GENETIC ANALYSIS OF DROUGHT TOLERANCE IN RICE (*Oryza sativa* L.)

by

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(2013 - 21 - 117)

THESIS

Submitted in partial fulfilment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF PLANT BREEDING AND GENETICS

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM – 695 522
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2017

DECLARATION

I, hereby declare that this thesis entitled **"GENETIC ANALYSIS OF DROUGHT TOLERANCE IN RICE (*Oryza sativa* L.)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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ACKNOWLEDGEMENT

It is a great pleasure for me to express gratitude to several personalities who guided and extended all help required directly or indirectly during my study.

I am pleased to place my profound etiquette to ***Dr. C. Lekha Rani Professor, Department of Plant Breeding and Genetics, College of Agriculture, Vellayani*** *and esteemed Chairman of my Advisory Committee for her meticulous guidance, transcendent suggestions, constructive criticism and constant encouragement right from the conceptualization of the research work, to preparation of the thesis. She play a role of mother during my study programme. It gives me immense pleasure to express my deep sense of gratitude to the members of my advisory committee Dr. Arya, K., Professor and Head, (Plant Breeding and Genetics), Dr. S. Leenakumary, Registrar, Kerala Agricultural University,Vellayanikkara Thrissur, Dr. Vijayaraghavakumar, Professor and Head, (Agricultural Statistics), Dr. Roy Stephen, Professor (Plant Physiology), Dr. V.G. Jayalekshmy, Professor (Plant Breeding and Genetics), College of Agriculture, Vellayani, for their valuable and expert suggestions, critical evaluation, everlasting patience and constant encouragement for the present investigation.*

I cordially offer my profound gratitude to my teachers in Department of Plant Breeding and Genetics, Dr. D.S. Radha Devi, Dr. Maya Devi, P., Dr. Mareen Abraham, Dr.P. Manju, Dr. Sunny K. Oommen, Dr. K. M. Abdul Khader, Dr. D.Wilson, Ms. Seeja and Dr. Beena Thomas for their excellent teaching and guidance which enabled me complete my course work. Dr. John Jekob, Dr. C. Gokulapalan, former Professor and Head Dept. of Plant Pathology, College of Agriculture, Vellayani. Dr. Beena,R. Beena chechi helped in my research.

I am extremely grateful to ***Dr. Babu Mathew****, Head of Instructional*

Farm *College of Agriculture, Vellayani for their help and co-operation during my research work.*

I cherish with appreciation the joyful and cheerful company of my colleague Ramling and Rajib who always shared the burden of my work, cheered me in the moments of despair and made the things much smoother.

With boundless affection and love, I would hearty acknowledge the timely help and encouragement of my beloved juniors Vivekanand Jaslum,Vishnu, Rameshwar, Bibhishan, Pritin, Gireesh, Ajinkya, Sachin, Yogesh, Vinay, Siddesh, Darshan, Hari Krishna, Sushama Bhande, Anju Abraham, Pinttu Roy, Pritam, Tejsree, Brunda, Anju Vijayan, Soumya Nair, Murali Krishna, Murali Nagaraju, Nikhitha, Sathishkumar, Aasha, Athul, Reshma, Jeena, Sharanya, Thouseem, Asoontha, Prathibha, Namitha, Ivy, Manu and bellowed seniors Sreenivas and Ganghadhar in whose cheerful company I have never felt my work as burden.

I allocate my highest respect and heartful regards from my inner core of hearts as no words are enough to express the greatest sacrifice, devotion and constant encouragement of my respected and adorable father ***Shri. Haunsajirao Yashawantrao Patil, mother Sou. Satvashila Haunsajirao Patil my brother Ajit and sister Shraddha (Didi), Shalantai*** *who have given me life and taught the concepts of life and their dedicated efforts to educate me to this level and also my grandfather* ***Subhanrao Yashawantrao Ghorpade (Sarkar) Saramjamdar, Deshing, Dist- Sangli*** *supported during childhood stage. My brothers Sayajirao, Dhairyashil, Keshavrao, Vitthoji, Siddharth, Vinayak, Ninad and sisters, Lata, Ujavala, Priyanka, Chhaya, Meena, Vaishali, Deepa, Suvarna, Pratibha also Vaini Sou. Joyti, Kavita, Shubhangi, Suvarna and my mama Rajesahebrao, Govindrao, Hindurao and mami Sau. Anita, Suvarna and Dhanshri.*

I owe immense gratitude to Kerala Agricultural University for providing KAU Senior Research Scholarship.

I express my immense and whole hearted thanks to all my near and dear for their cooperation, help and loving care and concern during the course of study and research.

Patil

KRANTIKUMAR. H. PATIL

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List of Abbreviations

ANOVA	Analysis of variance
BSA	Bovine serum albumin
CID	Carbon isotope discrimination
Cm	Centimeter
dCTP	De oxy cytidine triphosphate
dGTP	Deoxy guanosine triphosphate
DNA	Deoxy ribonucleic acid
dNTP	Deoxy nucleotide triphosphate
DRR	Directorate of rice research
dTTP	Deoxy thymidine triphosphate
EDTA	Ethylene diamine tetra acetic acid
FAO	Food and Agricultural Organization
gca	General combining ability
GCV	Genotypic coefficient of variation
HB	Better parent heterosis
IMD	Indian Meteorological Department
IRRI	International Rice Research Institute
KAU	Kerala Agricultural University
LAI	Leaf area index
Log e	Natural logaritham of X
MJ/g	Megajoule per gram
NAR	Net assimilation rate
NARP	National Agricultural Research Project
PCR	Polymerase Chain Reaction
PCV	Phenotypic coefficient of variation
Ph	Potential of Hydrogen
QTL	Quantitative trait loci
RBD	Randomized block design
RGR	Relative growth rate
RH	Relative heterosis
RLWC	Relative leaf water content
RM	Random markers
RUE	Radiation use efficiency
sca	Specific combining ability
SPAD	Soil and plant analysis
TBE	Tris Borate EDTA
TR	Transpiration rate
μl	Micro liter
UP	Uttar Pradesh
USA	United States of America
UV	Ultra violet rays
WUE	Water use efficiency

INTRODUCTION

1. INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food of more than half of the world human population (Gross and Zhao, 2013). It has the evolutionary particularity of being semi-aquatic. So irrigated or lowland rice is the most common ecosystem, comprising 55% of the global rice area and accounting for 75% of global rice production (Khush, 2005). Acute water scarcity which is on the increase has threatened this ecosystem making a switchover to upland rice ecosystem essential. Upland rice encompasses 12% of global rice production area and is generally the lowest yielding ecosystem.

Over 18 million hectares of cropped area were left unsown during the *kharif* season in 2002. The percentage of kharif crop per acreage cultivation was reduced as compared to the normal cultivation mainly in the states Kerala (-59.3%), followed by Rajasthan (-40.9%), Tamil Nadu (-27.3%) and Uttar Pradesh (-19.4%). During the rabi season, Rajasthan had only 31.95 lakh hectares sown against the normal of 66.69 lakh hectares. The other two states that were affected during the rabi season were Gujarat (-27.9%) and Tamil Nadu (-24.6%) (Karunakaran, 2008). Recently in 2014 the drought affected states include Uttar Pradesh, Punjab and Haryana. In UP there was 6.4 per cent acreage reduction for sugarcane cultivation. The IMD given criteria for determining drought year is that if rainfall is reduced to more than 20 per cent to that of the normal rainfall for that particular area, then that particular year is declared as a 'drought year'.

Kerala's climate is tropical monsoon and tropical savanna, according to Koppen's climatic classification. The state normally experiences excessive seasonal rainfall, with hot summers (except in the extreme southern districts like Trivandrum, where dry season and hot summer climate prevails). The three main seasons of the state are the hot season (March–May), southwest monsoon season (May– September), and northeast monsoon season (October– February). The annual rainfall of the state varies from 3,800 mm over the north to 1,800 mm in the extreme south. The potential rainy season for Kerala is the southwest monsoon period, which contributes more than 80% of the annual rainfall.

Monsoon rain decreases from the north to the south. In recent years, a trend of decreasing rainfall has been seen both in seasonal rainfall and 10-day extreme rainfall duration. In South Kerala, southwest and northeast monsoon rains have decreased by 5% and 8.3%, respectively. Mean annual rainfall is also decreasing in south Kerala. The decreasing rainfall over the region, the late onset of monsoon, the failure of monsoon and the break in monsoon lead to many drought situations in the state. Kerala had severe dry spells and droughts in 1983, 1985, 1986 and 1987, even though the state has a wet climate. There were dry spells of 5 and 4 weeks in 1985 and 1986, respectively, during the southwest monsoon period. Damage due to drought was particularly significant in Kerala in 1987. In 1989, drought resulted in the loss of 60% of the cropped area in Kerala. The southwest monsoon was about 40% of the normal during 1989 in the state.

The coverage of upland rice in India during 2011 was estimated to be 6 million hectares (Anon., 2011). Similar to the rice farming scenario in the country, rainfed uplands in Kerala constitute a negligible part of the total area under rice. NARP status report (KAU, 1984) records that upland (modan) paddy in Kerala constituted only 1.17 per cent of the total gross cropped area in upland agro-ecology of the central region. Statistics point to the existence of 97,069 ha (2.5per cent of total geographical area) cultivable fallow land in Kerala during 2013-14 (December, 2014). This is a pointer to the vast under utilized and untapped potential of upland rice cultivation in our state.

Since land and water is fast becoming a scarce commodity and the scope of expansion of irrigated area under rice in Kerala is very much limited, emphasis on upland rice has become imperative. In liu of this, ample technical and financial supports from state and national agencies have been given in the recent years for promotion of upland rice in the state. During 2011-12, the Department of Agriculture, Government of Kerala paid off with an area of 6539 ha being brought under upland rice cultivation during 2011-12 (Francis, 2013).

In uplands rainfall is the most variable and least predictable environmental component, the amount and distribution of which determines the productivity

(Luo and Zhang, 2001). Variable rainfall can induce water stress to rice at any stage of crop development.

Drought stress is the most severe abiotic stress in upland situations. Rice has relatively few adaptations to drought conditions and is extremely sensitive to drought stress. A definition for drought generally accepted by the plant breeder is "a period of no rainfall or irrigation that affects crop growth"(Fukai and Cooper, 1995). Drought tolerance may be broadly defined as the ability of plants to withstand water deficit while maintaining appropriate physiological activities (Xiong and Ishithani, 2006). According to FAO (2010), by 2050 the world food production will have to increase by 70 % to meet the demand of the growing population. Improving productivity of rice in the upland ecosystem is essential to meet rice food security needs in the future. In this context, breeding drought tolerant upland rice is an increasingly important goal. In this study, with this broad objective in view, an attempt is made to identify traits that contribute to grain yield in rainfed upland rice ecosystem and their inheritance.

Breeding approaches chosen for drought resistance in rice depend on the nature of moisture stress environments. Selection for yield under stress conditions has been reported to be insufficient due to its low heritability, as field variation in soil, water holding capacity and rooting depth begins to directly affect the grain yield. A widely accepted strategy is to select for yield under diverse array of drought prone environments. However, selection for yield under stress conditions, preferably after determining that a variety has reasonable yield potential under more optimum conditions is also practiced widely. A third strategy is the utilization of a number of morphological, physiological and biochemical traits known or suspected to play an important role in drought response. However simultaneous selection in non-stress environment for yield and in stress conditions for stability was recommended by Singh and Sarkar (1985) for selection of drought resistant genotypes.

Studies on heterosis and combining ability of drought adaptive morphological, physiological and biochemical traits under upland condition in addition to grain yield and yield components would provide useful information on the nature and magnitude of gene action involved in their inheritance. This will be a stepping stone in the identification of superior parents for inclusion in breeding programmes for drought situations. Further study of variability, heritability, correlations and path analysis for these traits would provide realistic estimates for screening of varieties for drought tolerance under rainfed upland condition. In this context the present investigation was undertaken at College of Agriculture, Vellayani, Thiruvananthapuram with the following objectives :

To estimate the nature and magnitude of gene effects in the inheritance of drought tolerance in rice under upland conditions.

To screen the parents and best progeny for the presence of molecular markers associated with drought tolerance.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The literature pertaining to the present investigation has been reviewed here under the following heads.

2.1 Upland rice and drought tolerance
2.2 Genetic parameters
2.3 Character association
2.4 Path coefficient analysis
2.5 Selection index
2.6 Combining ability and gene action
2.7 Heterosis estimate
2.8 Molecular analysis studies

2.1 UPLAND RICE AND DROUGHT TOLERANCE

Both stress tolerance and recovery often involve a complex network of molecular and biochemical processes that integrate together to achieve a specific response of the whole crop. Molecular and metabolic responses of plants to a combination of drought and heat stress are unique and cannot be directly extrapolated from the response of plants to each of these different stresses applied individually (Mittler, 2006). There exists a strong relationship between the plant water status and temperature, thus making it very hard to separate the contributions of heat and drought stress under field conditions. These aspects are even more important when we consider future climate change scenarios where seasonal changes in temperature and drought and occurrences of extreme weather events are highly expected. Changes in concentrations of carbon dioxide and other greenhouse gases have caused global surface air temperatures to rise by about 0. 8°C over the last century (IPCC, 2007). It has been suggested that variability in temperature extremes and water deficit events will be more critical in future climates. This was obvious from the 2003 summer heat wave in Europe that resulted in extreme temperature episodes (upto 5°C above normal temperatures) which were sustained throughout summer period

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(Rennenberg *et al.*, 2006). While understanding processes at molecular and cellular level is important, it is even more important to integrate these processes at whole-plant level.

Breeding for drought tolerance is usually performed by selecting genotypes for high yield under water limited conditions (Kumar *et al.*, 2008). This approach has led to the successful development and release of 17 high-yielding drought-tolerant rice varieties in South Asia, Southeast Asia, and Africa. In addition to this, 14 quantitative trait loci (QTLs) showing a large effect against high-yielding drought-susceptible popular varieties were identified using grain yield as a selection criterion. Six of these (*qDTY1.1*, *qDTY2.2*, *qDTY3.1*, *qDTY3.2*, *qDTY6.1*, and *qDTY12.1*) showed an effect against two or more high-yielding genetic backgrounds in both the lowland and upland ecosystems, indicating their usefulness in increasing the grain yield of rice under drought. The yield of popular rice varieties IR64 and Vandana has been successfully improved through a well-planned marker-assisted backcross breeding approach, and QTL introgression in several other popular varieties is in progress (Kumar *et al.*, 2014).

In the following sections will be provided fundamental knowledge of drought stress impacts on significant processes and on agricultural productivity. In addition, some of the important practical traits useful for determination of tolerance will be discussed. In this review, the term *drought stress* is assumed when leaf water contents are lower than optimum turgor for that particular process, growth stage, or plant species.

Impact of Drought on Physiological, Growth, and Developmental Processes

Impact of drought (water stress) on various physiological, growth, developmental, and yield processes are discussed. Although drought and heat stresses have been extensively studied, their effects on crop productivity is variable. Drought was found to alter physiological processes such as photosynthesis, accumulation of lipids, and transcript expression (Jagtap *et al.* , 1998; Jian and Huang, 2001). The impact of drought and heat stress in combination or isolation on important physiological, growth, developmental and yield processes are described in the following sections, which can be highly variable. Therefore, the effects are discussed in a more generalized fashion, and sufficient care should be taken while making specific conclusions regarding a particular crop or variety within a crop species which can differ in its responses. In addition, it should also be considered that drought impacts on these various processes and traits depend on the intensity, rate of increase, duration of stress, and stage of crop development.

2.1.1 Morphological Studies

2.1.1.1 Days to 50% Flowering

O'Toole and Chang (1979) have suggested that by appropriate selection, photoperiodic control of flowering could be used in regions of bimodal rainfall distribution to ensure that flowering and grain filling in rice would occur during the peak monsoon season. The link between earliness to flowering and yield under conditions of drought has been widely studied in rice (Krishnamurthy *et al.* , 1971).

In some cultivars, heading was significantly accelerated by drought and this might allow those cultivars to complete the sensitive processes of pollination and embryo development (Ekanayake *et al.*, 1990) before stress becomes too severe. Heading time in rice is controlled by a complex genetic system that interacts with environmental factors, such as photoperiod, temperature, and soil fertility (Li and Yu, 2003). Lafitte and Courtois (2002) reported that association between earliness and greater drought tolerance was observed in the upland evaluation of the donors in different experiments.

A negative association between leaf water potential and delay in flowering has been reported under upland and lowland stress conditions in rice (Sibounheuang *et al.*,2001), with a longer delay in flowering taken as an indication of a cultivar's susceptibility to drought (Pantuwan *et al.*, 2001). They also reported that delay in flowering under drought may be used as an integrative trait to identify drought resistant cultivars. Ontogenetic characters, especially appropriate flowering time, play an important role in drought avoidance of rainfed lowland rice (Fukai *et al.*, 1999).

Rajatasereekul *et al.* (1997) demonstrated the effect of flowering time in determining grain yield and Jongdee *et al.* (2002) pointed out that phenology is the most important factor. Timing, intensity, and occurrence of water deficit have been associated with delay in heading or flowering (Fukai *et al.*, 1999).

Water deficit at anthesis and during maturation stage delayed flowering and grain development resulting in high spikelet sterility and lower grain yield in rice (Kumar and Kurju, 2003).

2.1.1.2 Nature of Panicle Exsertion

Inhibition of panicle exsertion (O'Toole and Namuco, 1983) is an interesting example because it is often only partially reversible on re-watering. The critical period for rice, when drought stress most severely affects yield, is in the panicle development-to-anthesis stage (Matsushima, 1966; Cruz and O'Toole, 1984).

Reduction in leaf water potential at anthesis may cause poor exsertion of the panicle (Cruz and O'Toole, 1984; Ekanayake *et al.*,1989) and increase the percentage of sterile spikelets because of pollination abnormalities (Ekanayake *et al.*, 1989, 1990).

Boonjung and Fukai (1996) reported that poor panicle exsertion was the main cause for spikelet sterility which in turn reduces the yield by about 30%. Panicle exsertion under drought situation indicated its importance in determining the yield and is positively correlated with grain yield and harvest index (Subashri *et al.*, 2008).

Spikelet sterility was also found to be affected by a slower rate of panicle exsertion due to water stress (O'Toole and Namuco, 1983).

2.1.1.3 Number of Productive Tillers Plant^{1}

Rice plants respond to drought by decreasing numbers of new tillers and leaves, reducing leaf elongation, rolling existing leaves, and promoting leaf death

(Cutler *et al.*,1980; Hsiao *et al.*,1984; Turner *et al.*,1986 and Abarshahr *et al.*, 2011). Drought stress suppresses leaf expansion, tillering and midday photosynthesis. In rice, tillering is associated with the development of new roots from tillers. Therefore profuse tillering is generally associated with dense and shallow roots while limited tillering is associated with sparse and deeper roots and this is one of the reasons why most of the cereal crop cultivars developed in dry regions show the habit of limited tillering (Kramer and Boyer, 1995).

Vijayalakhsmi and Nagarajan (1994) reported that reduction in tiller production of drought resistant varieties was marginal under drought situations as compared to susceptible varieties. A mild stress at vegetative growth stage decreased tiller number (Cruz *et al.*, 1986).

2.1.1.4 Plant Height at Maturity

Growth involves both cell growth and development which is a process consisting of cell division, cell enlargement and differentiation and these processes are very sensitive to water deficit because of their dependence upon turgor (Jones and Lazenby, 1988). The general reduction in plant height with increase in water deficit in rice agrees with results of Siddique *et al.* (2000) in wheat. The inhibition of cell expansion is usually followed closely by a reduction in cell wall synthesis which affects plant height in rice (Salisbury and Ross, 1992).

In general, moisture stress results in reduced plant height and the susceptible types are more sensitive than upland rice varieties (Basu Raychaudhuri and Das Gupta, 1981).

Vijayalakshmi and Nagarajan (1994) reported a marginal reduction in plant height in resistant rice varieties with well developed root system. Russo (2000) observed that plant height was slightly lowered in aerobic condition than standard types of culture.

Lafitte *et al.* (2006) reported that relationship between plant height and drought resistance is particularly relevant to the presence of the semi-dwarf gene, *sd1*. The *sd1* gene, which affects gibberelic acid synthesis (Ashikari and Sasaki

2002), was reported to have pleiotropic effects on yield-related traits such as sink size. In addition, the semi-dwarf habit is often associated with characteristics like high tillering and shallow rooting, due either to pleiotropic effects or genes closely linked to *sd1*.

2.1.1.5 Panicle Length

Abarshahr *et al.* (2011) reported highest panicle length of 35. 86 cm under optimum irrigation regimes and 35. 2 cm under drought condition in the rice cultivar Nemat, while the lowest panicle length was observed in the cultivar Araguaya which was 27. 35 and 22. 30 cm under optimum irrigation regime and drought condition respectively.

Kuixian *et al.* (2012) observed a slight reduction in panicle length under drought in *Zhenshan* 97B but a rate of reduction upto 8% was observed in the cultivar IRAT109.

2.1.1.6 Number of Spikelets Panicle^{-1}

Abarshahr *et al.* (2011) estimated genetic variability and relationships among some agronomic traits of rice in an experiment conducted with 30 varieties of rice under two irrigation regimes. They observed that Nemat cultivar had the highest spikelet number of 209. 33 under optimum irrigation regimes which was reduced to 104 under drought condition.

2.1.1.7 Number of Filled Grains Panicle^{-1}

Wopereis *et al.* (1996) pointed out that severe drought in the reproductive phase resulted in large yield reductions, mainly due to increased numbers of unfilled grains and reduced grain weight.

Significant reduction in number of panicles plant^{-1}, per cent of filled grains panicle^{-1} and harvest index (HI) was reported in rice under water stress condition (Neog *et al.*, 2002).

Abarshahr *et al.* (2011) reported that Nemat cultivar showed high phenotypic value under both irrigation regimes for number of filled grains panicle^{-1} which was 209.33 and 104 under optimum irrigation and drought condition respectively.

2.1.1.8 Spikelet Sterility (%)

When water deficit occurs near the time of flowering, it reduces rice yield primarily as a result of increased spikelet sterility and is closely related to minimum leaf or panicle water potential during the stress period (Cruz and O' Toole, 1984). In a study Boonjung and Fukai (1996) reported that the most sensitive yield component was spikelet fertility, and it was most sensitive at about flowering. Among the events known to be drought-sensitive at this stage are anther dehiscence (Ekanayake *et al*., 1989, 1990) and panicle exsertion (O'Toole and Namuco, 1983).

Stress soon after panicle initiation reduces the number of spikelet primordia that develop. When drought stress occurs later during meiotic division or at anthesis, then sterility of florets is increased and consequently there is a lower percentage of filled grains (O'Toole and Chang, 1979).

Cruz and O'Toole (1984) observed a high spikelet sterility of 73% when drought stress developed during the flowering stage. They also found that upto 30% of this spikelet sterility was associated with poor panicle exsertion. Similarly, Cruz and O'Toole (1985) found that drought stress during flowering reduced the percentage of filled grains and number of grains per panicle. Ekanayake *et al*. (1989) reported that drought stress had an adverse effect on pollen viability and this caused sterility.

Sheoran and Saini (1996) reported that changes in carbohydrate levels and enzyme activities associated with inhibition of starch accumulation in pollen, are potential causes of spikelet sterility. Spikelet sterility was also found to be affected by a slower rate of panicle exsertion due to water stress (O'Toole and Namuco, 1983).

Rice is more sensitive to drought stress during reproductive stage. Moisture stress at booting and flowering reduces height, dry matter production, delays panicle initiation and induces uneven flowering and sterility of spikelets. Studies on panicle water relations (Garrity and O'Toole, 1995; Pantuwan *et al.*, 2002), abnormalities of gamete formation and panicle exsersion (Cruz and O'Toole, 1984) established the impact of different causes resulting in spikelet sterility due to drought during the reproductive phase and finally ending up in yield loss.

Jongdee *et al*. (2002) observed that yield reduction of 40% occurred due to the increment of spikelet sterility when drought occurred during grain filling period.

Spikelet sterility is related to assimilation during anthesis and lots of genetic variations have been reported (Pantuwan *et al*., 2002; Babu *et al*., 2003). Lines able to regulate and conserve water loss from exserted spikelets and maintain higher panicle water potential (Pantuwan *et al*., 2002) appeared to be the most desirable for reducing drought induced sterility.

Liu *et al*. (2005) reported that spikelet sterility increased due to the incidence of water stress in the main field thereby reducing grain yield.

Pinheiro *et al*. (2006) reported that integrative and secondary traits of leaf rolling, good panicle exsertion and low level of spikelet sterility were used as selection criteria for drought resistance.

2.1.1.8 Grain Weight Panicle^{-1}

Abd Allah *et al*. (2010) Conducted a series of experiments under normal and drought conditions to examine the magnitude of yield response of diverse genotypes to drought stress and to identify traits that may confer drought resistance. He reported that grain weight panicle^{-1} was reduced under drought condition.

2.1.1.9 1000 Grain Weight

Drought stress occurring during the period of flowering can increase embryo abortion and/or reduce single grain weight (O'Toole and Chang, 1979; Rahman and Yoshida, 1985). Cruz *et al*. (1986) reported that mild stress at vegetative stage resulted in linear decrease in 1000 grain weight in rice. Grain number is determined by the number of spikelets at anthesis and the proportion of spikelets which produce grains (filled-grain percentage). The number of spikelets is directly related to the rate of assimilation between panicle initiation and anthesis, regardless of whether the assimilate production is altered by water stress or shading (Boonjung, 1993).

Liu *et al*. (1993) also observed that water stress at booting and heading to flowering stages reduced the number of productive tillers, grain number panicle^{-1}and 1000 grain weight.

Nieuwenhuis *et al*. (2002) reported that number of grains panicle^{-1} and 1000 grain weight were reduced when the crop was exposed to stress condition.

The reduction in grain yield in rice with water stress was mainly due to decrease in the number of filled grains panicle^{-1} and 1000 grain weight depending upon the severity of stress (Jana and Ghildyal, 1971; and Surek and Beser, 1999).

2.1.1.10 Grain Yield Plant^{-1}

The productivity of cereals depends not only on the accumulation of dry matter, but also on its effective partitioning to plant parts of economic importance and this is a key to yield stability particularly under drought stress. Remobilization of reserves to grain is critical for grain yield if the plants are subjected to water stress during grain filling (Nicolas *et al*., 1985; Palta *et al*., 1994; Ehdaie and Waines, 1996).

Among cereals, pre-anthesis assimilates help in yield stability during terminal drought stress (Blum *et al*., 1983). In wheat, pre-anthesis assimilate reserves from stem and sheaths contribute 25–33% of the final grain weight (Rawson and Evans, 1971; Gallagher *et al*., 1976; Hans, 1993; Gebbing and Schnyder, 1999). In cereals, grains are the most important sink for carbon and nitrogen after anthesis.

In rice, available carbon assimilates for grain production is determined by carbon assimilation during the grain-filling period plus assimilate reserves stored in the straw (Cook and Yoshida, 1972). Pre-anthesis storage may contribute to

20–40% of the final crop yield depending on cultivar, reflecting its importance for attaining higher grain yields (Yoshida, 1972; Murata and Matsushima, 1975).

Boonjung and Fukai (1996) reported that stress developed during panicle development stage reduces the yield by around 30% due to the reduction in number of spikelets panicle^{-1}.

Pantuwan *et al.* (2002) suggested that a drought intensity that causes a 50% yield reduction is considered a critical point for the expression of drought tolerance mechanisms in rice.

Jongdee *et al.* (2002) reported yield reduction of 40% due to increment of spikelet sterility when drought occurred during grain filling period.

Grain yield under drought has been reported to be a function of biomass production and harvest index at the vegetative and reproductive stages (Atlin *et al.*, 2008).

Abarshahr (2011) reported that the best paddy yield was obtained from Nemat cultivar under both optimum irrigation regime (7430.4 kg ha^{-1}) and drought stress conditions (5126.6 kg ha-1). By contrast, the lowest paddy yield was achieved from Domsephid cultivar under optimum irrigation regime and drought conditions which was 2094. 8 and 1565.9 kg ha^{-1}, respectively.

2.1.1.11 Straw Yield Plant $^{-1}$

Biomass production declines under water stress. Lilley and Fukai (1994a) reported that water stress reduces biomass production in rice and the degree of reduction depended upon the severity of moisture stress.

Yang *et al.* (1995) also reported that dry matter yield of rice genotypes was reduced by 11 to 37 percent and 30 to 65 percent under mild and severe stress conditions.

Simane *et al.* (1993) reported that the total dry matter accumulation rate differed between drought resistant and susceptible cultivars.

Chauhan *et al.* (1996) reported that cultivars differed in their ability to produce dry matter under stress. The total biological yield was the highest in continuous irrigation and the lowest in irrigation at eight day interval after tiller initiation (Surek and Beser, 1999).

2.1.1.12 Harvest Index

Harvest index indicates the efficiency of translocation of food assimilates from the vegetative tissue to the reproductive tissue and it serves as a means to predict grain yield in many crops. Harvest index is the ratio between economic yield and biological yield and it is a measure of production efficiency of the plant to partition its total photosynthate into economic and non-economic sinks.

Reuben, and Katuli (1990) reported that harvest index had shown a consistent association with grain yield under water stress.

Yamauchi *et al.* (1994) reported that grain yield is the product of dry matter accumulation and harvest index.

Rao and Saxena (1999) reported that harvest index could be one of the major selection criteria for yield improvement in rice under water stress.

Shanmugasundaram *et al.* (2002) suggested that while selecting superior genotypes for cultivation under rainfed situations, grain yield, harvest index and straw yield should be considered as selection criteria.

Lanceras *et al.* (2004) reported that the value of correlation coefficient of harvest index and grain yield as drought intensity increases, thereby confirming the importance of harvest index as an indicator of grain yield.

2.1.1.13 Leaf Rolling

Chang *et al.* (1974) used leaf rolling and leaf death for assessing levels of field tolerance for drought, while O'Toole *et al.* (1979) found that it could be used as an estimate of dehydration avoidance.

O'Toole and Moya (1978) reported that visual scoring techniques based on either leaf rolling or leaf tip drying were highly correlated with maintenance of leaf water potential.

0' Toole and Moya (1978) conducted studies by visual scoring and diurnal sampling on leaf water potential (LWP) in 20 days old plants and reported that leaf rolling and tip firing were highly correlated with maintenance of LWP.

O'Toole and Chang (1979) observed that leaf rolling under controlled conditions decreased the rate of transpiration by upto 50 percent. Leaf rolling is one of the water stress symptoms of rice utilised in visual scoring (O'Toole and Maguling, 1981). Leaf rolling decreases transpiration from rice leaves and along with stomatal closure may contribute to varietal difference in maintaining LWP. Leaf rolling and leaf death occurs as a result of soil water deficits.

Turner (1982) regarded leaf rolling (LR) as an alternate drought adaptive mechanism with reversible decrease in leaf area and is one of the effective ways of radiation shedding.

Hsiao *et al.* (1984) reported that when leaves roll, the effective area of light interception is reduced and the diffusive resistance to CO_2 is increased, both of which will reduce photosynthesis. However, Turner *et al.* (1986) contradicted this and opined that as leaf rolling (LR) does not occur in the absence of water stress and because it is reversible and reduces light interception there would be no yield penalty. They observed genotypic difference with reference to LR and attributed this to delayed or reduced LR to better osmotic adjustment in rice.

A limitation on the use of visual scoring as an index for drought tolerance is that it does not distinguish between tolerance and avoidance mechanisms. It is well known that one such avoidance mechanism involves the ability of deep roots to be able to gain access to water in the deeper soil horizons. Variation of leaf rolling and its physiological significance under soil water limiting conditions in rice was studied by Tanimoto *et al.* (1999).

Several mechanisms of drought resistance are associated with shoot related symptoms of rice. On reduction of their water status and loss of turgor under stress, plants display various and very distinct symptoms. Symptoms progress in proportion of plant water deficit and they can be visually scored and used in selection. Leaf rolling is an expression of wilting in rice and it has received much attention in selection process. Rolled leaves of rice transpired 4% less water than the unrolled ones (Singh and Singh, 2000).

Blum (2004) reported that leaf rolling reduces water loss in addition to reducing the leaf area exposed to heat and light radiation. Varieties differ in their ability to roll leaves under similar water deficit (Dingkuhn *et al.*, 1989a; Turner *et al.*, 1986; Price and Tomos, 1997). There is some evidence that enhanced ability to roll leaves confers a yield advantage under drought conditions (Singh and Mackill, 1991). But most breeders consider the triggering of leaf rolling as an indication of a plant suffering and select against its early manifestation (Price and Courtois, 1999).

2.1.1.14 Incidence of Pests and Diseases

Rice blast is the most common and destructive disease in irrigated rice of both temperate and subtropical areas of East Asia (Bonman *et al.*, 1991). The disease attacks on leaves, stem nodes, all parts of the panicle and grains (Chin, 1974). The disease was divided into leaf and panicle pathosystem (Teng *et al.*, 1991). Plants got the highest disease at maximum tillering stage then gradually declined, mainly due to adult plant resistance (Yeh and Bonman, 1886; Koh *et al.*, 1987). Then after it infects in panicle and neck node. Although leaf infection is sometimes found at the reproductive and ripening stages, the destructive symptoms during these stages is neck blast, characterized by infection at panicle base (Bonman *et al.*, 1991). Blast epidemic causes complete loss of seedling in nursery (Teng *et al.*, 1991 and Chaudhary *et al.*, 1994)).

Puri *et al.* (2006) reported that the severity of rice blast disease (*Pyricularia grisea*) of both leaf and neck varies with different environment and it becomes destructive under favorable condition in Nepal. The leaf and neck blast resistance and susceptible interaction of 30 different tropical rice lines were evaluated under low-, mid- and up-land conditions of Chitwan district and classified on the basis of disease severity with respect to susceptible check, Masuli. Out of these, 5, 10, 12 and 3 rice lines were resistant to leaf blast, moderately resistant, moderately susceptible and susceptible, respectively.

Similarly, for neck blast nine lines were resistant, thirteen moderately resistant, seven moderately susceptible and one was susceptible. The progenies from Masuli/MT4 had the highest leaf and neck blast susceptible reaction, while most of progenies from IPB (Irradiated Pusa Basmati), KalinghaIII, IR64, Radha 32 KIII and Masuli IR64 were resistant, and the most promising sources against leaf and neck blast resistance. The progeny of these parents can be used in plant breeding programme.

2.1.2 Physiological and Biochemical Studies

2.1. 2.1 Water Use Efficiency (WUE)

Water use efficiency (WUE) is the ratio between carbon gained for water used which is considered to be an important trait for conditions of limited water supply (Nguyen *et al*., 1997).

Dingkuhn *et al*. (1991) estimated the WUE in rice by the Carbon isotope discrimination technique and reported higher WUE in *Oryza sativa,* sub sp. *japonica* than *indica* rice. Considerable variation in WUE has been reported among different species of *Oryza* with wild species having higher WUE than cultivated species (Yeo *et al*., 1993). Genotypic differences for WUE have been reported (Dingkuhn *et al*., 1991 and Scartazza *et al*., 1998). Scartazza *et al*. (1998) reported that decreased carbon isotope discrimination in upper internodes and high WUE during flowering showed low spikelet sterility and high yield stability.

However, in wheat, most drought susceptible (lower yielding) genotypes had higher WUE, while the most drought resistant genotypes had the lowest WUE when subjected to conditions of soil moisture stress (Morgan *et al*., 1993). This is because of genotypic variation for moisture extraction capacity from deep soil. Similarly Kobata *et al*. (1996) reported that the high dry matter production of rice cultivars known to be drought resistant under field conditions could be related to an ability to maintain transpiration supported by deep root system and not because of higher WUE. Therefore, WUE can be either positively or negatively related to production under stress, which is largely dependent on the genotypic capacity to sustain transpiration and WUE alone might be questionable as a selection criterion (Price and Courtois, 1999). The technique of carbon isotope discrimination to measure WUE must be used very carefully if data are not to be confounded by differences in water availability which might exist between plants with different root architectures.

2.1.2.2 Relative Water Content (RWC)

Relative water content measures the water of a leaf relative to the maximum amount that the leaf can take under full turgidity and hence it is considered as an appropriate measure of plant water status under stress. Maintenance of requisite leaf water status is of paramount importance in rice (Cornic and Massacci, 1996). There was no relationship of water relations with stomatal conductance and transpiration rate, although it was strongly correlated with net photosynthesis. Cabuslay *et al.* (1999) reported that tolerant plants maintain the water content of tissues, or survive a reduction in tissue water content, or recover more completely after rewatering.

Sairam and Dube (1984) reported that relative water content in leaf tissue decreased in all the rice genotypes under moisture stress as compared to control plants. Plant water status, measured as leaf water potential, leaf rolling or drying score or leaf relative water content can differ significantly among cultivars exposed to same period of water exclusion (O'Toole and Moya, 1978).

Thangaraj and Siva Subramanian (1990) reported that drought resistant cultivars of rice maintained relatively higher RWC.

Drought resistant varieties showed higher leaf water potential in their tissues than susceptible ones under moisture deficit (Swamy *et al.,* 1983; Nadarajan and Kumaravelu, 1993). The genotypes maintaining higher relative water content accumulates more solutes and had higher photosynthesis (Krishnayya and Murthy, 1991) and higher recovery upon stress relief (Saxena *et al.*, 1996 and Jha and Singh, 1997).

The maintenance of plant water status more than plant functions, controls crop performance under drought (Blum, 2002). Leaf water potential is closely related to leaf relative water content, but it is confounded by osmotic adjustment, stronger correlations might be found between yield and RWC under water stress (Lafitte, 2002).

Kumar and Kujur (2003) pointed out that maintenance of higher water status under drought plays a major role in stabilizing the various plant processes and yield.

Teulat *et al.* (2003) reported that relative water content (RWC) was a relevant screening tool for drought resistance in cereals, as it was a good indicator of plant water status.

Water content is a commonly used measure of moisture status and is usually expressed as relative water content (RWC). According to Lawlor (1995), RWC of 100- 90% is related to stomatal closure and decreased cell expansion and growth of organs and 90-80% is related to changes in composition of tissues and some alterations in the relative rates of photosynthesis and respiration. Further, with RWC below 80% changes in metabolism become marked with cessation of photosynthesis, much increased respiration and accumulation of proline and ABA. The cultivars that are drought tolerant might suffer only mild water stress involving stomatal limitation of photosynthesis, whereas intolerant ones could have suffered effects on photosynthesis (Cabuslay *et al.*, 1999). Many scientists have used RWC as an indicator of drought tolerance in rice (Saxena *et al.*, 1996; Price *et al.*, 1999; Ravindrakumar *et al.*, 2002; Babu *et al.*, 2003).

2.1.2.3 Proline Content

Singh and Singh (1983) observed that proline accumulation under drought condition is a good indicator of drought tolerance capacity of plants. Proline is one of the important osmolytes which accumulates during moisture stress condition. It helps to maintain turgor and promotes continued growth in low water potential soils (Mullet and Whitsitt, 1996). High proline content is a good index for water deficit resistance in genotypes. In rice, proline accumulation in response to water stress (Zhang *et al.*, 1997) is more in shoots than in roots (Pandey *et al.*, 2004).

Vajrabhaya *et al.* (2001) reported that after five weeks of drought treatment, 9-15 fold increase in proline content was detected in the drought tolerant lines.

Increased proline accumulation was often observed with N supply in green bean plants (Sanchez *et al.*, 2001). Among the common response in plants to abiotic stresses is the production of different types of organic solutes (Serraj and Sinclair, 2002), which include small molecules such as proline (Szabados and Savouré, 2010; Tan *et al.*, 2008; Szabados and Savouré, 2010). Production and accumulation of proline by plant tissue during drought is an adaptive response. Proline acts as a compatible solute that adjusts the osmotic potential in the cytoplasm. It can be used as a metabolic marker in relation to stress (Caballero *et al.*, 2005).

Vendruscolo *et al.* (2007) stated that proline might confer drought stress tolerance to wheat plants by increasing the antioxidant system rather than as an osmotic adjustment.

Tatar and Gevrek (2008) reported stress enhanced proline content in leaves. It may possibly play an important role in the osmoregulation under moisture stress condition. Mostajeran and RahimiEichi (2009) suggested that the production of proline is a common response of plants under drought conditions. High proline content is a good index for moisture resistance in genotypes. Under moisture stress condition the protein degrades and consequently the proline content increases (Roy *et al.*, 2009). Both free proline and ABA generally showed an increase under water stress conditions and the varietal differences in the accumulation of these osmolytes were also reported (Abdellah *et al.*, 2011).

Maisura *et al.* (2014) reported that physiological characters of rice varieties differed in their response to drought stress. However, drought reduced chlorophyll a, chlorophyll a/b ratio, and grain yield, but increased proline. Tolerant rice varieties experiencing drought had better osmoregulation, in terms of proline and total sugar content. Meanwhile, tolerant varieties (Ciherang, Way Apo Buru, and Jatiluhur) tended to accumulate proline over a longer period of time and had a higher total sugar accumulation. Jatiluhur varieties experiencing drought showed higher yield and stability than other varieties. Lesser reduction in grain yield during drought, accumulation of proline over a longer period of time and an increase in total sugar accumulation at anthesis phase during drought were physiological characters that played an important role in tolerance against drought in paddy systems.

Kumar *et al.* (2014) reported that drought stress condition caused average increase in proline content (61.45%) across genotypes as compared to irrigated. Highest value of proline content was observed in IR83376-B-B-24-2 followed by IR83387-B-B-40-1 and IR84895-B-127-CRA-5-1-1 under drought stress condition.

2.1.2.4 Cell Membrane Stability Index

The cell membrane is one of the main cellular targets common to different stresses (Levitt, 1980). The extent of its damage is commonly used as a measure of tolerance to various stresses in plants such as freezing (Dexter, 1956), heat, drought (Blum and Ebercon 1981) and salt (Leopold and Willing 1983). Bewley (1979) reviewed the desiccation tolerance in higher plants and concluded that the critical features of desiccation tolerance depend on the abilities to limit membrane damage during water stress and to regain membrane integrity and membrane bound activities quickly upon rehydration. Cell-membrane stability or the reciprocal of cell membrane injury is a physiological index widely used for the evaluation of drought and temperature tolerance (Sullivan 1972; Martineau *et al.* 1979a; Blum and Ebercon 1981; Sadalla *et al.*1990a; Reynolds *et al.* 1994; Fokar *et al.*1998a). This method was developed for a drought and heat tolerance assay in sorghum and measures the amount of electrolyte leakage from leaf segments (Sullivan, 1972). Its reliability as an index of heat stress tolerance is supported in several plant species by a good correlation between CMS and plant performance in the field under high temperature stress (Martineau *et al.* 1979a).

Drought stress induces membrane deterioration leading to severe metabolic dysfunction. The maintenance of membrane stability during severe desiccation is important for normal physiological metabolism to continue under low water potential. Phenotype selection for CMS may not always yield accurate results for breeding purposes because of its complex nature and its strong interaction with the environment (Nir *et al.*1969; Buttrose and Swift 1975).

2.1.2.5 Chlorophyll Content

Mohan *et al.* (2000) stated that chlorophyll content is an indication of stress tolerance capacity of plants and its high value means that stress did not have much effect on chlorophyll content of tolerant plants.

Anjum *et al.* (2003) and Farooq *et al.* (2009) reported that drought in several plant species can cause a change in the chlorophyll a/b ratio and carotenoid content. A high chlorophyll a/b ratio was found in Silugonggo, followed by IPB 3S varieties. The value of the chlorophyll a/b ratio depends on the chlorophyll a and chlorophyll b content of each variety.

Gowri (2005) observed decrease in chlorophyll content under water scarcity situation than irrigated environment.

Maisura *et al.* (2014) reported that physiological characters of rice varieties differed in their response to drought stress. However, drought reduced chlorophyll a, chlorophyll a/b ratio, and grain yield, but increased chlorophyll b content.

Kumar *et al.* (2014) reported that chlorophyll content of drought tolerant genotypes as well as check varieties (IR64, Sahbhagi Dhan and Shusk Samrat) was higher under normal (irrigated) condition. Rice genotypes IR83376-B-B-24-2, IR83387-B-B-40-1 and IR84895-B-127-CRA-5-1-1 maintained higher chlorophyll content in comparison to other genotypes and check varieties under drought stress condition. Significant genotypic differences in chlorophyll content were observed under stress condition.

2.1.2.6 Chlorophyll Stability Index

Ananthi *et al.* (2013) reported that the chlorophyll stability index is indicative of the maintenance of photosynthetic pigments under drought situation. The cross KC 2 X MCU 13 in both F_1 and F_2 generations have recorded higher values (68.36 and 74.47%) at boll development stage than the rest of the combinations and parents irrespective of treatments, indicating that this combination possesses drought tolerance characteristics. Stress given at vegetative and squaring stages invariably show reduction in CSI. Among the genotypes KC 2 and AS 2 maintained good mean values (71.89, 73.31; 72.22; 68. 26, 68.74; 70.62 at vegetative, squaring and boll development stages, respectively) which indicates that these two genotypes are able to withstand drought condition. On the other hand, the genotypes MCU13 and KC3 were found to rank medium, indicating a moderately tolerant nature as far as moisture stress was concerned. The susceptible genotype Surabhi showed the lowest mean values of 56.13, 58.41 and 61.36 at vegetative, squaring and boll development stages, respectively. Higher levels of days to 70 percent RWC, chlorophyll stability index and lower levels of leaf rolling, leaf drying and drought recovery rate were observed in drought tolerant lines than in the susceptible ones (Gomez and Rangasamy, 2002; Anbumalarmathi *et al.*, 2005). Wider variation was noticed between the control and drought stress plants for chlorophyll stability index. Under a normal growth condition, a slight variation for CSI was seen among the genotypes. Significant differences were noticed when the same genotypes were exposed to water deficit condition. Higher CSI indicated that the level of polyunsaturated lipids stabilized chloroplast membrane and increased adaptive response to tolerance under water stress condition (Deivanai *et al.*, 2010).

2.1.2.7 Leaf Temperature

A cooler canopy temperature under stress has been reported to be a measure of drought avoidance (Blum, 1988), which indicates maintenance of higher transpiration. Canopy temperature is usually lower in plants having a better leaf water status and is negatively correlated with productivity under stress (Garrity and O'Toole, 1995; Blum *et al.*, 1999). Leaf temperature increased with increasing water stress and was generally low in drought tolerant cultivars (Ravindrakumar *et al.*, 2002).

Canopy temperature is an indicator of plant water status and must be used very carefully to give repeatable results. Canopy temperature is affected by the relative amount of dessicated and dead leaves in canopy (Lafitte *et al*., 2003).

2.1.2.8 Transpiration Rate (TR)

Transpiration is a vital process in the life cycle of plants, which gives cooling effect besides promoting water and nutrient absorption (O'Toole and De Datta, 1986). The rate of water intake is determined largely by the rate of water loss by transpiration (Kramer, 1937) and is most sensitive to water stress (Hsiao, 1973). Transpiration rate was reduced markedly by water stress (Dingkuhn *et al*., 1989b; Kobata *et al*.,1996; Cabuslay *et al*.,1999; Wade *et al*., 2000; Ravindrakumar *et al*., 2003). Cultivar differences for this trait were reported by many authors (Kobata *et al*., 1996; Cabuslay *et al*., 1999; Wade *et al*., 2000; Cabuslay *et al*., 2002). In general, cultivars with high relative transpiration were rated tolerant on the basis of leaf rolling and leaf drying, which further supports the role of transpiration in water uptake and cell enlargement. A high transpiration rate under conditions of water deficit also implies high stomatal conductance, which is associated with continued water extraction (Cabuslay *et al*.,1999 and Kamoshita *et al*., 2000). The results on genotypic variation in relative transpiration by Cabuslay *et al*. (1999) suggested that drought tolerant genotypes maintained fairly open stomatas under stress. Relative transpiration during water deficit was highly and positively correlated with relative leaf area (Cabuslay *et al*.,1999), which is expected because the leaf is the organ of transpiration. Leaf expansion is much more sensitive to water stress and maintenance of leaf area is necessary under rainfed environments. At the onset of drought and especially when solar radiation is high, having an initially large leaf area may be disadvantageous to plants because of high transpirational demand that is not met due to limited water supply. Initial leaf area was negatively correlated with relative transpiration and positively correlated with visual drought score. This indicates that small leaf area initially gives the advantage of having less leaf surface exposed to intense solar radiation so that, at the onset of drought, photorespiration and water loss from leaf tissues are minimized.

As the rate of transpiration decreases, the amount of dissipated heat increases, resulting in a decline in net photosynthesis (Yokota *et al.*, 2002). An early response to water deficit is a reduction in leaf area and plant growth, which allows plants to reduce their transpiration, thus increasing water use efficiencies (WUE) (Xu and Zhou, 2006; Monclus *et al.*, 2006; Aguirrezabal *et al.*, 2006), and promoting interspecies competition capacity under drought (Xu *et al.*, 2007).

Higher yielding genotypes of cotton, wheat and rice have greater stomatal conductance and transpiration under drought stress (Araus *et al.*, 2002; Blum *et al.*, 1983; Izanloo *et al.*, 2008; Sanguineti *et al.*, 1999). Evapotranspiration at the leaf surface lowers leaf temperature and higher stomatal conductance enhances this leaf cooling. Stomatal closure helps to maintain high leaf water content and thereby a higher leaf water potential, which leads to a reduction in photosynthetic activity. When plants undergo moisture stress, the decrease in the internal water potential results in the closure of stomata which inturn reduces the rate of transpiration and photosynthesis (Ishihara and Saito, 1987).

Sikuku *et al.* (2010) reported that transpiration rates in the NERICA rice varieties generally decreased with increase in soil water deficit. Decrease in transpiration may be due to increased hydraulic resistance to the movement of water at the leaf and root surfaces (Kingsbury *et al.*, 1983). Transpiration is controlled by the closing and opening of the stomata. Guard cells lose their turgidity under soil moisture deficit conditions causing stomatal closure. This limits the rate of CO_2 diffusion through the stomata causing a decline in the photosynthetic rates (Luvaha, 2005).

2.1.2.9 Stomatal Conductance (SC)

Stomatal conductance is the speed at which water evaporates from pores in a plant, and is directly related to relative size of the stomatal aperture. Basically, higher the evaporation rate, higher the conductance of the leaf. When the available water is limiting, plants tend to close their stomata (Cornic and Massacci, 1996), resulting in reduced inflow of CO_2 into the leaves for fixation.

Many studies have shown that water deficit leads to an increase in stomatal density (McCree and Davis, 1974; Cutler *et al.*, 1977; Yang and Wang, 2001; Zhang *et al.*, 2006), and a decrease in stomatal size (Cutler *et al.*, 1977; Quarrie and Jones, 1977; Spence *et al.*, 1986), indicating an enhanced adaptation of plant to drought (Cutler *et al.*, 1977; Spence *et al.*, 1986; Martinez *et al.*, 2007).

Fisher *et al.* (1998) reported that stomatal conductance, photosynthesis and canopy temperature were closely and positively correlated with yield in spring wheat. Plants exposed to water stress closed their stomata to maintain their inner moisture content and consequently, their transpiration and photosynthetic rates and productivity decreased (Turner *et al.*,1986).

Another mechanism of drought avoidance in rice is quick stomatal closure which acts to reduce water loss (O'Toole and Cruz, 1980). Genotypic differences in the sensitivity of stomatal conductance to leaf water status have been reported (Dingkuhn *et al.*, 1989; Dingkuhn *et al.*, 1991; Price *et al.*, 1997; Hoque and Kobata, 1998). The stomata of rice plants close noticeably in response to a reduction in leaf water potential causing marked reduction in photosynthetic rate (Hirasawa *et al.*, 1999).

Yeo *et al.* (1997) observed that plants had a stomatal conductance greater than expected for their carbon assimilation rate. They concluded that improvement in water acquisition is important than decreasing water loss. The contribution of stomatal conductance to drought performance in the field is yet unknown. However, a plant with sensitive stomata would only be adapted to a situation of relatively severe drought (Price and Courtois, 1999).

Price *et al.* (1997) reported varietal differences for stomatal response and its contribution to drought tolerance in Bala rice variety which could be because of better osmotic adjustment.

Kumar *et al.* (2014) reported that out of the better yield performing genotypes in drought stress condition, IR84895-B-127-CRA-5-1-1, IR83387-B-B-40-1, IR83376-B-B-24-2 and IR83373-B-B-24-3 showed higher photosynthetic rate and stomatal conductance in comparison to other high yielding genotypes as well as check varieties. Under control (irrigated) situation, all the 12 genotypes as well as check varieties showed higher photosynthetic rate and stomatal conductance in comparison to drought stress condition.

2.1.2.10 Leaf Soluble Protein Content

Beena *et al.* (2012) observed that water stress tolerant rice genotypes had comparatively higher protein content than susceptible lines under water stress condition. Reduction of soluble protein under water stress condition suggested that lipid peroxidation products hydrolyze protein coding mRNAs (Jiang *et al.*, 1992).

Kumar *et al.* (2014) reported that under drought stress condition, the genotypes, IR83387-B-B-40-1, IR83376-B-B-24-2 and IR 84895-B-127-CRA-5-1-1 showed less reduction in total soluble protein content compared to other genotypes and check varieties.

2.1.2.11 Radiation Use Efficiency (RUE)

Ahmad *et al.* (2009) reported that early transplanting (1st week of July) significantly enhanced LAI over late transplanting (3rd week of July) throughout the growth period. Peak LAI values were reached at 75 DAT in all the treatments. Similarly, early transplanting significantly enhanced cumulative IPAR (R2 = 94.4 - 97.9%). Seasonal differences in ATDM (areal total dry matter) production were mainly associated with the amount of IPAR (intercepted photosynthetic active radiation) and to a lesser degree on its efficiency of conversion. RUE for ATDM varied from 1.18 g MJ-1 to 1.94 g MJ-1 IPAR at different locations of conventional rice belt of Pakistan.

2.1.2.12 Chlorophyll Meter Reading (SPAD)

Chlorophyll pigments play decisive role in plant productivity, as they are the only pigments responsible for photosynthesis. Water stress decreased chlorophyll content in rice leaves (Zhu and Huang, 1994; Sheela and Alexander, 1996). The chlorophyll content of drought tolerant upland varieties was higher than that of the transplanted paddy under water deficit conditions (Peng *et al.*, 1996).

Abdellah Akhkha *et al.* (2011) also observed similar decrease in chlorophyll content under moderate and severe water stress situations. The chlorophyll meter (SPAD 501) provides a simple, quick and non destructive method for estimating leaf chlorophyll content (Watanabe *et al.*, 1980).

Jiang and Vergara (1986) reported that SPAD 501 was reliable in determining the relative chlorophyll content due to stresses such as drought. They also reported that a significant positive correlation of 0.989 was obtained between the SPAD reading and chlorophyll content. Leaf chlorophyll SPAD value was positively and significantly correlated to filled grain percentage and grain number per panicle (Maibangsa, 1998). The Minolta SPAD 502 chlorophyll meter (Spectrum Technologies, Inc., 1998) determines the leaf greenness which is the direct measure of leaf chlorophyll content and indirect method of determining the N content of the leaf. Hand held chlorophyll meters have been used successfully for field determination of leaf N concentration in several agronomic crops like corn (Ahmad *et al.*, 1999) and rice (Mahendra *et al.*, 2001). These meters make quick and easy measurements of leaf greenness, which is positively correlated to leaf chlorophyll content (Fahrurrozi *et al.*, 2001). Recent research in walnut trees (Simorte *et al.*, 2001) indicated a close correlation between leaf chlorophyll content measured with a chlorophyll meter and leaf N content.

Rajkumar (2001) reported that chlorophyll content was reduced due to drought. Total chlorophyll was found to decrease with the severity of stress and this decrease was strongly cultivar dependent. The decrease in chlorophyll is associated with a reduction in the flux of nitrogen into the tissue, as well as alteration in activity of enzyme systems such as nitrate reductase (Deivanai *et al.*, 2010).

2.1.2.13 Leaf Area Index (LAI)

Gloria *et al.* (2002) reported that water deficit in rice caused a larger reduction in leaf area than shoot dry matter demonstrating the greater sensitivity of leaf enlargement to water stress than dry matter accumulation.

Kumar *et al.* (2014) reported that reproductive stage moisture stress greatly influenced the performance of physiological traits such as leaf area index (LAI). Significant reduction in leaf area was observed among rice genotypes under drought stress compared to non-stressed condition. The highest leaf area was observed in IR84895-B-127-CRA-5-1-1 whereas lowest one in IR64.

2.1. 2.14 Relative Growth Rate (RGR)

Yao *et al.* (1990) reported that the evolution of relative growth rate was mainly dependent on net assimilation rate.

Ali *et al.* (2011) reprted that net assimilation rate was increased under nitrogen application in rice.

2.1.2.15 Net Assimilation Rate (NAR)

Yao *et al.* (1990) reported that a severe water stress has a negative effect on most of the growth indices (crop growth rate, CGR; relative growth rate, RGR; leaf area index, LAI; leaf area duration, LAD; net assimilation rate, NAR) except the leaf area ratio (LAR). They also showed that the evolution of RGR is mainly dependent on NAR since LAR has a constant declining rate. A strong assimilate demand during grain filling may increase net assimilation during water stress. Despite the importance of light intensity in photosynthetic activity, global solar radiation does not constitute a limiting factor for rice net assimilation.

Nobuhiro *et al.* (2007) reported that 11 days of water stress treatment was given to soybean then reduction in RGR was 44% in cultivar Shin-Tanbakuro and 15% in Midori. In this study, LAR was not affected in either cultivar; however NAR was significantly reduced under mild water stress. Decrease in NAR by water stress was greater in Shin-Tanbakuro compared to Midori, suggesting that the decrease in RGR due to water stress was mainly due a decrease in NAR.

Ahmad *et al.* (2009) reported that late transplanting significantly increased NAR over early transplanting at all the sites tested.

Ali *et al.* (2011) reported that statistical analysis indicated that grain yield decreased with increasing spacing.

2.1.2.16 Carbon Isotope Discrimination

Plants having a high carbon isotope discrimination (CID) tend to have higher yields in rainfed or irrigated environments because increased transpiration enables an increased biomass accumulation. Under dryer conditions plants growing more slowly and having a lower stomatal conductance (hence lower CID) may perform better as they achieve a larger biomass accumulation per gram of water transpired in rice (Impha *et al.*, 2005).

Akhter *et al.* (2010) reported that carbon isotope discrimination (Δ) has been suggested as an indirect tool for selecting plants having higher water use efficiency (WUE) and yield potential. Enhancing WUE is an important breeding objective as water scarcity is increasing with every passing day.

2.1.2.17 Number of Days Taken for Reaching Critical Stress Level

A delay usually occurs in flowering date, when rice experiences a water deficit before flowering (Lafitte *et al.*, 2003). The period of delay is partly related to the extent of stress the rice genotypes experienced and those with longer delay will tend to produce less grain (Ravindrakumar *et al.*, 2003).

The delay in heading under stress was negatively associated with plant water status indicators and stress yields (Blum *et al.*, 1999 and Babu *et al.*, 2003; Pantuwan *et al.*, 2002). The delay in heading is an expression of growth retardation during the drying cycle as well as upon recovery and this delay is a strong indication of susceptibility to stress (Blum *et al.*, 1999). The average reduction of 45% in biomass and 67-70% in grain yield has been reported to be due to drought stress in rice (Blum *et al.*, 1999 and Babu *et al.*, 2003).

Pantuwan *et al.* (2001) reported upto 80 percent reduction of grain yield under drought. These reductions represent high levels of stress, which brought stress yield to the range where true differences in genotype adaptation to stress are well expressed.

2.1.3 Soil moisture studies in the field

Initial drought adversely affected the germination and crop stand of upland rice. Rice seeds have to imbibe water at the rate of 25 to 35 per cent of its weight for germination. Therefore, screening of seeds for germination under osmotic stress of 0.5 MPa was found to be useful for soil moisture at germination (Murty, 1987). Soil moisture potential between -0.05 to -0.20 MPa was most favourable for seedling emergence (Jaggi and Bisen, 1984).

Soil moisture content at 50 to 75 per cent field capacity and soil moisture potential above -0.6 MPa was optimum for germination of rice seeds in a sandy loam soil. Due to moisture deficit at initial crop growth stage rice seedlings failed to emerge even until 13 days after sowing (Pathak *et al*., 1999).

2.1.4 Root Character Studies

2.1.4.1 Rooting Depth

Puckridge and O'Toole (1981) reported that a deep-rooted rice cultivar 'Kinangdang Patang' extracted more water at 40-70 cm depth than two shallow rooted cultivars namely IR 20 and IR 36.

O'Toole (1982) indicated that, for relatively large soil water reservoirs (deep soils), increase in rooting depth, conductance and root to shoot ratio (by weight) results in increased soil water uptake capacity.

Passioura (1982) reported that in deep wet soils, larger root density at depth is necessary to extract water from deeper layers.

Mumbani and Lal (1983) indicated similar results from their studies conducted on response of upland rice varieties to drought stress.

Mumbani and Lal (1983) also opined that rice plants with deep root system maintain high leaf water potential and delay leaf drying or death. Deep roots may also reduce the production of chemical signals from roots under drought conditions which may other wise reduce leaf growth, expansion and stomatal conductance (Turner *et al*., 1986).

O'Toole and DeDatta (1986) reported that increased rooting depth and density would increase the plant's capacity to extract water in rice. When plants are subjected to a moderate stress, it is supposed to put forth longer roots to absorb moisture from deeper layers.

Thangaraj and Sivasubramanian (1990) in their studies 011 line - source -- sprinkler system with induced moisture gradient have reported decreased root length. They attributed this decrease in root length to increased soil mechanical impedance. Root studies are arduous under actual field conditions. For convenience, some scientists have conducted root studies in aeroponics and hydroponics.

Gomathinayagam *et al.* (1988a) studied seminal roots with drought resistance.

Similar associations between total root length and drought tolerance was observed in aeroponic study by Gomathinayagam *et al.* (1992).

Several studies have been conducted to determine root length at different stages of crop growth. During vegetative stage, the root growth was rapid and declined towards the reproductive stage. Maximum root length was observed at panicle initiation stage by Beyrouty *et al.* (1988).

Sorte *et al.* (1993) quantified reduction in root length under water stress. They imposed water stress for five days at 30 days after sowing and observed 19 per cent reduction in root length when the reduction in the moisture content WIIS 44 per CCIII.

Venuprasad (1999) reported that tall genotypes maintain long, thick and few roots under water stress conditions. He also indicated increase in number of roots in some genotypes.

2.1.4.2 Root Volume

Ekanayake *et al.* (1985) found predominantly additive gene effects for root volume and root thickness, but Price *et al.* (1997) failed to detect significant additive or dominant gene effects for these traits.

Zuno-Altoveros *et al.* (1990) conducted an experiment to determine root volume of selected upland and low land rice varieties. They found that Rikuto Noriun l2 a Japanese upland variety had a very high root volume while, the low land variety IR 20 exhibited low root volume. Correlation of root volume with root length and shoot length was positive and significant. They also suggested that plant height could be used as a criterion for selecting drought resistant genotypes.

2.1.4. 3 Root Dry Weight

Root dry weight along with root thickness, root volume and number of thick roots was found to be significantly correlated to root pulling resistance (Ekanayake *et al.,* 1986).

Okuyama and Colasante (1987) speculated that root dry weight increased with increase in duration of crop growth.

On imposition of water stress, root weight decreased which was attributed to decrease in the associated traits (Cruz *et al.,*1986).

Jeena and Mani (1990) proposed root weight as a selection criterion in selecting drought tolerant genotypes.

Sorte *et al.* (1992) inferred from their studies that a 74% reduction in root weight was observed when soil moisture content was reduced by 44%. Survival during stress reflects on the capacity of the root to function. The drought tolerant genotypes should have greater root weight as compared to upland and drought susceptible cultivars (Vijayalakshmi and Nagarajan, 1994).

2.1.4.4 Root-Shoot Ratio

Cruz *et al.* (1986) presented that per cent reduction in shoot dry mass was less than that of total root dry mass, thereby decreasing root to shoot ratio under mild stress condition during vegetative stage in rice. They attributed this to a high soil strength or mechanical impedance, which decreased root length.

Haque *et al.* (1989) conducted root studies in both aeroponic and hydroponic cultures. They estimated all the root parameters required for determining drought reaction. They reported variation in root to shoot ratio between the two cultures. Sorte *et al.* (1992) differed from the general hypothesis of increase in root growth during stress.

2.2 GENETIC PARAMETERS

2.2.1 Variability, Heritability and Genetic advance for Morphological Traits

Possibility of achieving improvement in any crop plant depends heavily on the magnitude of genetic variability. Improvement of economic characters like yield through selection is conditioned by the nature and magnitude of variability existing in such populations. However, the phenotypic expression of complex characters like yield is a combination of genotype, environment and their interaction. This indicates the need for partitioning of overall variability into heritable and non-heritable components with the help of appropriate statistical techniques. Knowledge of genetic variability and extent and nature of association between yield and its attributing traits is helpful in selection of suitable genotypes for quicker improvement through appropriate breeding methodologies.

Unnikrishnan (1980) found higher phenotypic and genotypic coefficients of variation for grain yield and number of productive tillers in his study on three F_2 populations for 10 characters. Estimates of heritability and genetic advance were high to moderate for grain yield and number of productive tillers indicating that additive gene effects were involved.

Maurya (1982) evaluated 49 populations ($21F_1$, $21F_2$ and 7 parents) for yield attributing characters and the result indicated the presence of high heritability values in both the generations for days to heading, height, number of grains per panicle and test weight whereas, low values for sterile grains per panicle, total and ear bearing tillers. Both heritability and genetic advance were low for grain yield.

Venkataravana (1991), in an F_2 population, observed high phenotypic variability for grain yield, panicle weight, number of productive tillers and total tillers. High heritability (broad sense) values were recorded for plant height and days to maturity in both direct sown rainfed and irrigated conditions. The expected genetic advance was also high for panicle weight and productive tillers.

Lokaprakash *et al.* (1992) advanced H x H, H x L and L x L general combiners to F_2 and F_3 generations to study variability, heritability and genetic advance. In general, heritability showed an increasing trend from F_2 to F_3 generations, but the variances and genetic advance were decreased. Among the characters, panicle weight, 1000-grain weight and number of fertile spikelets panicle^{-1} recorded high heritability coupled with moderate to high genetic advance, indicating that they were governed by additive genes.

A study on genetic variability was conducted by Rama Bai *et al.* (1992) in 58 medium duration rice cultivars. In general, PCV was higher than GCV for all the characters studied, indicating the influence of environment on expression of the characters. Among the characters, plant height, flag leaf area, panicle exsertion and grain yield plant^{-1} expressed moderate to high estimates of heritability and GA.

Verma *et al.* (1994) revealed the importance of additive and dominance variance for grain yield as well as its component characters. Moderate heritability was recorded for effective tillers plant^{-1}, spikelets panicle^{-1} and grains panicle^{-1} while grain yield, panicle length, spikelet sterility and 100 grain weight had low heritability values. Genetic variability, broad sense heritability and genetic advance under selection for grain yield and its components were studied in 36 rice genotypes by Chakraborty *et al.*(1994). The characters *viz.,* grain yield and panicles plant^{-1} showed relatively low GCV, indicating the presence of significant influence of environment on these traits. On the contrary, high heritability with high GA was found for panicle weight and spikelets panicle^{-1}, indicating that these traits are mostly due to additive gene action. High heritability associated with moderate to low GA was observed in several characters like plant height and fertility percentage.

Chauhan (1996) reported presence of substantial genetic variability for grain yield, spikelets panicle^{-1}, grain weight, biological yield and harvest index along with high expected genetic advance and heritability. They opined that improvement in grain yield plant^{-1} could be achieved by excersising selection simultaneously for spikelet number, panicle weight, biological yield and harvest index owing to their positive and significant relationship with grain yield.

High heritability with higher genetic advance and coefficient of genetic variation was observed for spikelet number, spike number, grain number and leaf area. Heritability was also high for other characters but expected genetic advance and coefficient of variation were low for these characters. For grain yield, heritability as well as other parameters had low estimates. Number of panicles and grain number seemed to be reliable criteria for selection and further improvement (Panwar and Gupta, 2000).

Pantuwan *et al.* (2002) found significant variation in days to flowering among drought stressed genotypes which otherwise showed similar flowering time under irrigated condition.

Estimates on variability, heritability and genetic advance as per cent of mean were worked out for twenty two semi-deep rice genotypes by Bhandarkar *et al.* (2003) for yield and its attributing characters. High genotypic coefficient of variation was observed for panicles plant^{-1} followed by panicle weight, tiller plant^{-1} and grain yield plant^{-1}. High heritability with high genetic advance as percent of mean was observed for panicle weight.

Mahto *et al.* (2003) in a study of rainfed upland rice observed high heritability and genetic advance for plant height and grain yield plant^{-1}. Moderate to high heritability for grain yield under drought stress has been reported by many authors in recent times. Venuprasad *et al.* (2007) and Kumar *et al.* (2008) reported comparable heritability under stress and irrigated conditions.

Sinha *et al.* (2004) estimated variability, heritability and genetic advance in nineteen local landraces along with IR 36 for yield and its attributing characters. High genotypic coefficient of variation was observed in grain yield followed by test weight and panicles plant^{-1}. High heritability with high genetic advance was found for grain yield followed by test weight and panicles plant^{-1}.

Shukla *et al.* (2005) revealed high coefficients of variation as well as high values of heritability coupled with expected genetic advance for grain yield plant^{-1} followed by harvest index and biological yield plant^{-1}.

Genetic variability and heritability parameters were assessed in 114 genotypes and three checks by Suman *et al.* (2005). High coefficients of variation were observed for seedling dry weight followed by number of spikelets panicle^{-1}, number of filled grains panicle^{-1} and biological yield. High values of heritability coupled with high genetic advance as per cent of mean were observed for the characters *viz.* , total number of tillers plant^{-1}, productive tillers plant^{-1}, number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, plant yield, biological yield, harvest index and seedling vigour index.

Vaithiyalingan and Nadarajan (2006) reported significant differences among the F_2 populations for all the characters studied. Among the characters, grain yield showed high genotypic coefficient of variation, heritability along with genetic advance as per cent of mean, followed by the characters *viz.* , spikelet fertility per cent, productive tillers plant^{-1} and number of grains panicle^{-1}. These traits are highly amenable for selection while going for crop improvement in rice through inter sub-specific hybridization.

Panwar *et al.* (2007) observed high genotypic and phenotypic coefficients of variability for straw yield per plant, total biological yield per plant, number of fertile florets per panicle and number of branches per panicle. The heritability estimates were highest for days to fifty per cent flowering, days to maturity and 1000 grain weight. The genetic advance as per cent of mean were higher for number of branches per panicle, straw yield per plant, total biological yield per plant and grain yield per plant.

Verulkar *et al.* (2010) reported high heritability under severe stress condition for grain yield, days to 50% flowering, plant height and harvest index in medium to late duration breeding lines while low heritability was observed for grain yield under moderate stress in both early and late duration breeding lines. They also reported significant genetic variability among the tested lines for grain yield, days to 50% flowering, plant height and harvest index.

Nandeshwar *et al.* (2010) reported that twenty five F_2 progenies derived from the crosses involving HYV s and quality rices were evaluated during kharif 2005. Eleven biometrical characters were studied for estimating phenotypic variance, genotypic variance, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), genetic advance, heritability (broad sense) correlation coefficient and path coefficient among themselves. The analysis of variation revealed significant differences in the genotypes for all the characters studied. *Per se* performance of the progenies revealed that two F_2 progenies derived from the crosses IR-62 x Samba Mahsuri and Kunti x Dudheswar were promising in respect of grain yield and some yield related traits. High GCV and PCV were observed for grain yield per plant, panicle number per plant and panicle weight. High heritability was observed against all the characters studied excepting panicle weight, grain number per panicle and grain breadth. Grain yield plant $^{-1}$showed maximum genetic advance as percentage of mean followed by panicle number plant^{-1}, plant height and panicle weight respectively.

Akinwale *et al.* (2011) reported that genotypic coefficients of variation were lower than the corresponding phenotypic coefficients in all the traits studied, indicating considerable influence of the environment on the expression of these traits.

Singh *et al.* (2011) reported that coefficient of variation studied indicated that estimates of phenotypic coefficient of variation (PCV) were slightly higher than the corresponding genotypic coefficient of variation (GCV) for all the characters.

Sravan *et al.* (2012) in a study of 36 diverse rice genotypes under rainfed upland condition observed high genotypic variation for grain yield and harvest index while harvest index and grain yield exhibited high heritability coupled with high genetic advance as percent of mean.

Shrivastava *et al.* (2012) in an experiment conducted with 22 advanced breeding lines subjected to high temperatures at reproductive stage with different sowing dates, observed high heritability coupled with high genetic advance for biological yield.

Kiran *et al.* (2012) reported that grain yield can be improved indirectly by selecting F_2 plants with high total tillers plant^{-1}, productive tillers plant^{-1}, grains panicle $^{-1}$ and 1000-grain weight as these traits showed high heritability coupled with high genetic advance as per cent of mean.

Khare *et al.* (2014) reported high heritability coupled with high to moderate phenotypic and genotypic coefficients of variation and genetic advance as per cent of mean for grain yield plant^{-1}, plant height, test weight, fertile spikelet panicle^{-1}, total grains panicle^{-1} and number of effective tillers plant^{-1}.

Rahman *et al.* (2015) conducted studies to evaluate genetic variation among four parents and their 12 F_2 populations for various morphological attributes. Desirable segregants for maturity and panicle traits were obtained.

Kahanil and Hittalmani (2016) reported that genetic variability studies provide basic information on genetic parameters of the population based on which selection of genotypes and breeding strategy could be formulated for crop improvement. The estimates of heritability, coefficients of variability and genetic advance were computed in F_2 segregating populations of the 15 crosses for 14 characters. The selected F_2 plants were forwarded to generate F_3 families during dry season under aerobic conditions. The estimates of phenotypic coefficients of variation (PCV) were high and moderate for days between flowering and maturity (11.3%), number of tillers (20.0%), number of panicles (23.4%), 100 grain weight (18.7%), panicle exsertion (13.5%), panicle length (20.1%), leaf width (12.2%), straw weight (23.5%) and grain yield (36.2%) in different crosses. High estimates of heritability coupled with high and moderate genetic advance was observed for all the plant traits. Correlation analysis indicated that flowering time, plant height, number of tillers, number of panicles, grain length, grain width, panicle length and straw weight exhibited significant positives association with grain yield plant^{-1}. The correlation and regression coefficients between F_2 and F_3 generation for crosses MAS26 × IM88, OYC145 × MAS946-1 and IR64 × IM192 were significant for 50% flowering time, maturity time, plant height and productive tiller plant^{-1}.

2.3 CHARACTER ASSOCIATION

2.3.1 Character Association for Morphological Traits with Grain Yield

Productivity under moisture stress was negatively associated with days to flowering (Lanceras *et al.*, 2004) and delay in flowering under stress (Babu *et al.*, 2003) depicting that delayed flowering is a strong indication of susceptibility to drought resulting in retarded growth during the drying cycle and upon recovery (Blum *et al.*,1999). Grain yield under stress is the primary trait for selection in breeding programs for drought prone environments. It is also useful to screen for secondary traits which are associated with yield under stress. For a secondary trait to be useful in a breeding program, it must be genetically correlated with grain yield and least affected by environment with high heritability, genotypic variability must be predominant in the breeding population, rapid and economic measurement of the trait should be possible and the trait should not be linked to poor yields in the favourable environment (Lafitte *et al.*, 2003). Although direct selection for grain yield under stress is emphasized in practical drought breeding programme, indirect selection for carefully selected secondary traits can be helpful in improving selection response (Lafitte *et al.*, 2003; Babu *et al.*, 2003). The knowledge of association of yield components with yield is of paramount importance in formulating effective selection index. Correlation coefficients provide a measure of association among characters and can serve as indicators to identify secondary traits for high yielding ability. Many morphological and productivity traits that have been reported to be positively correlated with grain yield under drought are summarized in Table 1. These reports indicated that the traits which are significantly associated with yield under stress are important drought tolerant traits.

Gupta and Padalia (1971) reported that panicle weight and number of grains per panicle were highly correlated with yield in all the varieties studied. All the characters except length of panicle showed positive and highly significant correlation with yield. Panicle weight, numbers of grains per panicle and effective tillers had high positive direct effect on yield.

Direct and indirect association of four yield components with grain yield was analyzed in the drought tolerant lines grown in semi-dry conditions. Productive tillers had high direct effects on grain yield while panicle length and flowering duration had moderate direct effects. The effect of plant height was slightly negative. Productive tillers appeared to be the most reliable character to use in selecting genotypes for high grain yield under rainfed conditions (Anand Kumar, 1992).

Twenty-two advanced generations of saline tolerant genotypes were grown to obtain basic information on correlation among yield parameters. Grain yield showed positive and significant correlation with number of vegetative tillers, number of productive tillers, number of filled grains and dry matter plant^{-1}. Number of productive tillers and number of filled grains had positive direct effects on grain yield (Ravindra Babu, 1996).

Two hundred and fifty *indica* rice genotypes were evaluated by Verma and Mani (1997) who found positive association of panicle length with grains panicle^{-1} and grain yield per plant at phenotypic level.

