PHYSIOLOGICAL GENETICS OF CHARACTER ASSOCIATIONS IN HYBRID RICE *(Oryza sativa* L.*)*

By

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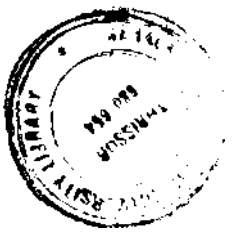

THESIS

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COLLEGE OF HORTICULTURE

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2001

DECLARATION

I hereby declare that the thesis entitled '**Physiological genetics of character associations in hybrid rice (*Oryza Sativa* L.)**' is a bonafide 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, fellowship or other similar title of any other University or society.

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CERTIFICATE

Certified that the thesis entitled **'Physiological genetics of character associations in hybrid rice (*Oryza Sativa* L.)'** is a record of research work done independently by **Miss. Sindhu. V.K.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, diploma or associateship to her.

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Sindhu, V.K.

Dedicated to my parents

&

to my Little Aishwarya

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INTRODUCTION

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important cereal crop of India and the second most important one in the world. Among the rice growing countries India has the largest area under rice followed by China and Bangladesh. Rice occupies a pivotal place in India's food security and livelihood system. The country has to produce about 135-140 million tonnes of rice by 2020 to meet its ever-increasing food requirements. With the population growth, the demand for rice worldwide will increase at the rate of 2.6 per cent over the next decade and beyond. About 60 per cent of rice production is concentrated in Asiatic countries, of which 23 per cent is produced in India and it is paradoxical that, India, which accounts for nearly one third of world's rice area, happens to produce a very low per hectare yield. Attempts are therefore made to maximize the productivity of this crop.

If the crop productivity improvement programmes are to be conducted successfully, the increased yield achieved must be stable and the higher production sustainable. This can be achieved by modifying the plant architecture or by exploiting heterosis. China reports an increased yield of 15 to 20 per cent through hybrid rice over conventional varieties. Hence, hybrids are considered an immediate answer to the food problem.

Heterosis in rice plants was first reported by Jones in 1926, who observed marked increase in culm number and grain yield in some F_1 hybrids in comparison to their parents. Since then, several rice researchers have reported the occurrence of this phenomenon for various agronomic traits, such as yield, grain weight, grains per panicle, panicles per plant, plant height, days to flowering, etc. Plant breeders realized that there were only two effective ways to increase the yield potential of crops through breeding, improving morphological traits and using heterosis. In India, more than 1,000 experimental hybrids were evaluated and 16 hybrids (13 from public sector and three from the private sector) have been released for commercial cultivation. Nowadays plant breeders realize that increasing the yield potential through heterosis breeding is limited because sometimes it will produce undesirable results, if it is not combined with improved plant morphology.

Many genetic theories have been developed to explain heterosis of F_1 hybrids. In spite of the large experimental evidence accumulated, it is not possible to conclusively accept or reject many of these theories. In this context, it is important to ascertain the character associations in hybrids on physiological basis, for explaining their yield advantage. We know that various metabolic reactions through physiological processes build up the harvestable yield in crop plants. The genes provide the basic blue print for expressivity of the characters, which is

conditioned by or modified by a physiologic process. Hence, the present study is proposed to analyse the physiology of heterosis in hybrids along with their parents for overall combining ability with respect to various characters in rice. This would be helpful to identify elite parents and potential crosses in further breeding or crop improvement programmes. Moreover, the inherent potentiality of the crop can be exploited only after knowing its physiological response in relation to the physical environment.

The present study assumes relevance in this context with the following objectives:

1. To characterize the morpho - metabolic associations in plant attributes that contribute to higher productivity in rice.
2. To understand how different genotypes may compliment one another physiologically.
3. To identify the stages at which the better physiological efficiency contribute to heterosis.
4. To understand the nutritional efficiency in relation to heterosis in hybrid rice.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

2.1. Plant characters

2.1.1. Plant height

Plant height refers to the longest distance between the plant base and the tip of the highest leaf or panicle, which is longer. Tanaka (1972) was of the view that tall rice varieties have lower growth efficiency and a larger proportion of maintenance respiration as against dwarf varieties.

Nijaguna and Mahadevappa (1983) reported that one hybrid out of three studied showed heterotic effects for plant height. Ponnuthurai (1984) suggested that taller plants may have better plant canopy for photosynthesis but also said that positive heterosis for height have some advantages. Blanco *et al.* (1986) indicated that the vigorous growth of F1 hybrids at the early vegetative stage was due to their high ability for leaf area development. Manuel and Palaniswamy (1989) evaluated 15 F_1 s for heterotic effects and found negative standard heterosis for plant height in all the hybrids. Chauhan *et al.* (1991) evaluated six cytoplasmic lines and their iso nuclear maintainers and found that cytoplasmic lines were significantly taller than their respective maintainers.

Rangaswamy *et al.* (1994) reported that CORH-1 matures in 104-115 days and is up to 75 cm tall. Virmani *et al.* (1991) noted that height of F_1 hybrids derived from semi-dwarf parents was almost equal or slightly taller

than the parents. Wu- Rong Hou *et al.* (1997) observed in a field trial that the height of the rice hybrid averaged to 111 cm.

2.1.2. Root length

Studies conducted in maize hybrids by Baligar and Barber (1979) observed that root length per gram of shoot was higher in hybrids than in their parents. In rice, the F_1's were found significantly superior in root pulling resistance and showed a positive heterosis for higher yield when compared with the parents (Ekanayake *et al.*, 1985).

A strong, deep and active root system in hybrid rice may also have potential for its adaptation in rainfed –uplands and in low lands. Bai- Shunong *et al.* (1988) reported that the root amount of hybrids is larger than that of their parents and the roots of hybrids have some characters from their male and female parents in length, diameter developing of lateral and top layer roots.

Vigorous growth of F_1 rice hybrids can be partially attributed to the development and function of the root system. F_1 hybrids surpassed parents in the total root length, root dry weight and total number of root apices (Hasegawa *et al.*, 1993).

2.1.3. Number of root tips

Damoder *et al.* (1978) observed heterosis for root activity in the sorghum hybrid as a result of increased number and improved growth of lateral

root branches. According to Kuzmin and Shumeiko (1985) the best hybrids were obtained when the maternal parent had very little well developed root system particularly in terms of primary root number.

2.1.4. Rooting density

Raj and Siddique (1986) reported that roots of rice hybrids showed appreciable heterosis over the mid parental, better parent and control values and also the hybrids showed the highest heterosis for root density at 0 to 15 to 30 cm depth. Sakai *et al.* (1986) indicated that F_1 hybrids were significantly superior in root pulling force to their parents and check variety.

2.1.5. Cataion exchange capacity (CEC) of roots

Monocotyledons tend to have a lower CEC than dicotyledons (Crooke, 1964). Rao *et al.* (1967) determined CEC for 11 varieties of sugar cane. They found a high correlation (0.87) between CEC of set roots and the mean yield of the cane. Crooke and Knight (1971) reported that each plant species appears to have its own characteristic CEC level, which is independent of location and found correlation between CEC of Leek roots and their yield.

2.2. Histo physiological studies

Electron microscopic studies have provided the evidence that hybrids are characterized to posses highly developed mitochondria, chloroplasts and vascular bundles and other cell Structures than their respective parents.

Sarkissian and Mac Daniel (1967) reported that new types of mitochondria arised by some process of hybridization. Hraska (1978) observed well-developed chloroplasts in wheat, sorghum, sugarcane and maize, which have direct relationship with magnitude of heterosis for grain yield.

Crosbie and Mock (1981) reported that hybrids possess a more highly developed chloroplast structure than their respective parents. One important characteristic of rice shoot is the presence of larger air space connected with culm and leaves by providing air passage system from shoot to root (Yoshida, 1981). He also reported that leaf blade of rice contains many large and small vascular bundles with large airspaces and large air space are found between vascular bundles of the leaf sheath.

2.3. Biochemical characters

The cause of heterosis at molecular level may be closely linked to changes in the enzyme systems or other biochemical characters. Physiological basis of heterosis is concerned with metabolic superiority of the hybrid vigour and the resultant effects on growth, size and other developmental characteristics. Robbins (1952) concluded that favourable combination of biochemical growth was produced as the consequence of conspicuous gene combinations.

Schwartz (1960) investigated the genetic control of an enzyme with esterase activity in maize. This is an example of pathway approach at

biochemical level to understand the cause of genotype –environment interaction. He also observed that heterozygotes form 'hybrid enzymes'.

2.3.1. Chlorophyll

The heterotic hybrids of cotton had higher chlorophyll contents in the leaves than their parents (Azizkhodizhaev *et al.*, 1975). Maize hybrids showed a higher content of chloroplast pigment than that of their parents (Vasev, 1977).

Zhebin (1991) reported that productivity advantage of hybrids depends on the assimilating area of the leaves and interaction between photosynthesis and respiration.

Nemoto *et al.* (1993) conducted a comparative study of the contents of leaf chlorophyll and protein of polished rice in seven low land-up land cross bred rice lines and found that early maturing lines had a higher protein than late maturing lines. Chlorophyll content averaged 4.39 mg/100cm^2 for up land rice and 4.03 mg/100cm^2 for low land-up land crossbred lines.

A comparison of the traditional varieties Ptb4 and Ptb20 with others showed that the highest yield of these two varieties is due to its consistently high chlorophyll content as well as a favourable ratio between the chlorophyll a and chlorophyll b pigments (Bridget et al, 1994). They also reported that the advantages of dwarfness and erect leaves brought about in hybrid derivatives can be off set by the poor development of chlorophyll b pigment in them and

thereby low yield. Higher heterosis for photosynthesis and chlorophyll content was reported by Kim and Lee (1994), which is responsible for higher growth rate and yield of rice hybrids.

There was not much difference in the leaf chlorophyll content, but the chlorophyll a/b ratio were lower in the hybrids and negatively correlated with photosynthetic rate (Geo – Peigeo *et al.*, 1996). Balasubramanian and Ilyas Ahmed (1999) reported that chlorophyll status of flag leaves of the hybrids at flowering was not consistent between the seasons.

2.3.2. Soluble protien

Islam (1983) reported that rice hybrids exhibited lower protein content than their parents but in terms of protein yield/ha or protein yield /day the hybrids showed consistently higher protein yield. Wang-Young Rai (1997) indicated that nutrient application (Nitrogen and potassium) enhanced soluble protein content of flag leaf.

2.3.3. Nitrate reductase activity (NRase)

Hageman *et al.* (1967) showed that nitrate reductase activity was positively correlated with water soluble protein content and negatively with nitrate content. He also reported that the increased NRase activity at harvesting stage is associated with the increased protein content and decreased nitrogen content. Zeng- FuHua (1996) reported that nitrate reductase activities are

higher in non-senescing hybrid than a senescing hybrid before the middle of the ripe stage but the reverse was true after the middle of the stage. He also observed that soluble protein content was higher in non-senescing hybrid than senescing hybrid.

2.3.4. Catalase activity

Catalase activity in hybrid rice from early panicle differentiation to heading was higher than its male parents and also favours photosynthesis and the transmission of assimilates to panicle (Wuhan university, 1977). Catalase is generally considered as H_2O_2 scavenger and H_2O_2 has been reported to be involved in the enhancement of senescence (Choudhari, 1988).

2.3.5. Peroxidase activity

Karve (1980) explained stability in the performance of hybrid on a biochemical basis. He noted that polyphenol oxidase activity was greater in hybrids of safflower than their parents.

2.4. Yield and yield components

2.4.1. Number of productive tillers per plant

Tillers in rice can be either ear bearing or non-ear bearing of which the former is of great economic value. Tillering has been reported to be a polygenic

character (Bhide 1962). According to Ghose *et al.* (1960) genes numbering 3 to 4 in some cases and more than four in others control tillering. Tillering capacity is an important character of a variety and the number of ear bearing tiller is highly related with environmental factors (Asana *et al.*, 1966).

Nijaguna and Mahadevappa (1983) observed both positive and negative heteroitic effects for tiller number varying from –14.36 to 8.4 per cent. Number of tiller per plant was higher in hybrids compared to better parent and check (Dwivedi, 1985).

Generally, 9 to 13 tillers per plant was an ideal range for good varieties (Sharma, 1989). Sathya *et al.* (1999) reported that productive tillers per plant was the principal character responsible for grain yield per plant followed by 100 grain weight, days to 50% flowering, plant height, harvest index as they had positive and significant association with yield.

Ramesh and Singh (1999) reported that reduced tillering generally resulted in larger and heavier panicles with increase in the number of panicle branches, spikelet and grain weight compared to the corresponding tillers in plants with an restricted tillering.

2.4.2. Days to 50 per cent flowering

Genetic variation in the date of ear emergence is found additive, highly heritable and under ploygenic control (Paroda *et al.* 1972). Young and Virmani

(1990) evaluated 70 F_1 s and their reciprocals along with 17 parents over six environments created by growing the experimental material at three nitrogen levels (N0, N60 and N120) and in two season, *viz.* dry (DS) and wet (WS) at IRRI. Hybrids generally flowered earlier than their parents. Out of the experimental hybrids, 90 % were flowered significantly earlier (2 to 35 days) than the highest yielding check included in the trial.

Chauhan *et al.* (1991) reported that the cytosterile lines in general flowered earlier than their respective maintainers. In a field study with 24 rice hybrids (based on IR 58025 A and IR 62829 A) and their respective restorers to identify the initiation of reproductive phase, he found that hybrids yielded better than their parents and the days to flowering was similar or later than their respective restorers.

2.4.3. Days to maturity

Maturity duration (length of growing season) is an important consideration for yield studies. Xu and Wang (1980) found that days to maturity in hybrids depended on the male parent. Ponnuthurai *et al.* (1984) noted hybrid growth duration similar to that of the short duration parent. Narayanan *et al.* (1987) observed that growth period to maturity was reduced by 45, 35 and 20 days in three different cotton hybrids.

Cao-Liyong *et al.* (1997) tested earliness of indica – japonica hybrid rice. Hybrids of five male sterile lines crossed with three wild compatible restorer lines and evaluated for days to heading indicated that crosses with a male sterile type A containing a dominant earlier gene showed a reduced growth period.

2.4.4. Panicle length

A number of rice crosses showed both positive and negative heterosis for panicle length (Paramasivan, 1979; Singh *et al.*, 1980; Srivastava and Seshu, 1982). Sharma (1990) opined that long panicle length was one of the major yield contributing characters and panicle number in turn contributed to high heterosis for grain yield. Wu- Rong-Hou *et al.* (1997) observed that in a yield trial of the hybrid rice panicle length averaged 21.8-24.8 cm and yielded 8.62-9.38 t ha^{-1}.

2.4.5. Grain weight per panicle

The potential size of rice grain is physically restricted by the size of hull and hence the grain weight is a quite stable character. Asana and Bagga (1966) estimated that growth rate per grain vary widely and up to a rate of 2.09 mg day^{-1}. Varietal difference in yields is more likely associated with duration of grain filling (Evans *et al.*, 1975). Selection for increased seed weight and size would be better as it showed high heritability estimates in rice (Ceng, 1997).

