while the tallest plants had height of 151 to 160 cm. The F_2 population showed a bimodal distribution for plant height with a low frequency in the 101 to 110 cm class (Figure XI-10) which divided the population into two distinct groups of talls and semidwarfs. Out of 347 F_2

FREQUENCY DISTRIBUTION (CROSSES BETWEEN MUTANTS)

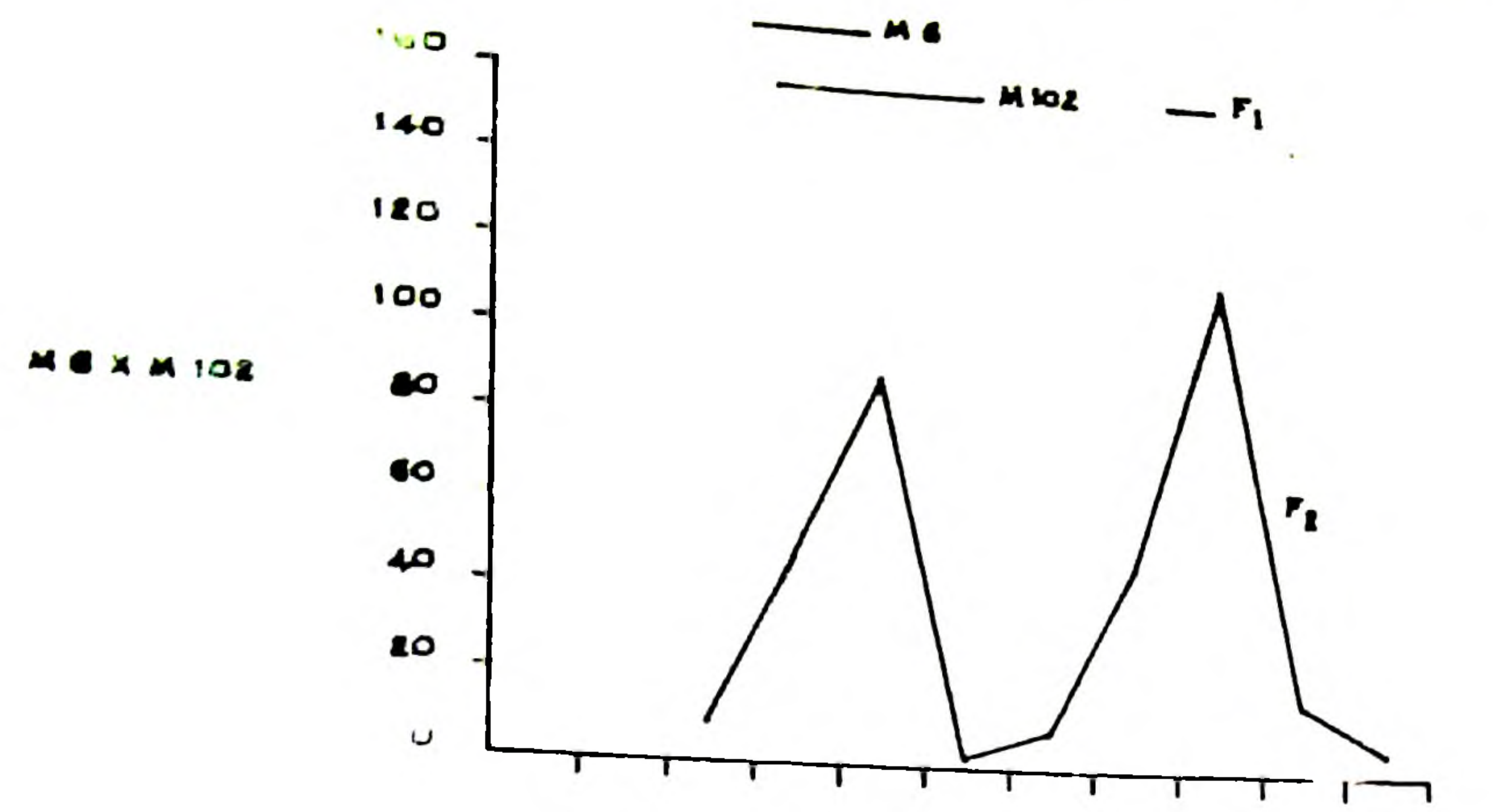


FIG XI-10

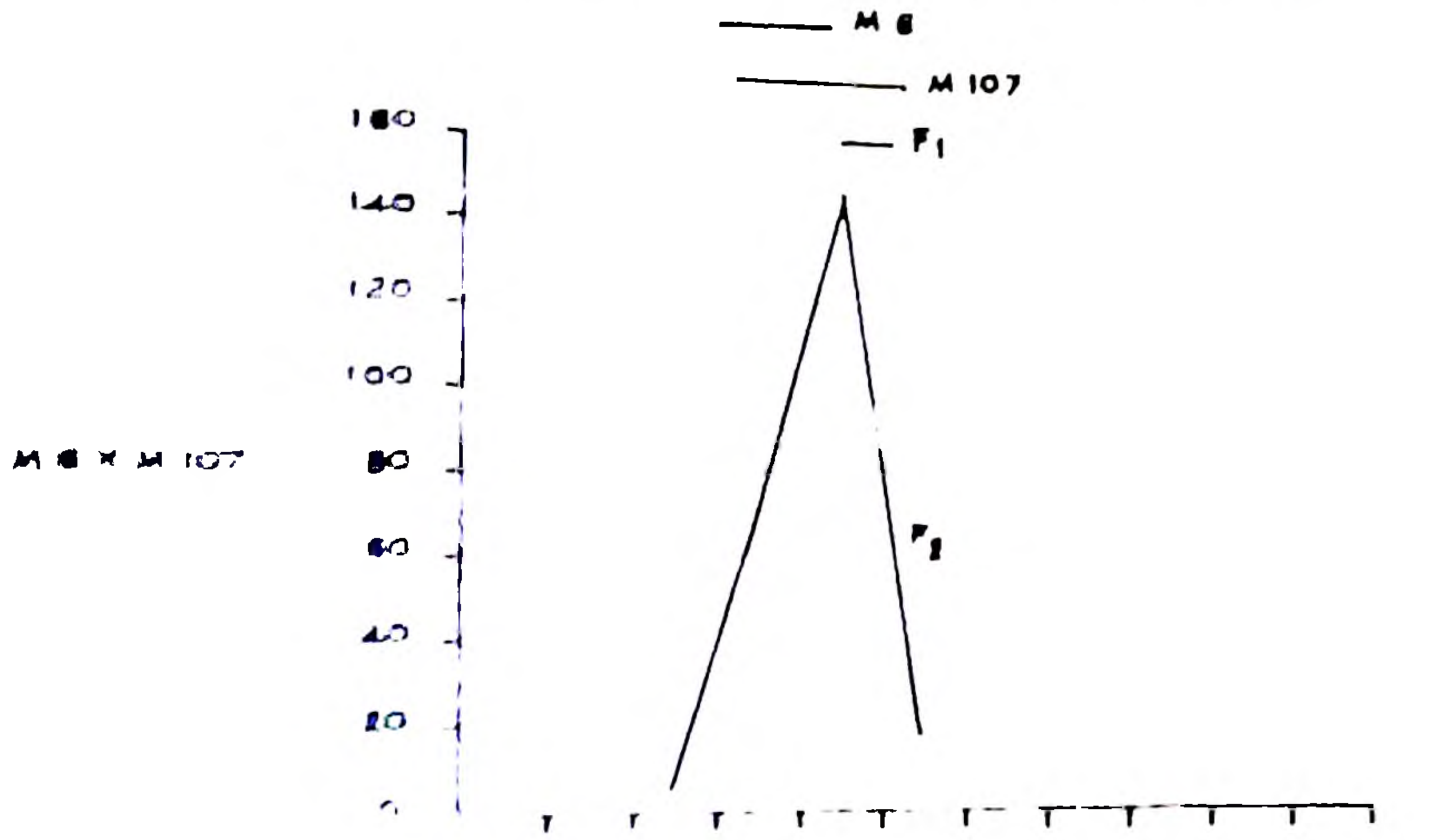


FIG XI-11

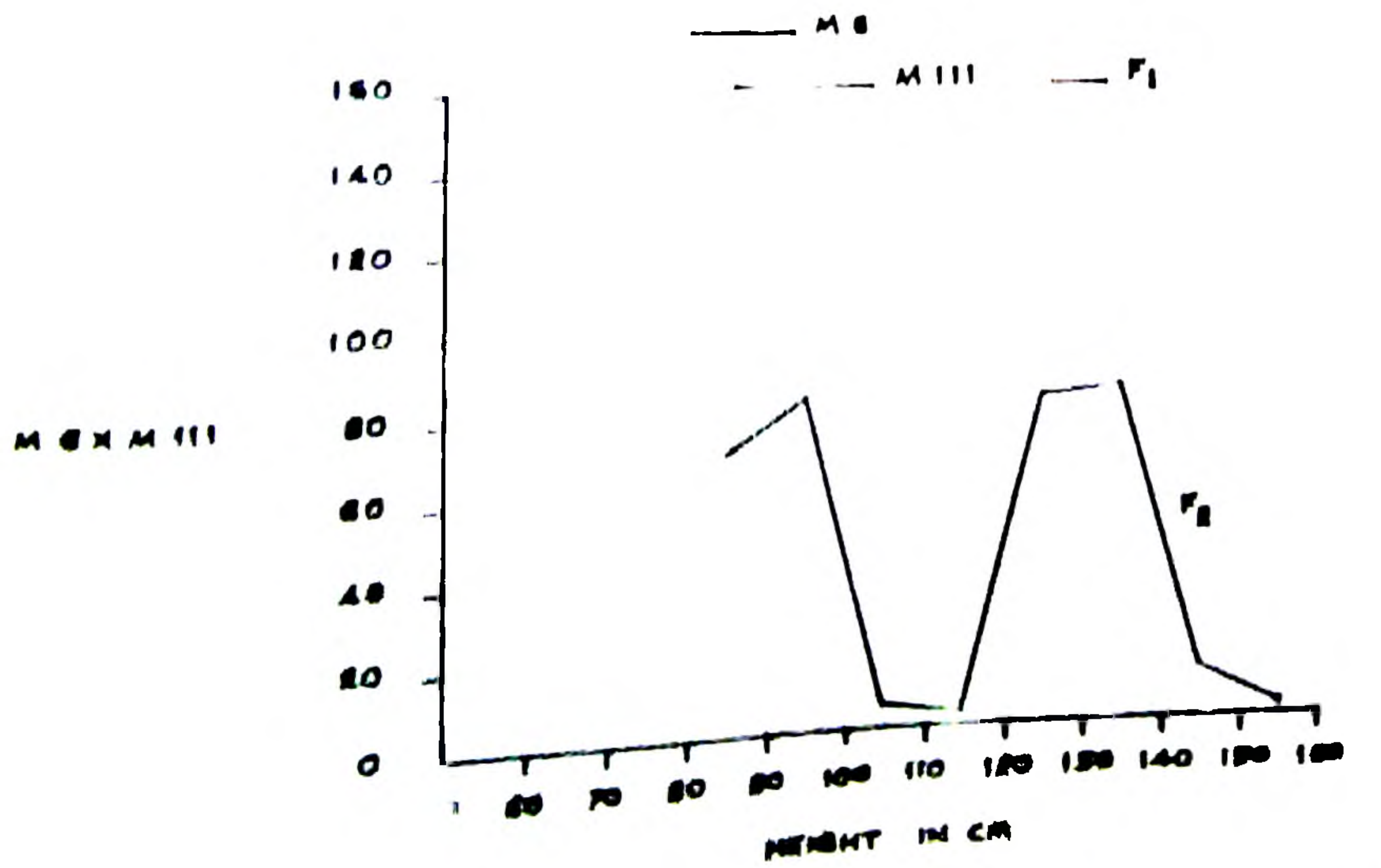


FIG XI-12

plants studied, 198 were either in the height class of 111 to 120 cm or above and the rest were either in the class 101 to 110 cm or below. The talls had a close similarity with F_1 plants even though within the tall plants the range of variation for height was more than that in the F_1. The long pale green drooping leaves, open habit and lodging nature made the plants look like F_1s. The semidwarfs were nonlodging with compact habit and short stout culm. The internode elongation pattern showed that both semidwarfs and talls had almost the same number of internodes, but in talls the internodes were much elongated than those in semidwarfs. The observed frequencies of talls and semidwarfs fitted with high probability to the ratio 9:7.

xi) [illegible] 6 x [illegible] 197: The F_1s had almost the same plant height as the mutant parents (97 cm). Like the mutants they also had compact habit, erect short leaves and short and stout culm. The pattern of internode elongation was also comparable. In F_2, plants ranged from 71 to 80 cm class to 101 to 110 cm class in height (Figure VI-11). Eventhough height variation is more in F_2 than in F_1, none of the plants had height below 70 cm or above 110 cm. The plants had erect dark green leaves and compact habit. They did not lodge presumably due to short and stout culm. The plant characters of 241 F_2s studied indicated that, they were almost uniform in height and associated characters.

xii) M 6 x M 111: M 6 was the mutant of Ptb-9 and M 111, the mutant of Ptb-28. Both the mutants were semidwarf and had erect dark green leaves. But the F_1s appeared to be tall (129 cm) with long pale green, drooping leaves. They showed the characteristic open plant habit and weak stand (Table 21). The susceptibility to lodging exhibited by the F_1s was due to the elongated internodes in contrast to the shortened internodes of semidwarf mutants. The distribution of F_2 plants for plant height showed two modal classes, a modal class of 131 to 140 cm for talls and another modal class of 91 to 100 cm for semidwarfs (Figure XI-12). The low frequencies of plants in the classes of 101 to 110 cm and 111 to 120 cm separated the two groups. The frequencies of the plants segregating above and below 110 cm fitted a 9:7 ratio with high probability (Table 22). The talls above 110 cm height were characterised by long culm, long pale green leaves and susceptibility to lodging while the semidwarfs below 110 cm had short dark green leaves and short culm. They were nonlodging.

xiii) M 6 x M 202: Even though derived from different varieties, both M 6 (88 cm) and M 202 (89 cm) were of almost equal height. But the plants in the F_1 generation of the cross M 6 x M 202 were all tall ranging from 122 to 130 cm with a mean of 126 cm (Table 21). Long curving or drooping leaves, open habit and lodging nature were observed in the F_1 plants in contrast to the mutant parents. A comparison of internodes on the main culm has revealed that the parents and the F_1 progeny had almost equal number of internodes but they differed in the pattern of elongation. The long culmed F_1s had elongated internodes. The F_2 distribution for plant height was bimodal with two modal classes of 81 to 90 cm and 121 to 130 cm (Figure XI-13). Out of 390 F_2s studied, 211 were tall and 185 semidwarf considering 110 cm as the upper limit for the semidwarfs. The frequencies of tall and semidwarf plants showed good fit with high probability to 9:7 ratio (Table 22). The semidwarfs even though having slight variations in other characters could not be classified further. The talls were typically open, weak culmed and exhibited lodging susceptibility. The semidwarfs carried erect dark green short leaves and compact habit and were nonlodging.

xiv, 1 6 × 1 207: The plants in the F_1 generation were tall unlike the semidwarf mutant parents. While mean height of 1 6 was [illegible] cm and that of 1 207 was 91 cm, the F_1 had the mean height of 127 cm (Table 21). In contrast to the erect short dark green leaves of the parents the tall F_1 plants possessed long drooping leaves which were pale green. They had long culms with elongated internodes and open plant habit. While the semidwarf parents were nonlodging, the talls in the F_1 generation lodged at different periods after heading before ripening. In the F_2 generation, both tall and semidwarf plants

FREQUENCY DISTRIBUTION (CROSSES BETWEEN MUTANTS)

M 6 X M 262

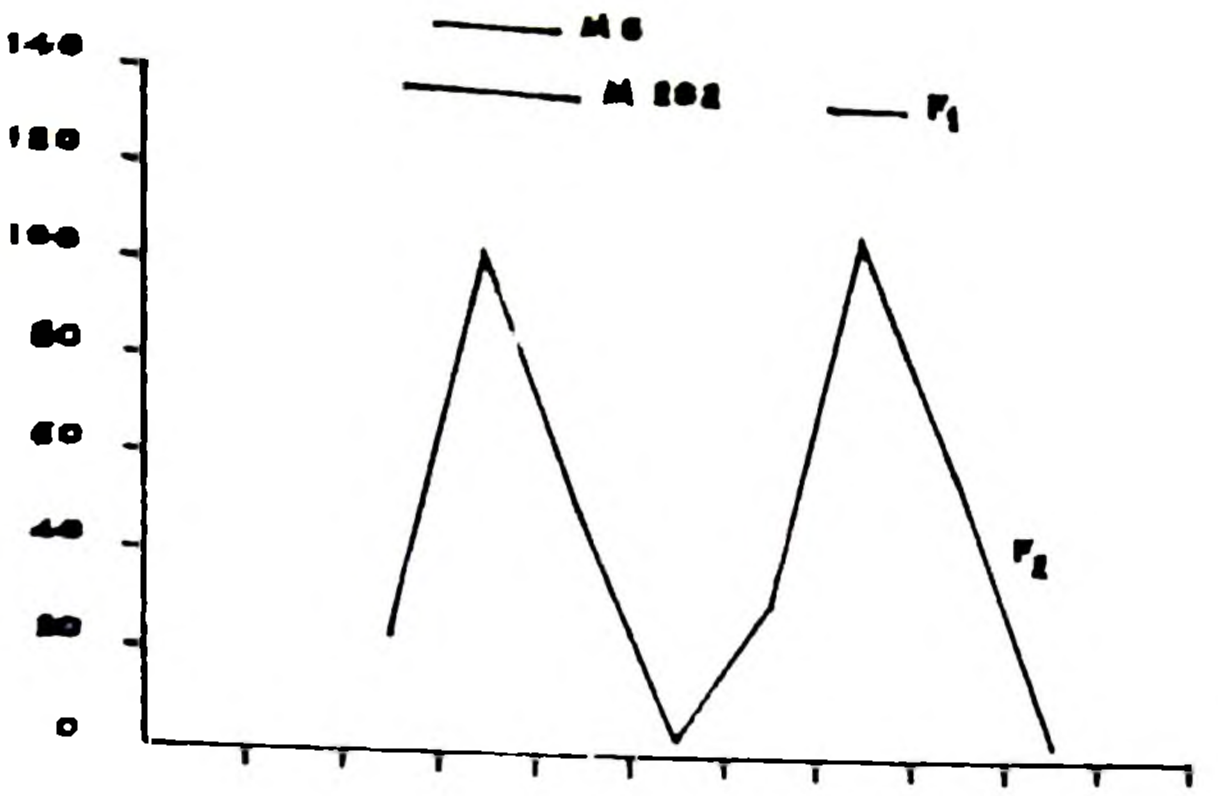


FIG XI-13

M 6 x M 207

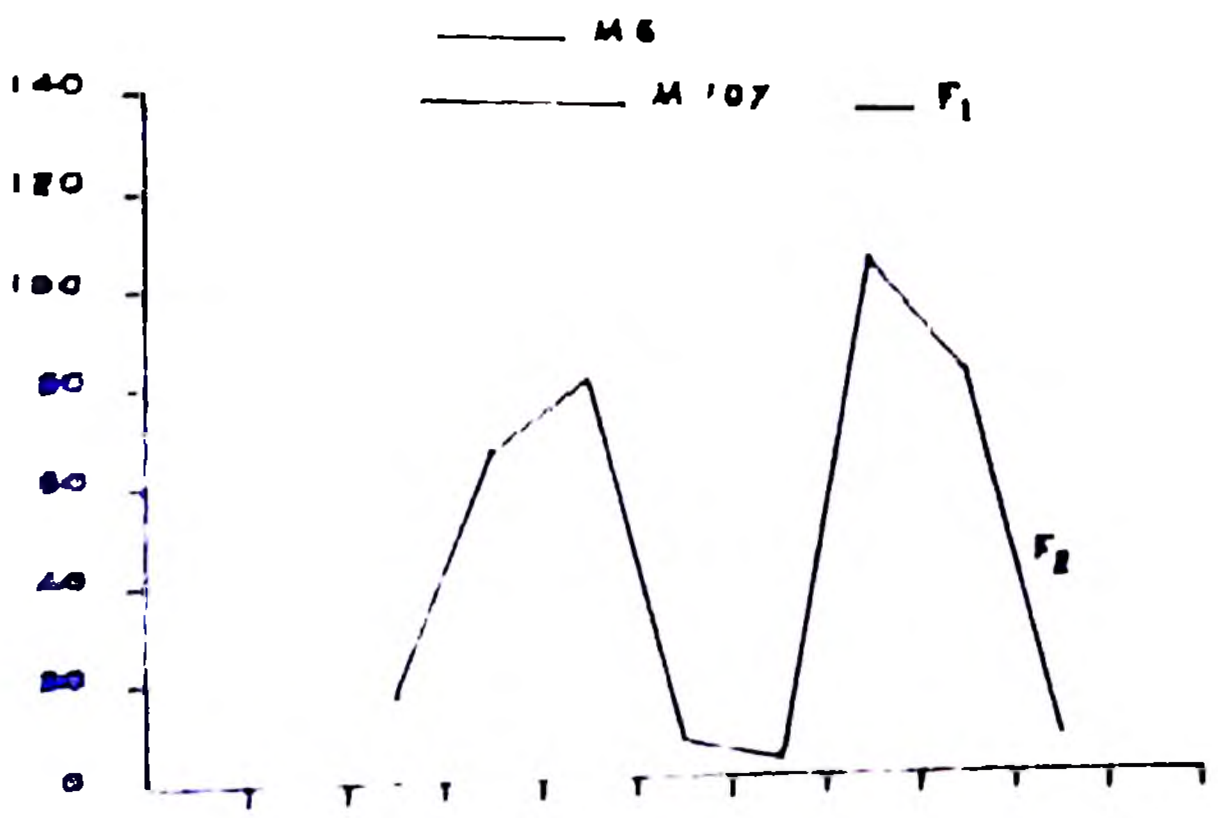


FIG XI-14

M 6 X M 210

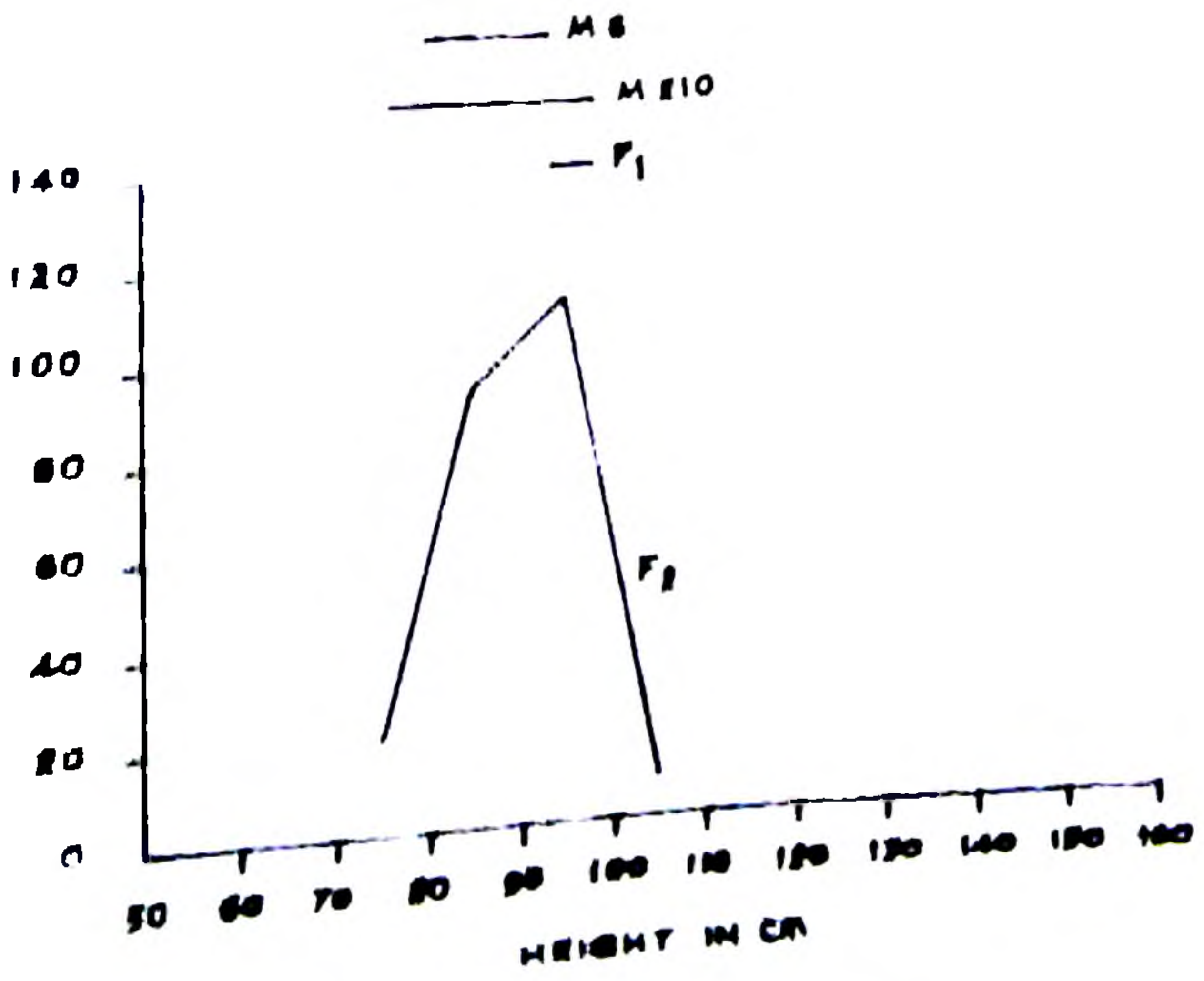


FIG XI-15

appeared. Among 383 F_2s, 209 were above 110 cm and 174 were below 110 cm (Figure XI-14). The talls resembled the F_1s in phenotype with long culms, lodging susceptibility and drooping long leaves. Semidwarfs were similar to the mutant parents in appearance. The internode elongation pattern showed that the talls and semidwarfs had equal number of internodes; but while the talls had elongated internodes the semidwarfs had shortened internodes. The observed frequencies of talls and semidwarfs were tested and found to fit to the 9:7 ratio (Table 22).