Significant positive correlations were observed for days to 50 percent flowering, days to maturity, plant height, grains per panicle and panicle length with yield. Gholipoor *et al.* (1998) reported significant positive association of grain yield with 100-grain weight, flag leaf length and width, number of secondary panicles and days to maturity, but negative significant genotypic correlation with plant height and length of top internode. They also opined that 100- grain weight could be used as a selection criterion in breeding programmes to improve grain yield.

In an F_2 population of the cross IR 50 x TNAU-801793, grain yield was significantly and positively associated with days to flowering, number of productive tillers and dry matter production (Selvarani and Rangasamy, 1998).

Bagali *et al.* (1999) noticed significant genotypic correlation of grain yield with panicle density, number of filled grains panicle^{-1}, panicle weight, harvest index and fertility and significant positive association was observed for harvest index and 1000 grain weight both at phenotypic and genotypic levels in a study involving 114 homozygous lines of *indica-japonica* double haploid rice populations. They also found that panicle weight exerted maximum positive direct effect, followed by number of grains panicle^{-1} and harvest index on grain yield plant^{-1} at phenotypic level.

In a study involving IR-36 x MW-10 under irrigated and upland conditions, Mishra (1999) noticed positive association of grain yield with plant height, tillers plant^{-1}, panicle weight, straw weight and biological yield in two environments but panicle length and grains panicle^{-1} were positively correlated with grain yield only in upland condition.

Eighteen divergent rice genotypes were assessed for association among yield and yield attributes under direct sown rainfed upland ecosystem by Rao and Srivastava (1999). They revealed positive association of days to flowering with days to maturity and fertile spikelets panicle^{-1} as well as harvest index with grain yield.

Pei *et al.* (2000) reported positive correlation between grain shape and length whereas, negative correlation between grain shape and width in two F_2 populations. There was non-significant relationship between grain length and width in both F_2 and BC_1F_2 populations. However, a positive correlation was observed in BC_3F_2.

Ishimaru *et al.* (2001) reported significant correlation between panicle number plant^{-1}and yield in a study of QTL analysis and comparison between QTLs and ESTs towards mapping of physiological and agronomic characters on a rice function map, which involved 98 backcross inbred lines of *japonica* Nipponbare x *indica* Kasalath. In a BC_2F_2 population derived from *Oryza sativa* x *Oryza rufipogon,* Moncada *et al.* (2001) observed significant positive correlation between yield and number of panicles plant^{-1}, plant height, panicle length and 1000-grain weight. However, they also observed a negative correlation between yield and days to heading and yield and per cent sterility.

Thomson *et al.* (2003) reported the mapping QTLs for yield, yield components and morphological traits in an advanced backcross population, reported strong positive correlation of yield with panicles plant^{-1}, grains panicle^{-1}

and spikelets panicle^{-1}. Number of grains panicle^{-1} also had a strong correlation with per cent seed set, panicle length and days to heading. There was a small negative correlation between grains panicle^{-1} and grain weight. For the morphological traits, strong positive correlation was found between plant height and panicle length and a negative correlation between panicle length and days to heading. High positive direct effect coupled with significant positive association of effective tillers plant^{-1} and high density grains panicle^{-1} with grain yield plant^{-1} indicate their role in selection for high yield.

Rajeshwari and Nadarajan (2004) worked out correlation coefficients for yield with seven other yield components in F_4 and F_5 generations of rice. Except panicle exsertion, all other traits showed positive and significant association with yield. Among the yield components, days to 50 percent flowering, number of productive tillers plant^{-1}, panicle length, number of grains panicle^{-1} and 100 grain weight were found to be dependable attributes on which the selection would be concentrated for enhancing the yield.

F_2 generations of 21 crosses were evaluated for genetic parameters as well as association of certain yield components in rice by Raju *et al.* (2004). Among the yield components, productive tillers plant^{-1} and 100 grain weight had significant correlation as well as direct positive effects on grain yield plant^{-1}.

Somnath and Ghosh (2004) conducted an experiment to study the association among yield and yield related traits in 24 landraces of rice. Path analysis along with correlation coefficient analysis revealed that panicle weight and duration to panicle initiation were the major contributions towards yield. Effective tiller number had negative association with yield and yield related traits.

A study on correlation and path coefficient analysis was conducted by Yogameenakshi *et al.* (2004) in rice and noticed that single plant yield was positively correlated with all the traits except days to 50 percent flowering. Number of grains per panicle, chlorophyll stability index and harvest index expressed highly positive correlation with grain yield.

Table 1. Association of morphological and productivity traits with grain yield

Character	Correlation	Reference
Days to 50 % flowering	Positive or negative	Manual and Palaniswamy, 1989; Yadav, 1992
	No association	Babu *et al.*, 2003
Number of productive tillers plant^{-1}	Positive	Dhanraj, *et al.*, 1987; Jangle *et al.*, 1987; Kupkunchanakul *et al.*, 1991; Yadav,1992; Surek *et al.*, 1998; Lanceras *et al.*,2004 ; Chandra *et al.*, 2009
Plant height at maturity	Positive	Jangle *et al.*, 1987; Majumder *et al.* , 1990; Namadarajan & Kumaravelu, 1994; Lanceras *et al.*, 2004
	Negative	Lafitte *et al.*,2004
Panicle length	Positive	Dhanraj *et al.*, 1987; Jangle *et al.*, 1987; Majumder *et al.*, 1990; Namadarajan and Kumaravelu, 1994; Chandra *et al.*, 2009
Number of spikelets panicle^{-1}	Positive	Lanceras *et al.*, 2004
Number of filled grains panicle^{-1}	Positive	Dhanraj *et al.*, 1987; Jangle *et al.*, 1987; Majumder *et al.*, 1990; Namadarajan & Kumaravelu, 1994; Sarawgi *et al.*, 1997; Chandra *et al.*, 2009
Spikelet sterility %	Negative	Garrity & O'Toole, 1994; Lanceras *et al.*, 2004

Grain weight panicle^{-1}	Positive	Jangle *et al.*, 1987
1000 grain weight	Positive	Dhanraj *et al.*, 1987; Jangle *et al.*, 1987; Surek *et al.*, 1998; Chandra *et al.*, 2009;
Straw yield plant^{-1}	Positive	Muhammmad *et al.*,2002
Harvest Index	Positive	Sarawgi *et al.*, 1997; Babu *et al.*, 2003; Lanceras *et al.*, 2004
	No association	Lafitte *et al.*, 2004
Leaf rolling score	Negative	Babu *et al.*, 2003
Days to flowering after stress relief	Negative	Lanceras *et al.*, 2004
Heading delay under stress	Negative	Garrity and OToole, 1994; Blum *et al.*, 1999; Babu *et al.*, 2003

Significant positive association of grain yield with plant height, productive tillers plant^{-1}, dry matter plant^{-1}, leaf weight and harvest index was reported by Shashidhar *et al.* (2005).

Suman *et al.* (2006) carried out an experiment on correlation studies in rice and the results indicated that biological yield had high correlation with single plant yield followed by harvest index, days to 50 percent flowering, panicle length, number of filled grains panicle^{-1}, number of spikelets panicle^{-1} and plant height.

Girish *et al.* (2006) noticed positive correlation of grain yield with plant height, number of tillers, panicle length, number of panicles plant^{-1}, single panicle weight, test weight, straw weight, biomass plant^{-1} and harvest index both at genotypic and phenotypic levels.

Monalisa *et al.* (2006) reported significant positive association of effective tillers plant^{-1}, panicle weight, number of spikelets and high density grains panicle^{-1}with grain yield plant^{-1}.

Padmaja *et al.* (2008) reported that correlation and path analysis studies for eleven characters on one hundred and fifty rice genotypes including five check varieties revealed that the genotypic correlations were higher than phenotypic correlations. Single plant yield showed maximum significant correlation with 100 seed weight and productive tillers plant^{-1} followed by spikelet fertility, total tillers plant^{-1}, grains panicle^{-1} and panicle length.

Abd Allah *et al.* (2010) reported that highly significant genotypic correlation was present between grain yield and number of panicles plant^{-1}, 100 grain weight, panicle weight and number of filled grains panicle^{-1}.

Nandeshwar *et al.* (2010) reported that grain yield plant^{-1} possessed significant positive correlation with panicle number plant^{-1}, panicle weight and grain number panicle^{-1} while it had significant negative correlation with plant height. Panicle number plant $^{-1}$ imparted maximum direct effect on grain yield followed by grain number panicle^{-1}, 1000 grain weight and panicle length in this regard.

Akinwale *et al.* (2011) reported that grain yield exhibited significantly positive correlation with number of tillers plant^{-1} (r =0.58**), panicle weight (r =0.60*) and number of grains panicle^{-1} (r=0.52*). Therefore, the results suggest that these traits can be used for grain yield selection.

Khare *et al.* (2014) reported that positive and significant associations were observed for days to 50 per cent flowering, days to maturity, plant height, panicle length, fertile spikelets panicle^{-1}, total grains panicle^{-1} and spikelet fertility with grain yield plant^{-1} at both genotypic and phenotypic levels.

Savitha and Usha Kumari (2015) In a study advanced six crosses of F_1 generation to F_2 and F_3 segregating generations for variability, heritability and genetic advance of rice genotypes. Among the six crosses studied, IR 72 x Veeradangan and ADT 39 x Kavuni exhibited superior *per se* performance in both F_2 and F_3 generations for almost all the biometrical characters studied including yield. The F_2 and F_3 populations of the IR 72 x Veeradangan and ADT 39 x Kavuni showed moderate PCV and GCV coupled with high heritability estimates and high genetic advance as percentage of mean for number of productive tillers plant^{-1}, number of filled grains panicle^{-1} and single plant yield.

Bhuvaneswari *et al.* (2015) reported that crosses studied for the traits productive tillers plant^{-1}, filled spikelets, spikelet fertility and 1000 grains weight showed significant positive correlation with grain yield whereas days to first flowering showed significant negative correlation with grain yield in cross I. Path analysis revealed that productive tillers plant^{-1} and filled spikelets panicle^{-1} had high positive direct effect on grain yield.

2.4 PATH CO-EFFICIENT ANALYSIS

2.4.1 Path Co-efficient Analysis for Morphological traits

Sarawgi *et al.* (1997) reported that path coefficient analysis revealed that direct selection for number of fertile spikelets panicle^{-1} and harvest index would likely be effective for increasing grain yield. Direct selection for number of effective tillers plant^{-1}, grain yield plant^{-1}, hundred grain weight, grain breadth, grain length and grain thickness would increase harvest index. This study also indicated that there is no common causal factor that directly influenced both grain yield and harvest index, though, hundred grain weight, grain length, grain breadth and grain thickness could be augmented in selection criteria for the simultaneous improvement of both the traits.

Padmaja *et al.* (2008) reported that results of path analysis indicated that productive tillers plant^{-1}, panicle length, spikelet fertility and grains panicle^{-1} were important as they contributed directly towards high single plant yield. Hence these characters need to be considered while designing a selection strategy for yield improvement in rice.

Chandra *et al.* (2009) reported that path analysis revealed that number of grains panicle^{-1}, days to 50 percent flowering, 1000-grain weight and number of productive tillers plant^{-1} showed high positive direct effects on grain yield.

Abd Allah *et al.* (2010) reported that direct effect of plant height on grain yield was negative and low (-0. 044). Indirect effect through number of panicles plant^{-1}, 100 grain weight, panicle weight, sterility percent, and number of filled grains was positive, but through number of tillers plant^{-1} it was negative. Maximum positive indirect effect (0. 008) was observed through total number of tillers plant^{-1}.

Reddy *et al.* (2013) reported that path analysis revealed that biological yield was the major contributor to grain yield plant^{-1} followed by number of spikelets panicle^{-1} and test weight. It can be concluded that higher biological yield (0.68), number of spikelets panicle^{-1} (0.17) and test weight (0.96) are important plant traits which should be considered when any breeding program for higher paddy yield in rice is to be planned.

Patel *et al.* (2014) reported that path analysis revealed that straw yield plant^{-1} had the highest positive direct effect on grain yield followed by grain length, harvest index, days to maturity, protein content, number of total tillers plant^{-1} and number of grains panicle^{-1}. For maximizing grain yield plant^{-1} emphasis should be given in selection for characters such as number of grains panicle^{-1}, straw yield plant^{-1}, harvest index and 1000 grain weight for further improvement in upland rice.

Khare *et al.* (2014) reported that highest positive direct effect on grain yield was recorded by number of fertile spikelets panicle^{-1}, total number of grains panicle^{-1}, plant height and days to 50% flowering.

2.5 SELECTION INDEX

Singh, *et al.* (2013) observed that relative efficiency of selection indices ranged from 0. 13 (Index III) – 33. 23 percent (Index XXI) and 4. 20 ((Index III) – 1093. 09 per cent (Index XXI), respectively. Two genotypes from index XXI and three genotypes from index XVI were isolated as diverse parents with Vandana and can be used in crossing programme to obtain better heterotic cross combinations with high relative efficiency and good character combination and may be helpful in improving the grain yield in upland rice.

2.6 COMBINING ABILITY AND GENE ACTION

2.6.1Combining Ability and Gene Action for Morphological traits

The ability of a genotype to produce superior progenies upon crossing is termed as combining ability. It is the ability of an inbred to transmit desirable performance to the hybrid progeny. The success of crop improvement programmes depend to a great extent on the types of parents used, their diversities for desired characters and their combining ability. Combining ability analysis provides information on additive and non additive variances and helps in selection of the desirable parents and crosses for the exploitation of heterosis.

Sprague and Tatum (1942) gave the concept of combining ability and proposed the idea of partitioning genetic variation into variances due to general combining ability (*gca*) and specific combining ability (*sca*). The *gca* is the average performance of a genotype in cross combinations and is the result of additive gene action, while *sca* is the specific expression of performance between any two inbred lines in relation to the average performance of all combinations and is the result of non additive gene action. In rice, several researchers reported nature of gene action for different characters through various biometrical techniques.

Chakraborty *et al.* (1994) observed additive gene effects for days to 50% flowering, spikelets per panicle, flag leaf length and hundred seed weight while non additive gene action was observed for plant height, panicles plant^{-1} and yield plant^{-1}. The crosses Mahsuri x Pankaj and Mahsuri x Manoharsali showed positive *sca* effects for grain yield. In another study by Rogbell and

Rogbell and Subbaraman (1997), it was found that magnitude of variance due to *sca* was higher than that due to *gca* for all the traits studied. Good general combiners among the parents for grain yield were IR 61457-8-3-3-1, IR 10198-66-2 and IR 54717-C10-113-1-2-2-2.

Manonmani and Ranganathan (1998) found predominance of non additive gene action for days to flowering, plant height, productive tillers, panicle length, number of grains panicle^{-1}, 100 seed weight and grain yield. Among the parents IR 50, Co 37 and ASD 17 were found to be good combiners for grain yield. The crosses ASD 16 x Kalyani II, IR 50 x ASD 8 and ASD 16 x ASD 17 showed high *sca* effects for days to flowering, productive tillers and grain yield, respectively.

Babu *et al.* (2000) studied the combining ability and observed a preponderance of non additive gene action for all the traits studied. Among the parents, two lines *viz.*, IR 58025A and IR 62829A and three testers WGL 3962, IET 9762 and IET 10021 were found to be good general combiners for yield and related traits. Among the crosses, IR62829A x WGL 3962, IR62829A x IR 276-301-06-01R, IR 62829A x MTU9992, and APMS 2A x IET 9762 were found to have high *sca* effects for grain yield.

Swain *et al.* (2003) reported importance of both additive and non additive gene actions for all characters studied. Days to flowering, panicles plant^{-1} and grain yield plant^{-1} showed non additive effects while additive effects were observed for plant height, panicle length, spikelets panicle^{-1}, 1000 seed weight, harvest index and straw yield plant^{-1}. Good combining parents were found to be Ketanangka and Rahaspanjar for yield and component traits, except for plant height. Among the crosses, Rahaspanjar x Swarna and CR-260-77 x Ketanangka showed high *sca* effects and were found to be promising crosses.

In a study by Banumathi *et al.* (2003) reported non additive gene action played a major role in grain yield and associated traits. Among the parents, the lines IR 58025A, IR 69616A and IR 70364A and testers CB 95066, IR 10198-66-2r, IR 65515-47-2-1-19, TNAU 94241, and TNAU 94301 were good general combiners for grain yield.

Bisne and Motiramani (2005) observed a preponderance of non additive gene action for plant height, productive tillers plant^{-1}, spikelets panicle^{-1}, 100 seed weight, harvest index and seed length. Among parents, lines DRR 2A and PMS 10A and testers BKP 232, R 827-287, R 1060-1674-2-103 and R 714-2-103 were found to be good general combiners for grain yield and among the crosses DRR 2A x R 827-287 and DRR 2A x R 1060-1674-1-1 showed high *sca* effects.

Anand Kumar *et al.* (2006) in their study found IR 68886A and IR 58025A to be good general combiners for earliness and grain yield respectively. Among testers, Pusa 1040, PSRM-1-16-48-11, RAU 1411-4 and RAU 1414-10 were good general combiners for grain yield. Among crosses IR 68886A x Pusa 1040, IR 58025A x RAU 1411-10 and IR 68886A x PSRM-1-16-48-1 showed high *sca* effects and recorded significant heterosis for yield and its contributing traits.

In another study of combining ability by Kumar *et al.* (2007) it was found that both additive and non additive gene actions played equal role in expression of traits. Preponderance of additive gene action was observed for plant height, days to flowering and 100 seed weight. Non additive gene action was observed for panicle length and grain length while both additive and non additive effects were observed for leaf area index and grain yield plant^{-1}. Parents HPR 2047, VL 93-3613 and J08 were good general combiners for grain yield and associated traits. Among the crosses HPR 2047 x VL 93-3613, HPR 1164 x IR 57893-8, VL 91-1754 x J08, VL 91-1754 x VL 93-3613 showed high *sca* effects for grain yield and associated traits.

Venkatesan *et al.* (2007) found non additive gene action for plant height, days to fifty percent flowering and grain yield. The lines AD 25157, AD 25137 and MDU 5 and testers ADT 36, ADT 43 and IR 50 appeared good general combiners for grain yield and its component traits.

Biswas and Haque (2007) reported that six parent diallel cross without reciprocal was studied to investigate the genetic behaviour of different agronomic traits in rice. The analysis of Wr-Vr graph showed that panicle length, thousand grain weight and grain yield plant^{-1} did not follow the additive dominance model indicating epistatic gene action responsible for the expression of these traits. All other traits under study were conditioned by overdominance gene action except grains per panicle, which was controlled by partial dominance. The Yr – (Vr +Wr) graph revealed random distribution of dominant and recessive genes in expressing different traits in different parents, while correlation between parental mean and parental order of dominance indicated increasing effect of dominant gene for all the traits except days to heading and % spikelet sterility.

Muthuramu *et al*. (2010), in a study of combining ability analysis through diallel cross for drought tolerance in rice observed a preponderance of non additive gene action for most of the traits except plant height which showed additive gene action. Among the parents, Nootripathu, Mattaikar and Vellaichithiraikar appeared to be good general combiners for grain yield while the hybrids NPT 107 x MDU 5 and NPT 107 x Nootripathu were found to be promising crosses for drought conditions.

Saidaiah *et al*. (2010) in a combining ability study for rice hybrids evaluation in three agro climatic zones, observed prevalence of non additive gene action for all the traits. In the study lines APMS 6A, PUSA 5A and CRMS 32 A and testers 1096, 1005, IBL-57 and SC59-3 were found to be good general combiners for yield and majority of traits while the crosses with high *sca* effects for yield and other related traits were APMS 6a x SC5 9-3, APMS 6a x 1005 and APMS 6a x GQ 25.

Study of combining ability and heterosis were conducted on 12 F_1 hybrids along with seven rice genotypes (three cytoplasmic male sterile lines and four restorer varieties) to know the pattern of inheritance of some morphological traits for selecting superior genotypes. The experiment was carried out according to line x tester mating design, during 2007-08. Analysis of variance revealed significant differences among genotypes, crosses, lines, testers and line x tester interactions for tiller number, plant height, days to 50% flowering, panicle length, number of spikelets panicle^{-1}, spikelet fertility and grain yield traits. Variances of *sca* were higher than the *gca* variances for traits except for plant height which indicated predominance of non-additive gene action in the inheritance of the traits (Nadali and Nadali, 2010).

El-Namaky *et al.* (2010) reported that the hybrid combinations M101 × M201 and Giza177 × GZ6214 gave highly significant and negative values of *sca* effect for plant height. For days to heading, the crosses Giza177 × M101, M201 × M202 and GZ6214 × M101 gave highly significant and negative values of *sca* effects. These crosses could be used in rice breeding programs due to their desirable stature and earliness and negative *gca* effects. The negative values of *gca* effects for these traits are required from a breeding perspective since they refer to short stature plant types and earliness.

Adilakshmi and Reddy (2012) reported that combining ability analysis of 7 varieties for yield components, physiological traits and yield in a diallel fashion revealed that the progenies differed significantly for all characters indicating the involvement of both additive and non-additive type of gene action in expression of the characters. The relative magnitude of estimates of *sca* variance was higher than that of *gca* variance for all the characters indicating the predominance of non-additive gene action. The parent Indra was the best combiner among all the seven parents studied as it recorded positive *gca* effects for 6 characters *viz.* , panicle length, ear bearing tillers, number of seeds panicle^{-1}, biological yield, flag leaf nitrogen content and grain yield plant^{-1}. The crosses Samba Mahsuri/Polasa Prabha and Samba Mahsuri/ Nellore Mahsuri recorded high specific combining ability effects for exploitation. From an overall analysis all characters *viz.,* days to 50 percent flowering, ear bearing tillers/plant, harvest index, biological yield and flag leaf nitrogen content which influenced grain yield were predominantly governed by non-additive gene action.

Sanghera and Hussain (2012) while studying the combining ability in rice hybrids for temperate conditions found preponderance of non additive gene action for all the traits. Estimates of *gca* effect indicated the male parent K-08-61-2 and the female parent SKAU 11A to be good general combiners for grain yield and other yield contributing traits. The crosses SKAU 7A x K-08-61-2, SKAU 7A x SR-2, SKAU 11A x K-08-60-2, SKAU 11A x K-08-59-3, SKAU 11A x SKAU-389 were found to be promising cross combinations for grain yield and other desired traits.

Patel (2015) reported that nature of gene interaction in the inheritance of 12 yield and yield component traits was studied deploying generation mean analysis following 5 parameter model for parents, F_1, F_2, and F_3 generations of four crosses of rice. Straw yield plant^{-1} was governed by non-additive gene action. The results indicated that gene action differs over crosses. In general, most of the traits were governed by non- additive gene action.

2.6.2 Combining Ability and Gene Action for Physiological and Biochemical Traits

Won *et al.* (2002) reported that the effects of dominance were highly significant for amylose content and protein content. Especially, the effect of dominance was greater than that of additive for protein content.

Yogameenakshi *et al.* (2003) reported that high order *gca* effects was exhibited by the lines ADT 43 (LS), ADT 36 (L4), IR 50 (L8), ADT 45 (L6) and ASD 18 (L3) and by the testers Kallurundaikar (T4) and Nootripathu (T2) for more number of traits. Among them, ADT 43 (LS), ADT 36 (L4), Kallurundaikar (T4) and Nootripathu (T2) registered significant *gca* effects for single plant yield. ADT 43 also expressed significant *gca* effects for all other traits except plant height. Similarly, high *gca* effects were recorded by ADT 36 for days to 50 per cent flowering, 100 grain weight and relative water content; Kallurundaikar for number of productive tillers plant^{-1}, panicle length, 100 grain weight, proline content, chlorophyll stability index, relative water content and harvest index and

Nootripathu for days to 50 per cent flowering, plant height, number of productive tillers plant^{-1}, number of grains panicle^{-1} and chlorophyll stability index.

Mohamad *et al.* (2007) reported that five maize genotypes (CMT 033066, CMT 033060, CMTQ 033072, CMS 983046, CMTQ 033070) were used in 5 x 5 diallel crossing without reciprocals. Combining ability for some quantitative and physiological traits was studied. F$_1$ hybrids and the parental genotypes were grown in a Randomized Complete Block Design with three replications. The analysis of data was carried out according to Griffing (1956) Method 2 (fixed model). Significant mean squares due to genotypes were exhibited for all traits. Highly significant mean squares due to *gca* was exhibited for all traits, except photosynthetic rate which was found to be non significant. Also highly significant mean squares due to *sca* was obtained for all traits except photosynthetic rate and transpiration rate. Stomatal conductance was found not significant . The ratio 6^2GCA/6^2SCA was less than one for all traits, indicating the importance of non additive gene effect, with the exception of plant height which was more than one, indicating the importance of additive gene effect, and the average degree of dominance values was more than one for all traits, except plant height, indicating the role over dominance gene effect in controlling these characters. Heritability in broad sense was high for all characters studied, while narrow sense heritability was high for plant height and moderate for transpiration rate and stomatal conductance.

Kumar *et al.* (2008) reported that non-additive type of gene action governed leaf area index and net assimilation rate in rice.

Goncharova (2010) reported that nutrition, content of a, b chlorophylls and carotenoids specific for physiological heterosis in hybrids was investigated in six rice varieties and 30 hybrid combinations. It was shown that resulting determinant manifestation was determined both by intergenic and intraloci interaction, but the main role belong to additive gene effects. The polygenic character of inheritance and nondirectional domination among studied determinants were revealed. Superdominance was specific for stem growth speed, but incomplete dominance was observed for majority of the other determinants.

Jayasudha and Sharma (2010) reported that thirty (30) genotypes from F_1 were obtained from six soybean strains (Anjasmoro, Tanggamus, Argopuro, Grobogan, Brawijaya 2 and Brawijaya 1) which were hybridized in the diallel cross scheme. These genotypes were used to analyze the combining ability and maternal effect of physiological characters in soybean strains such as CO_2 exchange rates (CER), intercellular CO_2 concentration (Ci), stomatal conductance (SC), and transpiration (E). The result showed that Tanggamus, Brawijaya 2 and Brawijaya 1 strains have positive general combining ability and were significantly different from the other strains. Thus these strains have a good possibility to be crossed with others. Brawijaya 2 (male) x Tanggamus (female), Brawijaya 2 x Argopuro, Argopuro x Brawijaya 1, Brawijaya 1 x Grobogan, Brawijaya 1 x Brawijaya 2, and Brawijaya 1 x Argopuro were the selected genotypes which have positive specific combining ability from most of the characters observed.

Akter *et al.* (2010) reported significant positive and negative *gca* and *sca* effects of parents and crosses in rice for panicle weight and leaf area index. These traits were governed by non-additive gene action.

John *et al.* (2011) examined combining abilities for physiological traits in peanut to understand the type of gene action governing these traits and to identify peanut genotypes suitable for use as parents in breeding for improvement in physiological traits. SPAD chlorophyll meter reading was highest in K-1375. Among the parents K-1375, TIR-25 and TCGS-647 were found to be superior as evident from its highest significant positive general combining ability effects for specific leaf area. The best combiner for transpiration rate was ICGV-91114 and for photosynthetic rate was TIR-25. For water use efficiency TPT-4 was the best combiner. The hybrid TPT-4 x TIR-25 was the specific hybrid for high water use efficiency. For SPAD chlorophyll meter reading only one cross, K-1375 x TCGS647 was considered to be a good performing hybrid. Two hybrids *viz.*, TIR-25 x TCGS- 647 and ICGV-91114 x JL-220 were found to be good specific combiners for harvest index. A perusal of results of combining ability analysis indicated considerable non-additive gene action in the inheritance of majority of the attributes studied. The non-fixable dominance deviation and epistatic effects are likely to hinder improvement through simple pedigree selection, which is commonly followed in groundnut. Alternatively, intermating of the F_2 segregants followed by recurrent selection and pedigree breeding can harness the different kinds of gene - effects. Repeated selection and inter-mating of segregating materials for two or three cycles makes it possible to achieve simultaneous improvement in physiological attributes.

Gopikannan and Ganesh (2013) reported non-additive type of gene action for the traits proline content, total chlorophyll content and chlorophyll stability index in rice.

In order to identify parents suitable for use in a breeding program for the development of high quality and high yield varieties of bread wheat with drought tolerance the combining ability and gene action for certain physiological traits were investigated in half-diallel crossings among eight parental lines. The cultivars investigated (Irena/Babax//Pastor, S-78-11, Tajan, Chamran, Moghan 3, Hamoon, Veery/Nacozari and Hirmand) possess different tolerance levels to drought stress. Eight parental genotypes, and their resulting 28 F_2 generations were grown in a triplicate randomised complete block design. Drought stress and non-stress conditions were achieved through irrigation at 75% and 25% soil moisture depletion. Data were subjected to analysis of variance, combining abilities factor analysis and correlation analysis between drought tolerance indices and factor scores (according to Griffing's method 2, model 1). General combining ability and specific combining ability effects were significant for traits; however, non-additive gene effects were dominant over additive effects. The cultivar Chamran transmitted high relative water content (RWC) to its progeny, based on general combining ability. Broad-sense heritability was high and strict-sense heritability was low for the traits, confirming the importance of non-additive gene effects. The results of factor analysis revealed that three factors explained approximately 70%.of total variation; these factors were strongly influenced by chlorophyll *a* and *b*, proline content, cell membrane stability index, RWC and plant yield. Based on drought stress indices (STI and GMP), the cross Irena×Chamran was the most tolerant genotype. Correlation coefficients between two drought stress indices and the third factor from the factor analysis, which influenced RWC and plant yield, were positive and significant. Thus RWC may be a good criterion for selection of tolerant genotypes with higher yields in breeding programme (Mohammad *et al*., 2013).

Rad *et al.* (2013) reported that analysis of variance showed significant differences in traits studied. Phenotypic values of chlorophyll *a* and *b,* cell membrane stability index (MSI), proline content, (RWC), stomatal conductance and plant grain yield differed significantly among the eight parental lines and 28 F_2 hybrids ($P \leq 0.01$). Both *gca* and *sca* were highly significant for chlorophyll *a* and *b,* stomatal conductance, proline content, RWC and plant grain yield ($P \leq 0.01$), but *gca* variance was not significant for the MSI. Mean square values were higher for *gca* than for *sca* for chlorophyll *a*, stomatal conductance and proline content; however, for chlorophyll *b*, RWC, MSI and plant grain yield, the mean square of *sca* was higher than the mean square of *gca*, indicating the importance of both additive and non-additive gene effects.

Shal *et al.* (2014) reported that five landraces of wheat (*Triticum aestivum* L.) collected from diverse areas of Egypt and their ten possible crosses were used to establish the experimental material for an investigation. The variation among wheat genotypes and available crosses was observed to estimate the magnitude of general combining ability (*gca*) and specific combining ability (*sca*) for physiological traits, yield and yield components. Mean squares for parents showed high significance for net photosynthesis rate (Pn), transpiration rate (E) and stomatal conductance (SC).

Anyanwu and Obi (2015) reported that mean square due to *gca*, *sca* and reciprocal effects were highly significant for percentage protein content in the diallel analysis, implying the presence of genetic diversity among the genotypes. About 50% of the parents showed desirable positive *gca* effects and included: CT7127-49, EMPASC 105, WAB 96-1-1 and Max. 20 crosses showed positive *sca* effects.

2.7 HETEROSIS ESTIMATE

The concept of hybrid vigour was first put forth by Shull (1908) which has given birth to heterosis breeding. Heterosis is a phenomenon in which F_1 hybrids show superiority over their parents (mid parent or better parent heterosis) or over standard check (standard heterosis).

In rice, heterosis was reported by Jones (1926) who observed in F_1 hybrids, higher culm growth and yield over their parents. Since then, several studies have been made to estimate the extent of heterosis in rice for yield and contributing characters. The earlier reports were on relative heterosis and heterobeltiosis. However, since 1976, after the success of F_1 rice hybrids in China, that standard heterosis is being considered. The literature pertaining to heterosis in rice has been reviewed and tabulated as follows.

2.7.1 Heterosis for Morphological Traits

Young and Virmani (1990) reported 23.2 to 28.5%, -35.5 to 21.6% and - 36.0 to 16 of heterosis, heterobeltiosis and standard heterosis for the character plant height. They also reported -22.0 to 20.7%, -26.4 to 9.7% and -34.2 to 7.0% of mid parent heterosis, heterobeltosis and standard heterosis for the character days to fifty per cent flowering.

Vidya chandra (1991) reported standard heterosis of -35.9 to 30.0%, -35. 9 to 30.3%, -56.2 to 9.6% and -45.1 to 18.0% for the characters plant height, days to fifty per cent flowering, panicles plant^{-1} and number of spikelets panicle^{-1} respectively.

Leenakumary (1994) reported standard heterosis of -21.0 to 38.5%, -42.1 to 67.6%, -15.8 to 28.5%, -22.5 to 105%, -82.7 to 81.5% and -79.9 to 111% for the characters plant height, panicles per plant, panicle length, number of spikelets plant^{-1}, number of filled spikelets panicle^{-1} and grain yield plant^{-1} respectively.

Patel *et al.* (1994) gathered information on heterosis for 10 yield components in 30 F_1 hybrids from line x tester crosses of 13 rice genotypes grown during 1987 in Navasari. Estimates of heterotic effects were highest for days to 50% flowering, grains per panicle and yield per plant, whereas days to maturity, panicle length and harvest index had the least heterotic effects. Hybrids Kalhari x S34-36, Khalhari x GR3, IRTP 9298 x IRTP 10800 and N 53 x OR 3 had the greatest heterosis for yield.

Reddy and Nerkar (1995) provided information on heterosis and inbreeding depression (ID) from upland rice crosses. There was highly significant mid parent and better parent heterosis for grain yield in 4 hybrid combinations. In the F_2 population of these 4-hybrids there was inbreeding depression (ID). They also concluded that high heterosis for yield was due to additive heterotic effect of one or more yield components. They indicated high heterosis and ID for effective tillers plant^{-1} and number of filled grains panicle^{-1} indicating non-additive gene action governing these traits.

Murthy (1996) reported that selected hybrids grown under purely rainfed conditions recorded yield in the range of 0.7 to 3.2 t per ha. The highest yielding hybrids were APHR2, MTUHR 2023, MTUHR 2029 and MTUHR 2028. Form their studies it was evident that the hybrids MTUBR 2000, MTUHR 2023, MTUHR 2028, MTUHR 2029 and APHR-2 exhibited higher productivity under natural moisture stress situation and had better prospects under rainfed ecosystem.

Chen-Shun Hui *et al.* (1997) reported 13.9 to 20% heterosis for grain yield plant^{-1} and 26.8 to 29.90% heterosis for spikelets panicle^{-1} in the crosses TGMS x WCVs and WCVs x TGMS hybrids respectively. They also reported negative heterosis for fertility, plant height and days to heading. They indicated that yield plant^{-1} appeared to be controlled by nonadditive effects while plant height and heading days were conditioned by additive gene effects.

Nadali and Nadali (2010) reported highest heterosis (106.60%) in cross IR68899A x Poya followed by other eight crosses for yield and most of its related traits. The proportional contribution of testers was observed to be higher than that of the interactions of line x tester that revealed the higher estimates of GCA variance that is additive gene action among the testers used. Within CMS parents, IR62829A and among male parents, IR50 and Poya were observed to be good general combiners for most of the characters studied. The cross combinations IR62829A x Mosa-tarom, IR68899A x Poya, IR58025A x IR50 and IR58025A x

Poya were observed to be good specific cross combinations for grain yield and most of its related traits due to highly significant *sca* and heterotic effects.

El-Namaky *et al.* (2010) reported that heterobeltiosis for plant height ranged from -2.06 to 29.43%.

Veeresha *et al.* (2013) reported that standard heterosis ranged from -13.17 to -0.4 for panicle weight under aerobic condition. The performance of 44 hybrids developed by line x tester crossing was estimated for heterosis over KRH-2 in respect of seed yield and its contributing characters. The analysis of variance indicated highly significant differences among genotypes and hybrids for all the characters. The hybrid IR-68897A X KMR3 showed standard heterosis and heterobeltiosis for panicles plant^{-1}, panicle weight, 1000 seed weight and grain yield plant^{-1}. Relative heterosis for grain yield plant^{-1} ranged between -57.26 to 421.22 coupled with significant heterobeltiosis from -59.89 to 364.41. The standered heterosis ranged from -65.52 to 204.52 for grain yield plant^{-1}. Based on per se performance and standered heterosis, the hybrids IR68897A x KMR3 and IR-68897A x IR-65912-90-1-6-3R were identified as the superior hybrids for panicle length, grains panicle^{-1} and grain yield.

Pourmohammad *et al.* (2014) reported that canopy temperatures, chlorophyll index, relative water content, leaf water potential, proline content and yield were controlled by additive effects under mild stressed conditions. Under severe stress conditions however, canopy temperatures, leaf water potential and proline content were controlled by additive effects, while chlorophyll index and relative water content were controlled by both additive and dominant effects, as seed yield was mainly influenced by dominant effects. Narrow sense heritability ranged from 47-97% for all traits, except for chlorophyll fluorescence. Yield correlated positively with chlorophyll index and relative water content, and negatively with canopy temperature and leaf water potential. Therefore, under drought stressed conditions in breeding programs, canopy temperatures, chlorophyll index and relative water content can be reliable criteria for the selection of tolerant genotypes with prospect to higher yields.

Bhati *et al.* (2015) reported that hybrid rice technology is one of the most important and practically feasible technologies to enhance rice productivity. This study was conducted to assess the hybrids for *per se* performance and heterosis with respect to yield and yield related traits and to identify and best hybrid combination for commercial utilization. Result indicated that the magnitude of heterosis for grain yield over better parent was significantly superior in 21 hybrids with the highest value of 93.3% in Pusa 6A x Akshaya Dhan. Eighteen hybrids showed significant positive heterosis over standard variety (BPT 5204) with the highest value of 66.9% in Pusa 6A x Akshaya Dhan cross for grain yield plant^{-1}. Out of 32 hybrids, 12 showed significant positive heterosis over standard hybrid (Arize-6444) with highest value of 34.8% in Pusa 6A x Akshaya Dhan for grain yield plant^{-1}. Top two higher yield heterotic crosses over the standard variety (BPT 5204) were Pusa 6A x Akshaya Dhan (66.9%) and IR79156A x MTU-7029 (60.1%). These 2 hybrids also exhibited significant positive yield heterosis over standard hybrid (Arize 6444) 34.8% and 29.2% respectively. Both the hybrids exhibited significant positive standard heterosis for almost all the desirable yield attributing traits and significant negative standard heterosis for days to 50% flowering and days to maturity. The top heterotic crosses *viz.,* Pusa 6A x Akshaya Dhan, IR79156A x MTU-7029, Pusa 6A x MTU-7029, Pusa 6A x IET 22202 and IR79156A x Danteswari and others which expressed more than 20% standard heterosis for grain yield along with other desirable yield components need to be tested on a larger scale.

Tiwari (2015) reported that estimates of heterosis over better and mid parents ranged from -15.00 to 40.65 and -5.92 to 25.57, respectively. Out of 45 crosses, 42 exhibited significant positive heterosis over better parent, whereas, in case of mid parent out of 45 crosses 44 exhibited significant positive heterosis. The positive significant heterosis for straw yield plant^{-1} indicate that maximum number of leaves which accumulate higher amount of photo synthates (food material) which increase the grain weight. Maximum straw yield indicate maximum number of vascular bundles in stem which provide strength to the palnt and maintain internal communication of plant for better growth.

2.7.2 Heterosis for Physiological and Biochemical Traits

Singh (1997) reported that heterosis for chlorophyll a content ranged from -58.18 to 54.62 per cent over mid parent. The range was from -39.70 to 53.82 per cent for total chlorophyll content, -55.96 to 29.75 percent for soluble protein content and -35.80 to 59.44 per cent for stomatal conductance in rice.

A pot experiment was conducted to study photosynthetic rate in terms of carbon dioxide exchange rate (CER), chlorophyll meter reading (SPAD value) and specific leaf area (SLA) of 12 F_1 hybrids from crosses between *japonica* and *indica* rice and their parents, and to estimate the heterosis in F_1 hybrids at active tillering, flowering and dough ripe stages. In all F_1 hybrids and parent cultivars, CER was high at the active tillering stage with a small heterosis value. A positive heterosis for this trait was found at the flowering stage. The magnitude of heterosis for CER depended on the cross combinations. Although a positive heterosis for SPAD value was found at the active tillering stage, there was no correlation between heterosis for SPAD value and that for CER at the flowering stage, at which heterosis for CER was positive. Heterosis for SLA was high at the active tillering stage and gradually decreased thereafter. Heterosis for CER might be dependent not only on negative heterosis for SLA but also on other photosynthetic factors such as N content, soluble protein content and Rubisco activity (Sarker *et al.*, 2001).

Won *et al.* (2002) reported that all of the crossed seed in rice showed positive mid-parent heterosis for protein content and the differences were not significant among the hybrids.

Anna Dura (2002) reported that out of the three types of heterosis, standard heterosis is more important since the hybrid to be released is expected to outperform the superior local variety or hybrid (standard check). At IRRI, the yield of promising F_1 rice hybrids bred using CMS lines showed high mid parental heterosis of 59 per cent and standard heterosis of 35 per cent. In the present study, IR 58025A1Ponni showed highest heterosis for LAI (54.49 per cent) which also exhibited moderate level of SH for yield (23.62 per cent). However the hybrid IR 62829A x BR 736-20-3-1 which recorded the highest SH for yield recorded only 28. 97 per cent SH for LA. Another cross, IR 62829A x MDU 3 showing negative heterosis for LAI exhibited negative heterosis for yield (-29.19 percent). These observations suggested that to get heterotic hybrids for grain yield, LAI during maximum tillering stage should be moderate as the two hybrids manifesting high and low SH for LAI recorded less heterosis for yield. Mid parent heterosis and heterobetiosis ranged from -36 to 28.2 and -37.6 to 25.7 percent respectively for total chlorophyll content.

Cuong *et al.* (2003) conducted studies to determine the effects of soil nitrogen levels (0.22, 0.44 and 0.88gN pot $^{-1}$) on photosynthetic characters, dry matter production and grain yield in F_1 hybrid rice obtained from thermo-sensitive genic male sterile line. Net CO_2 exchange rate (CER) and other related characters viz. , SPAD reading, leaf N content, soluble protein content and ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) activity increased significantly with increasing N level in all the F_1 hybrids and parental cultivars. With increasing N level, the number of tillers, leaf area, root weight, whole plant dry weight and grain yield also increased. Under low N level, the F_1 hybrid did not show heterosis for most photosynthetic characters. However, at high N level, heterosis for CER over of the male parent and the mean of parents was obtained.

Cheema and Sadaqat (2004) reported that heterotic effects were not found significant under normal as well as drought conditions for conductance, tissue water contents, chlorophyll b and carotenoids in Canola.

Kindred and Gooding (2005) reported that varieties Hynoratna and Hynorista exhibited -2.7 and 0.2 mid parent heterosis and -7 and -1.4 per cent better parent heterosis for radiation use efficiency in wheat.

Kumar and Sharma (2008) reported that hybrids HPR 2047 x JD 8, VL 93-3613 x IR 57893-08 and VL 93-6052 x VL Dhan 221 were identified as the best crosses on the bases of grain yield plant^{-1} along with net assimilation rate, dry matter and leaf area index. This information on the extent of heterosis would help in the choice of further breeding programmes.

Amudha *et al.* (2010) reported that highest standard heterosis over check CT-6510-24-1-2 was observed for the traits relative water content (4%), membrane integrity (26.33%), transpiration rate (87.50 %), and stomatal conductance (134.63%) for a rice hybrid under upland situations.

El-Namaky *et al.* (2010) reported that heterobeltiosis for chlorophyll content ranged from -12.24 to 13.87 % in rice.

Amiribehzadi *et al.* (2012) reported heterobeltiosis in pearl millet ranged from -65.24 to 42.01 for chlorophyll a, -65.41 to 192.94 for chlorophyll b and -55. 56 to 114.46 for carotenoides.

Lal *et al.* (2013) reported that heterosis and heterobeltiosis ranged from -14.14 to 28.36 percent and 3.33 to 26.32 per cent over mid and better parents for chlorophyll stability index in wheat. Heterosis for grain protein ranged from 10. 94 to 19.63 and 2.98 to 27.91 over mid and better parents respectively.

Cuong *et al.* (2014) reported that heterosis is defined as increased vigour of hybrids in comparison to their parents. In this study, seven cultivars of upland inbred rice (male parents) and their F_1 hybrids generated by crossing with a thermo–sensitive genic male sterile (TGMS) 103S line (female parent). The cultivars were examined for characters of photosynthesis and dry matter production under drought stress at flowering stage and recovery at ripening stage. The results showed that under drought, all F_1 hybrids exhibited very low negative heterosis for CO_2 exchange rate, stomatal conductance, mesophyll conductance and transpiration rate, but high positive heterosis for intercellular CO_2 concentration. The heterosis value increased much more in the F_1 hybrids under drought recovery than under well–watered conditions. During drought stress, heterosis value decreased slightly for dry matter accumulation compared to well–irrigated conditions. Although CO_2 exchange rate significantly decreased, dry matter accumulation was maintained in all F_1 hybrids after drought recovery, which suggests the potential for using upland rice as male parent to produce F_1 hybrids from TGMS lines for drought tolerance. They further reported that relative heterosis and heterobeltiosis ranged from 7.6 to 40.5 and -20.4 to 32.8 percent respectively under drought at flowering stage for water use efficiency. Under control it ranged from -31 to 2.1 and 30.2 to 6.8 for relative heterosis and heterobeltiosis for the character. Ripening stage it ranged from -35.9 to-3.8 for heterobeltiosis and-32 to -7.9 per cent for relative heterosis under drought and from -44.7 to -0.4 percent (heterobeltiosis) and -33.8 to -5.3 percent (relative heterosis) under control in rice.

Manasa *et al.* (2014) carried out experiments to identify best heterotic combinations for three drought tolerant traits *viz.*, SPAD chlorophyll meter reading (SCMR), specific leaf area (SLA) and proline content and grain yield in maize. Thirty six hybrids derived from crossing twelve lines and three testers were raised along with their parents. Significant heterosis over two standard checks *viz.*, NAH-2049 and NAH-1137 was observed in the cross 2422 x HKI-164-4-1-3 for SCMR and proline content. Significant mid parent heterosis was observed in the cross MAI-105 x CML411 for SCMR, proline content and yield.

Liu *et al.* (2014) reported that photosynthetic rate had the highest coefficient of variation in parents but stomatal conductance had the highest coefficient of variation in hybrid rice combinations. Total chlorophyll content and chlorophyll b content had the lowest values in both parents and hybrid combinations. The average of stomatal conductance and transpiration rate of hybrid rice combinations were higher than that of the parents. It indicated that it is conclusive to breed for photosynthetic rate of hybrid in rice combinations. Mid parent heterosis was found for photosynthetic rate, stomatal conductance and transpiration rate. Better parent heterosis was found for photosynthetic rate and stomatal conductance.

Singh *et al.* (2015) recorded heterosis for different traits in hybrid rice. Significant heterosis ranged from -14.89 to 10.12% for the trait membrane thermo stability under irrigated condition. Under drought condition heterosis for membrane thermo stability decreased.

Giancarla *et al.* (2015) reported that the effects of parents and crosses were significant for proline content in barley. The presence of variability among hybrids and their parents was observed. The highest value of heterosis was manifested in the hybrid combination Adi x DH 260/18 (36.17). The lowest values of heterosis correlated with an inferior value of proline content. Among the varieties studied, Andrew (91.50%), and Djerbel (82.50%) had high proportion of dominant alleles and Adi (90%) and Dh 260/18 (81.5%) had more of recessive alleles.

Anyanwu and Obi (2015) carried out studies on a set of 56 F_1s and their F_2s in rice. The parental lines consisting of eight genotypes were grouped into low, medium and high protein parents and crosses were made in all possible combinations. Positive heterosis was observed in all the hybrids in the F_1 and 37 hybrids in the F_2 over their MP indicating dominance in the positive direction. On the other hand, negative heterosis was recorded in 14 hybrids in the F_1 over the HP.

Nayak *et al.* (2015) reported that heterosis and heterobeltiosis ranged from -1.18 to 19.95 and -7.40 to 14.86 respectively for protein content in aromatic rice.

El-Shouny *et al.* (2015) reported that water shortage is one of the major limitations that affect plant growth and cause severe reduction in the crop yield. 15 F_1 hybrids obtained from a 6 x 6 half diallele mating design in barley along with their parents were evaluated in a RBD. Analysis revealed that drought stress caused significant reduction in all traits. Such reduction reached 19.24% in number of grains spikes^{-1}, 15.68 in number of spikes plant^{-1} and grain yield plant^{-1} and 7.74% in 100-kernel weight. RWC was significantly decreased (30.67%), while proline content was significantly increased (73.39%) when plants were subjected to drought stress. Hybrids are considered to the more desirable to be grown under water shortage conditions for increasing grain yield unit area^{-1} could be identified.

2.8 MOLECULAR ANALYSIS STUDIES

Steele *et al.* (2006) conducted marker-assisted selection for root traits in rice. Out of the five loci selected for MAS , only one locus had a significant and positive effect on root traits.

Chaitra *et al.* (2006) reported that root traits^{-1} are difficult to record and require destructive sampling of the plants. DNA-based molecular markers represent a non-destructive method for gathering information regarding the root characteristics. Two root length specific markers, BH14 and RM201 were utilized to determine the maximum root length of 81 diverse genotypes. Polymerase chain reaction analysis revealed all deep-rooted cultivars amplifying 1.57 kb and 140 bp band and shallow-rooted cultivars 1.40 kb and 158 bp band for BH14 and RM201, respectively. Single marker analysis statistically linked the markers to maximum root length, BH14 ($R2$ 22.24%, $P = 0.0001$) and RM201 (R_2 14.62%, $P = 0.0004$).

Lin *et al.* (2007) detected chromosomal regions associated with drought tolerance in rice using SSR mapping system. A total of 525 SSR DNA markers were used to screen polymorphisms between parents. There were 121 SSR DNA markers showing polymorphisms and were mapped in the F_2 population.

Chetan Kumar *et al.* (2012) highlighted the importance of using SSR markers in maintaining the genetic purity of parental lines. Thirty five simple sequence repeats (SSR) markers were employed for fingerprinting of two popular rice hybrids and their parental lines. Six SSR markers were found polymorphic across the hybrids and produced unique fingerprint for the two hybrids.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation was conducted in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani, Thiruvananthapuram during the period from May, 2014 to July, 2016.

In the present study, twenty diverse rice genotypes were screened for drought tolerance. Screening was carried out in the target environment *i. e.* upland virippu and under protected condition imposing reproductive stage moisture stress. Morpho-physiological, biochemical and root characters of the genotypes were studied. A selection index was developed for identifying the best six parents combining yield and drought tolerance. Hybridization was done in half diallel pattern and the fifteen F_1s were evaluated along with their parents. F_2 lines from five superior F_1 hybrids along with parents were evaluated in the target environment *i.e.* upland virippu. Isolation of probable transgressive segregants with drought tolerance and high yield was done.

Experiment I

3.1 PERFORMANCE OF RICE GENOTYPES FOR DROUGHT TOLERANCE UNDER UPLAND CONDITION

Twenty diverse rice genotypes including traditional upland varieties, recommended for uplands and popular high yielding varieties were screened for drought tolerance under upland conditions. Morphological observations were taken at appropriate plant growth stages following the Standard Evaluation System for Rice (IRRI, 1996). The screening of genotypes was done as per the protocols of DRR (Directorate of Rice Research, 2012).

Layout

Design : RBD

Treatment : 20

Replication : 3

Plot size : 2 x 5 m^2

Spacing : 20 x 15 cm

Genotypes selected for study

The genotypes selected for study were Katta Modan (PTB 28), Karutha Modan (PTB 29), Chuvanna Modan (PTB 30), Vyttila 2, Vyttila 6, Jyothi (PTB 39), Swarnaprabha (PTB 43), Kanchana (PTB 50), Aathira (PTB 51), Aiswarya (PTB 52), Harsha (PTB 55), Vaishak (PTB 60), Kanakom (MO 11), Uma (MO 16), Prathyasha (MO 21), Parambuvattan, Arimodan, Kalladiaryan, Karuthadukkan and Thottacheera.

Experiment II

3.2 SCREENING OF RICE GENOTYPES FOR DROUGHT TOLERANCE IMPOSING REPRODUCTIVE STAGE MOISTURE STRESS UNDER PROTECTED CONDITION

The twenty rice genotypes were screened for drought tolerance under protected condition imposing soil moisture stress. Single plants were grown in 20 cm wide and 100 cm long polythene tubes filled with soil with seven replications and forty treatments in a rain shelter. The plants were irrigated upto field capacity till moisture stress treatment was given. Reproductive stage moisture stress was imposed at panicle initiation and at heading. At these two stages moisture was withheld till the point when plants exhibited a leaf rolling score of 7 or relative leaf water content (RLWC) of 70%. Full irrigation was resumed thereafter till harvest. Indirect estimation of water use efficiency (WUE) was done. Observations on relative leaf water content (RLWC) and proline content were taken immediately before giving stress and when plants reached the critical stress level.

Destructive sampling was done for relative growth rate (RGR), leaf area index (LAI), net assimilation rate (NAR) and root character studies immediately before giving stress and when plants reached the critical stress level. One time observations were taken for carbon isotope discrimination and biomass studies. Observations on other morphological characters were taken at appropriate plant growth stages following the Standard Evaluation System for Rice (IRRI, 1996). The screening of genotypes were done as per the protocols of DRR (2012).

Layout

Design : CRD

Treatment : 40 [Factor A (Condition - Normal/ Drought)]

Factor B (Variety)

Replication : 7

Season : Virippu, 2014

Experiment III

3.3 CROSSING BLOCK: RAISING PARENTS AND DEVELOPMENT OF HYBRIDS

Six superior genotypes were selected as parents based on yield and drought tolerance traits. They were hybridized in half diallel pattern and F_1 seeds were collected.

Experiment IV

3.4 FIELD EXPERIMENT FOR EVALUATION OF F_1 AND PARENTS

The six superior varieties and their fifteen hybrids were evaluated in a Randomized Block Design with three replications as rainfed upland crop during virrippu 2015 at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram. The cultural and management practices were followed as per the package of practices recommendation of KAU (KAU, 2011). Data on thirty two characters were recorded replication wise from random sample of five plants after completely excluding the border rows and the mean values were used for statistical analysis. Observations were taken at appropriate plant growth stages. Seeds were collected from F_1 for raising F_2 generation.

Experiment V

3.5 FIELD EXPERIMENT FOR EVALUATION OF F_2 LINES

F_2 lines from the five best F_1 hybrids were evaluated along with parents in a Randomized Block Design with three replications in the target environment *i. e.* upland virippu, 2015 at the instructional farm, College of Agriculture, Vellayani, Thiruvananthapuram during crop season of 2015. The cultural and management practices were followed as per the package of practices recommendation of KAU (KAU, 2011). Data on thirty two characters were recorded replication wise from random sample of thirty plants after completely excluding the border rows and the mean values were used for statistical analysis Observations were taken at appropriate plant growth stages. F_3 seeds were collected from the five best F_2 populations.

3.6.1 Morphological studies (Experiments I, II, IV and V)

3.6.1.1 Days to 50 % Flowering

Number of days taken from sowing to 50 percent flowering of the plant population was recorded.

3.6.1.2 Nature of Panicle Exsertion

The panicle exsertion of the plant was scored based on exsertion of panicle from the flag leaf standardized for rice by DRR (2004).

Sl. No.	Type of panicle exsertion	Percent panicle exsertion from flag leaf
1	Partly exserted	(Less than 80 %)
2	Mostly exserted	(81-99%)
3	Well exserted	(100%)

DRR, 2004

3.6.1.3 Number of Productive Tillers plant^{-1}

Number of productive tillers in a plant was recorded prior to harvest.

3.6.1.4 Plant Height at Maturity (cm)

Plant height at maturity was measured in centimeters from ground level to tip of the tallest panicle about one week prior to harvest.

3.6.1.5 Panicle Length (cm)

Length of panicle was measured from the base of the panicle to the tip of the panicle and expressed in centimeters.

3.6.1.6 Number of Spikelets panicle^{-1}

Number of spikelets per panicle from fifteen panicles was counted and the mean was worked out.

3.6.1.7 Number of Filled Grains Panicle^{-1}

Number of filled grains per panicle from fifteen panicles was counted and the mean was worked out.

3.6.1. 8 Spikelet Sterility (%)

The number of sterile spikelets (unfilled grains) in the primary panicle of the selected plants was counted and recorded as percentage.

$$\text{Spikelet sterility} = \frac{\text{Number of unfilled grains}}{\text{Total number of spikelets}} \text{x } 100$$

3.6.1.9 Grain Weight Panicle^{-1} (g)

The weight of fifteen panicles was taken and then the average weight was worked out for single panicle and was recorded in grams.

3.6.1.10 1000 Grain Weight (g)

The weight of 1000 grains selected at random from each genotype was recorded in grams.

3.6.1.11 Grain Yield Plant^{-1} (g)

The total weight of grains separated from all the panicles per plant was recorded as grain yield per plant in grams.

3.6.1.12 Straw Yield Plant^{-1} (g)

The weight of straw after removing panicles was recorded as straw yield per plant and recorded in grams.

3.6.1.13 Harvest Index (%)

Harvest index is the proportion of economic yield reported over biological yield, which is expressed in percentage.

$$\text{Harvest Index} = \frac{\text{Grain yield (g)}}{\text{Biological yield (grain+ straw yield) (g)}} \text{ X } 100$$

3.6.1.14 Leaf Rolling Score

One week after the start of drought, leaf rolling score was recorded based on standard evaluation system for rice. Leaf rolling scores ranged from 1 (no leaf rolling) to 9 (leaves completely rolled). Leaf rolling score measurements were taken between 11 and 12 noon at twenty days after stress imposition using the scoring scale standardized for rice by IRRI (1996).

Table 2. Leaf rolling scores (IRRI, 1996)

Decimal score	Leaf rolling description
0	Leaves healthy (No rolling)
1	Leaves start to fold (Shallow V shape)
3	Leaves folding (deep V shape)
5	Leaves fully cupped (U-shape)
7	Leaf margins touching (O-shape)
9	Leaves tightly rolled

3.6.1.15 Incidence of pests and diseases

Pest and disease incidence was scored using standard procedure as mentioned in standard evaluation system for rice (IRRI, 1996).

$$\text{Disease incidence \%} = \frac{\text{Total number of infected plants}}{\text{Total number of plants observed}} \times 100$$

$$\text{Pest infestation \%} = \frac{\text{Total number of infected plants}}{\text{Total number of plants observed}} \times 100$$

3.6.2 Physiological and Biochemical Studies (Experiments II and IV)

3.6.2.1 Water Use Efficiency (WUE) (g/l)

Water use efficiency is defined as kilograms or grams of biomass accumulated unit^{-1} of water transpired and WUE is expressed as gram per kilograms.
Water Use Efficiency = Biomass accumulated (gram)/ water transpired (kilogram)

3.6.2.2 Relative Leaf Water Content (RLWC) (%)

RWC was measured twice during the stress period. Leaves were sampled at midday after the dew had dried. One uppermost fully expanded leaf per plot was sampled and placed in pre-weighed centrifuge tubes. Samples were stored on ice and weighed immediately upon return to the lab for the fresh weight. Tubes were then filled with water and stored overnight in the dark at 4°C. The next morning, leaves were blotted dry with paper towels using the standard procedure that required about 30s per sample, and were weighed immediately. After recording fully turgid weight, leaves were dried at 70 °C to constant weight.

$$\text{RWC \%} = \frac{\text{Fresh weight} - \text{Dry weight (g)}}{\text{Turgid weight} - \text{Dry weight (g)}} \text{ X } 100$$

3.6.2.3 Proline Content (mg/g)

The standard procedure for determination of proline content as outlined by Bates *et al*. (1973) was adopted and proline content of leaf sample for each treatment of particular replication was determined and results expressed as milligram gram^{-1} of fresh weight of leaf.

3.6.2. 4 Cell Membrane Stability Index (%)

Leaf discs (10 numbers) from the third fully opened leaves were taken in a 50 ml beaker with 10 ml distilled water. Initial EC was measured for detecting the small degree of leakage by the discs caused by the punching treatment using conductivity electrode (ECa). After 30 minute incubation the leakage of solutes in this bathing medium was measured (ECb). Then the beakers were boiled at 100 °C for 10 minutes and the EC was again recorded (ECc). The membrane integrity of leaf tissue was calculated using the following formula.

$$\% \text{ leakage} = \frac{\text{ECb- ECa}}{\text{ECc}} \times 100$$

3.6.2. 5 Chlorophyll Content (mg/g)

Chlorophyll content of leaf samples were estimated as per the procedure described by Arnon (1949). A weighted quantity of leaf sample (0. 5g) was taken from fully expanded third leaf and cut in to small bits. These bits were put in test tubes and incubated overnight at room temperature, after pouring 10 ml DMSO: 80% acetone mixture (1:1 v/v). The coloured solution was decanted in to a measuring cylinder and made up to 25 ml with DMSO- acetone mixture. The absorbance was measured at 663,645,480 and 510 nm. The chlorophyll content was measured by substituting the absorbance values in the given formulae.

$$\text{Chlorophyll a} = (12.7 \text{ x A } 663 - 2.69 \text{ x A } 645) \text{ x } \frac{V}{1000} \text{ x } \frac{1}{\text{Fresh weight}}$$

$$\text{Chlorophyll b} = (22.9 \text{ x A } 645 - 4.68 \text{ x A } 663) \text{ x } \frac{V}{1000} \text{ x } \frac{1}{\text{Fresh weight}}$$

$$\text{Total Chlorophyll (a + b)} = (8.02 \text{ x } A\,663 - 20.2 \text{ x } A\,645)\text{x}\frac{V}{1000}\text{x}\frac{1}{\text{Fresh weight}}$$

$$\text{Carotenoides content} = \left\{ \frac{7.6 \text{ x } A_{480} - 1.49 \text{ x } A_{510} \text{ x } V}{W \text{ x } 1000} \right\}$$

3.6.2.6 Chlorophyll stability index (%)

Chlorophyll stability index (CSI) is the ratio of total chlorophyll content under stress to total chlorophyll content under control and calculated as follows (Sairam *et al.* 1997):

$$\text{CSI (\%)} = \frac{\text{Total Chlorophyll under stress}}{\text{Total Chlorophyll under control}} \text{ X } 100$$

Where,

CSI (%) = Chlorophyll stability index in percentage

3.6.2.7 Leaf Temperature (^{0}C)

Leaf temperature was measured using steady-state porometer (Li-Cor Biosciences, USA). Porometer readings were taken during mid-morning on the youngest fully expanded leaf blade of a main culm or primary tiller.

3.6.2. 8 Transpiration Rate (TR) (mmol m^{-2} s^{-1})

Transpiration rate was measured using SAI-1 Porometer (Delta T devices) and expressed as (mmol m^{-2} s^{-1}). It was measured twenty days after stress imposition. Porometer readings were taken during mid-morning on the youngest fully expanded leaf blade of a main culm or primary tiller.

3.6.2.9 Stomatal Conductance (SC) (mmol mol^{-2} s^{-1})

Stomatal conductance was measured using SAI-1 Porometer of company Delta T devices and expressed as (mmol mol^{-2} s^{-1}). Porometer readings were taken during mid-morning on the youngest fully expanded leaf blade of a main culm or primary tiller.

3.6.2.10 Leaf Soluble Protein Content(mg/g)

Leaf soluble protein content was estimated using simple protein dye binding assay of Marion and Bradford (1976) using bovine serum albumin (BSA) as the standard. One hundred milligram of CBB 250 was dissolved in 50 ml of 95 % ethanol. To this 100 ml of 85% (w/v) Orthophosphoric acid was added. The resulting solution was diluted to a final volume of 200 ml with distilled water. 0.1 g leaf samples were taken from third fully opened leaves was ground to a thin paste and soluble protein extracted with 10 ml of phosphate buffer (pH 7.8). The extract was centrifuged at 5000 rpm for 10 minutes. To the 20 µl of the supernatant a known volume (5ml) of diluted dye binding solution was added. The solution was mixed well and allowed to develop a blue colour for at least 5 minutes but no longer than 30 minutes and the absorbance was measured at 596 nm. Protein content was calculated using the BSA standard in the range of 10-100µg. The protein content was expressed as mg/g of fresh weight.

3.6.2.11 Radiation Use Efficiency (RUE) (MJ/g)

The fraction of intercepted radiation (Fi) was estimated from LAI using the exponential attenuation equation suggested by Monteith and Elston (1983). $F_i = 1 - \exp(-K \times LAI)$ where K is the extinction co-efficient for total solar radiation (Monteith, 1977). The coefficient is equal to 0. 306. The PAR was assumed to be equal to one half of the total incident radiation (Szeicz, 1974). Multiplying these totals by the appropriate estimates of F_i gave an estimate of the amount of radiation intercepted by a crop canopy (Sa):

$S_a = F_i \times S_i$

Where, S_i is the total amount of incident PAR. The radiation utilization efficiency of TDM was defined as;

$RUETDM = TDM/\Sigma S_a$

A seasonal value of ΣS_a was also estimated from the regression of TDM on accumulated intercepted PAR (Hussain and Field, 1993; Hussain *et al.* , 1998). This analysis was extended to calculate the efficiency of seed yield (e SY).

3.6.2.12 Chlorophyll Meter Reading (CMR)

Leaf chlorophyll content was measured by light absorbance in the range of red and infrared with a chlorophyll meter (SPAD-502, Minolta France SA, Currieres-sur-Seine France) in the middle region of second fully opened leaf from the top in 10 plants. The mean SPAD reading was recorded. SPAD reading is equivalent to chlorophyll content in g/cm^2 (Herve *et al.*, 2001 and Teng *et al.*, 2004).

3.6.2.13 Leaf Area Index (LAI)

Leaf area index is used to calculate leaf area per unit land area. Leaf area index is the ratio between leaf area to ground area. It has no unit

$$\text{Leaf area index} = \frac{\text{Leaf area plant}^{-1}}{\text{Spacing of plant}}$$

3.6.2.14 Relative Growth Rate (RGR) (mg/g/day)

Relative growth rate is the amount of growing material unit dry weight^{-1} of plant unit^{-1} time. It is the milligram of dry matter produced by one gram of existing dry matter in a day. It is expressed in milligram per gram per day.

$$RGR = \frac{\log_e w_2 - \log_e w_1}{t_2 - t_1}$$

Where, w_2 and w_1 are dry weight of plant at time t_2 and t_1 respectively.

3.6. 2.15 Net Assimilation Rate (NAR) (g/cm²/day)

Net assimilation rate indirectly indicates net photosynthesis. It measures dry weight of plant per unit leaf area per unit time. NAR is expressed as gram of dry matter produced per cm^2 of leaf area in a day.

$$NAR = \frac{w_2 - w_1}{t_2 - t_1} \times \frac{\log_e A_2 - \log_e A_1}{A_2 - A_1}$$

Where,

W_1, W_2 and A_1 and A_2 are dry weight of plant and leaf area at time t_1 and t_2 respectively.

3.6.2.16 Carbon Isotope Discrimination (per mil)

The stable isotope of carbon ^{13}C makes up very close to 1% of the carbon in atmospheric CO_2. C_3 plants discriminate against ^{13}C during photosynthesis. (Primarily because the proportion of ^{13}C in dry matter of C_3 plants is fractionally less than in atmosphere.) (Condon *et al.*, 2004). Carbon isotope discrimination is a measure of $^{13}C/^{12}C$ ratio in plant material relative to the value of same ratio in the air on which plant feed.

$$\Delta^{13}C = [(Ra/Rp) - 1].\ 1000$$

Where,

Ra- Relative value air (ratio of $^{13}C/^{12}C$)

Rp- Relative value plant

$\Delta^{13}C$ expressed as per thousand i. e. fractional difference from unity is multiplied by 1000 (Condon *et al.*, 2002).

The third fully opened leaf of experimental plants were collected, oven dried at 80 ^{O}C and ground to a very fine powder. The samples were sent to the National Facility for carbon isotope studies in the Department of Crop Physiology 'UAS' GKVK Bangalore where analysis was done using the Isotope Ratio Mass Spectrophotometer (IRMS) coupled with the elemental analyzer for the continuous flow measurement of carbon isotope ratios in plant samples.

3.6.2.17 Number of Days Taken for Reaching Critical Stress Level.

Reproductive stage moisture stress was imposed at panicle initiation and at heading. At these two stages moisture was withheld till the point when plants exhibited a leaf rolling score of 7 or a Relative Leaf Water Content (RLWC) of 70%. The number of days for reaching the critical stress level was recorded.

3.6.3 Soil moisture studies in the field (Experiments I, IV and V)

Percentage soil moisture changes at periodical intervals

Gravimetric method is the most commonly used and the most reliable technique for the determination of soil moisture content in the main field at various levels of depth. A special type of auger (screw auger) is used for taking samples from different replications and in different depths like 10 cm, 15-20 cm and 30 cm. Then the samples were weighed to determine the initial weight of the soil sample (Ww) and then dried at 105°C in hot air oven until it losses no more weight and then determining the percentage of moisture. After drying, the samples were again weighed (Wd). Soil moisture content was calculated by using the formula given below :

$$\text{Soil moisture content on dry weight basis (\%)} = \frac{Ww - Wd}{Wd} \times 100$$

3.6.4 Root character studies (Experiment II)

3.6.4.1 Rooting Depth (cm)

Rooting depth in polythene tube was measured from the base of the plant (collar region) to the tip of the longest root in 'cm'.

3.6.4.2 Root Volume (cc)

Root volume was measured based on the Archimedes principle. A Graduated measuring cylinder was filled with water and the initial volume was recorded. Then the root system was immersed in the measuring cylinder and the over flow was noted after proportionate water displacement had occurred. The difference of the two readings gave root volume in cc (cubic centimetre).

3.6.4.3 Root Dry Weight (g)

The root of each plant was oven dried after separation at 60°C for 145 hours. The dry weights of root samples were recorded in grams.

3.6.4. 4 Root-Shoot Ratio (g/g)

This was computed by dividing the root dry weight of a sample plant by its shoot dry weight.

3.6. 4. 5 Deep Root-Shoot Ratio (mg/g)

It is ratio of deep root to the shoot of genotype. This was computed by finding ratio between total weight of root below 30 cm soil depth and shoot uppermost portion from collar region of root. The so obtained value was recorded in mg/grams.

3.7 MOLECULAR ANALYSIS STUDIES (EXPERIMENT VI)

Observations on the amplified products of DNA with respective primers for the presence of Quantitative Trait Loci (QTL) linked to drought tolerance was made.

Screening of the parents and the best progeny for the presence of Quantitative Trait Loci (QTL) associated with drought tolerance using specific SSR markers (Kanagaraj *et al.*, 2010) was done.

Table 3. List of SSR primers and their sequences

Sl. no	**Primer Name**	**Forward sequence 5'→ 3'**	**Reverse sequence 3'→ 5'**
1	RM201	CTCGTTTATTACCTACAGTACC	CTACCTCCTTTCTAGACCGATA
2	RM263	CCCAGGCTAGCTCATGAACC	GCTACGTTTGAGCTACCACG
3	RM451	GATCCCCTCCGTCAAACAC	CCCTTCTCCTTTCCTCAACC

Plant material

Six parents and five best hybrids comprised the material for molecular studies For DNA isolation, fresh leaf tissues from 20-days old seedlings were harvested in mesh bags. DNA was isolated from genotypes according to CTAB method (Murray and Thompson, 1980). DNA concentration was determined by spectrophotometric analysis at 260 and 280 nm wave length.

DNA isolation

Sample Details

Total No. of Samples : 11

Analysis : PCR using given primers

111

No.	Code
1	1
2	2
3	3
4	4
5	5
6	6
7	H_1
8	H_2
9	H_3
10	H_4
11	H_5

I Protocols

DNA isolation using NucleoSpin® Plant II Kit (Macherey-Nagel)

About 100 mg of the tissue is homogenized using liquid nitrogen and the powdered tissue is transferred to a microcentrifuge tube. Four hundred microlitres of buffer PL1 is added and vortexed for 1 minute. Ten microlitres of RNAase A solution is added and inverted to mix. The homogenate is incubated at 65°C for 10 minutes. The lysate is transferred to a Nucleospin filter and centrifuged at 11000 x g for 2 minutes. The flow through liquid is collected and the filter is discarded. Four hundred and fifty microlitres of buffer PC is added and mixed well. The solution is transferred to a Nucleospin Plant II column, centrifuged for 1 minute and the flow through liquid is discarded. Four hundred microlitre buffer PW1 is added to the column, centrifuged at 11000 x g for 1 minute and the flow through liquid is discarded. Then 700 µl PW2 is added, centrifuged at 11000 x g and the flow through liquid is discarded. Finally 200 µl of PW2 is added and centrifuged at 11000 x g for 2 minutes to dry the silica membrane. The column is transferred to a new 1. 7 ml tube and 50 µl of buffer PE is added and incubated at 65°C for 5 minutes. The column is then centrifuged at 11000 x g for 1 minute to elute the DNA. The eluted DNA was stored at 4°C.

Agarose Gel Electrophoresis for DNA Quality check

The quality of DNA isolated was checked using agarose gel electrophoresis. 1µl of 6X gel-loading buffer (0. 25% bromophenol blue, 30% sucrose in TE buffer pH-8. 0) was added to 5µl of DNA. The samples were loaded to 0. 8% agarose gel prepared in 0. 5X TBE (Tris-Borate-EDTA) buffer containing 0. 5 µg/ml ethidium bromide. Electrophoresis was performed with 0. 5X TBE as electrophoresis buffer at 75 V until bromophenol dye front had migrated to the bottom of the gel. The gels were visualized in a UV transilluminator (Genei) and the image was captured under UV light using Gel documentation system (Bio-Rad).

PCR Analysis

PCR amplification reactions were carried out in a 20 µl reaction volume which contained 1X Phire PCR buffer (contains 1.5 mM $MgCl_2$), 0. 2mM each dNTPs (dATP, dGTP, dCTP and dTTP), 1 µl DNA, 0.2 µl Phire Hotstart II DNA polymerase enzyme, 0.1 mg/ml BSA and 3% DMSO, 0. 5M Betaine, 5pM of forward and reverse primers.

Primers used

RM201

RM263

RM451

The PCR amplification was carried out in a PCR thermal cycler (Gene Amp PCR System 9700, Applied Biosystems).

PCR amplification profile

98 °C - 30 sec

$$\left.\begin{array}{lll} 98\,^{\circ}\mathrm{C} & - & 5\ \mathrm{sec} \\ 58\,^{\circ}\mathrm{C} & - & 10\ \mathrm{sec} \end{array}\right\}\ 40\ \mathrm{cycles}$$

72 °C - 15 sec

72 °C - 60 sec
4 °C - ∞

Agarose Gel electrophoresis of PCR products

The PCR products were checked in 1. 5% agarose gels prepared in 0. 5X TBE buffer containing 0.5 µg/ml ethidium bromide. 1 µl of 6X loading dye was mixed with 5 µl of PCR products and was loaded and electrophoresis was performed at 75V power supply with 0.5X TBE as electrophoresis buffer for about 1-2 hours, until the bromophenol blue front had migrated to almost the bottom of the gel. The molecular standard used was a 2-log DNA ladder (NEB). The gels were visualized in a UV transilluminator (Genei) and the image was captured under UV light using Gel documentation system (Bio-Rad).

SSR markers assay and detection of polymorphism and presence of Quantitative Trait Loci (QTL) linked to drought tolerance

Three SSR markers (RM 451, RM 201 and RM 263) (Table 3) associated with drought tolerance QTLs, were evaluated for their use in marker assisted selection (MAS) in the six parents and their best five hybrids.

3.8 STATISTICAL ANALYSIS: EXPERIMENT I , II AND V

3.8.1 ANOVA (Panse and Sukhatme, 1967)

3.8.1 Analysis of Variance for fourteen characters in twenty rice varieties

To test the significance of differences between treatments, the analysis of variance for randomized block design (RBD) was carried out by following Panse and Sukhatme (1967), for all characters under study. The model of ANOVA used is presented below

Table 4. Analysis of Variance

Source of variation	**Degree of freedom**	**Sum of square**	**Mean sum of square**	**Expected mean squares**	**F value**
Replications	(r-1)	Sr	RSS	$\sigma^2 e + t\, \sigma^2 r$	MSr/MSe
Treatments	(t-1)	St	TSS	$\sigma^2 e + r\, \sigma^2 t$	MSt/Mse
Error	(r-1) (t-1)	Se	MSe	$\sigma^2 e$	

Where,

r = Number of replications
t = Number of treatments
d.f. = Degrees of freedom
S. S. = Sum of square
MSS = Mean sum of squares
RSS = Replication sum of squares
TSS = Treatment sum of squares
MSe = Error sum of squares

Standard error (SE), critical difference (CD) and coefficient of variation (CV) were calculated as follows,

SE (±) = $\sqrt{Mse/r}$

CD = $SE\ x\ \sqrt{2}$ x t value

CV%= $\frac{\sigma}{X}$x100

Where,

Mse : Error mean square

t : Table't' value at error degrees of freedom at 5 and 1 per cent level.

r : Number of replications

σ : Standard deviation

$\overline{x}$: Mean

3.8.2 Estimation of genetic parameters:

The co-efficient of variability both at phenotypic and genotypic levels for all the characters were computed according to the formulae suggested by Burton and Dewane (1953) and Burton (1952).