2.4.6. Grain yield

Negative heterosis for panicle number per square meter was observed on a number of rice hybrids (Virmani *et al.*; 1982). Roy and Smetanin (1984) attributed the increased grain yield in rice hybrids to more dry matter in the plant and harvest index. Hybrid rice has given a yield advantage of about 20 per cent over pure type varieties (Dikshit *et al.*, 1988). Rangaswamy *et al.* (1988) reported that standard heterosis for grain yield was only 8 %.

Blanco *et al.* (1986) noted 10-20 % superiority of hybrids for total biological yield and grain yield. Rice hybrids showed higher yield potential not only in irrigated conditions but also under some rain fed conditions (Virmani *et al.*, 1991). Efficient sink formation per unit dry matter production in hybrids was reported by Kabaki (1993). Lin-Jy (1994) found that, with the same level of inputs the yield advantage of hybrid rice over the conventional modern varieties is 19 %.

Rangaswamy *et al.* (1994) reported that mean grain yield for hybrid rice CORH-1 at 74 locations *viz.*, in research station, on farm and national rice trial was 5-9 t/ha. Higher yield in rice hybrids was attributed to increased dry matter by Yamuchi (1994).

Soundararaj (1997) observed that the short duration rice hybrid ADRH-4 was found to be promising with a mean grain yield of 6840 kg ha^{-1} and Venkitaswamy (1997) reported that grain yield of MGR hybrid rice CV

CORH-1 ranged from 6-7 t ha^{-1} when a fertilizer dose of (150 kg Nitrogen + 50 kg Potassium) ha^{-1} was applied in four equal splits to 7.37 t when applied in three splits.

Akita *et al.* (1998) observed that F_1 hybrids obtained using cytoplasmically male sterile lines showed improved canopy structure and more effective partitioning of photosynthate to grain at later growth stages.

2.4.7. Straw yield

Chandraratna (1964) reported that the number of grains per panicle had highly significant correlation with yield followed by yield of straw. Rao (1965) recorded that hybrids that gave high grain yield also produced high straw yield. According to Reddy and Nerkar (1992) yield was correlated significantly with straw yield and number of productive tillers.

2.4.8. Harvest index (HI)

Hagemann *et al.* (1967) viewed that crossing parents having high overall photosynthetic efficiency (high biological yield) with parents having high HI (efficient partitioning) maximizes the probability of recombining yield genes to give an optimal balance among the inter acting physiological processes which will give economic yield.

Morphological characters associated with high yield potential were short, small, thick and erect leaves, short and thick culms, tight leaf sheaths

upright and compact tillers, high tillering ability, high fertility of spikelets at high nitrogen rates and high harvest index (Yoshida *et al.*, 1972).

Though genetic control of HI in an important aspect of differential partitioning of photosynthates, little information is available in the pattern of variation of this attribute in the segregating population following a cross (Gupta, 1992).

2.5. Nutrient uptake studies

Emergence and development of tiller primordia are greatly influenced by such factors nitrogen supply, solar radiation and temperature. Hageman *et al.* (1967) reported that maize hybrid HY 2 X OH-7 consistently out yielded the parents through efficient Nitrogen metabolism. Phosphorus level also closely related with tillering.

A rice crop takes up more than 90% of the total nitrogen required for an average yield before the heading stage is reached (Inada, 1967).

Concentration of Nitrogen above 3.5% is necessary for active tillering at 2.5% tillering stops, and below 1.5% decline of tiller takes place (Ishizuka and Tanaka, 1963). Quantitatively Nitrogen required for vegetative growth is far more than that required for reproductive development. Maranville *et al.*, (1977) was of the opinion that lower average tissue concentration of the nutrients and their efficiency is not to be explained by high rate of nutrient uptake.

Concentration of elements is one of the appropriate and variable parameters for estimating genetic specificity of mineral nutrition for combined yield advantage in F_1 hybrids (Clark *et al.*, 1988). Dubey and Bisen (1989) reported that higher Nitrogen content at early stages of growth was due to greater cell division and rapid accumulation of protein up to panicle primordial stage. Decrease in Nitrogen content after 30 DAT might be due to reduced root activity and the dilution effect arising from greater dry matter accumulation.

Huang-Jz *et al.* (1991) observed that the potassium content in the leaves of rice seedlings was positively correlated with net photosynthetic effect. Uptake of potassium was greatest in rice hybrids but heterosis was greatest for nitrate- Nitrogen up take (Ichii *et al.*, 1990).

Song Sung Quan *et al.* (1996) reported that Calcium increased effective panicle number, filled grain number per panicle, 100 grain weight and grain yield. Wang-Young Rai *et al.* (1997) observed that application of Nitrogen and Potassium to rice hybrids at the start of panicle emergence increased the flag leaf, chlorophyll contents, photosynthetic rate, peroxidase and nitrate reductase but decreased flag leaf respiration at heading, milky and dough stages.

Effects of Ca^{2+} on senescence in detached leaves of hybrid rice were studied using the contents of chlorophyll and soluble protein as the physiological indexes by Duan- Young xin *et al.*, 1998. It was found that Ca^{2+}

slows down the loss of chlorophyll and soluble protein and increase the activity of catalase.

Fu-Qing-Lin *et al.* (1999) observed that leaf, culm, and root nitrogen concentration are highest during tillering in hybrid rice and the nitrogen concentration in these organs declined thereafter till maturity.

Takita (1999) observed that grain and total yields from *japonica indicia* rice hybrid in different doses of nitrogen application are high compared to other inbreds.

Higher specific activity of Rubisco was associated with relatively lower content of the enzyme, which in turn was associated with improved Nitrogen use efficiency in rice (Debabrate Ray *et al.*, 2000).

MATERIALS AND METHODS

MATERIALS AND METHODS

The present study was conducted in the Department of Plant Breeding and Genetics, College of Horticulture, Vellanikara, during the period 2000-2001. The field experiment was laid out at Agricultural Research Station, Mannuthy of Kerala Agricultural University during second crop season of 2000-2001. The Agricultural Research Station, Mannuthy is located at 10°31'N latitude and 76° 13' E longitudes and at an altitude of 40.29 m above mean sea level. It is situated about six km east of Thrissur on the southern side of Thrissur-Palakkad National Highway Number-47. The soil is laterite loam. The experiment materials (Table 1) for the study comprised of three rice hybrids and their respective parents collected from Tamil Nadu Agricultural University (Plate 1, 2 & 3).

The experiment was conducted using Randomised Block Design with eight treatments replicated thrice. Fertilizers were given as per the recommended dose.

The details of the observations recorded from the investigation are furnished under the following headings.

1. Plant characters
2. Histo physiological studies
3. Biochemical characters
4. Yield and yield components
5. Nutrient uptake studies.

Table 1. Details of materials used in the experiment

HYBRIDS	PARENTAGE	Duration (Days)	YEAR OF RELASE
CORH-1	IR-62829-A / IR-10198-66-2R	110-115	1994
CORH-2	IR-58025-A / C-20-R	120-125	1998
ADTRH-1	IR-58025-A/ IR-66-R	110-115	1998

Plate1.Hybrid CORH-1 and its parents

Plate2.Hybrid CORH-2 and its parents

Plate3.Hybrid ADTRH-1 and its parents

3. 1. Plant characters

a. Plant height

The plant height in centimeters was recorded at tillering, panicle initiation, and maturity stages.

b. Root length

Length of root from the base to the tip was measured for six plants from each plot at tillering, panicle initiation and harvesting stages and the average was worked out.

c. Number of root tips

Number of root tips was counted from six plants at tillering panicle initiation and harvesting stages and the average was worked out.

d. Rooting density

Rooting density during tillering, panicle initiation and harvesting stages were calculated using the formula given below

$$\text{Rooting density} = \frac{\text{Length of root (cm)}}{\text{Unit volume of the soil (cm}^3\text{)}}$$

e. Cation Exchange Capacity of root (CEC)

Cation Exchange Capacity of root during tillering, panicle initiation and harvesting stage were estimated in Milliequivalents Hundred gram^{-1} using the standard procedure suggested by Crooke (1964).

3. 2. Histo physiological studies

a. Root

Transverse sections were taken from the roots of hybrids and their respective parents. Sections were then made permanent following the procedure described by Prasad and Krishnaprasad (1970). Sections were stained and counter stained for five minutes in one per cent aqueous saffranine solution and washed in distilled water until excess stain was removed. They were dehydrated by passing through graded concentration of alcohol. The sections were then counter stained with light green SF in clove oil (1:1) for two minutes, washed in clove oil, passed through xylene and mounted in Canadabalsam.

b. Culm

Transverse sections were taken from mature culms and made permanent following the procedure described by Prasad and Krishna Prasad (1970).

c. Leaf sheath

Transverse sections were taken from the flag leaf sheath of mature plants and made permanent following the procedure described by Prasad and Krishna Prasad (1970)

d. Leaf blade

Transverse sections were taken from the flag leaf blade of mature plants and made permanent following the procedure described by Prasad and Krishna Prasad (1970).

3.3. Biochemical characters

a. Chlorophyll

Total Chlorophyll, chlorophyll and Chlorophyll b during active tillering, panicle initiation, and harvesting stage were estimated in milligram g^{-1} fresh tissue using the method suggested by Shoaf and Lium (1976) and given by the formulae.

$$\text{Total chlorophyll} = 2.8\ (OD\ 652) \times \frac{V}{W \times 100}\ (mg/g)$$

$$\text{Chlorophyll a} = 12.7\ (OD663) - 2.69\ (OD645) \times \frac{V}{W \times 100}$$

$$\text{Chlorophyll b} = 22.9(OD645) - 4.68(OD663) \times \frac{V}{W \times 100}$$

Where OD 652 is absorbance at 652 wave length.

OD663 is absorbance at 663 wave length

OD645 is absorbance at 645 wave length

V = volume, W = weight of the sample

b. Soluble protein

Soluble protein during tillering, panicle initiation and harvesting stages were estimated in milligram gram^{-1} fresh tissue using the method suggested by Lowry et *al.* (1951).

c. Nitrate reductase activity (NRase)

Nitrate reductase activity during tillering, panicle initiation, and harvesting stages were estimated in micromole nitrite produced min-1 mg-1 proton using the standard procedure suggested by Hageman *et al.* (1980).

d. Catalase activity

Catalase enzyme activity during tillering, panicle initiation and harvesting stages were estimated as enzyme activity units ml extract^{-1} using the standard procedure suggested by Sadasivam and Manickam(1992).

e. Peroxidase activity

Peroxidase enzyme activity during tillering, panicle initiation and harvesting stages were estimated as enzyme activity units l^{-1} using the standard procedure described by Sadasivam and Manickam (1992).

3.4. Yield and yield components

a. Number of productive tillers plant

The number of productive tillers were counted from six hills and the average expressed as number of productive tillers per plant

b. Days to 50 per cent flowering

Approximate number of days taken for 50 per cent flowering in each genotypes, were recorded.

c. Days to maturity

Number of days was counted from sowing to maturity of the crop.

d. Panicle length

The length of main panicle was measured in centimeters from the panicle base to the tip of the top most spikelet.

e. Grain weight panicle^{-1}

Weight of grains was taken for six panicle from each hill using electronic balance and the average was expressed as grain weight panicle^{-1}.

f. Grain yield

Grains harvested from each net plot were collected, winnowed and the weight was recorded.

g. Straw yield

Straw from each net plot was collected and the weight was recorded.

h. Harvest Index (HI)

The proportion of economic yield was represented over biological yield, using the formula (Donald and Hamblin, 1976)

$$\text{Harvest Index} = \frac{\text{Economic yield}}{\text{Economic yield} + \text{Biological yield}}$$

3.5. Nutrient uptake studies

For chemical analysis, three hills were selected at random from each plot. Plant samples were collected at different growth stages (Tillering, panicle initiation, and harvesting), dried in a hot air oven at 60 ± 5°C, powdered well and analysed for different nutrient contents (N, P, K, Ca, Mg, S, Fe, Mn and Zn). The methods used for the analysis of different nutrients are given in the Table 2.

3.6. Statistical analysis

The data were subjected to following statistical analysis

1. Analysis of variance

Data relating to different characters were analysed statistically by applying the technique of analysis of variance and treatment comparison was made by Duncan's Multiple Range Test.

Table 2. Methods used for plant nutrient analysis

Sl no	Nutrient	Method	Reference
1	Nitrogen	Microkjeldhal digestion and distillation method	Jackson, 1958
2	Phosphorus	Vanadomolybdo phosphoric yellow colour method using spectronic 20	"
3	Potassium	Diacid extract using flame photometer	"
4	Calcium	Diacid extract and direct iteration with EDTA	Hesse, 1971
5	Magnesium	Diacid extract and direct iteration with EDTA	Hesse, 1971
6	Sulphur	Turbido metric method using spectronic 20	Jackcon, 1958
7	Iron	Diacid extract using atomic absorption spectrophotometer	Jackson, 1958
8	Manganese	Diacid extract using atomic absorption spectrophotometer	Jackson, 1958
9	Zinc	Diacid extract using atomic absorption spectro photometer	Hart, 1961

RESULTS

RESULTS

4.1. Plant Characters

4.1.1. Plant height (cm)

The mean data on plant height recorded at various stages of growth of hybrids and parents are given in Table 3.

Analysis of variance for plant height showed significant difference among genotypes for the character. Among the three stages of growth, plant height was maximum at harvesting stage, which includes the panicle length also. Among the hybrids CORH-2 recorded a maximum plant height of 92.33 cm at harvesting stage. These was a significant increase when compared to one of its parents IR-58025 A that recorded a height of 56.33; 83.33 cm and 86cm at the three growth stages (viz; tillering, panicle initiation and harvesting).

Hybrid CORH-1and its parental genotypes did not differ significantly in plant height at tillering and harvesting stages. At panicle initiation stage the hybrid showed (68.67 cm) significant difference in plant height with the parent IR-10198-66-2R (74 cm), where as it was as on par with the other parent IR-62829-A (71.67 cm). Though plant height differed significantly at tillering stage for hybrid ADTRH-1 (68.33cm) with its parent IR-66-R (52.67 cm) and IR 580.25-A (56.33cm), at harvest stage both hybrid and parents did not differ significantly in plant height (ADTRH-1 - 86.33 cm; IR-66-R - 83 cm; IR-58025A - 86 cm). The hybrid CORH-1 showed 43% increase in plant height at

panicle initiation stage than at tillering stage and 11.2%increase at harvesting stage than at panicle initiation stage. But its parental genotypes IR-62829-A and IR-10198-66-2R showed 43 % and 36.9 % at panicle initiation stage, 0.46% and 2.7 % at harvesting stage respectively.

The hybrid ADTRH-1and one of its parental genotype IR-66-R showed an increase of 54.4 % at panicle initiation stage from the tillering stage. The hybrid CORH-2 revealed a lesser percentage increase of 21.7 % in plant height compared to parental genotypes IR-58025-A (48 %), C-20-R (27.4 %) at panicle initiation stage than at tillering stage. From panicle initiation stage to harvesting stage it was found increased to 17.87 % in the same hybrid, while in the parents it was 3.20 and 22.78 percentage respectively.

4.1.2. Root length (cm)

The mean data on root length are given in Table 4. Analysis of variance for root characters also showed a significant difference among genotypes for the character.