xv) M 6 x M 210: Like the parents, the F_1 plants were semidwarfs, the mean height being 96 cm (Table 21). In external appearance they resembled their parents in having erect short and dark green leaves with short and stout culms. The plants exhibited compact habit and resistance to lodging. In the F_2s plants ranged from 71 to [illegible] cm class to [illegible] to 110 cm class in height (Figure XI-15). Since none of the 234 plants had height below 70 cm and above 110 cm, all the F_2s should be considered as semidwarfs (Table 22). The orientation of leaves, the size and colour of leaves, the compact habit and resistance to lodging were also typical of semidwarfs. The F_2s had equal number of shortened internodes as the semidwarf mutant parents.

xvi) M 14 x M 102: Mutant M 14 was a derivative of Ptb-9 and M 202 a derivative of Ptb-28. The mean height of the mutants were 95 cm and 93 cm respectively while the F_1s had the mean height of 129 cm suggesting their tall stature (Table 21). Unlike the mutants, the talls were typically characterised by long curving leaves and long weak culm. The open habit and lodging nature were also associated with the tall F_1s. In the F_1, plant height ranged from 125 to 132 cm. But in F_2 unlike the F_1, the height showed great variation. It ranged from 51 to 60 cm class to 151 to 160 cm class. The distribution was characterised by 3 modal classes, viz., 61 to 70 cm, 91 to 100 cm and 121 to 130 cm (Figure XI-16). The low frequency of plants in classes between the successive modal classes divided the population into three groups, talls, semidwarfs and dwarfs. 70 cm was considered as the upper limit of dwarfs and 110 cm as that of the semidwarfs. The talls had long leaves, long and weak culms and open habit. The semidwarfs had dark green erect leaves and compact habit. The dwarfs had very thick and short dark green leaves and numerous compact tillers. The pattern of internode elongation indicated that the talls and semidwarfs had equal number of internodes but had different degrees of elongation. The semidwarfs were characterised by shortened internodes. The dwarfs appeared to possess very shortened internodes in general. The number of internodes that could be recognised was also less than that of talls and semidwarfs. The dwarfs and semidwarfs were nonlodging while the talls succumbed to lodging nearly at

FREQUENCY DISTRIBUTION (CROSSES BETWEEN MUTANTS)

M 14 × M 102

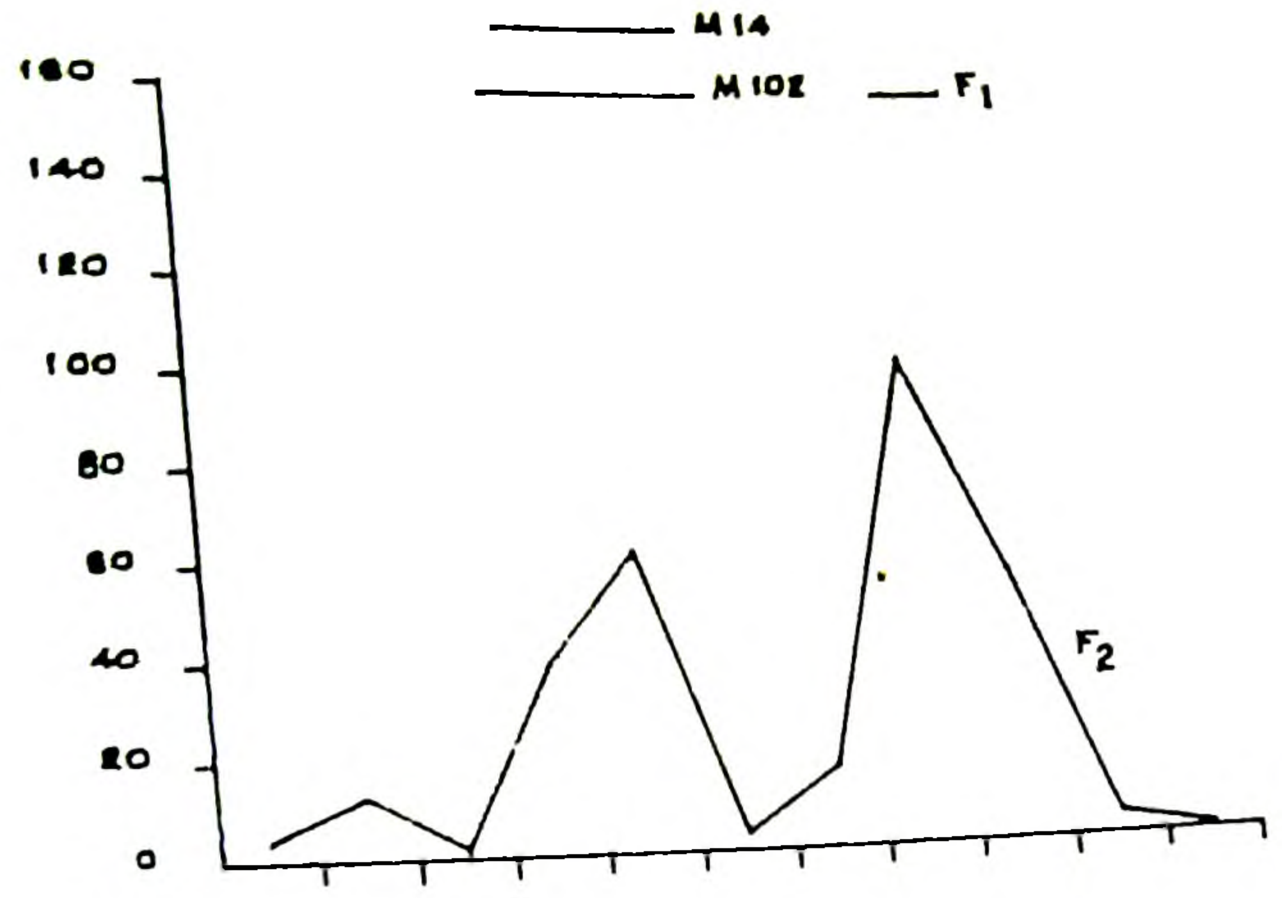


FIG XI-16

M 14 × M 107

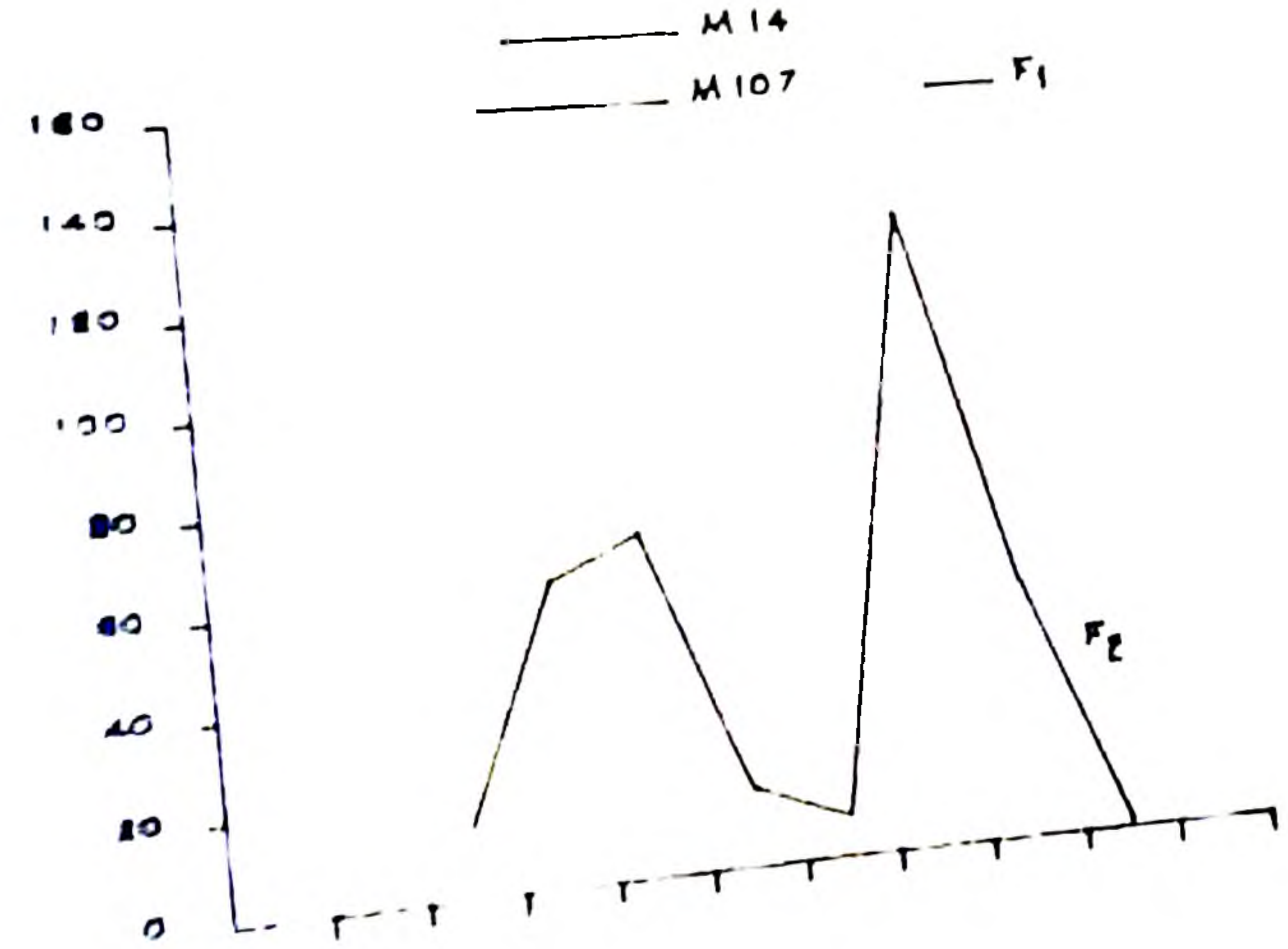


FIG XI-17

M 14 × M 111

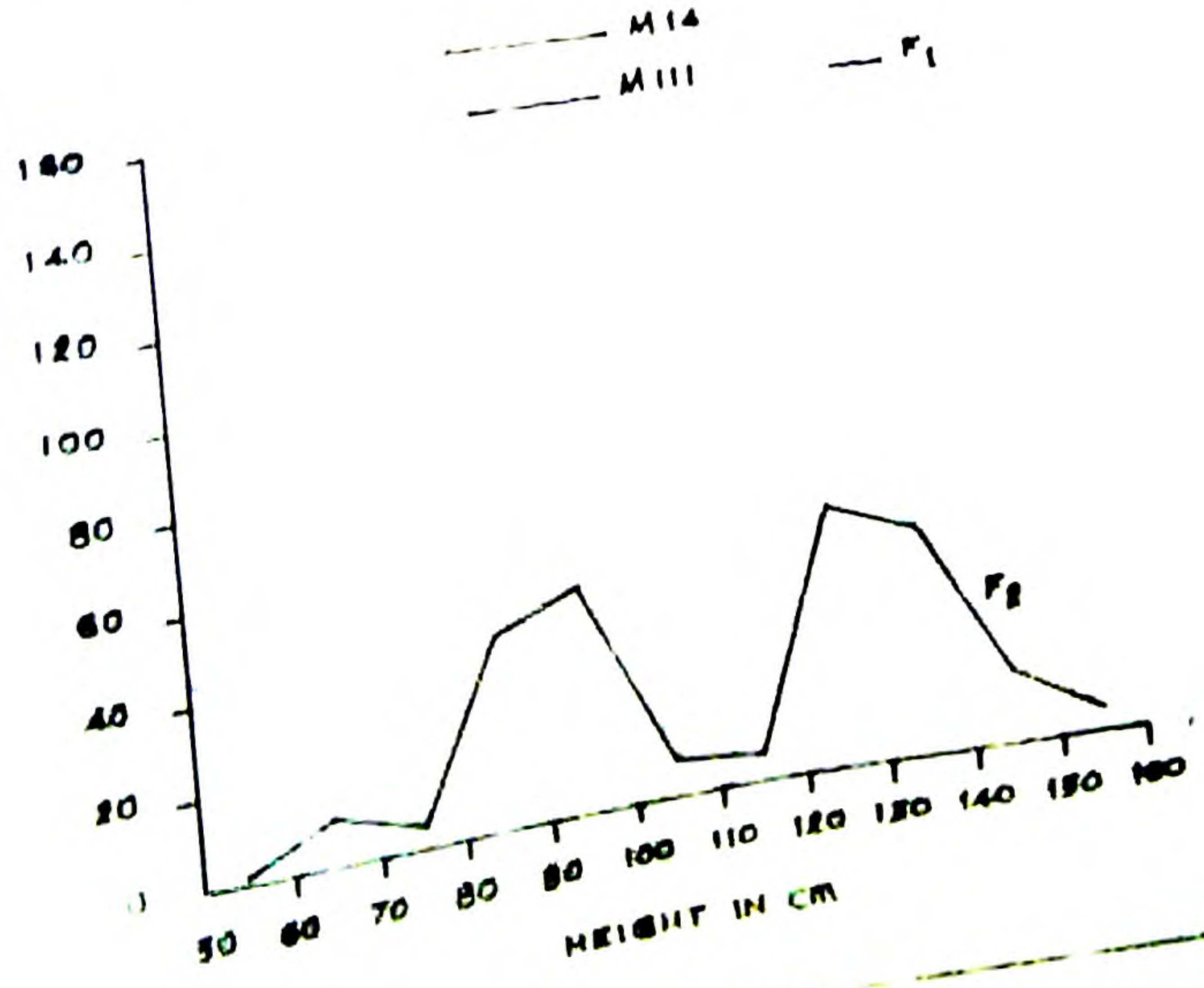


FIG XI-18

heading. The frequencies of the segregating plants showed a good fit to 9:6:1 model (Table 22).

xvii) M 14 x M 107: The height of the F_1 plants of the cross ranged from 130 to 137 cm suggesting tall nature of the progeny, unlike the semidwarf stature of the mutant parents (Table 21). Tallness was also typically associated with long pale green leaves which drooped and open habit with open tillers. Long culms with elongated internodes were also the features of the tall F_1s. F_2 population exhibited segregation for plant height. Tall plants above 110 cm and semidwarfs 110 cm or below appeared in the F_2 (Table 22). The distribution was typically bimodal. The modal classes observed were 91 to 100 cm and 121 to 130 cm with low frequency classes in between. The occurrence of low frequency of plants in the classes 101 to 110 cm and 111 to 120 cm separated the two groups of talls and semidwarfs (Figure XI-17). The talls resembled the F_1 phenotypically while the semidwarfs were more or less similar to the mutant parents. The internode elongation in talls and semidwarfs also had almost the same pattern as in F_1 plants and the mutant parents respectively. Out of 366 F_2s studied, 199 were tall above 110 cm and 167 were semidwarf. The test of goodness of fit indicated that the observed frequencies of the segregating plants agreed with the expected frequencies of plants in the ratio of 9:7.

xviii) M 14 x M 111: While M 14 and M 111 were semidwarfs (95 cm each) the F_1s appeared tall (133 cm). Unlike the parents with short and erect leaves, the F_1 plants possessed long pale green drooping leaves. The culms were long with internodes much elongated. The plants lodged after heading. While the mutant parents exhibited compact habit the F_1s were open with open tillers (Table 21). When the F_1s showed narrow range of variation for plant height, from 130 to 136 cm, the F_2s exhibited very wide range of variation from 51 to 60 cm class to 151 to 160 cm class. The F_2 distribution for plant height showed three modes, the modal classes being 61 to 70 cm, 91 to 100 cm and 121 to 130 cm (Figure VI-18). Classes with relative low frequency of individuals in between the modal classes divided the distribution into three groups, viz., talls, semidwarfs and dwarfs. The characteristic feature of the talls, viz., long pale green leaves, long culm, open habit and lodging susceptibility were observed in the tall segregants. The semidwarfs resembled the mutants in most of the characters. The dwarfs had very short culm with very short, erect, dark green and thick leaves; exhibited compact habit and had numerous tillers. The internode elongation pattern indicated that the lower most internode in the dwarfs was not distinguishable. Thus the number of internodes in dwarfs appeared to be low when compared to semidwarfs and talls. Out of 266 F_2 plants, 144 were talls, 109 semidwarfs and 13 dwarfs. The frequencies of the segregating plants showed a satisfactory fit to 9:6:1 ratio when tested using chi-square test of goodness of fit (Table 22).

xix) M 14 x M 202: The tall F_1s differed from the semidwarf mutant parents in plant height and associated characters. The mean height of plants in F_1 generation was 124 while that in M 14 and M 202 was 95 cm and 89 cm respectively. The colour, size and orientation of the leaves of the F_1s were different from that of the mutants. The long and weak culm of the F_1 plants made them lodge immediately after heading (Table 21). F_2 plants varied widely in plant height and associated traits. The shortest plants could be recognized under the class 51 to 60 cm while the tallest plants were included under the class 141 to 150 cm (Table 22). This is in contrast to the narrow range of variation for height in the F_1 generation. The pattern of distribution indicated the presence of three distinct height groups in F_2, viz., talls above 110 cm, semidwarfs between 71 and 110 cm and dwarfs of 70 cm or below (Figure VI-19). Out of the total 355 plants studied in the F_2 generation, 195 were talls, 143 semidwarfs and 17 dwarfs. The talls with their long culm, open habit and long drooping leaves resembled the F_1s while semidwarfs with their short dark green erect leaves and short and stout culms looked like the mutant parents. The frequencies of the segregating plants into talls, semidwarfs and

FREQUENCY DISTRIBUTION (CROSSES BETWEEN MUTANTS)