3.8.2.1 Genotypic and phenotypic co-efficients of variation (GCV and PCV)

$$\text{GCV\%} = \frac{\text{Genotypic standard deviation}}{\text{Grand Mean}} \times 100$$

$$\text{PCV\%} = \frac{\text{Phenotypic standard deviation}}{\text{Grand Mean}} \times 100$$

Per cent PCV and GCV were classified 0-10% low, 10-20% moderate and 20% and above as high as suggested by Sivasubramanian and Menon (1973).

3.8.2.2 Estimation of heritability values

Heritability estimates (broad sense) for different characters were computed using formula (Hanson *et al.* , 1956).

$$h^2 = \frac{Vg}{VP} x100$$

h^2 %= heritability expressed in percentage.

Vg and Vp are genotypic and phenotypic variances respectively.

The heritability estimates were categorised as 0-30 % low; 30-60% moderate and >60% as high (Robinson *et al.*, 1949).

Genetic advance:

Genetic advance was calculated using the formula given by Johnson *et al.* (1955).

$$GA = h^2 \text{ x } k \text{ x } \sigma P$$

Where,

h^2 = Heritability in broad sense.

k = Selection differential which is 2. 06 at 5% intensity of selection (Lush, 1949).

σ_P = Phenotypic standard deviation

$$\text{GA as percent of mean} = \frac{GA}{X} \, x \, 100$$

The genetic advance as percent mean was categorised as 0-10% low; 10- 20% moderate and 20% & > 20%as high, as suggested by Johnson *et al.* (1955b).

3.8.3 Character association

Correlation coefficients were computed to find the association amongst characters studied using the formula suggested by Sunderraj *et al.*, (1972).

$$r_{12} = \frac{\text{COV (X1 X2)}}{\sqrt{\text{V (x1)x(V(x2)}}}$$

Where,

r_{12} = Correlation coefficients between X_1 and X_2 characters.

$COV (X_1X_2)$ = Covariance between X_1 and X_2

Phenotypic and genotypic correlations were computed using the formula given by Singh and Chaudhary (1985).

$$rp_{12} = \frac{COVp\ (X1\ X2)}{\sqrt{Vp\ (X1)x(V(X2)}}$$

$$rg_{12} = \frac{COVp\ (X1\ X2)}{\sqrt{Vp\ (x1)x(V(x2)}}$$

Where.

rp_{12} and rg_{12} are phenotypic and genotypic correlations respectively. COVp (X_1X_2) and COVg (X_1X_2) are phenotype and genotypic covariances respectively. Vp (X_1) and Vp (X_2) are phenotypic variances and Vg (X_1) and Vg (X_2) are genotypic variances for X_1 and X_2 characters respectively. Significance of correlation coefficients were tested at (n-2) degrees of freedom table value from Fisher and Yates (1963) table at 5% and I % level of significance.

3.7.4 Path co-efficient analysis

Path-co-efficient analysis was carried out using genotypic correlation values of yield components on yield as suggested by Wright (1921) and illustrated by Dewey and Lu (1959). Standard path co-efficients which are the standardized partial regression co-efficients were obtained using statistical software package SPAR 1. These values were obtained by solving the following set of 'P' simultaneous equations by using the above package.

$P_{01} + P_{02}\, r_{12} + \text{----------} + P_{0P}\, r_{1P} = r_{01}$

$P_{01} + P_{12}\, r_{02} + \text{----------} + P_{0P}\, r_{2P} = r_{02}$

$P_{01} + r_{1P} + P_{02}\, r_{2P}\, \text{----------} + P_{0P} = r_{0P}$

Where P_{01}, P_{02}, ------------------------P_{0P} are the direct effects of variables 1,2, -------------p on the dependent variable 0 and r_{12}, r_{13} ,-------r_{1P}------ $r_P(P\text{-}1\ )$ are the possible correlation co-efficients between various independent variables and r_{01}, r_{02}, r_{03} ------- r_{0P} are the correlations between dependent and independent variables.

The indirect effect of the ith variable *via* jth variable is attained as ($P_{oj} \times r_{ij}$). The contribution of remaining unknown factor is measured as the residual factor, which is calculated as given below.

$P2ox = 1\text{-}\ [P2_{01} + 2P_{01}\ P_{02}\ r_{12} + 2\ P_{01}\ P_{03}\ r_{13} +\text{----------}+ P_{202} + 2P_{02}\ P_{03}\ r_{13} + \text{.........} +P_{20}P]$

Residual effect $(R^2) = 1\text{-}\sum \quad P_i r_{iy}$

3.8.5 Selection index for identification of best parents (Singh and Chaudhary, 1985)

General selection index was proposed by Hanson and Johnson in 1957. This is a modification of the scheme of Smith (1936). In this model the weights for various traits are based on the average statistics for several populations. The general form of selection index is given below

$I = b_1X_1+b_2X_2+b_3X_3 \text{..............................} b_nX_n$

Where,

X_1, X_2, X_3 and X_4 represent the phenotypic values of the character number 1,2,3 and n respectively and b_1,b_2,b_3 and b_n are the corresponding weights.

The b values are calculated from series of simultaneous equations involving the appropriate phenotypic and genotypic variances and covariances. The b values are worked out separately for various selection indices involving single, double, triple and multiple traits. The simultaneous equations are solved by elimination process and b values are obtained. The following simultaneous equations could be set with the help of appropriate variances and covariances of these traits.

Experiment IV

3.8.6 Half diallel analysis for estimation of combining ability (*gca* and *sca*) and type of gene action involved (Griffing, 1956)

Combining ability analysis was performed with the data obtained for parents and hybrids according to Model-I, Method-II proposed by Griffing (1956). This includes partitioning of variation among sources attributable to genenral combining ability (*gca*) and specific combining ability (*sca*) components. The analysis of variance for the combining ability is based on the following statistical model.

$$Y_{ijk} = \mu + g_i + g_j + s_{ij} + \varepsilon_{ij}\, k$$

Where,

Y_{ijk} = mean value of hybrid involving ith and jthparent in kth replication

μ = general mean

g_i = *gca* effect of ith parent

g_j = *gca* effect of jth parent

s_{ij} = *sca* effect for the cross between ith and jth parents such that $s_{ij} = s_{ji}$

ε_{ijk}= uncontrolled variation associated with ijkth observation

i, j = 1,2,..........p (p = number of parents)

k = 1,2,..........b (b = number of blocks)

The form of ANOVA for combining ability and expectation of mean square are given in Table 5.

Table 5. Analysis of variance for combining ability

Source	**d. f.**	**S. S.**	**M. S.**	**Expectation of mean squares**
GCA	(p -1)	S_g	M_g	$\sigma^2 e + \frac{(p+2)}{(p-1)} \sum_i g^2_i$
SCA	$\frac{p(p-1)}{2}$	S_s	M_s	$\sigma^2 e + \frac{2}{p(p-1)} \sum_i \sum_j s^2_{ij}$
Error	(r-1)(g-1)	S_e	M_e	σ^2_e

Sum of squares due to various sources were calculated as follow:

$$S_g = \frac{1}{(p+2)}\left[\left(\sum_i (Xi. + Xii)^2\right) - \frac{4}{p} X^2 \ldots\right]$$

$$S_s = \sum_i \sum_j X^2_{ij} - \frac{1}{(p+2)} \sum (Xi. + Xii)^2 + \frac{2}{(p+1)(p+2)} X^2..$$

S_g= Sum of square due to general combining ability

S_s= Sum of square due to specific combining ability

p= number of parents

$X_{i.}$ = mean value of ith parent

X. . = grand total of all the progenies and parental mean values

M_e = error mean square (M_e /r)

Further, the components of variance determining the additive and non-additive gene actions were computed using the following formula.

$$\sigma^2 gca = \frac{M_g - M_e}{p+2}$$

$$\sigma^2 sca = M_s - M_e$$

Where,

M_g = mean sum of square due to *gca* effect

M_s = mean sum of square due to *sca* effect

$M_e = M_e / b$ = error mean square

3.8.6.1 Test of Significance of Combining ability

The error mean square for combining ability (M_e) was obtained by dividing error mean square (M_e) in ANOVA for each character by number of replications. The following F ratios were used to test *gca* and *sca* variances

gca mean square : $F = M_g / M_e$

sca mean square : $F = M_s / M_e$

3.8.6.2 Estimation of General and Specific Combining ability Effects

The general and specific combining ability effects were estimated as under

$$\text{Population mean } (\mu) = \frac{2}{p\,(p+1)} Y..$$

$$\textit{gca} \text{ effect} = (g_i) = \frac{1}{(p+2)}\left(\Sigma(Yi. + Yii) - \frac{2}{p} Y..\right)$$

$$\textit{sca} \text{ effect} = (s_{ij}) = Y_{ij} - \frac{1}{(p+2)}(Y_{i.} + Y_{ii} + Y_{.j} + Y_{jj}) + \frac{2}{(p+1)(p+2)} Y..$$

Where,

p = number of parents

g_i = general combining ability effect of ith parent

s_{ij}= specific combining ability effect of the
Cross involving ith and jth parents

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

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

Y_{ii} = parental value of the ith parent

Y_{jj} = parental value of the j^{th} parent

$Y_{...}$ = Total of all $\frac{p(p+1)}{2}$ items of the diallel table

Various standard errors required to test the significance of *gca* and *sca* effects and differences between them are calculated as

$$S.E.(g_i) = \sqrt{\frac{(p-1)}{p(p+2)} M_e}$$

$$S.E.(s_{ij}) = \sqrt{\frac{(p^2+p+2)}{(p+1)(p+2)} M_e}$$

3.8.6.2 Test of Significance

The 't' test was used to test the significance of individual *gca* and *sca* effects as under.

To test $g_i : t = \frac{|g_i|}{S.E.(g_i)}$

To test $s_{ij} : t = \frac{|s_{ij}|}{S.E.(s_{ij})}$

To test the significance of differences of two estimates, critical differences (CD) was calculated as product of the 't' for error degrees of freedom and the standard error of difference of two estimates.

3.8.7 Heterosis estimates (Singh and Narayanan, 1993)

Heterobeltiosis was measured as the proportion of the deviation of the mean value from the better parent value and standard heterosis from the value of standard check. Following formulae were used to calculate different heterosis.

Mid parent value $(\overline{MP}) = \frac{\overline{P_1} + \overline{P_2}}{2}$

a) Relative heterosis $= \frac{\overline{F1} - \overline{MP}}{\overline{MP}} \times 100$

b) Heterobeltiosis $= \frac{\overline{F1} - \overline{BP}}{\overline{BP}} \times 100$

Where,

$\overline{MP}$: Mean performance of parent P_1 and P_2

$\overline{F_1}$: Average performance of F_1 hybrid

$\overline{BP}$: Mean values of Better parent

Mean mid parent heterosis and heterobeltiosis was worked out for all the characters by summing up the heterotic effects of all the hybrids and dividing it by the total number of hybrid combinations.

Test of significance

The heterosis was tested by least significant difference at 5 per cent and at 1 per cent level of significance for error degrees of freedom as follows:

For testing heterosis over better parents and standard check

$$\text{(Mean deviation for relative heterosis)} = \sqrt{\frac{3 \text{ x Me}}{2r}}$$

$$\text{SE (diff) (HB)} = \sqrt{2Me/r}$$

Where,

Me = Error variance

r = Number of replications

$$\text{For Heterobeltiosis (HB)} = \sqrt{\frac{2}{r} x\ Me}$$

Where,

Me = Error mean of square

r = Number of replications

Estimation of t value for all hybrids

1. t value for dii = $(\overline{F_1} - \overline{BP} / SE)$

Critical difference

CD = SE (diff) x (t at error d. f. at 5 and 1 per cent level of significance). Heterosis was considered significant when ($\overline{F_1} - \overline{BP}$) was higher than critical difference.

RESULTS

4. RESULTS

The present investigation entitled "Genetic analysis of drought tolerance in rice (*Oryza sativa.* L)" was aimed to estimate the nature and magnitude of gene effects in the inheritance of drought tolerance in rice under upland conditions. Screening of the parents and best progeny for the presence of molecular markers associated with drought tolerance was done. Twenty diverse rice genotypes were raised under rainfed upland condition at College of Agriculture, Vellayani during May to October 2014 and exposed to natural moisture stress. Screening was carried out in the target environment *i.e.* upland Virippu and under protected condition imposing reproductive stage moisture stress. Morpho-physiological, biochemical and root character aspects of the genotypes were studied. A selection index was developed for identifying the best six parents combining yield and drought tolerance. Hybridization was done in half diallel pattern and F_1s were evaluated along with parents. F_2 lines from the best five F_1 hybrids along with parents were evaluated in the target environment. General view of upland rice in Plate 1. The general view of upland rice at reproductive stage was shown in Plate 2. The results obtained are presented hereunder.

Experiment 1

4.1 GENETIC VARIABILITY

The analysis of variance (Table 6) revealed highly significant differences among the genotypes for all the characters studied. The mean values of each of the twenty genotypes for the fourteen characters studied are presented in Table 7 and graphically presented in Fig.1. Range in mean values is given in Table 8. The genotypes showed a wide range of variation for all the characters studied.

4.1.1 Days to 50 % Flowering

Significant differences were noticed among the genotypes for days to 50% flowering. The mean values ranged from 80.67 to 109 days. Karutha Modan was the earliest flowering type. Uma took the maximum time for flowering followed by Aathira and Kanakom (106 days each).

Plate 1. General field view of upland rice

Plate 2. General view at reproductive stage

4.1.2 Nature of Panicle Exsertion

Nature of panicle exsertion is presented in Table 12. The varieties *viz.*, Katta Modan, Karutha Modan, Vyttila 6, Swarnaprabha and Aathira had their panicles partly exserted from the flag leaf. Vyttila 2, Jyothi, Aiswarya, Harsha, Vaishak, Kanakom, Arimodan and Parambuvattan had their panicles mostly exserted and Chuvanamodan, Uma, Prathyasha, Kalladiaryan and Thottacheera had well exserted panicles.

4.1.3 Number of Productive Tillers Plant^{-1}

The varieties differed significantly for number of productive tillers plant^{-1}. The mean values ranged from 3.40 in Kanakom to 6.97 in Vyttila 2. The varieties Vyttila 6 (3.78) and Kanchana (3.66) were found to be on par with Kanakom.

4.1.4 Plant Height to Tip of Longest Leaf of Plant (cm)

A wide variation was observed among the varieties with mean values ranging from 72.07 to 147.46 cm for this trait. Jyothi was the shortest variety with Kanchana (74.67cm) on par whereas Vyttila 2 was the tallest with no entry on par.

4.1.5 Plant Height at Maturity (cm)

The genotypes exhibited significant wide variation for plant height with a range from 72.07 cm in Kanchana to 139.13cm in Chuvanna Modan. Jyothi (74.80 cm) was on par with Kanchana (73.07cm) and Vyttila 2 (138.73 cm) was on par with the tallest entry. The crop at vegetative stage shown in plate 5a and variatal difference at vegetative stage in upland rice in plate 5 b.

4.1.6 Panicle Length (cm)

Panicle length ranged from 14.85 cm in Aiswarya to 21.53 cm in Swarnaprabha. The varieties Kanchana and Jyothi (16.56cm) were on par with Aiswarya. The varieties Vyttila 2 (21.18cm) and Vaishak (20.84cm) were on par with Swarnaprabha.

4.1.7 Number of Spikelets Panicle^{-1}

The genotypes differed significantly for the character with means ranging from 41.85 to 85.72. Kanchana had the lowest number of spikelets as against Vyttila 2 with the highest value, with Swarnaprabha (85.52) on par. Crop at reproductive stage shown in Plate 6.

4.1.8 Number of Filled Grains Panicle^{-1}

The number of filled grains panicle^{-1} ranged from 11.68 in Uma to 68.94 in Vyttila 6. None of the varieties were found to be on par with either Uma or Vyttila 6 for this character.

4.1.9 Spikelet Sterility (%)

Spikelet sterility (%) ranged from 3.50 in Kalladiaryan to 78.10 per cent in Uma. None of the genotypes were on par with either of the extremes for this character.

4.1.10 Grain Weight Panicle^{-1} (g)

Grain weight panicle^{-1} ranged from 0.21 g to 1.67g. The variety Uma had the lightest panicles whereas Kalladiaryan had the heaviest panicles. The Variety Vaishak was on par with Kalladiaryan for this character.

4.1.11 1000 Grain Weight (g)

1000 grain weight ranged from 15.20 g (Katta Modan) to 27.13 g (Kalladiaryan) under rainfed upland condition. The varieties Uma, Aathira and Aiswarya were on par with Katta Modan and Vaishak, Harsha and Thottacheera were on par with Kalladiaryan.

4.1.12 Grain Yield Plant^{-1} (g)

A wide range of variation was observed for this character with mean values ranging from 0.51g in Uma to 11.67g in Vaishak. The variety

Kalladiaryan (10.70g) was on par with the highest yielder and the varieties Kanakom (1.27g) and Aathira (1.58g) were on par with the lowest yielder.

4.1.13 Straw Yield Plant^{-1} (g)

Straw yield plant^{-1} ranged from 5.07g in Katta Modanto 19g in Kalladiaryan. The varieties Uma and Parambuvattan were on par with Katta Modan.

4.1.14 Biological Yield Plant^{-1}(g)

A wide range of variation was observed for biological yield plant^{-1} with mean values ranging from 8.52g in Uma to 33g in Kalladiaryan. The varieties Kanchana and Parambuvattan were on par with Uma.

4.1.15 Harvest Index (%)

The harvest index ranged from 5.79% in Uma to 41.74% in Swarnaprabha.The variety Kanakom (8.99%) was on par with Uma and the varieties Vaishak (39.16%), Vyttila 6 (41.03%) and Thottacheera (37.57%) were on par with Swarnaprabha.

4.1.16 Leaf Rolling

The varieties Vyttila 6, Jyothi, Harsha, Kanakom and Kalladiaryan showed less pronounced leaf rolling under dry spell (Table 9, Fig.2 and Plate 4) whereasall the other varieties remained more prone to leaf rolling.The prone varieties showed the rolling symptoms 7 days after rain both in the morning and evening. The less prone varieties did not roll in the early morning hours, but rolling started at around 1 pm.

4.1.17 Percentage Soil Moisture Content

Percentage soil moisture content is presented in Table 10. Soil moisture content varied from 13.88% (seedling stage) to 8.19% (reproductive stage) and 6.61% (harvesting stage) (Plate 3).

Plate 3. Soil moisture estimation

Plate 4. Leaf rolling under upland condition

1. KattaModan

2. KaruthaModan

3. Chuvanamodan

4.Vyttila 2

5. Vyttila 6

6. Jyothi

7. Swarnaprabha

8. Kanchana

9. Aathira

10.Aiswarya

11. Harsha

12. Vaishak

13. Kanakom

14. Uma

15. Pratyasha

16. Arimodan

17. Kalladiaryan

18. Karuthadukkan

19. Parambuvattan

20.Thottacheera

4.1.18 Dry Spell During Crop Growth Season

Dry spell during crop growth season (31-5-2014 to 30-10-2016) is presented in Table 11. Rain started from 15th May 2014 onwards in Vellayani(Table 20.).Four dry spells occurred during crop growth stage. First dry spell was from14th June to 18th June,2014 for four days.Second was from 23rd to 29th June,2014 for 7days,third was from 6th to 13th September,2014 for eight days and fourthfrom 16th to 25thSeptember,2014 for 10 days.The last two dry spells affected most of the late flowering varieties.

4.1.19 Pest and Disease Incidence

The crop was monitored for the incidence of pests and diseases.Incidence of insect pests *viz.*,Gandhi bug and leaf folder were observed and incidence data is given in Table 13 and Figs. 3 and 4.Lowest Gandhi bug infestation was recorded in Swarnaprabha (PTB 43) (1.67%) and highest in Uma (6.33%).Harsha, Kanakom and Vyttila 2 showed immune reaction to leaf folder.

The percentage incidence of blast, bacterial leaf blight and brown spot were recorded in the rice field (Table 14 and Fig.5). Blast incidence ranged from 1% in Aathira to 4.33% in Vyttila 6 and Swarnaprabha. Vaishak (1%), Vyttila 2(1%) and Kalladiaryan were less affected by bacterial leaf blight. Immune reaction was shown by Aathira and Prathyasha for bacterial leaf blight andbrown spot.

4.1.20 Cooking Qualities of Rice Varieties

The variety Swarnaprabha had good cooking quality. Kanchana had excellent milling recovery and good cooking quality with high volume expansion on cooking and comparatively higher protein content. Prathyasha had high nutrient content and good cooking quality. Aathira possessed excellent milling recovery and cooking quality. Parambuvattan have high quality and was preferred for certain special preparations. The varieties *viz.*,Katta Modan,Karutha Modan, Chuvana Modan and Swarnaprabha had 78.6, 78.6, 76.5 and 72.9 % rice recovery respectively.

Plate 5a. Twenty rice varieties at vegetative stage–field view

1. **Katta Modan**

2. **Karutha Modan**

3. **Chuvana Modan**

4. **Vyttila 2**

5. Vyttila 6

6. Jyothi

7. Swarnaprabha

8. Kanchana

9. Aathira

10. Aiswarya

11. Harsha

12. Vaishak

13. Kanakom

14. Uma

15. Prathyasha

16. Arimodan

17. Kalladiaryan

18. Karuthadukkan

19. Parambuvattan

20. Thottacheera

Plate 5b. Variatal difference at vegetative stage in upland rice

Table 6. Analysis of variance for 14 characters in 20 rice varieties under rainfed upland condition

Sl.No	Traits	MSS Treatment df =19	MSS Replication df =2	MSS Error df =38	F value
1	Days to 50 % flowering	195.4134**	3.3187	1.7552	111.3371 **
2	Number of productive tillers plant^{-1}	2.4318**	0.1575	0.1203	20.2186 **
3	Plant height at tip of longest leaf of plant	1244.145**	1.7250	3.4109	364.7603 **
4	Plant height at maturity (cm)	1224.1910 **	1.2125	2.4921	491.2276
5	Panicle length (cm)	12.4167**	1.8758	1.1011	11.2771 **
6	Number of spickelets $^{-}$ ^{1}panicle	442.0367**	0.3653	4.4234	99.9315**
7	Number of filled grains panicle^{-1}	643.9979**	4.3867	3.9961	161.1569 **
8	Spikelet sterility (%)	1184.3930 **	1.1723	3.1799	372.4657**
9	Grain weight panicle^{-1} (g)	0.5056**	0.0152	0.0084	60.0772 **
10	1000 grain weight (g)	41.6992 **	0.4973	1.1448	36.4240 **
11	Grain yield plant^{-1} (g)	31.2364**	3.3135	1.0345	30.1945 **
12	Straw yield plant^{-1} (g)	36.9003**	0.2060	1.5193	24.2872**
13	Biological yield plant $^{-1}$(g)	113.6842**	14.1811	3.0362	37.4430
14	Harvest index (%)	326.2847**	13.2352	7.7909	41.8802 **

** Significant at 1% level
*Significant at 5% level

Table 7. Mean performance for 14 characters in 20 rice varieties under rainfed upland condition

Sl. No	Name of variety	Days to 50% flowering	Number of productive tillers plant^{-1}	Plant height at tip of leaf (cm)	Plant height at maturity (cm)	Panicle length (cm)	Number of spikelets panicles^{-1}	Number of filled grains panicle^{-1}	Spikelet sterility (%)	Grain weight panicle^{-1} (g)	1000 Grain weight (g)	Grain yield plant^{-1} (g)	Straw yield plant^{-1} (g)	Biological yield plant^{-1} (g)	Harvest Index (%)
		X_1	X_2	X	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}
1	Katta Modan (PTB28)	91.67	4.24	97.00	82.33	17.43	53.16	40.08	24.51	0.62	15.20	2.57	5.07	11.80	21.47
2	Karutha Modan (PTB29)	80.67	4.58	119.71	104.81	16.72	54.31	47.90	11.81	1.21	22.97	7.33	13.23	21.93	33.21
3	Chuvanna Modan (PTB 30)	92.67	5.49	114.80	139.13	16.29	47.95	36.14	24.65	0.97	24.47	5.73	12.22	18.73	30.43
4	Vyttila 2	105.67	6.97	147.47	138.73	21.18	85.72	24.14	71.82	1.04	23.20	6.55	11.64	18.84	34.81
5	Vyttila 6	101.67	3.78	102.47	93.60	18.91	74.83	68.94	15.96	1.60	24.63	9.73	13.33	23.67	41.03
6	Jyothi (PTB 39)	95.33	4.59	72.07	74.80	16.56	55.41	40.30	27.29	0.72	18.67	2.97	12.04	17.00	17.48
7	Swarnaprabha (PTB 43)	100.67	4.36	116.87	120.13	21.53	85.52	60.94	28.72	1.42	23.57	9.07	12.06	21.67	41.74
8	Kanchana (PTB 50)	94.67	3.66	74.67	73.07	15.63	41.85	36.43	12.93	0.66	18.23	2.50	7.72	11.00	22.59
9	Aathira (PTB 51)	106.00	4.11	109.33	97.07	18.13	49.74	34.18	31.27	0.59	16.17	1.58	8.00	13.53	11.70
10	Aiswarya (PTB 52)	97.67	4.98	99.87	94.80	14.85	64.31	29.17	54.65	0.49	16.77	2.77	7.67	12.49	21.71
11	Harsha (PTB 55)	84.67	4.87	82.13	79.33	16.20	54.61	31.82	45.00	0.88	26.73	4.67	11.20	16.47	28.41
12	Vaishak (PTB 60)	91.00	4.58	121.87	115.47	20.84	75.60	63.17	16.45	1.53	24.23	11.67	17.16	29.47	39.16
13	Kanakom (MO 11)	106.00	3.40	88.33	89.00	15.86	64.59	29.00	55.11	0.54	18.07	1.27	12.01	14.00	8.99
14	Uma (MO 16)	109.00	5.22	80.33	77.67	15.90	56.88	11.69	78.11	0.21	17.60	0.51	5.96	8.52	5.79
15	Prathyasha (MO 21)	98.67	5.02	97.80	95.73	18.52	53.01	37.19	29.86	0.86	23.07	4.60	9.80	15.00	30.76
16	Arimodan	83.67	6.16	112.67	99.20	17.82	46.90	30.97	38.35	0.73	23.53	5.00	10.59	18.00	27.72
17	Kalladiaryan	88.33	5.98	114.93	108.13	20.56	65.43	61.87	3.50	1.67	27.13	10.70	19.00	33.00	32.38
18	Karuthadukkan	95.00	5.73	120.60	114.67	17.16	62.64	41.35	33.97	0.90	21.59	5.67	9.01	16.47	34.20
19	Parambuvattan	92.33	4.13	110.93	101.20	18.57	60.04	38.49	35.86	0.79	20.43	3.50	6.54	11.36	30.78
20	Thottacheera	87.00	4.93	141.80	131.67	20.13	64.80	55.16	14.87	1.42	26.60	7.27	10.00	19.33	37.57
	General mean	95.11	4.83	106.28	101.52	17.93	60.86	40.94	32.73	0.94	21.64	5.28	10.71	17.6	27.59
	CD (0.05)	2.18	0.57	3.04	2.60	1.73	3.14	3.29	2.94	0.15	1.76	1.67	1.83	2.87	4.60

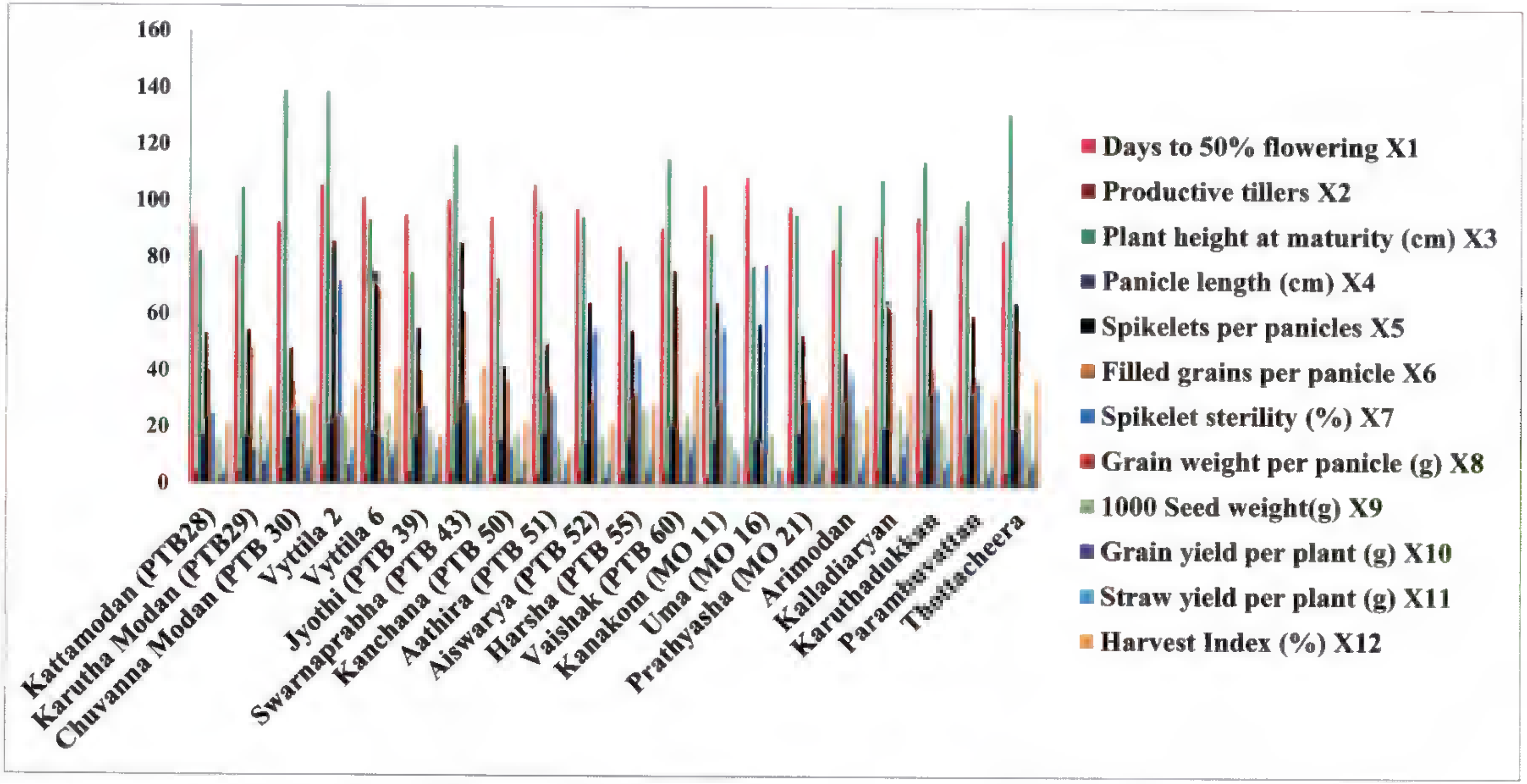


Fig. 1. Mean performance of rice genotypes for drought tolerance under rainfed upland condition

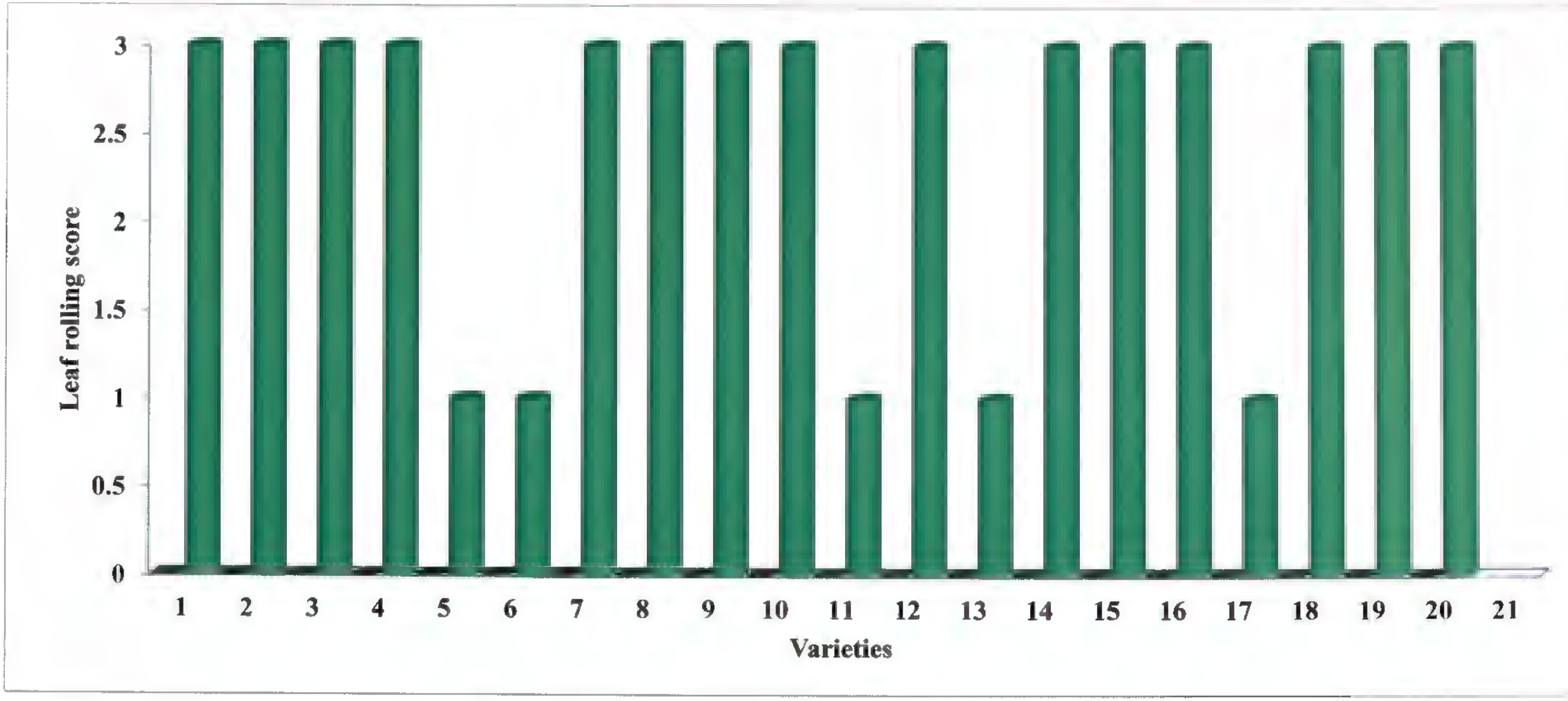
Table 8. Estimates of range in mean values for 14 characters in 20 rice varieties under rainfed upland condition

Sl.No.	Traits	Range
1	Days to 50 % flowering	80.66– 109 (Karutha Modan – Uma)
2	Number of productive tillers plant^{-1}	3.4– 6.96 (Kanakom – Vyttila 2)
3	Plant height at tip of longest leaf of plant (cm)	72.66 – 147.46 (Jyothi – Vyttila 2)
4	Plant height at maturity (cm)	73.07– 139.13 (Kanchana- Chuvanna Modan)
5	Panicle length (cm)	14.85-21.53 (Aiswarya –Swarnaprabha)
6	Number of spikelets panicle^{-1}	41.85– 85.72 (Kanchana – Vyttila 2)
7	Number of filled grains panicle^{-1}	11.69– 68.94 (Uma – Vyttila 6)
8	Spikelet sterility (%)	3.50– 78.11 (Kalladiaryan – Uma)
9	Grain weight panicle^{-1} (g)	0.20– 1.67(Uma – Kalladiaryan)
10	1000 grain weight (g)	15.20– 27.13(Katta Modan – Kalladiaryan)
11	Grain yield plant^{-1} (g)	0.50– 11.66 (Uma – Vaishak)
12	Straw yield plant^{-1} (g)	5.71 – 19 (Katta Modan – Kalladiaryan)
13	Biological yield plant^{-1} (g)	8.52– 33 (Uma – Kalladiaryan)
14	Harvest index (%)	5.79 – 41.74 (Uma – Swarnaprabha)

Table 9. Leaf rolling score in 20 rice varieties under rainfed upland condition

Sl.No.	Variety	Decimal score	Description
1	Kattamodan (PTB28)	3	Leaves folding (deep V shape)
2	Karutha Modan (PTB29)	3	Leaves folding (deep V shape)
3	Chuvanna Modan (PTB 30)	3	Leaves folding (deep V shape)
4	Vyttila 2	3	Leaves folding (deep V shape)
5	Vyttila 6	1	Leaves start to fold (shallow V shape)
6	Jyothi (PTB 39)	1	Leaves start to fold (shallow V shape)
7	Swarnaprabha (PTB 43)	3	Leaves folding (deep V shape)
8	Kanchana (PTB 50)	3	Leaves folding (deep V shape)
9	Aathira (PTB 51)	3	Leaves folding (deep V shape)
10	Aiswarya (PTB 52)	3	Leaves folding (deep V shape)
11	Harsha (PTB 55)	1	Leaves start to fold (shallow V shape)
12	Vaishak (PTB 60)	3	Leaves folding (deep V shape)
13	Kanakom (MO 11)	1	Leaves start to fold (shallow V shape)
14	Uma (MO 16)	3	Leaves folding (deep V shape)
15	Prathyasha (MO 21)	3	Leaves folding (deep V shape)
16	Arimodan	3	Leaves folding (deep V shape)
17	Kalladiaryan	1	Leaves start to fold (shallow V shape)
18	Karuthadukkan	3	Leaves folding (deep V shape)
19	Parambuvattan	3	Leaves folding (deep V shape)
20	Thottacheera	3	Leaves folding (deep V shape)

(IRRI, 1991)



1: Katta Modan
2: Thottacheera
3: Kalladiaryan
4: Vyttila 2
5: Vyttila 6
6: Jyothi
7: Swarnaprabha
8: Kanchana
9: Aathira
10: Aiswarya
11: Harsha
12: Vaishak
13: Kanakom
14: Uma
15: Prathyasha
16: Arimodan
17: Kalladiaryan
18: Karuthadukkan
19: Parambuvattan
20: Thottacheera

Fig. 2. Leaf rolling score in rainfed upland rice

Table 10. Percentage of soil moisture under rainfed upland condition
(May 2014 to October 2014)

Soil moisture content (%)	13.88	At seedling stage
	8.19	At reproductive stage
	6.61	At harvesting stage

Table 11. Dry spell during crop growth season (31-5-2014 to 30-10-2016)

Sl. No.	Duration of dry spell	Total number of days
1	14 June to 18 June,2014	4 days
2	23 June to 29 June,2014	7 days
3	6 September to 13 september,2014*	8 days
4	16 September to 25 september,2014*	10 days

* affected most of the late flowering varieties

(Data from Department of Agricultural Meteorology, College of Agriculture, Vellayani)

Table12. Panicle exsertion in 20 rice varieties under rainfed upland condition

Sl. No.	Name of variety	Panicle exsertion
1	Katta Modan (PTB28)	Partly exserted
2	Karutha Modan (PTB29)	Partly exserted
3	Chuvanna Modan (PTB 30)	Well exserted
4	Vyttila 2	Mostly exserted
5	Vyttila 6	Partly exserted
6	Jyothi (PTB 39)	Mostly exserted
7	Swarnaprabha (PTB 43)	Partly exserted
8	Kanchana (PTB 50)	Mostly exerted
9	Aathira (PTB 51)	Partly exserted
10	Aiswarya (PTB 52)	Mostly exserted
11	Harsha (PTB 55)	Mostly exserted
12	Vaishak (PTB 60)	Mostly exserted
13	Kanakom (MO 11)	Mostly exserted
14	Uma (MO 16)	Well exserted
15	Prathyasha (MO 21)	Well exserted
16	Arimodan	Mostly exserted
17	Kalladiaryan	Well exserted
18	Karuthadukkan	Well exserted
19	Parambuvattan	Mostly exserted
20	Thottacheera	Well exserted

(DRR, 2004)

Table 13. Incidence of Gandhi bug and Leaf folder in rainfed upland rice

Sl.No	Name of varieties	Incidence %	
		Gandhi bug	Leaf folder
1	Kattamodan (PTB28)	3.00	2.67
2	KaruthaModan (PTB29)	2.67	2.33
3	ChuvannaModan (PTB 30)	3.67	2.33
4	Vyttila 2	4.33	0.00
5	Vyttila 6	2.33	2.33
6	Jyothi (PTB 39)	3.00	2.33
7	Swarnaprabha (PTB 43)	1.67	3.00
8	Kanchana (PTB 50)	3.00	3.00
9	Aathira (PTB 51)	3.00	0.00
10	Aiswarya (PTB 52)	3.00	0.33
11	Harsha (PTB 55)	1.67	0.00
12	Vaishak (PTB 60)	1.67	0.00
13	Kanakom (MO 11)	1.67	0.00
14	Uma (MO 16)	6.33	1.67
15	Prathyasha (MO 21)	3.00	0.00
16	Arimodan	5.00	0.00
17	Kalladiaryan	4.33	4.33
18	Karuthadukkan	5.00	1.00
19	Parambuvattan	5.00	3.00
20	Thottacheera	4.33	4.33

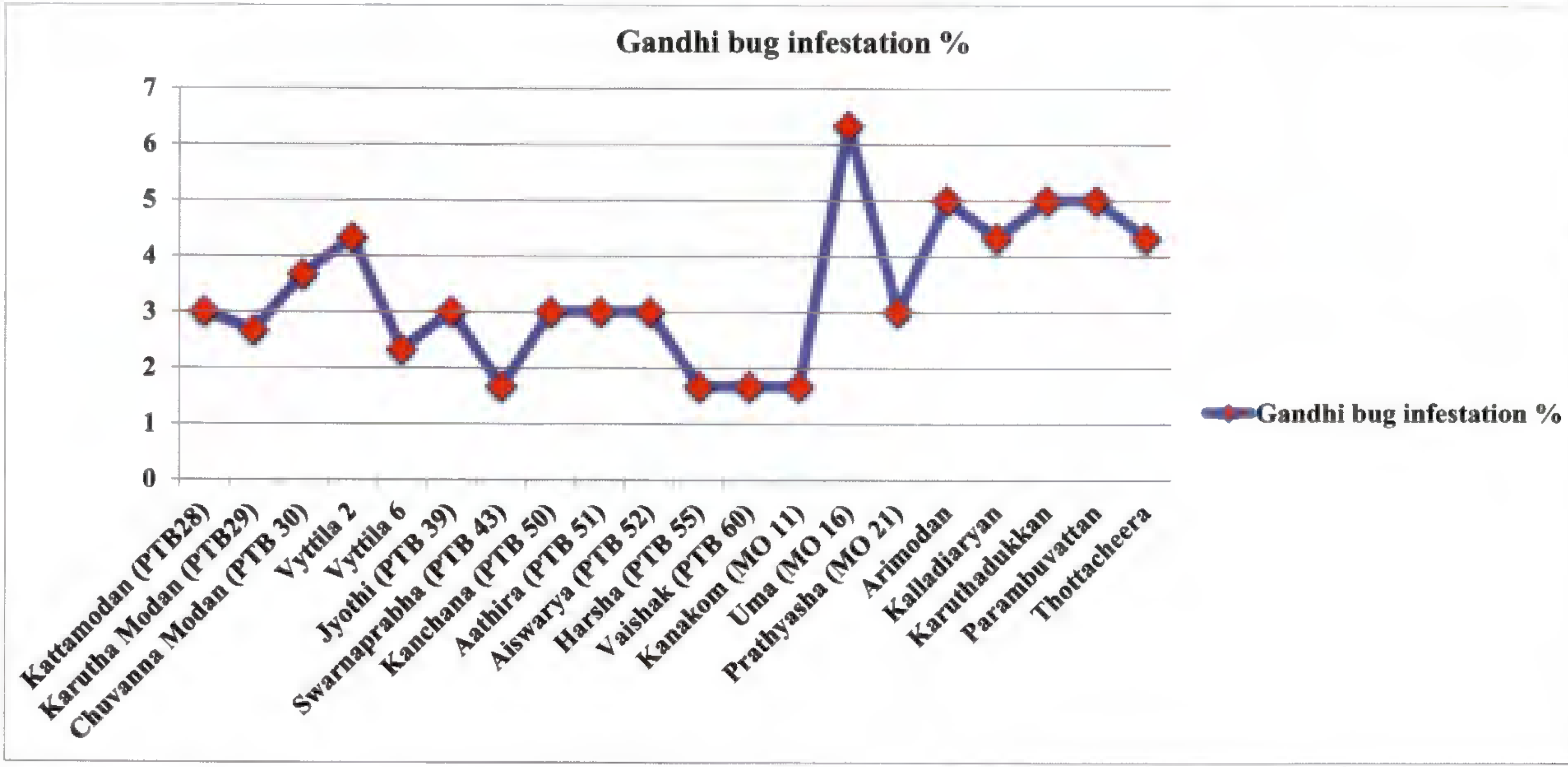


Fig. 3. Gandhi bug infestation in rainfed upland rice

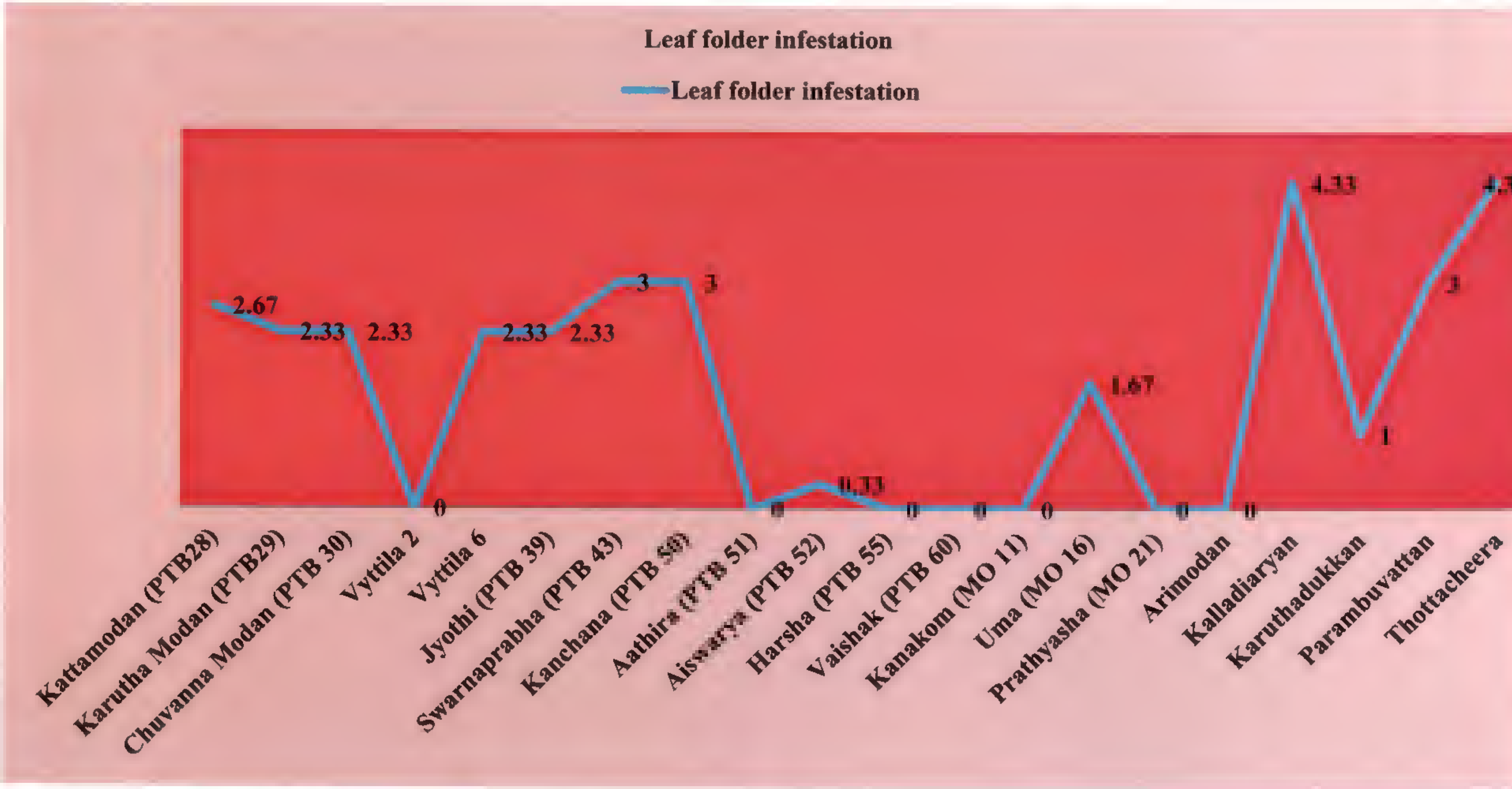


Fig. 4. Leaf folder infestation in rainfed upland rice

Table 14. Incidence of blast, bacterial blight and brown spot in rainfed upland rice

Sl.No	Name of varieties	Disease incidence %		
		Blast	Bacterial leaf blight	Brown spot
1	Kattamodan (PTB28)	3.67	4.33	1.67
2	KaruthaModan (PTB29)	4.33	3.00	1.00
3	ChuvannaModan (PTB 30)	3.67	3.00	3.00
4	Vyttila 2	2.33	1.00	1.00
5	Vyttila 6	4.33	7.00	1.00
6	Jyothi (PTB 39)	3.67	3.67	1.67
7	Swarnaprabha (PTB 43)	4.33	3.00	1.00
8	Kanchana (PTB 50)	3.00	2.33	2.33
9	Aathira (PTB 51)	1.00	0.00	0.00
10	Aiswarya (PTB 52)	2.00	3.00	1.00
11	Harsha (PTB 55)	1.67	5.00	1.00
12	Vaishak (PTB 60)	1.00	1.00	1.00
13	Kanakom (MO 11)	3.00	5.00	2.33
14	Uma (MO 16)	5.00	5.00	3.00
15	Prathyasha (MO 21)	1.67	0.00	0.00
16	Arimodan	2.33	5.00	5.00
17	Kalladiaryan	3.00	1.67	1.67
18	Karuthadukkan	3.00	3.00	1.67
19	Parambuvattan	3.00	3.00	3.00
20	Thottacheera	3.67	5.00	1.00

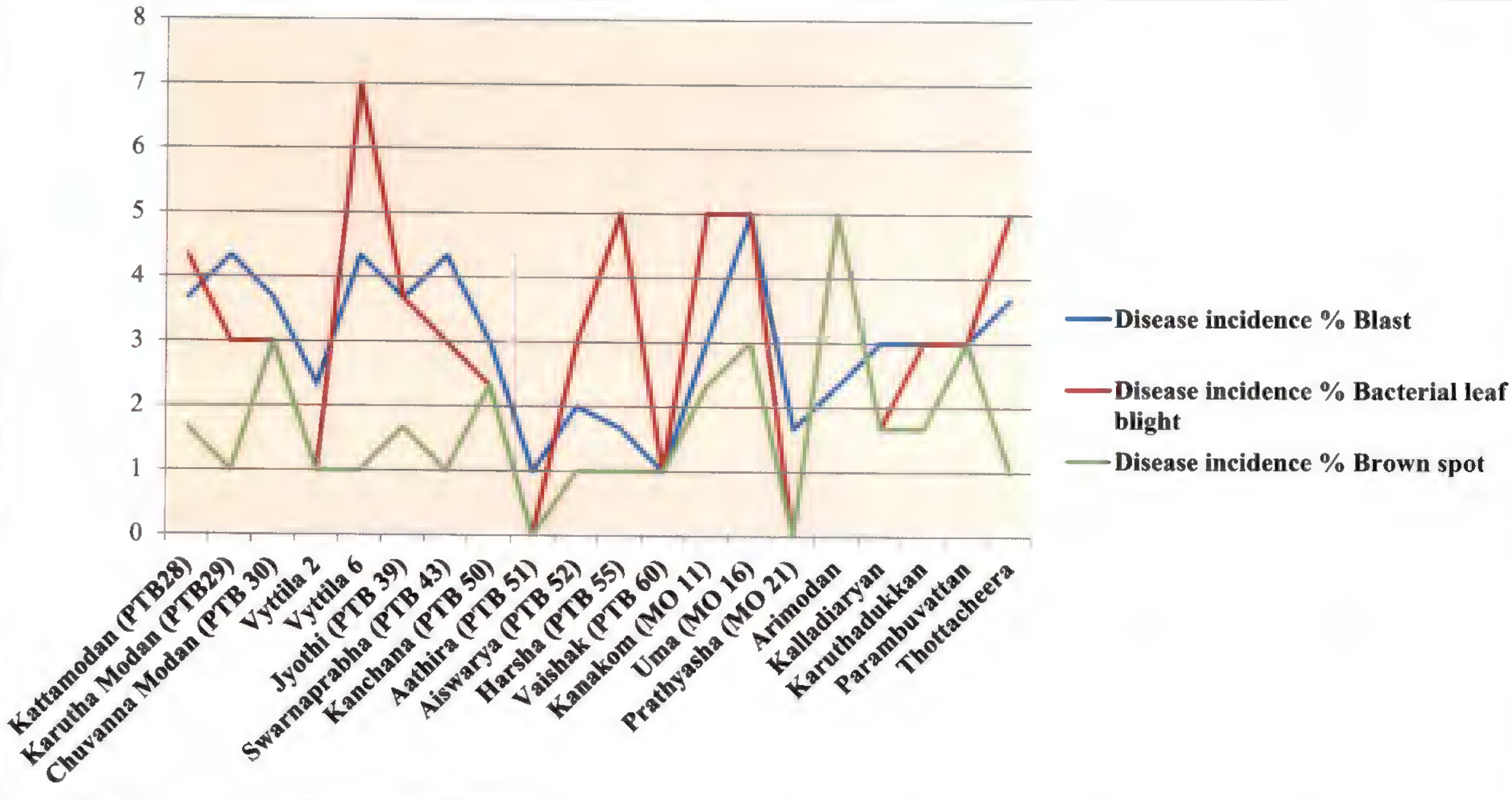
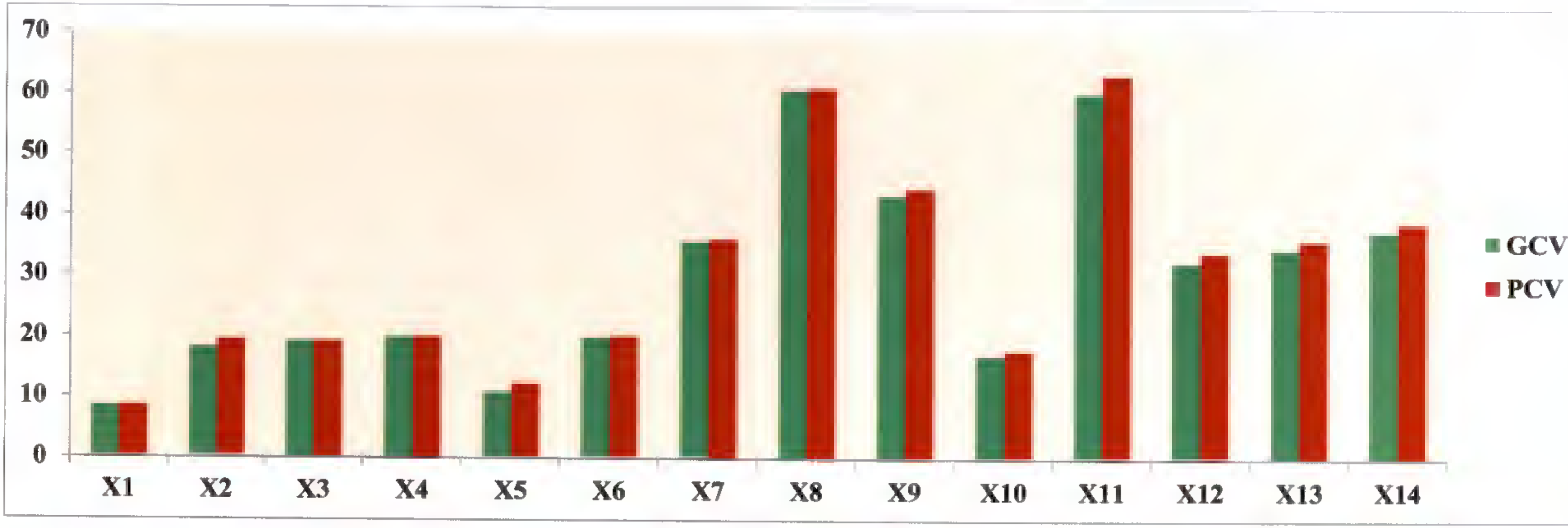


Fig. 5. Disease incidence in rainfed upland rice

Table15. Phenotypic and genotypic coefficients of variation for 12 traits in rainfed upland rice

Sl.No	Traits	Genotypic variance	Phenotypic variance	Coefficient of variation	
				GCV	PCV
1	Days to 50% flowering	64.55	66.30	8.44	8.56
2	Number of productive tillers plant^{-1}	0.77	0.89	18.14	19.50
3	Plant height at tip of leaf (cm)	413.57	416.98	19.13	19.21
4	Plant height at maturity (cm)	407.23	409.72	19.87	19.93
5	Panicle length (cm)	3.77	4.87	10.82	12.30
6	Number of spikelets panicles^{-1}	146.13	149.76	19.86	20.10
7	Number of filled grains panicle^{-1}	213.33	217.33	35.67	36.00
8	Spikelet sterility(%)	393.73	396.91	60.61	60.86
9	Grain weight panicle $^{-1}$(g)	0.16	0.17	43.21	44.29
10	1000 Grain weight (g)	13.51	14.66	16.98	17.69
11	Grain yield plant^{-1} (g)	10.06	11.10	60.06	63.08
12	Straw yield plant^{-1} (g)	11.88	13.12	32.18	33.81
13	Biological yield plant $^{-1}$(g)	36.88	39.91	34.47	35.87
14	Harvest index (%)	106.16	113.95	37.33	38.68

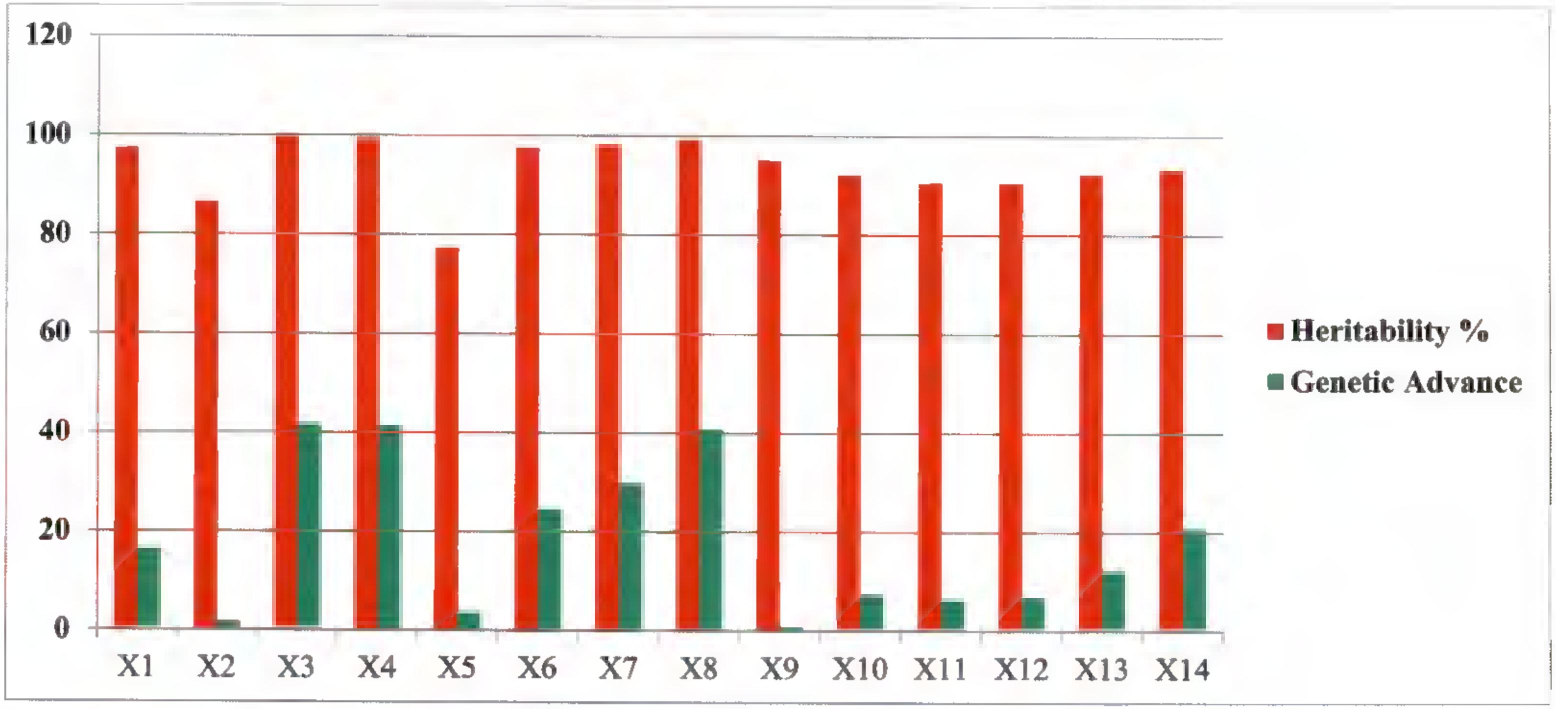


X1	Days to 50% flowering	X2	Number of productive tillers plant^{-1}
X3	Plant height at tip of longest leaf of plant (cm)	X4	Plant height at maturity (cm)
X5	Panicle length (cm)	X6	Number of spickelets panicles^{-1}
X7	Number of filled grains panicle^{-1}	X8	Spikelet sterility (%)
X9	Grain weight panicle^{-1} (g)	X10	1000 seed weight (g)
X11	Grain yield plant^{-1} (g)	X12	Straw yield plant^{-1} (g)
X13	Biological yield plant^{-1} (g)	X14	Harvest index (%)

Fig. 6. Genotypic (GCV) and phenotypic (PCV) coefficients of variation of fourteen traits in rainfed upland rice

Table16. Broad sense heritability and genetic advance for 14 traits in rainfed upland rice

Sl.No	Traits	Heritability %	Genetic advance as % of mean
1	Days to 50% flowering	97.35	16.33
2	Number of productive tillers per plant	86.50	1.68
3	Plant height at tip of longest leaf of plant (cm)	99.98	41.72
4	Plant height at maturity (cm)	99.39	41.44
5	Panicle length (cm)	77.40	3.51
6	Number of spickelets panicles^{-1}	97.58	24.59
7	Number of filled grains panicle^{-1}	98.16	29.81
8	Spikelet sterility(%)	99.20	40.71
9	Grain weight panicle $^{-1}$ (g)	95.17	0.81
10	1000 grain weight (g)	92.19	7.27
11	Grain yield plant^{-1} (g)	90.68	6.22
12	Straw yield plant^{-1} (g)	90.61	6.76
13	Biological yield plant^{-1} (g)	92.39	12.02
14	Harvest index (%)	93.16	20.48



X1	Days to 50% flowering	X2	Number of productive tillers plant^{-1}
X3	Plant height at tip of longest leaf of plant (cm)	X4	Plant height at maturity (cm)
X5	Panicle length (cm)	X6	Number of spickelets panicles^{-1}
X7	Number of filled grains panicle^{-1}	X8	Spikelet sterility (%)
X9	Grain weight panicle^{-1} (g)	X10	1000 seed weight (g)
X11	Grain yield plant^{-1} (g)	X12	Straw yield plant^{-1} (g)
X13	Biological yield plant^{-1} (g)	X14	Harvest index (%)

Fig. 7. Broad sense heritability and genetic advance of morphological traits in rainfed upland rice

Plate 6. Twenty rice varieties at reproductive stage-field view

1. **Katta Modan**

2. **Karutha Modan**

3. **Chuvanna Modan**

4. **Vyttila 2**

Plate 6. Twenty rice varieties at reproductive stage-field view (contd.)

5. Vyttila 6

6. Jyothi

7. Swarnaprabha

8. Kanchana

Plate 6. Twenty rice varieties at reproductive stage-field view (contd.)

9. Aathira

10. Aiswarya

11. Harsha

12. Vaishak

Plate 6. Twenty rice varieties at reproductive stage-field view (contd.)

13. Kanakom

14. Uma

15. Prathyasha

16. Arimodan

Plate 6. Twenty rice varieties at reproductive stage-field view (contd.)

17. Kalladiaryan

18. Karuthadukkan

19. Parambuvattan

20. Thottacheera

4.2 PHENOTYPIC AND GENOTYPIC COEFFICIENT OF VARIATION

The estimates of phenotypic and genotypic coefficients of variation for the fourteen characters from field evaluation of genotypes for drought tolerance are presented in Table15 and depicted in Fig.6.

High phenotypic coefficient of variation (PCV) was observed for several characters such as number of spikelets panicle^{-1} (20.10), number of filled grains panicle^{-1} (36), spikelet sterility (60.86), grain weight panicle^{-1} (44.29), grain yield plant^{-1} (63.08), straw yield plant^{-1} (33.81), biological yield plant^{-1} (35.87) and harvest index (38.68). Characters *viz.,* number of productive tillers plant^{-1} (19.50), plant height at tip of longest leaf of plant (19.21), plant height at maturity (19.93), panicle length (12.30) and 1000 grain weight (17.69) showed moderate estimates of PCV. Low level of GCV values was observed for days to 50% flowering (8.56).

High magnitude of genotypic coefficient of variation (GCV) was recorded for the traits number of filled grains panicle^{-1} (35.67), spikelet sterility (60.61), grain weight panicle^{-1} (43.21), grain yield plant^{-1} (60.069), straw yield plant^{-1} (32.18), biological yield plant^{-1} (35.87) and harvest index (37.33). Moderate values of PCV was observed for number of productive tillers plant^{-1} (18.14), plant height at tip of longest leaf of plant (19.13), plant height at maturity (19.87), panicle length (10.82), number of spikelets panicle^{-1} (19.86) and 1000 grain weight (16.98). Low value of PCV was evident for days to 50% flowering (8.44).

In general, phenotypic coefficient of variation was greater than genotypic coefficient of variation. The highest phenotypic and genotypic coefficients of variation were recorded for grain yield plant^{-1} (63.08 and 60.06, respectively) and spikelet sterility (60.86 and 60.61, respectively). The lowest PCV and GCV were for days to 50% flowering (8.56 and 8.44 respectively).

The difference between phenotypic and genotypic coefficients of variation was low for majority of the characters suggesting low environmental influence in character expression and thereby providing a better scope for selection.

4.3 HERITABILITY AND GENETIC ADVANCE

The estimates of heritability and genetic advance are furnished in Table 16 and Fig.7. High heritability in the broad sense was observed for all the characters under study *viz.,* days to 50 % flowering (97.35%), number of productive tillers plant^{-1} (86.50%), plant height at tip of longest leaf of plant (99.98%), plant height at maturity (99.39%), panicle length (77.40%), number of spikelets panicle^{-1}(97.58%), number of filled grains panicle^{-1} (98.16%), spikelet sterility (99.20%), grain weight panicle^{-1} (95.17%), 1000 grain weight (92.19%), grain yield plant^{-1} (90.68%), straw yield plant^{-1}(90.61%), biological yield plant^{-1} (92.39%) and harvest index (74.23%). Heritability estimates ranged from 77.40% to 99.98%.

High heritability coupled with high genetic advance was recorded for plant height at tip of longest leaf (99.98 and 41.72 respectively), plant height at maturity (99.39 and 41.44), spikelet sterility (99.20 and 40.71), number of filled grains panicle^{-1} (98.16 and 29.81), number of spikelets panicle^{-1}(97.58 and 24.59) and harvest index (93.16 and 20.48).

Moderate level of genetic advance was recorded for the traits *viz.,* days to 50 % flowering (16.33) and biological yield plant^{-1} (12.0). Genetic advance for number of productive tillers plant^{-1}, panicle length, grain weight panicle^{-1}, 1000 grain weight, grain yield plant^{-1}, and straw yield plant^{-1} was found to be low even through their heritability estimates were high.

4.4 CHARACTER ASSOCIATION

The genotypic and phenotypic correlation coefficients among all the characters are presented in Table 17. The genotypic and phenotypic correlation coefficients were found to agree very closely. Hence results pertaining to genotypic correlation alone are discussed to avoid repetitions.

Inter correlation among the yield component traits

4.4.1 Days to 50 % Flowering

Days to 50 % flowering showed highly significant and negative correlations with number of filled grains panicle^{-1} (-0.3370), grain weight panicle^{-1} (-0.3602), 1000 grain weight (-0.4901), grain yield plant^{-1} (-0.3753), biological yield plant^{-1} (-0.3701) and harvest index (-0.4367) whereas it had significant positive correlation with number of spikelets panicle^{-1} (0.3275) and spikelet sterility percent (0.5777).

4.4.2 Number of Productive Tillers Plant^{-1}

Number of productive tillers plant^{-1} showed positive correlations with plant height at tip of longest leaf (0.5229), plant height at maturity (0.5306), panicle length (0.3006), spikelet sterility (0.2955) and 1000 grain weight (0.4168).

4.4.3 Plant Height at Tip of Longest Leaf

Correlation analysis revealed highly significant positive correlation of plant height at tip of longest leaf with plant height at maturity (0.9085), panicle length (0.7248), number of spikelets panicle^{-1} (0.5194), number of filled grains panicle^{-1} (0.3334), grain weight panicle^{-1} (0.5713), 1000 grain weight (0.4924), grain yield plant^{-1} (0.5978), straw yield plant^{-1} (0.3011), biological yield plant^{-1} (0.4811) and harvest index (0.65).

4.4.4 Plant Height at Maturity

Correlation analysis revealed highly significant positive correlation of plant height at maturity with panicle length (0.6274), number of spikelets panicle^{-1} (0.489), grain weight panicle^{-1} (0.5487), 1000 grain weight^{-1} (0.5478), grain yield plant^{-1} (0.5799), straw yield plant^{-1} (0.3692), biological yield plant^{-1} (0.4749) and harvest index (0.6294).

4.4.5 Panicle Length

Panicle length showed significant positive correlation with number of spikelets panicle^{-1} (0.7163), number of filled grains panicle^{-1} (0.6166), grain weight panicle^{-1} (0.7715), 1000 grain weight (0.5609), grain yield plant-1 (0.7724), straw yield plant^{-1} (0.489), biological yield plant^{-1} (0.6726) and harvest index (0.6999) at genotypic level.

4.4.6 Number of Spikelets Panicle^{-1}

At genotypic level number of spikelets showed significant positive correlation with number of filled spikelets panicle^{-1} (0.4112), grain weight panicle^{-1} (0.5514), 1000 grain weight (0.324), grain yield plant^{-1} (0.5868), straw yield plant^{-1} (0.4092), biological yield plant^{-1} (0.4767) and harvest index (0.5138).

4.4.7 Number of Filled Spikelets Panicle^{-1}

Number of filled spikelets panicle^{-1} had highly significant positive correlations with grain weight panicle^{-1} (0.9011), 1000 grain weight (0.5317), grain yield plant^{-1} (0.8438), straw yield plant^{-1} (0.6272), biological yield plant^{-1} (0.7822) and harvest index (0.7328) at the genotypic level.

4.4.8 Spikelet Sterility (%)

Spikelet sterility (%) showed significant negative correlation at genotypic level with grain weight panicle^{-1} (-0.64), 1000 grain weight (-0.3594), grain yield plant^{-1} (-0.5528) and biological yield plant^{-1} (-0.5598).

4.4.9 Grain Weight Panicle^{-1}

Correlation analysis revealed highly significant positive correlation at the genotypic level for grain weight panicle^{-1} with 1000 grain weight (0.8983), grain yield plant^{-1} (0.971), straw yield plant^{-1} (0.779), biological yield plant $^{-1}$(0.9079) and harvest index (0.8578).

4.4.10 1000 Grain Weight

Correlation analysis demonstrated highly significant positive correlation between 1000 grain weight and grain yield plant^{-1} (0.8035), straw yield plant^{-1} (0.7016), biological yield plant^{-1} (0.743) and harvest index (0.7702).

4.4.11 Grain Yield Plant^{-1}

Grain yield plant^{-1} was positively and significantly ($P \leq 0.01$) correlated with grain weight panicle^{-1} (0.9710), biological yield plant $^{-1}$ (0.9296), harvest index (0.8720), number of filled grains panicle^{-1} (0.8438), 1000 grain weight (0.8035), straw yield plant^{-1} (0.7980), panicle length (0.7724), plant height to tip of longest leaf of plant (0.5978), number of spikelets panicle^{-1} (0.8438) and plant height at maturity (0.5799) at genotypic level. Biological yield plant^{-1} was also positively and significantly correlated with straw yield plant^{-1} (0.9381), grain yield plant^{-1} (0.9296), grain weight panicle^{-1}(0.9079), number of filled grains panicle $^{-1}$(0.7822), 1000 grain weight (0.7430), panicle length (0.6726), harvest index (0.6608), plant height at tip of longest leaf of plant (0.4811), number of spikelets panicle^{-1} (0.4767) and plant height at maturity (0.4749) at genotypic level.

4.4.12 Straw Yield Plant^{-1}

Straw yield plant^{-1} had highly significant positive correlation with biological yield plant^{-1} (0.9381) and harvest index (0.4846) at the genotypic level.

4.4.13 Biological Yield Plant^{-1}

Biological yield plant^{-1} had high significant positive correlation with harvest index (0.6608). The character was negatively correlated with spikelet sterility (%) and days to 50% flowering.

Biological yield plant^{-1} was positively correlated with straw yield plant^{-1} (0.9381), grain yield plant^{-1} (0.9296), grain weight panicle^{-1} (0.9079), number of filled grains panicle^{-1}(0.7822), 1000 grain weight (0.743), panicle length (0.6726), harvest index (0.6608), plant height at tip of longest leaf of plant

(0.4811), number of spikelets panicle^{-1} (0.4767) and plant height at maturity (0.4749) at genotypic level.

4.4.14 Harvest Index

Harvest index was positively correlated with all traits except days to 50% flowering and spikelet sterility.

4.5 PATH COEFFICIENT ANALYSIS

The component characters selected for path analysis were days to 50 % flowering, plant height at tip of longest leaf of plant, plant height at maturity , panicle length, number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, spikelet sterility, grain weight panicle^{-1}, 1000 grain weight, grain yield plant^{-1}, straw yield plant^{-1} and harvest index. The direct and indirect effects at genotypic level of the selected characters on grain yield are estimated and given in Table 18.

The highest direct effect on grain yield plant^{-1} was shown by biological yield plant^{-1} (1.0771) followed by harvest index (0.3639), 1000 grain weight (0.2624), number of spikelets panicle $^{-1}$(0.2495), days to 50% flowering (0.1201), plant height at tip of longest leaf (0.0361) and filled grains panicle^{-1} (0.0055).

The direct effect of days to 50% flowering on grain yield was positive (0.1201) but it recorded high negative genotypic correlation with grain yield due to high negative indirect effect through biological yield plant^{-1} (-0.3987) and harvest index (-0.1589).

Plant height at tip of longest leaf of plant showed positive direct effect (0.0361) and its genotypic correlation with grain yield was high (0.5978) because of its high positive indirect effect (0.5978) through biological yield plant^{-1}.

Direct effect of plant height at maturity on grain yield was negative (-0.529) but its indirect effect *via* biological yield plant^{-1} was positive (0.5182) which has accounted for the total genotypic correlation with grain yield (0.5799).

Direct effect of panicle length on grain yield was negative (-0.1173) but its indirect effect *via* biological yield plant^{-1} was positive (0.7244) which nearly accounted for the total genotypic correlation with grain yield (0.7724).

Number of spikelets panicle^{-1} showed positive direct effect (0.2495) and its genotypic correlation with grain yield was high (0.5668) because of its indirect effect (0.5668) through biological yield plant^{-1}.

Direct effect of filled grains panicle^{-1} was low and positive (0.0055) whereas its genotypic correlation with grain yield was high (0.8438) because of its indirect effect *via* biological yield plant^{-1} being positive (0.8425).

Direct effect of spikelet sterility was negative (-0.2193) and its genotypic correlation with grain yield was high but in negative direction (-0.5528) because of its indirect effect *via* biological yield plant^{-1} being negative (-0.6030).

Grain weight panicle^{-1} showed positive direct effect (0.3650) and its genotypic correlation with grain yield was high with positive magnitude (0.9710). Its indirect effect (0.9779) through biological yield plant^{-1} was also high.

Direct effect of 1000 grain weight was positive (0.2624) and its genotypic correlation with grain yield was high (0.8035) and the indirect effect *via* biological yield plant^{-1} was positive (0.8003).

Straw yield plant^{-1}showed negative direct effect (-0.3908) but its genotypic correlation with grain yield was positive (0.3980) because of its indirect effect (1.0104) through biological yield plant^{-1} which was positive and high.

Biological yield plant^{-1} showed the highest positive direct effect (1.0771) on grain yield and its genotypic correlation with grain yield was high (0.9296). Its indirect effect through straw yield plant^{-1} (1.0104) was high.

Direct effect of harvest index was positive (0.3639) and its genotypic correlation with grain yield was high (0.8720) and its indirect effect *via* biological yield $^{-1}$ plant was also high (0.7117).

The highest negative indirect effect on grain yield plant^{-1} was contributed by spikelet sterility (-0.603) through biological yield plant^{-1}. The highest positive indirect effect was contributed by straw yield plant^{-1} (1.1048) through biological yield plant^{-1}.

The residual value was only 0.0956 indicating that 99.90 per cent of the variation in yield was accounted by the component characters selected for analysis.