Root length which was maximum at tillering stage, declined during panicle initiation stage and then increased at harvesting stage for all hybrids except CORH-1. In CORH-1 root length increased 30% at panicle initiation stage than at tillering stage and this was maintained at harvesting stage also. In hybrid CORH-2 highest root length at tillering was 10.33 cm, which decreased to 8cm during panicle initiation and then increased to 9 cm at harvesting stage. In ADTRH-1, it was 18.33cm; 8.67cm; and 10.67cm in the respective stages.

Table 3. Mean plant height (cm) at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	48.00^{d}	68.67^{f}	76.33^{ef}
IR-62829-A	52.33^{cd}	71.67^{ef}	72.00^{f}
IR-10198-66-2R	50.67^{cd}	74.00^{de}	76.00^{ef}
CORH-2	64.33^{a}	78.33^{cd}	92.33^{ab}
IR-58025-A	56.33^{bc}	83.33^{abc}	86.00^{bcd}
C-20-R	62.00^{ab}	79.00^{bcd}	97.00^{a}
ADTRH-1	68.33^{a}	86.00^{a}	86.33^{bcd}
IR-66-R	52.67^{cd}	81.33^{abc}	83.00^{cde}

Treatments having common letter in a column do not differ significantly

Table 4. Mean root length (cm) at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	9.33^{c}	12.33^{a}	12.33^{a}
IR-62829-A	12.00^{b}	7.33^{cd}	7.67^{b}
IR-10198-66-2R	6.67^{d}	7.33^{cd}	10.67^{ab}
CORH-2	10.33^{bc}	8.00^{bcd}	9.00^{ab}
IR-58025-A	10.00^{c}	5.67^{d}	9.67^{ab}
C-20-R	10.67^{bc}	8.67^{abcd}	12.00^{a}
ADTRH-1	18.33^{a}	8.67^{abcd}	10.67^{ab}
IR-66-R	10.33^{bc}	9.33^{ab}	10.33^{ab}

Treatments having common letter in a column do not differ significantly

Regarding the parental genotype of CORH-2, maximum root length was observed at harvesting stage for C-20-R (12 cm) where as in IR-58025 growth pattern was similar to the hybrid (i.e. 10 cm; 5.67 cm; 9.67 cm at tillering, panicle initiation and harvesting stage respectively).

When the plant growth changed from tillering to panicle initiation stage, the hybrid ADTRH-1 showed 52.7 % decrease in root length where as from panicle initiation to harvesting stage there was 23.06 % increase in root length. At the same time its parental genotype IR-58025-A showed 43.3 % decrease and 70.5% increase in the above phenophases of growth. The value for root length of the other parent viz; IR-66-R was 9.6% decrease and 10.7%, increase at respective stages.

4.1.3. Number of root tips

The mean data on number of root tips (Table 5) revealed a maximum number of roots at harvesting stage. Among the three hybrids CORH-1 (205.33) registered the highest number followed by CORH-2 (119.67) and ADTRH-1 (91.33). Number of root tips observed at three stages were 101; 179 and 197 .33 for IR-62829-A and 124.67; 180.33, and 203.67 for IR-10198-66-2R, which were the parental genotypes of CORH-1.

Table 5. Mean number of root tips at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	81.67^{c}	198.33^{a}	205.33^{a}
IR-62829-A	101.00^{b}	179.00^{b}	197.33^{a}
IR-10198-66-2R	124.67^{a}	180.33^{b}	203.67^{a}
CORH-2	107.00^{b}	110.33^{c}	119.67^{ab}
IR-58025-A	130.33^{a}	110.00^{c}	121.33^{b}
C-20-R	78.33^{c}	95.67^{d}	97.33^{bc}
ADTRH-1	83.33^{c}	89.33^{d}	91.33^{bc}
IR-66-R	80.33^{c}	85.33^{d}	83.00^{c}

Treatments having common letter in a column do not differ significantly

In the case of hybrid ADTRH-1 there was no significant difference between the hybrid and one of its parental genotype IR-66-R at all the three stages of growth. Number of root tips for parental genotypes of CORH-2 ranged from 78.33 to 130.33 at tillering, 95.67 to 110 at panicle initiation and 97.33 to 121.33 at harvesting stages.

Number of root tips increased to 143 % at panicle initiation and 3.5 % at harvesting stage for hybrid CORH-1. Where as its parental genotypes IR-62829-A and IR-10198-66-2R showed 77.2 %; 44.6 % increase at panicle initiation stage and 10.2 %; 12.9 % at harvesting stage.

IR-58025-A, one of the parental genotype of ADTRH-1, showed 15.5 % reduction in number of root tips at panicle initiation stage and 10.3 % increase at harvesting stage. In contrast to this hybrid ADTRH-1 and IR-66-R sighted an increase in number of root tips (7.2 %; 6.2 %) at panicle initiation than at tillering stage.

4.1.4. Rooting density

The mean data on rooting density at various stages of growth of hybrids and parental genotypes are given in Table 6. Analysis of variance for rooting density did not show any significant difference among genotypes for the character during phenophases like panicle initiation and harvesting. Among the genotypes the character showed significant difference during tillering stage only.

Table 6. Mean rooting density at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	0.30[ab]	0.30[a]	0.40[a]
IR-62829-A	0.10[b]	0.20[a]	0.30[a]
IR-10198-66-2R	0.20[ab]	0.20[a]	0.20[a]
CORH-2	0.30[a]	0.30[a]	0.20[a]
IR-58025-A	0.10[ab]	0.20[a]	0.20[a]
C-20-R	0.10[ab]	0.20[a]	0.20[a]
ADTRH-1	0.30[a]	0.30[a]	0.20[a]
IR-66-R	0.20[ab]	0.20[a]	0.30[a]

Treatments having common letter in a column do not differ significantly

All the three hybrids showed the same value 0.30 during tillering and panicle initiation for rooting density but at harvesting stage. CORH-1 recorded the highest value of 0.40 and the other two hybrids CORH-2 and ADTRH-1 recorded a value of 0.20. Rooting density was found decreased to 33.3 % at harvesting stage in CORH-2 and ADTRH-1, but increased to 33.3 % in CORH-1 at the same stage

Both the two stages *viz.* tillering and panicle initiation, the parental genotypes of the three hybrids (CORH-1, CORH-2 and ADTRH-1) recorded a lower value compared to their combinations. Two hybrids CORH-2 and ADTRH-1 gave a lower value (0.20; 0.20) during harvesting stage compared to their values at tillering (0.30; 0.30) and panicle initiation stage (0.30; 0.30). *The hybrid CORH-1 showed higher value (0.40) during harvesting stage* compared to the values at panicle initiation and harvesting stage.

Parental genotypes of three hybrids did not reveal any significant difference in rooting density during tillering and panicle initiation.

4.1.5. Cation Exchange Capacity of root (CEC) (meq g^{-1})

The analysis of variance indicated significant differences among genotypes for Cation Exchange Capacity (CEC) of root as given in the Table 7. In general, CEC was found to be higher at harvesting stage for hybrids and genotypes except CORH-2.

Table 7. Mean cation exchange capacity of root (CEC in meq g^{-1}) at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	9.96^{c}	14.76^{cd}	17.38^{d}
IR-62829-A	13.31^{a}	20.00^{ab}	22.64^{b}
IR-10198-66-2R	12.77^{a}	20.73^{ab}	21.45^{bc}
CORH-2	11.97^{ab}	19.05^{b}	18.45^{cd}
IR-58025-A	12.95^{a}	21.51^{a}	25.75^{a}
C-20-R	13.67^{a}	15.16^{cd}	16.68^{d}
ADTRH-1	9.29^{c}	13.55^{d}	16.42^{d}
IR-66-R	12.67^{a}	16.04^{c}	21.02^{bc}

Treatments having common letter in a column do not differ significantly.

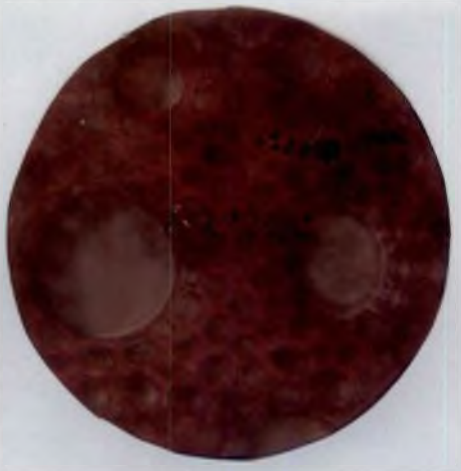
Hybrid CORH-2 showed highest value for CEC of root as 11.99; 19.05 and 18.45 meq g^{-1} during tillering, panicle initiation and harvesting stage respectively than the other two hybrids CORH-1 and ADTRH-1 at the same stages.

Parental genotypes of CORH-1 did not show any significant difference in CEC at all the three stages of growth (viz, tillering, panicle initiation and harvesting stages). The same trend was observed for parental genotypes of CORH-2 and ADTRH-1 during tillering stage. CEC of roots showed an increase of 54.3 % at panicle initiation stage and 18 % at harvesting stage in hybrid CORH-1.Where as its parental genotypes (IR-62829-A and IR-10198-66-2R) registered an increase of 50.2 % and 62.3 % at panicle initiation stage than at tillering stage, 13.2 % and 3.5 % at harvesting stage than at panicle initiation stage.

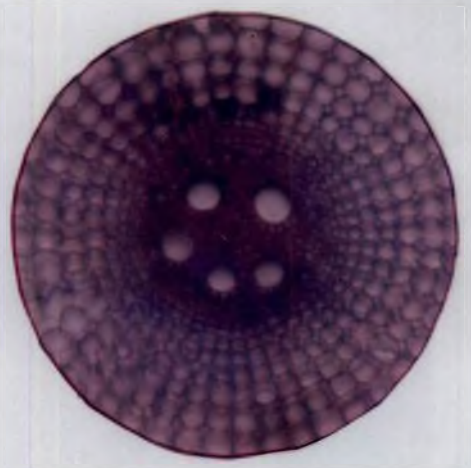
A very highly significant difference was showed by parental genotypes of CORH-2 for CEC of root during panicle initiation and harvesting stage. It was interesting to observe that all the hybrids recorded a low value of CEC at tillering stage when compared to their respective parental genotypes.

4.2. Histo physiological studies

Histo physiological observations on root, stem and leaf sheath of hybrids and their respective parents were made and given in Plates 4, 5 & 6.