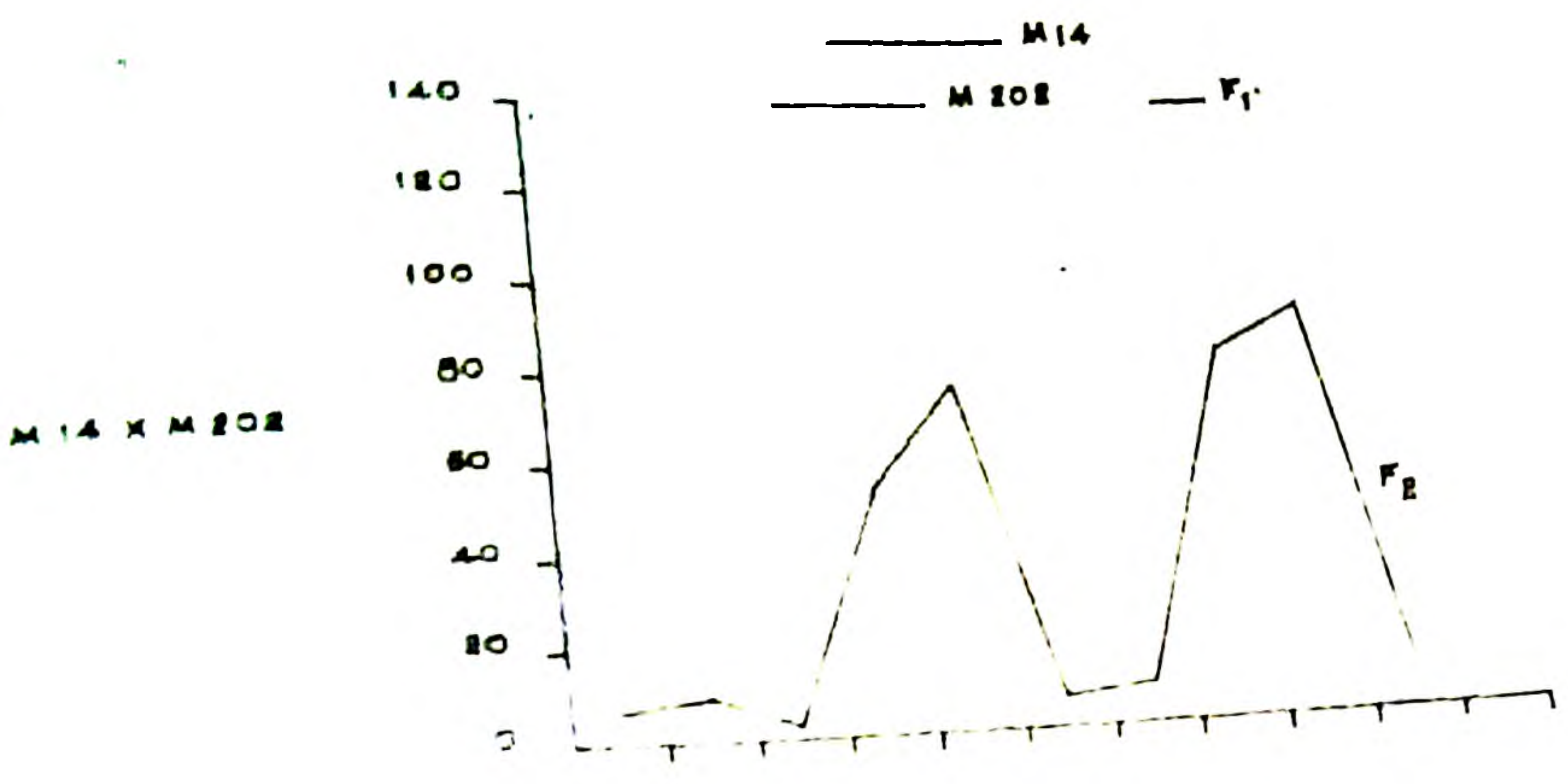


FIG XI-19

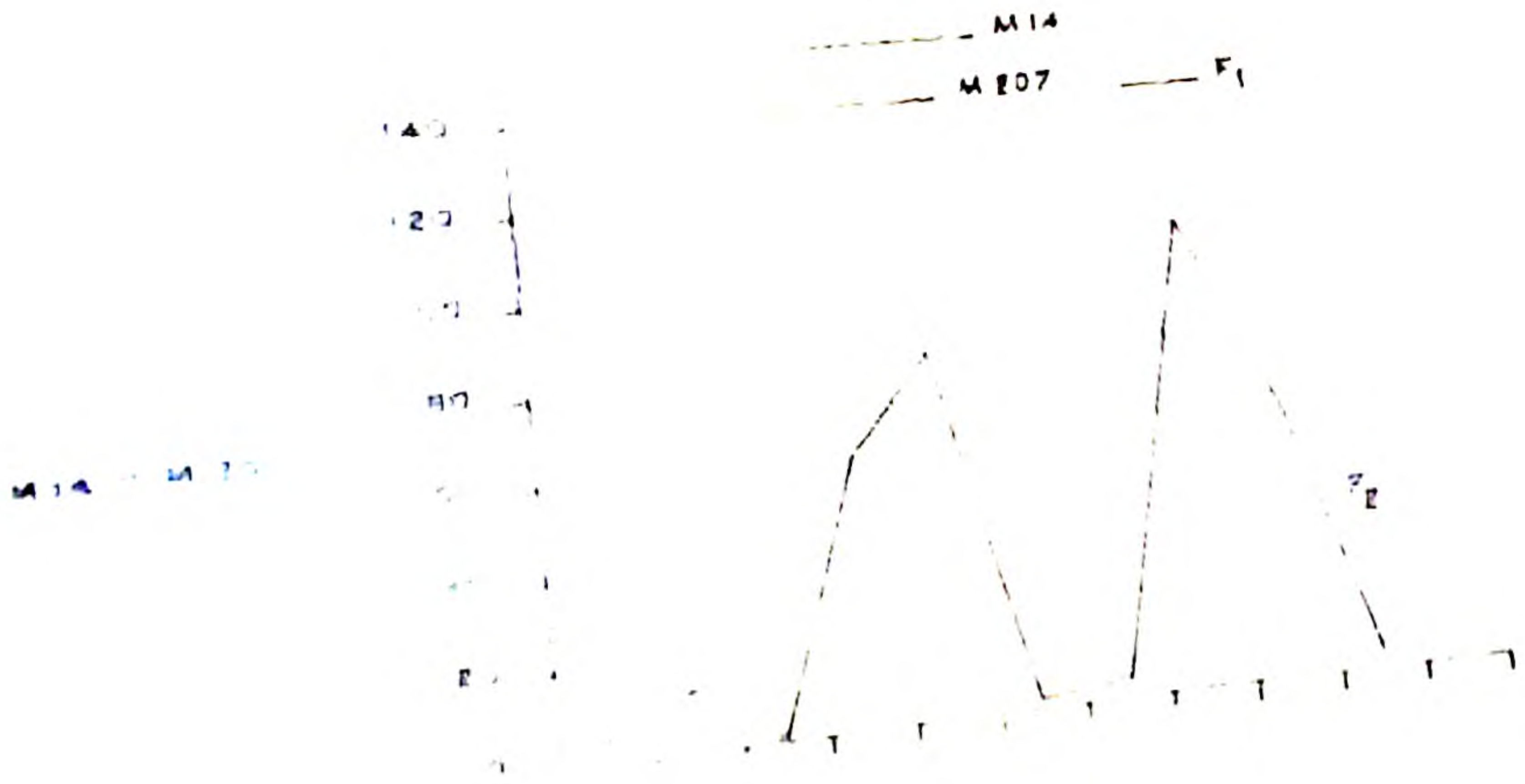


FIG XI-20

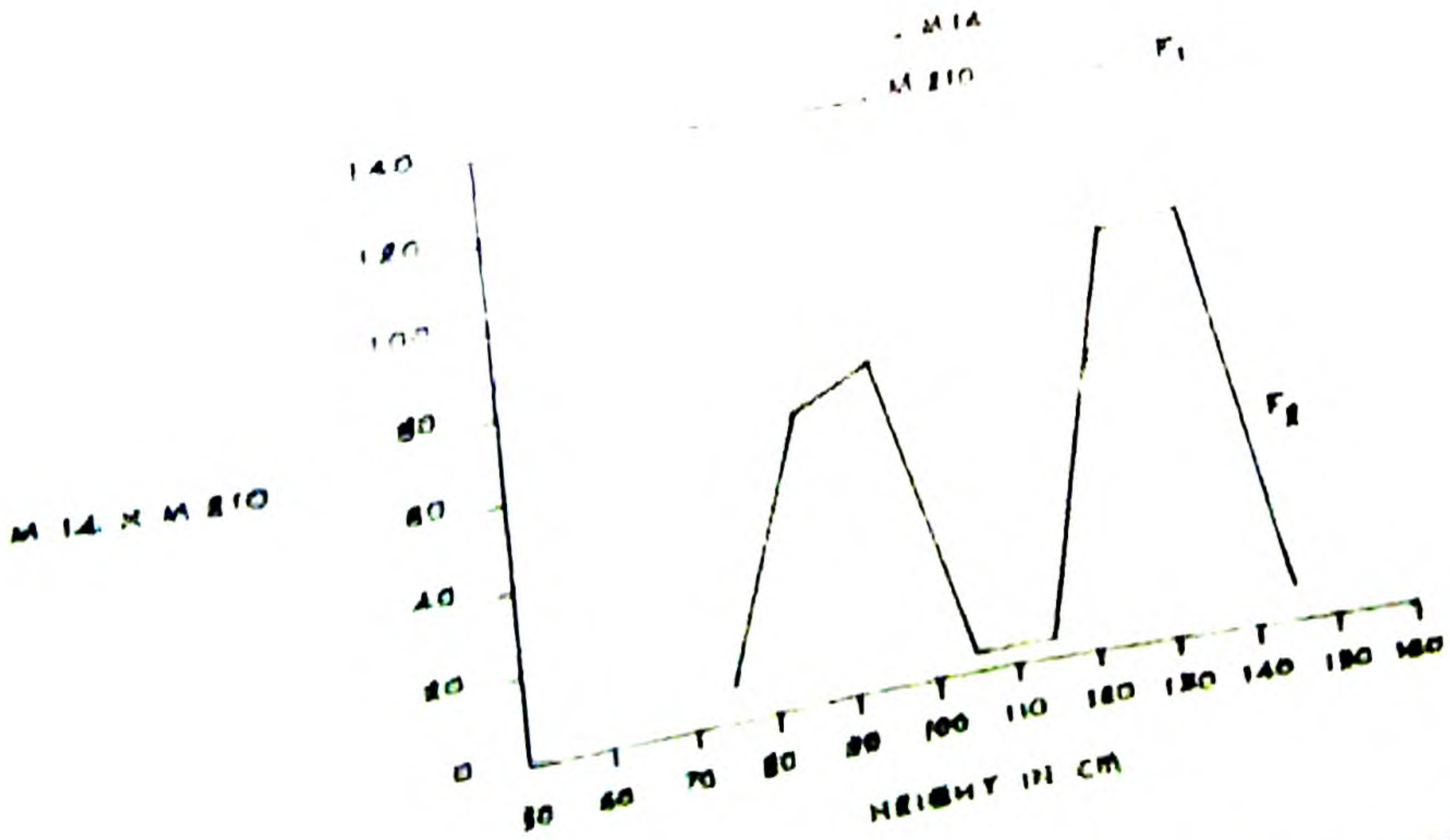


FIG XI-21

dwarfs showed good fit to 9:6:1 ratio. The model 9:3:3:1 was not used since the semidwarfs could not be further grouped based on height and associated characters.

xx) M 14 x M 207: Unlike the parents, M 14 and M 207 the F_1s were tall with mean height of 126 cm. The mutants were characterised by short erect dark green leaves, short and stout culms and compact habit. But the tall F_1s had long pale green drooping leaves, weak and long culm and open habit. The tall plants lodged before ripening of the grain (Table 21). In the F_2 generation, wide range of segregation was noticed unlike in the F_1. Height ranged from the class 51 to 60 cm to the class 141 to 150 cm. Three modal classes were observed in the distribution curve (Table 22). The classes corresponded with 61 to 70 cm, 91 to 100 cm and 121 to 130 cm. Distinct segregation for three different height groups was indicated by the low frequency of plants in the classes 71 to 80 cm, 101 to 110 cm and 111 to 120 cm (Figure VI-20). The talls were typically long and weak culmed and succumbed to lodging after heading. The open plant habit was also distinct from the compact habit of semidwarfs and dwarfs. The semidwarfs had short and stout culms and compact habit which made them lodging resistant. The dwarfs were distinct from the talls and semidwarfs with their very short culm and thick, dark green and short leaves. The pattern of internode elongation indicated that the talls and semidwarfs had almost equal number of internodes, but of different length while the dwarfs appeared to possess less number of recognisable internodes. The observed frequencies of talls, semidwarfs and dwarfs, showed good fit to the expected frequencies when the model 9:6:1 was used. A further classification of semidwarfs was difficult.

xxi) M 14 x M 210: Though the mutants were semidwarfs, the F_1 plants were tall typified by elongated and weak culms; open habit, drooping, pale green and long leaves and susceptibility to lodging (Table 21). The long culm resulting in lodging appeared to be due to the elongation of internodes. The range of variation for plant height was much greater in the F_2 generation. Plants with height of 71 to 80 cm to 141 to 150 cm occurred in the F_2 generation unlike in the F_1. The F_2 distribution for plant height was typically bimodal with the modal classes of 91 to 100 cm and 131 to 140 cm (Figure XI-21). The low frequencies of plants in classes 101 to 110 cm and 111 to 120 cm separated distinctly the talls and semidwarfs. No plant could be classified as dwarfs since none of the F_2 segregants fell below 71 cm (Table 22). The talls resembled the F_1 plants in appearance while the semidwarfs resembled the mutants. Further classification of semidwarfs was difficult and therefore the observed frequencies of the segregating talls and semidwarfs were tested for goodness of fit to the 9:7 ratio. The observed frequencies showed good fit to the expected frequencies.

xxii) M 102 x M 107: Both M 102 and M 107 were mutants of Ptb-28 and were semidwarfs. But the F_1 plants from the cross were tall with a mean height of 136 cm. The F_1s looked exactly like Ptb-28 with tall culms, weak and open habit, long and drooping leaves and lodging susceptibility (Table 21). In the F_2 generation, segregation for plant height occurred. Segregants with height of 71 to 80 cm to 151 to 160 cm appeared. The distribution curve (Figure XI-22) revealed two modal class of 91 to 100 cm and 131 to 140 cm. The low frequencies in the height classes 101 to 110 cm and 111 to 120 cm separated the plants into two distinct height groups of talls and semidwarfs. Out of 369 F_2 plants studied, 195 were talls and 174 semidwarfs (Table 22). The semidwarfs showed slight variation, but further grouping was not possible. They resembled more or less the mutants while the talls were indistinguishable from Ptb-28. The test of goodness of fit indicated that the observed frequencies of talls and semidwarfs showed good fit to a 9:7 model with high probability.

xxiii) M 102 x M 111: In contrast to the semidwarf mutant parents, the F_1 plants were tall. The parents and the F_1s differed in other associated characters also (Table 21). The F_1s with their tall stature, long and weak culm, open habit and pale green drooping long leaves resembled Ptb-28. While the F_1s lodged before ripening of the grains, the mutant

FREQUENCY DISTRIBUTION (CROSSES BETWEEN MUTANTS)

M 102 × M 107

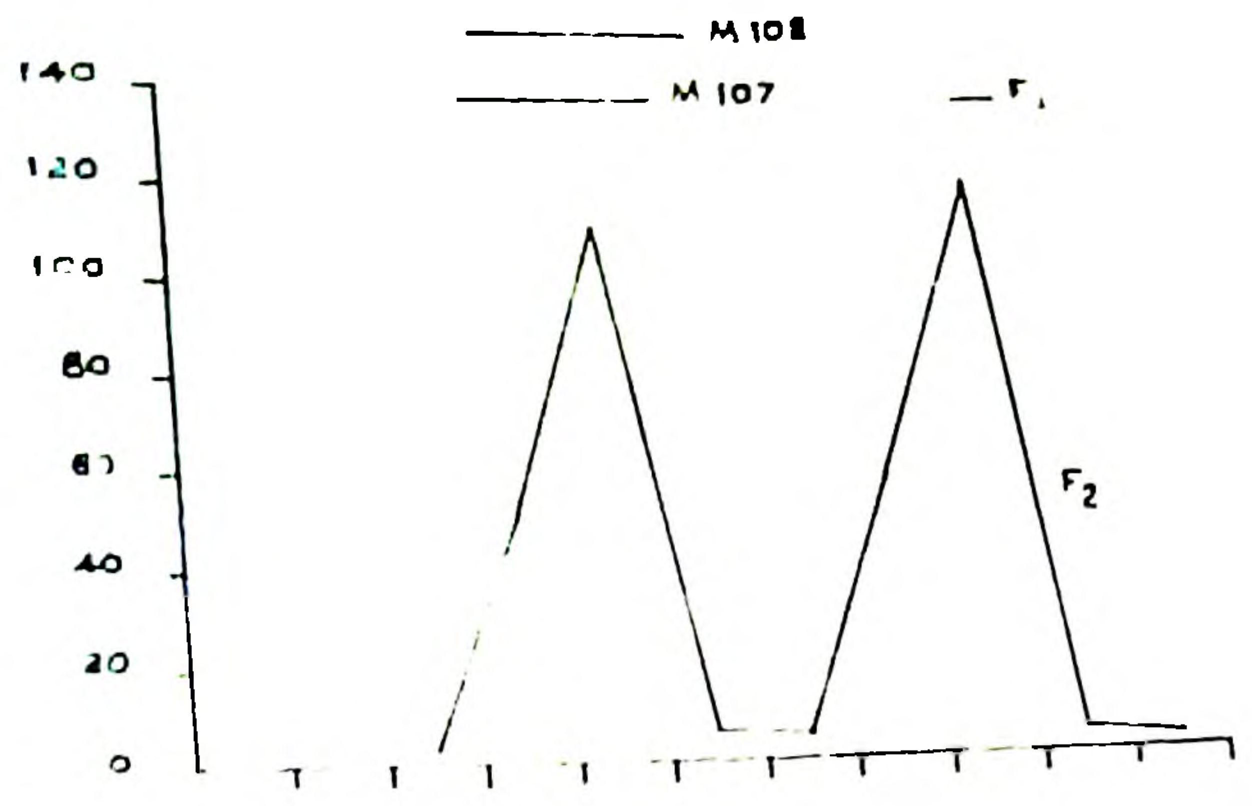


FIG XI-22

M 102 × [illegible]

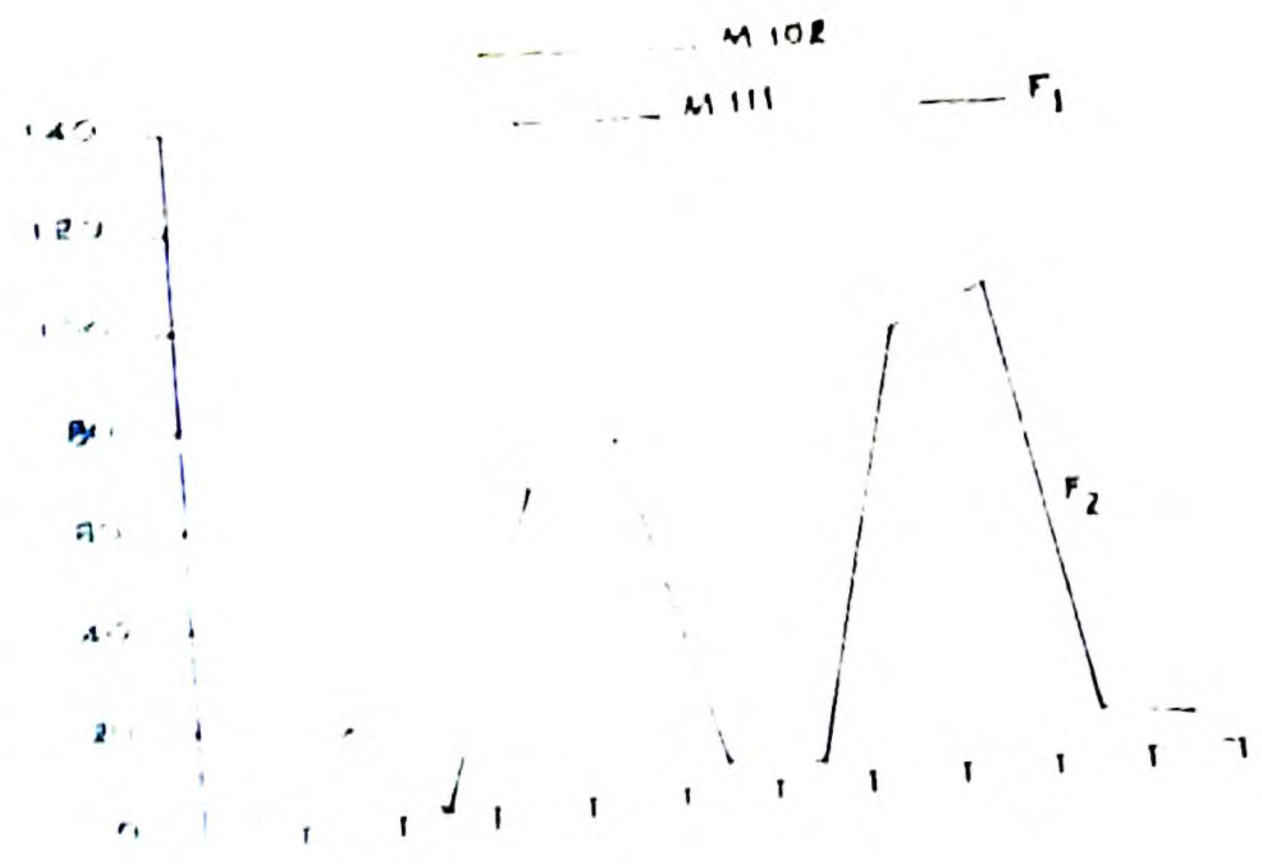


FIG XI-23

M 102 × M 202

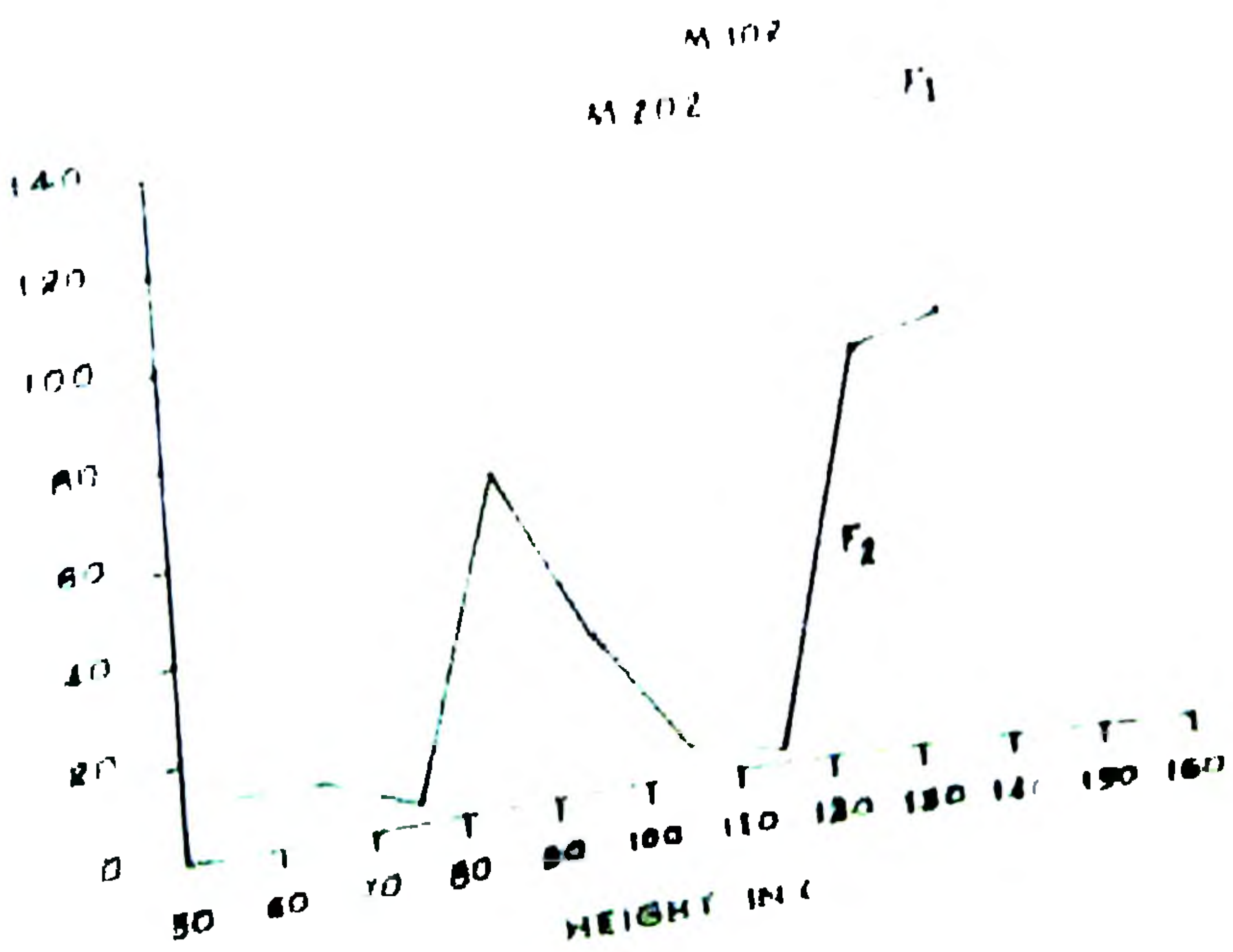


FIG XI-24

parents were nonlodging. The range of variation for plant height was greater in the F_2 generation. The shortest plants were included in the height class of 51 to 60 cm while tallest segregants were in the height class of 151 to 160 cm (Table 22). The distribution curve showed three modal classes of 61 to 70 cm, 91 to 100 cm and 131 to 140 cm (Figure XI-23). The low frequencies of plants in 71 to 80 cm, 101 to 110 cm and 111 to 120 cm classes separated the plants into three distinct height groups, viz., talls above 110 cm, semidwarfs between 71 and 110 cm and dwarfs below 71 cm. Out of the 384 F_2 segregants, 218 were talls, 144 semidwarfs and 22 dwarfs. The talls could well be recognised due to their resemblance to Ptb-28. They also exhibited lodging tendency after heading. Dwarfs formed a distinct group with much reduced culm length; very short, thick, dark green and erect leaves and with large number of tillers. The semidwarfs resembled the mutant parents. The frequencies of the segregating plants in the F_2 suggested a ratio of 9:6:1. The observed frequencies showed good fit to the ratio when tested with chi-square test.

xxiv) M 102 x M 202: While M 102 and M 202 were semidwarfs with mean height of 93 cm and 89 cm respectively, the hybrid had a mean height of 128 cm. Unlike the parents, the F_1s had elongated internodes, open habit, long drooping pale green leaves and lodging nature (Table 21). The pattern of segregation in the F_2 gave a three modal distribution curve suggesting three height groups of talls above 110 cm, semidwarfs between 71 and 110 cm and dwarfs below 71 cm (Figure XI-24). Out of 323 F_2s, 185 were tall with long curving leaves and long culm with elongated internodes, 114 were semidwarfs with stout and short stem and erect leaves and 24 were dwarfs with very short culm and thick dark green erect leaves (Table 22). While the talls and semidwarfs had almost equal number of internodes, the dwarfs had less number of recognisable internodes. The observed frequencies of the different height groups showed good fit to the 9:6:1 ratio.

xxv) M 102 x M 207: The F_1 plants resembled the mutants phenotypically. While the mutants had mean height of 93 cm and 91 cm respectively, the mean height of the F_1s was 93 cm (Table 21). There was similarity in the pattern of internode elongation. In the colour, size and orientation of leaves; in the plant habit and resistance to lodging the F_1s had close resemblance with mutant parents. Even though the F_2 generation showed a wider range of variation in plant height than the F_1 generation, all the 218 plant studied could be classified as semidwarfs since none of them had height below 71 cm and above 110 cm (Table 22, Figure XI-25). All the F_2 plants had short and stout culm, erect short leaves and shortened internodes and were nonlodging. They resembled the mutant parents.