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4.6 SELECTION INDEX

Discriminant function technique was adopted for the construction of a selection index using grain yield and component characters. The selection indices for the twenty genotypes are given in Table19. The indices were worked out on the basis of yield and eight component characters *viz.*, panicle length, number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, grain weight panicle^{-1}, 1000 grain weight, straw yield plant^{-1}, harvest index and biological yield plant^{-1} having high significant genotypic correlation with grain yield. Among the twenty genotypes Vaishak ranked first with the highest index value followed by Thottacheera, Kalladiaryan, Vyttila 6, Harsha and Swarnaprabha. The genotypes with least index value were Uma, Pratyasha and Kanchana.

Experiment II

4.7 SCREENING OF RICE GENOTYPES FOR DROUGHT TOLERANCE IMPOSING REPRODUCTIVE STAGE MOISTURE STRESS UNDER PROTECTED CONDITION

The twenty rice genotypes were screened for drought tolerance under protected condition imposing soil moisture stress. Single plants were grown in polythene tubes of 20 cm width and 100 cm length filled with soil giving seven replications and forty treatments in a rain shelter. The plants were irrigated upto field capacity till moisture stress treatment was given. Reproductive stage moisture stress was imposed at panicle initiation and at heading. At these two stages moisture was withheld till the point when plants exhibited a leaf rolling score of 7 or relative leaf water content (RLWC) of 70%. Full irrigation was resumed thereafter till harvest. Indirect estimation of water use efficiency (WUE) was done.

Table 17. Genotypic and phenotypic correlation of yield and yield attributing traits in rainfed upland rice

		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}
X_2	G	-0.1554	1												
	P	-0.1388	1												
X_3	G	-0.1669	0.5229**	1											
	P	-0.1688	0.4869**	1											
X_4	G	-0.085	0.5306**	0.9085**	1										
	P	-0.0866	0.4962**	0.9049**	1										
X_5	G	0.0073	0.3006*	0.7248**	0.6274**	1									
	P	-0.0089	0.2345	0.6444**	0.5586**	1									
X_6	G	0.3275*	0.1639	0.5194**	0.489**	0.7163**	1								
	P	0.3118*	0.156	0.5146**	0.4837**	0.6512**	1								
X_7	G	-0.337*	-0.2387	0.3334*	0.2886	0.6166**	0.4112**	1							
	P	-0.3307*	-0.212	0.3291*	0.2854	0.5699**	0.4145**	1							
X_8	G	0.5777**	0.2955*	-0.1163	-0.0927	-0.2732	0.168	-0.8067**	1						
	P	0.5687**	0.2717	-0.1181	-0.0934	-0.2417	0.166	-0.7992**	1						
X_9	G	-0.3602*	0.1113	0.5713**	0.5487**	0.7715**	0.5514**	0.9011**	-0.6400**	1					
	P	-0.3453*	0.1155	0.5547**	0.5348**	0.6983**	0.5477**	0.8859**	-0.6279	1					
X_{10}	G	-0.4901**	0.4168**	0.4924**	0.5478**	0.5609**	0.321*	0.5317**	-0.3594*	0.7983**	1				
	P	-0.4785**	0.3892*	0.477**	0.5303**	0.4973**	0.3161*	0.5132**	-0.3461*	0.7768**	1				
X_{11}	G	-0.3753*	0.2356	0.5978**	0.5799**	0.7724**	0.5868**	0.8438**	-0.5528**	0.971**	0.8035**	1			
	P	-0.3468*	0.2577	0.5665**	0.55**	0.6662**	0.5711**	0.8146**	-0.5291	0.9492**	0.7609**	1			
X_{12}	G	-0.2776	0.1975	0.3011*	0.3692*	0.489**	0.4092**	0.6272**	-0.4375	0.779**	0.7016**	0.798**	1		
	P	-0.2588	0.2081	0.2835	0.3511*	0.4629**	0.4048**	0.6098**	-0.4189	0.764**	0.6651**	0.7942**	1		
X_{13}	G	-0.3701*	0.2555	0.4811**	0.4749**	0.6726**	0.4767**	0.7822**	-0.5598**	0.9079**	0.743**	0.9296**	0.9381**	1	
	P	-0.3459*	0.2634	0.4606**	0.4552**	0.5998**	0.4705**	0.7613**	-0.5409**	0.8894**	0.7041**	0.9253**	0.9358**	1	
X_{14}	G	-0.4367**	0.2411	0.65**	0.6294**	0.6999**	0.5138**	0.7328**	-0.4957	0.8578**	0.7702**	0.872**	0.4846**	0.6608**	1
	P	-0.4158**	0.2514	0.6228**	0.606**	0.6062**	0.4983**	0.7134**	-0.4828	0.8386**	0.7413**	0.8624**	0.4817**	0.6504**	1

X_1: Days to 50 % flowering
X_2: Number of productive tillers plant^{-1}
X_3:Plant height at tip of longest leaf
X_4:Plant height at maturity
X_5 :Panicle length
X_6:Number of spikelets panicle^{-1}
X_7:Number of filled spikelets panicle^{-1}
X_8:Spikelet sterility (%)
X_9:Grain weight panicle^{-1}
X_{10}:1000 Grain weight
X_{11}: Grain yield plant^{-1}
X_{12}:Straw yield plant^{-1}
X_{13}:Biological yield plant^{-1}
X_{14}:Harvest index

Table 18. Estimates of direct and indirect effects at genotypic level for different traits in rainfed upland rice(Season 31 May 2014 to 30 October, 2014)

Character	Days to 50% flowering	Plant height at tip of longest leaf of plant	Plant height at maturity	Panicle length	Number of spikelets panicles^{-1}	Number of filled grains panicle^{-1}	Spikelet sterility %	Grain weight panicle^{-1}	1000 grain weight	Straw yield plant^{-1}	Biological yield plant^{-1}	Harvest Index	Genotypi correlatio with grai yield
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	
X1	**0.12013**	-0.0060	0.0045	-0.0009	0.0817	-0.0019	-0.1267	0.1314	-0.1286	0.1084	-0.3987	-0.1589	-0.3753*
X2	-0.0200	**0.0361**	-0.0481	-0.0850	0.1296	0.0018	0.0255	-0.2085	0.1292	-0.1177	0.5182	0.2365	-0.5978**
X3	-0.0102	0.0328	**-0.0529**	-0.0736	0.1220	0.0015	0.0203	-0.2003	0.1437	-0.1443	0.5115	0.2290	0.5799**
X4	0.0008	0.0262	-0.0332	**-0.1173**	0.1787	0.0033	0.0599	-0.2816	0.1471	-0.1911	0.7244	0.2547	0.7724**
X5	0.0393	0.0187	-0.0259	-0.0840	**0.2495**	0.0022	-0.0368	-0.2013	0.0842	-0.1599	0.5134	0.1870	0.5668**
X6	-0.0405	0.0120	-0.0153	-0.0723	0.1026	**0.0055**	0.1769	-0.3289	0.1395	-0.2451	0.8425	0.2667	0.8438**
X7	0.0694	-0.0042	0.0049	0.0320	0.0419	-0.0044	**-0.2193**	0.2336	-0.0943	0.1709	-0.6030	-0.1804	-0.5528**
X8	-0.0433	0.0206	-0.0290	-0.0905	0.1376	0.0049	0.1403	**-0.3650**	0.2094	-0.3044	0.9779	0.3122	0.9710**
X9	-0.0589	0.0178	-0.0290	-0.0658	0.0801	0.0029	0.0788	-0.2914	**0.2624**	-0.2742	0.8003	0.2803	0.8035**
X10	-0.0333	0.0108	-0.0195	-0.0574	0.1021	0.0034	0.0959	-0.2844	0.1841	**0.3908**	1.0104	0.1763	0.3980**
X11	-0.0445	0.0173	-0.0251	-0.0789	0.1189	0.0043	0.1227	-0.3314	0.1949	-0.3666	**1.0771**	0.2405	0.9296**
X12	-0.0525	0.0234	-0.0333	-0.0821	0.1282	0.0040	0.1087	-0.3131	0.2021	-0.1894	0.7117	**0.3639**	0.8720**
Residual effect=0.09564													

Coloured figures are direct effects

Table 19. Index scores according to morphological traits in 20 rice varieties in rainfed upland rice

Sl.No.	Name of variety	Index score
1	Kattamodan (PTB28)	137.7965 (16)
2	Karutha Modan (PTB29)	183.3884 (8)
3	Chuvanna Modan (PTB 30)	157.9608 (12)
4	Vyttila 2	189.4600 (7)
5	**Vyttila 6**	**227.2757 (4)**
6	Jyothi (PTB 39)	146.3599 (13)
7	**Swarnaprabha (PTB 43)**	**189.4619 (6)**
8	Kanchana (PTB 50)	127.7195 (18)
9	Aathira (PTB 51)	120.9686 (19)
10	Aiswarya (PTB 52)	139.6101 (15)
11	**Harsha (PTB 55)**	**204.5798 (5)**
12	**Vaishak (PTB 60)**	**240.8918 (1)**
13	Kanakom (MO 11)	129.1689 (17)
14	Uma (MO 16)	90.7445 (20)
15	Prathyasha (MO 21)	158.5236 (11)
16	Arimodan	145.3451 (14)
17	**Kalladiaryan**	**238.2462 (3)**
18	Karuthadukkan	175.1748 (9)
19	Parambuvattan	158.6314 (10)
20	**Thottacheera**	**238.3552 (2)**

Coloured names are superior varieties for yield

Table 20. Weather data during the cropping period of field evaluation of 20 rice varieties under rainfed upland condition from 31 st May 2014 to 4th November 201

Week No.	Date	Temperature (0C)				Max.	Min.	Soil Temperature (^{0}C) 20cm	RH (%)		Wind Vel.	Sunshine	Rain	Evapn.
		Dry	Wet	Dry	Wet				I	II	(km/h)	Hours	(mm)	(mm)
1	28-5-2014 to 3-6-2014	27.35	25.20	30.90	27.00	30.14	24.49	35.05	92.50	75.17	9.06	9.27	1.80	3.00
2	4-6-2014 to 10-06-2014	25.70	24.80	28.50	27.80	30.70	25.07	31.53	94.29	83.29	8.23	8.22	4.90	1.87
3	11-6-2014 to 17-6-2014	26.45	27.00	29.97	28.30	31.13	25.66	31.00	90.86	77.43	9.62	8.99	3.29	3.21
4	18-06-2014 to 24-06-2014	27.10	26.60	30.28	28.00	30.51	25.03	32.26	92.29	77.71	10.95	9.28	2.77	3.76
5	25-06-2014 to 1-07-2014	26.67	26.55	29.57	27.50	30.40	24.71	33.07	92.71	79.14	7.61	9.49	4.84	4.39
6	2--07-2014 to 8-07-2014	25.90	24.93	29.06	26.90	29.70	24.20	31.09	90.86	79.00	9.98	9.17	2.53	3.43
7	9-07-14 to 15-07-2014	25.17	23.90	28.76	26.67	30.06	24.21	30.74	92.86	80.43	8.64	8.67	4.84	3.54
8	16-07-15 to 22-07-2014	25.82	24.80	29.51	27.00	29.94	24.23	31.14	90.43	76.71	11.16	9.35	6.47	3.49
9	23-07-14 to 29-7-14	25.62	24.80	29.59	-	29.20	23.46	31.84	91.57	73.57	9.98	9.34	3.65	3.90
10	30-07-2014 to 5-08-2014	24.85	24.80	28.33	27.47	29.37	23.47	30.07	95.29	85.86	9.51	8.62	15.70	6.80
11	6-08-2014 to 12-08-2014	24.97	23.50	28.13	26.20	29.70	24.00	28.99	88.57	77.29	9.51	8.73	22.18	6.10
12	13-08-2014 to 19-08-2014	25.62	25.10	28.59	26.60	29.80	23.96	30.59	89.71	79.57	-	-	2.00	3.40
13	20-08-2014 to 26-08-2014	25.41	24.66	28.04	24.00	29.89	23.86	30.87	94.00	80.86	7.10	8.08	73.00	4.03
14	27-08-2014 to 2-09-2014	26.24	24.66	28.23	26.40	29.19	23.87	30.79	87.57	84.14	7.30	8.65	34.43	9.00
15	03-09-2014 to 9-09-2014	25.028	-	28.40	-	30.09	24.49	30.50	96.14	79.29	7.56	8.82	16.00	-
16	10-9-2014 to 16-09-2014	26.38	25.80	29.49	-	30.54	24.57	31.74	89.29	74.14	10.70	-	1.50	-
17	17-09-2014 to 23-09-2014	26.90	25.45	29.67	26.85	31.11	24.09	32.37	85.00	75.57	8.69	-	-	3.07
18	24-09-2014 to 30-09-2014	25.68	24.66	28.36	27.10	30.67	23.91	32.49	93.29	84.86	5.09	-	18.60	4.40
19	1-10-2014 to 7-10-2014	25.64	-	29.67	-	30.69	24.20	31.66	95.43	73.57	5.14	-	3.00	-
20	8-10-2014 to 14-10-2014	30.071	26.20	28.16	28.10	30.34	23.74	32.80	73.57	85.71	7.56	-	6.87	3.80
21	15-10-2014 to 21-10-2014	27.98	24.50	27.06	27.50	30.23	23.54	31.44	82.43	92.43	4.99	7.01	23.29	5.97
22	22-10-2014 to 28-10-2014	28.17	24.66	26.21	27.80	30.50	23.54	31.54	80.86	93.57	5.71	7.69	7.12	1.40
23	29-10-2014 to 4-11-2014	26.90	23.9	26.57	-	30.70	23.10	30.90	86.14	85.14	5.04	7.46	4.80	-

Table 21. Analysis of variance (Factor A, B and A x B interaction) for morphological traits

Trait	Source of significance	df	M.S.S	C.D.	S.E.(m)
1.	Days to 50% flowering				
	Condition	1	4953.750**	0.382	0.136
	Variety	19	451.467**	1.210	0.430
	Condition x Variety	19	45.599**	1.711	0.608
	Error	80	1.108		
2.	Number of productive tillers plant^{-1}				
	Condition	1	35.208**	0.272	0.096
	Variety	19	14.06**	0.859	0.305
	Condition x Variety	19	0.436	N.S.	0.431
	Error	80	0.558		
3.	Plant height at maturity (cm)				
	Condition	1	3167.250**	0.460	0.163
	Variety	19	1262.569**	1.454	0.517
	Condition x Variety	19	61.740**	2.056	0.730
	Error	80	1.601		
4.	Panicle length (cm)				
	Condition	1	179.586 **	0.248	0.088
	Variety	19	42.212**	0.784	0.279
	Condition x Variety	19	0.728	N.S.	0.394
	Error	80	0.466		
5.	Number of spikelets panicle^{-1}				
	Condition	1	2543.34**	0.702	0.249
	Variety	19	877.090**	2.220	0.789
	Condition x Variety	19	12.294**	3.140	1.116
	Error	80	3.733		
6.	Number of filled grains panicle^{-1}				
	Condition	1	33266.688**	0.566	0.201
	Variety	19	786.132**	1.789	0.636
	Condition x Variety	19	63.686**	2.530	0.899
	Error	80	2.424		
7.	Spikelet sterility (%)				
	Condition	1	57731.820**	0.445	0.158
	Variety	19	286.315**	1.406	0.499
	Condition x Variety	19	226.104**	1.988	0.706
	Error	80	1.497		
8.	Grain weight panicle^{-1}(g)				

	Condition	1	15.462**	0.019	0.007
	Variety	19	0.683**	0.060	0.021
	Condition x Variety	19	0.060**	0.085	0.030
	Error	80	0.003		
9. 1000 grain weight (g)					
	Condition	1	0.969*	0.180	0.064
	Variety	19	92.141**	0.568	0.202
	Condition x Variety	19	3.842**	0.803	0.285
	Error	80	0.244		
10 Grain yield plant^{-1} (g)					
	Condition	1	781.853**	0.375	0.133
	Variety	19	45.034**	1.184	0.421
	Condition x Variety	19	5.023**	1.675	0.595
	Error	80	1.062		
11. Straw yield plant^{-1} (g)					
	Condition	1	1928.008**	0.332	0.118
	Variety	19	38.986**	1.049	0.373
	Condition x Variety	19	8.319**	1.484	0.527
	Error	80	0.833		
12. Harvest index(%)					
	Condition	1	2281.586**	1.157	0.411
	Variety	19	338.350**	3.659	1.300
	Condition x Variety	19	66.827**	5.175	1.838
	Error	80	10.138		

Table 21(contd.)Analysis of variance (Factor A, B and A x B interaction) for physiological and biochemical traits

1. Water use efficiency (WUE) (g/l)					
Trait	Source of significance	df	M.S.S	C.D.	S.E.(m)
	Condition	1	14.987**	0.037	0.013
	Variety	19	0.488**	0.115	0.041
	Condition x Variety	19	0.065**	0.163	0.058
	Error	80	0.010		
2. Relative leaf water content (%)					
	Condition	1	12169.750**	0.400	0.142
	Variety	19	138.836**	1.263	0.449
	Condition x Variety	19	41.365**	1.787	0.635
	Error	80	1.209		
3. Proline content					
	Condition	1	1.300**	0.004	0.001
	Variety	19	0.101**	0.012	0.004

	Condition x Variety	19	0.025**	0.017	0.006
	Error	80	0.000		
4. Cell membrane stability index					
	Condition	1	1943.938**	0.339	0.121
	Variety	19	184.602**	1.074	0.381
	Condition x Variety	19	79.918**	1.518	0.539
	Error	80	0.873		
5. chlorophyll a content (mg/g)					
	Condition	1	2.180	0.029	0.010
	Variety	19	2.107	0.093	0.033
	Condition x Variety	19	0.508	0.132	0.047
	Error	80	0.007		
6. chlorophyll b content (mg/g)					
	Condition	1	3.388**	0.023	0.008
	Variety	19	1.528**	0.072	0.026
	Condition x Variety	19	0.013**	0.102	0.036
	Error	80	0.004		

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Observations for relative leaf water content (RLWC) and proline content were taken immediately before giving stress and when plants reached the critical stress level. Destructive sampling was done for relative growth rate (RGR), leaf area index (LAI), net assimilation rate (NAR) and root character studies immediately before giving stress and when plants reached the critical stress level. One time observations were taken for carbon isotope discrimination and biomass studies. Observations on other morphological characters were taken at appropriate plant growth stages following the Standard Evaluation System for Rice [IRRI, 1996]. The screening of genotypes were done as per the protocols of DRR (2012).

4.8 ANALYSIS OF VARIANCE (FACTOR A), (B) AND (A x B) INTERACTION FOR MORPHOLOGICAL TRAITS

Analysis of variance for factor A, B and A x B interaction is presented in Table 21. Analysis of variance for factor A (control/ drought condition) and factor B (varieties) revealed significant differences for all the morphological characters studied. The interaction effect *i.e* (condition x variety) was significant for the traits days to 50 % flowering, plant height at maturity (cm), number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, spikelet sterility (%), grain weight panicle^{-1} (g), 1000 grain weight (g), grain yield plant^{-1} (g), straw yield plant^{-1} (g) and harvest index (%) and non-significant for number of productive tillers plant^{-1} and panicle length (cm).

4.8 MEAN PERFORMANCE FOR MORPHOLOGICAL TRAITS IN RICE (*Oryza sativa* L.) UNDER PROTECTED CONDITION

Mean performance for morphological traits in rice (*Oryza sativa* L.) under control, drought and protected condition are presented in Tables 22 to 33 and Figs. 8 to 17. Percentage change in morphological traits due to imposed moisture stress is presented in Table 35. Plate 7. Expt. II. Twenty varieties under control and Plate 8. Expt. II. Twenty varieties under drought condition.

4.8.1 Days to 50% Flowering

Significant increase was noticed for days to 50% flowering under imposed drought condition as compared to control for all the twenty varieties under study (Table 22). Karutha Modan (PTB 29) was the earliest flowering variety both under control and under imposed moisture stress taking 78.67 days and 90.33 days respectively to come to 50% flowering. The late flowering types under control were Aathira and Uma with 105 days each to flower. Aathira and Kanchana were the late flowering varieties with 120.67 days each to flower under induced drought condition.

The increase in number of days to 50% flowering under imposed drought was less prominent in the varieties *viz.*, Jyothi (6.74%) and Kanakom (7.67%) as well as the local upland varieties *viz.*, Kalladiaryan (6.92%), Karuthadukkan (8.36%), Parambuvattan (9.03%) and Thottacheera (8.59%).

4.8.2 Number of Productive Tillers Plant^{-1}

No significant differences were noticed for number of productive tillers plant^{-1} under imposed drought as compared to control (Table 23). Number of productive tillers plant^{-1} was the highest in Vaishak (PTB 60) (10.67) and lowest in Vyttila 2, Aathira, Aiswarya and Thottacheera (4.33 each) under control. Under stress condition also it ranged from Vaishak (9.33) to Aathira (2.33) and Aiswarya (2.67).

4.8.3 Plant Height at Maturity (cm)

Significant decrease was noted for plant height at maturity under imposed drought condition (Table 24). The decrease was less pronounced for varieties Uma (3.18%), Chuvanna Modan (3.61%), Vaishak (3.68%), Prathyasha (5.14%) and Vyttila 6 (5.81%) whereas it was prominent for Thottacheera (21.69%), Kanchana (19.30%) and Swarnaprabha (15.98%).

4.8.4 Panicle Length (cm)

No significant differences were observed for panicle length under artificial drought condition (Table 25). Panicle length (cm) under control ranged from Aiswarya (13.50 cm) to Thottacheera (21.73 cm) and Vyttila 2 (22.00 cm). Under stress condition also it ranged from Aiswarya (10.17cm) to Thottacheera (19.30cm), Vyttila 2 (19.00 cm) and Swarnaprabha (19.33 cm).

4.8.5 Number of Spikelets Panicle^{-1}

Number of spikelets panicle^{-1} decreased significantly under imposed drought condition in all the varieties studied (Table 26). Spikelet number ranged from Aathira to Vyttila 2 under control (47.67 to 96.00) and under moisture stress (39.35 to 82.90) respectively. The varieties Kanchana, Aiswarya and Harsha were considerably affected by drought whereas the varieties Katta Modan and Chuvanna Modan were less affected, as is evidenced from the percentage reduction for the character.

4.8.6 Number of Filled Spikelets Panicle^{-1}

The number of filled spikelets panicle^{-1} decreased drastically due to water stress at reproductive stage in all the varieties (Table 27). The range was from Aathira (46.67) to Vyttila 2 (91.67) under control and from Aathira (12.67) to Thottacheera (50.00) under stress condition. The varieties Kanchana, Aathira and Harsha were more affected by drought as compared to Kalladiaryan and Swarnaprabha which were less affected as is revealed by the percentage variation in their mean values.

7. Total chlorophyll content (a+b) (mg/g)					
	Source of significance	df	M.S.S	C.D.	S.E.(m)
	Condition	1	10.100**	0.048	0.017
	Variety	19	9.758**	0.152	0.054
	Condition x Variety	19	0.020	N.S.	0.076
	Error	80	0.017		
8. carotenoides content (mg/g)					
	Condition	1	0.722**	0.074	0.026
	Variety	19	0.702**	0.233	0.083
	Condition x Variety	19	0.019	N.S.	0.117
	Error	80	0.041		
9. Leaf temperature (OC)					
	Condition	1	32.969**	0.194	0.069
	Variety	19	6.414**	0.613	0.218
	Condition x Variety	19	0.989**	0.866	0.308
	Error	80	0.284		
10.Transpiration rate (mmolesH$_2$O/m^2/sec)					
	Condition	1	4.752**	0.014	0.005
	Variety	19	0.851**	0.044	0.016
	Condition x Variety	19	0.065**	0.063	0.022
	Error	80	0.001		
11. Stomatal conductance (SC)					
	Condition	1	37694.750**	0.525	0.186
	Variety	19	11867.950**	1.659	0.589
	Condition x Variety	19	1045.132**	2.346	0.834
	Error	80	2.084		
12. Leaf soluble protein content(mg/g)					
	Condition	1	254.803**	1.701	0.604
	Variety	19	21.709 **	N.S.	1.910
	Condition x Variety	19	13.496**	N.S.	2.702
	Error	80	21.898**		
13. Radiation use efficiency					
	Condition	1	62.943	0.1204	0.0391
	Variety	19	9.278	0.3808	0.1309
	Condition x Variety	19	1.654	0.5386	0.1843
	Error	80	0.114		
14. Chlorophyll meter reading (SPAD)					
	Condition	1	218.469**	0.177	0.063
	Variety	19	162.004**	0.560	0.199
	Condition x Variety	19	3.650**	0.792	0.281
	Error	80	0.237		

15. Leaf area index					
	Condition	1	18.475**	0.081	0.029
	Variety	19	12.303**	0.256	0.091
	Condition x Variety	19	0.487**	0.361	0.128
	Error	80	0.049		
16. Relative growth rate (mg/g/day)					
	Condition	1	2666.444**	0.423	0.150
	Variety	19	103.086**	1.338	0.475
	Condition x Variety	19	102.907**	1.893	0.672
	Error	80	1.356		
17. Net assimilation rate (g/m^2/day)					
	Condition	1	31.341**	0.177	0.063
	Variety	19	45.257**	0.559	0.199
	Condition x Variety	19	27.113**	0.791	0.281
	Error	80	0.237		
18. Carbon isotope discrimination					
	Condition	1	0.203	N.S.	0.083
	Variety	19	5.136**	0.736	0.262
	Condition x Variety	19	2.588**	1.041	0.370
	Error	80	0.411		

Table 21 (contd.) Analysis of variance (Factor A, B and A x B interaction) for root characters

1. Root depth (cm)

Trait	Source of significance	df	M.S.S	C.D.	S.E.(m)
	Condition	1	416.531**	0.251	0.089
	Variety	19	228.036**	0.792	0.282
	Condition x Variety	19	8.562**	1.121	0.398
	Error	80	0.476		
2. Root volume (cc)					
	Condition	1	38.584**	0.278	0.099
	Variety	19	163.565**	0.880	0.313
	Condition x Variety	19	75.181**	1.245	0.442
	Error	80	0.587		
3. Root dry weight (g)					
	Condition	1	28.644**	0.239	0.085

	Variety	19	97.648**	0.756	0.269
	Condition x Variety	19	2.162**	1.069	0.380
	Error	80	0.433		
4. Root shoot ratio (g/g)					
	Condition	1	6.162**	0.025	0.009
	Variety	19	0.474**	0.078	0.028
	Condition x Variety	19	0.123**	0.110	0.039
	Error	80	0.005		
5. Deep root shoot ratio (mg/g)					
	Condition	1	578703.875**	6.557	2.329
	Variety	19	63490.113**	20.735	7.366
	Condition x Variety	19	25442.053**	29.323	10.417
	Error	80	325.562		

Plate 7. Expt. 2. Twenty rice varieties under protected condition- control

Plate 8. Expt. 2. Twenty varieties under protected condition- imposing reproductive stage moisture stress

Table 22. Effect of imposing reproductive stage moisture stress under protected condition
Trait : Days to 50% flowering

Sl.No.	Variety	Days to 50% flowering		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	100.00	89.67	94.84
2	Karutha Modan (PTB 29)	90.33	78.67	84.50
3	Chuvanna Modan (PTB 30)	104.33	89.67	97.00
4	Vyttila 2	124.00	102.00	113.00
5	Vyttila 6	115.67	102.00	108.84
6	Jyothi (PTB 39)	100.33	94.00	97.17
7	Swarnaprabha (PTB 43)	106.33	95.67	101.00
8	Kanchana (PTB 50)	120.67	92.33	106.50
9	Aathira (PTB 51)	120.67	105.00	112.84
10	Aiswarya (PTB 52)	117.33	100.67	109.00
11	Harsha (PTB 55)	99.67	83.00	91.34
12	Vaishak (PTB 60)	106.67	91.33	99.00
13	Kanakom (MO 11)	112.33	104.33	108.33
14	Uma (MO 16)	115.67	105.00	110.34
15	Prathyasha (MO 21)	105.67	93.33	99.50
16	Arimodan	96.33	82.00	89.17
17	Kalladiaryan	92.67	86.67	89.67
18	Karuthadukkan	103.67	95.67	99.67
19	Parambuvattan	100.67	92.33	96.50
20	Thottacheera	92.67	85.33	89.00
	Average	106.28	93.43	99.86
CD (0.05)	Condition	0.382		
	Variety			1.210
	Condition × Variety interaction	1.711		

Table 23. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Number of productive tillers plant^{-1}

Sl. No.	Variety	Number of productive tillers plant^{-1}		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	5.33	6.33	5.83
2	Karutha Modan (PTB 29)	4.67	6.00	5.34
3	Chuvanna Modan (PTB 30)	4.67	6.00	5.34
4	Vyttila 2	3.67	4.33	4.00
5	Vyttila 6	5.00	5.67	5.34
6	Jyothi (PTB 39)	4.33	6.67	5.50
7	Swarnaprabha (PTB 43)	2.67	3.67	3.17
8	Kanchana (PTB 50)	6.00	7.00	6.50
9	Aathira (PTB 51)	2.33	4.33	3.33
10	Aiswarya (PTB 52)	2.67	4.33	3.50
11	Harsha (PTB 55)	6.33	7.00	6.67
12	Vaishak (PTB 60)	9.33	10.67	10.00
13	Kanakom (MO 11)	4.33	5.00	4.67
14	Uma (MO 16)	6.00	7.00	6.50
15	Prathyasha (MO 21)	4.33	5.33	4.83
16	Arimodan	3.33	4.33	3.83
17	Kalladiaryan	4.67	5.00	4.84
18	Karuthadukkan	4.00	5.33	4.67
19	Parambuvattan	4.67	6.00	5.34
20	Thottacheera	4.33	4.33	4.33
	Average	4.63	5.72	5.17
CD (0.05)	Condition	0.272		
	Variety			0.859
	Condition × Variety interaction	N.S.		

Table 24. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Plant height at maturity (cm)

Sl. No.	Variety	Plant height at maturity (cm)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	76.33	82.33	79.33
2	Karutha Modan (PTB 29)	98.33	103.67	101.00
3	Chuvanna Modan (PTB 30)	89.00	92.33	90.67
4	Vyttila 2	110.67	123.00	116.84
5	Vyttila 6	81.00	86.00	83.50
6	Jyothi (PTB 39)	62.83	75.00	68.92
7	Swarnaprabha (PTB 43)	101.67	121.00	111.34
8	Kanchana (PTB 50)	76.67	95.00	85.84
9	Aathira (PTB 51)	93.50	109.00	101.25
10	Aiswarya (PTB 52)	81.67	95.33	88.50
11	Harsha (PTB 55)	66.00	77.00	71.50
12	Vaishak (PTB 60)	104.67	108.67	106.67
13	Kanakom (MO 11)	75.33	83.67	79.50
14	Uma (MO 16)	71.00	73.33	72.17
15	Prathyasha (MO 21)	80.00	84.33	82.17
16	Arimodan	84.33	93.33	88.83
17	Kalladiaryan	89.83	100.00	94.92
18	Karuthadukkan	100.67	112.00	106.34
19	Parambuvattan	92.83	99.00	95.92
20	Thottacheera	100.50	128.33	114.42
	Average	86.84	97.12	91.98
CD (0.05)	Condition	0.460		
	Variety			1.454
	Condition × Variety interaction	2.056		

Table 25. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Panicle length (cm)

Sl. No.	Variety	Panicle length (cm)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	15.90	17.27	16.59
2	Karutha Modan (PTB 29)	14.23	15.73	14.98
3	Chuvanna Modan (PTB 30)	18.50	19.83	19.17
4	Vyttila 2	19.00	22.00	20.50
5	Vyttila 6	14.20	15.83	15.02
6	Jyothi (PTB 39)	14.27	16.83	15.55
7	Swarnaprabha (PTB 43)	19.33	20.67	20.00
8	Kanchana (PTB 50)	11.83	14.73	13.28
9	Aathira (PTB 51)	12.80	15.50	14.15
10	Aiswarya (PTB 52)	10.17	13.50	11.84
11	Harsha (PTB 55)	13.00	16.33	14.67
12	Vaishak (PTB 60)	18.73	21.73	20.23
13	Kanakom (MO 11)	14.40	16.27	15.34
14	Uma (MO 16)	13.00	15.50	14.25
15	Prathyasha (MO 21)	16.50	19.00	17.75
16	Arimodan	16.17	19.33	17.75
17	Kalladiaryan	18.27	20.67	19.47
18	Karuthadukkan	15.50	18.50	17.00
19	Parambuvattan	17.33	20.40	18.87
20	Thottacheera	19.30	21.73	20.52
	Average	15.62	18.07	16.84
CD(0.05)	Condition	0.248		
	Variety			0.784
	Condition × Variety interaction	N.S.		

Table 26. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Number of spikelets $panicle^{-1}$

Sl. No.	Variety	Number of spikelets $panicle^{-1}$		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	57.10	62.00	59.55
2	Karutha Modan (PTB 29)	48.25	53.33	50.79
3	Chuvanna Modan (PTB 30)	50.99	55.33	53.16
4	Vyttila 2	82.90	96.00	89.45
5	Vyttila 6	75.09	83.67	79.38
6	Jyothi (PTB 39)	57.34	67.00	62.17
7	Swarnaprabha (PTB 43)	76.12	81.33	78.73
8	Kanchana (PTB 50)	40.16	50.00	45.08
9	Aathira (PTB 51)	39.35	47.67	43.51
10	Aiswarya (PTB 52)	44.93	59.67	52.30
11	Harsha (PTB 55)	51.98	65.33	58.66
12	Vaishak (PTB 60)	67.23	78.00	72.62
13	Kanakom (MO 11)	60.78	68.67	64.73
14	Uma (MO 16)	54.36	64.67	59.52
15	Prathyasha (MO 21)	50.37	58.00	54.19
16	Arimodan	54.36	65.67	60.02
17	Kalladiaryan	67.85	77.67	72.76
18	Karuthadukkan	55.85	66.67	61.26
19	Parambuvattan	57.21	67.00	62.11
20	Thottacheera	71.94	80.67	76.31
	Average	58.21	67.42	62.81
CD(0.05)	Condition	0.702		
	Variety			2.220
	Condition × Variety interaction	1.578		

Table 27. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Number of filled grains panicle^{-1}

Sl.No.	Variety	Number of filled grains panicle^{-1}		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	32.00	58.00	45.00
2	Karutha Modan (PTB 29)	19.33	49.33	34.33
3	Chuvanna Modan (PTB 30)	26.33	50.67	38.50
4	Vyttila 2	40.00	91.67	65.84
5	Vyttila 6	40.00	72.33	56.17
6	Jyothi (PTB 39)	31.33	59.67	45.50
7	Swarnaprabha (PTB 43)	46.33	78.33	62.33
8	Kanchana (PTB 50)	13.33	49.00	31.17
9	Aathira (PTB 51)	12.67	46.67	29.67
10	Aiswarya (PTB 52)	20.33	54.00	37.17
11	Harsha (PTB 55)	19.33	63.00	41.17
12	Vaishak (PTB 60)	45.00	77.00	61.00
13	Kanakom (MO 11)	38.00	64.67	51.34
14	Uma (MO 16)	16.33	56.67	36.50
15	Prathyasha (MO 21)	19.00	56.00	37.50
16	Arimodan	31.00	64.00	47.50
17	Kalladiaryan	45.00	74.33	59.67
18	Karuthadukkan	36.00	65.00	50.50
19	Parambuvattan	27.33	65.33	46.33
20	Thottacheera	50.00	79.00	64.50
	Average	30.43	63.73	47.08
CD (0.05)	Condition	0.566		
	Variety			1.789
	Condition × Variety interaction	2.530		

Table 28. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Spikelet sterility (%)

Sl.No.	Variety	Spikelet sterility (%)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	43.96	6.46	25.21
2	Karutha Modan (PTB 29)	59.93	7.51	33.72
3	Chuvanna Modan (PTB 30)	48.34	7.33	27.84
4	Vyttila 2	51.72	4.51	28.12
5	Vyttila 6	46.72	13.56	30.14
6	Jyothi (PTB 39)	45.33	11.76	28.55
7	Swarnaprabha (PTB 43)	39.13	3.69	21.41
8	Kanchana (PTB 50)	66.81	2.00	34.41
9	Aathira (PTB 51)	67.84	2.10	34.97
10	Aiswarya (PTB 52)	54.74	9.48	32.11
11	Harsha (PTB 55)	62.70	3.55	33.13
12	Vaishak (PTB 60)	33.04	1.28	17.16
13	Kanakom (MO 11)	37.48	5.83	21.66
14	Uma (MO 16)	69.95	12.34	41.15
15	Prathyasha (MO 21)	62.24	3.45	32.85
16	Arimodan	42.95	1.54	22.25
17	Kalladiaryan	33.63	3.03	18.33
18	Karuthadukkan	35.51	2.49	19.00
19	Parambuvattan	52.21	2.97	27.59
20	Thottacheera	30.49	2.47	16.48
	Average	49.24	5.37	27.30
CD (0.05)	Condition	0.445		
	Variety			1.406
	Condition × Variety interaction	1.988		

Table 29. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Grain weight panicle $^{-1}$(g)

Sl.No.	Variety	Grain weight panicle $^{-1}$(g)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	0.46	0.86	0.66
2	Karutha Modan (PTB 29)	0.42	1.09	0.76
3	Chuvanna Modan (PTB 30)	0.62	1.24	0.93
4	Vyttila 2	0.81	1.93	1.37
5	Vyttila 6	0.79	1.45	1.12
6	Jyothi (PTB 39)	0.81	1.55	1.18
7	Swarnaprabha (PTB 43)	1.16	1.44	1.30
8	Kanchana (PTB 50)	0.39	1.41	0.90
9	Aathira (PTB 51)	0.20	0.73	0.47
10	Aiswarya (PTB 52)	0.33	0.89	0.61
11	Harsha (PTB 55)	0.41	1.33	0.87
12	Vaishak (PTB 60)	1.12	1.90	1.51
13	Kanakom (MO 11)	0.75	1.36	1.06
14	Uma (MO 16)	0.25	0.98	0.62
15	Prathyasha (MO 21)	0.47	1.41	0.94
16	Arimodan	0.74	1.54	1.14
17	Kalladiaryan	1.19	1.96	1.58
18	Karuthadukkan	0.87	1.54	1.21
19	Parambuvattan	0.57	1.36	0.97
20	Thottacheera	1.31	2.08	1.70
	Average	0.68	1.40	1.04
CD (0.05)	Condition	0.019		
	Variety			0.060
	Condition × Variety interaction	0.085		

Table 30. Effect of imposing reproductive stage moisture stress under protected condition

Trait: 1000 grain weight (g)

Sl.No.	Variety	1000 grain weight (g)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	14.51	14.61	14.56
2	Karutha Modan (PTB 29)	21.76	22.59	22.18
3	Chuvanna Modan (PTB 30)	23.42	24.18	23.80
4	Vyttila 2	20.14	20.93	20.54
5	Vyttila 6	19.86	19.79	19.83
6	Jyothi (PTB 39)	25.71	24.93	25.32
7	Swarnaprabha (PTB 43)	25.14	18.74	21.94
8	Kanchana (PTB 50)	29.54	28.65	29.10
9	Aathira (PTB 51)	15.94	15.70	15.82
10	Aiswarya (PTB 52)	16.43	16.47	16.45
11	Harsha (PTB 55)	21.34	21.05	21.20
12	Vaishak (PTB 60)	24.84	24.60	24.72
13	Kanakom (MO 11)	19.71	20.88	20.30
14	Uma (MO 16)	15.56	17.33	16.45
15	Prathyasha (MO 21)	24.64	25.02	24.83
16	Arimodan	23.99	24.02	24.01
17	Kalladiaryan	26.39	26.32	26.36
18	Karuthadukkan	24.10	23.70	23.90
19	Parambuvattan	20.90	20.84	20.87
20	Thottacheera	26.27	26.28	26.28
	Average	22.01	21.83	21.92
CD (0.05)	Condition	0.180		
	Variety			0.568
	Condition × Variety interaction	0.803		

Table 31. Effect of imposing reproductive stage moisture stress under protected condition

Trait : Grain yield plant^{-1} (g)

Sl.No.	Variety	Grain yield plant^{-1} (g)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	2.48	5.67	4.08
2	Karutha Modan (PTB 29)	1.99	6.72	4.36
3	Chuvanna Modan (PTB 30)	2.88	7.65	5.27
4	Vyttila 2	2.97	8.67	5.82
5	Vyttila 6	3.99	9.25	6.62
6	Jyothi (PTB 39)	3.52	10.48	7.00
7	Swarnaprabha (PTB 43)	3.11	6.00	4.56
8	Kanchana (PTB 50)	2.36	10.13	6.25
9	Aathira (PTB 51)	0.47	3.50	1.99
10	Aiswarya (PTB 52)	0.94	4.00	2.47
11	Harsha (PTB 55)	2.62	9.40	6.01
12	Vaishak (PTB 60)	10.45	20.67	15.56
13	Kanakom (MO 11)	3.25	7.00	5.13
14	Uma (MO 16)	1.53	6.97	4.25
15	Prathyasha (MO 21)	2.03	7.62	4.83
16	Arimodan	2.51	6.73	4.62
17	Kalladiaryan	5.55	10.30	7.93
18	Karuthadukkan	3.47	8.30	5.89
19	Parambuvattan	2.66	8.40	5.53
20	Thottacheera	5.73	9.13	7.43
	Average	3.23	8.33	5.78
CD (0.05)	Condition	0.375		
	Variety			1.184
	Condition × Variety interaction	1.675		

Table 32. Effect of imposing reproductive stage moisture stress under protected condition

Trait : Straw yield plant $^{-1}$(g)

Sl.No.	Variety	Straw yield plant^{-1} (g)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	4.33	11.33	7.83
2	Karutha Modan (PTB 29)	3.33	18.00	10.67
3	Chuvanna Modan (PTB 30)	4.00	16.00	10.00
4	Vyttila 2	7.67	18.67	13.17
5	Vyttila 6	7.33	11.33	9.33
6	Jyothi (PTB 39)	4.67	11.33	8.00
7	Swarnaprabha (PTB 43)	5.67	14.00	9.84
8	Kanchana (PTB 50)	4.00	12.00	8.00
9	Aathira (PTB 51)	4.00	11.00	7.50
10	Aiswarya (PTB 52)	2.67	11.67	7.17
11	Harsha (PTB 55)	4.33	12.33	8.33
12	Vaishak (PTB 60)	13.67	22.67	18.17
13	Kanakom (MO 11)	4.33	10.33	7.33
14	Uma (MO 16)	4.67	12.33	8.50
15	Prathyasha (MO 21)	4.33	10.33	7.33
16	Arimodan	4.67	13.00	8.84
17	Kalladiaryan	7.00	14.17	10.59
18	Karuthadukkan	6.33	14.00	10.17
19	Parambuvattan	5.33	11.83	8.58
20	Thottacheera	7.67	14.00	10.84
	Average	5.50	13.52	9.51
CD (0.05)	Condition	0.332		
	Variety			1.049
	Condition × Variety interaction	1.484		

Table 33. Effect of imposing reproductive stage moisture stress under protected condition

Trait : Harvest index (%)

Sl.No.	Variety	Harvest index (%)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	33.83	35.02	34.43
2	Karutha Modan (PTB 29)	22.06	26.60	24.33
3	Chuvanna Modan (PTB 30)	31.37	31.66	31.52
4	Vyttila 2	26.08	30.56	28.32
5	Vyttila 6	34.02	45.06	39.54
6	Jyothi (PTB 39)	35.48	46.42	40.95
7	Swarnaprabha (PTB 43)	23.49	28.93	26.21
8	Kanchana (PTB 50)	29.55	44.56	37.06
9	Aathira (PTB 51)	12.00	22.78	17.39
10	Aiswarya (PTB 52)	18.78	23.77	21.28
11	Harsha (PTB 55)	32.28	41.38	36.83
12	Vaishak (PTB 60)	37.33	46.61	41.97
13	Kanakom (MO 11)	30.50	38.59	34.55
14	Uma (MO 16)	15.10	34.80	24.95
15	Prathyasha (MO 21)	14.00	39.45	26.73
16	Arimodan	24.14	32.52	28.33
17	Kalladiaryan	40.51	40.89	40.70
18	Karuthadukkan	29.32	36.57	32.95
19	Parambuvattan	31.98	39.84	35.91
20	Thottacheera	36.10	38.60	37.35
	Average	27.90	36.23	32.06
CD (0.05)	Condition	1.157		
	Variety			3.659
	Condition × Variety interaction	5.175		

Table 34. Leaf rolling score in 20 rice varieties under protected condition imposing reproductive stage moisture stress

Sl.No.	Variety	Decimal score	Description
1	Kattamodan (PTB28)	3	Leaves folding (deep V shape)
2	Karutha Modan (PTB29)	3	Leaves folding (deep V shape)
3	Chuvanna Modan (PTB 30)	3	Leaves folding (deep V shape)
4	Vyttila 2	3	Leaves folding (deep V shape)
5	Vyttila 6	3	Leaves folding (deep V shape)
6	Jyothi (PTB 39)	3	Leaves folding (deep V shape)
7	Swarnaprabha (PTB 43)	3	Leaves folding (deep V shape)
8	Kanchana (PTB 50)	3	Leaves folding (deep V shape)
9	Aathira (PTB 51)	3	Leaves folding (deep V shape)
10	Aiswarya (PTB 52)	3	Leaves folding (deep V shape)
11	Harsha (PTB 55)	3	Leaves folding (deep V shape)
12	Vaishak (PTB 60)	3	Leaves folding (deep V shape)
13	Kanakom (MO 11)	1	Leaves start to fold (Shallow V shape)
14	Uma (MO 16)	3	Leaves folding (deep V shape)
15	Prathyasha (MO 21)	1	Leaves start to fold (Shallow V shape)
16	Arimodan	3	Leaves folding (deep V shape)
17	Kalladiaryan	3	Leaves folding (deep V shape)
18	Karuthadukkan	3	Leaves folding (deep V shape)
19	Parambuvattan	3	Leaves folding (deep V shape)
20	Thottacheera	3	Leaves folding (deep V shape)

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4.8.7 Spikelet Sterility (%)

Spikelet sterility (%) increased tremendously under drought condition. Significant differences were recorded in all varieties due to water stress at reproductive stage (Table 28). Highest spikelet sterility (%) was observed in Vyttila 6 (13.56%) and lowest in Vaishak (1.28%), Arimodan (1.54%) and Kanchana (2%) under control. The varieties Uma (69.95), Aathira (67.84) and Kanchana (66.81%) showed the highest spikelet sterility under drought. In general the local upland varieties were less affected by induced stress as is revealed by their low percentage variation *viz.,* 28.02% for Thottacheera, 30.60% for Kalladiaryan, 33.039 for Karuthadukkan and 49.23% for Parambuvattan. This percentage change was high in Kanchana (72.79%), Aathira (72.86), Uma (71.18%) and Harsha (69.31%) showing that they were seriously affected by moisture stress.

4.8.8 Grain Weight Panicle $^{-1}$(g)

Significant differences were noted for grain weight panicle^{-1} for all varieties considered due to imposed drought condition (Table 29). The highest grain weight panicle^{-1} was recorded in Thottacheera (2.08g) followed by Kalladiaryan (1.96g) and Vyttila 2 (1.93g) whereas the lowest grain weights were observed in Aathira (0.73g), Katta Modan (0.86g) and Aiswarya (0.89g) under control. Under moisture stress condition also Thottacheera (1.31g) followed by Kalladiaryan (1.19g) recorded the highest values and Aathira (0.20g), Uma (0.25g) and Aiswarya (0.33 g) recorded the lowest values (Table 28). Percentage reduction due to moisture stress was less pronounced for varieties Swarnaprabha (18.92%), Thottacheera (36.78%) and Kalladiaryan (39.37%) whereas it was more pronounced for Uma (74.14%), Kanchana (72.12%) and Aathira (72.45%).

4.8.9 1000 Grain Weight (g)

Significant reduction was observed for 1000 grain weight under imposed drought condition (Table 30). Maximum 1000 grain weight (g) was recorded in Kanchana (28.65g) followed by Kalladiaryan (26.32g) and Thottacheera (26.28g) whereas minimum value was recorded in Kattamodan (14.61 g) under control. Kanchana had maximum grain weight of 29.54 g under drought condition followed by Kalladiaryan (26.39g). The varieties Kattamodan (14.51g) followed by Uma (15.56g) and Aathira (15.94g) recorded low 1000 grain weights under drought. The percentage decrease in 1000 grain weight under moisture stress was exorbitantly high for Swarnaprabha (34.16%) and Uma (10.21%) whereas it was considerably low for Thottacheera (0.03%), Aiswarya (0.25%), Kalladiaryan (-0.25%) and Parambuvattan (-0.30%).

4.8.10 Grain Yield Plant^{-1} (g)

The grain yield plant^{-1} exhibited significant reduction under water stress condition. Grain yield plant^{-1} was the highest in Vaishak (20.67g) followed by Jyothi (10.48g) and Kalladiaryan (10.30g) whereas it was the lowest in Aathira (3.50g) under control (Table 31). The varieties Vaishak (10.45g), Thottacheera (5.73g) and Kalladiaryan (5.55g) were the highest grain yielders under drought. With respect to grain yield plant^{-1} the greatest yield reduction was observed in Aathira, Uma, Kanchana and Aiswarya under drought whereas the reduction was less pronounced in Thottacheera and Kalladiaryan.

4.8.11 Straw Yield Plant^{-1} (g)

Significant reduction was exhibited by all varieties for straw yield plant^{-1} under water stress condition (Table 32). Maximum straw yield plant^{-1} was recorded in the variety Vaishak (22.67g) followed by Vyttila 2 (18.67g), Chuvanna Modan (16 g) and Kalladiaryan (10.30g) whereas minimum values were recorded in Kanakom (MO 11) and Prathyasha (MO 21) (10.33 each) under control. The varieties Vaishak (13.67g), Thottacheera (7.67g), Vyttila 2 (7.67g), Vyttila 6 (7.33g) and Kalladiaryan (7.00g) were the highest straw yielders under drought. Drought brought about drastic reduction in straw yield in Karutha Modan, Chuvanna Modan and Aiswarya whereas Vaishak and Vyttila 6 were less affected by the condition.

4.8.12 Harvest Index (%)

Significant differences were noted for harvest index under drought condition. Maximum harvest index was recorded by Vaishak (46.61%) followed by Kanchana (44.56%) and Harsha (41.38%) whereas lowest harvest index was noted in Aathira (22.78) and Aiswarya (23.77%) under control (Table 33). The varieties Kalladiaryan (40.51%), Vaishak (37.33%), Thottacheera (36.10%), Jyothi (35.48%), Vyttila 6 (34.02%), Katta Modan (33.83%) and Harsha (32.28%) showed high values for harvest index under drought (Table33). Tremendous reduction in harvest index was observed in Prathyasha, Uma and Kanchana under drought whereas the upland local and improved varieties *viz*., Kalladiaryan, Chuvanna Modan, Katta Modan and Thottacheera showed less prominent reduction.

4.8.13 Leaf Rolling

Information pertaining to leaf rolling under imposed moisture stress is presented in Table 34.

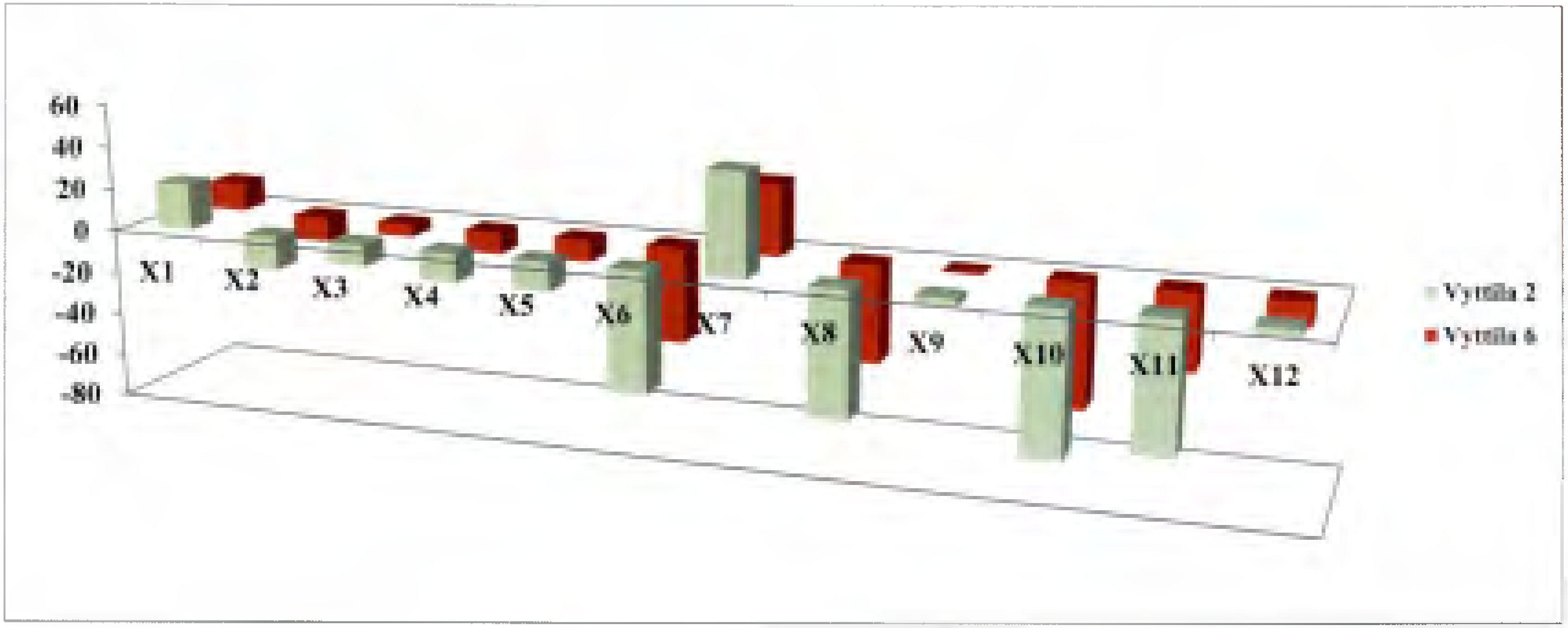
Under normal condition all the varieties showed leaves folding in a deep 'V' shape except Kanakom and Prathyasha where leaves folded in a shallow 'V'shape. Leaf rolling was most pronounced in the varieties Katta Modan, Chuvana Modan, Vyttila 2, Swarnaprabha and Aathira under reproductive moisture stress condition. For leaf rolling (L.R), the susceptible varieties showed scores upto 7 while the resistant varieties did not roll in the early morning hours. Rolling started at around 1 p.m.

Table 35. Percentage change for morphological traits in rice varieties under protected condition imposing reproductive stage moisture stress

Sl.No	Name of variety/Traits	Days to 50% flowering	Number of productive tillers per plant	Plant height at maturity (cm)	Panicle length (cm)	Number of spikelets per panicle	Number of filled grains per panicle	Spikelet sterility (%)	Grain weight per panicle(g)	1000 grain weight (g)	Grain yield per plant (g)	Straw yield per plant (g)	Harvest index (%)
1	Kattamodan (PTB28)	11.52	-15.79	-7.29	-7.92	-7.91	-44.83	37.51	-45.86	-0.73449	-56.15	-61.76	-1.19
2	Karutha Modan (PTB 29)	14.83	-22.22	-5.14	-9.53	-9.52	-60.81	52.42	-61.31	-3.64374	-70.47	-81.48	-4.54
3	Chuvanna Modan (PTB 30)	16.36	-22.22	-3.61	-6.72	-7.85	-48.03	41.01	-50.12	-3.16471	-62.41	-75.00	-0.29
4	Vyttila 2	21.57	-15.38	-10.03	-13.64	-13.65	-56.36	47.22	-58.33	-3.79777	-65.74	-58.93	-4.48
5	Vyttila 6	13.40	-11.76	-5.81	-10.32	-10.25	-44.70	33.16	-45.09	-0.36725	-56.88	-35.29	-11.04
6	Jyothi (PTB 39)	6.74	-35.00	-16.22	-15.25	-14.41	-47.49	33.57	-48.02	3.12032	-66.47	-58.82	-10.94
7	Swarnaprabha (PTB 43)	11.15	-27.27	-15.98	-6.45	-6.41	-40.85	35.44	-18.92	34.15510	-48.21	-59.52	-5.44
8	Kanchana (PTB 50)	30.69	-14.29	-19.30	-19.68	-19.68	-72.79	64.81	-72.12	3.13242	-76.67	-66.67	-15.01
9	Aathira (PTB 51)	14.92	-46.15	-14.22	-17.42	-17.44	-72.86	65.74	-72.45	1.53536	-86.61	-63.64	-10.78
10	Aiswarya (PTB 52)	16.56	-38.46	-14.34	-24.69	-24.70	-62.35	45.26	-62.43	-0.25096	-76.53	-77.14	-4.99
11	Harsha (PTB 55)	20.08	-9.52	-14.29	-20.41	-20.44	-69.31	59.14	-68.98	1.37424	-72.14	-64.86	-9.10
12	Vaishak (PTB 60)	16.79	-12.50	-3.68	-13.80	-13.80	-41.56	31.75	-41.16	0.97548	-49.42	-39.71	-9.28
13	Kanakom (MO 11)	7.67	-13.33	-9.96	-11.48	-11.48	-41.24	31.65	-44.92	-5.60255	-53.51	-58.06	-8.09
14	Uma (MO 16)	10.16	-14.29	-3.18	-16.13	-15.94	-71.18	57.61	-74.14	-10.21346	-78.11	-62.16	-19.7
15	Prathyasha (MO 21)	13.21	-18.75	--5.14	-13.16	-13.16	-66.07	58.79	-66.72	-1.53049	-73.35	-58.06	-25.45
16	Arimodan	17.48	-23.08	-9.64	-16.38	-17.22	-51.56	41.41	-51.69	-0.10963	-62.75	-64.10	-8.38
17	Kalladiaryan	6.92	-6.67	-10.17	-11.61	-12.64	-39.46	30.60	-39.37	0.25836	-46.13	-50.59	-0.38
18	Karuthadukkan	8.36	-25.00	-10.12	-16.22	-16.22	-44.62	33.03	-43.79	1.65659	-58.21	-54.76	-7.25
19	Parambuvattan	9.03	-22.22	-6.23	-15.03	-14.61	-58.16	49.23	-58.10	0.30870	-68.31	-54.93	-7.86
20	Thottacheera	8.59	0.00	-21.69	-11.20	-10.82	-36.71	28.02	-36.78	-0.03805	-37.31	-45.24	-2.50

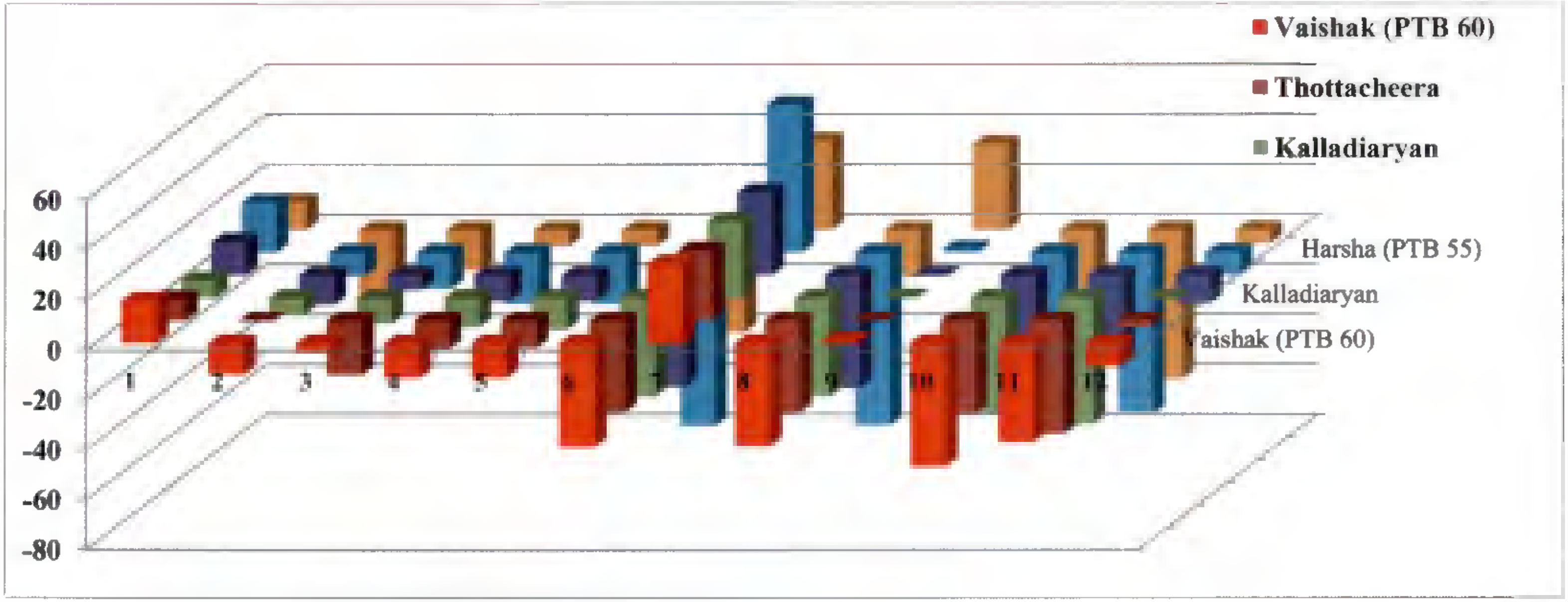
with (-): indicate percentage decrease in mean performance of character under moisture stress

without (-): indicate percentage increase in mean performance of character under moisture stress



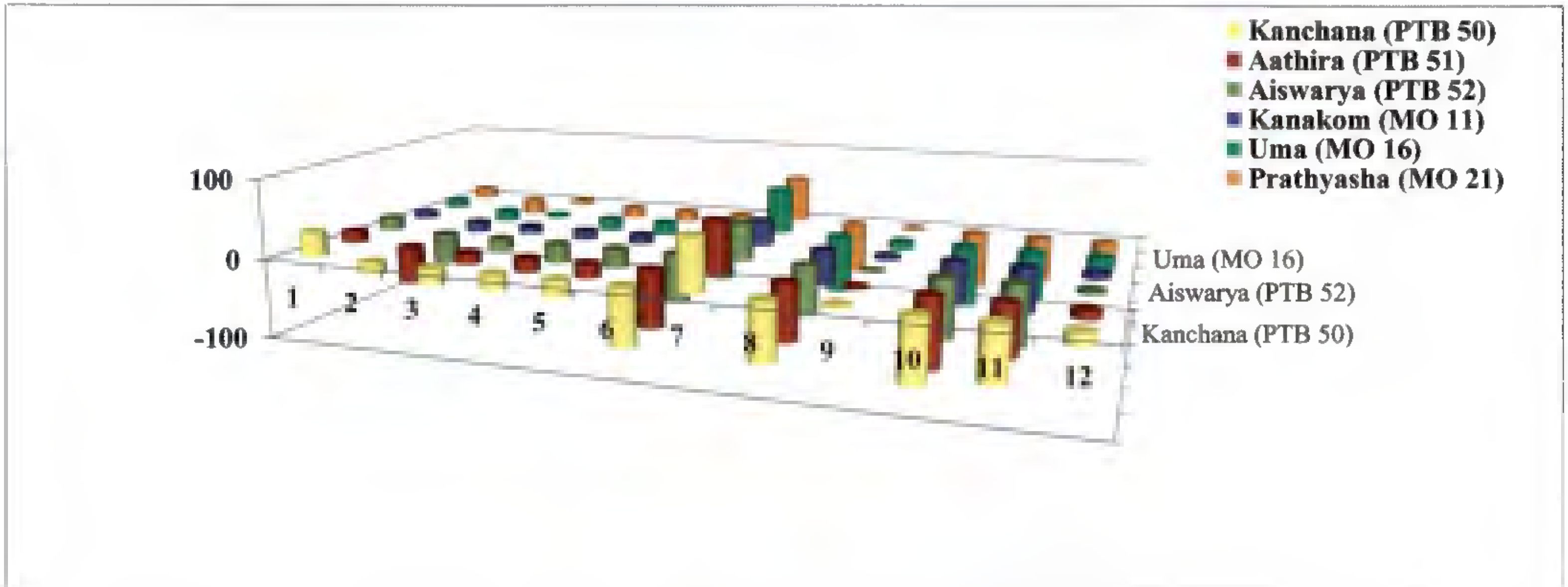
X1	Days to 50% flowering	X2	Number of productive tillers plant^{-1}
X3	Plant height at maturity (cm)	X4	Panicle length (cm)
X5	Number of spickelets panicles^{-1}	X6	Number of filled grains panicle^{-1}
X7	Spikelet sterility (%)	X8	Grain weight panicle^{-1} (g)
X9	1000 grain weight (g)	X10	Grain yield plant^{-1} (g)
X11	Straw yield plant^{-1} (g)	X12	Harvest index (%)

Fig. 8. Percentage change in morphological traits of Vyttila 2 and Vyttila 6 under reproductive stage moisture stress



1	Days to 50% flowering	2	Number of productive tillers plant^{-1}
3	Plant height at maturity (cm)	4	Panicle length (cm)
5	Number of spickelets panicle^{-1}	6	Number of filled grains panicle^{-1}
7	Spikelet sterility(%)	8	Grain weight per panicle (g)
9	1000 grain weight (g)	10	Grain yield plant^{-1} (g)
11	Straw yield plant^{-1} (g)	12	Harvest index(%)

Fig. 9. Percentage change in morphological traits of six selected superior varieties under reproductive stage moisture stress



1	Days to 50% flowering	2	Number of productive tillers plant^{-1}
3	Plant height at maturity (cm)	4	Panicle length (cm)
5	Number of spickelets panicle^{-1}	6	Number of filled grains panicle^{-1}
7	Spikelet sterility(%)	8	Grain weight panicle $^{-1}$(g)
9	1000 grain weight (g)	10	Grain yield plant^{-1} (g)
11	Straw yield plant^{-1} (g)	12	Harvest index (%)

Fig. 10. Percentage change in morphological traits of varieties affected severely by reproductive stage moisture stress

4.9 ANALYSIS OF VARIANCE (FACTOR A, B AND A x B INTERACTION) FOR PHYSIOLOGICAL AND BIOCHEMICAL TRAITS

Analysis of variance (factor A, B and A x B interaction) for physiological and biochemical traits is presented in Table 21.

All the physiological and biochemical traits were significant under control/drought condition except the traits chlorophyll a and carbon isotope discrimination. Factor B (varieties) showed significant differences in all the traits except chlorophyll a content. A x B interaction effects (condition x varieties) were significant for all the traits except total chlorophyll content, carotenoides content and leaf soluble protein content.

Mean performance for physiological and biochemical traits under protected condition under control and induced drought is presented in Tables 36 to 53. Percentage change for physiological and biochemical traits under induced drought is presented in Table 54.

4.9.1Water Use Efficiency (WUE) (g/l)

Significant differences were recorded between control and imposed drought condition for water use efficiency in all varieties studied (Table 36). Vaishak had recorded the highest water use efficiency under both control (2.38g/l) and drought (1.29g/l). The other varieties showing high water use efficiency under control condition and drought were Kalladiaryan, Vyttila 2 and Thottacheera. These three varieties along with Vyttila 6, Kanakom and Swarnaprabha showed consistently efficient water use under both control and moisture stress.

4.9.2 Relative Leaf Water Content (RLWC) (%)

Significant differences were recorded among the varieties for relative leaf water content under drought (Table 37). The variety Karuthadukkan consistently showed high relative leaf water content in both the conditions i.e. under control (94.21%) and under drought (71.14%). The other varieties having high RLWC include Swarnaprabha (90.97%), Kalladiaryan and Vaishak (90% each), Vyttila

2(88.63%), Jyothi (88.30%), Thottacheera (87.60%) Kanchana (87.33%) and Harsha (85.48%). The lowest values of RLWC were recorded in Aiswarya (75.67), followed by Aathira (77.67%) and Prathyasha (79%) under control condition. Swarnaprabha (72.33%) had higher RLWC followed by Karuthadukkan (71.14%), Thottacheera (70%) and Vaishak (69.49%) whereas minimum RLWC percentage was observed in Kattamodan (50%), Aathira (52.88%) and Prathyasha (58.27%) under moisture stress condition. Percentage decrease in RLWC due to moisture stress was less pronounced in Arimodan, Chuvanna Modan, Karutha Modan and Uma.

4.9.3 Proline Content (mg/g)

Proline content increased significantly under drought condition. Proline content was the highest in variety Harsha (0.64mg/g) followed by Vaishak (0.57mg/g) and Kattamodan (0.53mg/g) whereas minimum in Vyttila 2 (0.23mg/g) and Vyttila 6 (0.23mg/g) under control (Table 38). The varieties Vaishak, Thottacheera, Karuthadukkan (0.90mg/g each) and Kattamodan, Chuvanna Modan and Parambuvattan (0.69mg/g each) recorded high proline content under drought. Increase in proline content was less pronounced in Harsha (8.30%), Karutha Modan (19.44%) and Arimodan (25.45%). The increase was more pronounced in Thottacheera (227.73 %), Karuthadukkan (82.99%) Aathira and Kanakom (75.23%).

4.9.4 Cell Membrane Stability Index (%)

Cell membrane stability index decreased significantly under moisture stress conditions. The variety Jyothi (95.66%) had the highest cell membrane stability index among all the varieties under control condition (Table 39). The varieties Swarnaprabha (95.46%), Thottacheera (95.18%), Arimodan (91.90%), Kanakom (91.76%) and Chuvanna Modan (90.77) also had high indices whereas Kanchana (73.09%) Vyttila 2 (75.11%) and Karutha Modan (76.68%) recorded low cell membrane stability under control. The varieties Swarnaprabha (87.43%), Parambuvattan (86.56%) Karuthadukkan (86.31%) and Thottacheera (84.56%)

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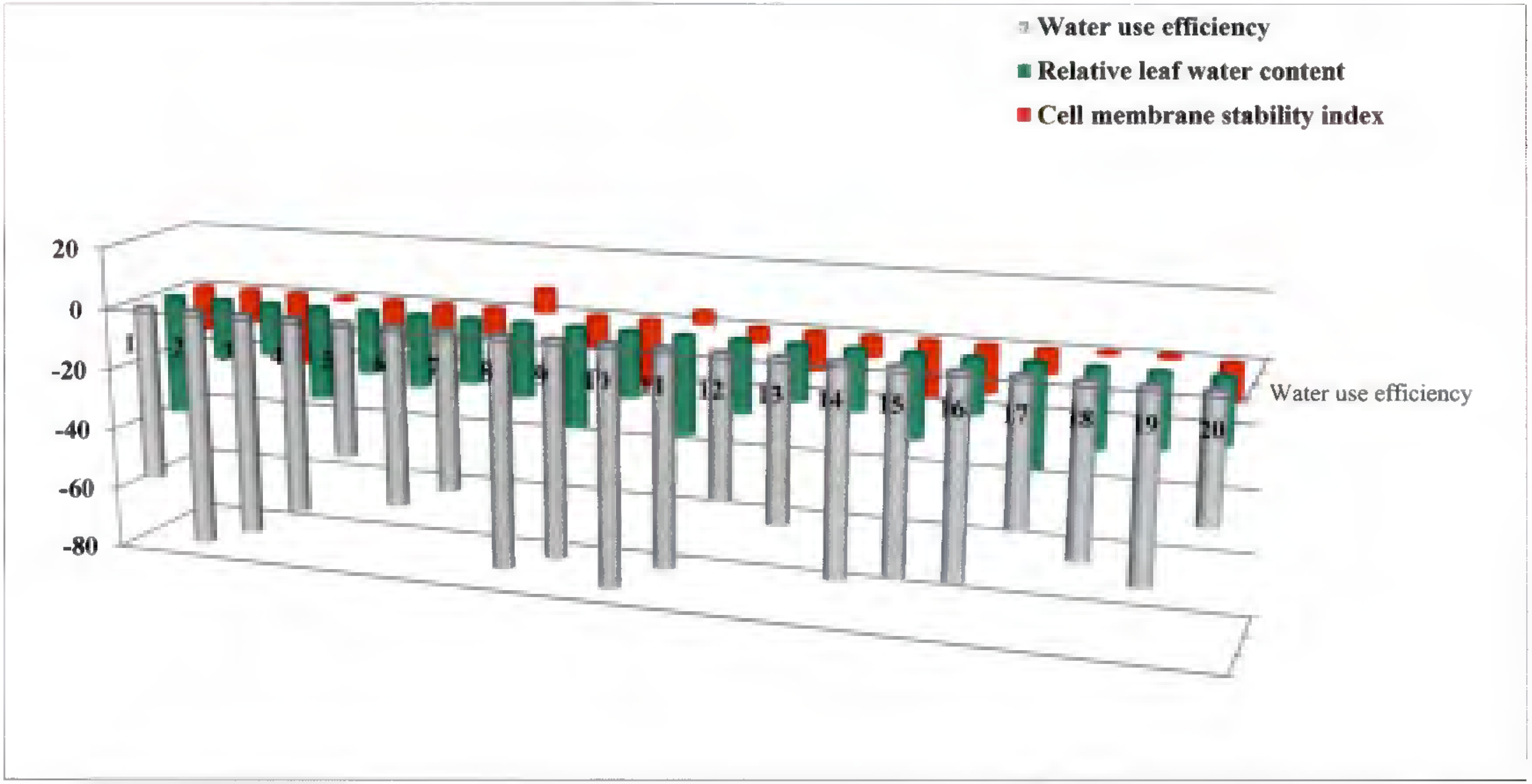


1 .Katta modan
2.Karutha Modan
3.Chuvana modan
4.Vyttila2
5. Vyttila 6
6. Jyothi
7.Swarnaprabha
8. Kanchana
9. Aathira
10. Aiswarya
11. Harsha
12. Vaishak
13. Kanakom
14. Uma
15. Prathyasha
16.Arimodan
17. Kalladiaryan
18. Karuthadukkan
19. Parambuvattan
20. Thottacheera

Fig. 11. Percentage change in osmotic potential traits in rice genotypes imposing reproductive stage moisture stress under protected condition

had high cell membrane stability index under drought condition. Cell membrane stability index was less affected by moisture stress in Karuthadukkan, Parambuvattan, Vyttila 2, Harsha and Vaishak whereas it was greatly affected in Chuvanna Modan, Arimodan and Prathyasha.

4.9.5 Chlorophyll a Content (mg/g)

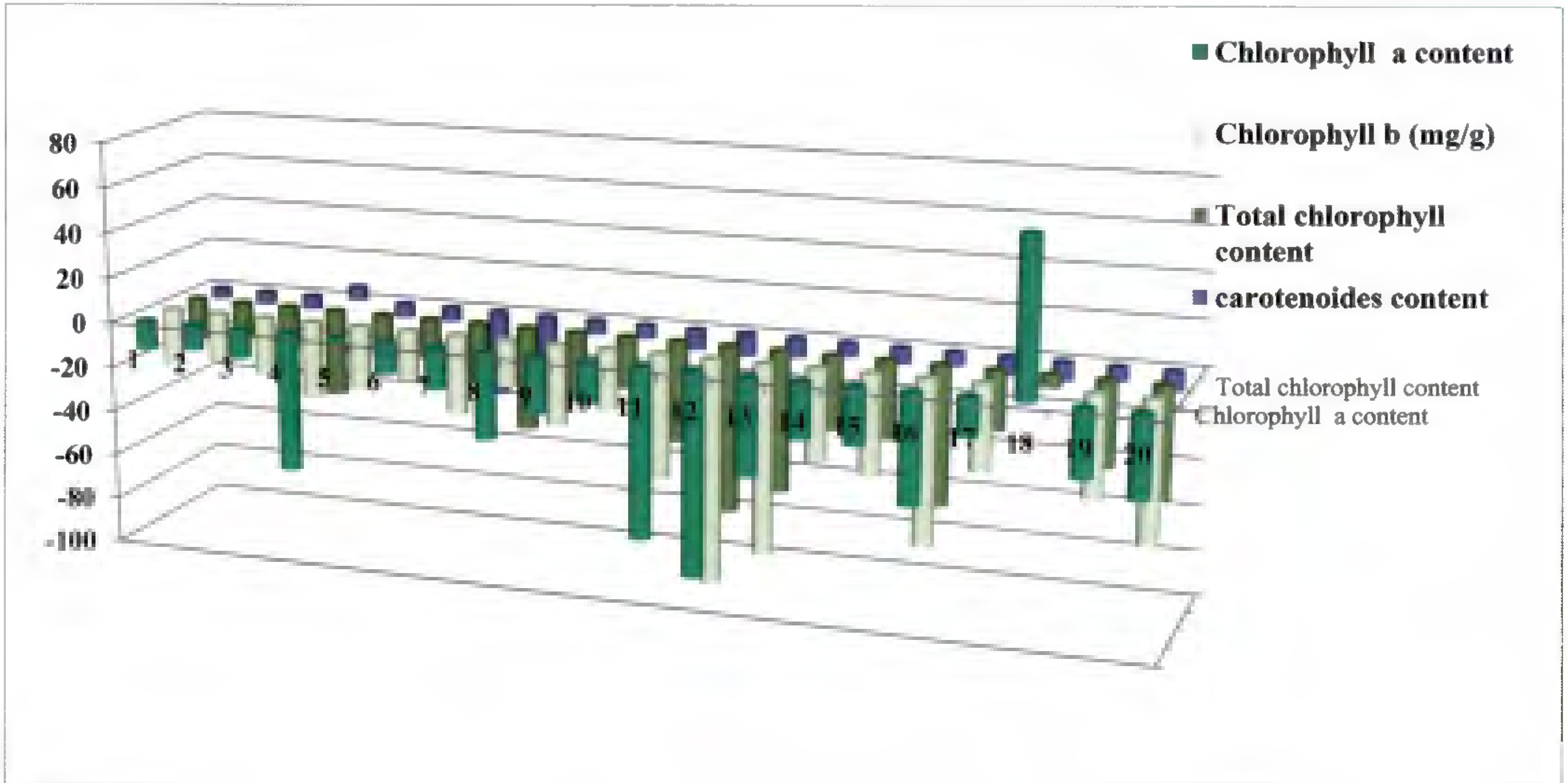
No significant differences were noted for chlorophyll a content under drought as compared to control (Table 40). Karuthadukkan had the highest chlorophyll a content both under control (2.22 mg/g) and imposed moisture stress (3.74 mg/g) whereas the lowest was observed in Arimoodan (0.41mg/g) and Kanakom (0.47mg/g) under control. Karutha Modan (1.58mg/g) and Vyttila 6 (1.47mg/g) had high chlorophyll a content but it was low in Vaishak (0.20mg/g) followed by Arimodan (0.22mg/g) under drought.