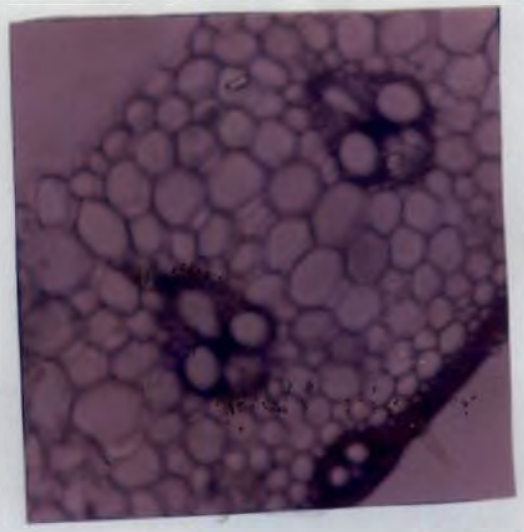
CORH-1



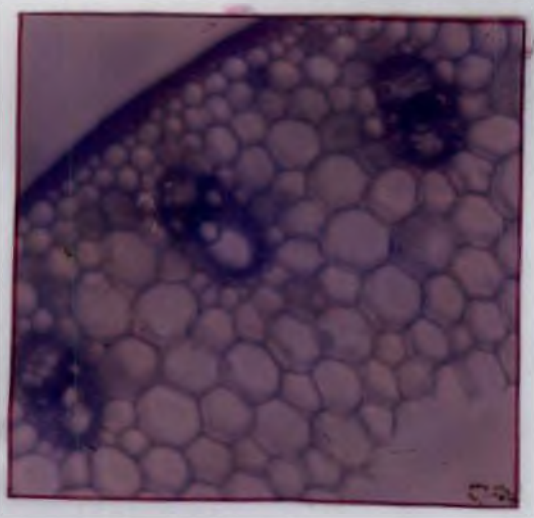
CORH-2

ADTRH-1

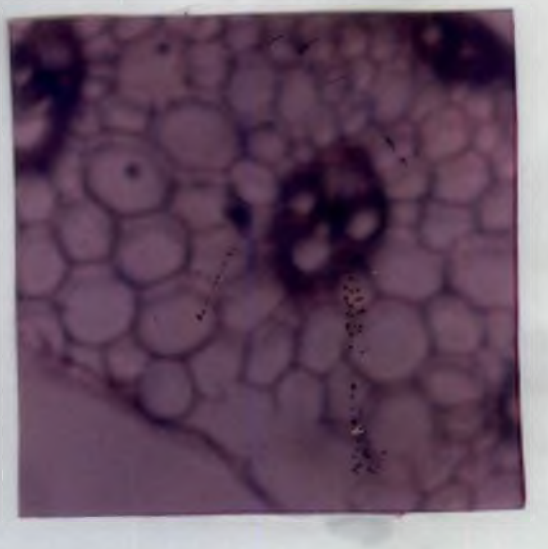
Plate4.Root anatomy of hybrids



CORH-1

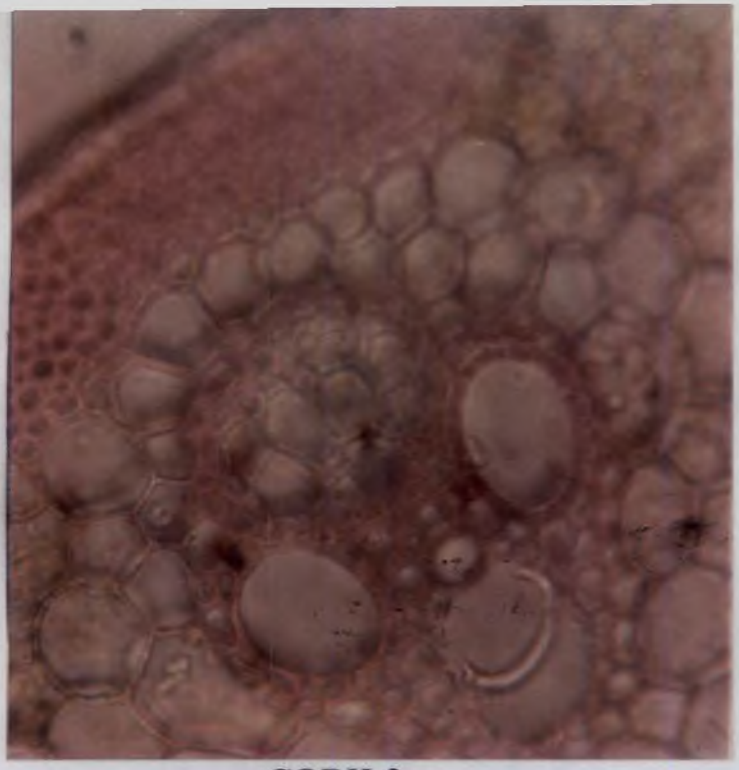


CORH-2

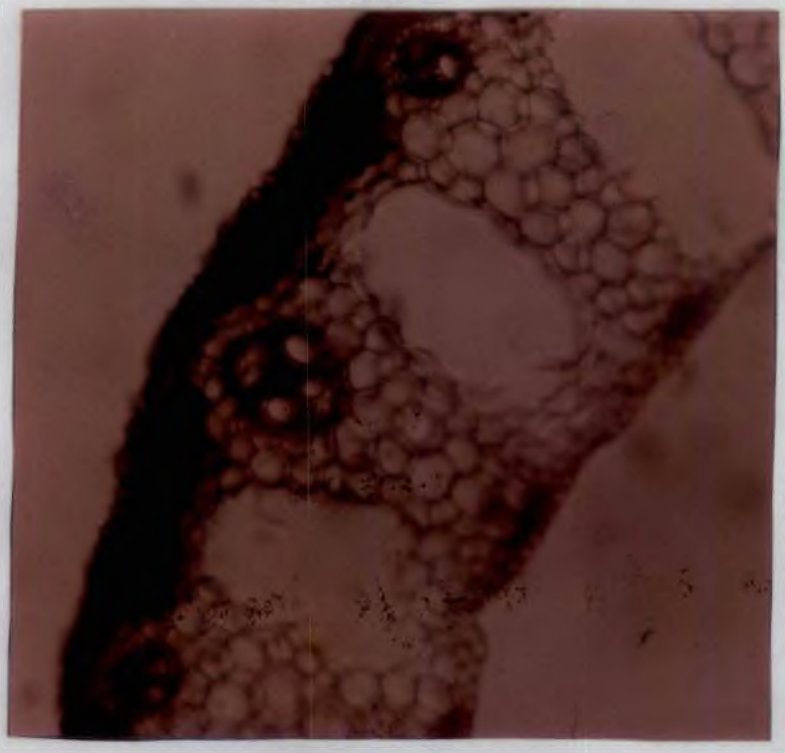


ADTRH-1

Plate5.Stem anatomy of hybrids



CORH-2



ADTRH-1

Plate 6. Leaf sheath anatomy of hybrids

The hybrids and parents expressed some significant variation on structural aspects especially in vascular bundles in root, stem and leaf sheath. The xylem and phloem of roots, which are arranged alternately and not in bundles, were seen well developed in CORH-2 and ADTRH-1 than the other hybrid CORH-1. In general stem vascular bundles were seen arranged in two rows, as smaller ones near epidermis and bigger ones towards central portion. The hybrid and parents differed significantly in the number of smaller and bigger vascular bundles. The bigger vascular bundles ranged from 6-7 in hybrid CORH-2 and ADTRH-1 where as it was in the range of 4-5 in CORH-1.Similarly the number of smaller bundles ranged from 5-6 in CORH-2 and ADTRH-1 while it was only 3-4 in CORH-1.

Leaf sheath showed another general pattern for the arrangement of vascular bundles as larger ones and smaller ones alternate in the same row. Here also CORH-2 and ADTRH-1 had 1-3 smaller and 2-5 bigger vascular bundles in leaf sheath when compared to their hybrids.

4.3. Biochemical characters

4.3.1 Chlorophyll content (mg g^{-1} fresh tissue)

The mean data presented in the Table 8a showed that significant difference was present for total chlorophyll content among the genotypes. Total

chlorophyll content was low at tillering stage and progressively increased to harvesting stage in all genotypes observed.

ADTRH-1 recorded the highest total chlorophyll content (5.50 mg g^{-1} fresh tissue) at panicle initiation stage where as other hybrids CORH-1 and CORH-2 recorded a value of 4.94 and 4.24 mg g^{-1} fresh tissue respectively at the same stage.

The parental genotypes of CORH-1 and CORH-2 did not show any significant difference in total chlorophyll content at tillering and harvesting stage, but significant difference was observed during panicle initiation stage.

Hybrid CORH-1 and CORH-2 could maintain the highest chlorophyll content at panicle initiation (4.94 and 4.24 mg g^{-1} fresh tissue) and harvesting stage (4.93 and 4.27 mg g^{-1} fresh tissue). But ADTRH-1 showed an 8.36 per cent reduction in total chlorophyll content at harvesting stage.

The chlorophyll a content significantly differed among genotypes as given in Table 8b at panicle initiation and harvesting stages. At tillering stage chlorophyll a was very low for all genotypes ranging from 0.1 to 0.12 mg g^{-1} fresh tissue. Hybrid CORH-1 showed an increase of 1.5 % chlorophyll a content at harvesting stage than at panicle initiation stage where as CORH – 2 and ADTRH – 1 showed a decrease of 8 % and 2.1 % at harvesting stage than at panicle initiation stage.

Table 8a. Mean total chlorophyll content (mg g^{-1} fresh tissue) at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	0.68^{ab}	4.94^{c}	4.93^{ab}
IR-62829-A	0.57^{b}	3.16^{e}	3.35^{cd}
IR-10198-66-2R	0.71^{ab}	5.62^{a}	4.06^{bcd}
CORH-2	0.61^{b}	4.24^{d}	4.27^{bc}
IR-58025-A	0.59^{b}	4.05^{d}	4.05^{bcd}
C-20-R	0.68^{ab}	5.05^{bc}	5.05^{ab}
ADTRH-1	0.65^{ab}	5.50^{ab}	5.04^{ab}
IR-66-R	0.64^{ab}	5.43^{abc}	5.43^{a}

Treatments having common letter in a column do not differ significantly

Table 8b. Mean chlorophyll a content (mg g^{-1} fresh tissue) at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	0.10^{a}	3.21^{a}	3.26^{a}
IR-62829-A	0.10^{a}	2.91^{abc}	3.20^{ab}
IR-10198-66-2R	0.10^{a}	2.69^{bc}	3.12^{ab}
CORH-2	0.10^{a}	3.10^{ab}	2.85^{c}
IR-58025-A	0.11^{a}	3.02^{abc}	3.15^{ab}
C-20-R	0.12^{a}	3.25^{ab}	3.13^{ab}
ADTRH-1	0.11^{a}	3.24^{ab}	3.17^{ab}
IR-66-R	0.11^{a}	3.26^{a}	2.54^{d}

Treatments having common letter in a column do not differ significantly

The shift from tillering to panicle initiation stage showed a remarkably high increase in chlorophyll a content in all hybrids and their respective parents, which was about 27-32 times more when compared to tillering stage.

The mean data presented in the Table 8c showed that significant difference among genotypes for total chlorophyll b was observed during tillering and harvesting stage. Hybrids CORH-1 and ADTRH-1 showed (1.86; 1.88; mg g^{-1} fresh tissue.) a comparatively higher value than that of CORH-2 (1.17 mg g^{-1} fresh tissue) during harvesting stage.

No significant difference was noted for chlorophyll b content among the hybrid CORH-1 and its parental genotypes during the three stages of growth *viz.* tillering, panicle initiation and harvesting. At the same time hybrid CORH-2 significantly differed from one of its parent C-20-R in chlorophyll b content (2.79 mg g^{-1} fresh tissue). The chlorophyll b content registered a low value in CORH-2 when compared to its parents. The hybrid ADTRH-1 though not significantly different from its parents, recorded the highest value for chlorophyll b than its parents.

Chlorophyll a/b ratio worked out for different hybrids and their parental genotypes showed that (Table 8d) it was not significantly different at tillering stage but at harvesting stage significant variation was observed and the maximum value was recorded by CORH-2 (2.52), followed by ADTRH-1 (1.77) and CORH-1 (1.29).

Table 8c. Mean chlorophyll content b (mg g^{-1} fresh tissue) at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	0.68^{a}	0.32^{a} (1.14)	1.86^{b}
IR-62829-A	0.47^{ab}	0.39^{a} (1.48)	1.08^{bc}
IR-10198-66-2R	0.61^{ab}	0.32^{a} (1.11)	1.42^{bc}
CORH-2	0.66^{a}	0.34^{a} (1.20)	1.17^{bc}
IR-58025-A	0.41^{b}	0.31^{a} (1.03)	1.65^{b}
C-20-R	0.62^{ab}	0.40^{a} (1.51)	2.79^{a}
ADTRH-1	0.58^{ab}	0.40^{a} (1.49)	1.88^{b}
IR-66-R	0.63^{a}	0.43^{a} (1.71)	0.64^{c}

Treatments having common letter in a column do not differ significantly. At panicle initiation stage logarithmic transformation was made and the original values are given in parenthesis

Table 8d. Mean chlorophyll a/b ratio at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	.12^{b}	2.35^{bcd}	1.29^{d}
IR-62829-A	0.21^{ab}	1.67^{e}	3.27^{b}
IR-10198-66-2R	0.16^{b}	2.43^{bcd}	2.41^{bc}
CORH-2	0.15^{b}	2.61^{bc}	2.52^{bc}
IR-58025-A	0.28^{a}	2.85^{b}	1.95^{cd}
C-20-R	0.20^{ab}	2.14^{cde}	1.14^{d}
ADTRH-1	0.17^{b}	2.22^{cd}	1.77^{cd}
IR-66-R	0.18^{ab}	1.91^{de}	4.51^{a}

Treatments having common letter in a column do not differ significantly.

4.3.2. Soluble protein content (mg g^{-1} fresh tissue)

Mean data on soluble protein content (Table 9) revealed that CORH-2 and ADTRH-1 had a maximum value at tillering stage which subsequently reduced towards harvesting stage. Where as the hybrid CORH-1 exhibited a reverse trend with maximum soluble protein at panicle initiation stage and harvesting stage (6.77 mg g^{-1} fresh tissue) and minimum at tillering stage (3.55 mg g^{-1} fresh tissue).

There was no significant difference in soluble protein content of CORH-1 and ADTRH-1 during panicle initiation stage and harvesting stage (6.67 mg g^{-1} fresh tissue) soluble protein content recorded by CORH-2 were (10.23; 2.11; 2.12 mg g^{-1} fresh tissue) during tillering, panicle initiation and harvesting stage respectively. It showed a 79 % reduction in soluble protein content from tillering to panicle initiation stage, which was 26.46 % in the hybrid ADTRH-1. But the hybrid CORH-1 recorded an extra ordinary increase of 90.70 % in soluble protein at the above stages.

No significant difference was noticed for parental genotypes and hybrid CORH-1 during tillering stage for soluble protein content, but during panicle initiation and harvesting stage a high significant difference among parent and hybrids was noticed for the save biochemical character. Soluble protein content observed at three stages of growth *i.e.*, tillering, panicle initiation,

harvesting were 2.56; 11.75; 13.58 mg g^{-1} fresh tissue for IR-62829 A; 4.99; 8.02; 13.56 mg g^{-1} fresh tissue fur IR-10198-66-2R.

4.3.3. Nitrate reductase activity(micromole nitrate produced g^{-1} fresh tissue hr^{-1})

Mean data on Nitrate reductase activity is given in Table 10. Nitrate reductase activity among genotypes shown that, its activity was high during harvesting stage and exhibited the same pattern of increase from tillering to harvesting stage. Among hybrids CORH-2 revealed high nitrate reductase activity in all the three stages of growth (202.56; 1564.61; 3845.75 micromole nitrite produced g-1 fresh tissue hr^{-1}).

The nitrate reductase activity showed a remarkably significant difference among CORH-1 and its parental genotypes at tillering and harvesting stage, but no significant difference was noticed between the parental genotypes during the above stages (during tillering stage IR-62829-A - 258.96; IR-10198-66-2R - 253.98 micro mole nitrite produced g^{-1} fresh tissue hr^{-1} and during harvesting stage IR-62829-A - 2668.72; IR-10198-66-2R-2998-51 micromole nitrate produced g^{-1} fresh tissue hr^{-1}).

Table 9. Mean soluble protein content (mg g^{-1} fresh tissue) at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	3.55^{b}	6.77^{bc}	6.77^{bc}
IR-62829-A	2.56^{b}	11.75^{a}	13.58^{a}
IR-10198-66-2R	4.99^{b}	8.02^{b}	13.56^{a}
CORH-2	10.23^{a}	2.11^{e}	2.12^{d}
IR-58025-A	9.11^{a}	2.75^{cd}	8.17^{b}
C-20-R	4.70^{b}	5.87^{cd}	5.88^{bc}
ADTRH-1	9.07^{a}	6.67^{bc}	6.67^{bc}
IR-66-R	4.25^{b}	8.44^{b}	8.44^{b}

Treatments having common letter in a column do not differ significantly

Table 10. Mean nitrate reductase activity (micro mole nitrite produced g^{-1} fresh tissue hr^{-1})

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	143.31^{c}	3.154^{ab} (1425.05)	3827.96^{b}
IR-62829-A	258.96^{a}	2.85^{bcd} (704.39)	2668.72^{c}
IR-10198-66-2R	253.98^{a}	2.77^{cd} (582.66)	2998.51^{c}
CORH-2	202.52^{b}	3.15^{ab} (1564.61)	3845.75^{b}
IR-58025-A	249.00^{a}	2.94^{bcd} (865.97)	3626.55^{bc}
C-20-R	139.55^{c}	3.20^{ab} (1595.81)	4313.79^{a}
ADTRH-1	195.32^{b}	2.35^{e} (221.33)	2718.52^{c}
IR-66-R	98.49^{d}	2.580^{de} (379.03)	7649.79^{b}

Treatments having common letter in a column do not differ significantly. At panicle initiation stage logarithmic transformation was made and the original values are given in parenthesis.

4.3.4. Catalase activity (units ml^{-1} extract)

Data pertaining to Catalase activity at tillering, panicle initiation and harvesting stage are presented in Table 11. It was evident from the data that all the genotypes had a significantly remarkable catalase activity at tillering stage that was reduced at panicle initiation and harvesting stages. All the genotypes registered a progressive decrease in the activity of catalase enzyme from tillering to harvesting stage. CORH-2 recorded a 2.8 times more catalase activity than ADTRH-1 and 1.9 times more than CORH-1 at tillering stage.

High catalase activity during harvesting stage was found in ADTRH-1 (1007 units ml^{-1} extract), though its value was noticeably less in its parental genotypes. There was no significant difference among the hybrids CORH-1 and CORH-2 for catalase activity during panicle initiation and harvesting stage.

During tillering stage CORH-1 and its parents IR-62829-A and IR 10198-66-2R showed a catalase enzyme activity of 9500, 2166.67, 3833.33 units ml^{-1} extract respectively. But there was no significant difference between CORH-1 hybrid and its two parental genotypes during panicle initiation and harvesting stage for the enzyme activity.

Table 11. Mean catalase activity (units ml^{-1}extract) at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	9500.00^{b}	1218.33^{ab}	803.33^{b}
IR-62829-A	2166.67^{e}	1187.00^{ab}	832.67^{b}
IR-10198-66-2R	3833.33^{de}	1160.00^{ab}	798.00^{b}
CORH-2	18333.33^{a}	1254.33^{a}	824.00^{b}
IR-58025-A	10166.67^{b}	1218.33^{ab}	983.33^{a}
C-20-R	5000.00^{cd}	1160.00^{ab}	736.67^{b}
ADTRH-1	6500.00^{c}	1218.33^{ab}	1007.00^{a}
IR-66-R	3333.33^{de}	1133.00^{b}	776.67^{b}

Treatments having common letter in a column do not differ significantly

4.3.5. Peroxidase activity (Enzyme activity units litre^{-1})

Peroxidase activity studied among genotypes disclosed a significant difference among the genotypes during the three stages of growth viz tillering, panicle initiation and harvesting stage (Table 12). Peroxidase activity decreased quantitatively from tillering to harvesting stage in all the genotypes, and the minimum value was expressed at harvesting stage. Hybrids ADTRH-1 (80.33 enzyme activity litre^{-1}) and CORH-1 (85.67 enzyme activity litre^{-1}) maintained a comparatively higher peroxidase activity during harvesting stage than the other hybrid CORH-2) which showed a lesser value (22 enzyme activity litere^{-1}) at this stage. At tillering stage the highest peroxidase activity was observed in CORH-2 (307 enzyme activity litre^{-1}) than all other genotypes.