FREQUENCY DISTRIBUTION (CROSSES BETWEEN MUTANTS)

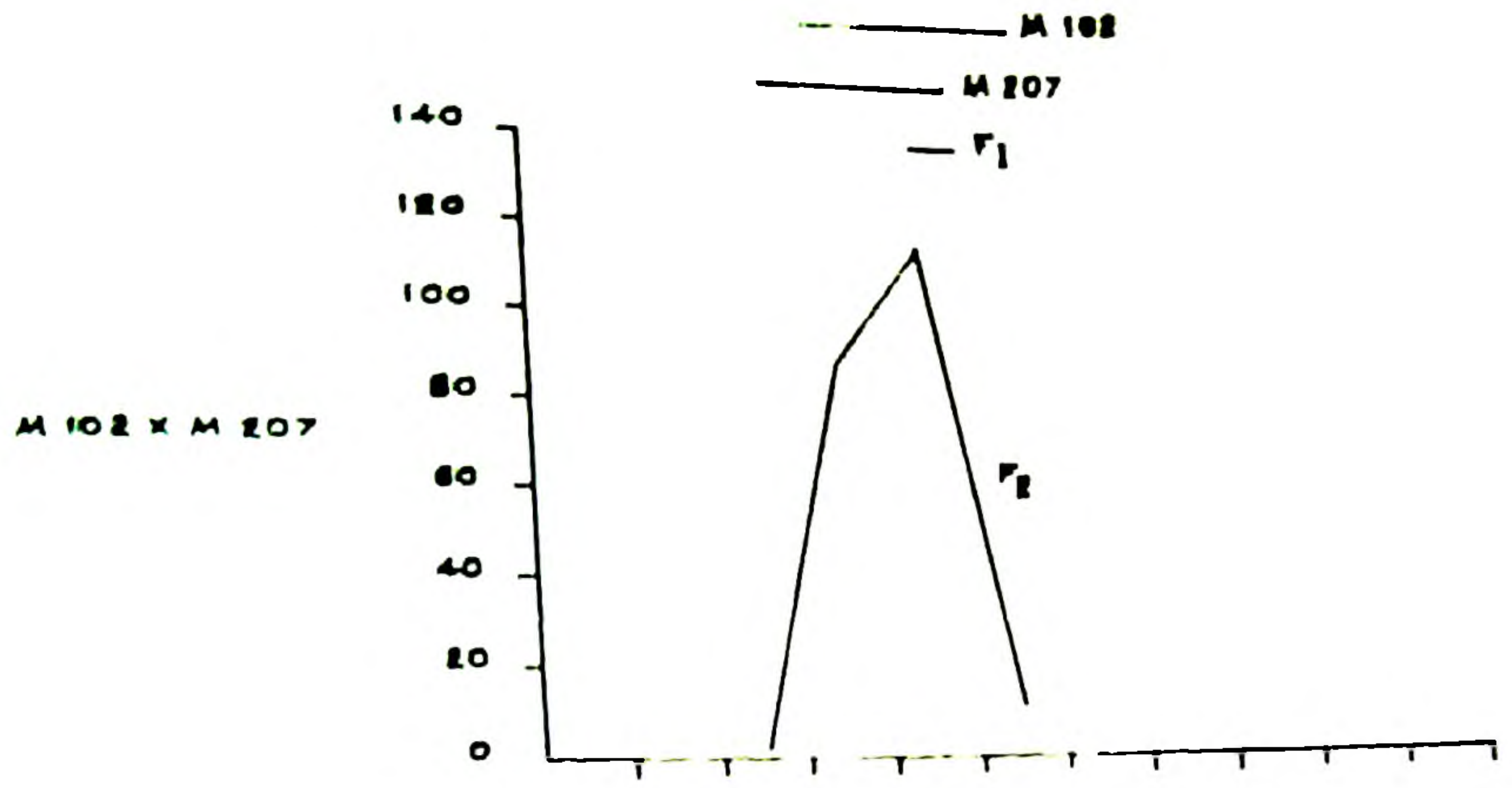


FIG XI-25

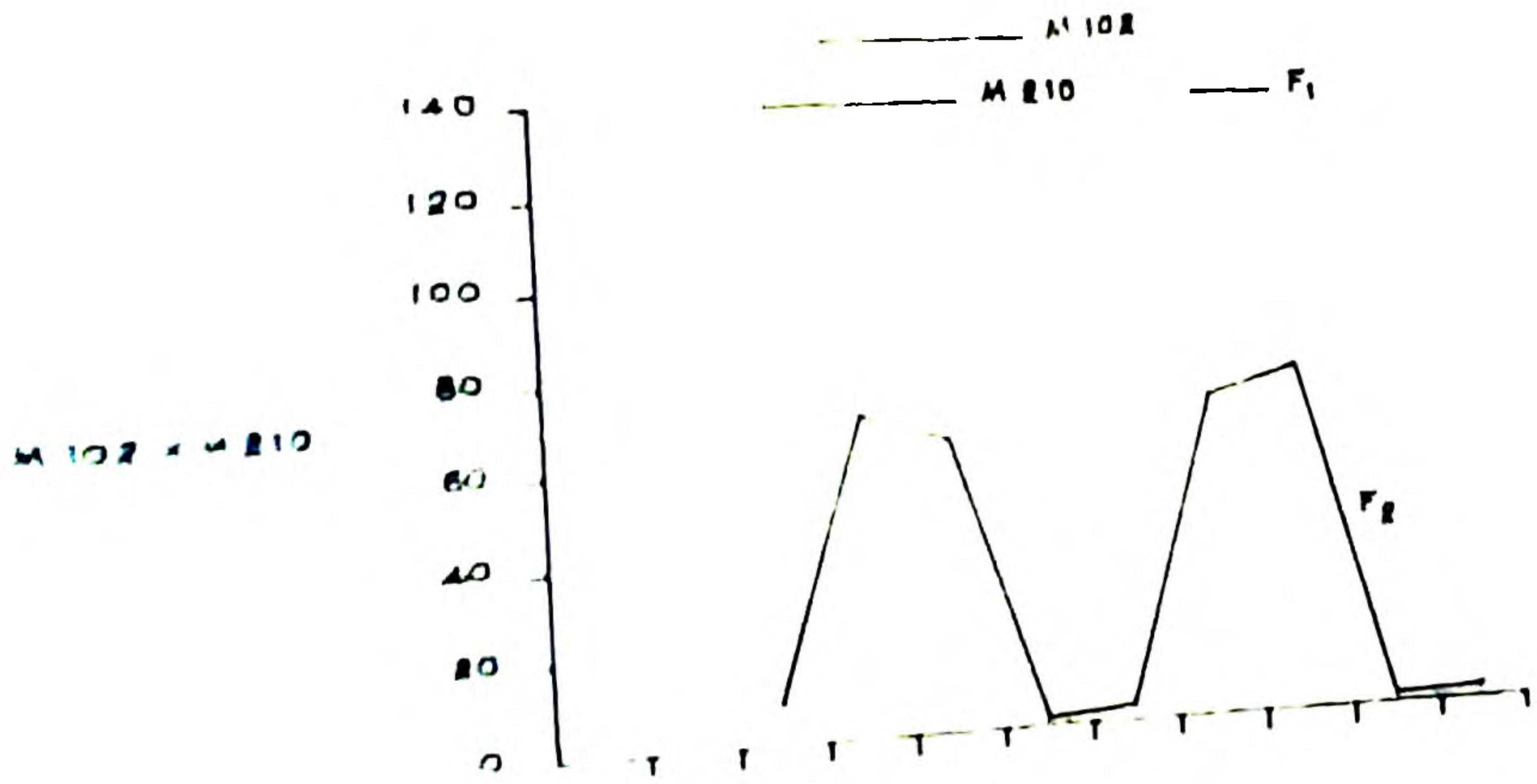


FIG XI-26

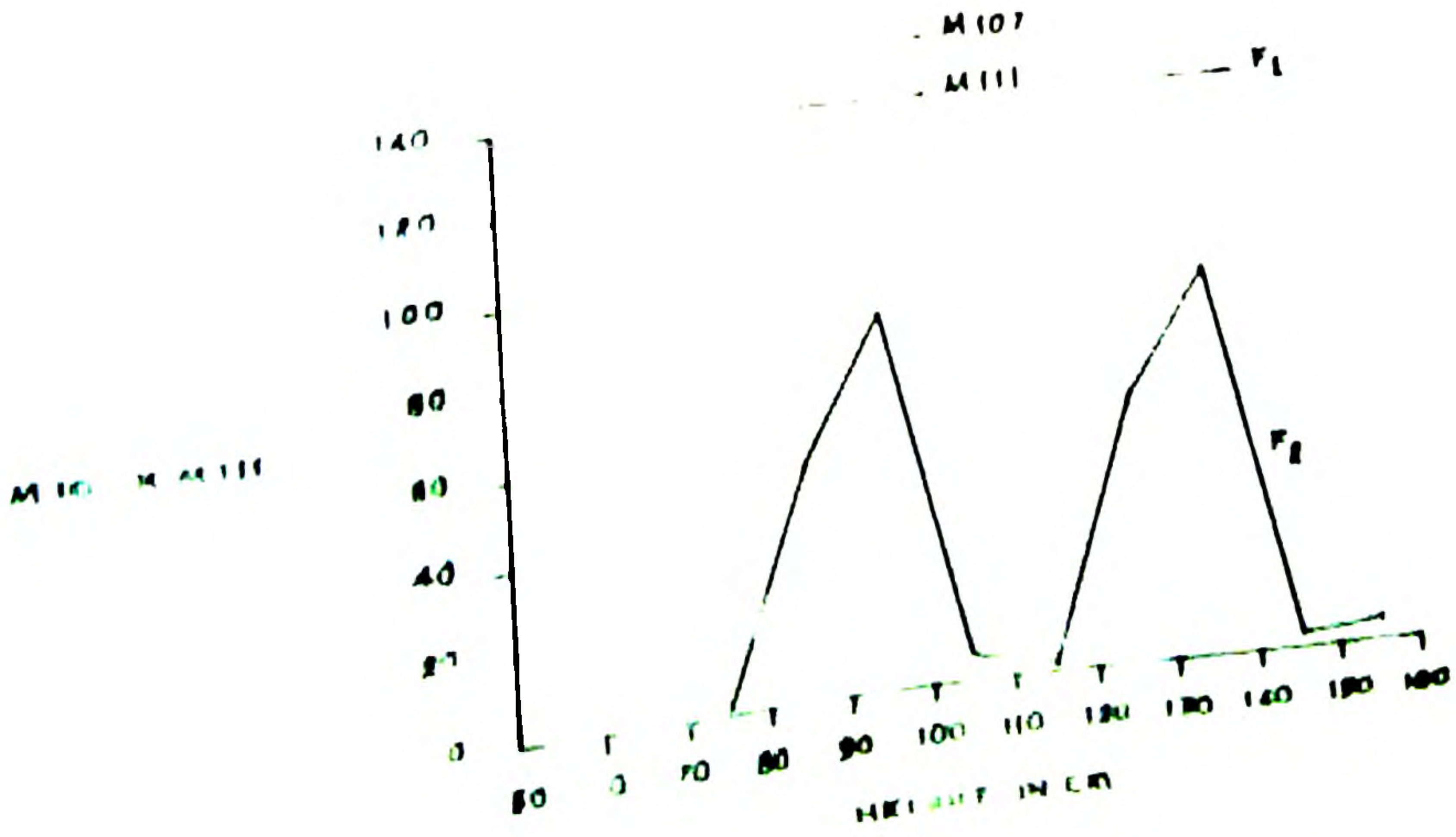


FIG XI-27

xxvi) M 102 x M 210: While both M 102 and M 210 were semidwarfs, the F_1 appeared to be tall with a mean height of 129 cm (Table 21). Elongation of the internodes imparted the increase in culm length. The weak and open habit of the plants made them susceptible to lodging unlike the parents. The F_1 plants were also associated with the typical characters of the talls, viz., long and drooping leaves, early senescence of leaves etc. The F_2 distribution curve for plant height showed two modes corresponding with the 91 to 100 cm and 131 to 140 cm classes (Figure VI-26). The low frequency of plants in the classes 101 to 110 cm and 111 to 120 cm separated the plants into two height groups, talls and semidwarfs. There was no plant which could be considered as dwarfs. Out of 306 F_2 plants, 160 were talls and 146 semidwarfs (Table 22). The semidwarfs could be easily recognised from the talls because of their short stature, erect short leaves, dark green colour, compact habit and nonlodging nature. Observations on the pattern of internode elongation indicated that both semidwarfs and talls had almost equal number of internodes but they differed in their length. The segregation into talls and semidwarfs gave a satisfactory fit to 9:7 ratio with high probability.

xxvii) M 107 x M 111: The F_1 plants in contrast to their parents, M 107 and M 111, were tall (137 cm) and resembled Ptb-28 the original plant from which the mutants were derived.

The F_1s showed long pale green leaves which were drooping. The long culms were the result of elongation of the internodes. The open habit and lodging susceptibility of Ptb-28 reappeared in the F_1 plants (Table 21). In the F_2, a wide range of variation for plant height was observed. It ranged from the 71 to 80 cm class to 151 to 160 cm class. The bimodal distribution with low frequency of plants in between the modal classes indicated the presence of two height groups (Figure XI-27). The F_2 population consisted of 168 talls and 153 semidwarfs (Table 22). The semidwarfs,could not be further classified. The frequencies of the segregating plants showed a satisfactory fit to 9:7 ratio when tested with chi-square test of goodness of fit. While the tall plants resembled the F_1s and Ptb-28, the semidwarfs, more or less, looked like their mutant parents, M 107 and M 111 in many characters. The talls and semidwarfs differed not only in plant height but also in the colour and orientation of leaves, plant habit and susceptibility to lodging.

xxviii) M 107 x M 202: The mean height of the F_1 plants was 126 cm as against the semidwarf stature of the mutant parents, M 107 and M 202. The tallness of the F_1 plants was typically associated with a cluster of other characters such as long drooping pale green leaves, open habit, lodging susceptibility, elongated internodes and long culm (Table 21). Out of 311 plants studied in the F_2 generation, 161 were above

111 cm and 150 cm were between 71 and 110 cm. The bimodal distribution for plant height and the absence of plants in the classes 51 to 60 cm and 61 to 70 cm (Figure XI-28) suggested only two height groups, viz., talls and semidwarfs. While the talls appeared to be similar to the F_1 plants in almost all the morphological features with their long drooping pale green leaves, susceptibility to lodging and long culm with elongated internodes, the semidwarfs with their short culm, erect dark green leaves and compact habit resembled M 107 and M 202, more or less. The frequencies of the talls and semidwarfs showed good fit to 9:7 ratio (Table 22).

xxix) M 107 x M 207: The F_1 plants registered a mean height of 130 cm suggesting tall stature in contrast to the semidwarf nature of the parents (Table 21). While the mutant parents had short erect dark green leaves and short culm which aided in resisting lodging, the F_1s possessed long drooping pale green leaves and long and weak culm with elongated internodes which made the plants susceptible to lodging. The F_2 population revealed the presence of both talls and semidwarfs. In a population of 346 F_2 plants, 201 were tall and 145 were semidwarfs (Table 22; Figure XI-29). None of the F_2 plants was below 71 cm. In appearance the talls were similar to the F_1s whereas the semidwarfs resembled the mutant parents. The semidwarfs exhibited compact plant type with short erect dark green leaves and shortened internodes. They were largely

FREQUENCY DISTRIBUTION (CROSSES BETWEEN MUTANTS)

M 107 × M 202

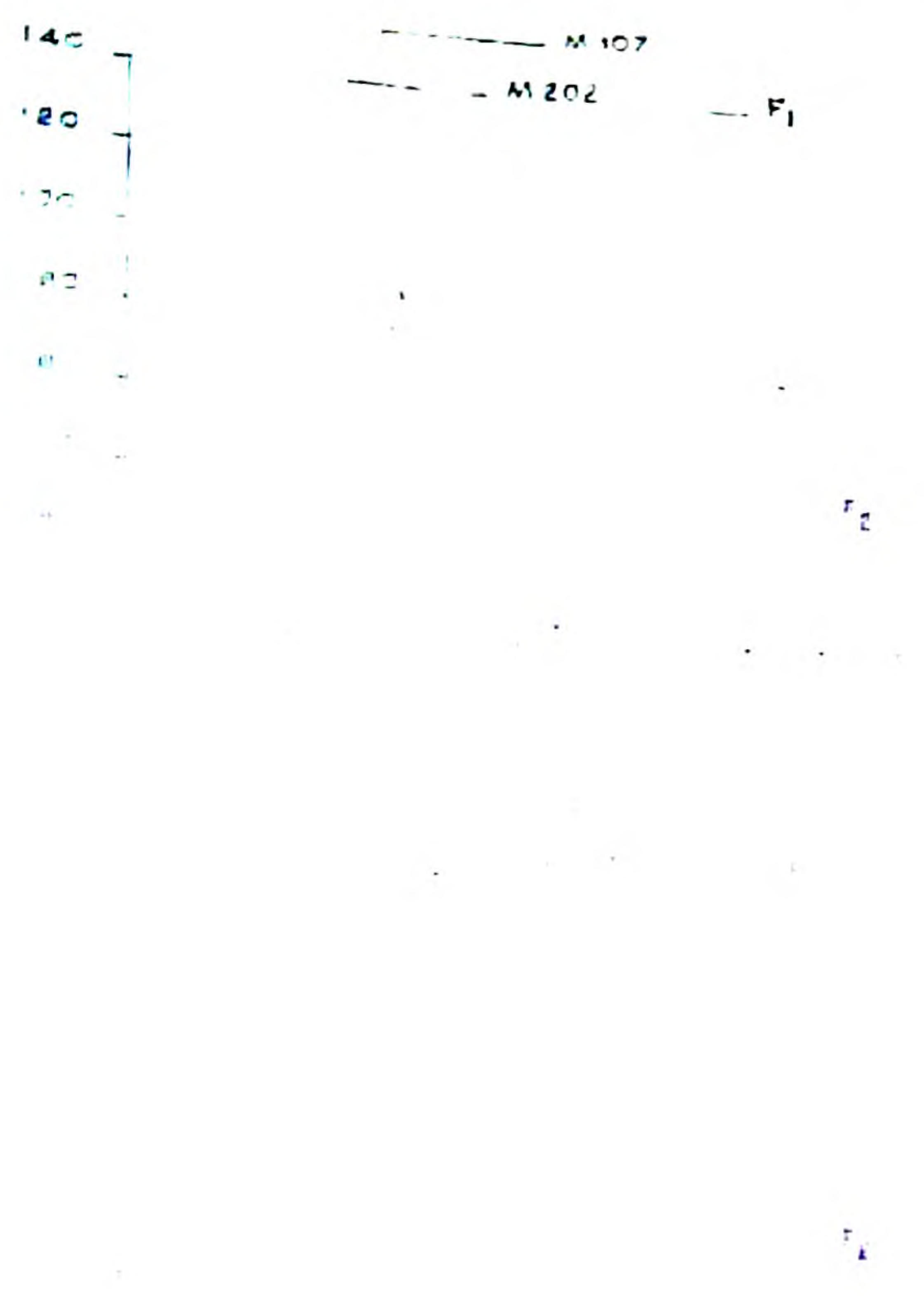


FIG XI-25

M × 210

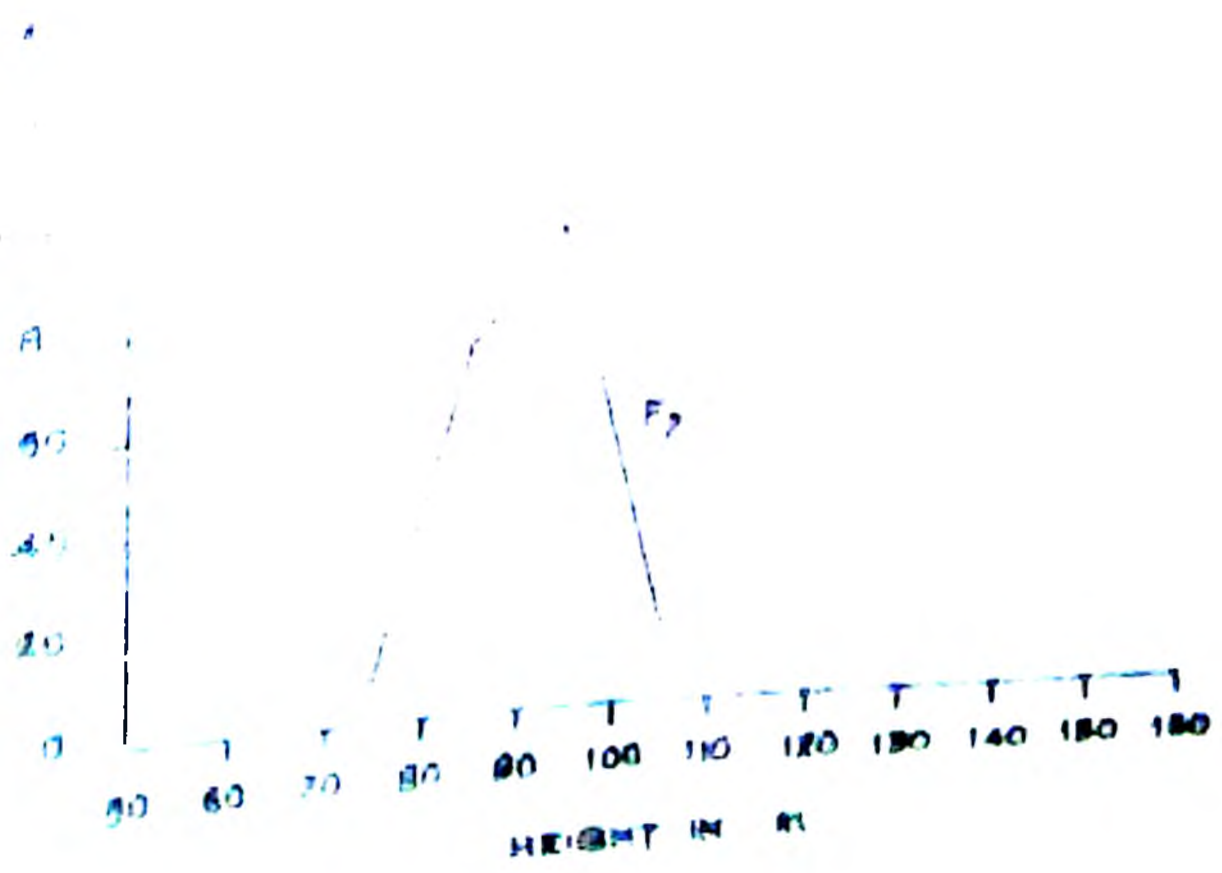


FIG XI-26

resistant to lodging while the talls succumbed to lodging immediately after the emergence of ears. The short culm of the semidwarfs appeared to be due to shortened internodes. The F_2 distribution gave a satisfactory fit to 9:7 ratio for talls and semidwarfs.