4.9.6 Chlorophyll b Content (mg/g)

No significant differences were noted for chlorophyll b content under drought as compared to control. Karuthadukkan had the highest chlorophyll b content both under control (2.22 mg/g) and drought (2.22 mg/g) (Table 41). Highest chlorophyll b was recorded in Karutha Modan (1.68mg/g) and Jyothi (1.68mg/g) whereas lowest chlorophyll b was recorded in the variety Vaishak (0.36mg/g) under control. Highest chlorophyll b content was observed in Chuvanna Modan and Jyothi (1.32mg/g each) and lowest in Vaishak (0.04 mg/g) followed by Kanakom (0.07 mg/g) under drought.

4.9.7 Total Chlorophyll Content (mg/g)

No significant differences were noted for total chlorophyll under drought as compared to control. Karuthadukkan had the highest total chlorophyll content under both control (6.32 mg/g) and drought (5.96 mg/g) (Table 42). Karutha Modan (3.46 mg/g), Jyothi (3.14 mg/g) and Vyttila 6 (3 mg/g) recorded high total chlorophyll content whereas lowest was recorded in Vaishak (0.76 mg/g) under control. Maximum total chlorophyll content was recorded in Karutha Modan



1.Katta modan
2.Karutha Modan
3.Chuvana modan
4.Vyttila2
5. Vyttila 6
6. Jyothi
7.Swarnaprabha
8. Kanchana
9. Aathira
10. Aiswarya
11. Harsha
12. Vaishak
13. Kanakom
14. Uma
15. Prathyasha
16.Arimodan
17. Kalladiaryan
18. Karuthadukkan
19. Parambuvattan
20. Thottacheera

Fig.12. Percentage change for chlorophyll content in rice genotypes imposing reproductive stage moisture stress under protected condition

(2.90mg/g) and minimum was recorded in Vaishak (0.24 mg/g) followed by Kanakom (0.07 mg/g) under drought.

4.9.8 Carotenoides content (mg/g)

No significant differences were noted for carotenoide content under drought as compared to control (Table 43). Carotenoide content was maximum in Arimodan (2.03mg/g) followed by Aiswarya (2.05mg/g), Kattamodan (2.01) and Vyttila 6 (2.01mg/g) under control and Arimodan (1.91mg/g) Kattamodan (1.91 mg/g) and Vyttila 6 (1.89 each) under drought. Lowest carotenide content was recorded in Swarnaprabha (1.24mg/g) under drought whereas Kanchana and Swarnaprabha recorded (0.78mg/g each) the lowest value under imposed moisture stress.

4.9.9 Chlorophyll Stability Index (%)

Details pertaining to chlorophyll stability index are presented in Table 54. Significant differences were noticed for chlorophyll stability index. The highest chlorophyll stability index was recorded in Karuthadukkan (94.33%) followed by Karutha Modan (83.88%), Jyothi (82.16%) and Vyttila 6 (81.25%). The lowest chlorophyll stability index was recorded in Vaishak (26.68%).

4.9.10 Leaf Temperature (^{0}C)

Significant differences were recorded for leaf temperature under drought as compared to control (Table 44). Leaf temperature was maximum in Arimodan (35.60^{0}C) followed by Kalladiaryan (34.93^{0}C) and Parambuvattan (34.37^{0}C) and minimum in Katta Modan (32.27^{0}C) under control. The varieties Parambuvattan (34.63^{0}C) and Arimodan (34.60^{0}C) had maximum leaf temperature whereas Vyttila 2 (29.97^{0}C) had the minimum under drought. This percentage change was highest in Vyttila 2 (9.65%) and lowest in Kanakom (0.20%) followed by Aiswarya (0.69%), Harsha (1.37%) and Vaishak (1.56%) (Table 55).

Table 36. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Water Use Efficiency (WUE) (g/l)

Sl.No.	Variety	Water Use Efficiency (WUE) (g/l)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	0.40	0.95	0.68
2	Karutha Modan (PTB 29)	0.34	1.52	0.93
3	Chuvanna Modan (PTB 30)	0.36	1.32	0.84
4	Vyttila 2	0.51	1.38	0.95
5	Vyttila 6	0.59	1.04	0.82
6	Jyothi (PTB 39)	0.49	1.17	0.83
7	Swarnaprabha (PTB 43)	0.52	1.06	0.79
8	Kanchana (PTB 50)	0.30	1.21	0.76
9	Aathira (PTB 51)	0.22	0.72	0.47
10	Aiswarya (PTB 52)	0.18	0.80	0.49
11	Harsha (PTB 55)	0.39	1.28	0.84
12	Vaishak (PTB 60)	1.29	2.38	1.84
13	Kanakom (MO 11)	0.42	0.86	0.64
14	Uma (MO 16)	0.32	0.95	0.64
15	Prathyasha (MO 21)	0.35	0.97	0.66
16	Arimodan	0.43	1.18	0.81
17	Kalladiaryan	0.75	1.40	1.08
18	Karuthadukkan	0.55	1.18	0.87
19	Parambuvattan	0.45	1.10	0.78
20	Thottacheera	0.81	1.34	1.08
	Average	0.48	1.19	0.84
CD (0.05)	Condition	0.037		
	Variety			0.115
	Condition × Variety interaction	0.163		

Table 37. Effect of imposing reproductive stage moisture stress under protected condition

Trait : Relative Leaf Water Content

Sl.No.	Variety	Relative Leaf Water Content (RLWC) (%)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	50.00	81.54	65.77
2	Karutha Modan (PTB 29)	66.44	82.22	74.33
3	Chuvanna Modan (PTB 30)	66.56	80.00	73.28
4	Vyttila 2	62.33	88.63	75.48
5	Vyttila 6	64.00	80.00	72.00
6	Jyothi (PTB 39)	67.92	88.30	78.11
7	Swarnaprabha (PTB 43)	72.33	90.97	81.65
8	Kanchana (PTB 50)	66.77	87.33	77.05
9	Aathira (PTB 51)	52.88	77.67	65.28
10	Aiswarya (PTB 52)	60.00	75.67	67.84
11	Harsha (PTB 55)	59.00	85.48	72.24
12	Vaishak (PTB 60)	69.49	90.00	79.75
13	Kanakom (MO 11)	66.89	81.00	73.95
14	Uma (MO 16)	66.89	82.67	74.78
15	Prathyasha (MO 21)	58.27	79.00	68.64
16	Arimodan	66.45	80.00	73.23
17	Kalladiaryan	61.18	90.00	75.59
18	Karuthadukkan	71.14	94.21	82.68
19	Parambuvattan	64.24	83.32	73.78
20	Thottacheera	70.00	87.60	78.80
	Average	64.14	84.28	74.21
CD (0.05)	Condition	0.400		
	Variety			1.263
	Condition × Variety interaction	1.787		

Table 38. Effect of imposing reproductive stage moisture stress under protected condition

Trait : Proline Content (mg/g)

Sl.No.	Variety	Proline Content (mg/g)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	0.69	0.53	0.61
2	Karutha Modan (PTB 29)	0.60	0.50	0.55
3	Chuvanna Modan (PTB 30)	0.69	0.50	0.60
4	Vyttila 2	0.36	0.23	0.30
5	Vyttila 6	0.37	0.24	0.31
6	Jyothi (PTB 39)	0.55	0.41	0.48
7	Swarnaprabha (PTB 43)	0.60	0.38	0.49
8	Kanchana (PTB 50)	0.47	0.30	0.39
9	Aathira (PTB 51)	0.39	0.27	0.33
10	Aiswarya (PTB 52)	0.42	0.29	0.36
11	Harsha (PTB 55)	0.69	0.64	0.67
12	Vaishak (PTB 60)	0.90	0.57	0.74
13	Kanakom (MO 11)	0.68	0.39	0.54
14	Uma (MO 16)	0.62	0.41	0.52
15	Prathyasha (MO 21)	0.59	0.35	0.47
16	Arimodan	0.65	0.52	0.59
17	Kalladiaryan	0.69	0.53	0.61
18	Karuthadukkan	0.90	0.49	0.70
19	Parambuvattan	0.69	0.48	0.59
20	Thottacheera	0.90	0.27	0.59
	Average	0.62	0.42	0.52
CD (0.05)	Condition	0.004		
	Variety			0.012
	Condition × Variety interaction	0.017		

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Table 39. Effect of imposing reproductive stage moisture stress under protected condition

Trait : Cell Membrane Stability Index

Sl.No.	Variety	Cell Membrane Stability Index		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	67.78	79.19	73.49
2	Karutha Modan (PTB 29)	68.47	76.68	72.58
3	Chuvanna Modan (PTB 30)	69.60	90.77	80.19
4	Vyttila 2	74.32	75.11	74.72
5	Vyttila 6	80.46	95.22	87.84
6	Jyothi (PTB 39)	81.88	95.66	88.77
7	Swarnaprabha (PTB 43)	87.43	95.46	91.45
8	Kanchana (PTB 50)	78.67	73.09	75.88
9	Aathira (PTB 51)	80.77	89.31	85.04
10	Aiswarya (PTB 52)	71.52	90.30	80.91
11	Harsha (PTB 55)	80.05	77.01	78.53
12	Vaishak (PTB 60)	77.77	81.38	79.58
13	Kanakom (MO 11)	80.92	91.76	86.34
14	Uma (MO 16)	82.45	87.88	85.17
15	Prathyasha (MO 21)	74.33	89.61	81.97
16	Arimodan	78.62	91.90	85.26
17	Kalladiaryan	81.52	87.85	84.69
18	Karuthadukkan	86.31	85.89	86.10
19	Parambuvattan	86.56	85.71	86.14
20	Thottacheera	84.54	95.18	89.86
	Average	78.70	86.75	82.72
CD (0.05)	Condition	0.339		
	Variety			1.074
	Condition × Variety interaction	1.518		

Table 40. Effect of imposing reproductive stage moisture stress under protected condition

Trait : Chlorophyll a Content(mg/g)

		Chlorophyll a (mg/g) Content		
Sl.No.	Variety	Stress	Normal	Mean
1	Kattamodan (PTB28)	1.33	1.53	1.43
2	Karutha Modan (PTB 29)	1.58	1.78	1.68
3	Chuvanna Modan (PTB 30)	1.33	1.53	1.43
4	Vyttila 2	0.59	1.52	1.055
5	Vyttila 6	1.47	1.48	1.475
6	Jyothi (PTB 39)	1.26	1.45	1.355
7	Swarnaprabha (PTB 43)	0.88	1.08	0.98
8	Kanchana (PTB 50)	0.67	1.08	0.875
9	Aathira (PTB 51)	0.61	0.81	0.71
10	Aiswarya (PTB 52)	0.91	1.1	1.005
11	Harsha (PTB 55)	0.4	1.57	0.985
12	Vaishak (PTB 60)	0.2	1.82	1.01
13	Kanakom (MO 11)	0.27	0.47	0.37
14	Uma (MO 16)	0.62	0.81	0.715
15	Prathyasha (MO 21)	0.6	0.8	0.70
16	Arimodan	0.22	0.41	0.315
17	Kalladiaryan	0.98	1.18	1.080
18	Karuthadukkan	3.74	2.22	2.980
19	Parambuvattan	0.48	0.67	0.575
20	Thottacheera	0.36	0.56	0.460
	Average	0.925	1.1935	1.05925
CD (0.05)	Condition	0.029		
	Variety			0.093
	Condition × Variety interaction	1.132		

Table 41. Effect of imposing reproductive stage moisture stress under protected condition

Trait : Chlorophyll b Content(mg/g)

Sl.No.	Variety	Chlorophyll b Content(mg/g)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	1.05	1.41	1.23
2	Karutha Modan (PTB 29)	1.32	1.68	1.5
3	Chuvanna Modan (PTB 30)	1.06	1.42	1.24
4	Vyttila 2	0.71	1.07	0.89
5	Vyttila 6	1.09	1.52	1.305
6	Jyothi (PTB 39)	1.32	1.68	1.5
7	Swarnaprabha (PTB 43)	0.67	1.03	0.85
8	Kanchana (PTB 50)	0.67	0.84	0.755
9	Aathira (PTB 51)	0.65	1.01	0.83
10	Aiswarya (PTB 52)	0.99	1.35	1.17
11	Harsha (PTB 55)	0.30	0.66	0.48
12	Vaishak (PTB 60)	0.10	0.36	0.23
13	Kanakom (MO 11)	0.07	0.43	0.25
14	Uma (MO 16)	0.54	0.9	0.72
15	Prathyasha (MO 21)	0.46	0.82	0.64
16	Arimodan	0.14	0.5	0.32
17	Kalladiaryan	0.6	0.96	0.78
18	Karuthadukkan	2.22	2.22	2.22
19	Parambuvattan	0.46	0.82	0.64
20	Thottacheera	0.23	0.59	0.41
	Average	0.7275	1.0635	0.8955
CD(0.05)	Condition	0.023		
	Variety			0.072
	Condition × Variety interaction	0.102		

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Table 42. Effect of imposing reproductive stage moisture stress under protected condition
Trait : Total Chlorophyll Content (a+b) (mg/g)

Sl.No.	Variety	Total Chlorophyll Content (a+b) (mg/g)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	2.39	2.95	2.67
2	Karutha Modan (PTB 29)	2.9	3.46	3.18
3	Chuvanna Modan (PTB 30)	2.39	2.95	2.67
4	Vyttila 2	1.3	2.11	1.705
5	Vyttila 6	2.44	3.00	2.72
6	Jyothi (PTB 39)	2.58	3.14	2.86
7	Swarnaprabha (PTB 43)	1.55	2.11	1.83
8	Kanchana (PTB 50)	1.15	2.11	1.63
9	Aathira (PTB 51)	1.26	1.82	1.54
10	Aiswarya (PTB 52)	1.9	2.46	2.18
11	Harsha (PTB 55)	0.69	1.25	0.97
12	Vaishak (PTB 60)	0.2	0.76	0.48
13	Kanakom (MO 11)	0.34	0.9	0.62
14	Uma (MO 16)	1.15	1.71	1.43
15	Prathyasha (MO 21)	1.07	1.62	1.345
16	Arimodan	0.36	0.91	0.635
17	Kalladiaryan	1.58	2.13	1.855
18	Karuthadukkan	5.96	6.32	6.14
19	Parambuvattan	0.94	1.49	1.215
20	Thottacheera	0.58	1.14	0.86
	Average	1.6365	2.217	1.92675
CD(0.05)	Condition	0.048		
	Variety			0.152
	Condition × Variety interaction	N.S.		

Table 43. Effect of imposing reproductive stage moisture stress under protected condition

Trait : Carotenoides Content(mg/g)

Sl.No.	Variety	Carotenoides Content (mg/g)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	1.91	2.01	1.96
2	Karutha Modan (PTB 29)	1.86	1.97	1.915
3	Chuvanna Modan (PTB 30)	1.82	1.93	1.875
4	Vyttila 2	1.86	1.98	1.92
5	Vyttila 6	1.89	2.01	1.95
6	Jyothi (PTB 39)	1.87	1.99	1.93
7	Swarnaprabha (PTB 43)	0.78	1.24	1.01
8	Kanchana (PTB 50)	0.78	1.29	1.035
9	Aathira (PTB 51)	1.87	1.99	1.93
10	Aiswarya (PTB 52)	1.93	2.05	1.99
11	Harsha (PTB 55)	1.24	1.36	1.3
12	Vaishak (PTB 60)	1.13	1.25	1.19
13	Kanakom (MO 11)	1.33	1.45	1.39
14	Uma (MO 16)	1.88	2	1.94
15	Prathyasha (MO 21)	1.61	1.73	1.67
16	Arimodan	1.91	2.03	1.97
17	Kalladiaryan	1.44	1.56	1.5
18	Karuthadukkan	1.34	1.46	1.4
19	Parambuvattan	1.84	1.96	1.9
20	Thottacheera	1.34	1.46	1.4
	Average	1.581	1.73	1.658
CD(0.05)	Condition	0.074		
	Variety			0.233
	Condition × Variety interaction	N.S.		

Table 44. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Leaf Temperature (^{O}C)

Sl.No.	Variety	Leaf Temperature (^{O}C)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	31.43	32.47	31.95
2	Karutha Modan (PTB 29)	31.2	33.17	32.18
3	Chuvanna Modan (PTB 30)	31.27	31.93	31.60
4	Vyttila 2	29.97	33.10	31.53
5	Vyttila 6	31.17	32.27	31.72
6	Jyothi (PTB 39)	31.33	33.67	32.50
7	Swarnaprabha (PTB 43)	31.53	33.57	32.55
8	Kanchana (PTB 50)	32.77	33.67	33.22
9	Aathira (PTB 51)	31.63	33.10	32.36
10	Aiswarya (PTB 52)	33.47	33.70	33.58
11	Harsha (PTB 55)	33.57	34.03	33.80
12	Vaishak (PTB 60)	33.47	34.00	33.73
13	Kanakom (MO 11)	34.07	34.13	34.10
14	Uma (MO 16)	32.9	33.80	33.35
15	Prathyasha (MO 21)	32.63	33.77	33.20
16	Arimodan	34.6	35.6	35.10
17	Kalladiaryan	34.17	34.93	34.55
18	Karuthadukkan	32.7	33.70	33.20
19	Parambuvattan	34.63	34.370	34.50
20	Thottacheera	33.07	33.57	33.32
	Average	32.579	33.627	33.10
CD(0.05)	Condition	0.194		
	Variety			0.613
	Condition × Variety interaction	0.866		

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Table 45. Effect of imposing reproductive stage moisture stress under protected condition

Trait : Transpiration Rate (mmol $m^{-2} s^{-1}$)

Sl.No.	Variety	Transpiration Rate mmol $m^{-2} s^{-1}$		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	0.82	1.03	0.93
2	Karutha Modan (PTB 29)	0.43	0.83	0.63
3	Chuvanna Modan (PTB 30)	0.38	0.69	0.54
4	Vyttila 2	0.53	0.80	0.67
5	Vyttila 6	1.63	2.13	1.88
6	Jyothi (PTB 39)	1.1	1.46	1.28
7	Swarnaprabha (PTB 43)	0.72	0.81	0.77
8	Kanchana (PTB 50)	0.86	1.25	1.06
9	Aathira (PTB 51)	0.80	1.14	0.97
10	Aiswarya (PTB 52)	0.32	0.62	0.47
11	Harsha (PTB 55)	0.53	1.53	1.03
12	Vaishak (PTB 60)	0.95	1.33	1.14
13	Kanakom (MO 11)	1.01	1.30	1.16
14	Uma (MO 16)	0.85	1.15	1.00
15	Prathyasha (MO 21)	1.25	1.53	1.39
16	Arimodan	1.60	2.00	1.80
17	Kalladiaryan	1.12	1.30	1.21
18	Karuthadukkan	0.43	0.92	0.68
19	Parambuvattan	0.62	1.37	1.00
20	Thottacheera	0.45	1.10	0.78
	Average	0.82	1.21	1.019
CD (0.05)	Condition	0.014		
	Variety			0.044
	Condition × Variety interaction	0.063		

Table 46. Effect of imposing reproductive stage moisture stress under protected condition

Trait : Stomatal Conductance (SC) mmol mol^{-2} s^{-1}

Sl.No.	Variety	Stomatal Conductance (SC) mmol mol^{-2} s^{-1}		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	44.43	88.17	66.30
2	Karutha Modan (PTB 29)	34.00	82.06	58.03
3	Chuvanna Modan (PTB 30)	39.83	73.60	56.72
4	Vyttila 2	151.90	176.57	164.24
5	Vyttila 6	158.27	211.23	184.75
6	Jyothi (PTB 39)	120.60	168.11	144.36
7	Swarnaprabha (PTB 43)	34.97	70.58	52.78
8	Kanchana (PTB 50)	80.03	138.38	109.21
9	Aathira (PTB 51)	40.67	54.00	47.34
10	Aiswarya (PTB 52)	19.83	41.12	30.48
11	Harsha (PTB 55)	85.67	213.08	149.38
12	Vaishak (PTB 60)	66.70	93.93	80.32
13	Kanakom (MO 11)	68.17	87.73	77.95
14	Uma (MO 16)	52.60	71.25	61.93
15	Prathyasha (MO 21)	84.47	103.45	93.96
16	Arimodan	63.33	74.27	68.80
17	Kalladiaryan	64.80	73.20	69.00
18	Karuthadukkan	25.50	52.33	38.92
19	Parambuvattan	40.57	92.00	66.29
20	Thottacheera	27.97	48.17	38.07
	Average	65.22	100.66	82.94
CD.(0.05)	Condition	0.525		
	Variety			1.659
	Condition × Variety interaction	2.346		

Table 47. Effect of imposing reproductive stage moisture stress under protected condition

Trait : Chlorophyll Meter Reading (SPAD)

Sl.No.	Variety	Chlorophyll Meter Reading (SPAD)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	36.93	41.13	39.03
2	Karutha Modan (PTB 29)	38.03	40.97	39.50
3	Chuvanna Modan (PTB 30)	38.93	39.47	39.20
4	Vyttila 2	29.60	31.90	30.75
5	Vyttila 6	32.20	34.70	33.45
6	Jyothi (PTB 39)	35.60	37.30	36.45
7	Swarnaprabha (PTB 43)	39.00	39.47	39.23
8	Kanchana (PTB 50)	36.00	38.20	37.10
9	Aathira (PTB 51)	37.00	42.30	39.65
10	Aiswarya (PTB 52)	39.00	41.70	40.35
11	Harsha (PTB 55)	34.13	35.60	34.87
12	Vaishak (PTB 60)	37.10	40.00	38.55
13	Kanakom (MO 11)	32.33	34.57	33.45
14	Uma (MO 16)	54.33	60.60	57.47
15	Prathyasha (MO 21)	34.80	40.27	37.53
16	Arimodan	38.93	39.73	39.33
17	Kalladiaryan	40.00	42.57	41.28
18	Karuthadukkan	35.00	37.57	36.28
19	Parambuvattan	36.00	38.70	37.35
20	Thottacheera	36.93	39.10	38.02
	Average	37.09	39.79	38.44
CD (0.05)	Condition	0.177		
	Variety			0.560
	Condition × Variety interaction	0.792		

Table 48. Effect of imposing reproductive stage moisture stress under protected condition

Trait : Leaf Soluble Protein Content(mg/g)

Sl.No.	Variety	Leaf Soluble Protein Content(mg/g)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	17.92	17.86	17.89
2	Karutha Modan (PTB 29)	13.19	17.18	15.185
3	Chuvanna Modan (PTB 30)	11.84	15.63	13.735
4	Vyttila 2	11.80	18.5	15.15
5	Vyttila 6	11.60	14.32	12.96
6	Jyothi (PTB 39)	12.87	13.61	13.24
7	Swarnaprabha (PTB 43)	12.29	15.26	13.775
8	Kanchana (PTB 50)	9.32	19.89	14.605
9	Aathira (PTB 51)	8.70	16.18	12.44
10	Aiswarya (PTB 52)	11.54	14.73	13.135
11	Harsha (PTB 55)	14.31	18.44	16.375
12	Vaishak (PTB 60)	13.19	13.62	13.405
13	Kanakom (MO 11)	13.08	18.22	15.65
14	Uma (MO 16)	12.32	15.42	13.87
15	Prathyasha (MO 21)	13.27	11.73	12.50
16	Arimodan	9.55	11.30	10.42
17	Kalladiaryan	12.82	13.06	12.94
18	Karuthadukkan	13.24	12.47	12.855
19	Parambuvattan	9.64	9.95	9.795
20	Thottacheera	13.93	17.31	15.62
	Average	12.321	15.234	13.7775
CD (0.05)	Condition	1.701		
	Variety			N.S.
	Condition × Variety interaction	N.S.		

Table 49. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Radiation Use Efficiency MJ/g

Sl.No.	Variety	Radiation Use Efficiency MJ/g		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	0.970	1.994	1.483
2	Karutha Modan (PTB 29)	1.085	3.645	2.365
3	Chuvanna Modan (PTB 30)	2.070	4.781	3.430
4	Vyttila 2	2.650	5.681	4.168
5	Vyttila 6	1.540	2.516	2.028
6	Jyothi (PTB 39)	1.130	2.535	1.833
7	Swarnaprabha (PTB 43)	0.960	1.618	1.289
8	Kanchana (PTB 50)	0.255	0.960	0.608
9	Aathira (PTB 51)	0.551	1.617	1.084
10	Aiswarya (PTB 52)	1.547	5.446	3.496
11	Harsha (PTB 55)	1.158	3.398	2.278
12	Vaishak (PTB 60)	0.502	1.003	0.753
13	Kanakom (MO 11)	0.119	0.289	0.204
14	Uma (MO 16)	0.345	0.986	0.665
15	Prathyasha (MO 21)	0.370	1.053	0.711
16	Arimodan	2.797	5.650	4.224
17	Kalladiaryan	2.584	4.021	3.302
18	Karuthadukkan	1.292	2.600	1.946
19	Parambuvattan	0.402	1.024	0.713
20	Thottacheera	2.239	2.923	2.581
	Average	1.229	2.687	1.958
CD(0.05)	Condition	0.1204		
	Variety			0.3808
	Condition × Variety interaction	0.5386		

Table 50. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Leaf Area Index

Sl.No.	Variety	Leaf Area Index		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	1.63	2.73	2.18
2	Karutha Modan (PTB 29)	1.52	2.33	1.93
3	Chuvanna Modan (PTB 30)	0.89	1.32	1.11
4	Vyttila 2	0.77	1.10	0.94
5	Vyttila 6	2.02	2.88	2.45
6	Jyothi (PTB 39)	1.29	2.72	2.01
7	Swarnaprabha (PTB 43)	0.69	1.30	0.99
8	Kanchana (PTB 50)	5.82	8.63	7.22
9	Aathira (PTB 51)	0.55	1.09	0.82
10	Aiswarya (PTB 52)	0.35	0.73	0.54
11	Harsha (PTB 55)	1.18	1.85	1.51
12	Vaishak (PTB 60)	1.49	1.86	1.67
13	Kanakom (MO 11)	1.32	2.05	1.68
14	Uma (MO 16)	0.67	1.28	0.98
15	Prathyasha (MO 21)	1.01	1.51	1.26
16	Arimodan	0.17	0.65	0.41
17	Kalladiaryan	1.40	2.39	1.90
18	Karuthadukkan	1.58	2.82	2.20
19	Parambuvattan	0.70	1.01	0.85
20	Thottacheera	0.74	1.21	0.97
	Average	1.289	2.073	1.681
CD(0.05)	Condition	0.081		
	Variety			0.256
	Condition × Variety interaction	0.361		

Table 51. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Relative Growth Rate (mg/g/day)

Sl.No.	Variety	Relative Growth Rate (mg/g/day)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	10.06	31.67	20.87
2	Karutha Modan (PTB 29)	10.05	19.81	14.93
3	Chuvanna Modan (PTB 30)	6.14	22.61	14.38
4	Vyttila 2	3.77	30.61	17.19
5	Vyttila 6	7.29	26.21	16.75
6	Jyothi (PTB 39)	2.74	16.03	9.38
7	Swarnaprabha (PTB 43)	4.71	11.03	7.87
8	Kanchana (PTB 50)	6.31	18.23	12.27
9	Aathira (PTB 51)	10.61	7.15	8.88
10	Aiswarya (PTB 52)	4.55	5.30	4.92
11	Harsha (PTB 55)	10.76	10.79	10.77
12	Vaishak (PTB 60)	7.29	20.29	13.79
13	Kanakom (MO 11)	7.69	6.09	6.89
14	Uma (MO 16)	9.14	17.15	13.14
15	Prathyasha (MO 21)	3.09	14.30	8.70
16	Arimodan	5.71	18.91	12.31
17	Kalladiaryan	7.01	20.97	13.99
18	Karuthadukkan	3.88	11.82	7.85
19	Parambuvattan	6.88	5.55	6.22
20	Thottacheera	8.49	10.20	9.35
	Average	6.81	16.24	11.52
CD(0.05)	Condition	0.423		
	Variety			1.338
	Condition × Variety interaction	1.893		

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Table 52. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Net Assimilation Rate (g/m^2/day)

Sl.No.	Variety	Net Assimilation Rate (g/m^2/day)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	0.65	1.62	1.14
2	Karutha Modan (PTB 29)	1.08	3.75	2.42
3	Chuvanna Modan (PTB 30)	3.71	5.35	4.53
4	Vyttila 2	2.71	9.96	6.33
5	Vyttila 6	1.00	1.83	1.41
6	Jyothi (PTB 39)	2.46	2.85	2.65
7	Swarnaprabha (PTB 43)	2.48	3.97	3.23
8	Kanchana (PTB 50)	0.37	0.73	0.55
9	Aathira (PTB 51)	2.15	2.65	2.40
10	Aiswarya (PTB 52)	2.79	1.91	2.35
11	Harsha (PTB 55)	1.55	4.89	3.22
12	Vaishak (PTB 60)	5.60	12.57	9.08
13	Kanakom (MO 11)	1.06	1.34	1.20
14	Uma (MO 16)	8.93	2.38	5.66
15	Prathyasha (MO 21)	3.18	5.10	4.14
16	Arimodan	17.56	5.26	11.41
17	Kalladiaryan	2.35	6.44	4.39
18	Karuthadukkan	0.66	3.60	2.13
19	Parambuvattan	2.59	6.20	4.40
20	Thottacheera	5.78	6.68	6.23
	Average	3.43	4.45	3.94
CD (0.05)	Condition	0.177		
	Variety			0.559
	Condition × Variety interaction	0.791		

Table 53. Effect of imposing reproductive stage moisture stress under protected condition

Trait : Carbon Isotope Discrimination (Per mil)

Sl.No.	Variety	Carbon Isotope Discrimination (per mil)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	23.00	22.81	22.91
2	Karutha Modan (PTB 29)	23.99	23.51	23.75
3	Chuvanna Modan (PTB 30)	24.12	23.69	23.91
4	Vyttila 2	24.73	24.92	24.83
5	Vyttila 6	24.98	23.18	24.08
6	Jyothi (PTB 39)	22.20	24.16	23.18
7	Swarnaprabha (PTB 43)	23.83	23.59	23.71
8	Kanchana (PTB 50)	24.09	22.53	23.31
9	Aathira (PTB 51)	23.50	22.37	22.94
10	Aiswarya (PTB 52)	23.12	23.86	23.49
11	Harsha (PTB 55)	24.33	22.98	23.66
12	Vaishak (PTB 60)	19.15	22.46	20.81
13	Kanakom (MO 11)	21.90	22.57	22.24
14	Uma (MO 16)	23.89	22.84	23.37
15	Prathyasha (MO 21)	22.77	24.78	23.78
16	Arimodan	23.55	25.08	24.32
17	Kalladiaryan	25.23	24.89	25.06
18	Karuthadukkan	23.86	24.12	23.99
19	Parambuvattan	23.03	22.95	22.99
20	Thottacheera	22.93	22.58	22.76
	Average	23.41	23.49	23.45
CD (0.05)	Condition	NS		
	Variety			0.736
	Condition × Variety interaction	1.041		

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4.9.11 Transpiration Rate (mmoles$H_2O/m^2/sec$)

Significant reduction was registered for transpiration rate under drought as compared to control (Table 45). All the varieties showed significant differences due to water stress. Transpiration rate was the highest in Vyttila 6 (2.133) followed by Arimodan (2.00) Harsha (1.533) and Prathyasha (1.530) under control. It was the lowest in Aiswarya (0.620) under control. The varieties Vyttila 6 (1.63), Prathyasha (1.60) and Kalladiaryan (1.12) had high transpiration rates whereas Aiswarya (0.32) had the lowest under drought. Percentage decrease in transpiration rate due to moisture stress was less pronounced in Swarnaprabha (10.70%), Kalladiaryan (14.29%) and Prathyasha (18.52%).

4.9.12 Stomatal Conductance (SC) (mmoles$H_2O/m^2/sec$)

High significant reduction was registered for stomatal conductance under drought as compared to control (Table 46). All varieties expressed significant differences under drought. Stomatal conductance was the highest in Harsha (213.08) followed by Vyttila 6 (211.23) and Vyttila 2 (176.53) and the lowest in Aiswarya (41.12) under control. The varieties Vyttila 6 (158.27), Vyttila 2 (151.90), and Jyothi (120.60) had high stomatal conductance whereas Aiswarya (19.83) had low stomatal conductance under drought. Percentage decrease in stomatal conductance due to moisture stress was less pronounced in Kalladiaryan (-11.48%) Vyttila 2 (-13.97%) and Prathyasha (-18.35%).

4.9.13 Leaf Soluble Protein Content (mg/g)

No significant differences were noted for leaf soluble protein content under drought as compared to control (Table 48). Leaf soluble protein content was the highest in Kanchana (19.89 mg/g) followed by Vyttila 2 (18.50) and Vaishak (18.44) whereas it was the lowest in Parambuvattan (9.95 mg/g) under control. It was High in Kattamodan (17.92mg/g) and Harsha (14.31 mg/g) and low in Arimodan (9.55mg/g) under drought.

Table 54. Chlorophyll Stability Index and Number of Days Taken for Reaching Critical Stress level under Reproductive stage moisture stress

Sl. No.	Variety	Chlorophyll Stability Index	Number of Days Taken for Reaching Critical Stress Level
1	Kattamodan (PTB28)	81.06	17.67
2	Karutha Modan (PTB29)	83.88	16.00
3	Chuvanna Modan (PTB 30)	81.16	8.67
4	Vyttila 2	69.95	14.00
5	Vyttila 6	81.25	17.33
6	Jyothi (PTB 39)	82.16	19.67
7	Swarnaprabha (PTB 43)	73.57	23.00
8	Kanchana (PTB 50)	54.49	10.00
9	Aathira (PTB 51)	69.28	13.00
10	Aiswarya (PTB 52)	77.29	13.67
11	Harsha (PTB 55)	55.46	11.67
12	Vaishak (PTB 60)	26.68	12.33
13	Kanakom (MO 11)	37.95	21.00
14	Uma (MO 16)	67.40	14.67
15	Prathyasha (MO 21)	65.65	13.00
16	Arimodan	39.02	14.33
17	Kalladiaryan	74.01	11.67
18	Karuthadukkan	94.33	15.33
19	Parambuvattan	62.71	12.33
20	Thottacheera	51.17	12.67
	Average	66.42	14.60
	CD (0.05)	12.24	1.62

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Table 55. Percentage change for physiological and biochemical traits in rice genotype under protected condition in polythene tube with imposing reproductive moisture stress (drought condition)

Sl.No.	Name of variety/Traits	Water Use Efficiency (WUE) (g/l)	Relative Leaf Water Content (RLWC) (%)	Proline Content (mg/g)	Cell Membrane Stability Index	Chlorophyll a (mg/g)	Chlorophyll b (mg/g)	Total Chlorophyll Content (a+b) (mg/g)	Carotenoides Content (mg/g)	Leaf Temperature (OC)	Transpiration Rate (TR)
1	Kattamodan (PTB28)	-57.31	-38.68	31.40	-14.40	-12.91	-25.48	-18.94	-4.75	-3.18	-20.97
2	Karutha Modan (PTB 29)	-77.60	-19.19	19.44	-10.70	-11.12	-21.42	-16.12	-5.45	-5.93	-48.80
3	Chuvanna Modan (PTB 30)	-72.30	-16.81	38.14	-23.32	-12.82	-25.31	-18.84	-6.06	-2.09	-44.98
4	Vyttila 2	-63.32	-29.67	57.14	-1.06	-60.94	-33.86	-38.22	--6.06	-9.47	-33.75
5	Vyttila 6	-43.37	-20.00	58.82	-15.50	-0.92	-28.17	-18.70	-6.05	-3.41	-23.44
6	Jyothi (PTB 39)	-58.05	-23.08	35.59	-14.40	-13.60	-21.46	-17.82	-6.06	-6.93	-24.77
7	Swarnaprabha (PTB 43)	-51.35	-20.49	57.93	-8.41	-18.33	-34.92	-26.43	-37.15	-6.06	-10.70
8	Kanchana (PTB 50)	-75.03	-23.54	58.14	7.63	-38.23	-20.28	-45.44	-39.51	-2.67	-31.56
9	Aathira (PTB 51)	-69.77	-31.92	42.37	-9.56	-24.52	-35.66	-30.72	-6.07	-4.43	-30.52
10	Aiswarya (PTB 52)	-77.48	-20.70	45.16	-20.80	-17.93	-26.60	-22.71	-5.89	-0.69	-48.39
11	Harsha (PTB 55)	-69.35	-30.97	8.30	3.94	-74.72	-54.84	-44.54	-8.87	-1.37	-65.65
12	Vaishak (PTB 60)	-45.68	-22.79	58.94	-4.44	-88.89	-98.81	-73.32	-9.65	-1.57	-28.93
13	Kanakom (MO 11)	-51.54	-17.42	75.23	-11.82	-42.52	-83.27	-62.05	-8.30	-0.20	-22.76
14	Uma (MO 16)	-66.95	-19.09	51.41	-6.18	-24.28	-40.10	-32.60	-6.04	-2.66	-26.30
15	Prathyasha (MO 21)	-64.35	-26.23	68.87	-17.05	-24.64	-43.78	-34.35	-6.97	-3.36	-18.52
16	Arimodan	-63.67	-16.93	25.45	-14.45	-47.77	-71.88	-60.98	-5.94	-2.81	-20.00
17	Kalladiaryan	-46.08	-32.02	30.70	-7.21	-16.49	-37.65	-25.98	-7.73	-2.19	-14.29
18	Karuthadukkan	-53.33	-24.49	82.99	0.50	68.42	0.00	-5.67	-8.23	-2.97	-53.07
19	Parambuvattan	-59.17	-22.91	41.43	0.99	-29.26	-43.90	-37.29	-6.16	0.78	-54.96
20	Thottacheera	-39.35	-20.09	227.73	-11.18	-35.65	-61.27	-48.82	-8.26	-1.49	-58.79

Table 55 (contd.) Percentage change for physiological and biochemical traits in rice genotype under protected condition imposing reproductive stage moistur stress under protected condition

Sl.No.	Name of variety/Traits	Stomatal Conductance (SC)	Leaf Soluble Protein Content(mg/g)	Radiation Use Efficiency	Chlorophyll Meter Reading (SPAD)	Leaf Area Index	Relative Growth Rate(mg/g/day)	Net Assimilation Rate (g/m2/day)	Carbon Isotope Discrimination
1	Kattamodan (PTB28)	-49.60	0.34	-51.21	-10.21	-40.55	-68.23	-60.01	0.87
2	Karutha Modan (PTB 29)	-58.57	-23.24	-70.22	-7.16	-34.90	-49.29	-71.22	2.05
3	Chuvanna Modan (PTB 30)	-45.88	-24.24	-56.50	-1.35	-33.21	-72.82	-30.56	1.81
4	Vyttila 2	-13.97	-36.23	-53.24	-7.21	-30.48	-87.68	-72.82	-0.78
5	Vyttila 6	-25.07	-19.00	-38.77	-7.20	-30.02	-72.20	-45.71	7.76
6	Jyothi (PTB 39)	-28.26	-5.43	-55.42	-4.56	-52.50	-82.94	-13.68	-8.14
7	Swarnaprabha (PTB 43)	-50.46	-19.49	-40.70	-1.18	-46.50	-57.28	-37.55	1.02
8	Kanchana (PTB 50)	-42.16	-53.14	-73.46	-5.76	-32.55	-65.41	-48.91	6.91
9	Aathira (PTB 51)	-24.69	-46.22	-65.92	-12.53	-49.17	--48.44	-19.04	5.08
10	Aiswarya (PTB 52)	-51.77	-21.63	-71.59	-6.47	-52.18	-14.18	-46.44	-3.08
11	Harsha (PTB 55)	-59.80	-22.42	-65.93	-4.12	-36.34	-0.32	-68.41	5.87
12	Vaishak (PTB 60)	-28.99	-3.15	-49.96	-7.25	-19.82	-64.06	-55.42	-14.72
13	Kanakom (MO 11)	-22.30	-28.23	-58.85	-6.46	-35.42	26.32	-20.54	-2.96
14	Uma (MO 16)	-26.18	-20.09	-65.00	-10.34	-48.03	-46.70	-11.42	-4.62
15	Prathyasha (MO 21)	-18.35	13.10	-64.89	-13.58	-33.16	-78.41	-37.62	-8.12
16	Arimodan	-14.73	-15.53	-50.49	-2.01	-73.26	-69.81	-13.95	-6.11
17	Kalladiaryan	-11.48	-1.85	-35.72	-6.03	-41.70	-66.57	-63.54	1.35
18	Karuthadukkan	-51.27	6.16	-50.30	-6.83	-43.92	-67.17	-81.54	1.09
19	Parambuvattan	-55.91	-3.18	-60.74	-6.98	-30.87	23.85	-58.24	0.33
20	Thottacheera	-41.94	-19.50	-23.39	-5.54	-38.63	-16.77	-13.57	1.55

with (-): indicate percentage decrease in mean performance of character under moisture stress

without (-): indicate percentage increase in mean performance of character under moisture stress

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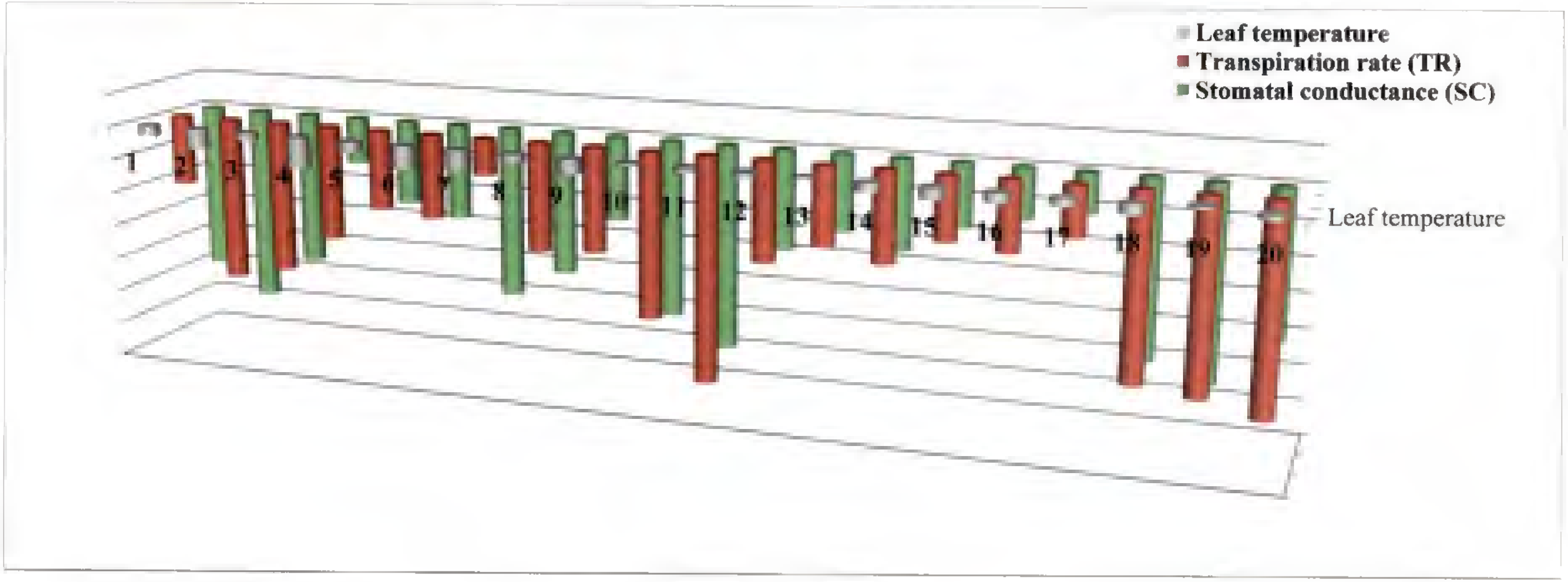
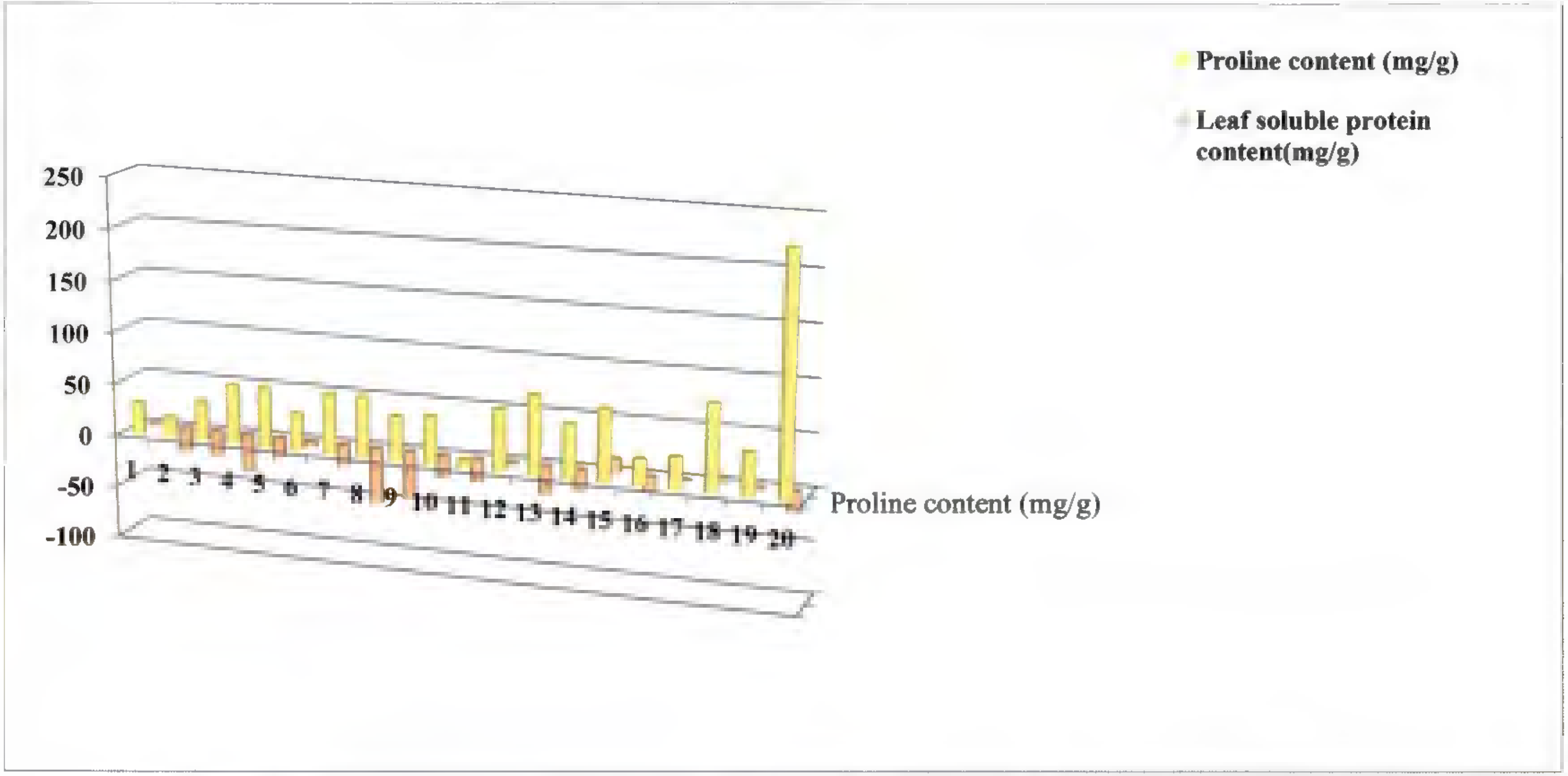


1.Katta modan
2.Karutha Modan
3.Chuvana modan
4.Vyttila2
5. Vyttila 6
6.Jyothi
7.Swarnaprabha
8. Kanchana
9. Aathira
10. Aiswarya
11. Harsha
12. Vaishak
13. Kanakom
14. Uma
15. Prathyasha
16.Arimodan
17. Kalladiaryan
18. Karuthadukkan
19. Parambuvattan
20. Thottacheera

Fig. 13.Percentage change for physiological traits in rice genotypes imposing reproductive stage moisture stress under protected condition



1.Katta modan
2.Karutha Modan
3.Chuvana modan
4.Vyttila2
5. Vyttila 6
6.Jyothi
7.Swarnaprabha
8. Kanchana
9. Aathira
10. Aiswarya
11. Harsha
12. Vaishak
13. Kanakom
14. Uma
15. Prathyasha
16.Arimodan
17. Kalladiaryan
18. Karuthadukkan
19. Parambuvattan
20. Thottacheera

Fig. 14. **Percentage change for biochemical traits in rice genotypes imposing reproductive stage moisture stress under protected condition**

4.9.14 Radiation Use Efficiency

Significant differences were registered for radiation use efficiency under drought as compared to control (Table 49). Highest radiation use efficiency was recorded in the variety Vyttila 2 (5.680) followed by Arimodan (5.6498) whereas it was the lowest in Kanakom (2.889) under control. Maximum RUE it was recorded in Arimodan (0.2797) and minimum values in Kanakom (0.1189) under drought. Percentage decrease in radiation use efficiency due to moisture stress was less pronounced in Thottacheera (23.39%), Kalladiaryan (35.72%) and Vyttila 6 (38.77%) and more pronounced in Kanchana (73.46%) and Aiswarya (71.59%) among the varieties studied.

4.9.15 Chlorophyll Meter Reading

Significant differences were registered for chlorophyll meter reading under drought condition (Table 47). Highest chlorophyll meter reading was recorded in the variety Uma (60.60) followed by Kalladiaryan (42.56) and Aathira (42.30) whereas it was the lowest in Vyttila 2 (31.90) under control. Uma (54.33) had high chlorophyll meter reading under drought and Kanakom (32.33) had low reading under drought. Percentage decrease in chlorophyll meter reading due to moisture stress was less pronounced in Swarnaprabha (1.18%), Chuvanna Modan (1.35%) and Arimodan (2.01%) and more pronounced in Prathyasha (13.58%), Aathira (12.53%) and Uma (10.34%). Local upland varieties showed moderate reduction in chlorophyll meter reading *viz.,* Thottacheera (5.54%), Kalladiaryan (6.03%), Karuthadukkan (6.83%) and Parambuvattan (6.98%).

4.9.16 Leaf Area Index

Significant reduction was noticed in leaf area index under imposed moisture stress (Table 50). Highest leaf area index was recorded in Vyttila 6 (2.884) followed by Karuthadukkan (2.882) and the lowest in Arimodan (0.652) under control. Katta Modan (1.63) had high leaf area index and Arimodan (0.17) had low value under drought. Percentage decrease in leaf area index due to

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moisture stress was less pronounced in Vaishak (19.82%) and more pronounced in Arimodan (73.26%).

4.9.17 Relative Growth Rate (RGR) (mg/g/day)

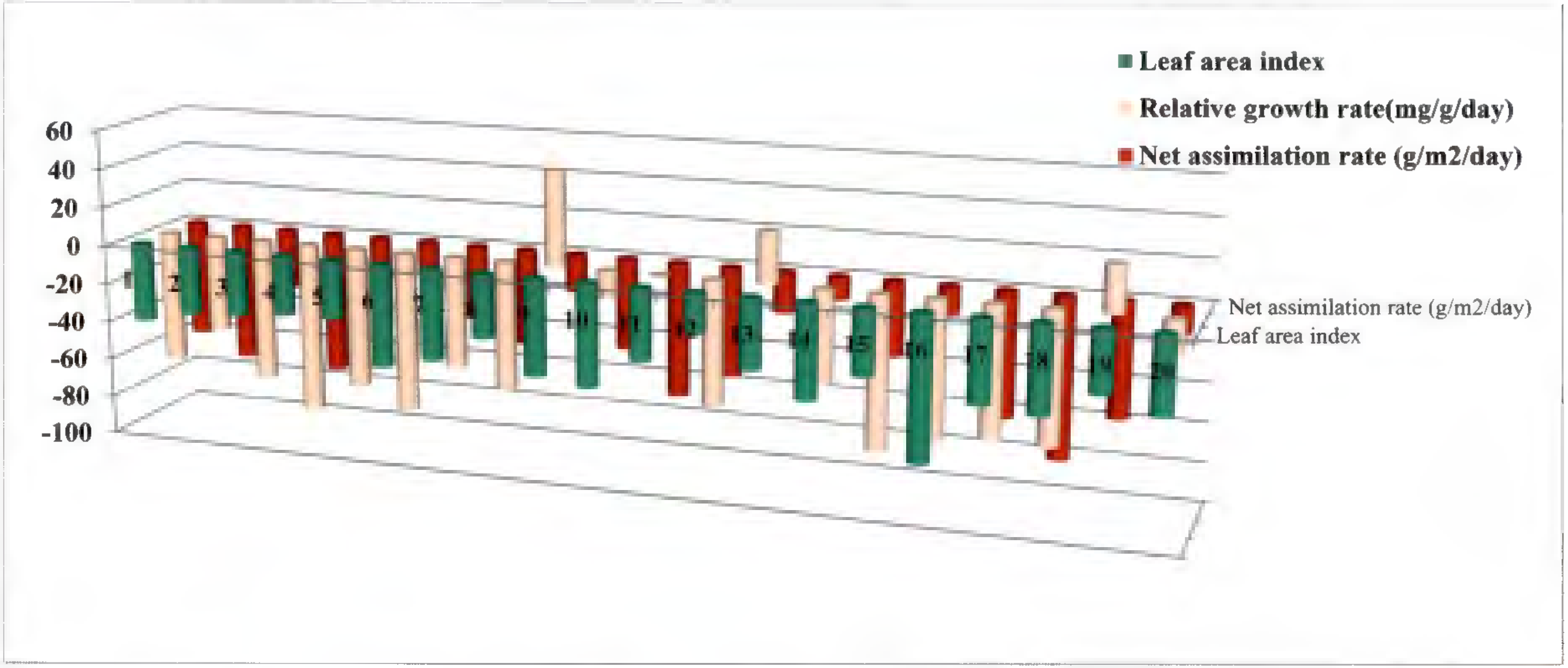
Significant differences were registered for relative growth rate under drought (Table 51). Highest relative growth rate was recorded in Katta Modan (31.67mg/g/day) followed by Vyttila 2 (30.60mg/g/day) and Vyttila 6 (23.208 mg/g/day) and lowest in Aiswarya (5.29mg/g/day) under control (Table 50). The varieties Harsha (10.75mg/g/day), Katta Modan (10.06mg/g/day) and Karutha Modan had high RGR and Prathyasha (3.08 mg/g/day) had low RGR under drought. Percentage decrease in relative growth rate due to moisture stress was less pronounced in Harsha (0.03%) and Aiswarya (PTB 52) (0.85 %) whereas it was more pronounced in Jyothi (13.29). The varieties Aathira, Kanakom and Parambuvattan were not affected by drought in terms of their relative growth from panicle initiation to harvesting stage but conversion of source into sink was low.

4.9.18 Net Assimilation Rate (NAR) (g/cm^2/day)

Significant differences were registered for net assimilation rate under drought condition (Table 52). Highest net assimilation rate was recorded in Vaishak (12.57g/cm^2/day) followed by Vyttila 2 (9.95 g/cm^2/day) and lowest rate was recorded in Kanchana (0.73 g/cm^2/day) under control (Table 51). The variety Uma (8.93 g/cm^2/day) had high NAR and Kanchana (0.37 g/cm^2/day) had low NAR under drought. Percentage decrease in net assimilation rate due to moisture stress was less pronounced in Uma (MO16) (11.42%), Thottacheera (13.57%) and Jyothi (PTB39) (13.68%) whereas it was more pronounced in Karuthadukkan.

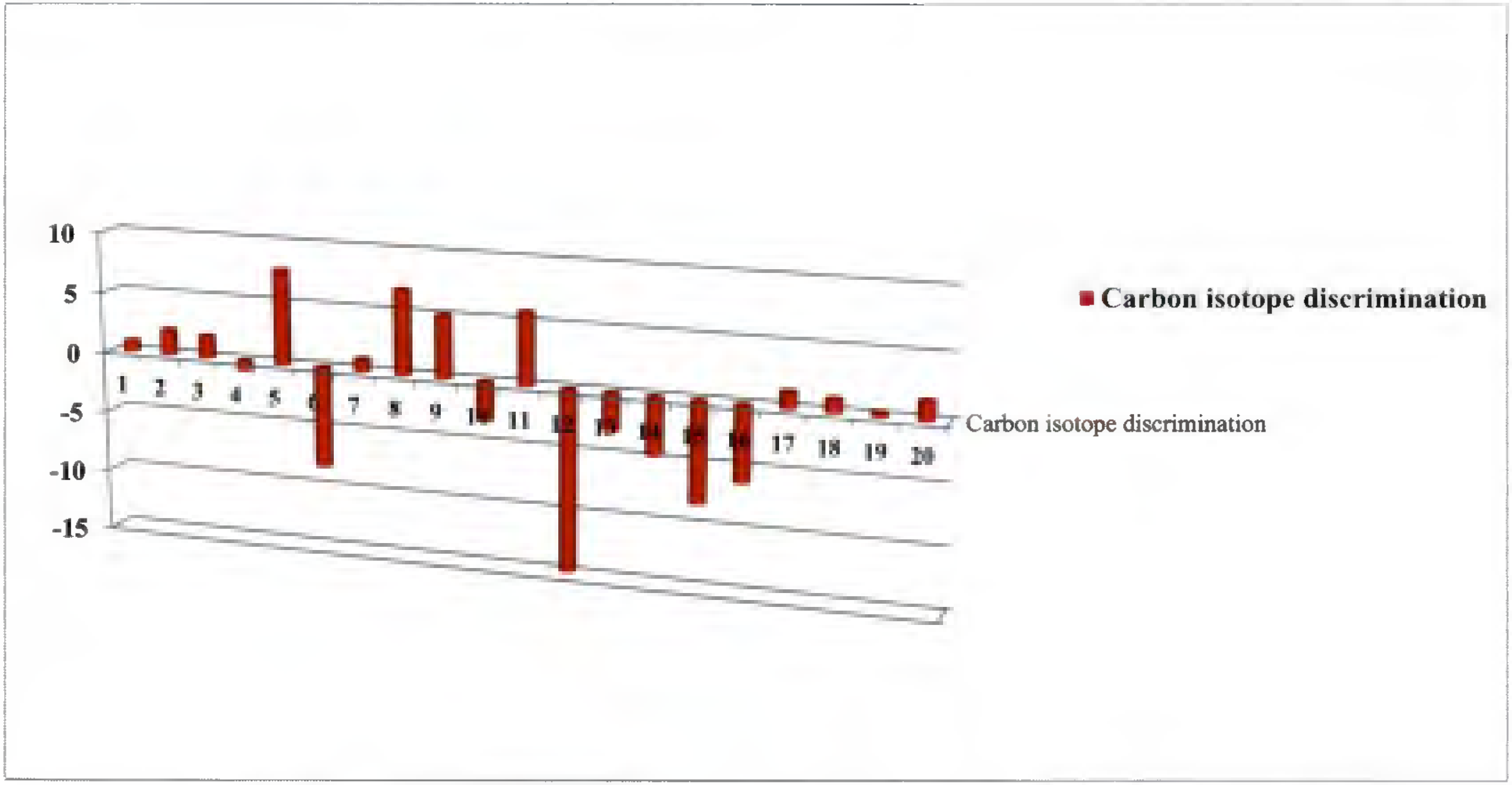
4.9.19 Carbon Isotope Discrimination (per mil)

Significant differences were registered for carbon isotope discrimination under drought condition (Table 53). Lowest carbon isotope discrimination was recorded in Aathira (22.46) followed by Vaishak (22.46), Kanakom (22.57) and Katta Modan (22.81) and highest discrimination was recorded in Arimodan



1.Katta modan
2.Karutha Modan
3.Chuvana Modan
4.Vyttila2
5. Vyttila 6
6.Jyothi
7.Swarnaprabha
8. Kanchana
9. Aathira
10. Aiswarya
11. Harsha
12. Vaishak
13. Kanakom
14. Uma
15. Prathyasha
16.Arimodan
17. Kalladiaryan
18. Karuthadukkan
19. Parambuvattan
20. Thottacheera

Fig. 15. Percentage change for growth indices in rice genotypes imposing reproductive stage moisture stress under protected condition



1.Katta modan
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3.Chuvana modan
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6.Jyothi
7.Swarnaprabha
8. Kanchana
9. Aathira
10. Aiswarya
11. Harsha
12. Vaishak
13. Kanakom
14. Uma
15. Prathyasha
16.Arimodan
17. Kalladiaryan
18. Karuthadukkan
19. Parambuvattan
20. Thottacheera

Fig. 16. Percentage change for carbon isotope discrimination in rice genotypes imposing reproductive stage moisture stress under protected condition

(25.08), Vyttila 2 (24.92) and Kalladiaryan (24.89) under control. The varieties Vaishak (19.15), Kanakom (21.90) and Jyothi (22.20) had relatively low carbon isotope discrimination whereas high discrimination was observed in Kalladiaryan (25.23), Vyttila 6 (24.98) and Vyttila 2 (24.73) under drought. Percentage decrease in carbon isotope discrimination due to moisture stress was less pronounced in Vaishak (14.72%), Jyothi (8.14%), Prathyasha (8.12%), Arimodan (6.11%) and Aiswarya (3.08%).

4.9.20 Number of Days Taken for Reaching Critical Stress Level

Pertinent details are presented in Table 54. The varieties Swarnaprabha (23days), Kanakom (21days) and Jyothi (19.67 days) took maximum days to reach critical stress level whereas Chuvanna Modan (PTB 30) (8.67 days) and Kanchana (10 days) took minimum days to reach critical stress level.

4.10 ANALYSIS OF VARIANCE (FACTOR A, B AND A x B INTERACTION) FOR ROOT CHARACTERS

Analysis of variance (factor A, B and A x B interaction) for root characters is presented in Table 21. The conditions, varieties and condition x varieties interaction were significant for all the root traits *i.e.* root depth (cm), root volume (cc), root dry weight (g), root / shoot ratio (g/g) and deep root/shoot ratio (mg/g).

MEAN PERFORMANCE FOR ROOT TRAITS IN RICE (*Oryza Sativa* L.) UNDER PROTECTED CONDITION

Mean performance for root traits under protected condition imposing reproductive stage moisture stress is presented in Tables 56 to 60. Percentage change in mean values for root traits under imposed moisture stress is presented in Table 61 and in Fig.17.

4.10.1 Root Depth (cm)

Significant differences were registered for root depth under drought as compared to control (Table 56). High root depth was recorded in Swarnaprabha

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(54.33 cm) followed by Arimodan (45.18cm), Vaishak (43.75cm), Uma (42.67cm), and Thottacheera (41.03 cm) and low root depth in Kanakom (30.69cm), Kattamodan (30.73cm) and Jyothi (30.83cm) under control. Swarnaprabha (56.67 cm), Uma (54.33cm), Vaishak (49.33cm) and Thottacheera (45.33cm) had the higher root lengths under drought. The varieties with shorter roots were Jyothi (30.90cm), Kanakom (32.83 cm) and Kattamodan (34cm). Percentage increase in root depth due to moisture stress was more pronounced in Uma (MO 16) (27.33%), Vaishak (12.76%), Karuthadukkan (12.70%), and Harsha (12.65%) whereas it was less pronounced in Jyothi (0.22%) and Swarnaprabha (4.29%).

4.10.2 Root Volume (cc)

Significant variation was observed for root volume under induced drought condition (Table 57). High root volume was recorded in Uma (38.32cc) followed by Harsha (26.17cc) and Arimodan (18.31cc) and low root volume was recorded in Chuvanna Modan (2.11cc), Vyttila 2 (4.13cc), Karuthadukkan (4.45cc) and Aiswarya (5.87cc) under control. Arimodan (18.98cc) Uma (14.94cc), Prathyasha (MO 21) (15.53cc) and Vaishak (13.06cc) had high root volume among the varieties under drought. The varieties in which less root volume was recorded were Chuvannamodan (5.42cc), Vyttila 2, (6.50cc) Karutha Modan (7.54cc), Kanakom (8.09cc) and Jyothi (9.01cc). Percentage increase in root volume due to moisture stress was more pronounced in Chuvanna Modan (157.26%), Karuthadukkan (98.81%) and Prathyasha (56.44%) and less pronounced in Arimodan whereas decrease in root volume was observed in Uma (-61.01%) and Harsha (-54.62%).

4.10.3 Root Dry Weight (g)

Root dry weight showed significant differences under drought (Table 58). Highest root dry weight was recorded in Jyothi (15.84g) followed by Thottacheera (13.14g), Uma (12.33g) Vaishak (10.23g), Prathyasha (7.35g) and Swarnaprabha (7.13g) under control. Lowest root dry weight was recorded in Katta Modan

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(0.49) followed by Vyttila 6 (1.27g), Kanakom (2.89 g), Karuthadukkan, (3.36g), Vyttila 2 (3.69g) and Karutha Modan (4.11g) under control. Uma (16.76g), Jyothi (14.71g), Thottacheera (13.10g) and Vaishak (12.42g) were the varieties having high root dry weight under drought. Katta Modan (0.49g) Vyttila 6 (2.12g), Karuthadukkan (3.37g) and Kanakom (3.64g) were the varieties having low root dry weight under drought. Percentage increase in root dry weight was more pronounced in Vyttila 6 (67.55%) and Chuvanna Modan (61.75%) and less pronounced in Karuthadukkan (0.37%) due to moisture stress at reproductive stage of crop. Higher percentage decrease in root dry weight was observed in Swarnaprabha (-7.64%) and Jyothi (-7.09%) due to moisture stress (Table 61).

4.10.4 Root Shoot Ratio (g/g)

Significant differences were registered for root-shoot ratio under moisture stress condition (Table 59). Highest root-shoot ratio was recorded in Jyothi (0.73) followed by Uma (0.62), Thottacheera (0.56) and Prathyasha (0.38) and lowest root shoot ratio was recorded in Katta Modan (0.03), Vyttila 2 (0.13), Kanakom (0.16) and Karuthadukkan (0.15) under control. The varieties Uma (1.74), Jyothi (1.55), Aiswarya (1.15), Kanchana (1.03) and Parambuvattan (0.86) had high root shoot ratios among the varieties under drought. In the varieties Vyttila 2 (3.78 times) Aiswarya (3.74 times), Chuvanna Modan (PTB 30) (3.44 times), Vyttila 6 (2.85 times) and Karutha Modan (PTB 29) (2.82 times) root shoot ratios were considerably increased by drought whereas the varieties Thottacheera (42.69%) Aathira (69.24%) and Vaishak (PTB 60) (93.80%) were considerably less affected, as is evidenced from the percentage increase for the character.

4.10.5 Deep Root-Shoot Ratio (mg/g)

Significant variations were observed for deep root-shoot ratio under drought condition. Highest deep root shoot ratio was recorded in Uma (176.54) followed by Swarnaprabha (151.30), Thottacheera (145.99) and Prathyasha (86.88) (Table 60).

Table 56. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Root Depth (cm)

Sl.No.	Variety	Root Depth (cm)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	34.00	30.73	32.37
2	Karutha Modan (PTB 29)	43.00	40.65	41.83
3	Chuvanna Modan (PTB 30)	41.00	36.83	38.92
4	Vyttila 2	41.50	36.87	39.19
5	Vyttila 6	41.33	36.99	39.16
6	Jyothi (PTB 39)	30.90	30.83	30.87
7	Swarnaprabha (PTB 43)	56.67	54.33	55.50
8	Kanchana (PTB 50)	44.27	40.74	42.51
9	Aathira (PTB 51)	41.10	37.30	39.20
10	Aiswarya (PTB 52)	42.00	37.43	39.72
11	Harsha (PTB 55)	35.33	31.37	33.35
12	Vaishak (PTB 60)	49.33	43.75	46.54
13	Kanakom (MO 11)	32.83	30.69	31.76
14	Uma (MO 16)	54.33	42.67	48.50
15	Prathyasha (MO 21)	43.67	39.83	41.75
16	Arimodan	44.67	45.18	44.93
17	Kalladiaryan	37.50	34.97	36.24
18	Karuthadukkan	35.50	31.50	33.50
19	Parambuvattan	39.33	35.38	37.36
20	Thottacheera	45.33	41.03	43.18
	Average	41.68	37.95	39.82
CD(0.05)	Condition	0.251	0.251	
	Variety			0.792
	Condition × Variety interaction	1.121	1.121	

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Table 57. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Root Volume (cc)

Sl.No.	Variety	Root Volume (cc)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	9.17	7.07	8.12
2	Karutha Modan (PTB 29)	7.54	8.47	8.005
3	Chuvanna Modan (PTB 30)	5.42	2.11	3.765
4	Vyttila 2	6.5	4.13	5.315
5	Vyttila 6	13.54	10.65	12.095
6	Jyothi (PTB 39)	9.01	16.4	12.705
7	Swarnaprabha (PTB 43)	9.55	8.90	9.225
8	Kanchana (PTB 50)	10.21	8.77	9.49
9	Aathira (PTB 51)	10.8	14.33	12.565
10	Aiswarya (PTB 52)	9.74	5.87	7.805
11	Harsha (PTB 55)	11.88	26.17	19.025
12	Vaishak (PTB 60)	13.06	11.22	12.14
13	Kanakom (MO 11)	8.09	15.14	11.615
14	Uma (MO 16)	14.94	38.32	26.63
15	Prathyasha (MO 21)	15.53	9.93	12.73
16	Arimodan	18.98	18.31	18.645
17	Kalladiaryan	10.06	7.94	9.00
18	Karuthadukkan	8.85	4.45	6.65
19	Parambuvattan	10.81	9.28	10.045
20	Thottacheera	12.62	11.54	12.08
	Average	10.815	11.95	11.3825
CD(0.05)	Condition	0.278	0.278	
	Variety			0.880
	Condition × Variety interaction	1.245	1.245	

Table 58. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Root Dry Weight (g)

Sl.No.	Variety	Root Dry Weight (g)		
		Stress	Normal	Mean
1	Katta Modan (PTB28)	0.49	0.49	0.49
2	Karutha Modan (PTB 29)	5.18	4.11	4.64
3	Chuvanna Modan (PTB 30)	7.15	4.42	5.78
4	Vyttila 2	4.11	3.69	3.90
5	Vyttila 6	2.12	1.27	1.69
6	Jyothi (PTB 39)	14.71	15.84	15.27
7	Swarnaprabha (PTB 43)	6.58	7.13	6.85
8	Kanchana (PTB 50)	7.67	7.05	7.36
9	Aathira (PTB 51)	6.78	5.69	6.23
10	Aiswarya (PTB 52)	5.04	4.02	4.53
11	Harsha (PTB 55)	6.39	5.43	5.91
12	Vaishak (PTB 60)	12.42	10.23	11.32
13	Kanakom (MO 11)	3.64	2.89	3.26
14	Uma (MO 16)	16.76	12.33	14.54
15	Prathyasha (MO 21)	8.54	7.35	7.94
16	Arimodan	5.58	4.13	4.85
17	Kalladiaryan	6.56	4.90	5.73
18	Karuthadukkan	3.37	3.36	3.36
19	Parambuvattan	6.59	5.80	6.19
20	Thottacheera	13.10	13.14	13.12
	Average	7.13	6.1635	6.65
CD(0.05)	Condition	0.239		
	Variety			0.756
	Condition × Variety interaction	1.069		

Table 59. Effect of imposing reproductive stage moisture stress under protected condition

Trait : Root Shoot Ratio (g/g)

Sl.No.	Variety	Root Shoot Ratio (g/g)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	0.11	0.03	0.07
2	Karutha Modan (PTB 29)	0.63	0.17	0.40
3	Chuvanna Modan (PTB 30)	0.81	0.18	0.49
4	Vyttila 2	0.63	0.13	0.38
5	Vyttila 6	0.24	0.06	0.15
6	Jyothi (PTB 39)	1.55	0.73	1.14
7	Swarnaprabha (PTB 43)	0.52	0.35	0.43
8	Kanchana (PTB 50)	1.03	0.31	0.67
9	Aathira (PTB 51)	0.63	0.37	0.50
10	Aiswarya (PTB 52)	1.15	0.24	0.69
11	Harsha (PTB 55)	0.89	0.24	0.56
12	Vaishak (PTB 60)	0.45	0.23	0.34
13	Kanakom (MO 11)	0.35	0.16	0.25
14	Uma (MO 16)	1.74	0.62	1.18
15	Prathyasha (MO 21)	0.78	0.38	0.58
16	Arimodan	0.62	0.20	0.41
17	Kalladiaryan	0.56	0.20	0.38
18	Karuthadukkan	0.30	0.15	0.22
19	Parambuvattan	0.86	0.28	0.57
20	Thottacheera	0.8	0.56	0.68
	Average	0.7325	0.2795	0.50
CD(0.05)	Condition	0.025		
	Variety			0.078
	Condition × Variety interaction	0.110		

Table 60. Effect of imposing reproductive stage moisture stress under protected condition

Trait: Deep Root Shoot Ratio (mg/g)

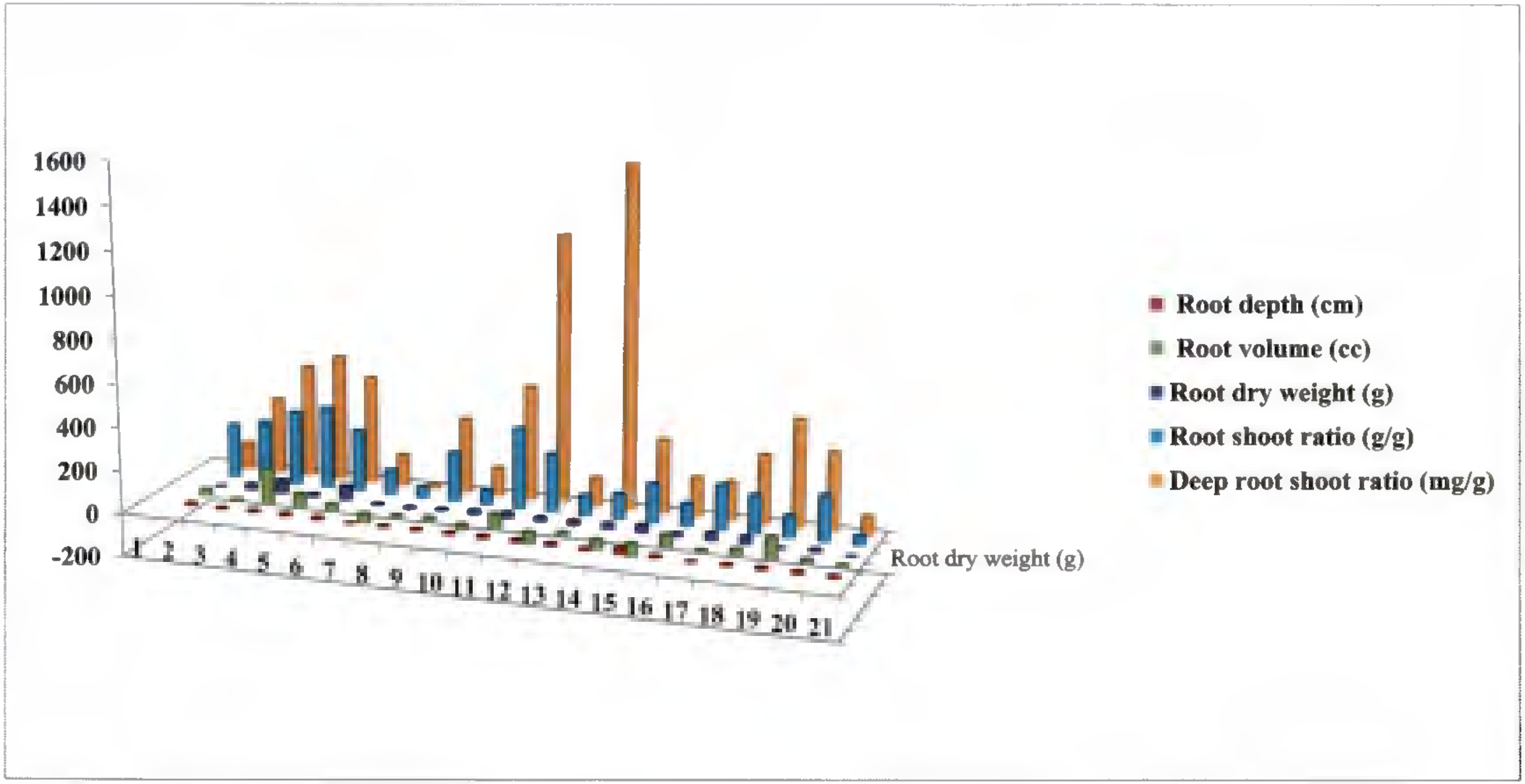
Sl.No.	Variety	Deep Root Shoot Ratio (mg/g)		
		Stress	Normal	Mean
1	Kattamodan (PTB28)	12.49	5.60	9.05
2	Karutha Modan (PTB 29)	190.72	42.43	116.58
3	Chuvanna Modan (PTB 30)	218.41	35.11	126.76
4	Vyttila 2	177.27	25.93	101.60
5	Vyttila 6	66.45	11.12	38.79
6	Jyothi (PTB 39)	46.49	19.06	32.78
7	Swarnaprabha (PTB 43)	182.45	151.30	166.88
8	Kanchana (PTB 50)	350.23	78.50	214.37
9	Aathira (PTB 51)	173.93	75.42	124.68
10	Aiswarya (PTB 52)	290.10	46.31	168.21
11	Harsha (PTB 55)	132.84	9.92	71.38
12	Vaishak (PTB 60)	175.50	76.05	125.78
13	Kanakom (MO 11)	30.15	1.80	15.98
14	Uma (MO 16)	777.99	176.54	477.27
15	Prathyasha (MO 21)	244.59	86.88	165.74
16	Arimodan	202.81	73.02	137.92
17	Kalladiaryan	120.93	28.97	74.95
18	Karuthadukkan	47.88	8.05	27.97
19	Parambuvattan	210.28	45.70	127.99
20	Thottacheera	269.99	145.99	207.99
	Average	196.08	57.19	126.63
CD(0.05)	Condition	6.557		
	Variety			20.735
	Condition × Variety interaction	29.323		

Table 61. Percentage change for root characters in rice genotype under protected condition in polythene tube with imposing reproductive moisture stress (drought condition)

Sl.No.	Name of variety/Traits	Root Depth (cm)	Root Volume (cc)	Root Dry Weight (g)	Root Shoot Ratio (g/g)	Deep Root Shoot Ratio (mg/g)
1	Kattamodan (PTB28)	10.63	29.74	1.72	253.31	122.86
2	Karutha Modan (PTB 29)	5.79	-10.91	25.87	282.84	349.47
3	Chuvanna Modan (PTB 30)	11.32	157.26	61.75	344.12	522.01
4	Vyttila 2	12.57	57.43	11.59	378.73	583.62
5	Vyttila 6	11.74	27.11	67.55	285.75	497.41
6	Jyothi (PTB 39)	0.22	-45.09	-7.09	113.69	143.90
7	Swarnaprabha (PTB 43)	4.29	7.35	-7.64	50.45	20.59
8	Kanchana (PTB 50)	8.67	16.42	8.80	229.58	346.16
9	Aathira (PTB 51)	10.19	-24.66	19.24	69.24	130.60
10	Aiswarya (PTB 52)	12.20	66.06	25.53	374.36	526.41
11	Harsha (PTB 55)	12.65	-54.62	17.73	269.76	1238.88
12	Vaishak (PTB 60)	12.76	16.44	21.35	93.80	130.78
13	Kanakom (MO 11)	6.99	-46.58	26.00	117.51	1578.38
14	Uma (MO 16)	27.33	-61.01	35.97	181.02	340.70
15	Prathyasha (MO 21)	9.65	56.44	16.23	105.85	181.53
16	Arimodan	-1.14	3.66	35.03	208.39	177.75
17	Kalladiaryan	7.22	26.72	33.68	177.70	317.40
18	Karuthadukkan	12.70	98.81	0.37	99.28	494.59
19	Parambuvattan	11.17	16.49	13.59	210.94	360.10
20	Thottacheera	10.48	9.40	-0.29	42.69	84.93

with (-) : indicate percentage decrease in mean performance of character under moisture stress

without (-) : indicate percentage increase in mean performance of character under moisture stress



1.Katta modan 4.Vyttila2 7.Swarnaprabha 10. Aiswarya 13. Kanakom 16.Arimodan 19. Parambuvattan
2.Karutha Modan 5. Vyttila 6 8. Kanchana 11. Harsha 14. Uma 17. Kalladiaryan 20. Thottacheera
3.Chuvana modan 6.Jyothi 9. Aathira 12. Vaishak 15. Prathyasha 18. Karuthadukkan

Fig. 17. Percentage change for root characters in rice genotype under protected condition with imposing reproductive stage moisture stress

Low deep root shoot ratios were recorded in Kanakom (1.80), Katta Modan (5.60), Karuthadukkan (8.05) Harsha (9.92), Vyttila 6 (11.12), Jyothi (19.06) and Vyttila 2 (25.93) under control. Uma (777.99), Kanchana (350.23), Aiswarya (290.10) and Thottacheera (269.99) recorded high deep root shoot ratios under drought. Highest percentage increase in deep root-shoot ratio was recorded in Kanakom (15.78 times) and lowest percentage variation in Swarnaprabha (PTB 43) (0.20 times) (Table 61).