There was a significant difference in peroxidase activity among the hybrid ADTRH-1 and its parental genotypes (IR-58025-A, and IR-66-R) during the three stages of growth. Parental genotypes of CORH-2 (IR-58025-A and C-20-R) also showed a significant difference among themselves for Peroxidase activity at all the three growth stages. Contrary to this, the other hybrid CORH-1 maintained a significantly high enzyme activity than its parent at all stages of growth.

Table 12. Mean peroxidase activity (Enzyme activity units litre^{-1}) at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	158.00^{c}	2.09^{a} (122.00)	85.67^{a}
IR-62829-A	35.67^{f}	1.45^{b} (27.67)	30.33^{a}
IR-10198-66-2R	63.67^{e}	1.57^{b} (36.00)	25.00^{cde}
CORH-2	307.00^{a}	1.98^{a} (170.67)	22.00^{de}
IR-58025-A	183.33^{b}	1.55^{b} (36.00)	24.67^{cde}
C-20-R	92.00^{d}	1.95^{a} (88.67)	63.33^{b}
ADTRH-1	94.67^{d}	2.04^{a} (111.00)	80.33^{a}
IR-66-R	55.33^{ef}	1.57^{b} (36.00)	27.67^{cd}

Treatments having common letter in a column do not differ significantly

4.4. Yield and yield contributing characters

The data (Tables 13 a & b) indicated that hybrids and parental genotypes differed significantly for various yield-contributing characters.

Among hybrids CORH-1 recorded the highest number of productive tillers (24.67) followed by ADTRH-1 (15.33) and CORH-2 (10.67). The three hybrids did not show any significant difference from their respective parental genotypes with regard to number of productive tillers except CORH-1.With regard to panicle length ADTRH-1 recorded the maximum value (28.27 cm) followed by CORH-1 (27.59 cm) and CORH-2 (21.83 cm). All the hybrids showed a highly significant variation in panicle length from their respective parents. Parental genotypes IR-58025A and C-20-R of CORH-2 differed significantly in panicle length (25.37 and 19.99 cm). Similar difference was observed for parental genotypes of CORH-1 also.

Data on grain weight panicle^{-1} indicated no significant difference between hybrids for the character. The hybrids recorded a value of 2.55 g for CORH-1, 3.03 g for CORH-2 and 3.01 g for ADTRH-1. All the three hybrids significantly differed from one of their parents' for grain weight panicle^{-1}. Parental genotypes of CORH-2 differed significantly in grain weight panicle^{-1} (IR-58025A - 1.17 g; C-20R - 2.75 g). Similar significant difference in grain weight panicle^{-1} was observed between parents of ADTRH-1 also (IR-58025-A - 1.17 g; IR-66R-2.52 g).

CORH-1 with a duration of 73.66 days for 50 per cent flowering was the earliest among the hybrids CORH-2, which took 87 days, was the latest among them. ADTRH-1 had a duration of 79.33 days, which was in between the other two hybrids.

Days to 50 per cent flowering for hybrid CORH-2 and ADTRH-1 varied significantly with their parental genotypes.

Among hybrids CORH-2 took maximum no of days to mature (121.67 days) followed by ADTRH-1 (109.33 days) and CORH-1 (107 days). Number of days taken for maturity varied significantly between hybrid CORH -2 and its parental genotypes IR 58025 A (107.67 days) and C-20-R (113.33 days).

CORH-2 recorded a significantly remarkable yield of 5350.17 kg ha^{-1} followed by other hybrids ADTRH-1 (4791.67 kg ha^{-1} and CORH-1 (3331.67 kg ha^{-1}). Both CORH-2 and ADTRH-1 recorded a significant difference in grain yield with their respective parents. The yield of CORH-1 was on par with one of its parent IR-10198-66-2R (3026 kg ha^{-1}). When compared to their respective male parents CORH-1 expressed a yield increase of 9.1 % and CORH-2 expressed 22.8 % and it was 37.8 % in ADTRH-1.

Though the parents and hybrids showed no significant variation for straw yield, the hybrids CORH-2 expressed a maximum straw yield of 6266.67 kg ha^{-1} compared to its parents IR-58025 A (5053.33 kg ha^{-1}) and C-20R (4833.33 kg ha^{-1}). The straw yields observed in the other two hybrids were 5350 kgha^{-1} for ADTRH-1 and 4900 kg ha^{-1} for CORH-1.

The hybrids CORH-2 and ADTRH-1 differed significantly from CORH-1 for harvest index. ADTRH-1 recorded highest value of (0.48) followed by CORH-2 (.46) and CORH-1 (.41).

Table 13a. Yield and yield components of parents and hybrids

Parents/Hybrids	Number of productive tillers	Panicle length (cm)	Grain weight Panicle^{-1} (gm)	Days to 50 % flowering
CORH-1	24.67^{a}	27.59^{a}	2.55^{a}	73.66^{e}
IR-62829-A	12.33^{bc}	21.15^{ef}	1.79^{b}	85.00^{b}
IR-10198-66-2R	19.67^{ab}	23.09^{cd}	1.41^{bc}	73.00^{e}
CORH-2	10.67^{c}	21.83^{de}	3.03^{a}	87.00^{ab}
IR-58025-A	11.33^{c}	25.37^{b}	1.17^{c}	77.67^{d}
C-20-R	9.00^{c}	19.99^{f}	2.75^{a}	82.00^{c}
ADTRH-1	15.33^{bc}	28.27^{a}	3.01^{a}	79.33^{d}
IR-66-R	12.67^{bc}	25.93^{b}	2.52^{a}	88.00^{a}

Treatments having common letter in a column do not differ significantly

Table 13 b. Yield and yield components of parents and hybrids

Parents/Hybrids	Days to maturity	Grain yield ($kg\ ha^{-1}$)	Straw yield ($kg\ ha^{-1}$)	Harvest index
CORH-1	107.00^{c}	3331.67^{c}	4900.00^{a}	0.41^{c}
IR-62829-A	109.00^{bc}	220.00^{e}	4666.67^{a}	0.05^{f}
IR-10198-66-2R	100.00^{d}	3026.00^{c}	5316.67^{a}	0.36^{d}
CORH-2	121.67^{a}	5350.17^{a}	6266.67^{a}	0.46^{b}
IR-58025-A	107.67^{bc}	273.33^{e}	5083.33^{a}	0.05^{f}
C-20-R	113.33^{b}	2206.67^{d}	4833.33^{a}	0.31^{e}
ADTRH-1	109.33^{bc}	4791.67^{b}	5350.00^{a}	0.48^{a}
IR-66-R	113.33^{b}	2978.33^{c}	4533.33^{a}	0.31^{e}

Treatments having common letter in a column do not differ significantly

4.5 Nutrient uptake studies

4.5.1. Nitrogen content (N %)

Mean data on nitrogen content in leaves is given in Table 14. Estimate of nitrogen content among genotypes had revealed that nitrogen content in percentage was high during tillering stage for all hybrids and parental genotypes studied. Among hybrids CORH-1 recorded highest nitrogen content at all stages of growth (2.69; 2.27; 1.65 %) except tillering stage. In CORH-2, the nitrogen content of leaves expressed that lowest value (0.82 %) at harvesting stage when compared to other two hybrids.

The nitrogen content of leaves showed a remarkably significant difference between CORH-1 and its parental genotypes at all stages of growth. Analysis of variance also showed that there was significant difference in nitrogen content among parental genotypes at tillering and harvesting stage.

But CORH-2 differed significantly from its parental genotypes at tillering stage and at panicle initiation stage, it was on par with its parents. At harvesting stage it recorded the lowest value compared to it parental genotypes .It was on par with one of its parent IR-58025-A which is the male sterile one.

In the third hybrid ADTRH-1 the nitrogen uptake pattern was little different from the above two hybrids. It differed from its parent at tillering stage, but at harvesting stage it shows the difference with one of its parent IR-66-R only.

Table 14. Mean nitrogen content (%) of leaves at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	2.69^{c}	2.27^{a}	1.63^{a}
IR-62829-A	3.11^{a}	0.95^{d}	0.88^{d}
IR-10198-66-2R	2.15^{e}	0.86^{d}	0.54^{e}
CORH-2	2.45^{d}	1.93^{bc}	0.82^{d}
IR-58025-A	2.95^{ab}	1.72^{c}	0.93^{cd}
C-20-R	2.78^{bc}	1.75^{c}	1.13^{b}
ADTRH-1	2.77^{bc}	2.06^{ab}	0.91^{cd}
IR-66-R	2.45^{d}	1.86^{c}	0.66^{e}

Treatments having common letter in a column do not differ significantly

4.5.2 Phosphorus content (P %)

The mean data for phosphorus content at different stages indicated a decreasing trend from tillering to harvesting as given in Table 15. Phosphorus content among genotypes varied significantly. All the genotypes sighted highest phosphorus content during tillering stage and lowest at harvesting stage.

There was a highly significant difference among parental genotypes of all the three hybrids in the three stages of growth (viz, tillering, panicle initiation and, harvesting) for phosphorus content. The hybrid CORH-1 (1.02 %) and its parents (IR-62829-A - 1.17 %; IR-1019866-2R - 0.77 %) showed a significant difference in Phosphorus content during tillering stage.

No significant difference was noticed in CORH-2 with one of its parental genotypes IR-58025A in phosphorus content during panicle initiation and harvesting stage. The other hybrid ADTRH-1 also showed significant difference in phosphorus content, from its parental type at tillering and harvesting stage. The highest value for phosphorus content was maintained at harvest stage by hybrid CORH-2 (1.05 %), where as the least was recorded by CORH-1 (0.80) at the same stage.

Table 15. Mean phosphorous content (%) of leaves at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	1.02^{d}	0.93^{de}	0.80^{e}
IR-62829-A	1.17^{c}	1.02^{cd}	0.11^{f}
IR-10198-66-2R	0.77^{e}	0.78^{e}	0.77^{cd}
CORH-2	1.59^{a}	1.03^{cd}	1.05^{b}
IR-58025-A	1.26^{bc}	1.03^{cd}	1.09^{ab}
C-20-R	1.60^{a}	1.18^{ab}	1.17^{a}
ADTRH-1	1.52^{a}	1.29^{a}	0.85^{c}
IR-66-R	1.22^{c}	1.13^{bc}	0.62^{c}

Treatments having common letter in a column do not differ significantly

4.5.3. Potassium content (K%)

Potassium content estimated during three stages of growth viz tillering, panicle initiation and harvesting stage disclosed a significant difference among the genotypes studied (Table 16) all genotypes recorded highest potassium content during tillering stage and later showed a declining trend to harvesting stage.

Potassium content in percentage for CORH-1 were 1.85; 1.67 and 1.20 during tillering, panicle initiation and harvesting stages respectively where as it was 1.95; 1.55, and 1.32 % in CORH-2 and 2.13,1.32, and 1.18 % in ADTRH-1 at the respective stages. The decrease in potassium uptake from tillering to harvesting were in the order of ADTRH-1 (44.60 %) > CORH-1 (35.15 %) > CORH-2 (32.3 %).

All the hybrids expressed a remarkable difference in potassium content with its respective parental genotypes at harvesting stage though the difference was not noticed in the other two stage. The parental genotypes of CORH-2 (IR-58025-A and C-20-R) did not show any significant difference in potassium content at the three stages of growth.

Table 16. Mean potassium content (%) of leaves at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	1.85^{d}	1.67^{a}	1.20^{ab}
IR-62829-A	1.80^{d}	1.58^{a}	0.97^{d}
IR-10198-66-2R	2.29^{b}	1.28^{bc}	0.98^{d}
CORH-2	1.95^{cd}	1.55^{a}	1.32^{a}
IR-58025-A	2.43^{a}	1.40^{b}	1.05^{d}
C-20-R	2.62^{a}	1.28^{bc}	1.07^{cd}
ADTRH-1	2.13^{bc}	1.32^{bc}	1.18^{bc}
IR-66-R	2.10^{bc}	1.23^{c}	0.97^{d}
IR-58025-B	1.60^{e}	1.37^{bc}	0.93^{d}

Treatments having common letter in a column do not differ significantly

4.5.4 Calcium content (Ca %)

The mean data for calcium content in percentage is given in Table 17. Calcium content was found varying among genotypes and exhibiting a progressive increase from tillering to harvesting stage.

The lowest value for calcium content was observed during tillering stage when compared to panicle initiation and harvesting stage for all genotypes and among genotypes the hybrids recorded the highest value than their respective parents at the same stage.

A very highly significant difference was expressed by ADTRH-1 (0.68; 0. 79; 0.92 %) and its parental genotypes IR-58025-A (0.45; 0.50; 0.60 %) and IR-66-R (0.57; 0.60; 0.62 %) at all the three stages of growth for calcium content.

4.5.5. Magnesium content (Mg %)

Among all the genotypes magnesium content in percentage enrolled the highest value during tillering stage and the lowest value at harvesting stage (Table 18). Hybrid CORH-2 registered higher value for magnesium content *viz.* 0.73 %, 0.49 %, 0.46 % during the three stages of growth *viz.* tillering, panicle initiation and harvesting respectively.

Table 17. Mean calcium content (%) of leaves at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	0.64^{ab}	0.66^{abc}	0.70^{bcde}
IR-62829-A	0.43^{ef}	0.60^{bcd}	0.77^{b}
IR-10198-66-2R	0.53^{d}	0.64^{bc}	0.73^{bcd}
CORH-2	0.60^{bc}	0.68^{ab}	0.75^{bc}
IR-58025-A	0.45^{e}	0.50^{d}	0.60^{e}
C-20-R	0.50^{dc}	0.62^{bcd}	0.64^{cde}
ADTRH-1	0.68^{a}	0.79^{a}	0.92^{a}
IR-66-R	0.57^{bc}	0.60^{bcd}	0.62^{de}

Treatments having common letter in a column do not differ significantly

Table 18. Mean magnesium content (%) of leaves at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	0.40^{c}	0.28^{e}	0.25^{d}
IR-62829-A	0.43^{c}	0.30^{de}	0.24^{d}
IR-10198-66-2R	0.44^{c}	0.38^{bcd}	0.34^{c}
CORH-2	0.73^{a}	0.49^{ab}	0.46^{a}
IR-58025-A	0.43^{c}	0.39^{bcd}	0.40^{bc}
C-20-R	0.49^{bc}	0.41^{abc}	0.38^{bc}
ADTRH-1	0.60^{ab}	0.48^{a}	0.43^{ab}
IR-66-R	0.41^{c}	0.37^{cd}	0.38^{bc}

Treatments having common letter in a column do not differ significantly

CORH-2 and its parental genotypes varied significantly in magnesium content during tillering and harvesting stage. Magnesium content of parental genotypes of ADTRH-1 (IR-58025-A (0.43 %) and IR66-R (0.41%)) did not vary significantly among themselves during tillering stage, but they showed a significant difference with the hybrid (0.60 %) at the same stage.