xxx) M 107 x M 210: The range of variation for plant height in the F_1 generation was from 88 to 96 cm with a mean of 92 cm. All the F_1s were semidwarfs like their parents. The compact tillers, reduced culm length with short internodes, short erect dark green leaves and resistance to lodging were the other features exhibited by the F_1s (Table 21). In the F_2 generation, plants ranged from 71 to 80 cm class to 101 to 110 cm class in height (Table 22). None of the plants were below 71 cm and above 110 cm suggesting the absence of both dwarfs and talls in the F_2. The pattern of distribution also indicated the presence of only semidwarfs in the F_2 population (Figure XI-30). Almost all plants were characterised by short culms, erect leaves, compact tillers and dark green colour of leaves. Observations on the pattern of internode elongation revealed that the reduction in height in the culm was due to the shortening of the internode and not due to the reduction in the number of internodes.

xxxi) M 111 x M 202: The mean height of F_1 plants was 90 cm with a range of 86 to 94 cm (Table 21). In the F_2, the shortest plants were included in the 71 to 80 cm class and the tallest in the 101 to 110 cm class (Figure XI-31). Even though the range of variation of plants in F_2 was more than in the F_1, all the plants could be considered as semidwarfs (Table 22). These semidwarfs in the F_2 also possessed characteristic short culm with reduced internode length, erect dark green leaves, compact tillers and resistance to lodging.

xxxii) M 111 x M 207: Unlike the mutant parents the F_1s were tall with the mean plant height of 128 cm. The F_1s showed open habit and had long drooping pale green leaves. They were also susceptible to lodging (Table 21). The pattern of internode elongation showed that the increased culm length was due to elongation of internodes which made the plants weak and susceptible to lodging. The F_2 plants showed a very wide range of variation in plant height and exhibited a three modal distribution with the modal classes of 61 to 70 cm, 91 to 100 cm and 121 to 130 cm (Figure XI-32). The three modal distribution and the presence of relatively less number of individuals in the classes in between the modal classes indicated the occurrence of three height groups, viz., talls, semidwarfs and dwarfs in the F_2. The talls were like the F_1 plants in their appearance with long drooping leaves and open habit and susceptibility to lodging, while the semidwarfs resembled the mutant parents in appearance with short, erect and dark green leaves. The dwarfs which were below 71 cm had very short thick and dark green leaves. Both the semidwarfs and dwarfs resisted

FREQUENCY DISTRIBUTION (CROSSES BETWEEN MUTANTS)

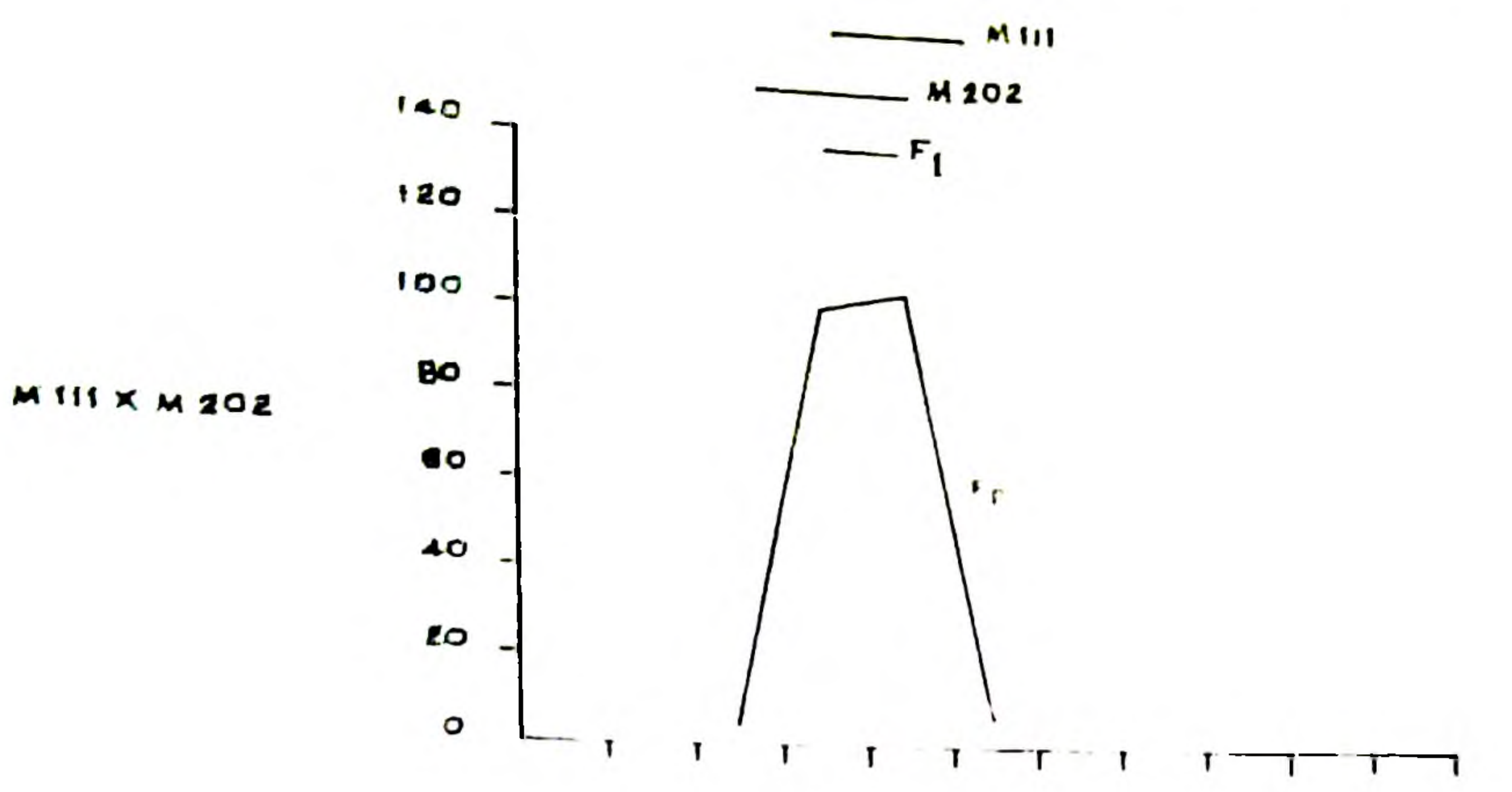


FIG XI 31

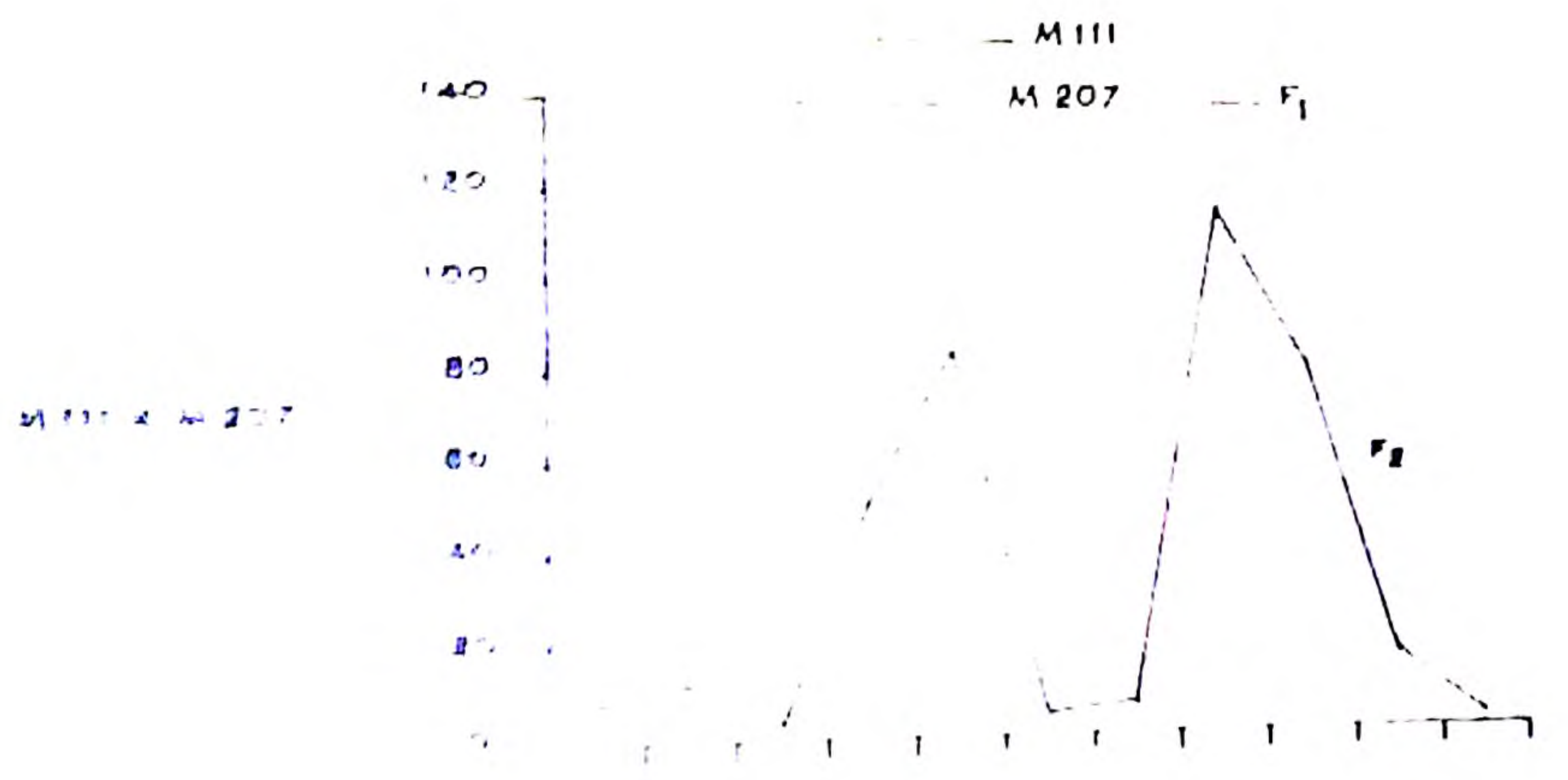


FIG XI-32

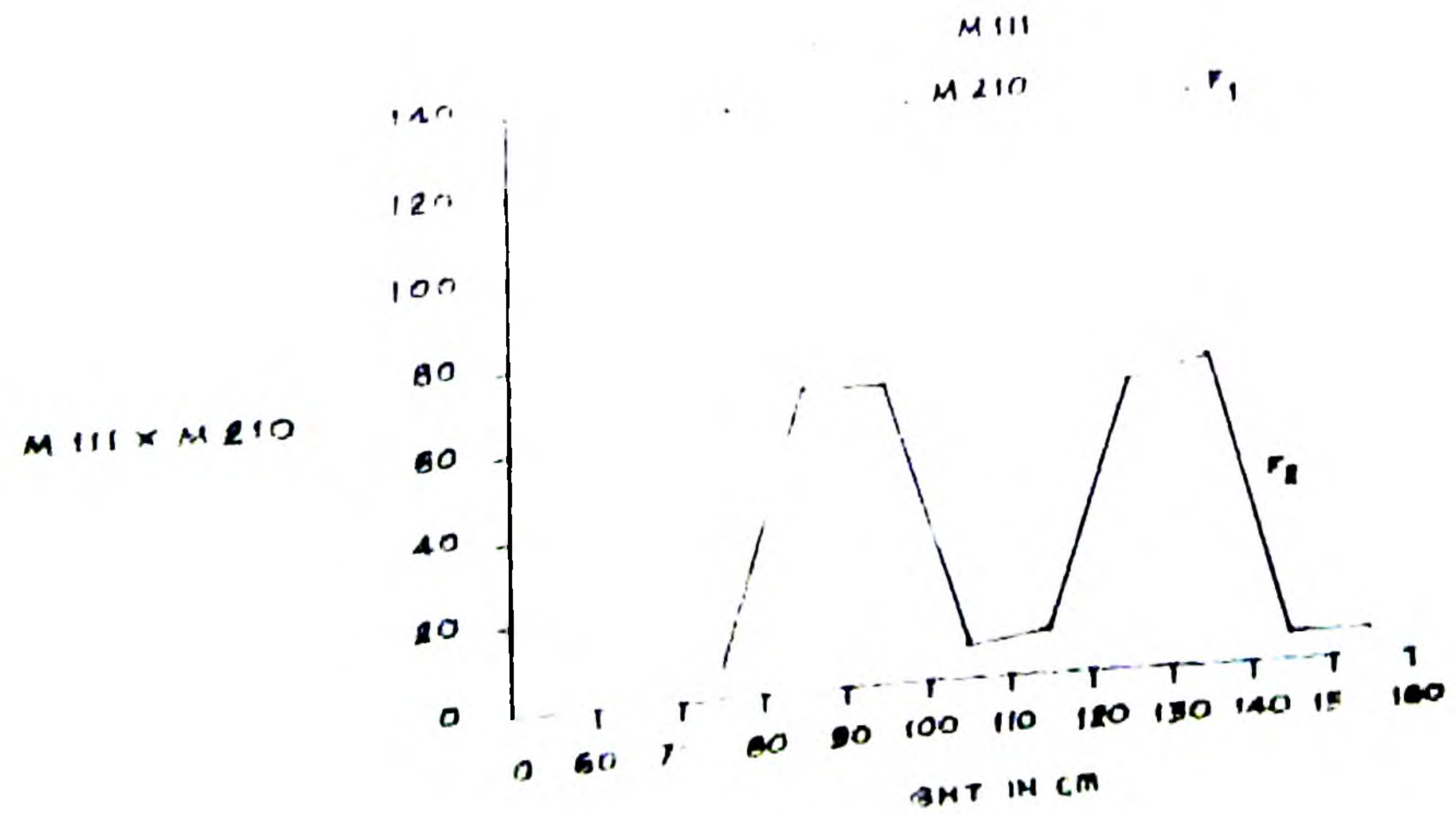


FIG XI-33

lodging. The pattern of internode elongation indicated that both talls and semidwarfs had almost equal number of distinguishable internodes even though the internodes of tall plants were distinctly elongated. The dwarfs had less number of distinguishable internodes which were much shortened. Out of 376 F_2 plants, 216 were tall, 141 semidwarf and 19 dwarf. Among the semidwarfs, a further grouping was not possible and therefore fitting of the normal dihybrid ratio of 9:3:3:1 was not attempted. The distribution in the F_2 gave, however, a satisfactory fit to 9:6:1 ratio with high probability (Table 22).

xxxiii) M 111 x M 210: Both M 111 and M 210 were semidwarfs; but the plants in the F_1 generation were all tall with mean height of 130 cm. The tall F_1s were associated with long drooping leaves, open tillers, weak straw and susceptibility to lodging in contrast to their parents (Table 21). The bimodal distribution of the F_2 population and the presence of low frequency classes between the modal classes divided the population into two distinct height groups (Figure XI-33). Out of 330 F_2 plants observed, 171 were talls and 159 semidwarfs (Table 22). While the talls resembled the F_1s the semidwarfs were similar to the mutants with short culm, erect and dark green leaves. The F_2 segregation for plant height gave a satisfactory fit to 9:7 ratio for talls and semidwarfs.

xxxiv) M 202 x M 207: The mean height of 125 cm for the F_1 plants indicated that they were tall unlike their mutant parents. The F_1s mostly resembled Ptb-10 from which both the mutant parents were evolved. The long and weak culm, open tillers, long pale green drooping leaves and susceptibility to lodging were the characteristic features of the F_1 plants (Table 21). The trimodal distribution and the occurrence of low frequency classes between the modal classes clearly indicated the presence of 3 distinct height groups in the F_2 (Figure XI-34). Based on height, 327 F_2 plants were grouped into 172 talls, 131 semidwarfs and 24 dwarfs (Table 22). The talls resembled the F_1s. The semidwarfs had short culm, short dark green erect leaves and were resistant to lodging. The dwarfs had short thin culm with dark green, thick erect and short leaves. They exhibited compact stand with numerous tillers. The segregation for height agreed to a 9:6:1 ratio with high probability.

xxxv) M 202 x M 210: The F_1 plants registered a mean height of 122 cm. In appearance the F_1s almost resembled Ptb-10. The F_1 plants possessed long, pale green, drooping leaves, long culm with elongated internodes and open tillers. The plants lodged after heading (Table 21). In the F_2 generation segregation for stature was observed. The bimodal distribution and the presence of low frequency classes between the modal classes indicated the occurrence of two distinct height groups (Figure XI-35). Out of 306 F_2 plants, 166 were tall and 140 were semidwarfs (Table 22). None of the F_2 plants

FREQUENCY DISTRIBUTION (CROSSES BETWEEN MUTANTS)