4.11 Ranking of Genotypes

The twenty genotypes were ranked considering selection index score from Experiment I. Further ranking was done considering morphological physiological and root traits in Experiment II. Taking both the experiments into account a final ranking was given. Index scores and ranks of the top six genotypes selected as parents are given in Table 62. Vaishak, Thottacheera, Kalladiaryan, Vyttila 6, Harsha and Swarnaprabha in that order are the selected parents (Plate 9).

The variety Vaishak performed well under upland condition. It gave the highest grain yield under upland field and induced moisture stress condition. This high yielding variety was released specifically for upland situations in Kerala. Thottacheera, the traditional upland rice variety performed well under upland field and protected condition. Here, the plant architecture differed from the high yielding ideotype. Plants presented a weedy apperarence with slightly creeping growth habit. The variety had the highest proline content under induced moisture stress condition along with other drought tolerance attributes. The traditional upland rice variety Kalladiaryan had attractive, lustrous seeds. It performed well under upland and protected condition through adopting drought resistance mechanism. Vyttila 6 was developed through hybridization and selection from a cross between (Cheruvirruppu x IR 5) x Jaya. The high yield and other desirable attributes of Jaya have combined with saline tolerance of Cheruvirruppu and has contributed to making Vyttila 6 a superior yielder under saline condition. It is non-photosensitive and tolerant to salinity, acidity and water stagnation.

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Table 62. Ranking of genotypes based on Experiment I and Experiment II in rainfed upland rice

Sl.No.	Variety	Index scores according to Experiment I	Ranking according to Experiment II			Rank
		Selection index score	Morphological traits	Physiological and biochemical traits	Root traits	
1	Vaishak (PTB 60)	240.89	4	1	3	I
2	Thottacheera	238.35	1	2	5	II
3	Kalladiaryan	238.24	2	3	4	III
4	Vyttila 6	227.27	5	4	1	IV
5	Harsha (PTB 55)	204.57	6	5	2	V
6	Swarnaprabha (PTB 43)	189.46	3	4	6	VI

Plate 9. Six superior varieties selected for hybridization

1. Vaishak

2. Thottacheera

3. Kalladiaryan

4. Vyttila 6

5. Harsha

6. Swarnaprabha

Harsha is a dwarf variety developed through hybridization and selection from M 210 x PTB 28. The variety is photoinsensitive, short duration, with moderate resistance to moisture stress, low susceptibility to blast and sheath blight, non lodging and non- shattering with excellent milling and cooking qualities. This variety shows drought escaping mechanism. Suvarnaprabha was developed through hybridization and selection from the cross Bhavani x Triveni. It is suitable for direct seeding in all three seasons and is resistant to blast, moderately resistant to stem borer, susceptible to sheath blight and tolerant to drought.

Experiment III

4.12 CROSSING BLOCK: RAISING PARENTS AND DEVELOPMENT OF HYBRIDS

The experimental material consisted of six varieties (Table 62) identified as parents based on selection index and ranking (developed from Experiments I and II). Selfed seeds from parents were raised in pots and hybridization programme was carried out in half diallel fashion during 2014-15 at College of Agriculture, Vellayani, Thiruvananthapuram. Synchronization in flowering was achieved by staggered planting of parents (Plate 10). Hand pollination was carried out after emasculation by wet cloth method as suggested by Chaisang *et al* (1967). The artificially pollinated panicles were labelled and protected with paper cover (Plate 11). The covers were retained for one day. The fifteen F_1 seeds (Table 63) and selfed seeds of parents were collected separately at maturity and used for field evaluation in Experiment IV.

4.13 MEAN PERFORMANCE OF SIX PARENTS AND THEIR HYBRIDS FOR MORPHOLOGICAL TRAITS IN RICE (*Oryza sativa.* L) UNDER RAINFED UPLAND CONDITION

The details of the six selected parents and their fifteen hybrid combinations in half diallel are presented in Table 63.

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Plate 10.Crossing block: Raising parents and development of hybrids

Plate 11. Expt. III. Hybridization Programme

Analysis of variance for testing the significance of the differences between the genotypes was done and the anova is furnished in Table 64. Highly significant differences were recorded among genotypes for all the characters studied indicating ample variability among the genotypes under study.

The mean values of all the genotypes for morphological traits are presented in Table 65 (Plate 12. Expt. IV Field view).

4.13.1 Days to 50 % Flowering

Days to 50% flowering was the lowest in Kalladiaryan (79.67 days) and the highest in Vaishak (93.33 days) and Swarnaprabha (92.67 days) among parental varieties. Among the hybrids the lowest and the highest values were recorded for Thottacheera x Harsha (PTB 55) (70.33 days) and Vyttila 6 x Swarnaprabha (PTB 43) (91 days) respectively.

4.13.2 Number of Productive Tillers Plant^{-1}

Number of productive tillers plant^{-1} was the lowest in Swarnaprabha (7.07) and the highest in Kalladiaryan (10.87) among the parents. Minimum and maximum values among the hybrids were recorded in Harsha (PTB 55) x Swarnaprabha (PTB 43) (9.53) and Thottacheera x Kalladiaryan (21.53) respectively.

4.13.3 Plant Height at Maturity (cm)

With respect to plant height at maturity (cm) Harsha (81.20cm) was the shortest parent and Vaishak (119cm), the tallest. Among the hybrids the lowest and highest values for this trait was shown by Harsha (PTB 55) x Swarnaprabha (PTB 43) (76.87 cm) and Vaishak (PTB 60) x Harsha (PTB 55) (118cm) respectively.

4.13.4 Panicle Length (cm)

Panicle length ranged from 16 cm (Kalladiaryan) to 19.22 cm (Vyttila 6) among parents. Among the hybrids minimum panicle length was recorded in

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Plate 12. Expt. IV. Field view

Plate 12. Expt. IV. Field view (contd.)

Plate 12. Expt. IV. Field view (contd.)

Table 63. Details of six selected parents and their hybrid combinations in half diallel

SI.No.	Parents/Hybrids	Name of variety/Hybrids
1	P_1	Vaishak (PTB 60)
2	P_2	Thottacheera
3	P_3	Kalladiaryan
4	P_4	Vyttila 6
5	P_5	Harsha (PTB 55)
6	P_6	Swarnaprabha (PTB 43)
7	P_1 x P_2	Vaishak (PTB 60) x Thottacheera
8	P_1 x P_3	Vaishak (PTB 60) x Kalladiaryan
9	P_1 x P_4	Vaishak (PTB 60) x Vyttila 6
10	P_1 x P_5	Vaishak (PTB 60) x Harsha (PTB 55)
11	P_1 x P_6	Vaishak (PTB 60) x Swarnaprabha (PTB 43)
12	P_2 x P_3	Thottacheera x Kalladiaryan
13	P_2 x P_4	Thottacheera x Vyttila 6
14	P_2 x P_5	Thottacheera x Harsha (PTB 55)
15	P_2 x P_6	Thottacheera x Swarnaprabha (PTB 43)
16	P_3 x P_4	Kalladiaryan x Vyttila 6
17	P_3 x P_5	Kalladiaryan x Harsha (PTB 55)
18	P_3 x P_6	Kalladiaryan x Swarnaprabha (PTB 43)
19	P_4 x P_5	Vyttila 6 x Harsha (PTB 55)
20	P_4 x P_6	Vyttila 6 x Swarnaprabha (PTB 43)
21	P_5 x P_6	Harsha (PTB 55) x Swarnaprabha (PTB 43)

Table 64. Analysis of variance for 12 morphological traits in six parents and fifteen hybrids in rainfed upland rice

Sl. No.	Morphological traits	Source of variation Mean sum of square Treatment D.F.=20	 Error DF=40
1	Days to 50 % flowering	165.3873**	2.7278
2	Number of productive tillers plant^{-1}	84.7126**	19.3464
3	Plant height at maturity (cm)	473.3635**	50.3826
4	Panicle length (cm)	24.2031 **	2.9263
5	Number of spikelets panicle^{-1}	1503.1485**	253.2065
6	Number of filled grains panicle^{-1}	805.4107 **	212.6627
7	Spikelet sterility (%)	388.2165**	131.3841
8	Grain weight panicle $^{-1}$(g)	0.3077**	0.0368
9	1000 grain weight (g)	37.3489**	1.4540
10	Grain yield plant $^{-1}$ (g)	111.1757**	28.1423
11	Straw yield plant^{-1} (g)	100.4768**	31.8907
12	Harvest index (%)	160.7550*	82.8444

* Significant at 5 per cent ** Significant at 1 per cent

Thottacheera x Swarnaprabha (PTB 43) (16.28 cm) and maximum in Vaishak (PTB 60) x Harsha (PTB 55) (23.77cm) followed by Vaishak (PTB 60) x Vyttila 6 (23.61 cm), Vyttila 6 x Swarnaprabha (PTB 43) (23 cm) and Vaishak (PTB 60) x Thottacheera (22.82cm) (Plate 13).

4.13.5 Number of Spikelets Panicle^{-1}

Number of spikelets panicle^{-1} was the lowest in Thottacheera (61.87) and the highest in Vyttila 6 (83.20) among the parents. Minimum number of spikelets was recorded in Kalladiaryan x Harsha (PTB 55) (48.50) and maximum in Vyttila 6 x Harsha (PTB 55) (120.92) among the hybrids.

4.13.6 Number of Filled Spikelets Panicle^{-1}

Number of filled spikelets panicle^{-1} was minimum in Vaishak (PTB 60) (57.53) and maximum in Vyttila 6 (72.57) among the parents. Minimum number of filled spikelets was scored in Kalladiaryan x Harsha (PTB 55) (39.07) and maximum in Vyttila 6 x Harsha (PTB 55) (98.94) among the hybrids.

4.13.7 Spikelet Sterility (%)

The highest spikelet sterility was expressed by Harsha (14.22%) and the lowest by Thottacheera (9.69%) among the parents. Among the hybrids the highest and lowest sterility percentages were observed in Vaishak (PTB 60) x Kalladiaryan (55.59%) and Harsha (PTB 55) x Swarnaprabha (PTB 43) (10.57%) respectively.

4.13.8 Grain Weight Panicle $^{-1}$(g)

Grain weight panicle^{-1} ranged from 0.81g in Thottacheera to 1.19 g in Vaishak. The hybrids showed a variation from 0.53 (Vaishak (PTB 60) x Kalladiaryan) to 1.30 g in Vaishak (PTB 60) x Harsha (PTB 55).

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4.13.9 1000 Grain Weight (g)

1000 grain weight ranged from 21g (Swarnaprabha and Vyttila 6 each) to 24 g (Kalladiaryan). The hybrids showed a range from 14.07 (Vaishak (PTB 60) x Kalladiaryan) to 27.10 g (Thottacheera x Vyttila 6) among the parents.

4.13.10 Grain Yield Plant $^{-1}$(g)

Grain yield plant^{-1} was minimum in Swarnaprabha (PTB 43) (6.03 g) and maximum in Kalladiaryan (10.45g) among the parents. The hybrids showed a remarkably wide range from 7.35 g (Harsha (PTB 55) x Swarnaprabha (PTB 43)) to 30.83 g (Vyttila 6 x Harsha (PTB 55)).

4.13.11 Straw Yield Plant^{-1} (g)

For straw yield plant^{-1} the lowest value was recorded in Thottacheera (14.33 g) and the highest in Vyttila 6 (22.87g) among the parents. The hybrids showed a wide variation ranging from 10.60 (Harsha (PTB 55) x Swarnaprabha (PTB 43)) to 30.27 g (Vyttila 6 x Swarnaprabha (PTB 43).

4.13.12 Harvest Index (%)

Harvest index (%) was the lowest in Swarnaprabha (PTB 43) (27.76%) and the highest in Kalladiaryan (40.59%) among the parents. The hybrids recorded considerable variation ranging from 26.25 (Vaishak (PTB 60) x Kalladiaryan) to 51.25% (Vyttila 6 x Harsha (PTB 55)).

4.13.13 Leaf Rolling Score

Folding of leaves in deep V shape was observed in the varieties Vaishak, Thottacheera and Harsha as well as the hybrids Vaishak (PTB 60) x Thottacheera, Vaishak (PTB 60) x Harsha (PTB 55), Thottacheera x Kalladiaryan, Kalladiaryan x Harsha (PTB 55) and Kalladiaryan x Swarnaprabha (PTB 43) (Table 66). All the remaining parents and leaves of hybrids showed a leaves folding in shallow V shape. The variety Swarnaprabha showed folding of leaves in U shape.

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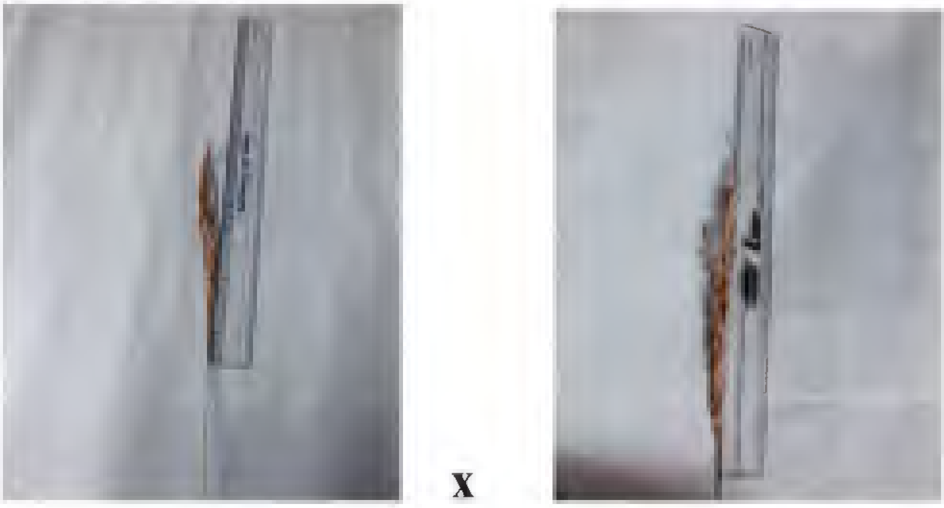
Plate 13. Expt. IV. Panicles of parents and F_1 hybrids



Vaishak

Thottacheera

Vaishak X Thottacheera (7)

Plate 13. Expt. IV. Panicles of parents and F_1 hybrids (contd.)

Vaishak

X

Kalladiaryan

Vaishak X Kalladiaryan (8)

Plate 13. Expt. IV. Panicles of parents and F_1 hybrids (contd.)

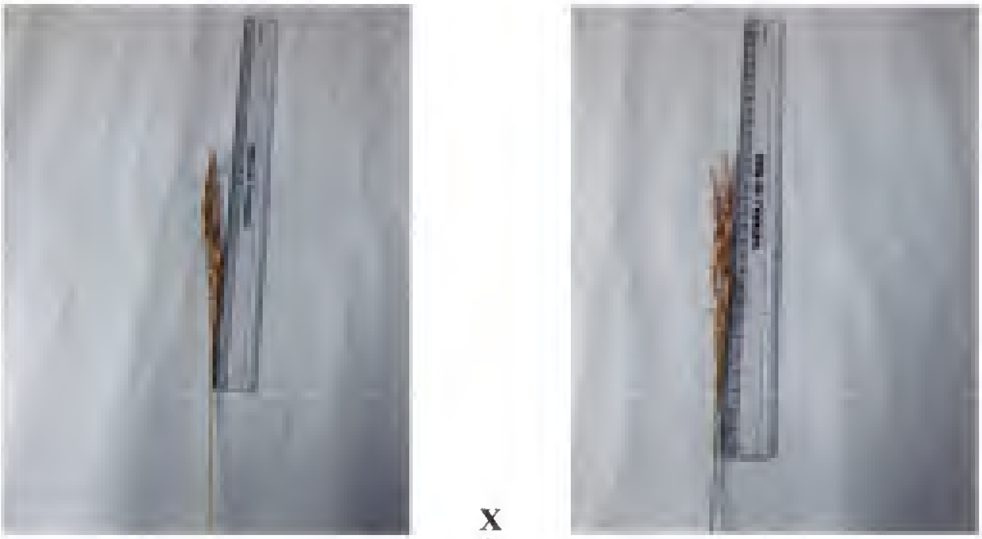
Vaishak

X

Vyttila 6

Vaishak X Vyttila 6 (9)

Plate 13. Expt. IV. Panicles of parents and F_1 hybrids (contd.)



Vaishak

Harsha

Vaishak X Harsha (10)

Plate 13. Expt. IV. Panicles of parents and F_1 hybrids (contd.)

Vaishak

X

Swarnaprabha

Vaishak X Swarnaprabha (11)

Plate 13. Expt. IV. Panicles of parents and F_1 hybrids (contd.)

Thottacheera

X

Kalladiaryan

↓

Thottacheera X Kalladiaryan (12)

Plate 13. Expt. IV. Panicles of parents and F_1 hybrids (contd.)

Thottacheera

X

Vyttila 6

Thottacheera X Vyttila 6 (13)

Plate 13. Expt. IV. Panicles of parents and F_1 hybrids (contd.)

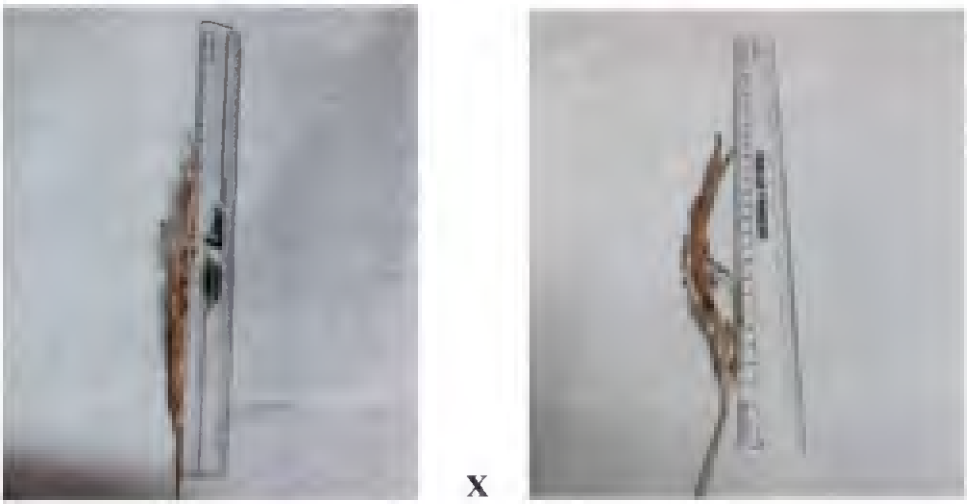
Thottacheera

X

Harsha

Thottacheera X Harsha (14)

Plate 13. Expt. IV. Panicles of parents and F_1 hybrids (contd.)



X

Thottacheera

Swarnaprabha

Thottacheera X Swarnaprabha (15)

Plate 13. Expt. IV. Panicles of parents and F_1 hybrids (contd.)

Kalladiaryan

X

Vyttila 6

Kalladiaryan X Vyttila 6 (16)

Plate 13. Expt. IV. Panicles of parents and F_1 hybrids (contd.)

Kalladiaryan

X

Harsha

Kalladiaryan X Harsha (17)

Plate 13. Expt. IV. Panicles of parents and F_1 hybrids (contd.)

Kalladiaryan

X

Swarnaprabha

Kalladiaryan X Swarnaprabha (18)

Plate 13. Expt. IV. Panicles of parents and F_1 hybrids (contd.)

Vyttila 6

X

Harsha

Vyttila 6 X Harsha (19)

Plate 13. Expt. IV. Panicles of parents and F_1 hybrids (contd.)

Vyttila 6

X

Swarnaprabha

Vyttila 6 X Swarnaprabha (20)

Plate 13. Expt. IV. Panicles of parents and F_1 hybrids (contd.)

Harsha

X

Swarnaprabha

Harsha X Swarnaprabha (21)

4.13.14 Nature of Panicle Exsertion

Panicles were partly exserted in the varieties Vyttila 6, Harsha and Swarnaprabha (PTB 43) and the hybrid Thottacheera x Vyttila 6 (Table 67). Thottacheera and Kalladiaryan had well exserted panicles whereas Vaishak had mostly exserted panicles among the selected parents. The hybrids Vaishak (PTB 60) x Thottacheera, Vaishak (PTB 60) x Kalladiaryan, Vaishak (PTB 60) x Harsha (PTB 55), Vaishak (PTB 60) x Swarnaprabha (PTB 43), Kalladiaryan x Harsha (PTB 55), Kalladiaryan x Swarnaprabha (PTB 43) and Vyttila 6 x Swarnaprabha (PTB 43) had well exserted panicles. The panicles of Vaishak (PTB 60) x Vyttila 6, Thottacheera x Harsha (PTB 55), Thottacheera x Swarnaprabha (PTB 43), Kalladiaryan x Vyttila 6, Vyttila 6 x Harsha (PTB 55) and Harsha (PTB 55) x Swarnaprabha (PTB 43) had mostly exserted panicles.

4.13.15 Percentage Soil Moisture Content

Soil moisture content during crop growth season of parents and F_1 hybrids varied from stage of crop (Table 68). At seedling stage it was 12.007%, at reproductive stage it was 10.24% and at harvesting stage it was 8.53% under rainfed upland condition.

4.14 MEAN PERFORMANCE OF SIX PARENTS AND FIFTEEN F_1 HYBRIDS FOR PHYSIOLOGICAL AND BIOCHEMICAL TRAITS IN RICE (*Oryza sativa* L.) UNDER RAINFED UPLAND CONDITION

Analysis of variance for testing the significance of the differences between the genotypes for physiological and biochemical traits was done and the anova is furnished in Table 69. Highly significant differences were recorded among genotypes for all the characters studied indicating considerable variability.

The mean values of all the genotypes for physiological and biochemical traits are presented in Table 70.

Table 65. Mean performance of six parents and fifteen F_1 hybrids for morphological traits in rainfed upland rice

Symbols	Parents / Hybrids	Days to 50 % flowering	Number of productive tillers $plant^{-1}$	Plant height at maturity (cm)	Panicle length (cm)	Number of spikelets $panicle^{-1}$	Number of filled grains $panicle^{-1}$	Spikelet sterility (%)	Grain weight $panicle^{-1}$ (g)	1000 grain weight (g)	Grain yield $plant^{-1}$ (g)	Straw yield $plant^{1}$(g)	Harvest index (%)
P_1	Vaishak (PTB 60)	93.33	7.80	119.00	18.75	65.53	57.53	12.05	1.19	21.74	9.54	19.53	32.69
P_2	Thottacheera	80.67	7.33	103.67	17.28	61.87	60.00	9.69	0.81	21.33	6.05	14.33	29.60
P_3	Kalladiaryan	79.67	10.87	90.67	16.00	64.67	57.93	11.24	0.89	24.00	10.45	15.27	40.59
P_4	Vyttila 6	96.67	9.13	87.20	19.22	83.40	72.57	11.96	1.17	21.00	10.02	22.87	32.02
P_5	Harsha (PTB 55)	83.00	7.13	81.20	16.32	68.10	58.33	14.22	0.99	22.33	7.23	16.33	31.79
P_6	Swarnaprabha (PTB 43)	92.67	7.07	115.73	17.17	70.00	62.00	11.50	1.00	21.00	6.03	17.27	27.76
P_1 x P_2	Vaishak (PTB 60) x Thottacheera	80.00	20.73	104.73	22.82	115.46	72.06	36.76	0.86	15.81	19.17	24.87	42.66
P_1 x P_3	Vaishak (PTB 60) x Kalladiaryan	82.00	19.20	110.20	23.61	102.05	46.70	55.59	0.53	14.07	11.98	28.07	26.25
P_1 x P_4	Vaishak (PTB 60) x Vyttila 6	80.33	15.53	115.33	22.43	105.53	83.27	21.39	0.88	19.00	17.33	21.87	41.57
P_1 x P_5	Vaishak (PTB 60) x Harsha (PTB 55)	79.67	10.47	118.00	23.77	105.78	70.31	31.12	1.30	19.09	15.28	23.07	37.59
P_1 x P_6	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	77.33	16.07	107.87	22.78	87.80	61.20	30.74	0.76	15.93	14.30	21.93	38.96
P_2 x P_3	Thottacheera x Kalladiaryan	78.67	21.53	98.00	19.92	67.64	45.91	32.94	0.82	17.53	16.52	27.87	35.00
P_2 x P_4	Thottacheera x Vyttila 6	70.67	19.40	101.73	16.19	49.72	36.63	27.13	1.03	27.10	17.60	26.40	40.90
P_2 x P_5	Thottacheera x Harsha (PTB 55)	70.33	16.47	84.67	17.57	60.07	46.47	19.96	0.96	21.03	16.03	16.13	48.23
P_2 x P_6	Thottacheera x Swarnaprabha (PTB 43)	70.67	11.33	86.40	16.28	56.13	47.93	14.82	1.05	24.51	12.70	14.60	48.27
P_3 x P_4	Kalladiaryan x Vyttila 6	80.00	19.00	96.13	17.30	76.40	63.50	15.65	0.64	14.53	15.00	29.27	33.82
P_3 x P_5	Kalladiaryan x Harsha (PTB 55)	76.33	20.07	97.53	17.10	48.50	39.07	17.61	0.82	22.18	16.60	18.00	48.12
P_3 x P_6	Kalladiaryan x Swarnaprabha (PTB 43)	80.00	18.20	106.13	16.70	56.27	41.13	23.89	0.65	17.80	11.86	23.87	32.59
P_4 x P_5	Vyttila 6 x Harsha (PTB 55)	90.33	20.67	91.87	22.03	120.92	98.94	17.18	1.22	22.77	30.83	29.07	51.25
P_4 x P_6	Vyttila 6 x Swarnaprabha (PTB 43)	91.00	19.13	89.53	23.00	104.27	88.70	15.21	1.16	19.93	24.58	30.27	45.50
P_5 x P_6	Harsha (PTB 55) x Swarnaprabha (PTB 43)	78.33	9.53	76.87	18.39	71.24	63.44	10.57	0.86	15.01	7.35	10.60	40.83
	General mean	81.51	14.60	99.16	19.27	78.16	60.65	21.01	0.93	19.89	14.12	21.50	38.38
	CD (0.05)	2.723	7.25	11.718	2.827	26.257	24.069	18.911	0.313	3.283	8.758	9.316	15.013

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Table 66. Leaf rolling score in six parents and fifteen F_1 hybrids of rice under rainfed upland condition

Sl. No.	Parents/ Hybrids	Decimal score	Description
1	Vaishak (PTB 60)	3	Leaves folding(deep V shape)
2	Thottacheera	3	Leaves folding (deep V shape)
3	Kalladiaryan	1	Leaves start to fold (Shallow V shape)
4	Vyttila 6	3	Leaves folding (deep V shape)
5	Harsha (PTB 55)	3	Leaves folding (deep V shape)
6	Swarnaprabha (PTB 43)	5	Leaves folding (U shape)
7	Vaishak (PTB 60) x Thottacheera	3	Leaves folding (deep V shape)
8	Vaishak (PTB 60) x Kalladiaryan	1	Leaves start to fold (Shallow V shape)
9	Vaishak (PTB 60) x Vyttila 6	1	Leaves start to fold (Shallow V shape)
10	Vaishak (PTB 60) x Harsha (PTB 55)	3	Leaves folding (deep V shape)
11	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	1	Leaves start to fold (Shallow V shape)
12	Thottacheera x Kalladiaryan	3	Leaves folding (deep V shape)
13	Thottacheera x Vyttila 6	1	Leaves start to fold (Shallow V shape)
14	Thottacheera x Harsha (PTB 55)	1	Leaves start to fold (Shallow V shape)
15	Thottacheera x Swarnaprabha (PTB 43)	1	Leaves start to fold (Shallow V shape)
16	Kalladiaryan x Vyttila 6	1	Leaves start to fold (Shallow V shape)
17	Kalladiaryan x Harsha (PTB 55)	3	Leaves folding (deep V shape)
18	Kalladiaryan x Swarnaprabha (PTB 43)	3	Leaves folding (deep V shape)
19	Vyttila 6 x Harsha (PTB 55)	1	Leaves start to fold (Shallow V shape)
20	Vyttila 6 x Swarnaprabha (PTB 43)	1	Leaves start to fold (Shallow V shape)
21	Harsha (PTB 55) x Swarnaprabha (PTB 43)	1	Leaves start to fold (Shallow V shape)

Table 67. Nature of panicle exsertion in six parents and fifteen F_1 hybrids in rainfed upland rice

SL. No.	Name of parents and hybrids	Nature of panicle exsertion
1	Vaishak (PTB 60)	Mostly exserted
2	Thottacheera	Well exserted
3	Kalladiaryan	Well exserted
4	Vyttila 6	Partly exserted
5	Harsha (PTB 55)	Partly exserted
6	Swarnaprabha (PTB 43)	Partly exserted
7	Vaishak (PTB 60) x Thottacheera	Well exserted
8	Vaishak (PTB 60) x Kalladiaryan	Well exserted
9	Vaishak (PTB 60) x Vyttila 6	Mostly exserted
10	Vaishak (PTB 60) x Harsha (PTB 55)	Well exserted
11	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	Well exserted
12	Thottacheera x Kalladiaryan	Well exserted
13	Thottacheera x Vyttila 6	partly exserted
14	Thottacheera x Harsha (PTB 55)	Mostly exserted
15	Thottacheera x Swarnaprabha (PTB 43)	Mostly exserted
16	Kalladiaryan x Vyttila 6	Mostly exserted
17	Kalladiaryan x Harsha (PTB 55)	Well exserted
18	Kalladiaryan x Swarnaprabha (PTB 43)	Well exserted
19	Vyttila 6 x Harsha (PTB 55)	Mostly exserted
20	Vyttila 6 x Swarnaprabha (PTB 43)	Well exserted
21	Harsha (PTB 55) x Swarnaprabha (PTB 43)	Mostly exserted

(DRR, 2004)

Table 68. Percentage of soil moisture under rainfed upland condition (Experiment IV)

Sl. No.	Soil moisture content (%)	Stage of crop
1	12.007	Seedling stage
2	10.24	Reproductive stage
3	8.53	Harvesting stage

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4.14.1 Water use efficiency (g/l)

The highest water use efficiency was recorded in Vyttila 6 (2.51g/l) and the lowest in Thottacheera (1.79g/l) among the parents. Among the hybrids the highest and the lowest values were recorded in Harsha (PTB 55) x Swarnaprabha (PTB 43) (1.60g/l) and Vyttila 6 x Harsha (PTB 55) (4.75g/l) respectively.

4.14.2 Relative Leaf Water Content (%)

The highest relative leaf water content was observed in Vyttila 6 (95.34%) and the lowest in Swarnaprabha (PTB 43) (89.06%) among the parents. Among the hybrids the highest and the lowest relative leaf water contents were recorded in Vaishak (PTB 60) x Swarnaprabha (PTB 43) (95.32%) and Kalladiaryan x Harsha (PTB 55) (77.33%) respectively.

4.14.2 Proline Content (mg/g)

Proline content ranged from 0.34 (Harsha) to 0.46 mg (Vyttila 6) in parents. Among the hybrids minimum proline content was recorded in Vaishak (PTB 60) x Harsha (PTB 55) (0.32mg) and maximum in Vaishak (PTB 60) x Kalladiaryan (0.56 mg) followed by Vaishak (PTB 60) x Vyttila 6 (0.47mg), Vyttila 6 x Swarnaprabha (PTB 43) and Vaishak (PTB 60) x Thottacheera (0.44mg each).

4.14.3 Cell Membrane Stability Index (%)

Cell membrane stability index ranged from 61.51 (Harsha) to 85.91% (Vyttila 6) in parents. Among the hybrids highest and lowest values were recorded in Vaishak (PTB 60) x Swarnaprabha (PTB 43) (87.23%) and Harsha (PTB 55) x Swarnaprabha (PTB 43) (52.92%) respectively.

4.14.5 Chlorophyll b Content (mg/g)

Among the parents Harsha (PTB 55) had minimum chlorophyll b content (0.54mg/g) and Thottacheera (1.46 mg/g) had the maximum value.

Table 69. Analysis of variance for 20 physiological and biochemical traits of six parents and fifteen hybrids in rainfed upland rice

Sl. No.	Physiological and biochemical traits	Source of variance	
		Mean Sum of Square	
		Treatment	Error
1	Water use efficiency (WUE) (g/l)	2.4378**	0.5457
2	Relative leaf water content (RLWC) (%)	44.3646*	21.9939
3	Proline content	0.0078**	0.0003
4	Cell membrane stability index	326.3141**	18.6946
5	Chlorophyll content (mg/g)	0.0816**	0.0013
6	Chlorophyll b content (mg/g)	0.0297**	0.0004
7	Carotenoide content (mg/g)	0.0016**	0.0002
8	Total chlorophyll content (mg/g)	0.7773**	0.0236
9	Chlorophyll stability index	193.8721**	14.5547
10	Leaf temperature (^{0}C)	15.5956**	0.0572
11	Transpiration rate (TR)	1.5631**	0.0282
12	Stomatal conductance (SC)	6118.5367**	21.8781
13	Leaf soluble protein content(mg/g)	183.6803**	4.1278
14	Radiation use efficiency	0.0907 NS	0.0527
15	Chlorophyll meter reading (SPAD)	13.3673*	6.4612
16	Leaf area index (LAI)	4.4206**	2.2384
17	Relative growth rate (RGR) (mg/g/day)	12.1423 NS	11.3726
18	Net assimilation rate (NAR) (g/m2/day)	4.2658 NS	3.4910
19	Carbon isotope discrimination (per mil)	0.5824**	0.1240
20	Number of days taken for reaching critical stress level	13.3811**	0.0290

* Significant at 5 per cent level

** Significant at 1 per cent level

The maximum and minimum chlorophyll b contents were recorded in the hybrids Vyttila 6 x Harsha (PTB 55) (1.40mg/g) and Kalladiaryan x Harsha (PTB 55) (0.28mg/g) respectively.

4.14.6 Carotenoide Content (mg/g)

The parents Vyttila 6 and Harsha exhibited maximum carotenoides (0.86mg/g each) and Vaishak (0.81mg/g) exhibited the minimum value. The hybrids Thottacheera x Swarnaprabha (PTB 43) and Kalladiaryan x Harsha (PTB 55) exhibited maximum carotenoides (0.87mg/g each) and Harsha (PTB 55) x Swarnaprabha (PTB 43) (0.76mg/g) recorded the minimum value.

4.14.7 Total Chlorophyll Content (mg/g)

Thottacheera (2.71mg/g) registered the highest total chlorophyll content value and Harsha (PTB 55) (1.93 mg/g) recorded the lowest value among the parents. Among the hybrids maximum total chlorophyll content was observed in Vyttila 6 x Harsha (PTB 55) (2.75 mg/g) and the minimum was recorded in Kalladiaryan x Harsha (PTB 55) (0.93mg/g).

4.14.8 Chlorophyll Stability Index (%)

Maximum and minimum chlorophyll stability indices were indicated by Kalladiaryan (86.02%) and Vaishak (66.75%) respectively among the parents. The maximum chlorophyll stability index was recorded in Vaishak (PTB 60) x Swarnaprabha (PTB 43) (95.96%) followed by Vyttila 6 x Harsha (PTB 55) (93.13%) among hybrids.

4.14.9 Leaf Temperature (^{0}C)

Leaf temperature was the highest in Vyttila 6 (36.07^{0}C) and the lowest in Kalladiaryan (35.11^{0}C) among parents. Vaishak (PTB 60) x Vyttila 6 (41.75°C) and Thottacheera x Swarnaprabha (PTB 43) (40.91^{0}C) recorded the highest leaf temperatures among hybrids and Harsha x Swarnaprabha (33.89 ^{0}C) recorded the lowest.

4.14.10 Transpiration Rate (mmoles$H_2O/m^2/sec$)

Transpiration rate varied from 0.78 mmoles$H_2O/m^2/sec$ (Swarnaprabha) to 1.77 mmoles$H_2O/m^2/sec$ (Vyttila 6) among the parents. The highest transpiration rates were recorded in the hybrids Vaishak (PTB 60) x Kalladiaryan (3.15) followed by Vyttila 6 x Swarnaprabha (PTB 43) (2.86) and the lowest in Vaishak (PTB 60) x Swarnaprabha (PTB 43) (1.17) among the hybrids.

4.14.11 Stomatal Conductance (mmol $mol^{-2}\ s^{-1}$)

Stomatal conductance varied from 32.61 mmol $mol^{-2}\ s^{-1}$ (Kalladiaryan) to 203.39 mmol $mol^{-2}\ s^{-1}$(Vyttila 6) among the parents. The highest stomatal conductance was recorded in the hybrid Vyttila 6 x Swarnaprabha (PTB 43) (212.53 mmol $mol^{-2}\ s^{-1}$) followed by Thottacheera x Vyttila 6 (106.45 mmol $mol^{-2}\ s^{-1}$) and the lowest in Thottacheera x Harsha (PTB 55) (51.91 mmol $mol^{-2}\ s^{-1}$).

4.14.12 Leaf Soluble Protein Content (mg/g)

Swarnaprabha (PTB 43) (16.45mg/g) registered the lowest leaf soluble protein content (mg/g) of 16.45mg/g and Vyttila 6 (PTB 55) recorded the highest value of 30.66mg/g among the parents. Among the hybrids maximum value was registered in Vyttila 6 x Swarnaprabha (PTB 43) (37.50mg/g) and minimum value in Thottacheera x Swarnaprabha (PTB 43) (9.83mg/g).

4.14.13 Radiation Use Efficiency (Mj/g)

Radiation use efficiency was the highest in Harsha (4.19) and the lowest in Thottacheera (3.45) among the parents (Table 70). Among the hybrids the highest and lowest RUE were recorded in Thottacheera x Swarnaprabha (PTB 43)) (9.28) and Harsha (PTB 55) x Swarnaprabha (PTB 43) (4.55) respectively.

4.14.14 Chlorophyll Meter Reading

High chlorophyll meter reading value was recorded in Harsha (PTB 55) (42.92) and low in Vaishak (37.23) among the parents (Table 70). Among the hybrids high chlorophyll meter reading was recorded in Harsha (PTB 55) x

Swarnaprabha (PTB 43) (44.38) followed by Vyttila 6 x Swarnaprabha (PTB 43) (43.61) and Vyttila 6 x Harsha (PTB 55) (41.76) while low values were observed in Vaishak (PTB 60) x Harsha (PTB 55) (38.31).

4.14.15 Leaf Area Index

Maximum leaf area index was recorded in Vaishak (PTB 60) (4.37) and minimum in Harsha (PTB 55) (2.68) among the parents (Table70). The hybrids Kalladiaryan x Swarnaprabha (PTB 43) (6.41) and Vaishak (PTB 60) x Thottacheera (6.08) had the highest leaf area indices whereas Thottacheera x Harsha (PTB 55) (2.21) had the lowest index.

4.14.16 Relative Growth Rate (mg/g/day)

The relative growth rate (RGR) was recorded from panicle initiation to harvesting stage of the crop (reproductive stage to harvesting stage). The highest and the lowest relative growth rates were calculated in Kalladiaryan (13.85mg/g) and Thottacheera (11.34mg/g) respectively among the parents. Highest RGR was recorded in Thottacheera x Swarnaprabha (PTB 43) (16.82mg/g) followed by Thottacheera x Harsha (PTB 55) (16.16mg/g) and Vyttila 6 x Harsha (PTB 55) (16.03mg/g) whereas the lowest was noted in Vaishak (PTB 60) x Kalladiaryan (9.29mg/g) among the hybrids.

4.14.17 Net Assimilation Rate (g/m^2/day)

The net assimilation rate (NAR) was recorded from panicle initiation to harvesting stage of the crop (reproductive stage to harvesting stage). The highest and the lowest net assimilation rates were computed in Harsha (2.74g/m^2/day) and Swarnaprabha (1.93 g/m^2/day) respectively among the parents. Highest NAR was recorded in Thottacheera x Swarnaprabha (PTB 43) (5.85 g/m^2/day) followed by Thottacheera x Harsha (PTB 55) (5.39 g/m^2/day) and Vaishak (PTB 60) x Swarnaprabha (PTB 43) (5.33 g/m^2/day) whereas the lowest was reported in Thottacheera x Kalladiaryan (2.24 g/m^2/day) among the hybrids.

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4.14.18 Carbon Isotope Discrimination (per mill)

The highest carbon isotope discrimination was recorded in Harsha (PTB 55) (23.27 per mill) and the lowest in Thottacheera (22.09 per mill) among the parents. The highest and lowest values for the character were registered in Harsha (PTB 55) x Swarnaprabha (PTB 43) (23.41 per mill) and Vyttila 6 x Harsha (PTB 55) (22.26 per mill) respectively among the hybrids (Plate 19).

4.14.19 Number of Days Taken for Reaching Critical Stress Level

The maximum days taken for reaching critical stress level was recorded in Swarnaprabha (PTB 43) (15.33 days) and the minimum in Harsha (PTB 55) (10 days) among the parents. The maximum and minimum days taken for reaching critical stress level were recorded in Vaishak x Swarnaprabha (15.67 days) and Thottacheera x Swarnaprabha (PTB 43) (10 days) respectively among the hybrids.

4.15 ANALYSIS OF VARIANCE FOR COMBINING ABILITY FOR MORPHOLOGICAL TRAITS IN UPLAND RICE (*Oryza sativa* L.)

The analysis of variance for 12 characters are presented in Table 64. The analysis of combining ability is given in Table 71.

Among the parents and the crosses there were significant differences for all the characters studied. On further analysis it was found that there were no significant differences among the parents for the trait harvest index for general combining ability while for specific combining ability all traits were significant. Estimates of $\sigma^2 gca$ and $\sigma^2 sca$ suggest that non-additive component of heritable variation is many times larger than the additive components for all the morphological traits in rainfed upland condition. The general combining ability effects of parents and specific combining ability effects of hybrids for 12 traits under rainfed upland condition are given in Table 72 and 73 respectively.

4.15.1 Days to 50% Flowering

The combining ability analysis revealed that days to 50% flowering differed significantly among all the parents. The parents Vaishak (1.931), Vyttila 6

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(4.389) and Swarnaprabha (1.514) showed highly significant positive effects. Parents Thottacheera (-4.861), Kalladiaryan (-1.778) and Harsha (PTB 55) (-1.194) recorded significant negative *gca* effects (Table 72).

Among the hybrids high negative and significant *sca* effects were shown by Thottacheera x Vyttila 6 (10.369), Vaishak (PTB 60) x Swarnaprabha (PTB 43) (-7.619), Vaishak (PTB 60) x Vyttila 6 (-7.494), Thottacheera x Swarnaprabha (PTB 43) (-7.494), Thottacheera x Harsha (PTB 55) (-5.119), Kalladiaryan x Vyttila 6 (-4.119), Harsha (PTB 55) x Swarnaprabha (PTB 43) (-3.494) Vaishak (PTB 60) x Harsha (PTB 55) (-2.577), and Kalladiaryan x Harsha (PTB 55) (-2.202), while Vyttila 6 x Harsha (PTB 55) (5.631), Thottacheera x Kalladiaryan (3.798) and Vyttila 6 x Swarnaprabha (PTB 43) (3.589) had significant positive *sca* effect (Table 73).

4.15.2 Number of Productive Tillers Plant^{-1}

Among the parents significant positive *gca* effect was shown by Kalladiaryan (2.189) for this character while Swarnaprabha (-1.728) had significant negative *gca* effect.

The hybrids Vaishak (PTB 60) x Thottacheera (6.469), Vyttila 6 x Harsha (PTB 55) (6.186), Vyttila 6 x Swarnaprabha (PTB 43) (5.036), Kalladiaryan x Harsha (PTB 55) (4.619) and Thottacheera x Kalladiaryan (4.502) were found to have significant positive *sca* effect for number of productive tillers plant^{-1}.

4.15.3 Plant Height at Maturity (cm)

Vaishak (12.49) had significant positive *gca* effect for plant height whereas Vyttila 6 (-3.144) and Harsha (-7.853) showed significant negative effects among the parents.

Among the hybrids high positive and significant *sca* effect was shown by Vaishak (PTB 60) x Harsha (PTB 55) (14.19) while Harsha (PTB 55) x

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Table 70. Mean performance of six parents and fifteen hybrids for physiological and biochemical traits in rainfed upland rice (*Oryza sativa* L.)

Symbols	Name of parents and hybrids	Water use efficiency (WUE) (g/l)	Relative leaf water content (%)	Proline content (mg/g)	Cell membrane stability index	Chlorophyll a content (mg/g)	Chlorophyll b content (mg/g)	Carotenoides content (mg/g)	Total chlorophyll content (mg/g)	Chlorophyll stability index	Leaf temperature (^{O}C)	Transpiration Rate (TR)
P_1	Vaishak (PTB 60)	2.25	90.93	0.40	63.78	1.26	0.94	0.81	2.20	66.75	35.65	1.73
P_2	Thottacheera	1.79	92.60	0.42	82.24	1.25	1.46	0.83	2.71	82.78	35.71	0.84
P_3	Kalladiaryan	2.30	90.08	0.41	75.75	1.28	1.22	0.83	2.50	86.02	35.11	0.80
P_4	Vyttila 6	2.51	95.34	0.46	85.91	1.32	0.73	0.86	2.05	85.13	36.07	1.77
P_5	Harsha (PTB 55)	1.98	91.26	0.34	61.51	1.36	0.57	0.86	1.93	85.83	35.34	0.94
P_6	Swarnaprabha (PTB 43)	1.81	89.06	0.42	79.91	1.31	1.12	0.83	2.43	82.23	35.37	0.78
P_1 x P_2	Vaishak (PTB 60) x Thottacheera	3.86	91.86	0.44	83.21	1.30	1.34	0.83	2.64	93.51	40.27	2.04
P_1 x P_3	Vaishak (PTB 60) x Kalladiaryan	3.34	90.11	0.56	74.04	1.29	1.39	0.83	2.69	86.82	40.27	3.15
P_1 x P_4	Vaishak (PTB 60) x Vyttila 6	3.38	94.32	0.47	83.00	1.31	1.24	0.83	2.55	92.79	41.75	2.54
P_1 x P_5	Vaishak (PTB 60) x Harsha (PTB 55)	3.36	93.53	0.32	79.22	1.40	0.50	0.86	1.90	88.77	38.71	2.46
P_1 x P_6	Vaishak (PTB 60) x Swarnaprabha	3.15	95.32	0.43	87.23	1.36	0.73	0.84	2.09	95.96	38.11	1.17
P_2 x P_3	Thottacheera x Kalladiaryan	3.89	89.68	0.41	61.99	1.30	1.33	0.83	2.64	90.11	36.61	1.34
P_2 x P_4	Thottacheera x Vyttila 6	4.19	93.10	0.36	61.83	1.37	0.63	0.85	1.99	92.26	37.70	2.00
P_2 x P_5	Thottacheera x Harsha (PTB 55)	3.09	90.43	0.42	75.74	1.09	0.46	0.84	1.55	80.67	40.07	1.54
P_2 x P_6	Thottacheera x Swarnaprabha (PTB 43)	2.55	88.76	0.43	67.38	1.07	0.38	0.87	1.46	71.02	40.91	2.42
P_3 x P_4	Kalladiaryan x Vyttila 6	3.85	93.30	0.41	79.37	1.39	0.80	0.83	1.85	86.25	38.27	2.84
P_3 x P_5	Kalladiaryan x Harsha (PTB 55)	3.12	77.23	0.40	60.22	0.64	0.28	0.87	0.93	68.13	35.91	2.46
P_3 x P_6	Kalladiaryan x Swarnaprabha (PTB 43)	3.08	90.93	0.43	55.49	1.30	1.17	0.83	2.47	88.70	35.63	2.15
P_4 x P_5	Vyttila 6 x Harsha (PTB 55)	4.75	91.82	0.43	74.54	1.35	1.40	0.84	2.75	93.13	35.46	1.57
P_4 x P_6	Vyttila 6 x Swarnaprabha (PTB 43)	4.32	91.88	0.44	76.13	1.34	1.00	0.86	2.64	87.75	35.65	2.86
P_5 x P_6	Harsha (PTB 55) x Swarnaprabha	1.60	86.03	0.35	52.92	1.21	0.26	0.76	1.47	88.29	33.86	2.09
	General mean	3.06	90.84	0.42	72.45	1.26	0.90	0.84	2.16	85.38	37.26	1.88
	CD (0.05)	1.219	7.737	0.028	7.136	0.058	0.294	0.024	NS	6.293	0.395	0.272

Table 70 (Contd.). Mean performance of six parents and fifteen hybrids for physiological and biochemical traits in rainfed upland rice (*Oryza sativa*.L)

Symbols	Parents /Hybrids	Stomatal conductance (SC)	Leaf soluble protein content (mg/g)	Radiation use efficiency (Mj/g)	Chlorophyll meter reading (SPAD)	Leaf area index	Relative growth rate (mg/g/day)	Net assimilation rate (g/m^2/day)	Carbon isotope discrimination (per mill)	Number o days taker for reaching critical stress leve
P_1	Vaishak (PTB 60)	74.97	28.11	3.70303	37.23	4.37	10.57	2.018923	22.14	10.89
P_2	Thottacheera	32.61	18.92	3.45128	40.17	3.08	11.34	2.206602	22.09	10.78
P_3	Kalladiaryan	72.07	17.91	3.75317	40.45	3.79	13.85	2.028908	22.34	11.78
P_4	Vyttila 6	203.39	30.66	4.05748	38.80	4.35	12.45	2.422381	22.29	14.56
P_5	Harsha (PTB 55)	59.44	17.94	4.19126	42.98	2.68	12.53	2.742171	23.27	10.00
P_6	Swarnaprabha (PTB 43)	71.10	16.45	3.57383	37.93	3.04	12.09	1.938750	22.91	15.33
P_1 x P_2	Vaishak (PTB 60) x Thottacheera	76.45	18.96	6.62344	40.85	6.08	15.03	3.451854	23.37	15.33
P_1 x P_3	Vaishak (PTB 60) x Kalladiaryan	69.36	17.91	7.04419	40.27	3.36	9.29	3.241174	22.94	15.00
P_1 x P_4	Vaishak (PTB 60) x Vyttila 6	76.33	32.14	6.38487	39.75	3.61	15.94	3.951972	23.39	14.00
P_1 x P_5	Vaishak (PTB 60) x Harsha (PTB 55)	87.06	19.62	6.03292	38.31	4.41	12.34	3.911210	22.77	15.33
P_1 x P_6	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	43.93	24.30	7.52608	39.89	3.79	13.49	5.330105	22.38	15.67
P_2 x P_3	Thottacheera x Kalladiaryan	52.60	10.47	5.13082	38.33	5.33	13.09	2.249453	22.76	13.11
P_2 x P_4	Thottacheera x Vyttila 6	106.45	26.08	7.66345	40.30	3.59	13.33	3.727774	22.98	10.11
P_2 x P_5	Thottacheera x Harsha (PTB 55)	51.91	19.42	7.79567	41.35	2.21	16.16	5.393720	22.77	11.00
P_2 x P_6	Thottacheera x Swarnaprabha (PTB 43)	73.45	9.83	9.28138	35.41	2.40	16.82	5.855777	23.46	10.00
P_3 x P_4	Kalladiaryan x Vyttila 6	103.65	10.61	7.85396	41.47	3.93	11.12	3.580941	22.81	13.00
P_3 x P_5	Kalladiaryan x Harsha (PTB 55)	90.04	10.16	6.43492	39.83	2.94	15.55	4.232630	22.97	13.67
P_3 x P_6	Kalladiaryan x Swarnaprabha (PTB 43)	101.89	14.85	6.08931	40.41	6.41	12.11	2.903917	22.41	12.67
P_4 x P_5	Vyttila 6 x Harsha (PTB 55)	97.63	29.78	7.89094	41.76	4.52	16.03	4.962495	22.26	15.67
P_4 x P_6	Vyttila 6 x Swarnaprabha (PTB 43)	212.53	37.50	5.91056	43.61	5.71	12.82	3.055829	22.55	15.00
P_5 x P_6	Harsha (PTB 55) x Swarnaprabha (PTB 43)	52.77	16.88	4.55660	44.38	2.29	13.40	2.744388	23.41	10.67
	General mean	86.17	20.40	5.9500	40.17	3.90	13.30	3.426237	22.77	13.03
	CD (0.05)	7.711	3.355	4.194	2.468	NS	NS	NS	0.58	0.284

Swarnaprabha (PTB 43) (-14.96) and Thottacheera x Swarnaprabha (PTB 43) (-11.868), had significant negative *sca* effects for plant height and the remaining thirteen hybrids recorded non-significant *sca* effects.

4.15.4 Panicle Length (cm)

Estimates of *gca* effects manifested by Vaishak (2.255) was significant and positive among the parents while for the parents Kalladiaryan (-1.031) and Thottacheera (-0.942) it was significant and negative. Among the hybrids *sca*effects ranged between -2.700 (Thottacheera x Vyttila 6) to 3.591 (Vyttila 6 x Swarnaprabha (PTB 43).

The hybrids Vyttila 6 x Swarnaprabha (PTB 43) (3.591), Vaishak (PTB 60) x Kalladiaryan (3.116), Vyttila 6 x Harsha (PTB 55) (2.617), Vaishak (PTB 60) x Harsha (PTB 55) (2.673) Thottacheera x Kalladiaryan (2.626) and Vaishak (PTB 60) x Thottacheera (2.242) showed significant positive *sca* effect while Thottacheera x Vyttila 6 (-2.700) showed significant negative *sca* effect.

4.15.4 Number of Spikelets Panicle^{-1}

Parents showing significant positive *gca* effects for number of spikelets panicle^{-1} were Vaishak (12.572) and Vyttila 6 (9.565) whereas Kalladiaryan (-8.365) and Thottacheera (-9.295) showed significant negative *gca* effects.

The hybrids Vaishak (PTB 60) x Thottacheera (34.024), Vyttila 6 x Harsha (PTB 55) (33.743), Vyttila 6 x Swarnaprabha (PTB 43) (20.468) and Vaishak (PTB 60) x Kalladiaryan (19.684) were found to have significant positive *sca* effect for number of spikelets panicle^{-1}, while Kalladiaryan x Harsha (PTB 55) (-20.743) and Thottacheera x Vyttila 6 (-28.710) were found to have significant negative *sca* effects among the hybrids.

4.15.5 Number of Filled Spikelets Panicle^{-1}

Positive and significant *gca* effect was expressed by Vyttila 6 (11.453) among the parents. Thottacheera and Kalladiaryan displayed significant negative *gca* effects of -6.943 and –9.046 respectively among the parents.

Table 71. Analysis of combining ability for twelve morphological traits of six parents and fifteen hybrids in rainfed upland rice

Sl.No.	Morphological traits	Source of variance		
		gca	*sca*	Error
1	Days to 50% flowering	85.5981**	44.9728**	0.9093
2	Number of productive tillers plant^{-1}	18.3499*	31.5334**	6.4488
3	Plant height at maturity (cm)	368.5646**	87.5289**	16.7942
4	Panicle length (cm)	12.3351**	6.6452*	0.9754
5	Number of spikelets panicle^{-1}	674.6042**	443.198**	84.4022
6	Number of filled grains panicle^{-1}	435.1601**	212.907**	70.8876
7	Spikelet sterility (%)	131.5389**	128.694**	43.7947
8	Grain weight panicle $^{-1}$(g)	0.0654**	0.0335**	0.0123
9	1000 grain weight (g)	8.4821**	13.7721**	0.4847
10	Grain yield plant^{-1} (g)	25.6282*	40.8687**	9.3808
11	Straw yield plant^{-1} (g)	48.7428**	28.4088**	10.6302
12	Harvest index (%)	24.7661ns	63.1913*	27.6148

*Significant at 5 per cent level

** Significant at 1 per cent level

Table 72. Estimates of general combining ability of the parents for morphological traits in rainfed upland rice (*Oryza sativa* L.)

Sl.No	Parents	Days to 50% flowering	Number of productive tillers plant^{-1}	Plant height at maturity (cm)	Panicle length (cm)	Number of spikelets panicle^{-1}	Number of filled grains panicle^{-1}	Spikelet sterility (%)
1	Vaishak (PTB 60)	1.931**	-0.578	12.497**	2.255**	12.572**	3.008	6.578**
2	Thottacheera	-4.861**	0.239	-1.411	-0.942**	-9.295**	-6.943*	0.491
3	Kalladiaryan	-1.778**	2.189*	-0.603	-1.031**	-8.365**	-9.046**	2.636
4	Vyttila 6	4.389**	1.222	-3.144**	0.565	9.565**	11.453**	-3.322
5	Harsha (PTB 55)	-1.194**	-1.34	-7.853**	-0.423	-0.551	1.294	-2.775
6	Swarnaprabha (PTB 43)	1.514**	-1.728*	0.514	-0.424	-3.926	0.234	-3.607
	S.E.(gi)	0.3078	0.8196	1.3226	0.3188	2.9651	2.7174	2.1359
	S.E. (gi-gj)	0.4768	1.2697	2.049	0.4938	4.5935	4.2097	3.3089
	C.D. (gi-gj) at 5%	0.9636	2.56606	4.1410	0.9979	9.2834	8.50	6.6872
	C.D. (gi-gj) at 1%	1.2906	3.4370	5.5466	1.3367	12.4300	11.3900	8.9571

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Table 72 (contd.) Estimates of general combining ability of the parents for morphological traits in rainfed upland rice (*Oryza sativa* L.)

Sl.No.	Parents	Grain weight panicle^{-1} (g)	1000 grain weight (g)	Grain yield plant^{-1} (g)	Straw yield plant^{-1} (g)	Harvest index (%)
1	Vaishak (PTB 60)	0.022	-1.482**	-0.210	1.047	-2.032
2	Thottacheera	-0.023	1.177**	-0.587	-1.494	0.700
3	Kalladiaryan	-0.160**	-0.640**	-0.746	0.889**	-1.463
4	Vyttila 6	0.091*	0.762**	3.322**	4.014*	1.050
5	Harsha (PTB 55)	0.076*	0.689**	0.218	-2.619	2.618
6	Swarnaprabha (PTB 43)	-0.006	-0.506*	-1.997	-1.836	-0.873
	S.E.(gi) (i ≠j)	0.0358	0.2247	0.9885	1.0523	1.696
	S.E. (gi-gj) (i ≠ j)	0.0554	0.3481	1.5314	1.6302	2.6275
	C.D. (gi-gj) at 5%	0.1119	0.7035	3.0949	3.2946	5.3101
	C.D. (gi-gj) at 1%	0.1499	0.9423	4.1454	4.4129	7.1126

*Significant at 5 per cent level, ** Significant at 1 per cent

Table 73. Estimates of specific combining ability of the hybrids for morphological traits in rainfed upland rice (*Oryza sativa* L.)

Sl.No	Hybrids	Days to 50% flowering	Number of productive tillers plant^{-1}	Plant height at maturity (cm)	Panicle length (cm)	Number of spikelets panicle^{-1}	Number of filled grains panicle^{-1}
1	Vaishak (PTB 60) x Thottacheera	1.423	6.469**	-5.518	2.242*	34.024**	15.346
2	Vaishak (PTB 60) x Kalladiaryan	0.339	2.986	-0.860	3.116**	19.684*	-7.911
3	Vaishak (PTB 60) x Vyttila 6	-7.494**	0.286	6.815	0.346	5.237	8.157
4	Vaishak (PTB 60) x Harsha (PTB 55)	-2.577**	-2.214	14.190**	2.673**	15.600	5.363
5	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	-7.619**	3.769	-4.310	1.684	0.994	-2.691
6	Thottacheera x Kalladiaryan	3.798**	4.502*	0.849	2.626**	7.145	1.250
7	Thottacheera x Vyttila 6	-10.369**	3.336	7.124	-2.700**	-28.710**	-28.532**
8	Thottacheera x Harsha (PTB 55)	-5.119**	2.969	-5.235	-0.337	-8.247	-8.533
9	Thottacheera x Swarnaprabha (PTB 43)	-7.494**	-1.781	-11.868**	-1.623	-8.806	-6.006
10	Kalladiaryan x Vyttila 6	-4.119**	0.986	0.715	-1.506	-2.959	0.444
11	Kalladiaryan x Harsha (PTB 55)	-2.202*	4.619*	6.824	-0.715	-20.743*	-13.831
12	Kalladiaryan x Swarnaprabha (PTB 43)	-1.244	3.136	7.057	-1.114	-9.602	-10.704
13	Vyttila 6 x Harsha (PTB 55)	5.631**	6.186**	3.699	2.617**	33.743**	25.542**
14	Vyttila 6 x Swarnaprabha (PTB 43)	3.589**	5.036*	-7.001	3.591**	20.468*	16.365*
15	Harsha (PTB 55) x Swarnaprabha (PTB 43)	-3.494**	-1.998	-14.960**	-0.031	-2.439	1.267
	S.E.(sij)\	0.8258	2.1992	3.549	0.8553	7.9562	7.2915
	C.D. (sij-sik) at 5% i≠j≠k≠1	2.5492	6.7893	10.9562	2.6404	24.5618	22.5097
	C.D. (sij-sik) at 1%	3.4146	9.0938	14.6751	3.5366	32.8989	30.1503
	C.D. (sij-skl) at 5%	2.3603	6.2857	10.1436	2.4446	22.7398	20.8399
	C.D. (sij-skl) at 1%	3.1615	8.4193	13.5867	3.2743	30.4586	27.9137

Table 73 (contd.) Estimates of specific combining ability of the hybrids for morphological traits in rainfed upland rice (*Oryza sativa* L.)

Sl.No	Hybrids	Spikelet sterility (%)	Grain weight panicle $^{-1}$(g)	1000 grain weight (g)	Grain yield plant^{-1} (g)	Straw yield plant^{-1} (g)	Harvest index (%)
1	Vaishak (PTB 60) x Thottacheera	8.683	-0.073	-3.773**	5.852*	3.815	0.809
2	Vaishak (PTB 60) x Kalladiaryan	25.362**	-0.265**	-3.702**	-1.181	4.632	0.196
3	Vaishak (PTB 60) x Vyttila 6	-2.879	-0.167	-0.171	0.099	-4.693	-0.218
4	Vaishak (PTB 60) x Harsha (PTB 55)	6.304	0.269**	-0.009	1.153	3.140	0.469
5	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	6.760	-0.186	-1.970**	2.389	1.224	0.453
6	Thottacheera x Kalladiaryan	8.806	0.070	-2.894**	3.733	6.974*	0.806
7	Thottacheera x Vyttila 6	8.956	0.033	5.269**	0.751	2.382	0.648
8	Thottacheera x Harsha (PTB 55)	1.230	-0.028	-0.728	2.287	-1.251	0.253
9	Thottacheera x Swarnaprabha (PTB 43)	-3.079	0.143	3.949**	1.167	-3.568	-0.092
10	Kalladiaryan x Vyttila 6	-4.670	-0.228*	-5.479**	-1.695	2.865	0.218
11	Kalladiaryan x Harsha (PTB 55)	-3.261	-0.026	2.243**	3.008	-1.768	0.189
12	Kalladiaryan x Swarnaprabha (PTB 43)	3.850	-0.113	-0.945	0.488	3.315	0.349
13	Vyttila 6 x Harsha (PTB 55)	2.266	0.116	1.425*	13.177**	6.174*	1.371
14	Vyttila 6 x Swarnaprabha (PTB 43)	1.129	0.137	-0.214	9.136**	6.590*	1.132
15	Harsha (PTB 55) x Swarnaprabha (PTB 43)	-4.060	-0.142	-5.060**	-4.990	-6.443*	-0.881
	S.E.(sij)	5.7311	0.0959	0.6029	2.6525	2.8236	4.5509
	C.D. (sij-sik) at 5%	17.6928	0.2962	1.8613	8.1884	8.7167	14.0493
	C.D. (sij-sik) at 1%	23.6984	0.3968	2.4931	10.9679	11.6755	18.8182
	C.D. (sij-skl) at 5%	16.3804	0.2742	1.7231	7.5811	8.0702	13.0071
	C.D. (sij-skl) at 1%	21.9405	0.3673	2.3079	10.1545	10.8095	17.4222

*Significant at 5 per cent level

**Significant at 1 per cent level

Only two hybrid combinations *viz*., Vyttila 6 x Harsha (PTB 55) (25.054) and Vyttila 6 x Swarnaprabha (PTB 43) (16.362) had significant positive *sca* effects for number of filled spikelets panicle^{-1} while the hybrid Thottacheera x Vyttila 6 displayed significant negative *sca* effects. All other hybrids displayed non-significant *sca* effects.

4.15.6 Spikelet Sterility (%)

Among the parents only Vaishak exhibited significant positive *gca* effect for spikelet sterility. All other parents displayed non-significant *gca* effects.

Among the hybrids Vaishak (PTB 60) x Kalladiaryan (25.362) exhibited significant positive *sca* effects for spikelet sterility percentage.

4.15.7 Grain Weight Panicle^{-1} (g)

Among the parents Harsha (0.076) and Vyttila 6 (0.091) had significant positive *gca* effects while Kalladiaryan (-0.159) exhibited significant negative *gca* effects.

Among the hybrids Vaishak (PTB 60) x Harsha (PTB 55) (0.269) exhibited significant positive *sca* effects while Kalladiaryan x Vyttila 6 (-0.228) and Vaishak (PTB 60) x Kalladiaryan (-0.265) exhihited significant negative *sca* effects.

4.15.8 1000 Grain Weight (g)

Among the parents significant and positive *gca* effects were exhibited by Thottacheera (1.177), Vyttila 6 (0.762) and Harsha (0.689) whereas significant negative *gca* effects were observed in Kalladiaryan (-0.640) and Swarnaprabha (PTB 43) (-0.506).

The hybrids Thottacheera x Vyttila 6 (5.269), Thottacheera x Swarnaprabha (PTB 43) (3.949), Kalladiaryan x Harsha (PTB 55) (2.243) and Vyttila 6 x Harsha (PTB 55) (1.425) exhibited significant positive *sca* effects.

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4.15.9 Grain Yield Plant $^{-1}$(g)

Among the parents Vyttila 6 alone (3.322) had significant positive *gca* effect while other parents exhibited non-significant *gca* effect.

Among the hybrids Vyttila 6 x Harsha (PTB 55) (13.177) and Vyttila 6 x Swarnaprabha (PTB 43) (9.136) exhibited significant positive *sca* effects.

4.15.10 Straw Yield Plant^{-1} (g)

Among the parents Vyttila 6 (4.014) and Kalladiaryan (0.889) exhibited significant positive *gca* effects. All the other parents recorded non-significant *gca* effects. Maximum positive *sca* effects were exhibited by Thottacheera x Kalladiaryan (6.974), Vyttila 6 x Swarnaprabha (PTB 43) (6.590) and Vyttila 6 x Harsha (PTB 55) (6.174) among the hybrids. Significant negative *sca* effects was observed in Harsha (PTB55) x Swarnaprabha (PTB 43) (-6.443) for straw yield plant^{-1}.

4.15.11Harvest Index (%)

None of the hybrids exhibited significant *sca* effects for the trait harvest index.

4.16 ANALYSIS OF VARIANCE FOR PHYSIOLOGICAL AND BIOCHEMICAL TRAITS

The anova is furnished in Table 69.

The mean values of all the genotypes for physiological and biochemical traits are presented in Table 70. Anova indicates that highly significant differences exsist among genotypes for the characters water use efficiency (WUE) (g/l), relative leaf water content (RLWC), proline content (mg/g), cell membrane stability index, chlorophyll content(mg/g), chlorophyll stability index, leaf temperature (^{0}C), transpiration rate (TR) (mmolesH_2O/m^2/sec), stomatal conductance (SC) (mmol mol^{-2} s^{-1}), leaf soluble protein content(mg/g), chlorophyll meter reading (SPAD), leaf area index (LAI), carbon isotope discrimination (per mil) and number of days taken for reaching critical stress level indicating ample variability among the genotypes under study whereas non-significant differences were noted for radiation use efficiency (RUE), relative growth rate (RGR) (mg/g/day) and net assimilation rate (NAR) (g/cm^2/day) under upland condition.

4.17 ANALYSIS OF VARIANCE FOR COMBINING ABILITY FOR PHYSIOLOGICAL AND BIOCHEMICAL TRAITS IN UPLAND RICE (*Oryza sativa* L.)

Analysis of variance for combining ability in17 characters are presented in Table74. Among the parents and among the crosses there were significant differences for water use efficiency (WUE)g/l, relative leaf water content (RLWC), proline content (mg/g), cell membrane stability index, chlorophyll content (mg/g), chlorophyll stability index, leaf temperature, transpiration rate, stomatal conductance, leaf soluble protein content (mg/g), chlorophyll meter reading (SPAD), leaf area index (LAI), carbon isotope discrimination (per mill) and number of days taken for reaching critical stress level whereas non-significant differences were noted for radiation use efficiency (RUE), relative growth rate (RGR) (mg/g/day) and net assimilation rate (NAR) (g/cm^2/day).

4.17.1 Water Use Efficiency (WUE) (g/L)

Among the parents Vyttila 6 (0.515) had significant positive *gca* effect for water use efficiency. The variety Swarnaprabha (-0.385), showed significant negative *gca* effects (Table 75).

Among the hybrids high positive and significant *sca* effects were shown by Vyttila 6 x Harsha (PTB 55) (1.371), Vyttila 6 x Swarnaprabha (PTB 43) (1.132), Vaishak (PTB 60) x Thottacheera (0.809) and Thottacheera x Kalladiaryan (0.806) whereas significant negative *sca* effect was exhibited by Harsha x Swarnaprabha (-0.881) (Table 76).

4.17.2 Relative Leaf Water Content (RLWC)

Among the parents Vyttila 6 (2.05) had significant positive *gca* effect. The variety Kalladiaryan (-1.805), showed significant negative *gca* effects.

Among the hybrids negative and significant *sca* effect was shown by Kalladiaryan x Harsha (-10.015).

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Table 74. Analysis of variance of combining ability for physiological and biochemical traits in upland rice

Sl. No.	Physiological and biochemical traits	Source of variance		
		gca	*sca*	Error
		d.f.=5	d.f.=15	d.f.=40
1	Water use efficiency (WUE) (g/l)	0.7257**	0.8416**	0.1819
2	Relative leaf water content (RLWC) (%)	23.5252*	11.8759	7.3313
3	Proline content (mg/g)	0.0039**	0.0021**	0.0001
4	Cell membrane stability index	118.6358**	105.483**	6.2315
5	chlorophyll a (mg/g)	0.0198**	0.0297**	0.0004
6	chlorophyll b (mg/g)	0.1956**	0.1479**	0.0067
7	carotenoides (mg/g)	0.0003*	0.0006**	0.0001
8	Total chlorophyll content(a+b) (mg/g)	0.24001**	0.26549**	0.00976
9	Chlorophyll stability index	18.9299**	79.8554**	4.8516
10	Leaf temperature (^{O}C)	5.4314**	5.1209**	0.0191
11	Transpiration rate (TR) (mmolesH2O/m2/sec)	0.3601**	0.5747**	0.0094
12	Stomatal conductance (SC) (mmolesH2O/m2/sec)	5370.8104**	929.08**	7.2927
13	Leaf soluble protein content(mg/g)	152.505**	30.8007**	1.3759
14	Chlorophyll meter reading (SPAD)	5.0318ns	4.2637*	2.1537
15	Leaf area index (LAI)	1.3466ns	1.5158*	0.7461
16	Carbon isotope discrimination (per mil)	0.0902ns	0.2288**	0.0413
17	Number of days taken for reaching critical stress level	5.1208**	4.2402**	0.0097

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 75. Estimates of general combining ability of the parents for physiological and biochemical traits in rice (*Oryza sativa* L.)

Sl.No	Name of parents	Water use efficiency (WUE) (g/l)	Relative leaf water content (RLWC) (%)	Proline content (mg/g)	Cell membrane stability index	Chlorophyll a (mg/g)	Chlorophyll b (mg/g)	Carotenoides content (mg/g)	Total chlorophyll content (mg/g)	Chlorophyll stability index	Leaf temperatu (°C)
1	Vaishak (PTB 60)	0.026	1.393	0.013**	3.391**	0.043**	0.097**	-0.008**	0.141**	-0.786	1.200**
2	Thottacheera	-0.028	0.397	-0.003	0.939	-0.025**	0.093**	0.003	0.070**	-0.563	0.770**
3	Kalladiaryan	0.060	-1.805*	0.015**	-3.066**	-0.044**	0.136**	-0.002	0.052**	-0.699	-0.489**
4	Vyttila 6	0.515**	2.405**	0.016**	4.943**	0.070**	0.026	0.008**	0.090**	3.101**	0.018
5	Harsha (PTB 55)	-0.188	-1.788*	-0.042**	-5.185**	-0.054**	- 0.284**	0.003	-0.340**	-0.871	-0.764**
6	Swarnaprabha(PTB43)	-0.385**	-0.602	0.001	-1.022	0.009	-0.068*	-0.004	-0.020**	-0.182	-0.735**
	S.E.(gi)	0.1377	0.8739	0.0031	0.8057	0.0068	0.0264	0.0028	0.0318	0.7109	0.0446
	S.E. (gi-gj)	0.2132	1.3538	0.0049	1.2482	0.0105	0.0408	0.0043	0.0800	1.1013	0.0690
	C.D. (gi-gj) at 5%	0.4308	2.7360	0.0099	2.5226	0.0212	0.0824	0.0086	0.1300	2.2257	0.13944
	C.D. (gi-gj) at 1%	0.5771	3.6647	0.0132	3.3788	0.0284	0.1104	0.0116	0.1990	2.9812	0.1867

Table 75 (Contd.) Estimates of General combining ability of the parents for physiological and biochemical traits in rice (*Oryza sativa* L.)