4. 5.6 Sulphur content (S %)

Sulphur estimation values among the hybrids were maximum at tillering stage and showed a decreasing trend during panicle initiation and again got increased during harvesting stage as evidenced from Table 19. CORH-2 recorded highest sulphur content during tillering (1.33 %), panicle initiation (0.42 %) and harvesting stage (0.74 %) compared to other hybrids.

Only CORH-1 (0.74 %) and its parental genotypes (IR-62829-A-0.40%; IR-10198-66-2R-0.40 %) showed a significant d8ifference in sulphur content during harvesting stage.

There was no significant difference among parental genotypes of CORH-2 for sulphur content in all the three stages of growth. But it was interesting to note that the hybrid showed an increase of 54.16 % from panicle initiation to harvesting stage, where the parents exhibited a decline of 8.33 % and 2.6 % respectively at the same stage.

Table 19. Mean sulphur content (%) of leaves at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	1.33^{a}	0.42^{ab}	0.74^{b}
IR-62829-A	0.66^{b}	0.51^{a}	0.40^{c}
IR-10198-66-2R	0.40^{c}	0.31^{cd}	0.40^{c}
CORH-2	1.33^{a}	0.24^{de}	0.37^{c}
IR-58025-A	0.45^{c}	0.36^{bc}	0.33^{c}
C-20-R	0.50^{c}	0.38^{bc}	0.37^{c}
ADTRH-1	0.41^{c}	0.18^{e}	0.42^{c}
IR-66-R	0.36^{c}	0.22^{de}	0.41^{c}

Treatments having common letter in a column do not differ significantly

During tilllering stage both CORH-1 and CORH-2 varied significantly in leaf sulphur content with their parental genotypes, where as ADTRH-1 did not show any significant difference with its parental genotypes at tillering and harvesting stages.

4.5.7. Iron content (Fe ppm)

The different genotypes differed in the iron content as shown in Table 20. The Fe content was seen increasing from tillering to harvesting stage. The highest value of Fe content was expressed by CORH-1 and its parental genotype even at harvesting stage. In CORH-1 the iron content was found increasing from tillering to harvesting stage (220; 240; 270 ppm). The three hybrids differed in their Fe uptake pattern during different phenophases of growth. But CORH-2 exhibited a decline from tillering to panicle initiation with an increase at harvesting (440; 153.30; 180 ppm).

ADTRH-1 showed a decreasing trend in iron content from tillering to harvesting stage. Its value decreased by 24 % at panicle initiation and then again by 26 % during harvesting stage. One of its parents IR-66-R showed the same pattern of decrease in iron content.

4.5.8. Manganese content (Mn ppm)

The change in manganese content at various stages of growth was found in a different pattern for genotypes observed as given in Table 21.

Table 20. Mean iron content (ppm) of leaves at different stages of growth

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	220.00^{c}	240.00^{a}	270.00^{a}
IR-62829-A	253.33^{c}	243.33^{a}	243.33^{a}
IR-10198-66-2R	346.67^{b}	233.33^{a}	249.67^{a}
CORH-2	440.00^{a}	153.33^{bc}	180.00^{b}
IR-58025-A	253.33^{c}	96.67^{c}	260.00^{a}
C-20-R	360.00^{b}	136.67^{bc}	150.00^{bc}
ADTRH-1	223.33^{c}	170.00^{b}	126.67^{bc}
IR-66-R	213.33^{c}	143.33^{bc}	106.67^{c}

Treatments having common letter in a column do not differ significantly

Table 21. Mean manganese content (ppm) of leaves at different stages of growth of hybrids and parental genotypes

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	141.67^{ab}	118.33^{ab}	88.33^{e}
IR-62829-A	145.00^{ab}	151.67^{a}	141.67^{bcd}
IR-10198-66-2R	141.67^{ab}	146.67^{a}	163.33^{ab}
CORH-2	170.00^{a}	156.67^{a}	193.33^{a}
IR-58025-A	83.33^{c}	98.33^{ab}	146.67^{bc}
C-20-R	93.33^{c}	85^{b}	176.67^{ab}
ADTRH-1	113.33^{bc}	73.33^{b}	108.33^{cde}
IR-66-R	118.33^{bc}	116.67^{ab}	103.33^{de}

Treatments having common letter in a column do not differ significantly

There was a significant difference among the parental genotypes of ADTRH-1 during harvesting stage (for IR-58025-A and IR-66-R manganese content values were 146.67, 103.33 ppm respectively). In CORH-1 the Mn content was progressively decreasing from tillering to harvesting stage, where as it's parental genotypes exhibited entirely different pattern of Mn content at different stages. IR-62829-A expressed 4.6 % increase in Mn content from tillering to panicle initiation stage and it declined to 6.5 % at harvesting stage.

4.5.9. Zinc (Zn ppm).

The mean data given in Table 22 indicated that the genotypes showed significant difference in zinc content at tillering stage only. Among hybrids ADTRH-1 registered higher zinc content than the other two hybrids in all the three stages (216.67; 133.33; 150.33 ppm).

CORH-1 exhibited a decline of 28.5% in Zinc content during harvesting stage than at panicle initiation stage where as one of its parent IR-62829-A showed an increase of 67 % at harvesting stage than at panicle initiation stage. The zinc content pattern was different for three hybrids i.e. in CORH-1 it increased from tillering (100 ppm) to panicle initiation (116.67ppm) and then declined from panicle initiation to harvesting (83.33ppm). Where as in CORH-2, it showed continuous decline from tillering to harvesting (216.67, 166.67, 150ppm). At the same time, the pattern was entirely different in ADTRH-1 where the Zn content declined at panicle initiation stage (133.33 ppm) and then increased to harvesting stage (150.33 ppm).

Table 22. Mean zinc content (ppm) of leaves at different stages of growth of hybrids and parental genotypes

Parents/Hybrids	Tillering	Panicle initiation	Harvesting
CORH-1	100.00[b]	116.67[a]	83.33[a]
IR-62829-A	150.00[ab]	100.00[a]	166.67[a]
IR-10198-66-2R	166.67[ab]	116.67[a]	100.00[a]
CORH-2	216.67[a]	166.67[a]	150.00[a]
IR-58025-A	150.00[ab]	83.33[a]	133.33[a]
C-20-R	100.00[b]	100.00[a]	83.33[a]
ADTRH-1	216.67[a]	133.33[a]	150.33[a]
IR-66-R	200.00[a]	100.00[a]	133.33[a]

Treatments having common letter in a column do not differ significantly

DISCUSSION

DISCUSSION

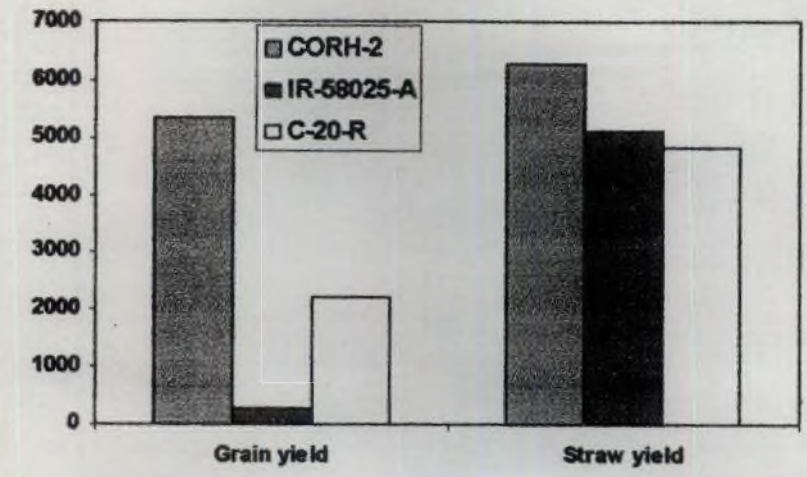
Hybrids offer an excellent opportunity to break through the yield ceilings set by high yielding varieties. Usually the F_1 hybrids are utilized commercially with a view to exploit heterosis for selecting superior segregants of the hybrids in the subsequent generation and relating the best performing recombinant after attaining homozygosity. Heterosis in dry matter production and grain yield are highly variable depending on physiological efficiency and environmental conditions. In the present investigation, attempts have been made to evaluate three rice hybrids and their parental genotypes to identify the physiological and genetic efficiency of the genotypes, which can enhance the quantum of heterosis in grain yield. The results obtained have been discussed as follows.

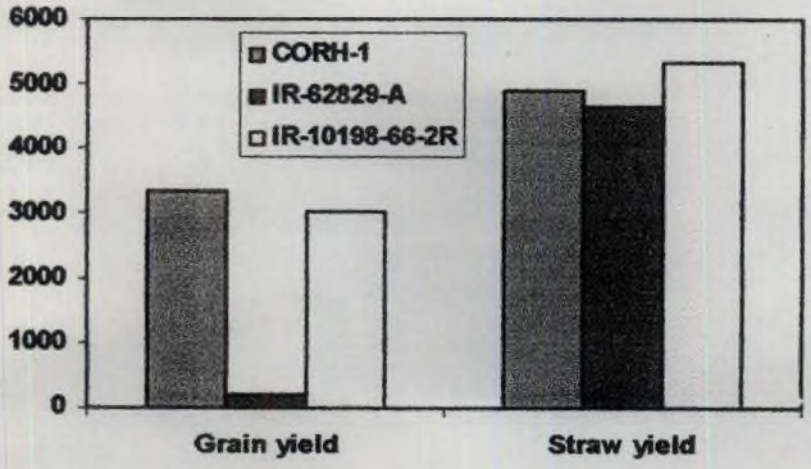
The study has brought to light the specific and the differential identities of the three hybrids in the genetic and functional contexts. CORH – 2 has recorded the high yield of 5.4 tonnes ha^{-1} grain, which had manifested a heterotic advantage of 142 per cent over the better parent. This was followed by ADIRH – 1 which manifested heterotic advantage in grain yield alone of the order of 60 per cent over the better parent. CORH – 1 had failed to improve upon the parents (Fig. 1).

A closer scrutiny of data will show that heterotic advantage results basically in two ways *viz.*, generalized morphologic improvement in growth

and yield attributes as in ADTRH – 1 and efficiency enhancement as in CORH – 2. The former shall be termed as improvement on morphological efficiency and the latter as improvement on physiological efficiency. Thus a 66 % increase in productive tillers and 16 % increase in panicle length led to 1700 kg grain yield in the former, while a 10 per cent improvement in productive tillers and panicle length brought about 150 per cent increase in grain yield in the latter. Akitha (1988) and Agatha (1966) have reported that heterotic advantage resulted from both physiological and morphological improvement. Functional heterosis probably is characterized by enhanced duration and morphologic heterosis appears to be associated with reduced functional efficiency. The study has brought out a classical example of this in CORH – 1, in which heterotic advantage in number of productive tillers and panicle length failed to bring about yield improvement (Fig. 2).

These results therefore tend to indicate that integrated heterosis- integrating morphological facility and physiological efficiency- shall be the most desirable and comprehensive approach. Achieved functional efficiency is normally the integrated product of structural capability and environmental stresses. As the latter shall be manipulated effectively, the study implies that the breeding for heterosis should consider structural proportions as well.





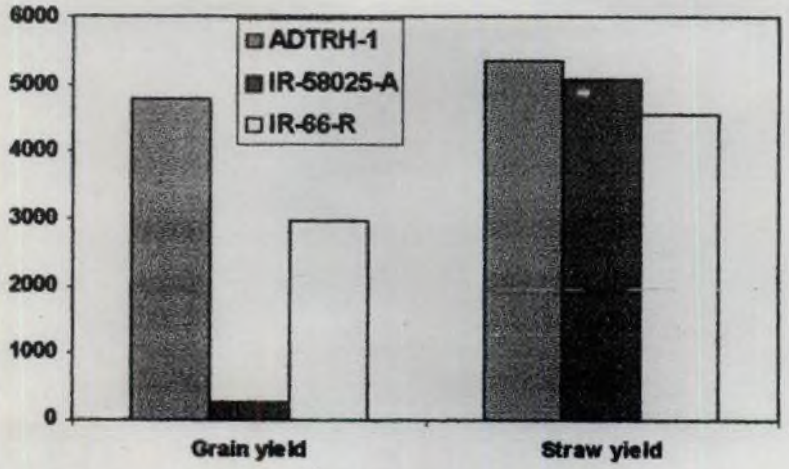
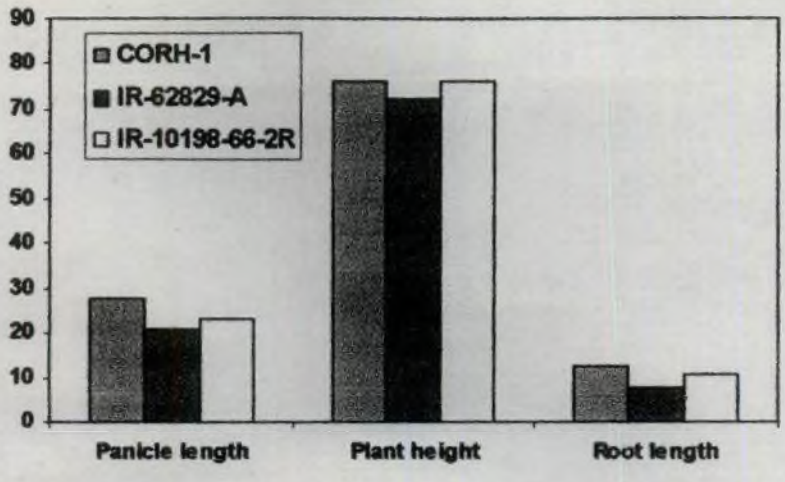
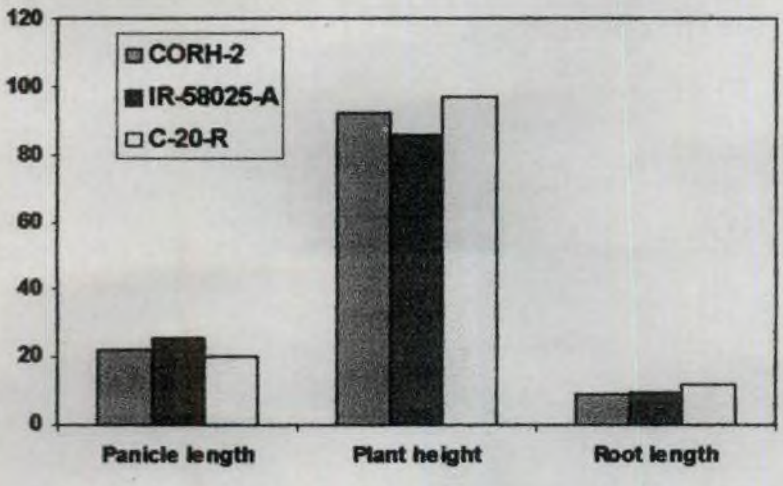


Fig. 1. Grain yield (kg ha^{-1}) and straw yield (kg ha^{-1}) of hybrids and thei parental genotypes





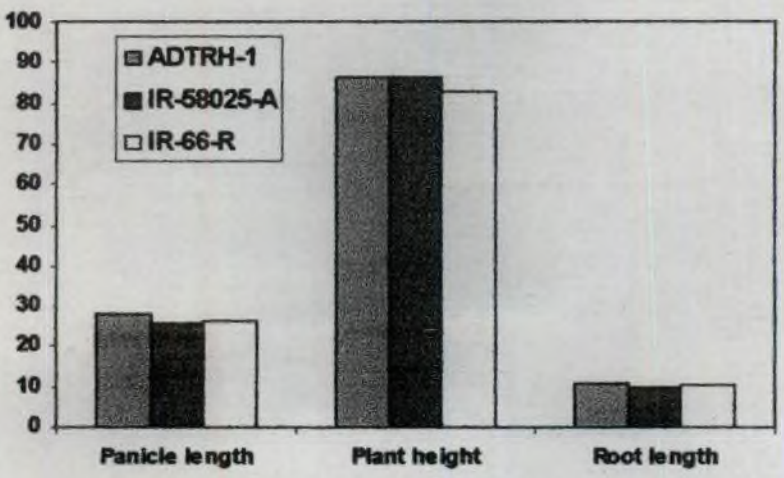


Fig. 2. Panicle length (cm), plant height (cm) and root length (cm) of hybrids and their parental genotypes

Data on the growth and yield attributes further underlined the importance of heterotic functional efficiency over morphological heterosis. CORH – 2 had recorded a better height of plants over the other two hybrids. Height of plants in rice is an indirect measure of the leaf area per tiller (Fig. 2). Thus every tiller in CORH – 2 had the advantage of more photosynthetic area, which might have contributed to more carbohydrate available for dry matter biosynthesis and thereby improved grain and straw yield. Supporting evidence was reported by Virmani *et al.* (1991) that height of the F_1 hybrids derived from semi dwarf parents were equal or higher than their parents and contributed higher grain yield. All the hybrids recorded higher percentage increase in plant height from panicle initiation to harvesting stage. This may be due to the force of elasticity at the time of panicle emergence. The elongation was found significantly different in hybrids. Positive correlation between plant height and grain yield observed in tall plants, indicates the availability of large source to contribute to the fine sink or grain yield. Rosamma (1998) has also obtained similar result. The ideotype concept proposed by Peng *et al.* (1994) have fixed medium tillering combined with height up to 145 cm as ideal characteristic in the place of totally dwarf plants.