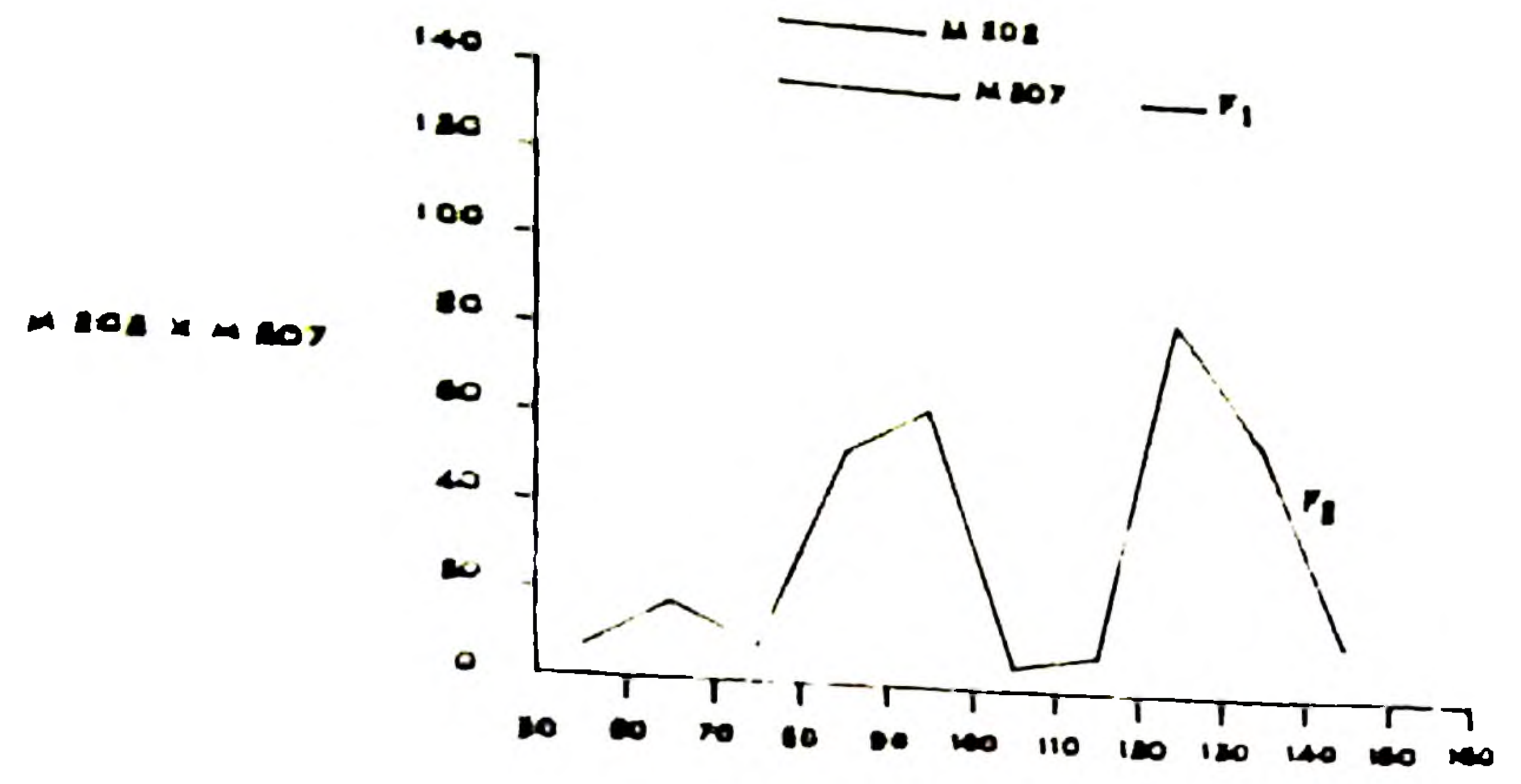


FIG XI-34

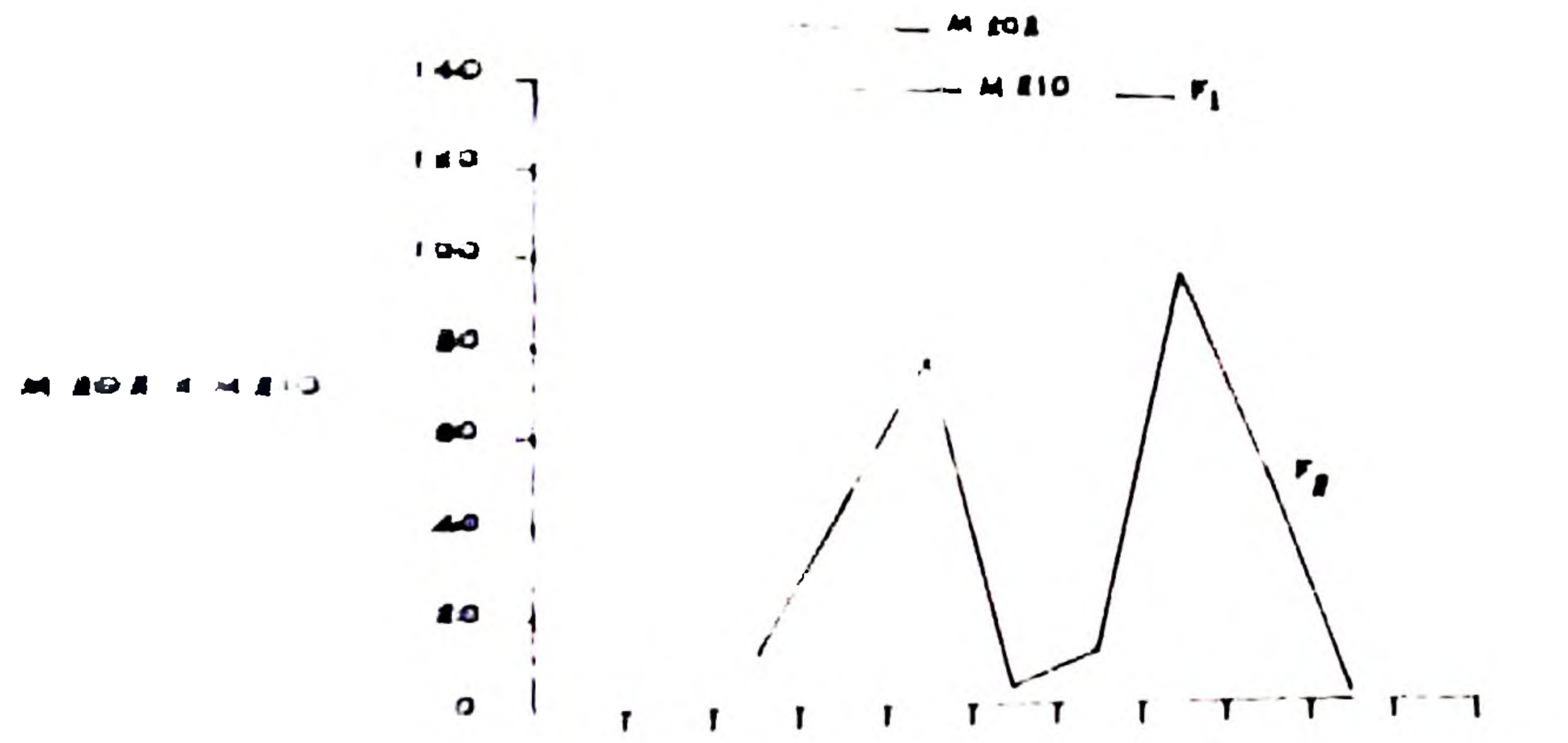


FIG XI-35

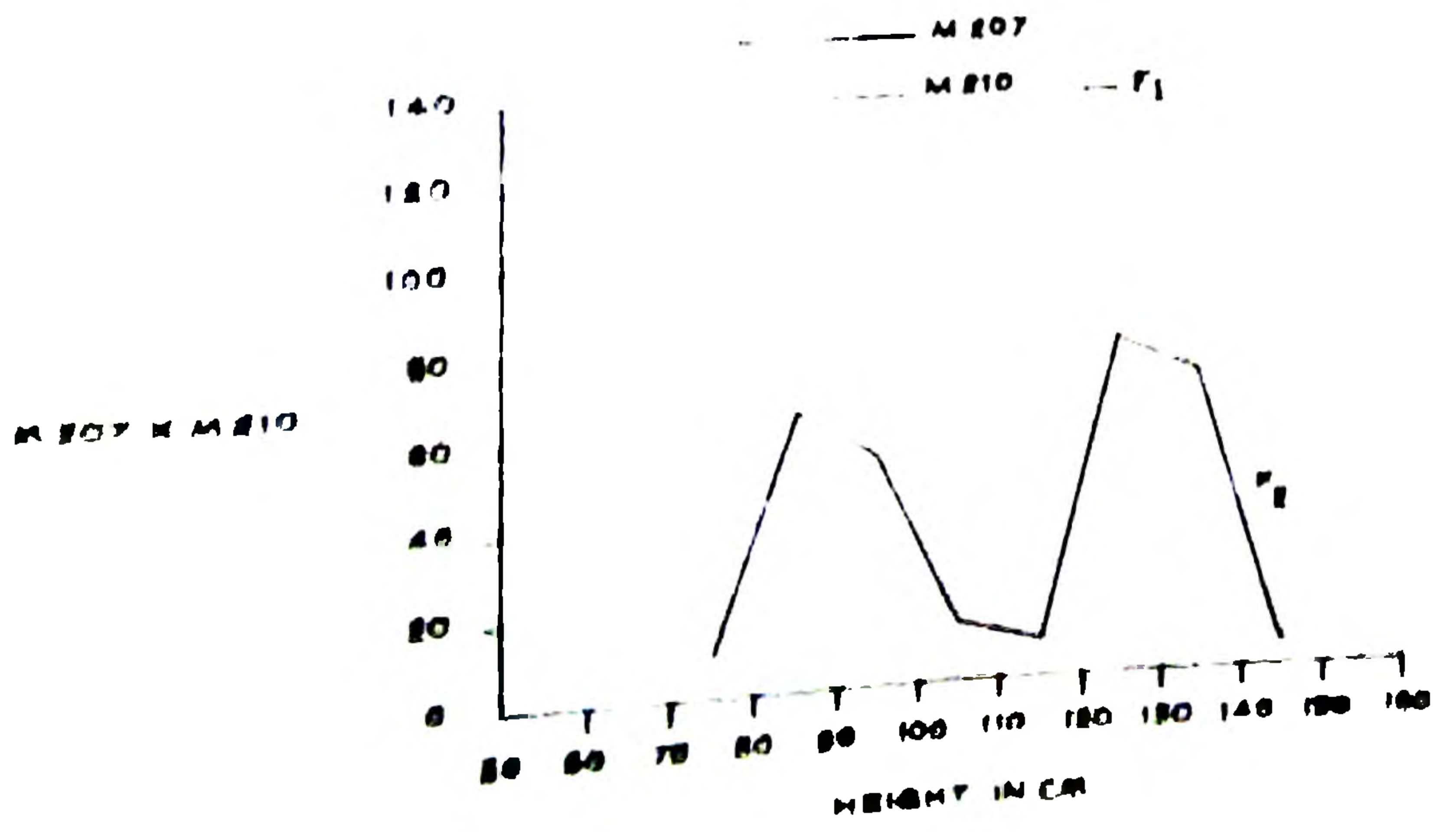


FIG XI-36

could be considered as dwarf. The tall plants resembled the F_1s in the colour and orientation of leaves and in the pattern of internode elongation. The semidwarfs were almost similar to the mutant parents, but a further grouping was not possible. The chi-square test of goodness of fit confirmed the segregation of talls and semidwarfs in the 9:7 ratio.

xxxvi) M 207 x M 210: While the mutants, M 207 and M 210 were semidwarfs, the F_1 plants were tall with the mean height of 123 cm. In contrast to the short erect dark green leaves and compact tillers of the mutants, the F_1 had long pale green drooping leaves and open habit (Table 21). They lodged after heading. The F_2 distribution showed two height groups viz., talls and semidwarfs (Figure XI-36). The tall plants looked like the F_1s whereas the semidwarfs resembled the mutant parents. The F_2 population of 318 plants studied, consisted of 171 talls and 147 semidwarfs (Table 22). The chi-square analysis indicated satisfactory fit to 9:7 ratio.

DISCUSSION

DISCUSSION

Induction of mutations by radiations and chemical mutagens has become a quite useful tool in modern plant breeding. The success of mutation breeding largely depends on our understanding of the process of induction and recovery of mutations and the screening methods for identifying the desired mutants. Basic information on the type and doses of mutagens, frequency and spectrum of mutations induced and the relative effectiveness and efficiency of the different mutagens is essential in utilising mutation breeding effectively for crop improvement. Although in the present study, more emphasis was given for the practical aspect of mutation breeding, viz., induction of plant type [illegible], [illegible] chlorophyll [illegible] of the information already available.

I. Mutagenesis

a) Effect of mutagens in the M_1 generation

Physical and chemical mutagens were reported to induce the following effects in the biological material (Gaul, 1970).

i) Physiological injury (Primary injury)
ii) Factor mutations (Gene mutations)
iii) Chromosome mutations (Chromosomal aberrations)

For a given mutagenic treatment, there is a correlation between M_1 damage and M_2 mutation frequency (Gaul, 1959). Therefore a quantitative determination of M_1 damage has become a routine procedure in mutation breeding experiments (Nair, 1971). Eventhough several criteria are followed for measuring the damage to plants, the M_1 effects in the present study were estimated by observing germination, survival, plant height and seed fertility.

Germination of rice seeds was not affected appreciably by gamma rays even at high doses of 40 or 45 krad. But survival of seedlings and plants was reduced progressively with increasing doses of radiation. This finding agrees with the reports of previous workers (Gaul et al., 1[illegible]7; [illegible], 1967; Ganashan, 1970 and Nair, 1971). Prolonged lethal effect of gamma rays was evident in the present study by the low number of plants surviving at flowering. Such prolonged lethal action of radiation was reported by Yamagata et al. (1965), [illegible] et al. (1967) and Nair (1971). In contrast to gamma rays, [illegible] inhibited germination considerably and the reduction in germination was progressive with increasing doses. However, even at the highest dose of the chemical mutagen, nearly all the surviving seedlings reached the flowering stage. Yamagata et al. (1965), Ganashan (1970) and Nair (1971) reported that EMS inhibits germination considerably. Nair (1971) also observed that in chemical mutagen treatments, M_1 seedlings reaching the fourth leaf stage almost always survived upto maturity. Thus the present work also revealed the difference in the nature of the lethal effects between gamma irradiation and EMS treatment. Radiation induced lethality was manifested subsequent to germination through a prolonged lethal action even at the advanced stages of plant growth, whereas chemical induced letality was mostly expressed through inhibition of germination.

Seedling injury as measured by the rate of reduction in shoot growth has been used as a reliable estimate of damage in several biological experiments. Siddiq (1967) and Singh (1970) observed a linear relationship between dose of gamma rays and reduction in shoot growth. The results recorded in the present investigation also indicated the same trend. Eventhough EMS also reduced the height of shoot progressively with increased doses, the effect was less drastic as compared to that of gamma rays. Similar results were reported by many workers (Siddiq, 1967; Singh, 1971; Nair, 1971). The rate of reduction in growth was more significant during the seedling stage than at later stages of growth, indicating an apparent recovery of M_1 plants from injury as growth advanced. Nair (1971) explained this phenomenon as due to the growth of uninjured meristematic cells which replaced the injured ones as growth proceeded.

Seed fertility in M_1 was found to decrease considerably with increasing doses of gamma rays. At the highest dose of 45 krad, fertility was as low as 13%. Increase in seed sterility with increased dose of radiation was reported by Bekendam (1961), Henderson (1963), Siddiq (1967), Nair (1971) and many others. The low incidence of sterility after treatment with EMS even at higher doses was a conspicuous feature observed in the present study. At 1.5% concentration of EMS, seed fertility remained at the level of 64 to 68% in contrast to 13 to 17% at 45 krad of gamma rays. Rao and Ayengar (1964), Siddiq and Swaminathan (1968a) and Nair (1971) also pointed out such a feature in rice.

b) Mutations in the M_2 generation

Several terms have been used for characterising the different types of mutations without being clearly defined (Gaul, 1964). Vital mutations were classified by Gaul (1961) based on the method of detection, that is, whether the mutation could be recognised in a single plant or in a group of plants, into macromutations and micromutations, respectively. Macromutations were further classified into transpecific and intraspecific, whereas micromutations were grouped into manifest and cryptic. Swaminathan (1964) classified mutations into the following four groups.

i) Micromutations: All mutations that could be isolated through the adoption of biometrical procedures.

ii) Visible mutations: This group included mutations that could be identified either by the naked eye or by the use of appropriate screening procedures. They could be either lethal or viable.

iii) Macromutations: Mutations in which the change, though inherited as a single unit of recombination, yet affecting a constellation of characters.

iv) Systematic mutations: Mutations, that either simulated an already existing taxon or necessitated the creation of a new systematic unit by virtue of the character affected being a key one.

In the present investigations, mutations were broadly grouped into chlorophyll mutations and viable mutations. The chlorophyll mutations were further classified according to the system suggested by Gustafsson (1940) and expanded by Konzak et al. (1965). Among the viable mutations, macromutations (Swaminathan, 1964) were studied in detail.

An accurate method of estimating induced mutation frequencies must compensate for the bias introduced by factors such as diplontic selection, small progeny size and increased size of mutated sector at higher doses (Nilan, 1964). In a tillering cereal like rice where the embryo has already differentiated into a number of spike primordia, the estimate based on M_1 plants will always make an over estimation of the mutation frequency in comparison with the other methods.

In contrast to the estimate based on M_2 plants, the M_1 spike estimate will be influenced by the size of the mutated sector of the M_1 spike and the M_2 progeny size (Gaul, 1960). These may distort the functional relationship between dose and mutational response to a very serious degree. Therefore the estimate of the M_2 mutant frequency will be the best estimate of the initial mutation frequency. According to Konzak et al. (1965), the M_2 seedling basis for estimating mutation frequency permits the resolution of separate mutational events occurring within M_1 spike. Muller (1965) in _Arabidopsis_ also found that the M_2 mutant frequency was the best estimate especially at higher doses. However, urvella et al. (1962) reported that in barley, the mutation rates of apical spikes remained independent of the degree of tillering and therefore, a reliable estimate of mutation frequency could be made by utilizing the apical spikes for scoring mutations.

Mutation frequencies were estimated as the number of mutations per 100 M_1 plants, the number of mutations per 100 M_1 spikes and the number of mutants per 100 M_2 plants. The frequencies estimated as the number of mutations per 100 M_1 plants gave higher values than the other two estimates at each of the doses for both the mutagens. This evidently was an over estimation of the mutation event in consideration of the differentiated nature of the embryo. The chlorophyll mutation frequency estimated in the present investigations reached a maximum at 30 or 35 krad of gamma rays and 1.0 or 1.5% of EMS. At still higher doses of gamma rays, a reduction in the mutation frequency was observed. However, such a reduction at higher doses was low in the case of EMS. This phenomenon indicated elimination of mutations at the higher doses. Similar observations were made by Matsuo et al. (1958), Masima and Kawai (1959), Yamaguchi (1964), Miah et al. (1970) and Nair (1971).

Viable mutation frequencies estimated per 100 M_1 ears were found to increase with increasing doses of mutagens reaching a maximum at or near the highest doses employed. Gamma rays induced higher frequencies of viable mutants than EMS. While EMS at the highest dose of 1.5% yielded a mutation frequency of 40.4, gamma rays at 40 krad recorded the highest frequency of 41.7 mutations per 100 ears. Siddiq (1967) reported that at comparable doses of EMS and gamma rays, the frequencies of viable mutations were more or less the same in rice. Nair (1971) observed that irrespective of the criteria for efficiency, gamma rays and EMS appeared to be more efficient in inducing viable mutations in rice. The results of the present investigations also agree with the above observations.

EMS among the chemicals and fast neutrons among the radiations were reported to induce wider spectrum of mutations (Swaminathan, 1966b) and Swaminathan et al., 1970).

Swaminathan et al. (1962) suggested that the location of genes relating to chlorophyll development in the proximal segments and the high susceptibility of such regions to EMS action might be the factors involved in the induction of a large number of chlorophyll mutants with EMS. The result obtained in the present investigations revealed that the spectrum of induced mutants differ between gamma rays and EMS. Albina was the most frequent type following treatment with gamma rays at the doses tried. An increase in the frequency of viridis followed by a corresponding decrease in the frequency of albina was observed in EMS treatments. Such significant differences in the spectrum of mutants between radiations on the one hand and chemical mutagens on the other were reported by Bekendam (1961), Chao and Chai (1961), Kawai (1966), Basu and Basu (1969) and Nair (1971) in rice. But Kawai and Sato (1965), Siddiq (1967) and Siddiq and Swaminathan (1965) were of the view that the spectrum of chlorophyll mutations would be independent of mutagens used. The higher frequency of albinas was explained by Swaminathan et al. (1970) as due to the large number of loci governing this phenotype.

There are several reports of differences in the spectrum of viable morphological mutations induced by radiations and chemical mutagens. The strongest evidence comes from the erectoides mutants in barley (Ehrenberg et al., 1961 and Nilan et al., 1965). In the present study, viable mutants with altered height (tall, semidwarf and dwarf), duration (early, late and very late) and leaf shape, size, colour and orientation (narrow, short, erect, drooping, dark green) were observed. Nair (1971) reported that the spectrum of induced viable mutants included high frequency of mutants with altered duration and grain type following treatment with gamma rays and high frequency of mutants affecting culm length, following EMS treatments. Similar results were recorded in the present investigations also. While nearly 66% of the mutants with altered stature were recovered from the EMS treated material, more than 70% of the mutants with altered duration was induced by gamma irradiation. These observations suggested that the mutation spectrum can be altered through the use of different mutagens.

A large number of viable mutants were isolated in the present study. They appeared in low frequencies in the segregating ear-progenies in the M_2 generation. Their first appearance in the M_2 generation indicated the recessive nature. Ninetythree viable mutants were screened and 41 height mutants were initially selected. The height mutants included tall. semidwarf and dwarf types. Such mutants affecting culm length were reported by many workers following treatment with radiations and chemical mutagens. Tall mutants were recorded by Rutger and Carnahan (1981) and Hajra et al. (1982). Semidwarf and dwarf mutants were reported by Nair (1971), Sreerangasamy (1973), Chakrabarthi and Sen (1975), Dwivedi et al. (1973), Mahadevappa et al. (1981), Ashri (1982) and Ganashan and Whittington (1983) among many others. Short and narrow leaved mutants were also identified in the present study. The leaf of such a mutant measured a width of 0.5 cm. Narrow leaved mutants were reported to be most frequent in mutagen treated material (Hsieh, 1962; Shastry, 1965; Siddiq, 1967; Tanaka, 1968; Reddy, 1977 and Ganashan and Whittington, 1983). Ear type mutants included compact, semi-open and open types. Short panicle mutants with panicles as short as 9.5 cm were also observed. Tanaka (1968) observed such short panicles frequently after treatments with mutagens. Kawai and Narahari (1971) and Ganashan and Whittington (1983) observed that most of the short culm mutants had reduced panicle length. In the present study, the dwarf mutants had considerably reduced panicles while most of the semidwarf mutants had either normal panicles or slightly longer panicles. Govindaswamy et al. (1972) have reported such mutants with longer panicles. Even-though no attempt was made to study the grain shape and size in the present investigations, the occurrence of small sized grains was indicated by lower weight of the grains. A few mutants with as low weight as 21.9 g for 1000 grains were recorded. According to Kawai (1962) and Ganashan (1970), short grain types were more frequent than large grain types.

Grain type mutants were reported by other workers also (Nair, 1971; Mallick et al., 1980 and Okuno, 1983).

c) Plant type mutants

The plant type concept in rice emerged through the development of short statured *indica* strains in Taiwan. These semidwarf *indica* varieties have established that fertilizer responsiveness is conditioned more by morphological features than by physiological ones (Swaminathan, 1966a). Although many environmental and cultural factors are associated with low yields, the type of the plant capable of more efficient performance under tropical conditions is more important. Jennings (1964) viewed the ideal plant type for the tropics as one having erect, short, thick and dark green leaves and short sturdy stem. The plant type concept has, however, been changing with the changing breeding requirements. Early maturity; insensitivity to day length; relatively short, upright, narrow, thick and dark green leaves; short sturdy culm to reduce lodging and resistance to serious pests and diseases were considered by Beachell (1966) as the characters associated with ideal plant type. The improved tropical plant type was defined by Chandler (1972) as a plant of short stature that, under good growing conditions, had a height of 90 to 100 cm with short, thick and sturdy culm that did not bend or break at high fertility levels; with inherent heavy tillering capacity that produced more panicles per unit area and with erect, short, dark green leaves that permitted greater penetration of sunlight. Beachell and Jennings (1965), Swaminathan (1966a), Seetharaman (1969) and many others described the ideal plant type for the tropics. Many workers suggested that plant type in rice is associated with semidwarf or dwarf stature (Jennings, 1964; Beachell and Jennings, 1965; Swaminathan, 1966a; Ramiah, 1966; Tanaka, 1967; Seetharaman, 1969; Reddy and Reddy, 1973; Singh et al., 1977 and Rutger, 1981).

Nine mutants conforming to the plant type were selected in the present study. They had short culm; erect, thick, dark green leaves and non-lodging habit. In rice, such plant type mutants were reported after gamma irradiation by [illegible] et al. (1961), Tanaka (1968), Rajagopalan (1968), Swaminathan (1970), Escuro et al. (1971), Govindaswamy et al. (1972), Sreerangasamy (1973), Kaul (1980), Tsai (1980), Yamaguchi et al. (1981), Gao (1981), Guo (1981) and Ganashan and Whittington (1983). Misra et al. (1971), Reddy and Padma (1976), Reddy et al. (1979), Hajra (1979), Sreedharan (1979), Kaul (1980), Sharma and Lal (1981), Sreerangasamy and Anandakumar (1983) and Ganashan and Whittington (1983) isolated many plant type mutants in rice following treatment with EMS.

II. Genetic analysis

In rice, height decides largely the plant type and therefore it is an important agronomic character. It is the association of height with the other components of the morphotype such as profuse tillering, upright leaves of appropriate size and sturdiness of stem that confers the ability to the plant to respond to good management. Therefore an understanding of the genetic basis of the induced plant type mutants in rice can be of considerable plant breeding value.

A set of crosses was undertaken to study the genetic nature of the induced semidwarf mutants. Ptb-9 was tall (138 cm) but the mutants derived from it (M 2, M 6 and M 14) were semidwarf with height ranging from 83 to 95 cm. The hybrids in each of the three crosses between the mutants and Ptb-9, were tall and were lodging like the tall parent. While the mutants had short, dark green, erect leaves, the hybrids had long, pale green, drooping leaves like the tall parent. The plant height in F_2 generation in each of the crosses showed a wide range of variation (71-80 cm class to 151-160 cm class). The frequency distribution in the F_2 was bimodal with maximum frequencies in the modal classes of 91 to 100 cm and 131 to 140 cm. Relatively very low frequencies were observed in 101 to 110 cm and 111 to 120 cm classes. The bimodal distribution and the low frequency of plants in the classes between the modal classes distinctly divided the F_2 population into two height groups, viz., the tall and the semidwarf. The frequencies of the plants segregating for height above and below 110 cm fitted a 3:1 ratio. All the tall plants above 110 cm had long pale green drooping leaves. The semidwarfs resembled the mutants in appearance. The tall stature of the F_1 and the monogenic segregation of 3 tall:1 semidwarf in the F_2 in each of the crosses indicated that the semidwarf mutants carried a recessive gene for stature. While Ptb-28 had a mean height of 135 cm, its mutants (M 102, M 107 and M 111) ranged from 82 to 106 cm in height. The F_1 in each of the crosses of the mutants with its parent were tall and the F_2s showed a bimodal distribution indicating the presence of two height groups, viz., the tall and the semidwarf. The frequencies of the talls and semidwarfs gave a good fit to 3:1 ratio. Ptb-28, the tall F_1s and the tall F_2 segregants had very close resemblence whereas the semidwarf segregants resembled the mutants. The appearance of the tall F_1s and the 3:1 segregation in the F_2 clearly indicated the monogenic recessive nature of the character. The F_1s of the crosses of Ptb-10 with its mutants were also tall, similar to the other F_1s. The distribution curve of the F_2 populations indicated the presence of both talls and semidwarfs. The pattern of segregation suggested a 3:1 ratio for the talls and the semidwarfs with high probability. While the F_1s and the tall segregants were phenotypically similar to the tall parent, the semidwarfs in the F_2 closely resembled the mutants. The 3:1 segregation in the F_2 and the appearance of tall F_1s indicated monogenic control of stature with the dominance of tallness over semidwarfness. Such monogenic recessive dwarfism and semidwarfism of both spontaneous and induced mutants in rice were reported (Anon., 1964, 1966a). Akemine (1925), Ramiah (1933a), Chang (1965), Suge and Murakami (1968), Seetharaman and Srivastava (1969), Foster and Rutger (1978), Ghosh et al. (1981), Singh and Sharma (1982) and Shinabashi (1982) reported spontaneous dwarfs (semidwarfs) in rice which behaved as simple recessives to tall plants. Simple recessive nature of the induced dwarf mutants in rice was also reported earlier (Anon., 1969; Narahari, 1969, 1977; Reddy and Reddy, 1971; Reddy and Padma, 1976; Rutger et al., 1976; Mohanty and Das, 1977; Prasad and Sinha, 1977; Mallick et al., 1980; Ghosh et al., 1981 and Okuno, 1983). The results recorded in the present investigations are however, not in agreement with the findings of Ramiah (1933a), Anon. (1966b, 1968) and Foster and Rutger (1978) who envisaged the inheritance of dwarfism on the basis of multiple factors or polygenic additive system with partial or incomplete dominance.