Sl.No	Name of parents	Transpiration rate (TR)	Stomatal conductance (SC)	Leaf soluble protein content (mg/g)	Number of days taken for reaching critical stress level
1	Vaishak (PTB 60)	0.207**	-12.518**	3.289**	0.741**
2	Thottacheera	-0.266**	-22.141**	-2.530**	-1.259**
3	Kalladiaryan	0.046	-5.193**	-5.377**	-0.023
4	Vyttila 6	0.273**	50.022**	6.825**	0.713**
5	Harsha (PTB 55)	-0.145**	-13.116**	-1.387**	-0.606**
6	Swarnaprabha (PTB 43)	-0.115**	2.946**	-0.820*	0.435**
	S.E.(gi)	0.0313	0.8716	0.3786	0.0317
	S.E. (gi-gj)	0.0485	1.3502	0.5865	0.0492
	C.D. (gi-gj) at 5%	0.09801	2.72875	1.18531	0.09943
	C.D. (gi-gj) at 1%	0.13128	3.65499	1.58765	0.13318

Table 76. Estimates of specific combining ability of the parents for physiological and biochemical traits in rice (*Oryza sativa* L.)

Sl.No	Hybrids/Traits	Water use efficiency (WUE) (g/l)	Relative leaf water content (RLWC) (%)	Proline content (mg/g)	Cell membrane stability index	chlorophyll a content (mg/g)	chlorophyll b content (mg/g)
1	Vaishak (PTB 60) x Thottacheera	0.809*	-0.772	0.013	6.434**	0.019	0.251**
2	Vaishak (PTB 60) x Kalladiaryan	0.196	-0.314	0.113**	1.271	0.032	0.258**
3	Vaishak (PTB 60) x Vyttila 6	-0.218	-0.310	0.023*	2.219	-0.064**	0.216**
4	Vaishak (PTB 60) x Harsha (PTB 55)	0.469	3.088	-0.071**	8.570**	0.147**	-0.212**
5	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	0.453	3.692	0.002	12.410**	0.041*	-0.201**
6	Thottacheera x Kalladiaryan	0.806*	0.254	-0.015	-8.327**	0.107**	0.203**
7	Thottacheera x Vyttila 6	0.648	-0.538	-0.070**	-16.499**	0.060**	-0.395**
8	Thottacheera x Harsha (PTB 55)	0.253	0.981	0.044**	7.541**	-0.097**	-0.251**
9	Thottacheera x Swarnaprabha (PTB 43)	-0.092	-1.872	0.015	-4.984*	-0.172**	-0.544**
10	Kalladiaryan x Vyttila 6	0.218	1.864	-0.034**	5.043*	0.098**	-0.266**
11	Kalladiaryan x Harsha (PTB 55)	0.189	-10.015**	0.007	-3.981	-0.522**	-0.473**
12	Kalladiaryan x Swarnaprabha (PTB 43)	0.349	2.499	-0.004	-12.868**	0.077**	0.194**
13	Vyttila 6 x Harsha (PTB 55)	1.371**	0.363	0.039**	2.333	0.067**	0.759**
14	Vyttila 6 x Swarnaprabha (PTB 43)	1.132**	-0.759	0.011	-0.236	-0.002	0.138
15	Harsha (PTB 55) x Swarnaprabha (PTB 43)	-0.881*	-2.421	-0.025**	-13.324**	-0.005	-0.289**
	S.E.(sij)	0.3694	2.3449	0.0084	2.1619	0.0181	0.0707
	C.D. (sij-sik) at 5%	1.140248	7.2390	0.0260	6.6739	0.0559	0.2184
	C.D. (sij-sik) at 1%	1.5272	9.6962	0.0349	8.9393	0.0749	0.2926
	C.D. (sij-skl) at 5%	1.0557	6.7020	0.0240	6.1788	0.0517	0.2023
	C.D. (sij-skl) at 1%	1.4141	8.9769	0.0322	8.2761	0.0692	0.2709

Table76 (Contd.).Estimates of specific combining ability of the parents for physiological and biochemical traits in rice(*Oryza sativa* L.)

Sl.No	Hybrids/Traits	Carotenoides content (mg/g)	Total chlorophyll content (a+b) (mg/g)	Chlorophyll stability index	Leaf temperature (^{O}C)	Transpiration r ate (TR)	Stomatal conductance (SC)
1	Vaishak (PTB 60) x Thottacheera	-0.003	0.270**	9.481**	1.044**	0.216*	24.932**
2	Vaishak (PTB 60) x Kalladiaryan	-0.002	0.331**	2.927	2.302**	1.019**	0.901
3	Vaishak (PTB 60) x Vyttila 6	-0.005	0.155	5.097*	3.275**	0.178*	-47.344**
4	Vaishak (PTB 60) x Harsha (PTB 55)	0.026**	-0.065	5.049*	1.010**	0.521**	26.520**
5	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	0.015*	-0.199*	11.556**	0.382**	-0.799**	-32.668**
6	Thottacheera x Kalladiaryan	-0.010	0.351**	5.997**	-0.928**	-0.317**	-6.240*
7	Thottacheera x Vyttila 6	0.000	-0.332**	4.342*	-0.348**	0.116**	-7.601**
8	Thottacheera x Harsha (PTB 55)	-0.001	-0.349**	-3.269	2.800**	0.073	0.990
9	Thottacheera x Swarnaprabha (PTB 43)	0.035**	-0.756**	-13.608**	3.619**	0.921**	6.475**
10	Kalladiaryan x Vyttila 6	-0.012	-0.456**	-1.528	1.477**	0.639**	-27.356**
11	Kalladiaryan x Harsha (PTB 55)	0.026**	-0.954**	-15.676**	-0.095	0.676**	22.175**
12	Kalladiaryan x Swarnaprabha (PTB 43)	0.000	0.274**	4.200*	-0.403**	0.337**	17.960**
13	Vyttila 6 x Harsha (PTB 55)	-0.010	0.827**	5.529**	-1.055**	-0.436**	-25.446**
14	Vyttila 6 x Swarnaprabha (PTB 43)	0.016*	0.406**	-0.546	-0.890**	0.817**	73.391**
15	Harsha (PTB 55) x Swarnaprabha (PTB 43)	-0.073**	-0.333**	3.970*	-1.875**	0.465**	-23.237**
	S.E.(sij)	0.0074	0.0875	1.9075	0.1196	0.0840	2.3387
	C.D. (sij-sik) at 5%	0.02283	0.2803	5.8887	0.3690	0.2592	7.2198
	C.D. (sij-sik) at 1%	0.0305	0.3890	7.8876	0.4942	0.3473	9.6704
	C.D. (sij-skl) at 5%	0.02122	0.2595	5.4520	0.3417	0.2400	6.6842
	C.D. (sij-skl) at 1%	0.02842	0.3602	7.3026	0.4577	0.3215	8.9531

Table 76(contd.)Estimates of specific combining ability of the parents for physiological and biochemical traits in rice (*Oryza sativa*L.)

Sl.No	Hybrids/Traits	Leaf soluble protein content (mg/g)	Chlorophyll meter reading (SPAD)	Leaf area index (LAI)	Carbon isotope discrimination	Number of days taken for raching critical stress level
1	Vaishak (PTB 60) x Thottacheera	-2.201*	2.213	2.037*	0.619**	2.825**
2	Vaishak (PTB 60) x Kalladiaryan	-0.408	1.054	-1.154	0.312	1.256**
3	Vaishak (PTB 60) x Vyttila 6	1.622	0.122	-0.972	0.761**	-0.480**
4	Vaishak (PTB 60) x Harsha (PTB 55)	-2.688*	-2.210	0.867	-0.131	2.173**
5	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	1.423	0.879	-0.371	-0.436*	1.464**
6	Thottacheera x Kalladiaryan	-2.032	-1.271	1.336	0.080	1.367**
7	Thottacheera x Vyttila 6	1.382	0.290	-0.462	0.300	-2.369**
8	Thottacheera x Harsha (PTB 55)	2.928**	0.452	-0.799	-0.179	-0.161
9	Thottacheera x Swarnaprabha (PTB 43)	-7.223**	-3.980**	-1.233	0.597**	-2.202**
10	Kalladiaryan x Vyttila 6	-11.244**	0.885	-0.602	0.246	-0.716**
11	Kalladiaryan x Harsha (PTB 55)	-3.476**	-1.647	-0.543	0.137	1.270**
12	Kalladiaryan x Swarnaprabha (PTB 43)	0.642	0.441	2.304**	-0.333	-0.772**
13	Vyttila 6 x Harsha (PTB 55)	3.933**	-0.125	0.973	-0.571**	2.534**
14	Vyttila 6 x Swarnaprabha (PTB 43)	11.093**	3.230**	1.544*	-0.192	0.825**
15	Harsha (PTB 55) x Swarnaprabha (PTB 43)	-1.314	3.111**	-0.839	0.395*	-2.188**
	S.E.(Sij)	1.0159	1.2709	0.7481	0.1761	0.0852
	C.D. (sij-sik) at 5%	3.1359	3.9235	2.3093	0.5434	0.2629
	C.D. (sij-sik) at 1%	4.2004	5.2553	3.0932	0.7279	0.3521
	C.D. (sij-skl) at 5%	2.9033	3.6325	2.1380	0.5032	0.2433
	C.D. (sij-skl) at 1%	3.8888	4.8655	2.8637	0.6740	0.3259

4.17.3 Proline Content (mg/g)

Vyttila 6 (0.016), Kalladiaryan (0.015) and Vaishak (0.013) had significant positive *gca* effects among the parents while Harsha (-0.042) showed significant negative *gca* effect.

Among the 15 hybrids evaluated, 8 hybrids manifested significant *sca* effects ranging from -0.071 in the cross Vaishak x Harsha to 0.113 in the cross Vaishak x Kalladiaryan. The effects were positive and significant in Vaishak x Kalladiaryan (0.113), Vaishak x Vytilla 6 (0.023), Vyttila 6 x Harsha (0.039), Thottacheera x Harsha (0.044) and negatively significant in Thottacheera x Kalladiaryan (-0.015), Harsha x Swarnaprabha (-0.025), Kalladiaryan x Vyttila 6 (-0.034), Thottacheera x Vyttila 6 (-0.070) and Vaishak x Harsha (-0.071).

4.17.4 Cell Membrane Stability Index (%)

Among the parents Vyttila 6 (4.943) and Vaishak (PTB 60) (3.391), had significant positive gca effects whereas Kalladiaryan (-3.066) and Harsha (PTB 55) (-5.185) showed significant negative *gca* effects.

Among the hybrids high positive and significant *sca* effects were shown by Vaishak (PTB 60) x Swarnaprabha (PTB 43) (12.410), Vaishak (PTB 60) x Harsha (PTB 55) (8.570), Thottacheera x Harsha (PTB 55) (7.541), Vaishak (PTB 60) x Thottacheera (6.434) and Kalladiaryan x Vyttila 6 (5.043) whereas significant negative *sca* effects were exhibited by Thottacheera x Swarnaprabha (PTB 43) (-4.984), Thottacheera x Kalladiaryan (-8.327), Kalladiaryan x Swarnaprabha (PTB 43) (-12.868), Harsha (PTB 55) x Swarnaprabha (PTB 43) (-13.324) and Thottacheera x Vyttila 6 (-16.499).

4.17.5 Chlorophyll a Content (mg/g)

Vyttila 6 (0.070) and Vaishak (PTB 60) (0.043) exhibited significant positive *gca* effects among the parents, whereas significant negative *gca* effects were found to be present in Thottacheera (-0.025), Kalladiaryan (-0.044) and Harsha (-0.054).

Among the hybrids significant positive *sca* effects were exhibited by Vaishak (PTB 60) x Harsha (PTB 55) (0.147), Kalladiaryan x Vyttila 6 (0.098), Kalladiaryan x Swarnaprabha (PTB 43) (0.077), Vyttila 6 x Harsha (PTB 55) (0.067), Thottacheera x Vyttila 6 (0.060), Vaishak (PTB 60) x Swarnaprabha (PTB 43) (0.041) and Thottacheera x Kalladiaryan (0.0107).

4.17.6 Chlorophyll b Content (mg/g)

The parents Kalladiaryan(0.136), Vaishak (PTB 60) (0.097) and Thottacheera (0.093) had significant positive *gca* effects and Harsha (PTB 55) (-0.284) and Swarnaprabha (PTB 43) (-0.068) had significant negative *gca* effects. All the hybrids showed significant *sca* effects except Vyttila 6 x Swarnaprabha (PTB 43) for chlorophyll b content. Among the hybrids Vyttila 6 x Harsha (PTB 55) (0.759), Vaishak (PTB 60) x Kalladiaryan (0.258), Vaishak (PTB 60) x Thottacheera (0.251),Vaishak (PTB 60) x Vyttila 6 (0.216), Thottacheera x Kalladiaryan (0.203) and Kalladiaryan x Swarnaprabha (PTB 43) (0.194) exhibited significant positive *sca* effects. Significant negative *sca* effects were recorded in the hybrids Vaishak (PTB 60) x Swarnaprabha (PTB 43) (-0.201), Vaishak (PTB 60) x Harsha (PTB 55) (-0.212), Thottacheera x Harsha (PTB 55) (-0.251), Kalladiaryan x Vyttila 6 (-0.266), Harsha (PTB 55) x Swarnaprabha (PTB 43) (-0.289), Thottacheera x Vyttila 6 (-0.395), Kalladiaryan x Harsha (PTB 55) (-0.473) and Thottacheera x Swarnaprabha (PTB 43) (-0.544).

4.17.7 Carotenides (mg/g) Content

The parentVyttila 6 (0.008) exhibited significant positive *gca* effect while Vaishak (PTB 60) (-0.008) showed significant negative *gca* effect among parents.

For carotenoides content Thottacheera x Swarnaprabha (PTB 43) (0.035), Vaishak (PTB 60) x Harsha (PTB 55) (0.026), Kalladiaryan x Harsha (PTB 55) (0.026), Vyttila 6 x Swarnaprabha (PTB 43) (0.016) and Vaishak (PTB 60) x Swarnaprabha (0.015) exhibited significant positive *sca* effects while only one hybrid *viz.,* Harsha (PTB 55) x Swarnaprabha (PTB 43) (-0.073) displayed significant negative *sca* effect among the hybrids.

4.17.8 Total Chlorophyll Content (mg/g)

Among the parents Vaishak (0.14), Vyttila 6 (0.09), Thottacheera (0.07) and Kalladiaryan (0.05) exhibited positive *gca* effects while Harsha (PTB 55) (-0.34) and Swarnaprabha (-0.02) showed negative *gca* effects.

The *sca* effects varied from -0.954 (Kalladiaryan x Harsha) to 0.827 (Vyttila 6 x Harsha) among the hybrids. Six hybrids showed significant positive *sca* effects whereas seven hybrids exhibited significant negative *sca* effects.

4.17.9 Chlorophyll Stability Index

Vyttila 6 (3.101) had maximum significant positive*gca* effects whereas all other parents displayed non-significant *gca* effects.

Among the hybrids maximum significant positive *sca* effects were exhibited for chlorophyll stability index by Vaishak (PTB 60) x Swarnaprabha (PTB 43) (11.55), Vaishak (PTB 60) x Thottacheera (9.48), Vyttila 6 x Harsha (PTB 55) (5.52), Thottacheera x Kalladiaryan (5.99), Vaishak (PTB 60) x Vyttila 6 (5.09), Vaishak (PTB 60) x Harsha (PTB 55) (5.04), Thottacheera x Vyttila 6 (4.34) Kalladiaryan x Swarnaprabha (PTB 43) (4.20) and Harsha (PTB 55) x Swarnaprabha (PTB 43) (3.97) whereas significant negative *sca* effects were displayed by Thottacheera x Swarnaprabha (PTB 43) (-13.60) and Kalladiaryan x Harsha (PTB 55) (-15.67).

4.17.10 Leaf Temperature (^{0}C)

Among the parents Vaishak (1.20) and Thottacheera (0.77) had maximum significant positive *gca* effects whereas negative *gca* effects were present in Kalladiaryan (-0.48), Swarnaprabha (PTB 43) (-0.73) and Harsha (PTB 55) (-0.76).All the hybrids showed significant *sca* effects for leaf temperature.

The hybrids Thottacheera x Swarnaprabha (PTB 43) (3.61), Vaishak (PTB 60) x Vyttila 6 (3.27), Vaishak (PTB 60) x Kalladiaryan (2.30), Thottacheera x Harsha (PTB 55) (2.80), Kalladiaryan x Vyttila 6 (1.47), Vaishak (PTB 60) x Thottacheera (1.04), Vaishak (PTB 60) x Harsha (PTB 55) (1.01), Kalladiaryan x Swarnaprabha (PTB 43) (0.40) and Vaishak (PTB 60) x Swarnaprabha (PTB 43)

(0.38) showed significant positive *sca* effects whereas significant negative *sca* effects were exhibited by Thottacheera x Vyttila 6 (-0.34), Kalladiaryan x Swarnaprabha (PTB 43) (-0.40), Vyttila 6 x Swarnaprabha (PTB 43) (-0.89), Thottacheera x Kalladiaryan (-0.92), Vyttila 6 x Harsha (PTB 55) (-1.05) and Harsha (PTB 55) x Swarnaprabha (PTB 43) (-1.87).

4.17.11Transpiration Rate

Among the parents Vyttila 6 (0.273) andVaishak (0.207) exhibited significant positive *gca* effects while Thottacheera (-0.26), Harsha (PTB 55)(-0.145) and Swarnaprabha (-0.115) showed significant negative *gca* effects.

Significant positive *sca* effects were recorded in 11 out of 15 hybrids while three hybrids exhibited significant negative *sca* effects. The maximum significant positive *sca* effect was displayed by Vaishak (PTB 60) x Kalladiaryan (1.019) and the minimum by Thottacheera x Vyttila 6 (0.11). Significant negative *sca* effects were exhibited by Thottacheera x Kalladiaryan (-0.317) Vyttila 6 x Harsha (PTB 55) (-0.436) and Vaishak (PTB 60) x Swarnaprabha (PTB 43) (-0.799).

4.17.12 Stomatal Conductance (SC)

Among the parents significant positive *gca* effects were displayed by Vyttila 6 (50.022) and Swarnaprabha (PTB 43) (2.946) while Kalladiaryan (-5.193), Vaishak (-12.518), Harsha (PTB 55) (-13.116) and Thottacheera (-22.141) displayed significant negative *gca* effects.

Among the 15 hybrids thirteen hybrids exhibited significant *sca* effects, six being positive and seven being negative. The maximum significant positive *sca* effects were displayed by Vyttila 6 x Swarnaprabha (PTB 43) (73.391) followed by Vaishak (PTB 60) x Harsha (PTB 55) (26.520). The lowest significant negative *sca* effects were exhibited by Vaishak (PTB 60) x Swarnaprabha (PTB 43) (-32.668) and Vaishak (PTB 60) x Vyttila 6 (-47.344).

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4.17.13Leaf Soluble Protein Content (mg/g)

Vyttila 6 (6.825) and Vaishak (3.289) had maximum significant positive *gca* effects whereas significant negative *gca* effects were displayed by Swarnaprabha (-0.820), Harsha(-1.387), Thottacheera (-2.530) and Kalladiaryan,(-5.377).

Among the hybrids significant positive *sca* effects were exhibited for leaf soluble protein content by Vyttila 6 x Swarnaprabha (PTB 43) (11.093), Vyttila 6 x Harsha (PTB 55) (3.933) and Thottacheera x Harsha (PTB 55) (2.928) whereas significant negative *sca* effects were displayed by Vaishak (PTB 60) x Thottacheera (-2.201), Vaishak (PTB 60) x Harsha (PTB 55) (-2.688), Kalladiaryan x Harsha (PTB 55) (-3.476), Thottacheera x Swarnaprabha (PTB 43) (-7.223) and Kalladiaryan x Vyttila 6 (-11.244).

4.17.14 Chlorophyll Meter Reading (SPAD)

Vyttila 6 x Swarnaprabha (PTB 43) (3.230) and Harsha (PTB 55) x Swarnaprabha (PTB 43) (3.111) displayed significant positive *sca* effects and the hybrid Thottacheera x Swarnaprabha (PTB 43) (-3.980) exhibited significant negative *sca* effects.

4.17.15 Leaf Area Index (LAI)

The hybrids Vaishak (PTB 60) x Thottacheera (2.037), Kalladiaryan x Swarnaprabha (PTB 43) (2.304) and Vyttila 6 x Swarnaprabha (PTB 43) (1.544) exhibited significant positive *sca* effects for the trait leaf area index.

4.17.16 Carbon Isotope Discrimination (per mil)

Vaishak (PTB 60) x Vyttila 6 (0.761), Vaishak (PTB 60) x Thottacheera (0.619), Thottacheera x Swarnaprabha (PTB 43) (0.597) and Harsha (PTB 55) x Swarnaprabha (PTB 43) (0.395) exhibited significant positive *sca* effects whereas Vaishak (PTB 60) x Swarnaprabha (PTB 43) (-0.436) and Vyttila 6 x Harsha (PTB 55) (-0.571) displayed significant negative *sca* effects for the trait carbon isotope discrimination.

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4.17.17 Number of Days Taken for Reaching Critical Stress Level

Vaishak (0.741), Vyttila 6 (0.713) and Swarnaprabha (0.435) had maximum significant positive *gca*effects whereas significant negative *gca* effects were displayed by Kalladiaryan (-0.606) and Thottacheera (-1.259).

Among the hybrids 12 out of 15 exhibited significant *sca* effects for the character. Very high significant positive *sca* effects were exhibited by Vaishak (PTB 60) x Thottacheera (2.825) followed by Vyttila 6 x Harsha (PTB 55) (2.534) and Vaishak (PTB 60) x Harsha (PTB 55) (2.173) whereas high significant negative *sca* effect was displayed by Thottacheera x Vyttila 6 (-2.369).

4.18 HETEROSIS

The pertinent data relating to the magnitude of heterosis over mid parent and better parent obtained from 6 x 6 half diallel fashion crossing for morphological traits and physiological and biochemical traits are presented in Table 77. The results of heterosis in crosses (hybrids) for various characters are described hereunder.

4.18 HETEROSIS ESTIMATE FOR MORPHOLOGICAL TRAITS UNDER NATURAL STRESS IN UPLAND RICE

4.18.1 Days to 50% Flowering

Among the fifteen hybrids, thirteenhybrids exhibited significant negative heterosis over mid parent for days to 50% flowering (Fig 18). The magnitude of heterosis over mid parent ranged between -20.30% (Thotacheera x Vyttila 6) to 0.56% (Vyttila 6 x Harsha). Heterobeltiosis for days to 50% flowering ranged from-16.55% (Vaishak x Swarnaprabha) to 8.84% (Vyttila 6 x Harsha (PTB 55)). Nine hybrids showed significant negative heterobeltiosis. The hybrid Vaishak (PTB 60) x Swarnaprabha (PTB 43) (-16.55%) showed earliness in flowering over better parent followed by Vaishak (PTB 60) x Vyttila 6 (-13.33%).

4.18.2 Number of Productive Tillers Plant^{-1}

All hybrids exhibited positive relative heterosis for number of productive tillers plant^{-1} out of which twelve were significant (Fig.19). The magnitude of heterosis ranged between 34.27% (Harsha x Swarnaprabha) to 174.01% (Vaishak x Thottacheera) over mid parent.Eleven out of 15 hybrids exhibited significant positive heterobeltiosis for the character. Values ranged from 33.64% (Harsha x Swarnaprabha) to 165.81% (Vaishak (PTB 60) x Thottacheera) over better parent.

4.18.3 Plant Height at Maturity (cm)

Among the fifteen hybrids, four hybrids exhibited significant positive heterosis and three hybrids showed significant negative heterosis over mid parent for plant height at maturity (Fig.20). The magnitude of heterosis over mid parent ranged between -21.94% (Harsha (PTB 55) x Swarnaprabha (PTB 43)) to 17.88% (Vaishak (PTB 60) x Harsha (PTB 55)).Heterobeltiosis for plant height ranged from -33.58% (Harsha (PTB 55) x Swarnaprabha (PTB 43)) to 7.57% (Kalladiaryan x Harsha (PTB 55)). Among the 15 hybrids, none showed significant positive heterobeltiosis for plant height. Five hybrids recorded significant negative heterosis over better parent.

4.18.4 Panicle Length (cm)

The range of heterosis over mid parent and better parent were observed to be from -11.29 (Thottacheera x Vyttila 6) to 35.87 % (Vaishak (PTB 60) x Kalladiaryan) and from -15.78 (Thottacheera x Vyttila 6) to 26.81 % (Vaishak(PTB 60) x Harsha (PTB 55)) (Fig. 21) respectively for panicle length. The crosses Vaishak (PTB 60) x Kalladiaryan (25.93),Vaishak (PTB 60) x Thottacheera (21.75 %), Vaishak (PTB 60) x Swarnaprabha (PTB 43) (21.53), Vyttila 6 x Swarnaprabha (PTB 43) (19.65), Vaishak (PTB 60) x Vyttila 6 (16.70) and Thottacheera x Kalladiaryan (15.29) recorded significant positive value over better parent.

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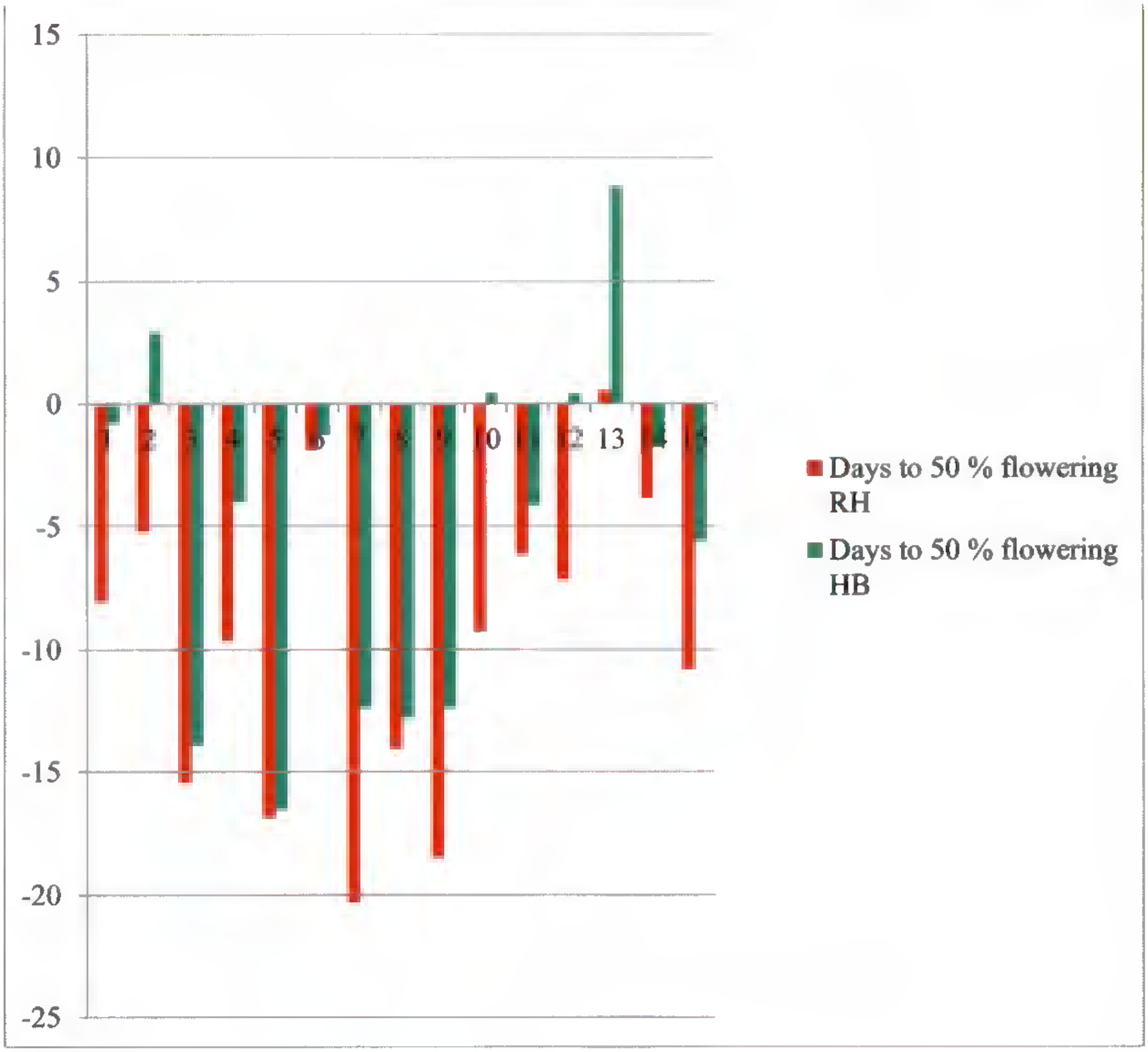
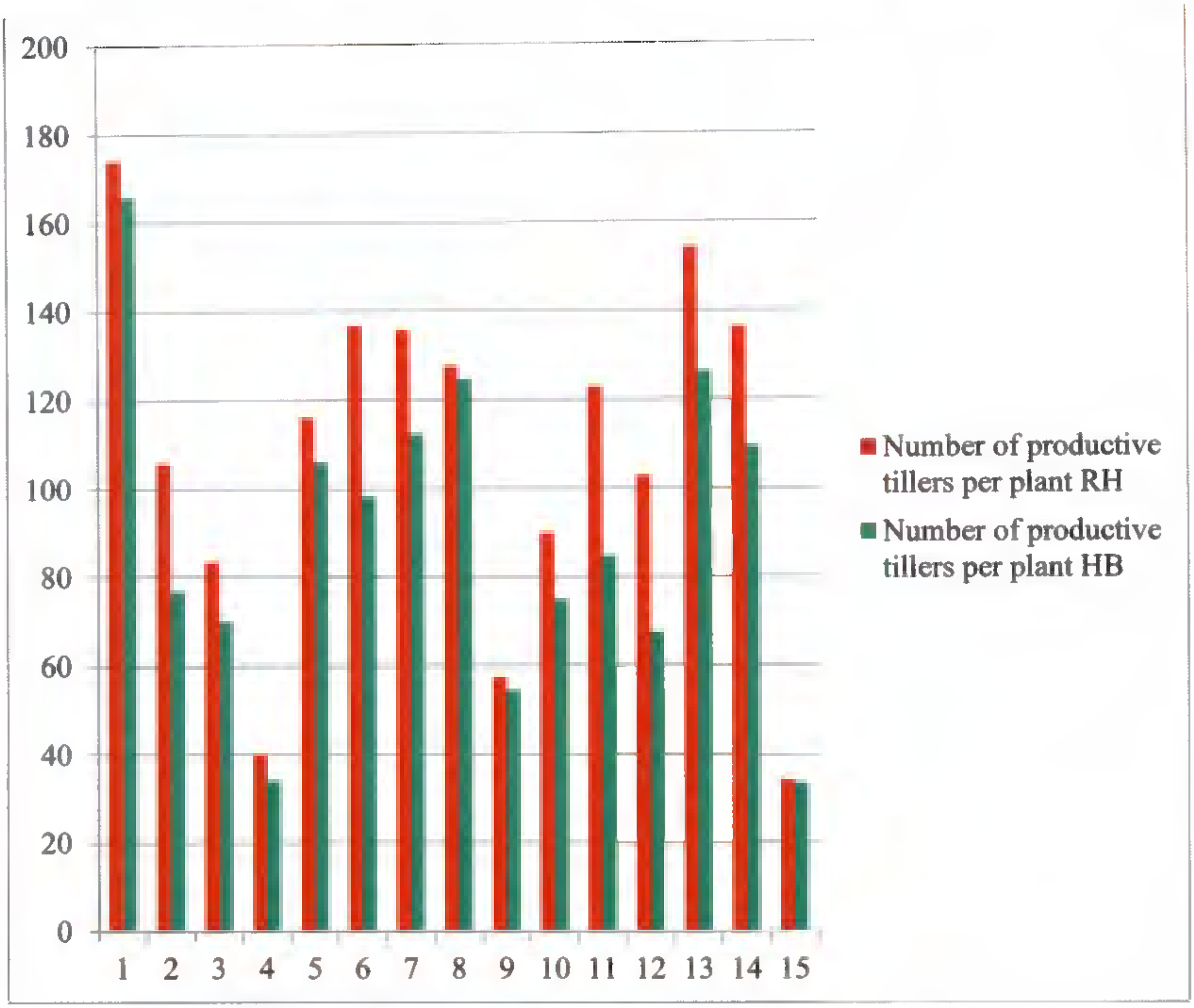


1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 18. Heterosis (%) for days to 50 percent flowering in upland rice



1. Vaishak (PTB 60) x Thottacheera

2. Vaishak (PTB 60) x Kalladiaryan

3. Vaishak (PTB 60) x Vyttila 6

4. Vaishak (PTB 60) x Harsha (PTB 55)

5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)

6. Thottacheera x Kalladiaryan

7. Thottacheera x Vyttila 6

8. Thottacheera x Harsha (PTB 55)

9. Thottacheera x Swarnaprabha (PTB 43)

10. Kalladiaryan x Vyttila 6

11. Kalladiaryan x Harsha (PTB 55)

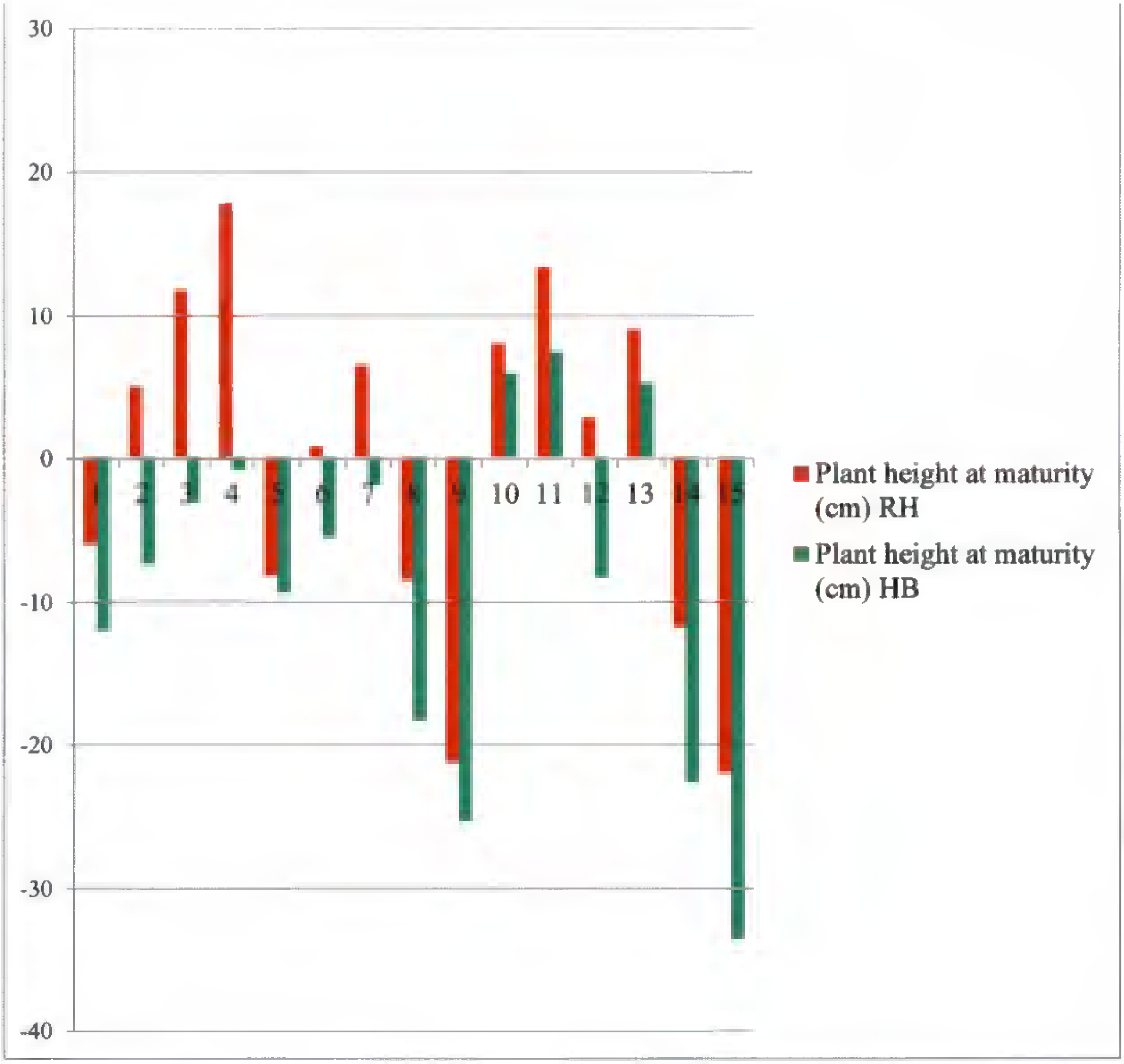
12 . Kalladiaryan x Swarnaprabha (PTB 43)

13. Vyttila 6 x Harsha (PTB 55)

14. Vyttila 6 x Swarnaprabha (PTB 43)

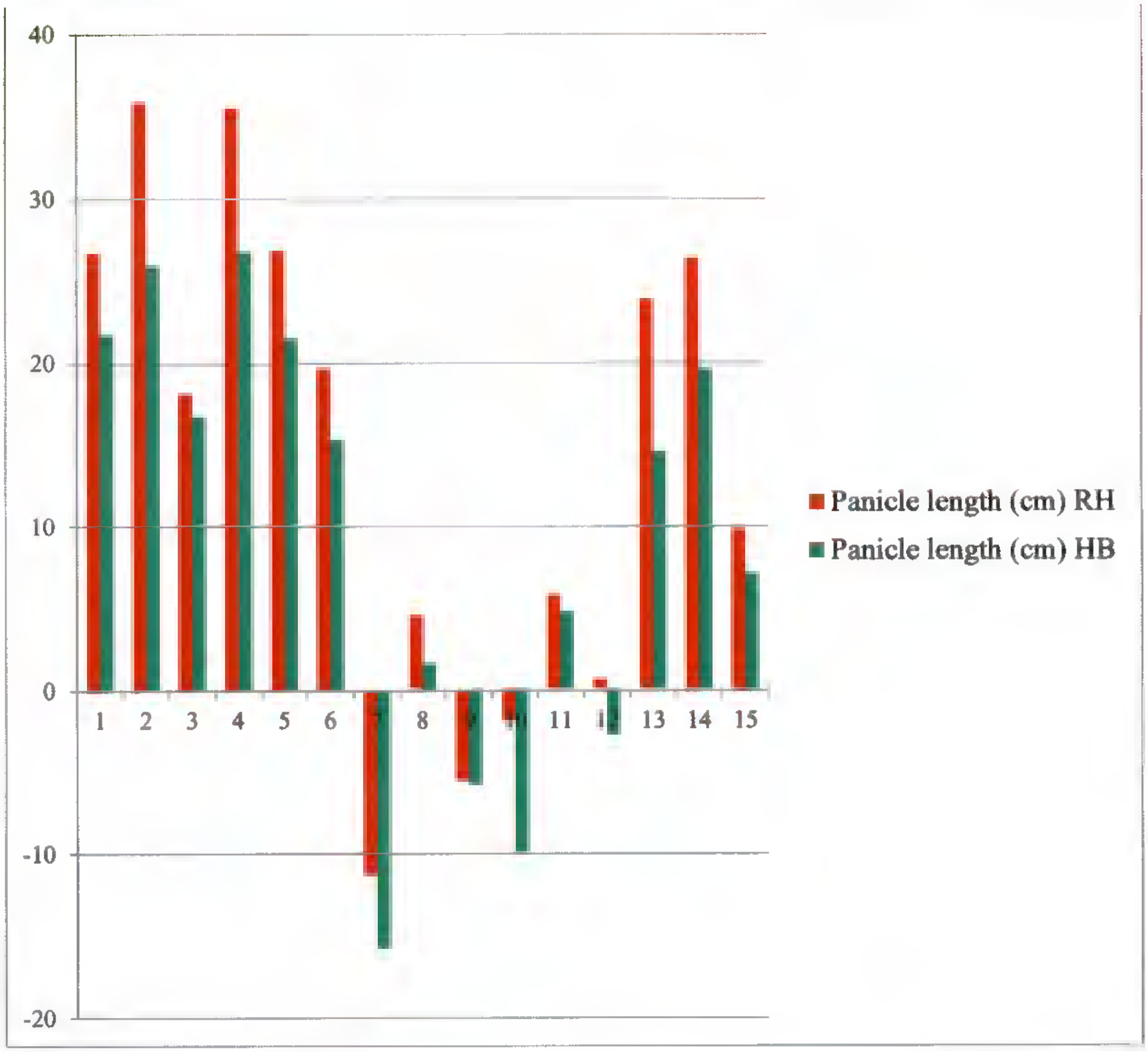
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 19. Heterosis (%) for number of productive tillers plant^{-1} in upland rice



1. Vaishak (PTB 60) x Thottacheera	2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6	4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)	6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6	8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)	10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)	12 . Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)	14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)	

Fig. 20. Heterosis (%) for plant height at maturity in upland rice



1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 21. Heterosis (%) for panicle length in upland rice

4.18.5 Number of Spikelets Panicle^{-1}

The magnitude of heterosis ranged from -31.55% (Thottacheera x Vyttila 6) to 81.26% (Vaishak (PTB 60) x Thottacheera) over mid parent and from -40.38% (Thottacheera x Vyttila 6) to 76.19% (Vaishak (PTB 60) x Thottacheera) over better parent, respectively (Fig.22). Six hybrids showed significant positive heterosis and three hybrids showed significant negative heterosis over mid parent whereas four hybrids showed significant positive heterosis over better parent.

4.18.6 Number of Filled Grains Panicle^{-1}

The data on percent heterosis for the hybrids ranged from –44.74 (Thottacheera x Vyttila 6) to 51.17% (Vyttila 6 x Harsha) and -49.53 (Thottacheera x Vyttila 6) to 36.34% (Vyttila 6 x Harsha (PTB 55) respectively over mid parent and better parent (Fig.23). Out of 15 hybrids 6 and 3 hybrids exhibited significant positive heterosis over mid parent and better parent respectively for the character. Among the 15 hybrids Vyttila 6 x Harsha (PTB 55) (51.17%) had maximum significant positive heterosis followed by Vyttila 6 x Swarnaprabha (PTB 43) (31.83%) and Vaishak (PTB 60) x Harsha (PTB 55) (21.37%) over the mid parent. Vyttila 6 x Harsha (PTB 55) (36.34%) showed significant positive heterosis over the better parent.

4.18.7 Spikelet Sterility (%)

Spikelet sterility showed high level of heterosis ranging from -17.81% (Harsha (PTB 55) x Swarnaprabha) to 377.31% (Vaishak (PTB 60) x Kalladiaryan) over mid parent and -8.08 (Harsha (PTB 55) x Swarnaprabha (PTB 43)) to 361.22% (Vaishak (PTB 60) x Kalladiaryan) over better parent (Fig. 24). The hybrids Thottacheera x Kalladiaryan (214.74%, 193.10%), Vaishak (PTB 60) x Thottacheera (238.10%, 205.63%), Vaishak (PTB 60) x Kalladiaryan (377.31%, 361.22%), Vaishak (PTB 60) x Swarnaprabha (PTB 43) (161.08%, 155.07%) and Vaishak (PTB 60) x Harsha (PTB 55) (136.88%, 118.82%) exhibited significant positive heterosis over mid parent and better parent respectively.

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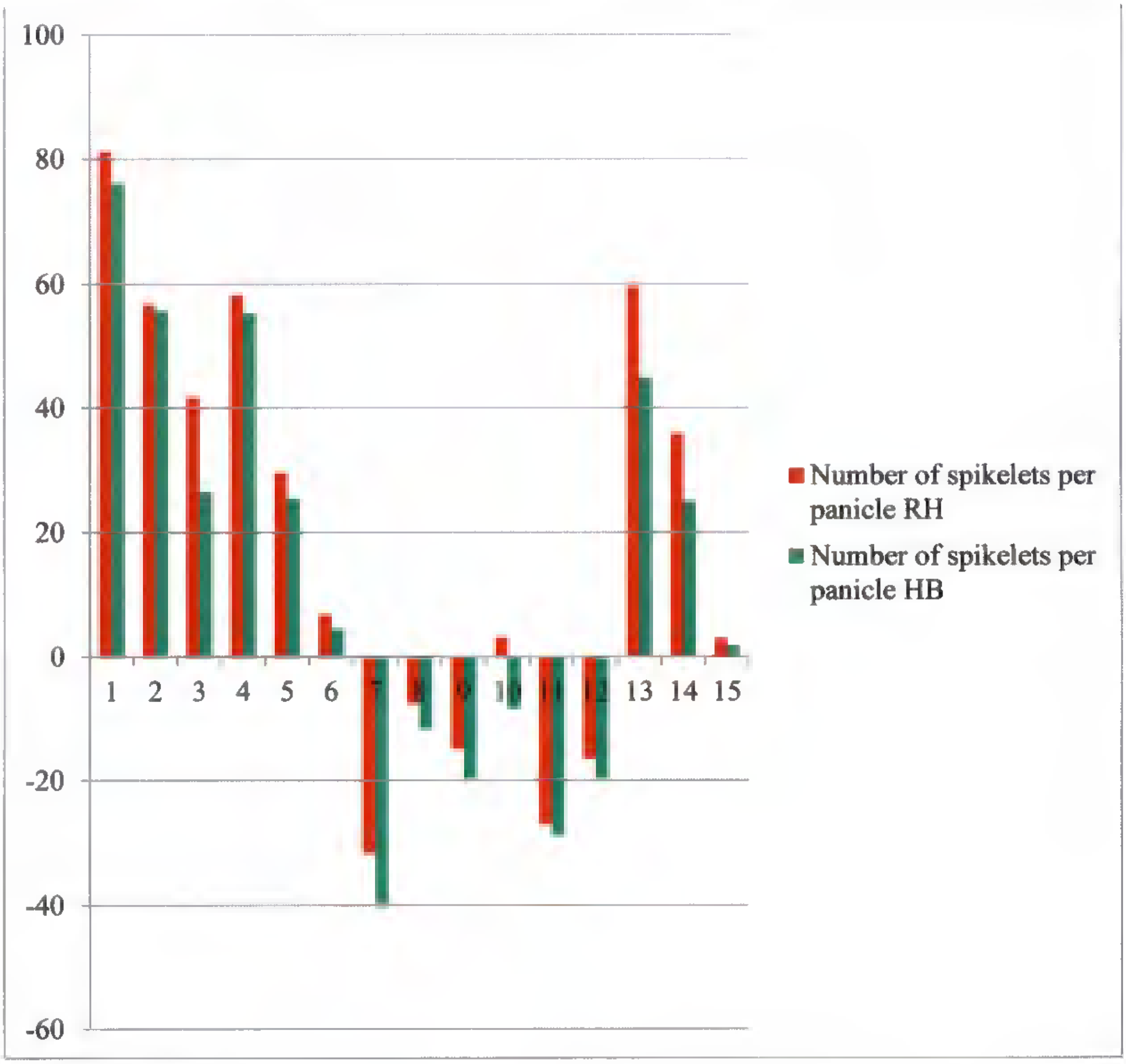
Table 77. Heterosis (%) for morphological traits under natural stress in upland rice

Sl. No.	Name of hybrid	Days to 50 % flowering		Number of productive tillers plant^{-1}		Plant height at maturity (cm)		Panicle length (cm)		Number of spikelets per panicle	
		RH	HB	RH	HB	RH	HB	RH	HB	RH	HB
1	Vaishak (PTB 60) x Thottacheera	-8.05**	-0.83**	174.01**	165.81**	-5.93	-11.99*	26.70**	21.75**	81.26**	76.19**
2	Vaishak (PTB 60) x Kalladiaryan	-5.20**	2.93	105.71**	76.69**	5.12*	-7.39	35.87**	25.93**	56.76**	55.72**
3	Vaishak (PTB 60) x Vyttila 6	-15.44**	-13.93**	83.46*	70.07	11.87**	-3.08	18.16**	16.70*	41.72**	26.54
4	Vaishak (PTB 60) x Harsha (PTB 55)	-9.64**	-4.02*	40.18	34.19	17.88**	-0.84	35.59**	26.81**	58.31**	55.33**
5	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	-16.85**	-16.55**	116.14**	105.98*	-8.09	-9.36	26.88**	21.53**	29.56	25.43
6	Thottacheera x Kalladiaryan	-1.87	-1.26	136.63**	98.16**	0.86	-5.47	19.71**	15.29**	6.92	4.60
7	Thottacheera x Vyttila 6	-20.30**	-12.40**	135.63**	112.41**	6.60	-1.86	-11.29	-15.78**	-31.55*	-40.38
8	Thottacheera x Harsha (PTB 55)	-14.05**	-12.81**	127.65**	124.55*	-8.40	-18.33**	4.57	1.66	-7.57	-11.8
9	Thottacheera x Swarnaprabha (PTB 43)	-18.46**	-12.40**	57.41	54.55	-21.24**	-25.35**	-5.48	-5.79	-14.86	-19.81
10	Kalladiaryan x Vyttila 6	-9.26**	0.42	90.00**	74.85*	8.10	6.03	-1.80	-10.02	3.20	-8.39
11	Kalladiaryan x Harsha (PTB 55)	-6.15**	-4.18*	122.96**	84.66*	13.50*	7.57	5.81	4.78	-26.94	-28.78
12	Kalladiaryan x Swarnaprabha (PTB 43)	-7.16**	0.42	102.97**	67.48*	2.84	-8.29	0.69	-2.72	-16.44	-19.62
13	Vyttila 6 x Harsha (PTB 55)	0.56	8.84**	154.10**	126.28**	9.11	5.35	23.94**	14.58	59.63**	44.98**
14	Vyttila 6 x Swarnaprabha (PTB 43)	-3.87**	-1.80	136.21**	109.49**	-11.76*	-22.64**	26.41**	19.65**	35.94*	25.02
15	Harsha (PTB 55) x Swarnaprabha (PTB 43)	-10.82**	-5.62**	34.27	33.64	-21.94**	-33.58**	9.84	7.13	3.18	1.78

Sl. No.	Name of hybrid	Number of filled grains panicle^{-1}		Spikelet sterility (%)		Grain weight panicle^{-1}(g)		1000 grain weight (g)	
		RH	HB	RH	HB	RH	HB	RH	HB
1	Vaishak (PTB 60) x Thottacheera	22.62	20.1	238.10**	205.03*	-14.13	-27.61*	-26.57**	-27.26**
2	Vaishak (PTB 60) x Kalladiaryan	-19.11	-19.39	377.31**	361.22**	-49.09**	-55.38**	-38.49**	-41.39**
3	Vaishak (PTB 60) x Vyttila 6	28.00	14.75	78.10	78.74	-25.37*	-25.9	-11.09**	-12.60**
4	Vaishak (PTB 60) x Harsha (PTB 55)	21.37**	20.54	136.88*	118.82*	19.47	9.57	-13.38**	-14.53**
5	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	2.40	-1.29	161.08*	155.07*	-30.28*	-35.69**	-25.44**	-26.71**
6	Thottacheera x Kalladiaryan	-22.14	-23.48	214.74**	193.10*	-4.01	-8.28	-22.65**	-26.94**
7	Thottacheera x Vyttila 6	-44.74**	-49.53**	150.56	179.90	4.29	-11.57	28.02**	27.02**
8	Thottacheera x Harsha (PTB 55)	-21.46	-22.56	66.89	40.33	6.26	-3.19	-3.69	-5.84
9	Thottacheera x Swarnaprabha (PTB 43)	-21.42	-22.69	39.82	28.87	15.27	4.44	15.80**	14.90**
10	Kalladiaryan x Vyttila 6	-2.68	-12.49	34.92	30.84	-38.41**	-45.69**	-35.41**	-39.44**
11	Kalladiaryan x Harsha (PTB 55)	-32.80	-33.03	38.34	23.23	-12.62	-16.88	-4.25	-7.57
12	Kalladiaryan x Swarnaprabha (PTB 43)	-31.41	-33.66	110.14	112.55	-31.06*	-34.81*	-20.89**	-25.83**
13	Vyttila 6 x Harsha (PTB 55)	51.17**	36.34*	31.21	20.80	12.62	3.96	5.08	1.94
14	Vyttila 6 x Swarnaprabha (PTB 43)	31.83**	22.23	29.66	27.12	6.43	-1.19	-5.08	-5.08
15	Harsha (PTB 55) x Swarnaprabha (PTB 43)	5.45	2.33	-17.81	-8.08	-13.54	-14.08	-30.71**	-32.77**

Sl. No.	Name of hybrid	Grain yield plant^{-1} (g)		Straw yield plant^{-1} (g)		Harvest index(%)	
		RH%	BPH%	RH%	BPH%	RH%	BPH%
1	Vaishak (PTB 60) x Thottacheera	146.00*	100.98*	46.85	27.3	36.97	30.49
2	Vaishak (PTB 60) x Kalladiaryan	19.87	14.65	61.30*	43.69	-28.35	-35.32
3	Vaishak (PTB 60) x Vyttila 6	77.13*	72.83	3.14	-4.37	28.48	27.15
4	Vaishak (PTB 60) x Harsha (PTB 55)	82.16	60.15	28.62	18.09	16.59	14.99
5	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	83.72	49.89	19.2	12.29	28.9	19.19
6	Thottacheera x Kalladiaryan	100.26*	58.08	88.29**	82.53**	-0.25	-13.76
7	Thottacheera x Vyttila 6	119.03	75.57	41.94	15.45	32.77	27.75
8	Thottacheera x Harsha (PTB 55)	141.45*	121.63*	5.22	-1.22	57.13*	51.71*
9	Thottacheera x Swarnaprabha (PTB 43)	110.37	110	-7.59	-15.44	68.32**	63.10*
10	Kalladiaryan x Vyttila 6	46.51	43.55	53.50*	27.99	-6.83	-16.67
11	Kalladiaryan x Harsha (PTB 55)	87.72*	58.85	13.92	10.2	32.98	18.57
12	Kalladiaryan x Swarnaprabha (PTB 43)	44.01	13.53	46.72	38.22	-4.64	-19.71
13	Vyttila 6 x Harsha (PTB 55)	257.30**	207.57**	48.30**	27.11	60.63**	60.06*
14	Vyttila 6 x Swarnaprabha (PTB 43)	206.24**	145.15**	50.83*	32.36	52.22*	42.10
15	Harsha (PTB 55) x Swarnaprabha (PTB 43)	10.81	1.55	-36.9	-38.61	37.13	28.43

RH-Relative heterosis HB-Heterobeltiosis *Significant at 5 per cent level ** Significant at 1 per cent level



1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
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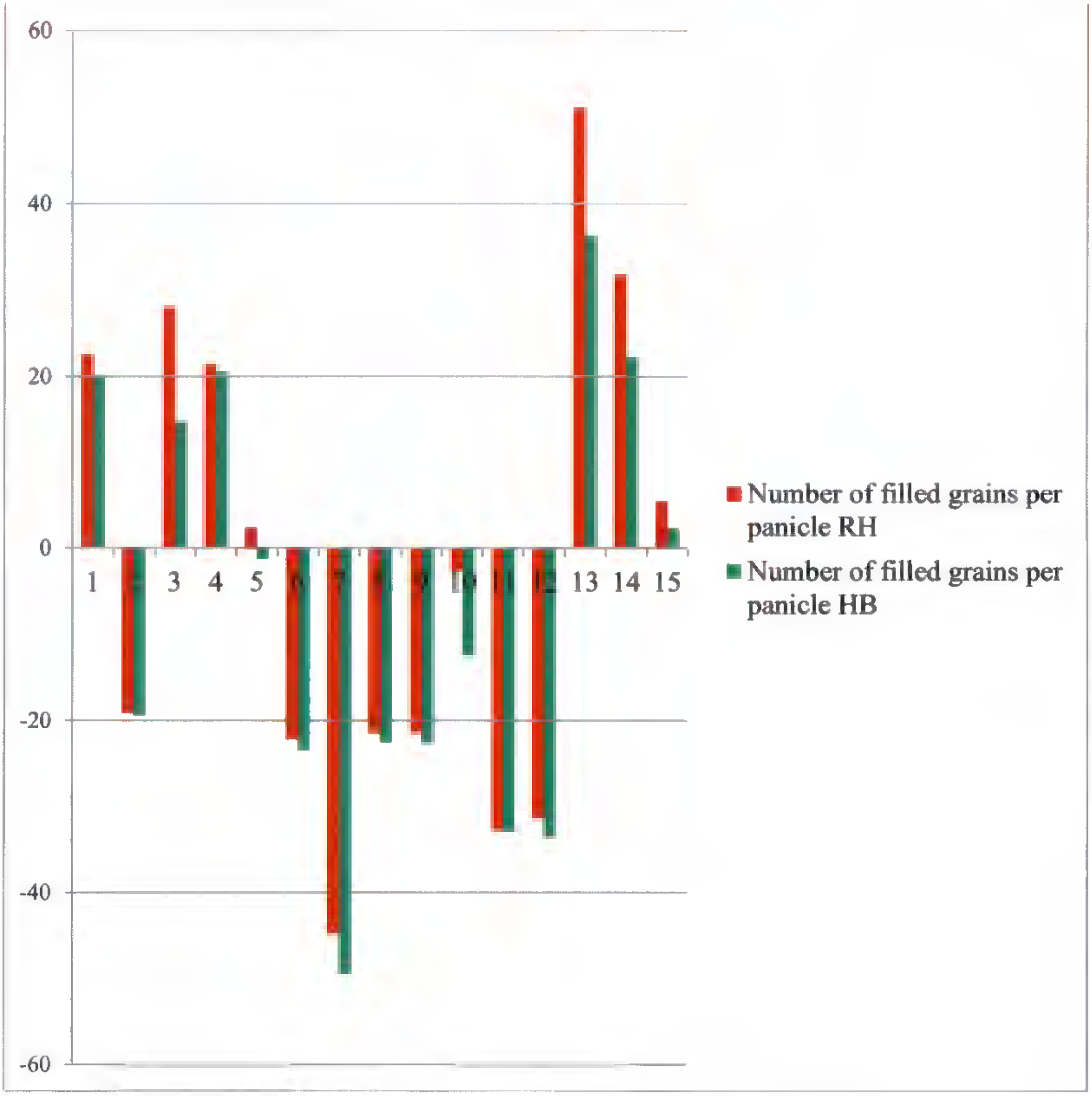
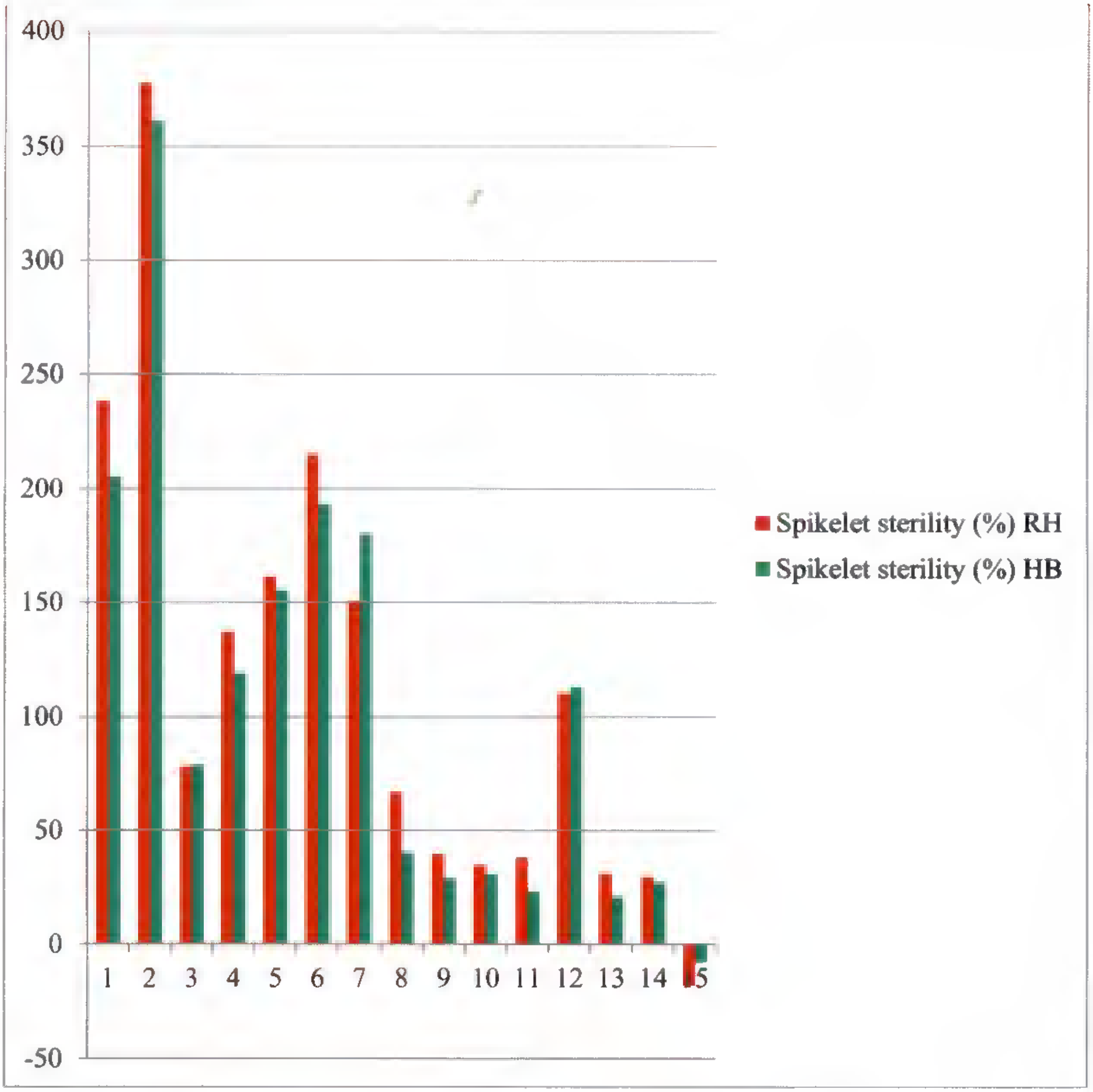
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 22. Heterosis (%) for number of spikelets panicle^{-1} in upland rice



1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 23. Heterosis (%) for number of filled grains panicle^{-1} in upland rice



1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
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10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 24. Heterosis (%) for spikelet sterility (%) in upland rice

4.18.8 GrainWeight Panicle $^{-1}$(g)

The magnitude of heterosis ranged between -49.09 (Vaishak (PTB 60) x Kalladiaryan) and 19.47% (Vaishak (PTB 60) x Harsha (PTB 55)) over mid parent and -55.38 (Vaishak (PTB 60) x Kalladiaryan) and 9.57% (Vaishak (PTB 60) x Harsha (PTB 55)) over better parent. None of the hybrids exhibited significant positive heterosis over mid parent or better parent for grain weight per panicle (Fig.25).

4.18.9 Thousand Grain Weight (g)

The magnitude of heterosis ranged between -38.49 (Vaishak (PTB 60) x Kalladiaryan) to 28.02% (Thottacheera x Vyttila 6) over mid parent and -41.39 (Vaishak (PTB 60) x Kalladiaryan) to 27.02% (Thottacheera x Vyttila 6) (Fig.26) over better parent. Thottacheera x Vyttila 6 (28.02%, 27.02%) andThottacheera x Swarnaprabha (PTB 43) (15.80%, 14.90%) showed significant heterosis over mid and better parents respectively (Fig. 26).

4.18.10 Grain Yield Plant $^{-1}$ (g)

The magnitude of heterosis ranged from 10.81 (Harsha (PTB 55) x Swarnaprabha (PTB 43)) to 257.30% (Vyttila 6 x Harsha (PTB 55)) over mid parent and 1.55 (Harsha (PTB 55) x Swarnaprabha (PTB 43)) to 207.57% (Vyttila 6 x Harsha (PTB 55)) (Fig. 28) over better parent. The hybridsVyttila 6 x Swarnaprabha (PTB 43) (206.24%),Vyttila 6 x Harsha (PTB 55) (157.30%),Vaishak (PTB 60) x Thottacheera (146%),Thottacheera x Harsha (PTB 55) (141.45%),Thottacheera x Kalladiaryan (100.26%), Kalladiaryan x Harsha (PTB 55) (87.72%) and Vaishak (PTB 60) x Vyttila 6 (77.13%) were highly significant over mid parent whereasVyttila 6 x Harsha (PTB 55) (207.57%),Vyttila 6 x Swarnaprabha (PTB 43) (145.15%), Thottacheera x Harsha (PTB 55) (121.63%) and Vaishak (PTB 60) x Thottacheera (100.98%)were positively significant over better parent(Fig 27).

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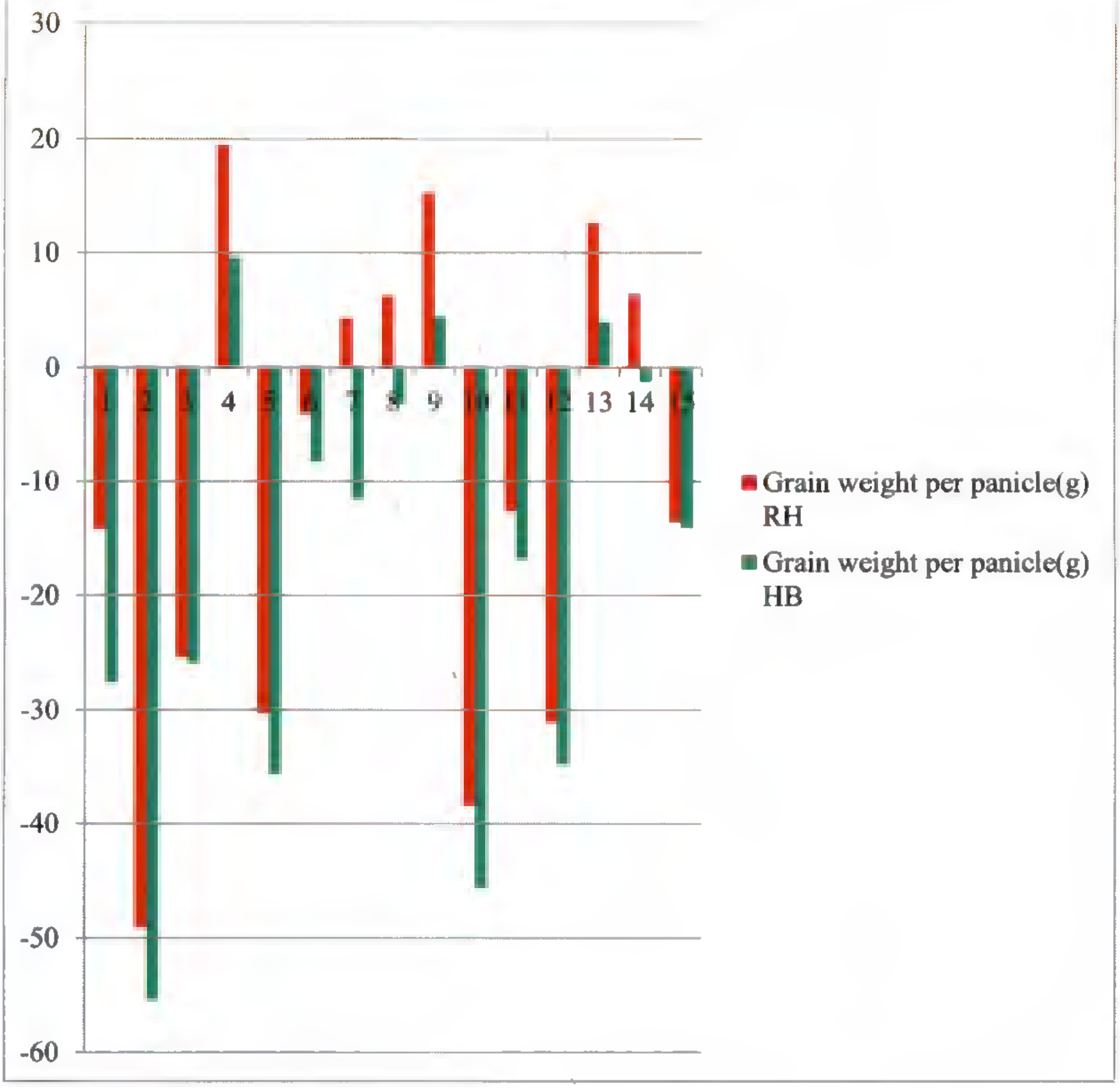
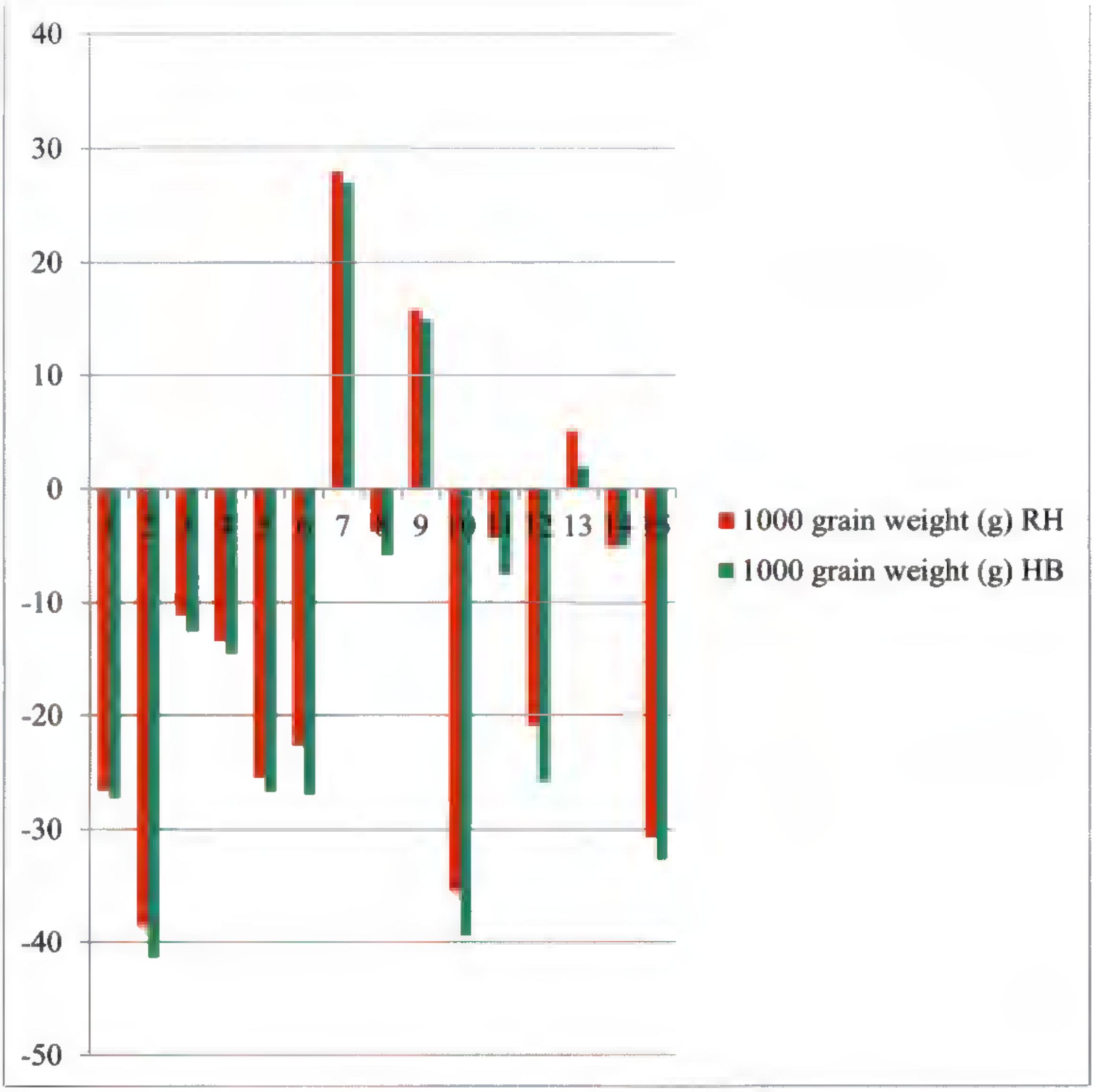


1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 25. Heterosis (%) for grain weight panicle^{-1} in upland rice



1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
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7. Thottacheera x Vyttila 6
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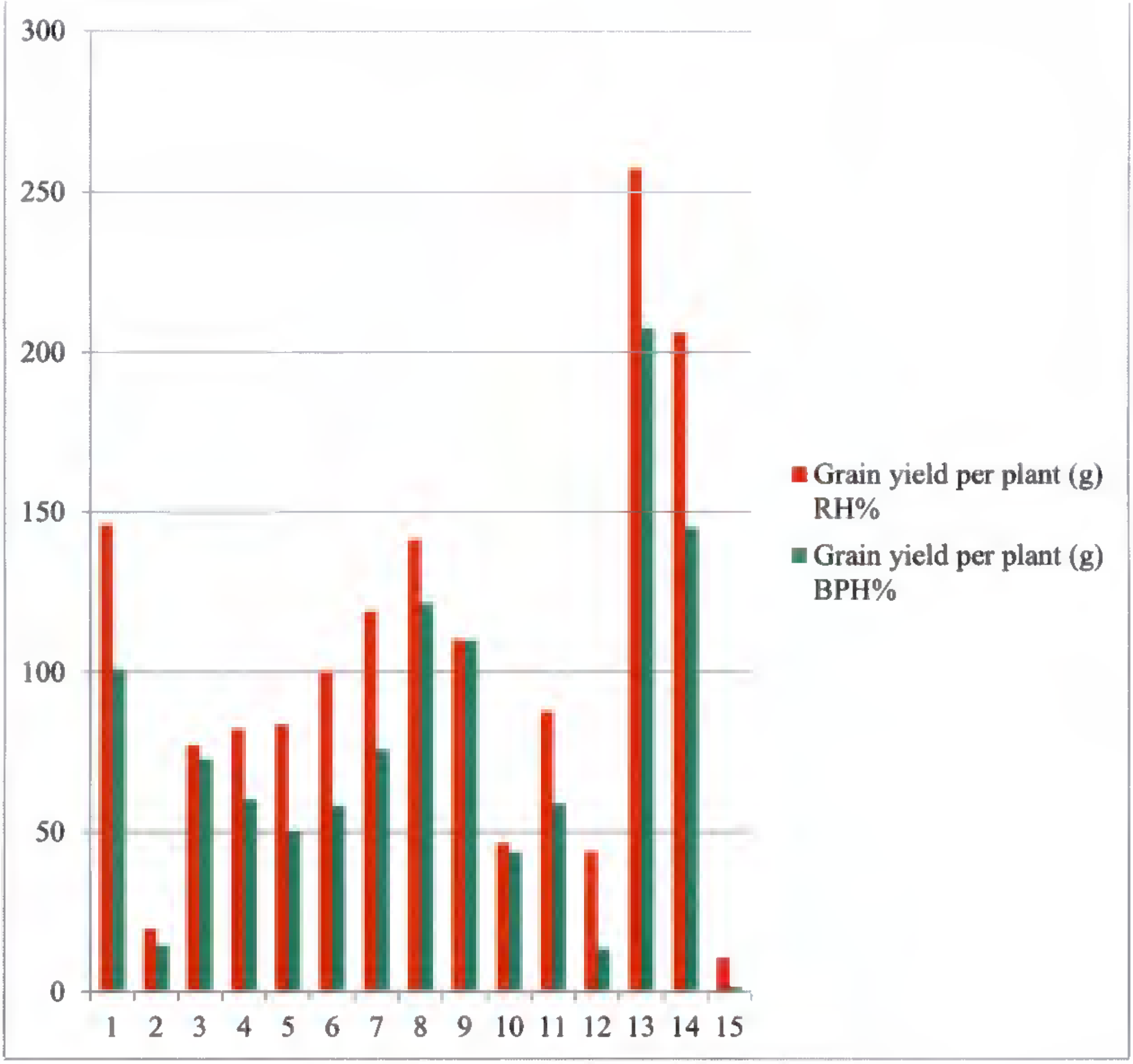
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 26. Heterosis (%) for 1000 grain weight in upland rice



1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
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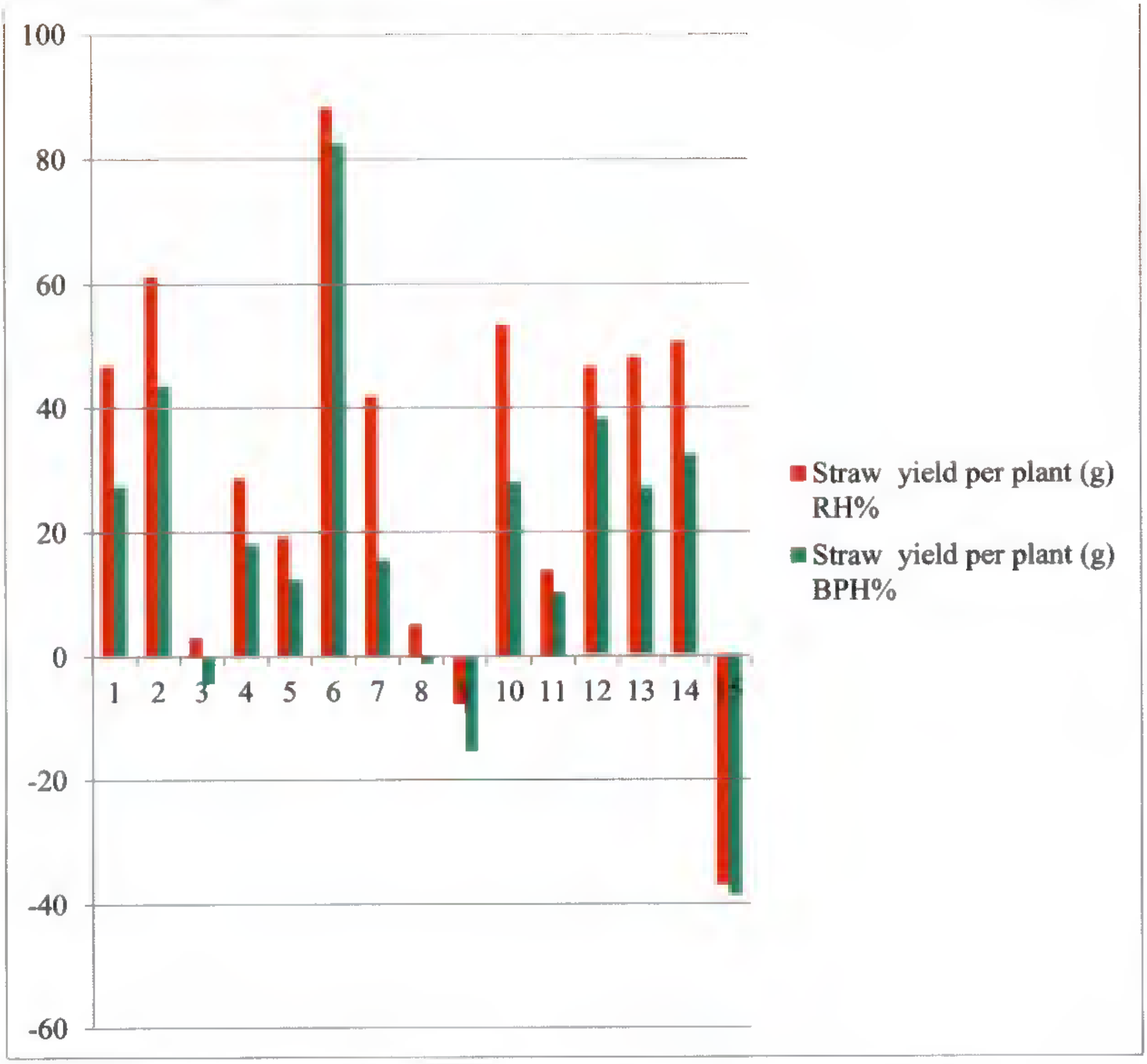
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 27. Heterosis (%) for grain yield plant^{-1} in upland rice



1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
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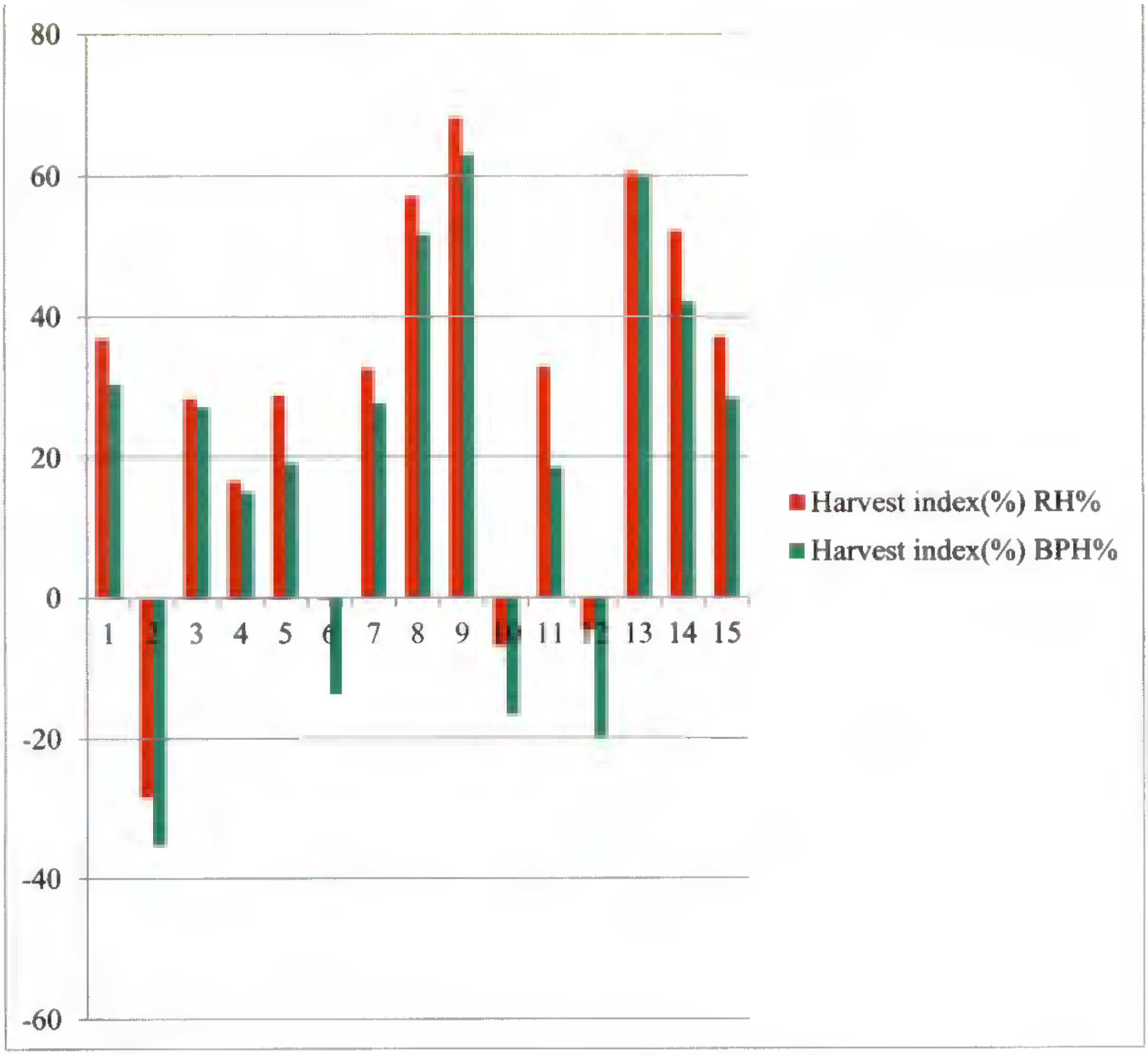
11. Kalladiaryan x Harsha (PTB 55)
12 . Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 28. Heterosis (%) for straw yield plant^{-1} in upland rice



1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
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7. Thottacheera x Vyttila 6
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9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 29. Heterosis (%) for harvest index in upland rice

4.18.11 Straw Yield Plant^{-1} (g)

The magnitude of heterosis ranged from -36.9 (Harsha (PTB 55) x Swarnaprabha (PTB 43)) to 88.29 % (Thottacheera x Kalladiaryan) and -38.61 (Harsha (PTB 55) x Swarnaprabha (PTB 43)) to 82.53 % (Thottacheera x Kalladiaryan) over mid parent and better parent respectively. Other four hybrids namely Vaishak (PTB 60) x Kalladiaryan (61.30%), Kalladiaryan x Vyttila 6 (53.50%), Vyttila 6 x Swarnaprabha (PTB 43) (50.83%) and Vyttila 6 x Harsha (PTB 55) (48.30%) (Fig.28) showed high magnitude of positive significance over mid parent whereas none of the other hybrids were significant over the better parent.