Realised yield and functional efficiency is actually the net balance between favourable and stress influences. Vulnerability to stress shall be observed morphologically as well in crops. Heading in rice is invariably

associated with an extension in the last internode and reflected in plant height. Stress influences inherit this in varying extents. In ADIRH – 1, there was no extension and increment in height. But in CORH – 1, it was only 8 cm increment between panicle initiation and harvest as against 14 cm in CORH – 2. The failure of morphologic heterosis of these types shall be attributed to the failure to resist the stress influences. Failure of high yielding exotic types and hybrid derivatives has also been reported by Powers (1944) and Stern (1948).

Observations on root length revealed that all the three hybrids showed increased root length compared to their parents. Earlier reports of Damodar *et al.* (1978), Ekanayake *et al.* (1985) and Hasegawa *et al.* (1993) also proved existence of increased vigour for root length in hybrids. The zigzag pattern of variation in root length and inverse relation of root tips to yield expression may appear confusing. The pattern would primarily mean many generation roots in the intervening period between tillering and harvesting. A near uniform trend in root length pattern in hybrids and parents would mean that this is a non-genetic but physiologic effect, through carbohydrates produced are drained away (Fig. 2).

The negative relationship between yield and number of root tips and root density is an indication that hybrid vigour can be judged better based on efficiency than morphological improvement. Efficiency in the case of roots can be seen to be affected by stability and hybrid vigour measured in terms of stability would appear to be the ideal index.

Stability of roots or otherwise would seem to be governed by histophysiology. Function of roots being nutrient absorption, instability of roots and low yield should be linked to redox-induced absorption, which shall be discriminately checked by histological modifications. Even though the grain yield of CORH – 1 is very low compared to other hybrids, it showed maximum number of root tips at the time of harvesting stage. This may be due to the survival mechanism of the plant where the photo assimilates are translocated for root development rather than grain sink development.

IR 58025A – CMS line was the maternal parent of hybrid CORH-2 and ADTRH-1- registered higher number of root tips at all stages of growth .This was in agreement with the findings of Kuzmin and Shumeiko (1985).

Cation exchange taking place on the surface of the plant root is an important reaction, related to plant productivity. It is seen that the capacity of roots for the amount of exchangeable cation per unit weight of the root vary from tillering to harvesting at an increasing ratio, except for CORH-2. High CEC of root expressed by CORH-2 at initial stages of growth evidently improved the absorption of exchangeable ions like Ca, Mg and K, which might have helped in maintaining a stable pH tuning the internal metabolic functions favourably.

Heritability of chlorophyll content per unit weight of fresh and dry leaf was found high and fluctuated depending on genotypes (Suge *et al.* 1991). This

suggests the importance of chlorophyll for consideration in solution criteria for better genotypes. Observation on total chlorophyll content revealed that the total content is not important in relation to yield as evidenced from the results given. The hybrid ADTRH-1 recorded 11.66 % less yield with high total chlorophyll content, when compared to high yielded hybrid CORH-2. Photosynthesis bring a sequential function of high absorption and utilization, the balance between Chlorophyll, a and b *i.e.* the a/b ratio shall serve as the index for selection.

Chlorophyll is a simple metabolic product and has been reported to be subject to more nutritional imbalances than by transmitted traits. The data have shown that stability of chlorophyll over the longest time in CORH-2 has given the maximum yield. Stability being a metabolic function, yield variation is not due to more genetic causes. Musthaffa (1995) have reported that loss of stability of chlorophyll a and chlorophyll a/b ratio is a reflection of nutritional stress. Nareshkumar and Singh (1996), also was of the view that, NAR and grain yield is positively correlated with chlorophyll a/b ratio. In this study also, though the parents failed to express this stability, it was manifested in hybrids, which may be due to the removal of physiologic inhibition through genetic association (Fig. 3).

The results on soluble protein content as well as enzyme actitivities of hybrids revealed that they follow more or less the same pattern. This would

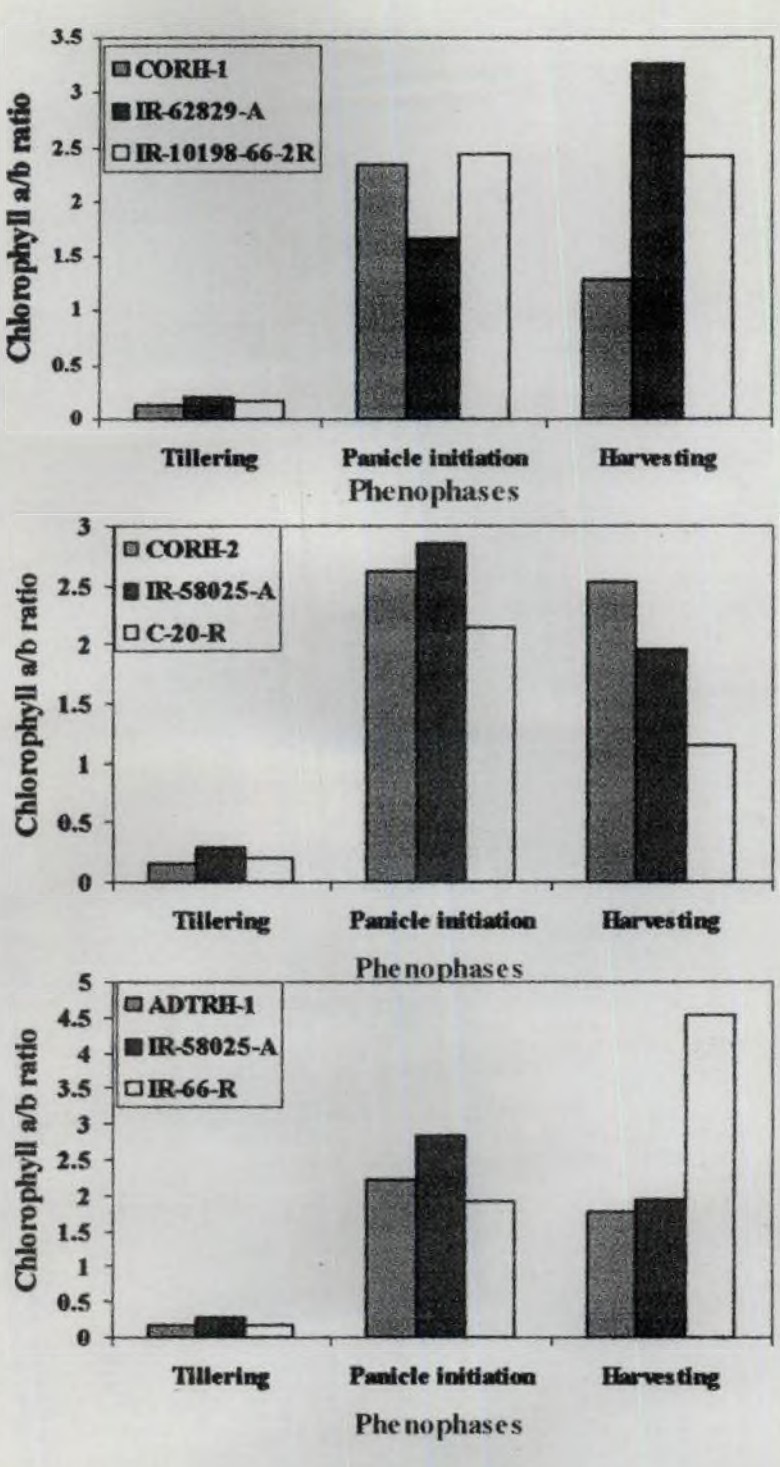


Fig. 3. Chlorophyll a/b ratio of hybrids and their parents at different phenophases

also imply that any one of them could serve as an index of the others. The pattern of change in soluble protein content or various enzyme activities at different phenophases of growth was found not related in any way with the parental growth expression. This would mean that the magnitude of physiologic expression is independent of genetic capabilities or genetic expressivity is conditioned by physiology of the plant. Soluble protein content of CORH-2 was 2.12 mg g^{-1} fresh tissue at harvesting stage and it took 121.67 days to achieve full maturity (Fig. 4). Nemato *et al* (1993) reported that early maturing ones had a higher protein content in leaves than the late maturing types. Genotypes with relatively lower level of leaf soluble protein content is found to have high carboxylation efficiency by virtue of high specific activity of Rubisco (Debabrate *et al* 2000). In the case of CORH-2 also it was evident that at panicle initiation and harvesting stage, the leaf soluble protein content was very low, whereas its' parental genotypes had a higher value (Fig. 5). The pattern of change in soluble protein content also suggests phasic significance of metabolic activity in crop improvement.

The hybrid CORH-1 recorded higher NRase activity than its' parents at panicle initiation and harvesting stages. The expression of higher enzyme activity by the hybrids than their parents at one or more stages was earlier reported in Legumes (Jayapragasam *et al.* 1998). Hybrid CORH-2 consistently had a higher NRase activity even at harvesting stage (Fig. 6). Therefore it could

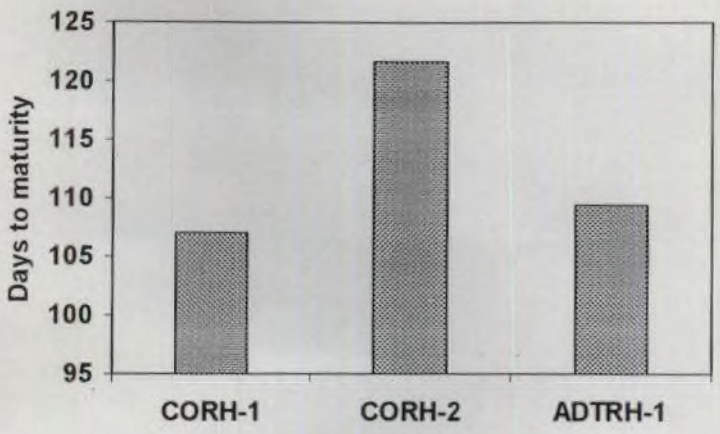


Fig. 4. Days to maturity of three hybrids

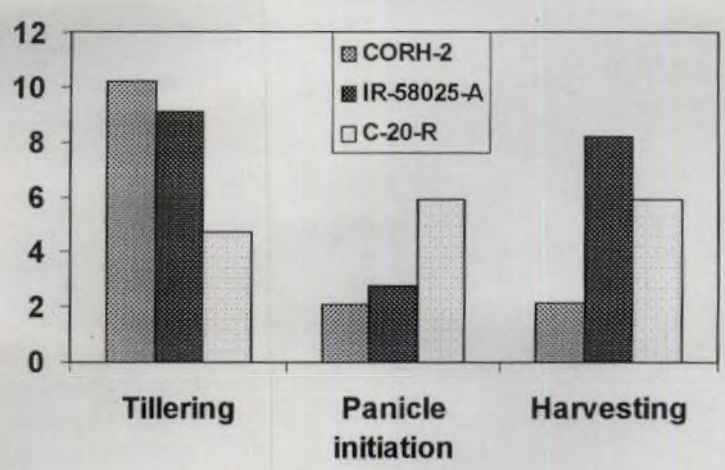


Fig. 5. Soluble protein content (mg g^{-1} fresh tissue) of hybrid CORH-2 at its parental genotype at different phenophases of growth

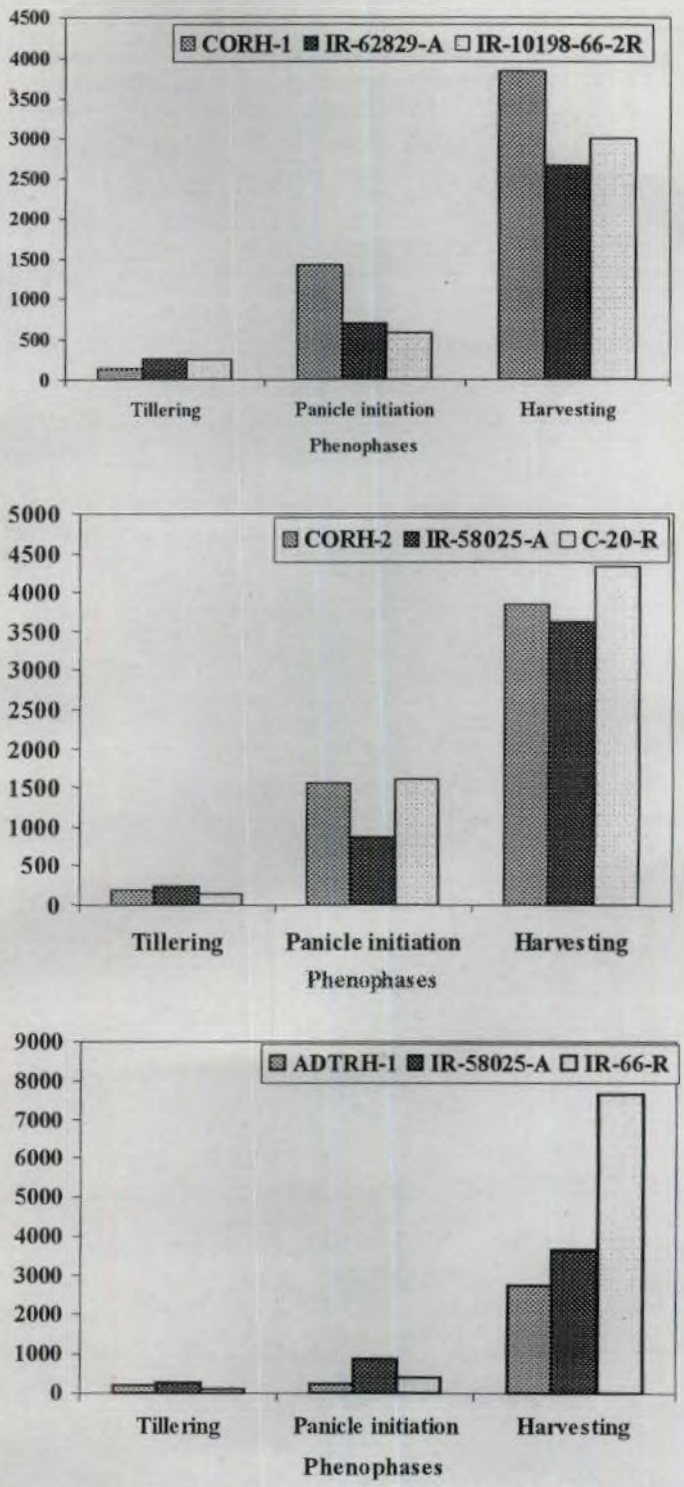


Fig.6.Nitrate reductase activity (Micro mole nitrite produced g-1fresh tissue hr-1) Of hybrids and parents at different stages of growth

mobilize and supply the required nitrogen for developing grains. This could perhaps be one of the reasons for the highest yield recorded by CORH-2, than the other two hybrids. But in the third hybrid ADTRH-1, the enzyme activity was significantly lower than its' parents at panicle initiation and harvesting stages. Wang Young Rui (1997) reported that NRase activities were found decreasing during panicle emergence in a Chinese rice hybrid. However the results envisage that, all the combinations, which showed heterosis for NRase activity need not necessarily give higher yield. Evidently differential changes in the enzyme activity among genotypes at various developmental stages need to be considered, while ascertaining activity of NRase is an index of crop productivity.