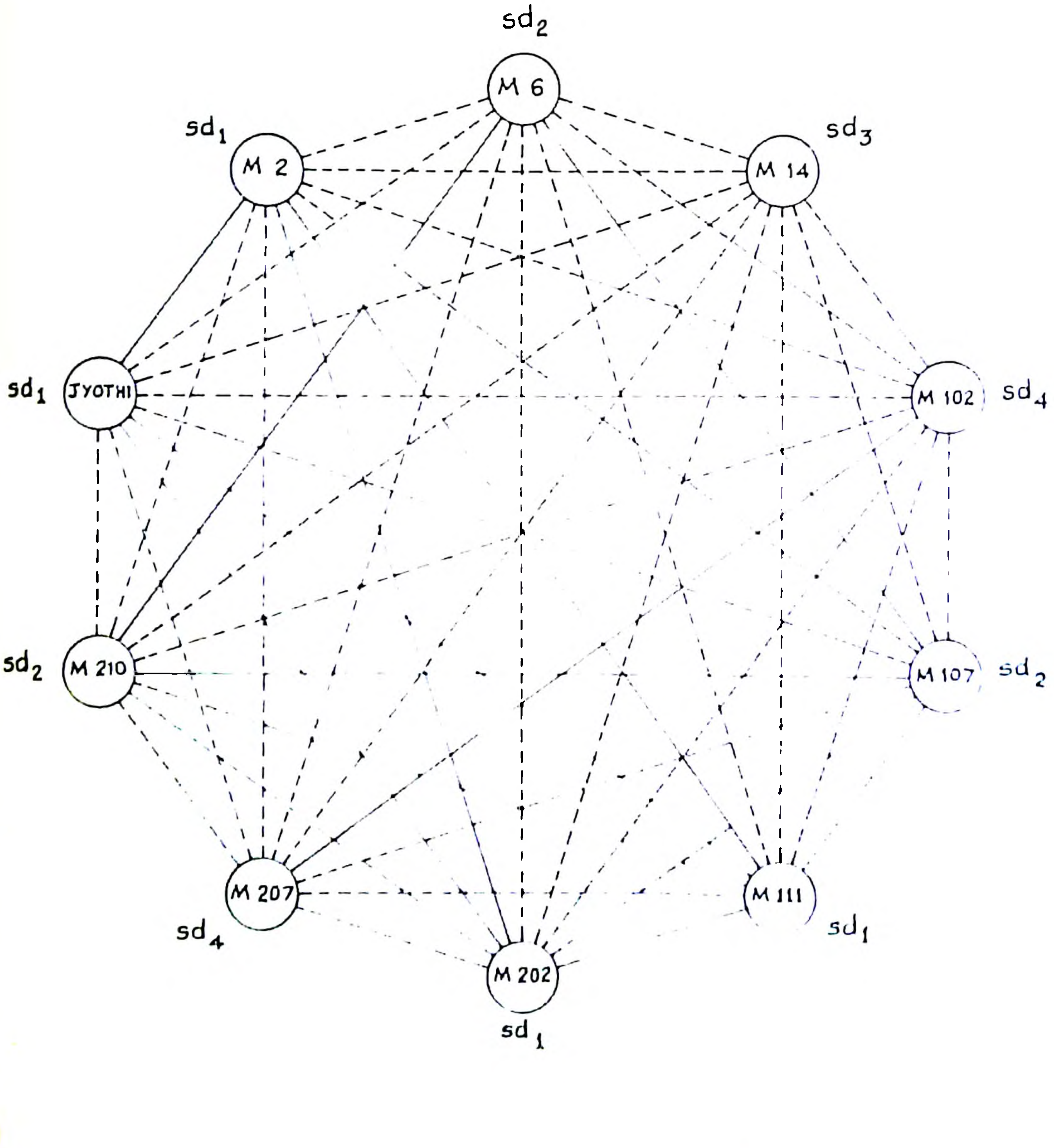
The fact that the mutants and the semidwarf segregants in F_2 had short, dark green, erect leaves and the tall F_1s and the tall segregants possessed long, drooping, pale green leaves like the tall parents indicated that the stature and the other characters went together. Similarly while all the tall plants were susceptible to lodging, semidwarfs were non-lodging. It is therefore suggested that the major gene controlling stature has influence on other characters such as leaf length, colour and orientation and lodging habit. The results thus showed the macromutational effect (Swaminathan, 1964) of the gene controlling stature, leading to several phenotypic consequences. That the gene controlling stature has pleiotropic effect on other characters like leaf orientation, leaf colour, leaf size, stiffness of culm, lodging habit etc. was reported by many workers. Parnell et al. (1922) and Ramiah (1933a and 1933b) in spontaneous mutants and Masima and Kawai (1958), Kawai and Narahari (1970), Reddy and Reddy (1971), Escuro et al. (1971), Dwivedi et al. (1979), Santos (1981) and Okuno (1983) in induced mutants in rice found macromutational effects of the gene controlling stature.

Jyothi is a semidwarf variety carrying Dgwg dwarfing gene inherited through IR-8. Dee-geo-woo-gen, Taichung Native-1, I-geo-tze and IR-8 all carry the same dwarfing gene (Chang et al., 1965; Anon., 1966, 1969; Aquino and Jennings, 1966; Mackill and Rutger, 1979). Dgwg dwarfing gene has been reported to be simply inherited as a recessive gene (Anon., 1964; Chang, 1965; Seetharaman and Srivastava, 1969). Crosses between the nine induced semidwarf mutants and Jyothi were undertaken to understand the allelic relationship between the induced dwarfing genes and the Dgwg dwarfing gene.

Crosses of the mutants M 2, M 111 and M 202 with Jyothi yielded semidwarf F_1s ranging in height from 78 to 102 cm indicating that these mutants had a dwarfing gene isoallelic to Dgwg gene (Figure XII). The unimodal distribution of the F_2 population in all the crosses and the maximum frequency of plants in the class of 91 to 100 cm indicated a single height group viz., semidwarf. The non-segregating semidwarf F_2s confirmed the isoallelic nature of the dwarfing gene of the mutants M 2, M 111 and M 202 with the Dgwg gene. Many of the dwarfs of spontaneous origin and several induced dwarfs were already reported to be allelic to the Dgwg dwarf (Pal et al., 1966; Seetharaman and Srivastava, 1969; Narahari, 1977; Anon., 1979; Singh et al., 1979; Manuel, 1981; Ikehashi and Kikuchi, 1982). The present findings thus agree with these reports. The mutants, Jyothi, their F_1s and F_2s had short, dark green erect leaves and nonlodging culm. The association of these characters with the semidwarf stature in parental, F_1 and F_2 generations indicated the macromutational effect of the gene controlling stature as reported by Jacomo et al. (1971), Dwivedi et al. (1979), Santos (1981) and Kuno (1983).

All the other six mutants in crosses with Jyothi produced tall F_1s ranging from 122 to 139 cm in height. The F_2s of the crosses involving M 6, M 107 and M 210 ranged in height from 71 to 150 cm. The populations showed bimodal distribution with modal classes corresponding to 91 to 100 cm and 121 to 130 cm in the F_2 of Jyothi x M 6 and Jyothi x M 107 and 91 to 100 cm and 131 to 140 cm in the F_2 of Jyothi x M 210. The

FIG. XII. GENIC RELATIONSHIP OF THE MUTANTS AND JYOTHI



———————	F_1 SEMI DWARF
- - - - - - - -	F_1 TALL

bimodal distribution and the occurrence of low frequency in classes between the modal classes divided the distribution into two height groups. Absence of plants below 71 cm permitted the classification of the population into semidwarfs (71-110 cm) and talls (above 110 cm). The segregation of plants into talls and semidwarfs fitted a 9:7 ratio. The complementary behaviour of each of the mutants in crosses with Jyothi for stature in the F_1 and the dihybrid segregation ratio in the F_2 suggested nonallelism for dwarfing genes between Jyothi and these mutants (Figure XII). The recombinants in F_2 carrying both the nonallelic dwarfing genes are indistinguishable from other semidwarfs. This nonappearance of a separate height group (double dwarf) in the F_2 suggested the nonadditive action of the dwarfing genes of the mutants with that of Jyothi. Thus the present study indicated that the dwarfing genes of M 6, M 107 and M 210 are nonallelic to Dgwg dwarfing gene. They are complementary and nonadditive in action. Such induced complementary dwarfing genes nonallelic to Dgwg gene have been reported in rice by Reddy and Padma (1976), Foster and Rutger (1978), Mackill and Rutger (1979), Singh et al. (1979), Ghosh et al. (1981) and Ikahashi and Kikuchi (1982).

The plant height in the F_2 in crosses involving M 14 and M 102 ranged from 51 to 160 cm and in the cross M 207 x Jyothi, from 51 to 150 cm. Three modes were observed in the frequency distribution curve of the F_2 in each of the crosses. The modal classes were 61 to 70 cm, 91 to 100 cm and 121 to 130 cm. The occurrence of low frequency of plants in 71 to 80 cm, 101 to 110 cm and 111 to 120 cm classes distinctly divided the distribution into three height groups, viz., tall (above 110 cm), semidwarf (71-110 cm) and dwarf (below 71 cm). Occurrence of plants in 51 to 60 cm and 61 to 70 cm classes revealed the presence of an additional height group, viz., dwarf, than those in the crosses involving M 6, M 107 and M 210. Segregation of the F_2 population into tall, semidwarf and dwarf gave a good fit to 9:6:1 ratio with high probability. The 9:3:3:1 model was not tried because of the difficulty in distinguishing between the two groups of semidwarfs. Tall F_1s and the dihybrid segregation in F_2 in each of the crosses confirmed the nonallelic nature of M 14, M 102 and M 207 with Jyothi at the locus controlling height (Figure XII). The difficulty in distinguishing the two groups of the semidwarfs suggest their similarity in nature. The dwarfs in the F_2 were evidently the result of additive action of the two dwarfing genes. The present investigations thus revealed that mutants M 14, M 102 and M 207 had dwarfing genes nonallelic to Dgwg gene and that the dwarfing gene in each of the mutants was additive with the Dgwg gene. The dwarfs were actually double recessive possessing dwarfing genes at two different loci. Singh et al. (1979) observed that while most of the dwarfs of spontaneous origin would have dwarfing genes allelic to Dgwg, the induced dwarfs in many cases had dwarfing genes nonallelic to Dgwg. Results recorded in the present study also revealed that some of the induced dwarfing genes are nonallelic to Dgwg. Such nonallelic induced dwarfing genes with additive action were reported by Mackill and Rutger (1979) and Ghosh et al. (1981).

All the mutants M 6, M 14, M 102, M 107, M 207 and M 210 and the variety Jyothi were semidwarf in stature with short erect, dark green leaves and nonlodging short culm, whereas the tall F_1s and the tall F_2 segregants realised in the crosses of these mutants with Jyothi had long pale green, drooping leaves and long lodging culm. The semidwarf segregants in F_2 resembled the mutants and Jyothi, showing the association of these characters with plant stature. The very short, dark green, thick leaves and the very short culm of the double dwarfs again confirmed this association and additive affect of the genes controlling the stature over other associated characters.

In crosses of mutants with Jyothi, it was shown that while M 2, M 111 and M 202 had dwarfing genes isoallelic with Dgwg gene, the other mutants had dwarfing genes nonallelic to Dgwg. The pattern of segregation in the F_2 generation revealed that the mutants possessing nonallelic dwarfing genes fell into two groups. M 6, M 107 and M 210 had dwarfing genes nonallelic and nonadditive to the Dgwg dwarfing gene. The nonallelic dwarfing genes of M 14, M 102 and M 207 were however, additive in action. Thus based on the results of the crosses with Jyothi, the nine mutants could be classified into three groups as follows:

i) M 2, M 111 and M 202 possessing dwarfing genes isoallelic with Dgwg dwarfing gene.

ii) M 6, M 107 and M 210 with dwarfing genes nonallelic and nonadditive with Dgwg dwarfing gene.

iii) M 14, M 102 and M 207 with dwarfing genes nonallelic and additive with Dgwg dwarfing gene.

F_1s of all the crosses among M 2, M 111 and M 202 were semidwarf like their parents (Figure XII). The range of variation for plant height in F_2s of these crosses was narrow. The unimodal distribution with the modal class of 91 to 100 cm suggested that all the F_2 plants could be considered under the same height group, viz., semidwarf. These observations indicated that the dwarfing genes in the induced semidwarf mutants M 2, M 111 and M 202 are isoallelic with one another and with the Dgwg dwarfing gene. This gene may be designated sd_1. Such isoallelic dwarfing genes were reported in TN-1, I-geo-tze and Dgwg (Aquino and Jennings, 1966; Hu et al., 1968;

Anon., 1964). Rutger (1978) showed that the induced short statured mutant D_{51} possessed the same gene for semidwarfism as Dee-geo-woo-gen. In subsequent crosses, another mutant D_7 was proved to be allelic to D_{51} and Dee-geo-woo-gen (Rutger, 1979). Mackill and Rutger (1979) reported that induced mutants D_{23}, D_{24} and D_{25} possessed isoallelic semidwarfing genes at the locus sd_4 and the mutants D_7 and D_{32} possessed isoallelic semidwarfing genes at another locus sd_1. Singh et al. (1979) also studied the allelic relationship of several dwarfs and reported that 13 out of the 14 mutants studied were allelic with Dee-geo-woo-gen. Ikehashi and Kikuchi (1982) were of the view that the same locus located in the third linkage group was responsible for semidwarfism which was utilised in the breakthrough of yield level independently in different regions of the world; in the tropics in the form of TN_1 and IR-8; in the South West Japan through the Jikkoku-derivatives; in the North East Japan by an induced mutant; in Korea as the base for the green revolution and in California in the form of Carlose 76.

In crosses between the semidwarf mutants M 6, M 107 and M 210, the plant height of the F_1s ranged from 94 to 101 cm indicating their semidwarf stature. The semidwarfing genes of these mutants were therefore expected to be isoallelic (Figure XII). The F_2 plants ranged from 71 to 110 cm in height indicating the presence of only semidwarfs. The semidwarf F_1s and the absence of segregation for plant height in the F_2 confirmed that the dwarfing genes in these mutants are isoallelic. In crosses with Jyothi, these mutants produced tall F_1s with F_2 populations segregating for height indicating nonallelism with Dgwg gene. Therefore M 6, M 107 and M 210 carried a dwarfing gene different from that of Dgwg. This gene, expected to be at a locus different from sd_1, was designated sd_2. Further evidence that these two dwarfing genes are nonallelic was provided by the crosses between the mutants carrying them. In the crosses M 2 x M 6, M 2 x M 107, M 2 x M 210, M 111 x M 6, M 111 x M 107, M 111 x M 210, M 202 x M 6, M 202 x M 107 and M 202 x M 210, the height of the F_1s ranged from 113 to 141 cm and that of the F_2s from either 71 to 80 cm or 81 to 90 cm to either 141 to 150 cm or 151 to 160 cm. Thus in these crosses, the F_1s were tall and the F_2s segregated for plant height into tall and semidwarf. These results confirmed that the dwarfing gene of M 2, M 111 and M 202 (sd_1) is different from that of M 6, M 107 and M 210 (sd_2). It is thus clear that genes sd_1 and sd_2 are nonallelic and that while sd_1 in isoallelic with Dgwg gene, sd_2 is nonallelic.

Crosses of M 14 with M 102 and M 207 produced F_1s ranging from 121 to 132 cm and F_2s from 51 to 130 cm in height. The F_1s were tall whereas the F_2s exhibited three height groups, viz., tall, semidwarf and dwarf. This clearly demonstrated that M 14 had a dwarfing gene nonallelic to that of M 102 and M 207. In crosses with Jyothi it was proved that the dwarfing gene of M 14 was nonallelic to sd_1 and sd_2. The dwarfing gene of M 14 may be designated sd_3. That sd_3 was nonallelic to sd_1 and sd_2 was further demonstrated by its crosses with the mutants carrying the genes sd_1 (M 2, M 111 and M 202) and sd_2 (M 6, M 107 and M 210). All the crosses M 2 x M 14, M 111 x M 14, M 202 x M 14, M 6 x M 14, M 107 x M 14 and M 210 x M 14 produced tall F_1s ranging from 121 to 142 cm in height. The F_2s of M 14 with M 2, M 111 and M 202 ranged from 51 to 160 cm with three distinct height groups, viz., tall, semidwarf and dwarf whereas the F_2s of M 14 with M 6, M 107 and M 210 ranged from 71 to 160 cm which segregated into talls and semidwarfs. The tall F_1s and the pattern of F_2 segregation confirmed that the dwarfing gene of M 14 (sd_3) was nonallelic to sd_1 and sd_2 (Figure XII).

In the cross M 102 x M 207, the F_1 height ranged from 95 to 100 cm suggesting semidwarf stature. The F_2 generation also did not show wide range of variation, all the individuals falling within the range of semidwarf. The semidwarf F_1 and the nonsegregating F_2 confirmed that the dwarfing genes of M 102 and M 207 are isoallelic (Figure XII). In crosses with Jyothi, M 102 and M 207 proved to be different from the first two sets of mutants viz., (M 2, M 111, M 202) and (M 6, M 107, M 210). This was further confirmed by their crosses with

M 2, M 111, M 202, M 6, M 107 and M 210. In all these crosses the F_1s were tall. The F_2 segregated into tall, semidwarf and dwarf in respect of crosses with M 2, M 111 and M 202 and into tall and semidwarf in crosses with M 6, M 107 and M 210. Thus the dwarfing gene of M 102 and M 207 was nonallelic to sd_1 and sd_2. The crosses M 102 x M 14 and M 207 x M 14 had already proved that M 14 had a gene (sd_3) different from that of M 102 and M 207. Thus the dwarfing gene of M 102 and M 207, is nonallelic to sd_1, sd_2 and sd_3. This gene may be indicated as sd_4.

Induced dwarfing genes both allelic and nonallelic to the Dgwg dwarfing gene were reported by many workers. Naturally occurring nonallelic dwarfing genes were reported by Nagao (1951). Several dwarfs and semidwarfs were reported to be nonallelic to Dgwg (Ji et al., [illegible]; Anon., [illegible], 1976). The Chinese semidwarfs Chen-chu-ai-11 and Chi-nan-[illegible] had genes for semidwarfing different from that of Dgwg (Anon., 1973 and 1976). Reddy and Padma (1976) demonstrated that five induced dwarf mutants, Dwarf-6 to Dwarf-10, were nonallelic to Dgwg. The present genetic analysis has also revealed the involvement of four nonallelic dwarfing genes (sd_1, sd_2, sd_3 and sd_4) in the nine induced mutants of which sd_1 is allelic to the Dgwg gene and the others are nonallelic. The nonallelic nature of sd_1, sd_2, sd_3 and sd_4 in the present study is in agreement with the report of Padma and Reddy (1977) that the induced dwarfing genes d_6, d_7, d_8, d_9 and d_{10} were nonallelic to each other. The view that unlike the dwarfs of spontaneous origin, which are usually allelic to the Dgwg gene, the induced dwarfs give rise to nonallelic genes (Singh et al., 1979), lends support to the results of the present study. Out of the four induced dwarfing genes, three were nonallelic to the Dgwg gene. The studies of Mackill and Rutger (1979) who induced three nonallelic genes (sd_1, sd_2 and sd_4) in the cultivar 'Carlose' also provide support to these results. Kinoshita and Shinbashi (1982) and Li and Chu (1982) have also reported nonallelic dwarfing genes in rice.

In all the crosses among the mutants carrying the genes sd_1 and sd_2, the F_1s appeared to be tall, with height ranging from 113 cm in M 202 x M 111 to 141 cm in M 2 x M 6. The distribution in the F_2 generations showed wider ranges varying from 71 to 80 cm or 81 to 90 cm classes to 141 to 150 cm or 151 to 160 cm classes. In each of the F_2, two distinct modal classes viz., 91 to 100 cm and 121 to 130 or 131 to 140 cm were observed. The presence of low frequency classes or the virtual absence of plants between the modal classes distinctly divided the distribution into two height groups, viz., semidwarfs and talls. The frequencies of plants segregating above and below 110 cm in all the crosses fitted a 9:7 ratio when tested for goodness of fit. The semidwarfs in the F_2 included recombinants carrying both the dwarfing genes, viz., $sd_1sd_1sd_2sd_2$.

That these double semidwarfs are phenotypically indistinguishable from single semidwarfs suggests that sd_1 and sd_2 are nonadditive in action. The difficulty in testing the F_2 dihybrid segregation using the 9:3:3:1 model was that the three types of semidwarfs were indistinguishable. Padma and Reddy (1977) and Mackill and Rutger (1979) have also reported such induced nonallelic dwarfing genes with nonadditive complementary action.

Crosses involving the genes sd_1 and sd_3 yielded tall F_1s ranging from 121 cm in the cross M 14 x M 202 to 130 cm in the cross M 2 x M 14. The F_2s in each of the crosses showed a wider range of variation for plant height and segregated with three modal classes corresponding to 61 to 70 cm, 91 to 100 cm and 121 to 130 or 131 to 140 cm. Three distinct height groups were recognised due to the low frequency classes between the modal classes. Within each height group, the distribution was unimodal and continuous with limited variation. Thus the F_2s in all the crosses segregated for tall, semidwarf and dwarf and their frequencies gave a good fit to the 9:6:1 ratio. The difficulty in distinguishing the two types of semidwarfs did not permit testing of the segregation ratio against the 9:3:3:1 model. The dwarfs were the results of recombination of the two dwarfing genes sd_1 and sd_3, their genotype being $sd_1sd_1sd_3sd_3$. That the segregants possessing both the dwarfing genes sd_1 and sd_3 exhibited much reduced culm length than the semidwarfs permitting them to be distinguished phenotypically indicated that the dwarfing genes sd_1 and sd_3 were additive in action. This observation is in conformity with the results of Mackill and Rutget (1979) that similar non-allelic additive induced dwarfing genes were present in Californian rice variety Carlose.

The F_1s of the crosses of the mutants carrying the dwarfing genes sd_1 and sd_4 were tall. The variation for plant height in the F_2 was greater ranging from 51 to 160 cm. Three modal classes were observed in each of the F_2 distributions indicating the presence of three height groups, viz., tall, semidwarf and dwarf. The frequencies of the F_2 plants segregating for tall, semidwarf and dwarf in each of the crosses fitted the 9:6:1 ratio. The dwarfs appeared through interaction of sd_1 and sd_4 in the recombinants carrying both the dwarfing genes, indicating that the genes sd_1 and sd_4 were additive in action.

The crosses of the mutants with genes sd_2 and sd_3 yielded tall F_1s. The height range in F_2 varied from 71 to 150 cm. The bimodal distribution of the F_2 population in each of the crosses with low frequency classes in between the modal classes permitted the classification of the population into talls and semidwarfs. The frequencies of plants above and below 110 cm fitted the 9:7 ratio with high probability. The semidwarf in the F_2 included three groups, viz., sd_2sd_2, sd_3sd_3 and

$sd_2sd_2sd_3sd_3$. They were phenotypically indistinguishable indicating that sd_2 and sd_3 were nonadditive in action. It is therefore suggested that sd_2 and sd_3 are nonallelic dwarfing genes with nonadditive action similar to those reported by Padma and Reddy (1977) and Mackill and Rutger (1979).

The study of the crosses involving sd_2 and sd_4 revealed that the F_1s were tall indicating the nonallelic relation between sd_2 and sd_4. The F_2 in the crosses exhibited a wider range of distribution from 71 to 160 cm. The pattern of segregation in each of the F_2s showed two modal classes corresponding to 81 to 90 cm and 121 to 130 cm or 131 to 140 cm. The low frequency classes in between the modal classes divided the population into two height groups, viz., tall and semidwarf. The frequencies of plants in these height groups fitted with high probability the 9:7 segregation ratio. The semidwarfs possessing both the dwarfing genes in the F_2 were indistinguishable from the other semidwarfs. This suggested that sd_2 and sd_4 were nonadditive in action.