Catalase activity was found decreasing progressively from tillering to panicle initiation stage in all genotypes. Generally catalase activity decreases at senescence stage and its' activity should be optimum or above optimum for maximum crop productivity, by avoiding accumulation of H_2O_2 in the cells. This enzyme is generally considered as H_2O_2 scavenger and H_2O_2 has been reported to be involved in the enhancement of senescence (Choudhary, 1998). The highest level of catalase activity shown by the hybrid CORH-2 at tillering and panicle initiation stage, indicates its' involvement in photorespiration by reacting with hydroxyl radicals to reduce senescence process. So it could prolong the number of days for the sink grain filling than the other hybrids. The

male sterile maternal parent IR-58025-A also exhibited higher values for this enzyme activity. The other hybrid CORH-1 expressed an improvement in the activity of the enzyme at tillering and panicle initiation stage, over its' parents, whereas hybrid ADTRH-1 had a medium range for this activity. This again implies the dependence of evaluating heterotic vigour on a physiologic context for better yields.

Peroxidase activity, which showed a sharp decline from tillering to harvesting stage, is reported to be an indicator of senescence. Senescence is found delayed, if the activity of the enzyme is high even at later stages of growth. From the results, it was evident that, the hybrids expressed differential response to this enzyme activity at different phenophases of growth. The highest activity of this enzyme was registered by CORH-2 at tillering stage, which was 48.5 % more than CORH-1 and 69.2 % more than ADTRH-1 at the same stage. As growth proceeded from tillering to panicle initiation, there was a sharp decline of 44 % in CORH-2, whereas it was only 22.7 % in CORH-1. Perhaps the high activity of this enzyme at every stages of growth would have helped in favourable association of peroxidase and IAA oxidase and thereby regulates auxin level in plant tissues, as reported by Glaziou (1969). The soluble protein and enzyme activity at tillering phase appears to be the most critical in deciding the yield of rice.

Significant features of the nutritional characteristics of the plants have revealed the independence of nutrition contents from yield, and metabolic

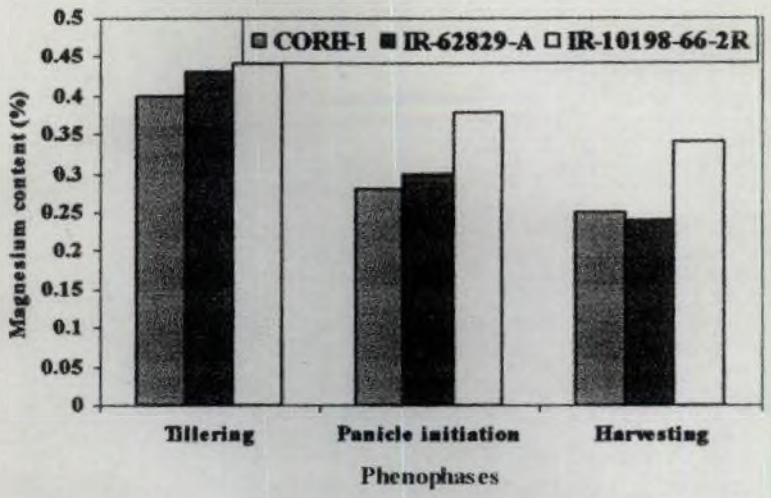
efficiency as evidenced in physiologic indices. Conspicuous absence of comparable pattern, within three groups was evident from the results obtained. The independent nature appears to be a reflection of poor adaptability, integration and unfavourable genotype environment interaction. The fact that highest yield had been recorded in CORH-2 at lower levels of nutrient contents in the tissues, would appear to be an indirect sign of non- metabolic accumulation of elements.

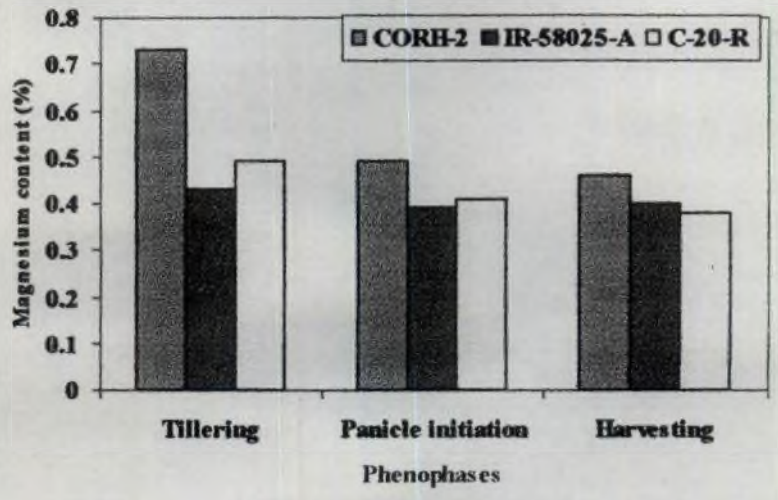
Tissue content of elements comes from active or passive absorption, both of which are dependent on histophysiology of the plant. The higher metabolic activity with lower tissue content, as evidenced in the hybrid CORH-2 would suggest that, yield is a function of dilution of nutrients, consequent on use and growth expansion. Thus, higher nutrient content is coupled with low metabolic activity and increased growth expansion and vice versa.

An overall scrutiny of the tissue content of nutrients in the light of the realized yield range of variation, showed that no element individually had been limiting or deficient. Yield under such a situation shall be limited only from the effect of excess content of one or more elements, which shall be manipulated through the antagonistic effect of some other ion. Highest yield of CORH-2 and ADTRH-1 appears to have come from the balancing effect of K and Iron in the post flowering phase.

A characteristic feature about nutrient absorption in the three-hybrid combination had been the absence of comprehensive superiority of any hybrid for all nutrients through out the growing period. CORH – 1 showed superiority over parents in uptake of N, K, S and Fe where as CORH – 2 manifested superiority over the parents in the uptake of K, Ca, Mg, Mn and Zn through out (Fig. 7). ADTRH –1 maintained the superiority in uptake of P, Ca, Mg and Zn through out different phenophases.

Hence from the present study it was evident that to achieve a complete heterotic effect in rice breeding, the biochemical as well as physiological aspects of heterosis are to be considered. This is essential because the genes provides the expressivity of a particular genotype under the broad frame work of metabolic activity as evidenced from the enzymes like NRase, Catalase and Peroxidase in CORH – 2; consequently the physiological basis of heterosis is concerned with metabolic superiority of the hybrid in growth and developmental characteristics at different phenophases. The high yield in CORH – 2 is found associated with high soluble protein and enzyme activity at tillering stage. So in the rice breeding programmes to evolve a hybrid with maximum yield, the parents should be selected based on biochemical, physiological and anatomical characteristics, as evident from the present study at different phenophases.





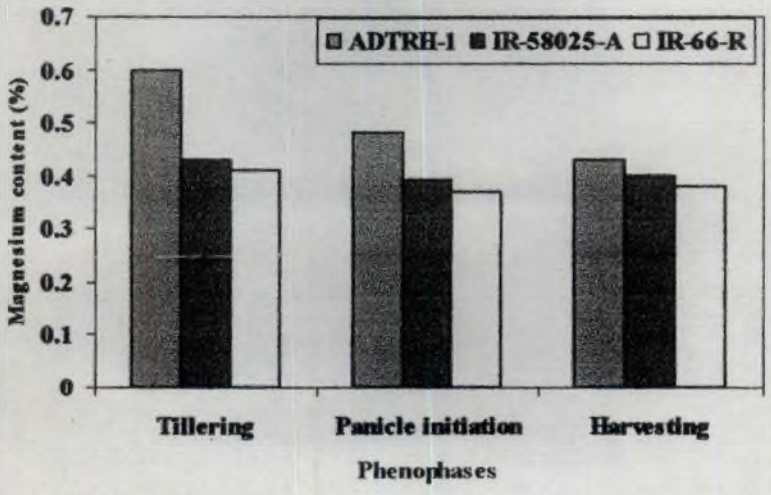


Fig. 7. Magnesium content (%) of hybrids and their parents at different phenophas

SUMMARY

SUMMARY

Crop improvement in its broadest sense seeks to increase productivity through two ways. One is the manipulation of germplasm by breeding to maximize genetic potential. The second one is the manipulation of the productive environment, using agronomic management, to minimize constraints for expression of that potential. In rice, though heterosis was first reported in 1926 (Jones), constraints still exist for complete exploitation of hybrid vigour. Hence, another break through in yield potential is only possible by combining the present level of genetic knowledge with a better understanding of the physiological basis of genotype and environmental component of plant response. Hence, the present study was undertaken at College of Horticulture, Vellanikkara to analyse the physiological basis of heterosis in rice hybrids along with their parents for over all combining ability with respect to various characters in rice. The experimental materials for the study comprised of three rice hybrids (CORH-1, CORH-2 and ADTRH-1) and their respective parents collected from TNAU. The field experiment was conducted at Agricultural Research Station, Mannuthy and was laid out in RBD with three replications. The main objectives of the study were

1. To characterize the morpho - metabolic associations in plant attributes that contribute to higher productivity in rice.

2. To understand how different genotypes may compliment one another physiologically.

3. To identify the stages at which the better physiological efficiency contribute heterosis.

4. To understand the nutritional efficiency in relation to heterosis in hybrid rice.

The study brought to light the specific and differential identities of three hybrids on the genetic and functional contexts as follows.

1. The heterotic advantages result in two ways *viz.*, generalized morphologic improvement in growth and yield attributes as in ADIRH – 1 which recorded a yield of 4791.67 kg ha^{-1} and efficiency enhancement as in CORH – 2 with an yield of 5350.17 kg ha^{-1}.

2. The improved physiological efficiency in CORH – 2 is manifested through better plant height, medium tillering and stability of roots. The negative relationship between yield and number of root tips and rooting density was observed in CORH-1which had a lowest yield among the hybrids.

3. The results also envisages the importance of heterotic functional efficiency over morphological efficiency. The failure of morphologic

heterosis was observed in ADTRH – 1 and CORH – 1as in the case of panicle length, plant height and productive tillers.

4. Cation exchange capacity of roots at initial stages of growth is an important factor to be considered while selecting genotypes.

5. The stability of chlorophyll over the longest time in CORH – 2 has given the maximum yield. Hence, the stability in chlorophyll a/b ratio at different phenophases shall serve as a better index for selection of genotypes in rice breeding programme.

6. The pattern of biochemical characters like soluble protein, enzymes, Peroxidase and catalase revealed that the magnitude of physiological expression are independent of genetic capabilities or genetic expressivity is conditioned by physiology of the plant. The soluble protein and enzyme activity at tillering phase is appears to be the most critical in deciding the yield of the rice. This also suggests that the phasic significance of metabolic activity in crop improvement.

7. The high NRase activity expressed by CORH – 2 at harvesting stage highlights the differential changes of this enzyme activity at different phenophases as an index of crop productivity.

8. The high Peroxidase activity at early stages of growth combined with decreased catalase activity from tillering to panicle initiation stage,

implies the dependence of evaluating heterotic vigour on a physiological contexts for better yields.

9. Tissue content of elements comes from active or passive absorption, both of which are dependent on histophysiology of the plant, as evidenced in CORH-2. Hence in future breeding programmes histophysiology of the genotype also should be considered.

10. An over all scrutiny of the tissue content of nutrients in the light of realized yield range of varieties showed that no elements individually has been limiting or deficient. Yield under such a situation shall be limited only from the effect of excess content of one or more elements, which shall be manipulated through the antagonistic effect of the one or the other ions.

11. In order to achieve a complete heterotic effect in rice breeding, the biochemical as well as physiological aspects at different growing stages should be given due importance .

12. In rice the maximum accumulation of photo-assimilates occurs before heading and differential portioning of the assimilates decided harvest index. Hence the selection of parental genotype for better heterotic advantage should be made by observing the various physiological and biochemical aspects as mentioned at early stage of growth.

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* Originals not seen.

PHYSIOLOGICAL GENETICS OF CHARACTER ASSOCIATIONS IN HYBRID RICE *(Oryza sativa* L.*)*

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The studies were conducted at the College of Horticulture, Vellanikara, to analyse the "Physiological Genetics of character associations in Hybrid rice (*Oryza Sativa L.)* ". The study mainly aims to characterize the morpho-metabolic associations in plant attributes that contribute to higher productivity in hybrid rice. Three hybrids and their parental genotypes were evaluated to understand how different genotypes may compliment one another physiologically and also to identify the stages at which the better physiological efficiency contribute heterosis.

From this study, it was revealed that the heterotic advantages result in two ways *viz.*, generalized morphologic improvement in growth and yield attributes and efficiency enhancement. The results also envisages the importance of heterotic functional efficiency over morphological efficiency. The stability of chlorophyll a/b ratio and the differential changes of Nrase enzyme activity, both at different phenophases shall serve as a better index for selection of genotypes in rice breeding programme.

The pattern of biochemical character like soluble protein, enzymes like Peroxidase, catalase revealed that the magnitude of physiological expression is independent of genetic capabilities or genetic expressivity is conditioned by physiology of the plant.

The soluble protein and enzyme activity at tillering phase appears to be the most critical in deciding the yield of the rice, in order to achieve a complete heterotic effect in rice breeding. The biochemical as well as physiological aspects at different growing stages should be given due importance.