The F_1s in the crosses between the mutants carrying the dwarfing genes sd_3 and sd_4 were tall. The F_2 populations showed a wide range of variation from 51 to 160 cm and three modal classes were observed in the distribution curves. The modal classes corresponded to 61 to 70 cm, 91 to 100 cm and either 121 to 130 cm or 131 to 140 cm. Distinct segregation for three different height groups was indicated by the low frequency of plants in the classes between the modal classes. The test of goodness of fit showed that the F_2 plants segregated into 9 tall:6 semidwarf:1 dwarf, indicating dihybrid segregation with additive action. The dwarf group in F_2 was the result of the interaction between the dwarfing genes sd_3 and sd_4, the genotype of the dwarfs being $sd_3sd_3sd_4sd_4$. The results are in conformity with the findings of Jorden and Beachell (1943); Mackill and Rutger (1979); Gu and Zu (1981) and Ghosh et al. (1981).

In the present investigations, four induced semidwarfing genes, viz., sd_1, sd_2, sd_3 and sd_4 were identified. These genes were found to be nonallelic to each other (Figure XIII). The gene sd_1 was isoallelic with Dgwg dwarfing gene, while the others were nonallelic with Dgwg gene. The gene sd_2 showed nonadditive action with the other genes. The genes sd_1, sd_3 and sd_4 in all combinations had additive action (Figure XIV).

III. Macromutational effects of the gene controlling plant height

The parental varieties Ptb-9, Ptb-28 and Ptb-10 were tall with long, pale green, drooping leaves, open habit and lodging tall culm. All the semidwarf mutants have erect dark green, short leaves, compact habit and nonlodging short culm. In the crosses of the mutants with their parents, the F_1s were tall and the F_2 segregated into 3 talls:1 semidwarf.

FIG XIII NON ALLELIC SEMIDWARFING GENES.

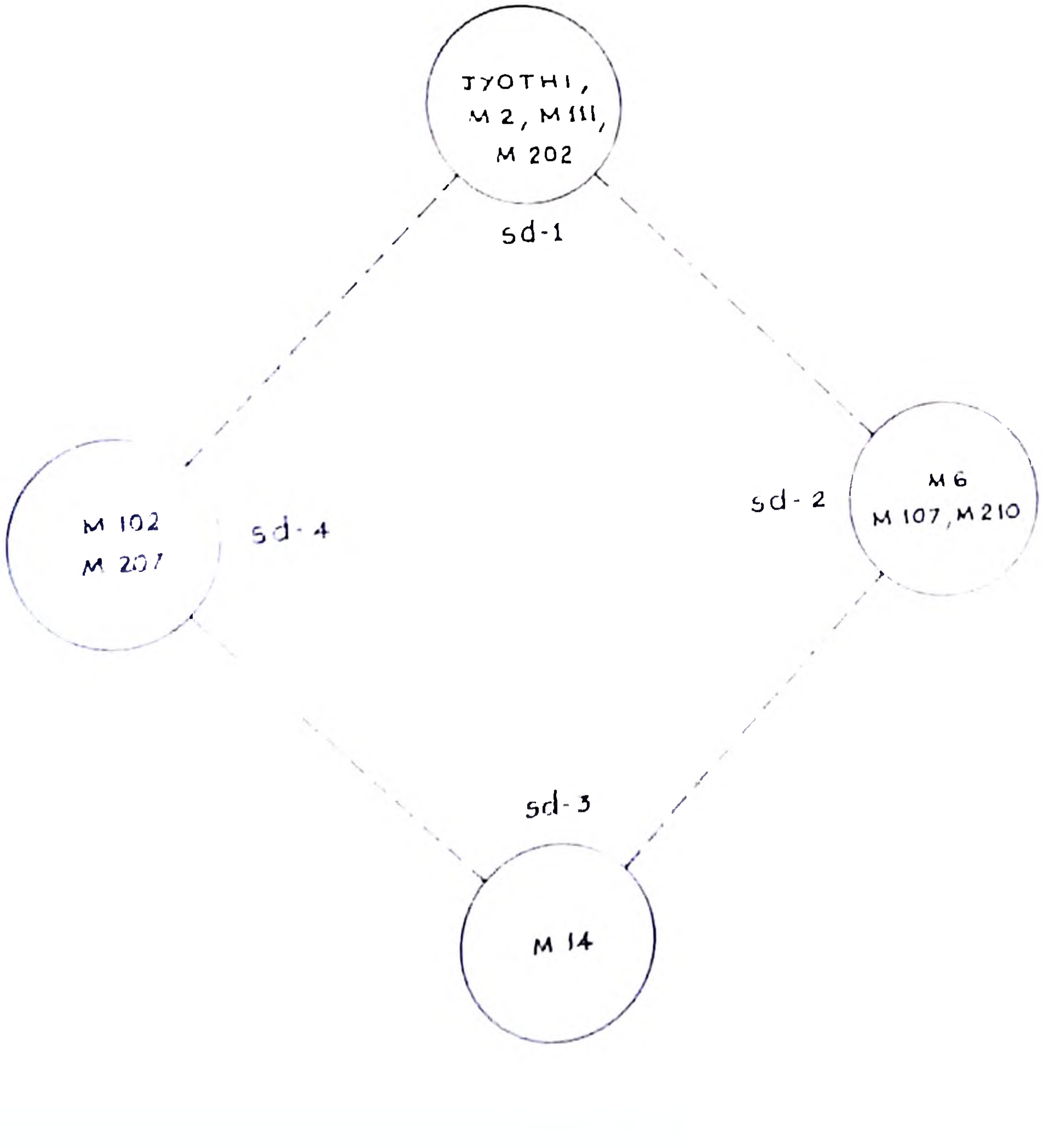
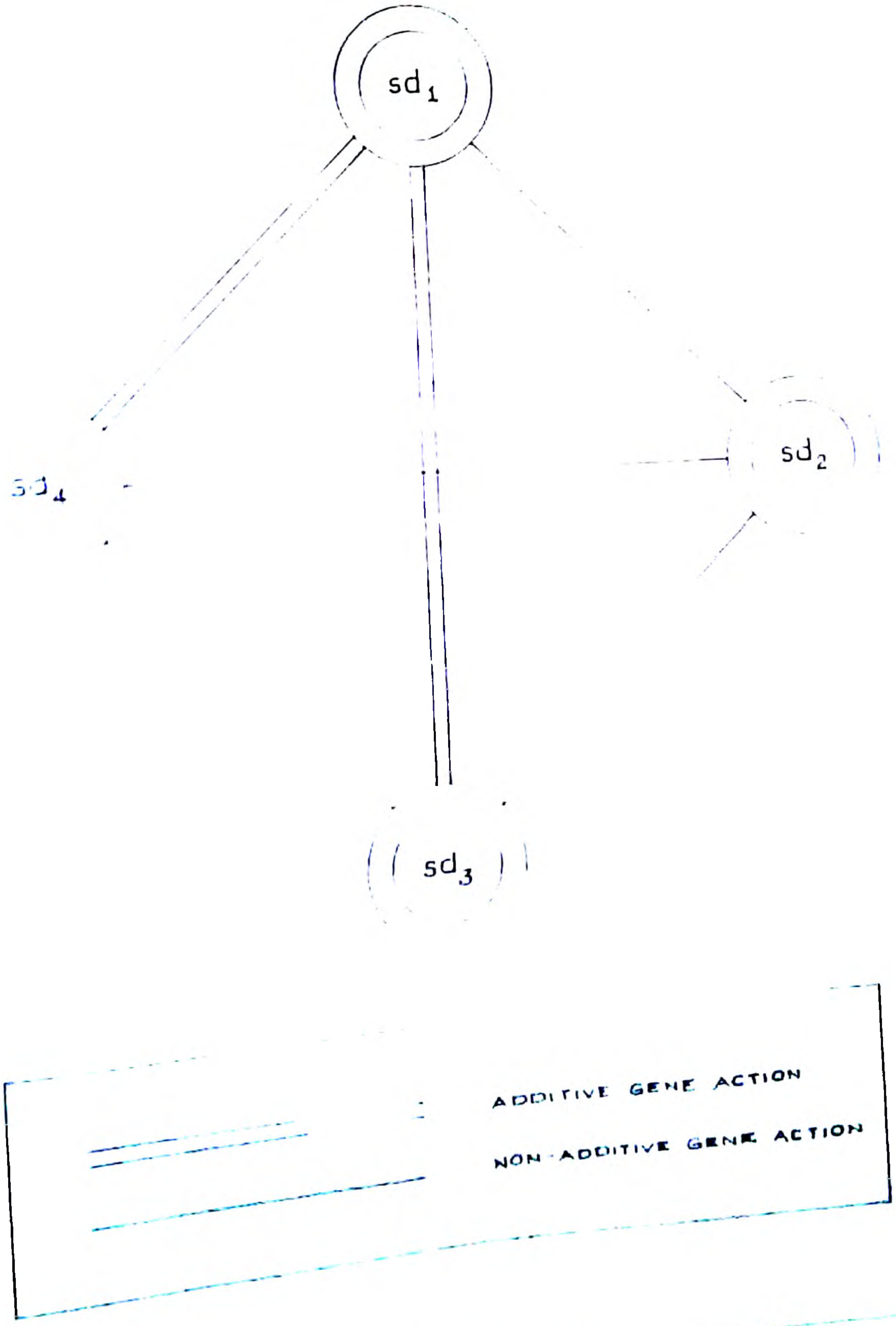


FIG XIV INTERACTION OF THE NON ALLELIC SEMIDWARFING GENES.



The tall F_1s and F_2s resembled the tall parents in all the leaf and culm characters while the semidwarf F_2s resembled the mutants. This indicated that the leaf and culm characters are always associated with plant height. The long, pale green and drooping leaves, open habit and lodging culm are associated always with tall plant stature while short, dark green and erect leaves, compact habit and nonlodging culm are always associated with semidwarf stature. The segregation of these characters in F_2 also follow the pattern of segregation for stature. In each of the crosses between the mutants carrying nonallelic genes for height (sd_1, sd_2, sd_3 and sd_4), the F_1s were tall. In contrast to the short, erect, dark green leaves and short nonlodging culm of the semidwarf mutants, the F_1s and the tall F_2 segregants had long pale green, drooping leaves and tall lodging culm. The semidwarf segregants in the F_2 resembled the mutants. In fact, the semidwarf stature, compact habit, nonlodging short culm and erect short leaves were inherited enbloc indicating that these characters are governed by a single genetic unit which behaves as a recessive to the normal stature. These results therefore strongly suggest the macromutational effect of the genes controlling semidwarf stature. It is evident from these observations that the mutant genes have pleiotropic effect on several characters such as plant height, leaf colour, leaf orientation, leaf size, lodging resistance, compact stand, internode elongation etc. This pleiotropic effect of the gene controlling plant type finds support in the reports by many workers such as Parnell et al. (1922), Ramiah (1933), Masima and Kawai (1959) and Beachell and Scott (1963). Nair (1971) reported several macromutant dwarfs and semidwarfs showing alteration in a number of vegetative as well as reproductive characters simultaneously. He further reported that the complex of characters expressed by these macromutants were inherited as a single genetic unit. Ganashan (1971), Reddy et al. (1975), Okuno (1983) and Ganashan and Whittington (1983) also reported pleiotropic effect of the major genes controlling plant type.

The pattern of internode elongation in the semidwarf mutants and the dwarf recombinants indicated that while the reduction in the total culm length in the semidwarfs was by the shortened internodes, the much reduced culm length in the dwarfs was the result of reduction in the internode length as well as their number. The reduction in length was relatively more for the lower internodes. Similar results were reported by Kawai et al. (1961), Kawai and Narahari (1971), Reddy et al. (1975) and Mallick et al. (1980). The apparent reduction in the number of internodes in the dwarfs might be due to the extreme reduction in length in the basal internodes and the consequent difficulty in recognising them.

Undoubtedly, the use of semidwarfs is one of the most brilliant successes in the area of rice breeding in this

Century. However, it should not be overlooked that the prevailing gene for semidwarfism is mostly the one identified in Dee-geo-woo-gen despite the difference in the donor varieties. With a single gene dominating large crop areas, there may be a potential danger of losing the genetic diversity. The alarming uniformity created by the narrow genetic base in respect of such an important gene or gene complex foretells the genetic vulnerability of the semidwarf rice varieties to many adverse conditions including disease and pest epiphytotics, and poor adaptability to diverse environments. The urgent need for creating genetic diversity for dwarfing genes to avoid this genetic suffocation has been felt keenly in the recent years. Of considerable interest, as suggested by the present study is the usefulness of induced mutagenesis in developing alternate sources for short stature. The dwarfing genes, nonallelic to Dgwg gene, isolated in the adapted genetic background can be expected to be valuable in guarding against excessive genetic uniformity in future breeding programmes. The genes induced and isolated in the present study have only favourable pleiotropic effects on vegetative as well as ear characters and hence can be of immense use in future rice breeding programmes.

In the conventional combination breeding method, in addition to the desirable dwarfing gene, many other genes also get incorporated into the genetic system of the adapted varieties. Even the very efficient selection procedures can help to avoid only those effects which are visible and conspicuous. But many undesirable genes may still persist along with the desirable ones. The non-adaptability to adverse environments and the susceptibility to various pests and diseases shown by many of the high yielding semidwarf varieties carrying the Dgwg dwarfing gene can be attributed to the presence of many alien non-adapted genes, whose individual effects are not visible and conspicuous to get sieved through the selection processes. Mutation breeding provides a tool by which the well adapted genetic background of the native varieties is disturbed to the minimum extent for incorporating the desired plant type. The semidwarf mutants are therefore expected to have the adapted genetic background.

One mutant each in Ptb-10 (M 210) and Ptb-28 (M 102) could be of direct use as commercial varieties, if they are found promising in the evaluation trials. Thus, the time involved in developing adapted semidwarf varieties could be considerably reduced by the mutational approach. Combination of different dwarfing genes with additive effect (sd_1, sd_3 and sd_4) might help in further stabilising the plant type. Eventhough such extreme dwarfs are of no practical value at the present, they might provide still higher production potential through additional lodging resistance and increased tillering capacity.

SUMMARY

SUMMARY

The major objectives of the study were to induce and identify plant type mutants in rice, to study their mode of inheritance and to investigate the allelic relationship of the induced dwarfing genes between themselves and with the Dgwg dwarfing gene. Mutations were thus induced in three well adapted tall *indica* strains, viz., Ptb-9, Ptb-28 and Ptb-10 using gamma rays and ethyl methane sulphonate. These varieties have tall lodging culm, long drooping pale green leaves and open spreading tillers. Observations on the effect of mutagens on the M_1 and M_2 generations were recorded.

Germination of rice seeds was not affected by gamma rays even at high doses. EMS inhibited germination and the reduction was progressive with increasing doses. Considerable delay in germination was observed at higher doses of both the mutagens. While gamma rays induced lethality of seedlings at all doses with drastic effect at high doses, the low doses of EMS were not lethal to the seedlings. Plant height was affected by the mutagens with increasing effect at high doses. Both gamma rays and EMS caused a linear decrease in fertility with increasing doses. EMS, as compared to gamma rays induced low degrees of sterility.

Chlorophyll mutations were induced by both the mutagens. While *albinas* were most frequent in gamma ray treatments,

viridis was predominant in EMS treatments. A large number of viable mutants were isolated. They exhibited a wide spectrum of morphological characters such as height, duration, leaf, panicle and grains. There was predominance of mutants affecting culm length and many dwarfs and semidwarfs were identified. Among the mutants with altered duration, late types were more frequent.

From among the 93 height mutants (6 talls, 65 semidwarfs and 22 dwarfs), 41 were selected for detailed morphological studies. The height of these mutants ranged from 61 to 159 cm. While the tall and semidwarf mutants had almost the same number of internodes as the parental types, the dwarfs had a low number of recognisable internodes. Talls appeared to have elongated internodes while semidwarfs and dwarfs had shortened internodes. The selected height mutants showed variation in duration upto maturity (78 to 175 days), leaf length (14 to 61 cm), leaf orientation (erect to drooping), leaf colour (dark green to pale green), number of panicle bearing tillers (4 to 76) and plant type (compact to open). Variation in ear and grain characters such as type of ears (open, semiopen and compact), exsertion of ears (fully exserted and partially exserted) and weight and length of ears were recorded. While most of the semidwarfs and dwarfs were nonlodging the talls succumbed to lodging.

From among 41 height mutants, nine plant type mutants (3 from each variety) which were morphologically distinct, were selected for genetic analysis. They were semidwarf with short sturdy culm, small erect dark green leaves, compact tillers and lodging resistance. The nine mutants were crossed with their respective tall parents to confirm the recessive genetic nature of the mutants and with Jyothi to ascertain the genic relationship of the induced dwarfing genes with that of Dgwg. The mutants were crossed among themselves in all possible combinations to study the allelic relationship of the induced dwarfing genes.

Crosses of the semidwarf mutants with the parents yielded tall F_1s in all cases. Segregation in F_2 gave a ratio of 3 talls:1 semidwarf confirming the monogenic recessive nature of the semidwarf mutants. The semidwarf F_1s and nonsegregating F_2s in crosses of M 2, M 111 and M 202 with Jyothi suggested that these mutants carried a dwarfing gene which is isoallelic with Dgwg dwarfing gene. The F_1s in the crosses of the other six mutants with Jyothi, were tall. The F_2s segregated for plant height and associated characters suggesting nonallelism between these dwarfing genes and the Dgwg dwarfing gene. The difference in the segregation pattern indicated that M 6, M 107 and M 210 carried a different dwarfing gene from that carried by M 14, M 102 and M 207.

Crosses between mutants confirmed that mutants M 2, M 111 and M 202 carried the same dwarfing gene which was found isoallelic with Dgwg gene. This gene was designated sd_1. The

F_1s and F_2s of the crosses among mutants M 6, M 107 and M 210 confirmed that these mutants carried a different dwarfing gene which was nonallelic to Dgwg gene. This gene was designated sd_2. Crosses of M 14 with M 102 and M 207 revealed that M 14 carried a dwarfing gene different from those of M 102 and M 207. This gene was designated sd_3. The cross M 102 x M 207 produced semidwarf F_1 and nonsegregating semidwarf F_2. These results suggested that M 102 and M 207 had another dwarfing gene, designated as sd_4.

The crosses between mutants carrying different dwarfing genes, viz., Sd_1, sd_2, sd_3 and sd_4 confirmed that these induced dwarfing genes were nonallelic to each other. They produced tall F_1s and F_2s segregating for height in all combinations. Dwarfing gene sd_2 in combination with other genes produced F_2s segregating with ratio of 9 tall:7 semidwarf. All other genes, viz., sd_1, sd_3 and sd_4, in all combinations produced the F_2 segregation ratio of 9 tall:6 semidwarf:1 dwarf. The results indicated that sd_2 was nonadditive in action with the other nonallelic dwarfing genes sd_1, sd_3 and sd_4 while they in combination showed additive interaction.

The macromutational effect of the genes controlling plant type was revealed by the study of plant characters such as length, width, orientation, colour and senescence of leaves; culm length; resistance to lodging; orientation of tillers etc.

These characters were found to be associated with plant height. While tall plants in the parental, F_1 and F_2 generations had long lodging culm, long pale green drooping leaves showing the tendency for early senescence, the semidwarfs in all the generations, had short nonlodging culm, short erect dark green leaves and compact tillers. These characters were found to be inherited enbloc. The semidwarf mutants are therefore considered as macromutants.

The study revealed the usefulness of mutational approach for evolving plant type mutants with alternate sources for dwarfing genes than the Dgwg dwarfing gene. This widens the genetic base of semidwarfs most of which at present depend directly or indirectly on the single Dgwg source.

The possibility of evolving plant type mutants in the native varieties without disturbing their well adapted genetic background has been confirmed in the present investigation. While two of the nine mutants appear to hold promise in preliminary studies to be used directly for commercial cultivation, the others may serve as alternate sources for dwarfing genes which can be exploited in combination breeding programmes.

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GENETIC STUDIES ON INDUCED VIABLE MUTANTS IN RICE (*Oryza sativa* L.)

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ABSTRACT OF A THESIS
submitted in partial fulfilment of the requirements
for the degree of
DOCTOR OF PHILOSOPHY
Faculty of Agriculture
Kerala Agricultural University

Department of Plant Breeding
COLLEGE OF AGRICULTURE
Vellayani, Trivandrum
1985

ABSTRACT

Almost all of the high yielding semidwarf varieties have derived their plant type from the Dgwg dwarfing gene, resulting in the alarming uniformity of these varieties in respect to this major gene, which has pleiotropic effect on several other characters. The necessity of evolving alternate sources of semidwarfing genes in the well adapted genetic background of the native varieties has been stressed by many workers. With this object in view, the present study was taken up in the Department of Plant Breeding, College of Agriculture, Vellayani. The major objectives of the investigation were to induce plant type mutants in three well adapted native varieties (Ptb-9, Ptb-10 and Ptb-28), to study the allelic relationship of the induced dwarfing genes between themselves and with Dgwg. Mutations were induced using varying doses of gamma rays and EMS.

The M_1 and M_2 generations were studied. The effect of the mutagens on seed germination, plant growth and sterility was observed in the M_1 generation. In the M_2, chlorophyll and viable mutations were studied. Among the viable mutants, height mutants were investigated in detail. Altogether 93 height mutants were identified. Finally, nine semidwarf plant type mutants (3 from each variety) with morphologically distinct characters were selected for genetic analysis.

Crosses of the mutants with their respective parents were undertaken to confirm their recessive genetic nature. In each of the crosses, the F_1 was tall and the F_2 gave a segregation ratio of 3 tall:1 semidwarf indicating the monogenic control and recessive nature of the semidwarf stature.

The mutants were crossed with Jyothi, a known carrier of Dgwg dwarfing gene, to understand the allelic relationship of the mutant dwarfing genes with Dgwg gene. Out of the nine mutants, three (M 2, M 111 and M 202) yielded semidwarf F_1s and nonsegregating semidwarf F_2s indicative of isoallelism. In all other crosses the F_1s were tall and the F_2s segregated for plant height suggesting the nonallelic nature of the dwarfing genes of the mutants with that of Dgwg. Mutants M 6, M 107 and M 210 yielded a 9:7 segregation ratio while mutants M 14, M 102 and M 207 gave a 9:6:1 segregation ratio in the F_2 indicating the difference between the dwarfing genes carried by the two sets of mutants.

Allelic relationships of the induced mutant dwarfing genes were studied in the crosses between the mutants. The F_1 and the F_2 studies confirmed that M 2, M 111 and M 202 had isoallelic dwarfing genes (sd_1). The dwarfing genes of M 6, M 107 and M 210 were found to be isoallelic (sd_2). M 14 had a different dwarfing gene (sd_3) while M 102 and M 207 had yet another dwarfing gene (sd_4).

The dwarfing gene sd_2 did not show additive effect with the other dwarfing genes whereas sd_1, sd_3 and sd_4 exhibited additive effect in all combinations.

The study revealed the macromutational effect of the major gene controlling plant type. Plant height was found to be associated with other characters such as orientation, size, colour and stage of senescence of leaves; orientation of tillers; lodging nature etc. which control the plant type.

The possibility of evolving alternate sources of dwarfing genes than that of Dgwg in the native varieties without disturbing their adapted genetic background has been established by the present study. The induced dwarfing genes nonallelic to Dgwg gene will be of use in widening the genetic base of the high yielding semidwarfs. Two of the selected plant type mutants hold promise for being used for direct commercial cultivation while others may be used in combination breeding programmes.