4.18.12 Harvest Index (%)

Among the hybrids only four and three hybrids were positively significant over the mid and the better parents respectively for harvest index (Fig.29).The magnitude of heterosis over mid parents ranged between -4.64 (Kalladiaryan x Swarnaprabha) and 68.32% (Thottacheera x Swarnaprabha (PTB43)). Heterobeltiosis for harvest index ranged from -19.71 (Kalladiaryan x Swarnaprabha) to 63.10% (Thottacheera x Swarnaprabha (PTB 43)). The hybrids Thottacheera x Harsha (PTB55) (57.13%, 51.71%), Thottacheera x Swarnaprabha (PTB43) (68.32%, 63.10%) and Vyttila 6 x Harsha (PTB 55) (60.63%, 60.06%) showed significant relative heterosis and heterobeltiosis for harvest index. Vyttila 6 x Swarnaprabha (PTB43) (52.22%) was positively significant over mid parent. None of thehybrids were negatively significant over mid and better parent.

4.19 HETEROSIS ESTIMATE FOR PHYSIOLOGICAL AND BIOCHEMICAL TRAITS IN UPLAND RICE UNDER NATURAL STRESS

4.19.1 Water Use Efficiency (WUE) (g/l)

The magnitude of heterosis ranged from -15.35 (Harsha (PTB 55) x Swarnaprabha (PTB 43)) to 111.69 % (Vyttila 6 x Harsha (PTB 55)) and -19.019 (Harsha (PTB 55) x Swarnaprabha) to 89.33% (Vyttila 6 x Harsha) over mid

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parent and better parent respectively (Table 78).Vyttila 6 x Harsha (PTB 55) (111.69%), Vyttila 6 x Swarnaprabha (PTB 43) (100.089%), Thottacheera x Vyttila 6 (94.97%),Vaishak (PTB 60) x Thottacheera (91.16%), Thottacheera x Kalladiaryan (90.67%),Thottacheera x Harsha (PTB 55) (64.16%), Kalladiaryan x Vyttila 6 (60.15%),Vaishak (PTB 60) x Harsha (PTB 55) (58.87%) and Vaishak (PTB 60) x Swarnaprabha (PTB 43) (55.22%) were positively significant over the mid parent. Seven hybrids viz., Vyttila 6 x Harsha (PTB 55) (89.33%), Vyttila 6 x Swarnaprabha (PTB 43) (71.98%), Vaishak (PTB 60) x Thottacheera (71.40%), Thottacheera x Kalladiaryan (69.56%), Thottacheera x Vyttila 6 (66.90%), Kalladiaryan x Vyttila 6 (53.29%) and Kalladiaryan x Harsha (PTB 55) (35.65%) were positively significant over the better parent(Fig.30).

4.19.2 Relative Leaf Water Content (RLWC) (%)

The magnitude of heterosis ranged from -14.83 (Kalladiaryan x Harsha) to 5.91% (Vaishak x Swarnaprabha) and -15.38 (Kalladiaryan x Harsha) to 4.83 % (Vaishak x Swarnaprabha) (Fig.32) over mid and better parents respectively (Table 78).The hybrid Kalladiaryan x Harsha (PTB 55) showed significant negative heterosis over mid (14.83%) and better parents (-15.38%).

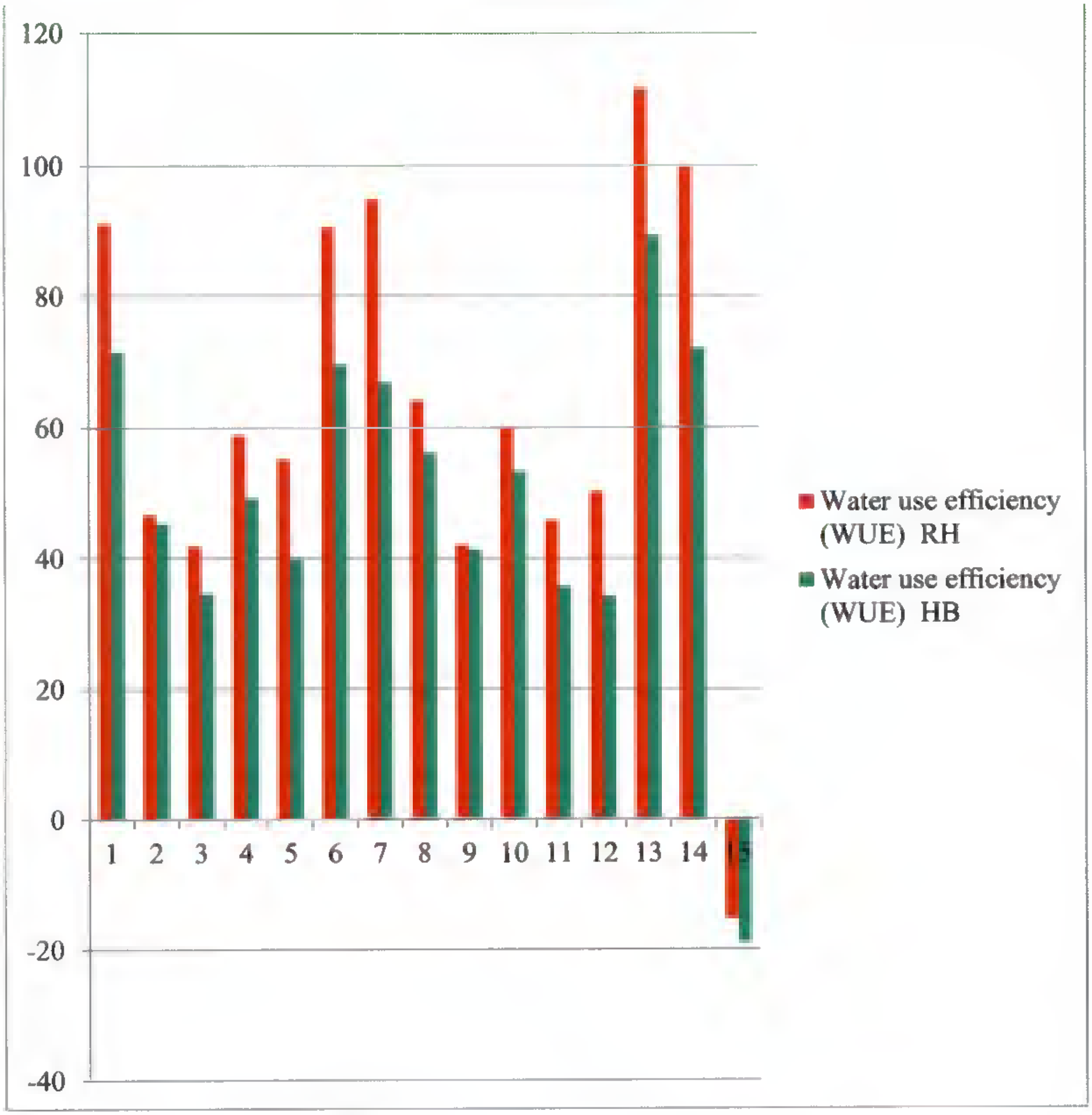
4.19.3 Proline Content (mg/g)

The magnitude of heterosis ranged from -18.30 (Thottacheera x Vyttila 6) to 36.55% (Vaishak (PTB 60) x Kalladiaryan) and -22.49 (Kalladiaryan x Harsha) to 35.03% (Vaishak (PTB 60) x Kalladiaryan) over mid and better parents (Fig32).

Among the hybrids three and two hybrids showed significant positive heterosis over mid and better parents, whereas four and six hybrids showed significant negative heterosis over the mid and the better parents respectively (Table 78).

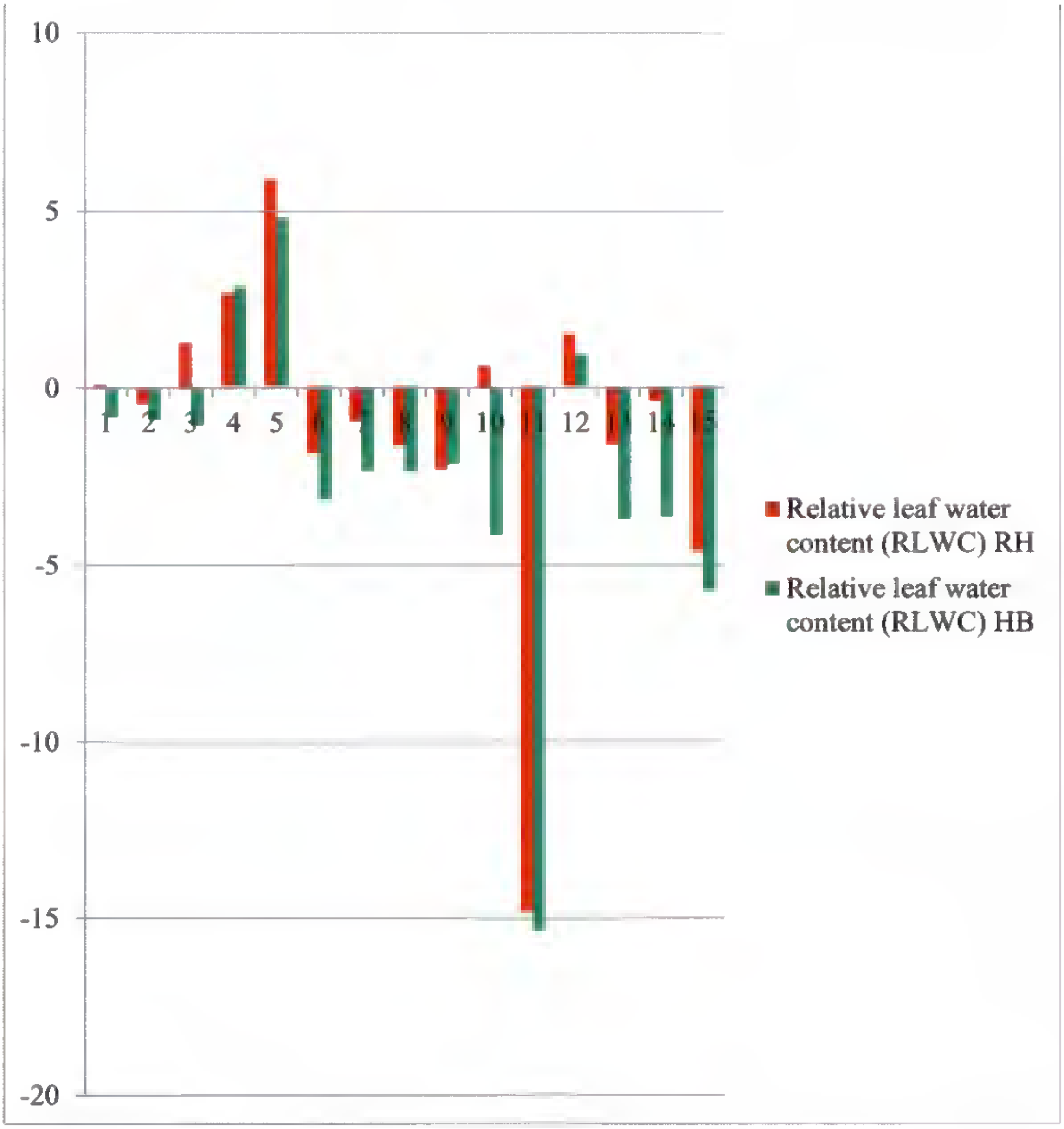
4.19.4 Cell Membrane Stability Index

Among the fifteen hybrids, four hybrids exhibited significant positive heterosis and seven hybrids showed significant negative heterosis over the mid



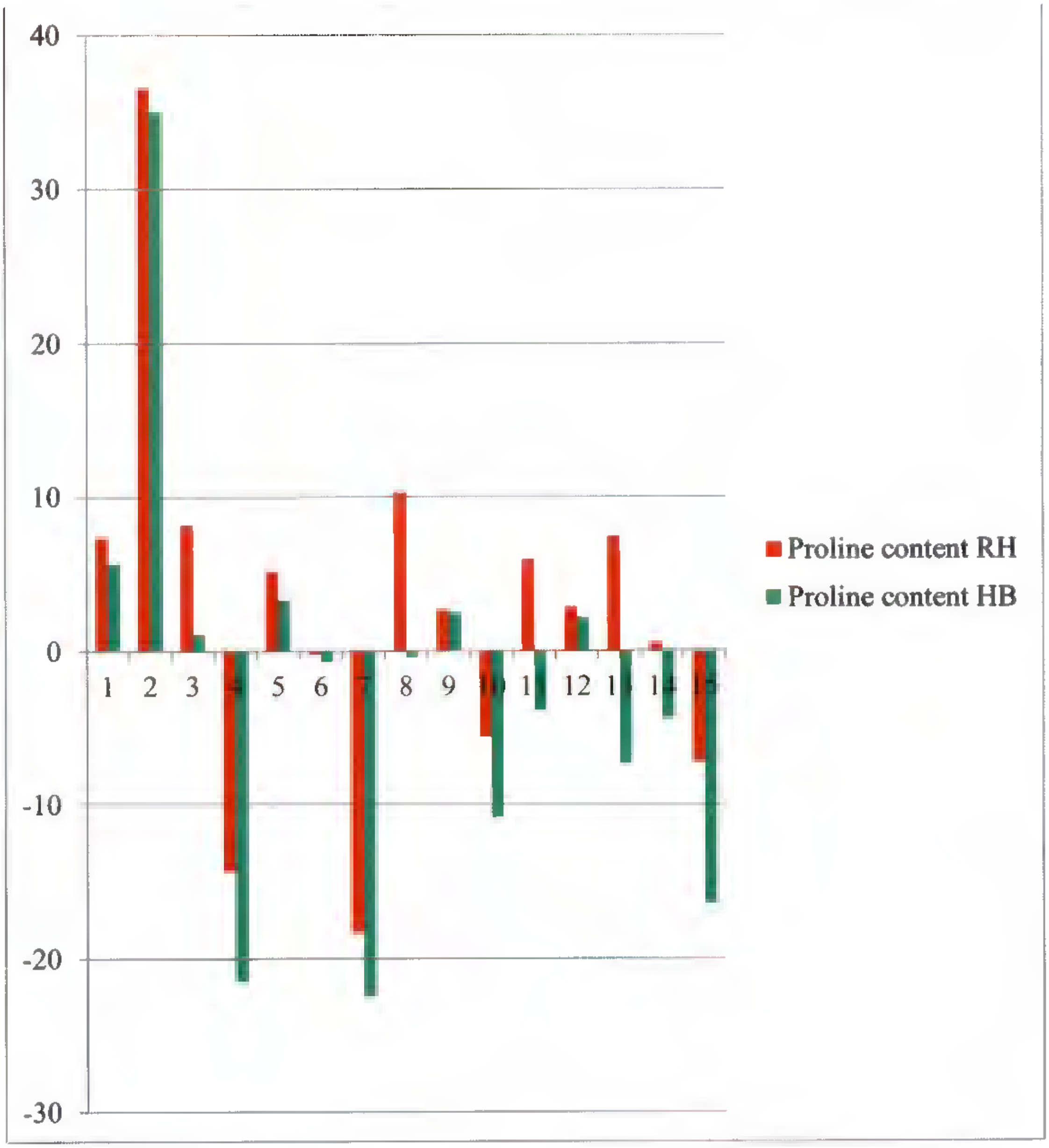
1. Vaishak (PTB 60) x Thottacheera	2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6	4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)	6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6	8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)	10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)	12 . Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)	14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)	

Fig. 30. Heterosis (%) for water use efficiency in upland rice



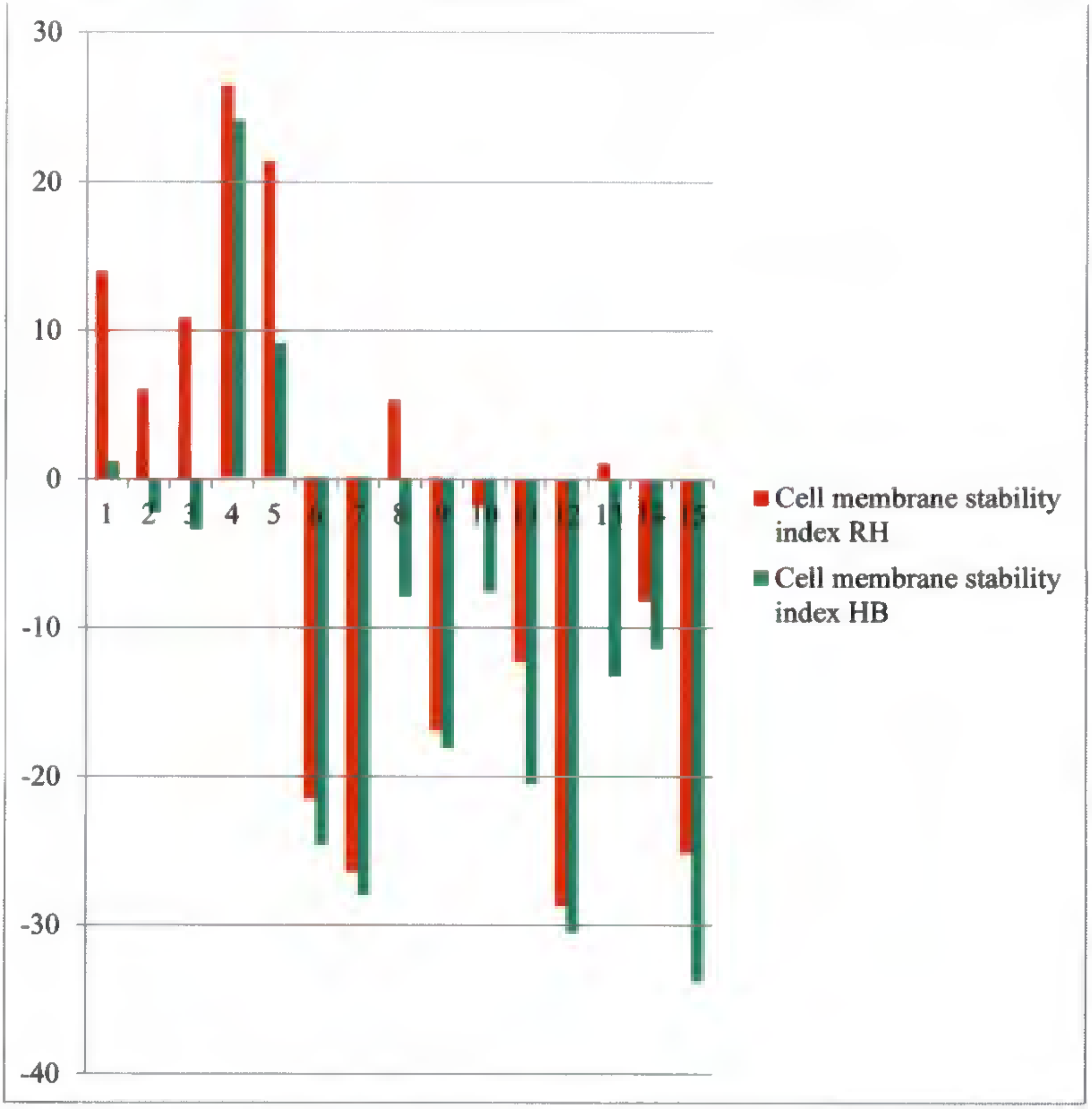
1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 31. Heterosis (%) for relative leaf water content in upland rice



1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 32. Heterosis (%) for proline content in upland rice



1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12 . Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 33. Heterosis (%) for cell membrane stability index in upland rice

parent. The magnitude of heterosis over mid parent ranged between -28.70 (Kalladiaryan x Swarnaprabha) to 26.47% (Vaishak x Harsha) (Table.79). Heterobeltiosis forcell membrane stability index ranged from -33.77% (Harsha (PTB 55) x Swarnaprabha (PTB 43)) to 24.22% (Vaishak x Harsha) (Fig.33). Three and nine hybrids exhibitedsignificant positive and negative heterosis over the better parent.

4.19.5 Chlorophyll a Content (mg/g)

The magnitude of heterosis ranged from -51.26 (Kalladiaryan x Harsha) to 6.79% (Vaishak x Harsha) and -52.69 (Kalladiaryan x Harsha) to 3.51% (Vaishak x Swarnaprabha) over the mid and the better parents respectively for chlorophyll content (Fig.34).

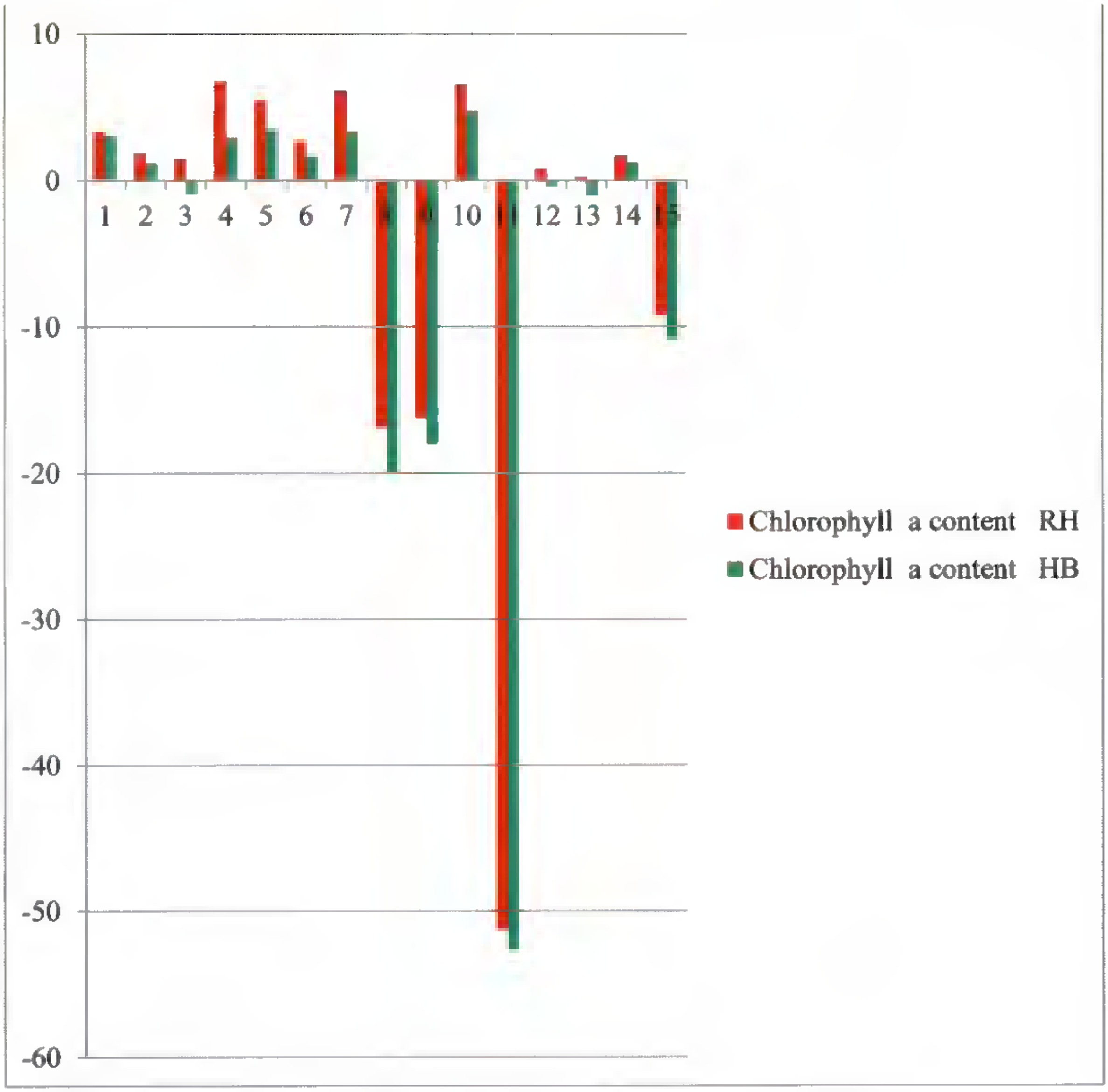
Among the hybrids, four hybrids each exhibited significant positive and negative heterosis respectively over the mid parent (Table 79). The hybrids Vaishak (PTB 60) x Harsha, Vaishak (PTB 60) x Swarnaprabha, Thottacheera x Kalladiaryan and Kalladiaryan x Vyttila 6 exhibited significant positive relative heterosis .

4.19.6 Chlorophyll b Content (mg/g)

Magnitude of heterosis ranged from -70.18 (Thottacheera x Swarnaprabha) to 116.51% (Vyttila 6 x Harsha) and -76.77 (Kalladiaryan x Harsha) to 92.90% (Vyttila 6 x Harsha) over the mid and the better parents respectively (Fig. 35). The hybrids Vyttila 6 x Harsha (PTB 55) (116.51%), Vaishak (PTB 60) x Vyttila 6 (48.86%) and Vaishak (PTB 60) x Kalladiaryan (29.25%), exhibited maximum positive significant heterosis over mid parent while Vyttila 6 x Harsha (PTB 55) (92.90%)andVaishak (PTB 60) x Vyttila 6 (32.07%) showed significant positive heterosis over better parent (Table 79).

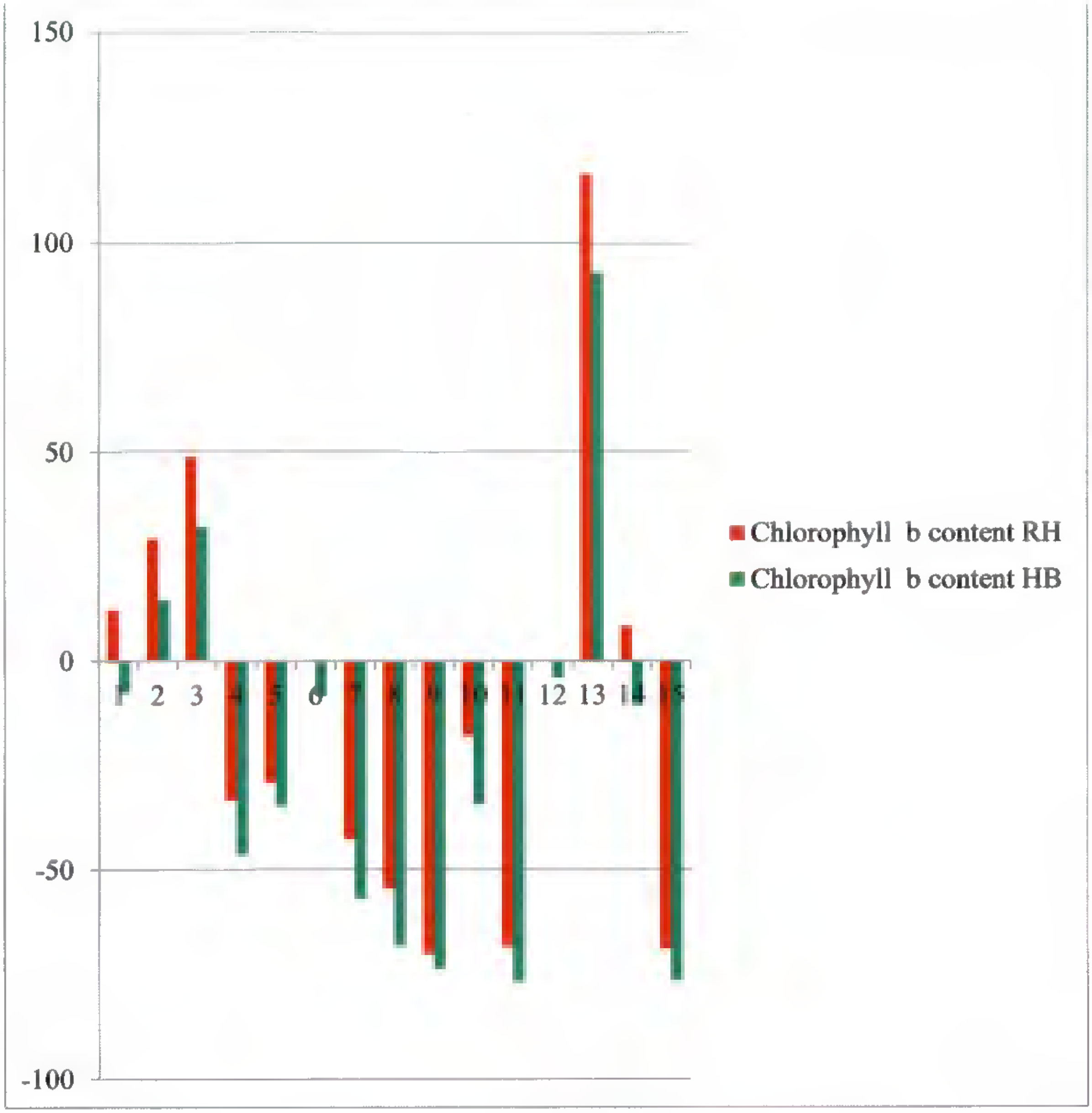
4.19.7 Carotenoides Content

The magnitude of heterosis ranged from -9.86 (Harsha x Swarnaprabha) to 4.56% (Thottacheera x Swarnaprabha) and -11.31 (Harsha (PTB 55) x



1.Vaishak (PTB 60) x Thottacheera	2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6	4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)	6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6	8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)	10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)	12 . Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)	14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)	

Fig. 34. Heterosis (%) for chlorophyll a content in upland rice



1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12 . Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 35. Heterosis (%) for chlorophyll b content in upland rice

1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 36. Heterosis (%) for carotenoides content in upland rice

Swarnaprabha (PTB 43)) to 4.52% (Thottacheera x Swarnaprabha (PTB 43)) over mid and better parents respectively (Table 80, Fig.36).The hybrid Vaishak (PTB 60) x Harsha (PTB 55) (3.02%) and Thottacheera x Swarnaprabha (PTB 43) (4.56%) exhibited significant positive heterosis whereas Harsha x Swarnaprabha (PTB 43) showed significant negative heterosis over better parent.

4.19.8 Total Chlorophyll Content

Among the fifteen hybrids, 6hybrids exhibited significant negative heterosis and four hybrid showed significant positive heterosis over the mid parent (Fig.37). The magnitude of heterosis over mid parent ranged between -58.16% (Kalladiaryan x Harsha) to 38.15% (Vyttila 6 x Harsha).Heterobeltiosis fortotal chlorophyll content ranged from -58.16 (Kalladiaryan x Harsha) to 38.15%(Vyttila 6 x Harsha).Two hybrids exhibited significant positive and seven hybrids exhibited significant negative heterosis over better parent (Table 80).

4.19.9 Chlorophyll Stability Index

The magnitude of heterosis over mid parent ranged from -20.71% (Kalladiaryan x Harsha) to 28.83% (Vaishak (PTB 60) x Swarnaprabha (PTB 43)).Heterobeltiosis for chlorophyll stability index ranged from -20.80 (Kalladiaryan x Harsha (PTB 55)) to 16.71% (Vaishak x Swarnaprabha) (Fig.38). Among the hybrids Vaishak (PTB 60) x Thottacheera (12.96%) and Vaishak (PTB 60) x Swarnaprabha (PTB 43) (16.71%)exhibited significant positive heterosis over the better parent whereas Kalladiaryan x Harsha (PTB 55) (-20.80%) and Thottacheera x Swarnaprabha (PTB 43) (-14.20%) showed significant negative heterosis over the better parent (Fig.38, Table 80).

4.19.10Leaf Temperature (^{0}C)

The magnitude of heterosis over mid parent ranged between -4.16 (Harsha (PTB 55) x Swarnaprabha) and16.43% (Vaishak (PTB 60) x Vyttila 6). Heterobeltiosis for leaf temperature ranged from -4.20 (Harsha (PTB 55) x Swarnaprabha) to 15.77% (Vaishak (PTB 60) x Vyttila 6) (Table 81, Fig.39).

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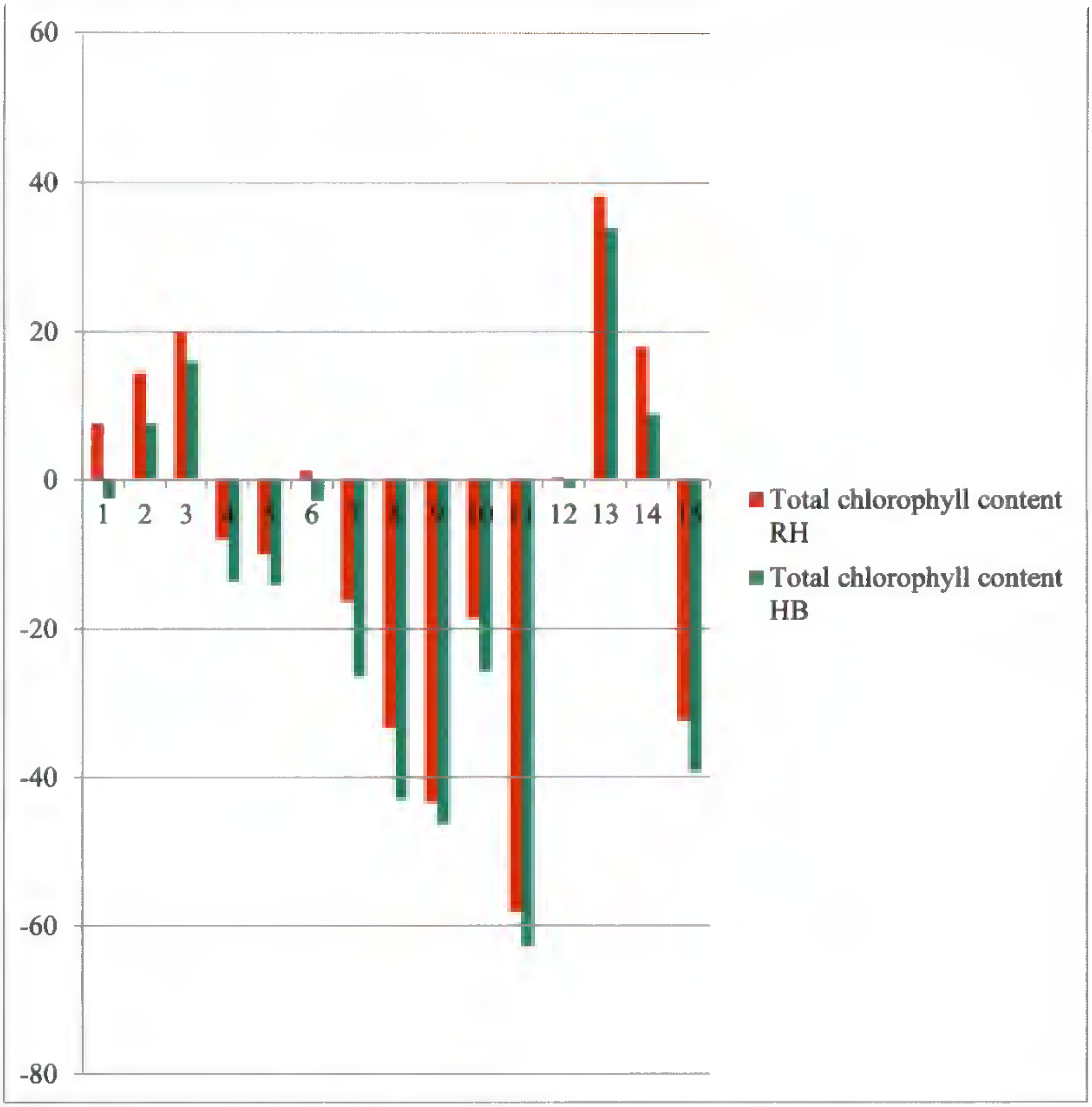


1.Vaishak (PTB 60) x Thottacheera

2. Vaishak (PTB 60) x Kalladiaryan

3. Vaishak (PTB 60) x Vyttila 6

4. Vaishak (PTB 60) x Harsha (PTB 55)

5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)

6. Thottacheera x Kalladiaryan

7. Thottacheera x Vyttila 6

8. Thottacheera x Harsha (PTB 55)

9. Thottacheera x Swarnaprabha (PTB 43)

10. Kalladiaryan x Vyttila 6

11. Kalladiaryan x Harsha (PTB 55)

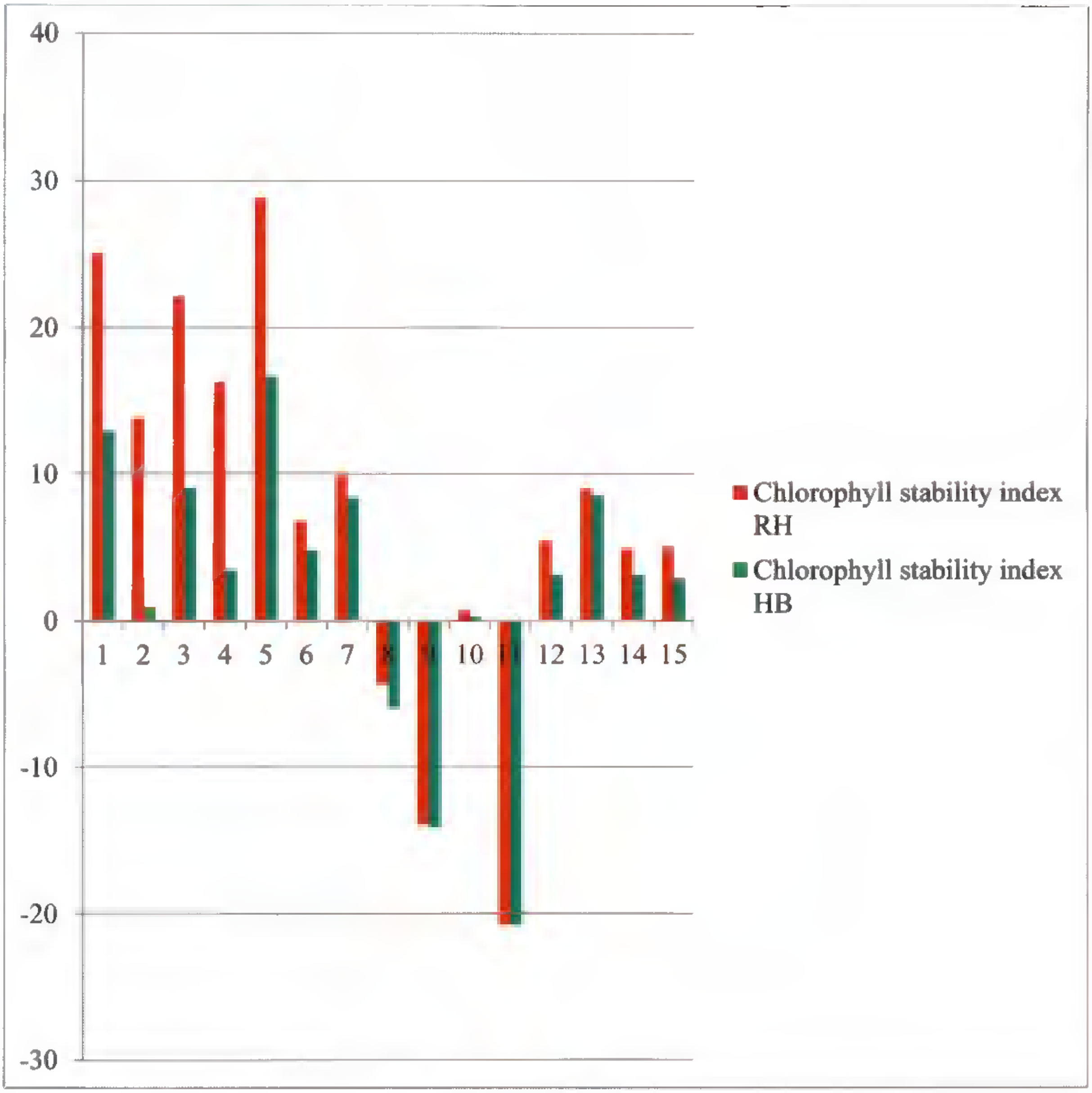
12. Kalladiaryan x Swarnaprabha (PTB 43)

13. Vyttila 6 x Harsha (PTB 55)

14. Vyttila 6 x Swarnaprabha (PTB 43)

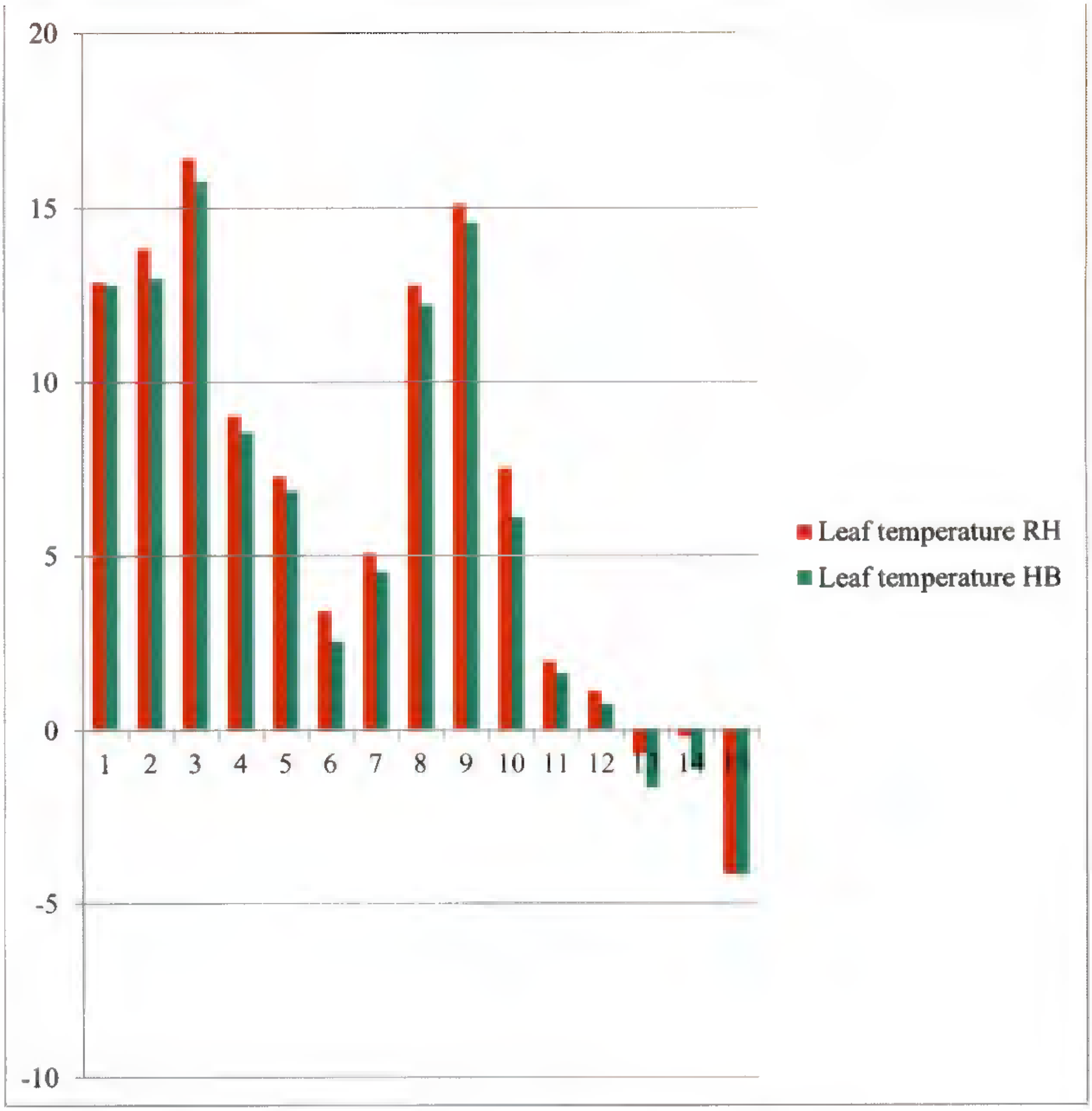
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 37. Heterosis (%) for total chlorophyll content in upland rice



1.Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 38. Heterosis (%) for chlorophyll stability index in upland rice



1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 39. Heterosis (%) for leaf temperature in upland rice

Table 78. Heterosis (%) for water use efficiency, relative leaf content and proline content under natural stress in upland rice

Sl.No	Physiological and biochemical traits	Water use efficiency (WUE)		Relative leaf water content (RLWC)		Proline content	
		RH	HB	RH	HB	RH	HB
1	Vaishak (PTB 60) x Thottacheera	91.16**	71.40*	0.10	-0.81	7.38	5.67**
2	Vaishak (PTB 60) x Kalladiaryan	46.69	45.34	-0.44	-0.90	36.55**	35.03**
3	Vaishak (PTB 60) x Vyttila 6	41.82	34.56	1.28	-1.06	8.18**	1.09
4	Vaishak (PTB 60) x Harsha (PTB 55)	58.87*	49.24	2.67	2.86	-14.32**	-21.51**
5	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	55.22*	39.79	5.91	4.83	5.19	3.31
6	Thottacheera x Kalladiaryan	90.67**	69.56*	-1.82	-3.16	-0.21	-0.69
7	Thottacheera x Vyttila 6	94.97**	66.90**	-0.93	-2.34	-18.30**	-22.49**
8	Thottacheera x Harsha (PTB 55)	64.16*	56.17	-1.64	-2.35	10.31**	-0.41
9	Thottacheera x Swarnaprabha (PTB 43)	41.99	41.29	-2.28	-2.13	2.69	2.48
10	Kalladiaryan x Vyttila 6	60.15**	53.29*	0.64	-4.15	-5.63*	-10.87**
11	Kalladiaryan x Harsha (PTB 55)	45.77	35.65**	-14.83**	-15.38**	5.98	-3.91*
12	Kalladiaryan x Swarnaprabha (PTB 43)	50.18	34.15	1.51	0.94	2.91	2.20
13	Vyttila 6 x Harsha (PTB 55)	111.69**	89.33**	-1.59	-3.69	7.49*	-7.40*
14	Vyttila 6 x Swarnaprabha (PTB 43)	100.089**	71.98**	-0.35	-3.63	0.55	-4.42
15	Harsha (PTB 55) x Swarnaprabha (PTB 43)	-15.35	-19.091	-4.59	-5.74	-7.25*	-16.42**

RH-Relative heterosis HB-Heterobeltiosis *Significant at 5 per cent level ** Significant at 1 per cent level

Table 79. Heterosis (%) for cell membrane stability index, chlorophyll a content and chlorophyll b content under natural stress in upland rice

Sl.No.	Physiological and biochemical traits	Cell membrane stability index		Chlorophyll a content		Chlorophyll b content	
		RH	HB	RH	HB	RH	HB
1	Vaishak (PTB 60) x Thottacheera	13.97**	1.18**	3.39	3.12	12.15	-7.72
2	Vaishak (PTB 60) x Kalladiaryan	6.14	-2.25	1.90	1.17	29.25**	14.54
3	Vaishak (PTB 60) x Vyttila 6	10.90**	-3.38	1.51	-0.91	48.86**	32.07**
4	Vaishak (PTB 60) x Harsha (PTB 55)	26.47**	24.22**	6.79**	2.94	-33.23*	-46.42**
5	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	21.41**	9.16*	5.50*	3.51	-29.01**	-34.66**
6	Thottacheera x Kalladiaryan	-21.52**	-24.62**	2.70**	1.69	-0.12	-8.31
7	Thottacheera x Vyttila 6	-26.46**	-28.02**	6.12	3.32	-42.62**	-56.97**
8	Thottacheera x Harsha (PTB 55)	5.38	-7.90**	-16.86**	-20.06**	-54.49**	-68.35**
9	Thottacheera x Swarnaprabha (PTB 43)	-16.89**	-18.07**	-16.22**	-18.01**	-70.18**	-73.64**
10	Kalladiaryan x Vyttila 6	-1.80	-7.61	6.56**	4.76	-17.88**	-34.40**
11	Kalladiaryan x Harsha (PTB 55)	-12.26**	-20.50**	-51.26**	-52.69**	-68.34**	-76.77**
12	Kalladiaryan x Swarnaprabha (PTB 43)	-28.70**	-30.55**	0.79	-0.41	-0.14	-4.22
13	Vyttila 6 x Harsha (PTB 55)	1.13	-13.23**	0.26	-1.03	116.51**	92.90**
14	Vyttila 6 x Swarnaprabha (PTB 43)	-8.17*	-11.38**	1.73	1.21	8.22	-10.68
15	Harsha (PTB 55) x Swarnaprabha (PTB 43)	-25.16**	-33.77**	-9.19**	-10.82**	-68.89**	-76.53**

RH-Relative heterosis HB-Heterobeltiosis *Significant at 5 per cent level ** Significant at 1 per cent level

Table 80. Heterosis (%) for carotenoides, total chlorophyll content and chlorophyll stability index content under natural stress in upland rice

Sl. No.	Physiological and biochemical traits	Carotenoides content		Total chlorophyll content		Chlorophyll stability index	
		RH	HB	RH	HB	RH	HB
1	Vaishak (PTB 60) x Thottacheera	1.24	-0.34	7.66	-2.46	25.07**	12.96**
2	Vaishak (PTB 60) x Kalladiaryan	0.79	-0.76	14.46**	7.68	13.83**	0.93
3	Vaishak (PTB 60) x Vyttila 6	0.02	-3.02	20.11**	16.03*	22.19**	8.99
4	Vaishak (PTB 60) x Harsha (PTB 55)	3.02*	-0.15	-7.82	-13.54	16.35**	3.42
5	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	2.48	0.92	-9.85	-14.07*	28.83**	16.71**
6	Thottacheera x Kalladiaryan	-0.42	-0.44	1.25	-2.74	6.77	4.76
7	Thottacheera x Vyttila 6	0.33	-1.20	-16.23**	-26.42**	9.89*	8.37
8	Thottacheera x Harsha (PTB 55)	-0.45	-2.01	-33.29**	-42.92**	-4.31	-6.01
9	Thottacheera x Swarnaprabha (PTB 43)	4.56**	4.52**	-43.28**	-46.23**	-13.91**	-14.20**
10	Kalladiaryan x Vyttila 6	-1.69	-3.22*	-18.49**	-25.76**	0.79**	0.27
11	Kalladiaryan x Harsha (PTB 55)	2.13	0.50	-58.16**	-62.93**	-20.71	-20.80**
12	Kalladiaryan x Swarnaprabha (PTB 43)	-0.10	-0.12	0.33	-1.04	5.44	3.11
13	Vyttila 6 x Harsha (PTB 55)	-2.44	-2.48	38.15**	33.98**	8.95*	8.51
14	Vyttila 6 x Swarnaprabha (PTB 43)	1.36	-0.23	18.05**	8.88	4.86	3.08
15	Harsha (PTB 55) x Swarnaprabha (PTB 43)	-9.86**	-11.31**	-32.30**	-39.28**	5.07	2.87

RH-Relative heterosis HB-Heterobeltiosis *Significant at 5 per cent level ** Significant at 1 per cent level

Table 81. Heterosis (%) for leaf temperature, transpiration rate and stomatal conductance under natural stress in upland rice

Sl.No.	Physiological and biochemical traits	Leaf temperature		Transpiration rate (TR)		Stomatal conductance (SC)	
		RH	HB	RH	HB	RH	HB
1	Vaishak (PTB 60) x Thottacheera	12.87**	12.79**	58.47**	17.90*	42.12**	1.97
2	Vaishak (PTB 60) x Kalladiaryan	13.83**	12.96**	149.88	82.45**	-5.65	-7.47
3	Vaishak (PTB 60) x Vyttila 6	16.43**	15.77**	45.15**	43.43**	-45.16**	-62.47**
4	Vaishak (PTB 60) x Harsha (PTB 55)	9.04**	8.56**	84.66**	42.55**	29.55**	16.13**
5	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	7.30**	6.88**	-6.38	-32.06**	-39.85**	-41.40**
6	Thottacheera x Kalladiaryan	3.41**	2.54*	63.95**	59.29**	0.50	-27.01**
7	Thottacheera x Vyttila 6	5.05**	4.53**	53.27	13.15	-9.79	-47.66**
8	Thottacheera x Harsha (PTB 55)	12.79**	12.21**	72.86**	63.97**	12.78	-12.67
9	Thottacheera x Swarnaprabha (PTB 43)	15.12**	14.58**	198.15**	186.96**	41.64**	3.30
10	Kalladiaryan x Vyttila 6	7.53**	6.10**	121.31**	60.38**	-24.75**	-49.04**
11	Kalladiaryan x Harsha (PTB 55)	1.96**	1.62**	183.21**	161.42**	36.93**	24.94
12	Kalladiaryan x Swarnaprabha (PTB 43)	1.12*	0.74	172.79**	170.16**	42.33**	41.38**
13	Vyttila 6 x Harsha (PTB 55)	-0.68	-1.68**	16.01	-11.19	-25.71**	-52.00**
14	Vyttila 6 x Swarnaprabha (PTB 43)	-0.19	-1.15*	124.00**	61.36**	54.85**	4.49**
15	Harsha (PTB 55) x Swarnaprabha (PTB 43)	-4.16**	-4.20**	142.48**	121.84**	-19.16**	-25.79**

RH-Relative heterosis HB-Heterobeltiosis *Significant at 5 per cent level ** Significant at 1 per cent level

Table 82. Heterosis (%) for leaf soluble protein content, radiation use efficiency and chlorophyll meter reading under natural stress in upland rice

Sl.No.	Physiological and biochemical traits	Leaf soluble protein content		Radiation use efficiency		Chlorophyll meter reading	
		RH	HB	RH	HB	RH	HB
1	Vaishak (PTB 60) x Thottacheera	-19.35**	-32.54**	85.16	78.87	5.56**	1.71**
2	Vaishak (PTB 60) x Kalladiaryan	-22.17**	-36.29**	88.95	87.69	3.69	-0.43**
3	Vaishak (PTB 60) x Vyttila 6	9.38	4.82	64.55	57.36	4.57	2.46
4	Vaishak (PTB 60) x Harsha (PTB 55)	-14.79*	-30.20**	52.84	43.94	-4.49**	-10.87*
5	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	9.04	-13.56*	106.85	103.24	6.16**	5.19
6	Thottacheera x Kalladiaryan	-43.16**	-44.68**	42.43	36.71	-4.91	-5.24
7	Thottacheera x Vyttila 6	5.21	-14.94**	104.12	88.87	2.07	0.33**
8	Thottacheera x Harsha (PTB 55)	5.36	2.63	104.01	86.00	-0.55	-3.80
9	Thottacheera x Swarnaprabha (PTB 43)	-44.41**	-48.02**	164.23	159.70	-9.31*	-11.83*
10	Kalladiaryan x Vyttila 6	-56.32**	-65.40**	101.11	93.57	4.67	6.89**
11	Kalladiaryan x Harsha (PTB 55)	-43.29**	-43.34	62.00	53.53	-4.52	-7.34
12	Kalladiaryan x Swarnaprabha (PTB 43)	-13.57	-17.08	66.22	62.24	3.13	-0.08
13	Vyttila 6 x Harsha (PTB 55)	22.53**	-2.89	91.32	88.27	2.13	-2.84
14	Vyttila 6 x Swarnaprabha (PTB 43)	59.19**	22.31**	54.90	45.67	13.68**	12.41*
15	Harsha (PTB 55) x Swarnaprabha (PTB 43)	-1.82	-5.88	17.36	8.72	9.71*	3.26

RH-Relative heterosis HB-Heterobeltiosis *Significant at 5 per cent level ** Significant at 1 per cent level

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Table 83. Heterosis (%) for leaf area index,relative growth rate, net assimilation rate under natural stress in upland rice

Sl.No.	Physiological and biochemical traits	Leaf area index (LAI)		Relative growth rate (RGR)		Net assimilation rate (NAR)	
		RH	HB	RH	HB	RH	HB
1	Vaishak (PTB 60) x Thottacheera	63.35	39.23	37.21	32.58	63.38	56.43
2	Vaishak (PTB 60) x Kalladiaryan	-17.58	-22.99	-23.89	-32.89	60.14	59.75
3	Vaishak (PTB 60) x Vyttila 6	-17.20	-17.33	38.48	28.02	77.96	63.14
4	Vaishak (PTB 60) x Harsha (PTB 55)	25.09	0.87	6.80	-1.52	64.30	42.63
5	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	2.22	-13.31	19.07	11.59	169.36**	164.01*
6	Thottacheera x Kalladiaryan	55.01	40.37	3.97	-5.46	6.22	1.94
7	Thottacheera x Vyttila 6	-3.28	-17.45	12.07	7.05	61.06	53.89
8	Thottacheera x Harsha (PTB 55)	-23.11	-28.12	35.47	29.05	117.98**	96.70
9	Thottacheera x Swarnaprabha (PTB 43)	-21.65	-22.12	43.59	39.11	182.52**	165.38**
10	Kalladiaryan x Vyttila 6	-3.61	-9.81	-15.42	-19.68	60.89	47.83
11	Kalladiaryan x Harsha (PTB 55)	-9.06	-22.46	17.94	12.31	77.43	54.35
12	Kalladiaryan x Swarnaprabha (PTB 43)	87.50**	68.87*	-6.66	-12.58	46.38	43.13
13	Vyttila 6 x Harsha (PTB 55)	28.67	3.88	28.37	27.99	92.18	80.97
14	Vyttila 6 x Swarnaprabha (PTB 43)	54.52	31.21	4.48	2.96	40.14	26.15
15	Harsha (PTB 55) x Swarnaprabha (PTB 43)	-20.05	-24.84	8.86	6.98	17.26	0.08

RH-Relative heterosis HB-Heterobeltiosis *Significant at 5 per cent level **Significant at 1 per cent level

Table 84. Heterosis (%) for carbon isotope discrimination, number of days taken for reaching critical stress level under natural stress in upland rice

Sl.No.	Physiological and biochemical traits	Carbon isotope discrimination		Number of days taken for reaching critical stress level	
		RH	HB	RH	HB
1	Vaishak (PTB 60) x Thottacheera	5.67^{**}	5.57^{**}	41.54^{**}	40.82^{**}
2	Vaishak (PTB 60) x Kalladiaryan	3.16	2.68^{*}	32.35	27.36^{**}
3	Vaishak (PTB 60) x Vyttila 6	5.30^{**}	4.94^{**}	10.04^{**}	-3.82^{**}
4	Vaishak (PTB 60) x Harsha (PTB 55)	0.28	2.86^{*}	46.81	40.82^{**}
5	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	-0.65	1.09	19.49	2.17^{*}
6	Thottacheera x Kalladiaryan	2.45^{*}	3.03^{*}	16.26^{**}	11.32^{**}
7	Thottacheera x Vyttila 6	3.56^{**}	3.10^{*}	-20.18	-30.53^{**}
8	Thottacheera x Harsha (PTB 55)	0.39	3.08	5.88^{**}	2.06
9	Thottacheera x Swarnaprabha (PTB 43)	4.26^{**}	2.39	-23.40^{**}	-34.78^{**}
10	Kalladiaryan x Vyttila 6	2.21	2.09	-1.27	-10.69^{**}
11	Kalladiaryan x Harsha (PTB 55)	0.70	-2.18	25.51^{**}	16.04
12	Kalladiaryan x Swarnaprabha (PTB 43)	-0.95	0.31	-6.56^{**}	-17.39^{**}
13	Vyttila 6 x Harsha (PTB 55)	-2.29^{*}	-4.36^{**}	27.60^{**}	7.63^{**}
14	Vyttila 6 x Swarnaprabha (PTB 43)	-0.21	1.18	0.37	-2.17^{*}
15	Harsha (PTB 55) x Swarnaprabha (PTB 43)	1.37	0.58	-15.79^{**}	-30.43^{**}

RH-Relative heterosis HB-Heterobeltiosis *Significant at 5 per cent level ** Significant at 1 per cent level

All the hybrids were significant over the mid parent except Vyttila 6 x Harsha (PTB 55) (-0.68%) and Vyttila 6 x Swarnaprabha (PTB 43) (-0.19%) and all the hybrids except Kalladiaryan x Swarnaprabha (PTB 43) (0.74%) were significant over the better parent.

4.19.11Transpiration Rate (TR)

The magnitude of heterosis ranged from -6.38 (Vaishak (PTB 60) x Swarnaprabha) to 198.15% (Thottacheera x Swarnaprabha) and 32.06% (Vaishak (PTB 60) x Swarnaprabha) to 186.96 % (Thottacheera x Swarnaprabha) over the mid and the better parents respectively (Table 81, Fig.40).

Among the fifteen hybrids 12 hybrids exhibited significant positive heterosis over the mid and better parents for transpiration rate.One hybrid *viz.*, Vaishak (PTB60) x Swarnaprabha (PTB 43) exhibited significant negative heterobeltiosis (-32.06) for the character.

4.19.12 Stomatal Conductance (SC)

The magnitude of heterosis ranged from -45.16 (Vaishak (PTB 60) x Vyttila 6) to 54.85% (Vyttila 6 x Swarnaprabha (PTB 43)) and -62.47 (Vaishak (PTB 60) x Vyttila 6) to 41.38 % (Kalladiaryan x Swarnaprabha (PTB 43)) over mid and better parents respectively (Table 81, Fig.41).

Among the 15 hybrids eight hybrids showed significant negativeheterosis over better parent. Three hybrids *viz.,*Kalladiaryan x Swarnaprabha (PTB 43) (41.38%), Vaishak (PTB 60) x Harsha (PTB 55) (16.13%) and Vyttila 6 x Swarnaprabha (PTB 43) (4.49%) showed significant positive heterosis over better parent.

4.19.13 Leaf Soluble Protein Content(mg/g)

The heterosis over mid parent varied from -56.32 (Kalladiaryan x Vyttila 6) to 59.19% (Vyttila 6 x Swarnaprabha (PTB 43)) and heterosis over better parent ranged from -65.40 (Kalladiaryan x Vyttila 6) to 22.31%(Vyttila 6 x Swarnaprabha) 22.31% (Table 82, Fig.42). One hybrid showed significant

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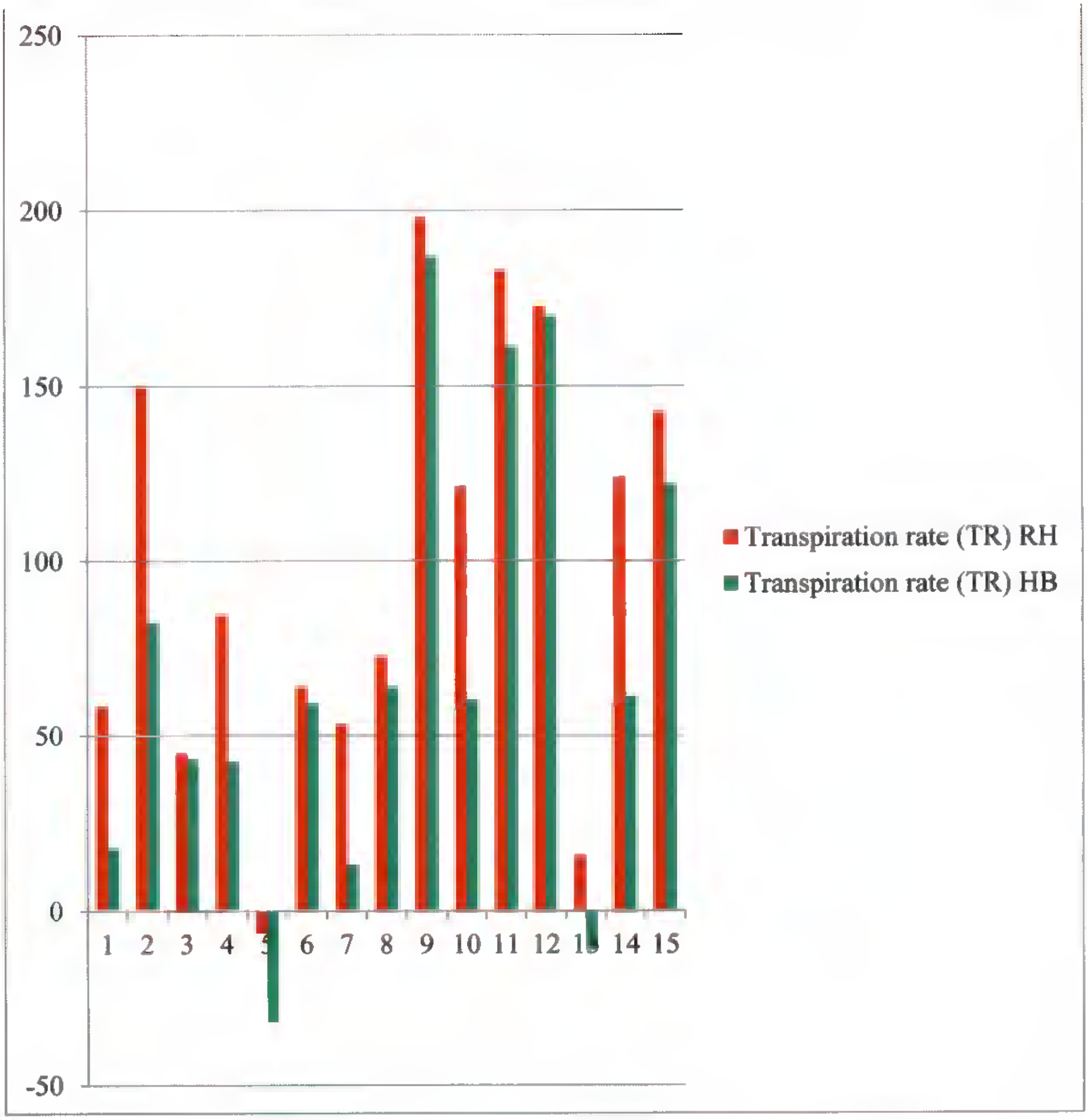
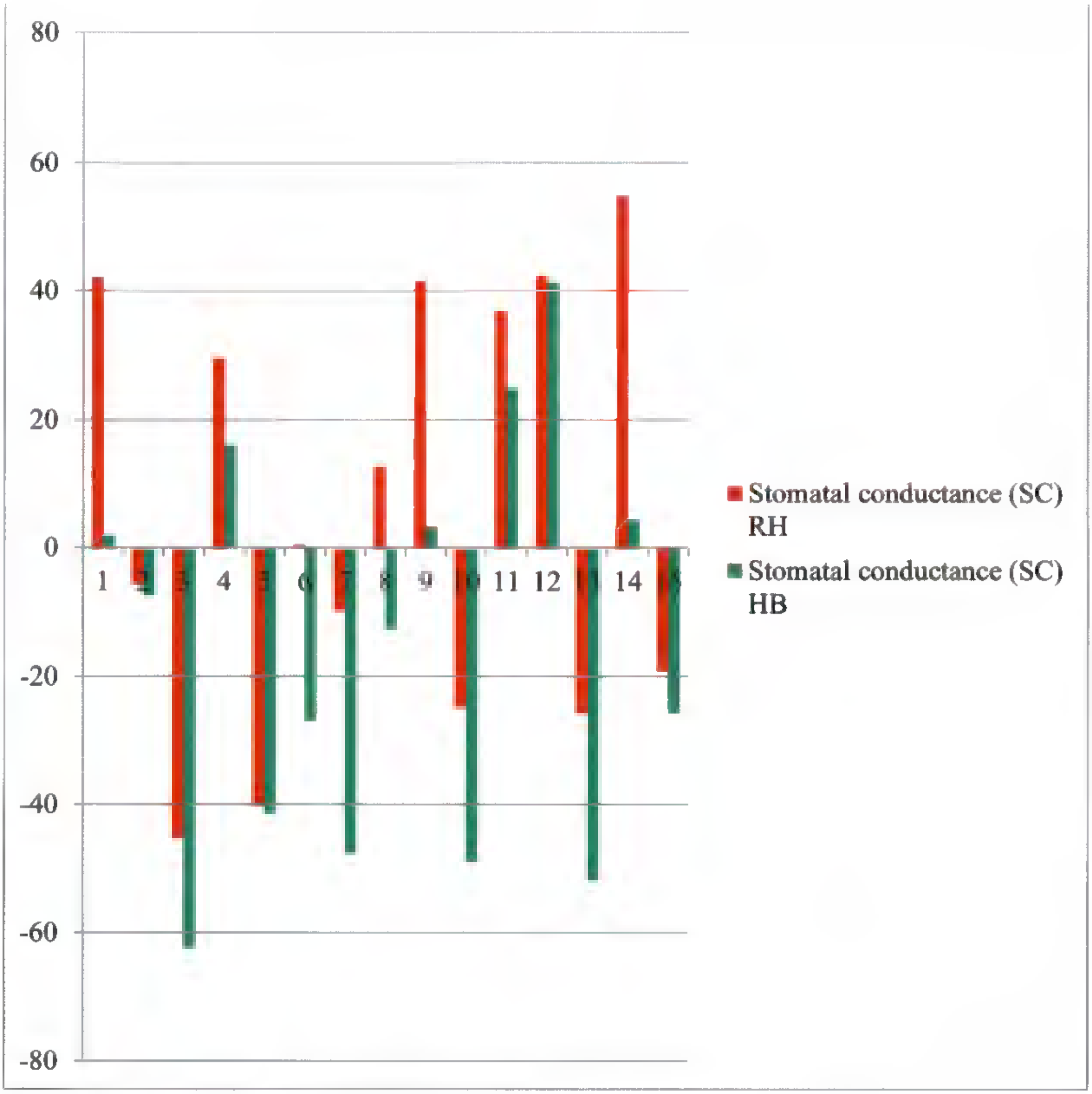


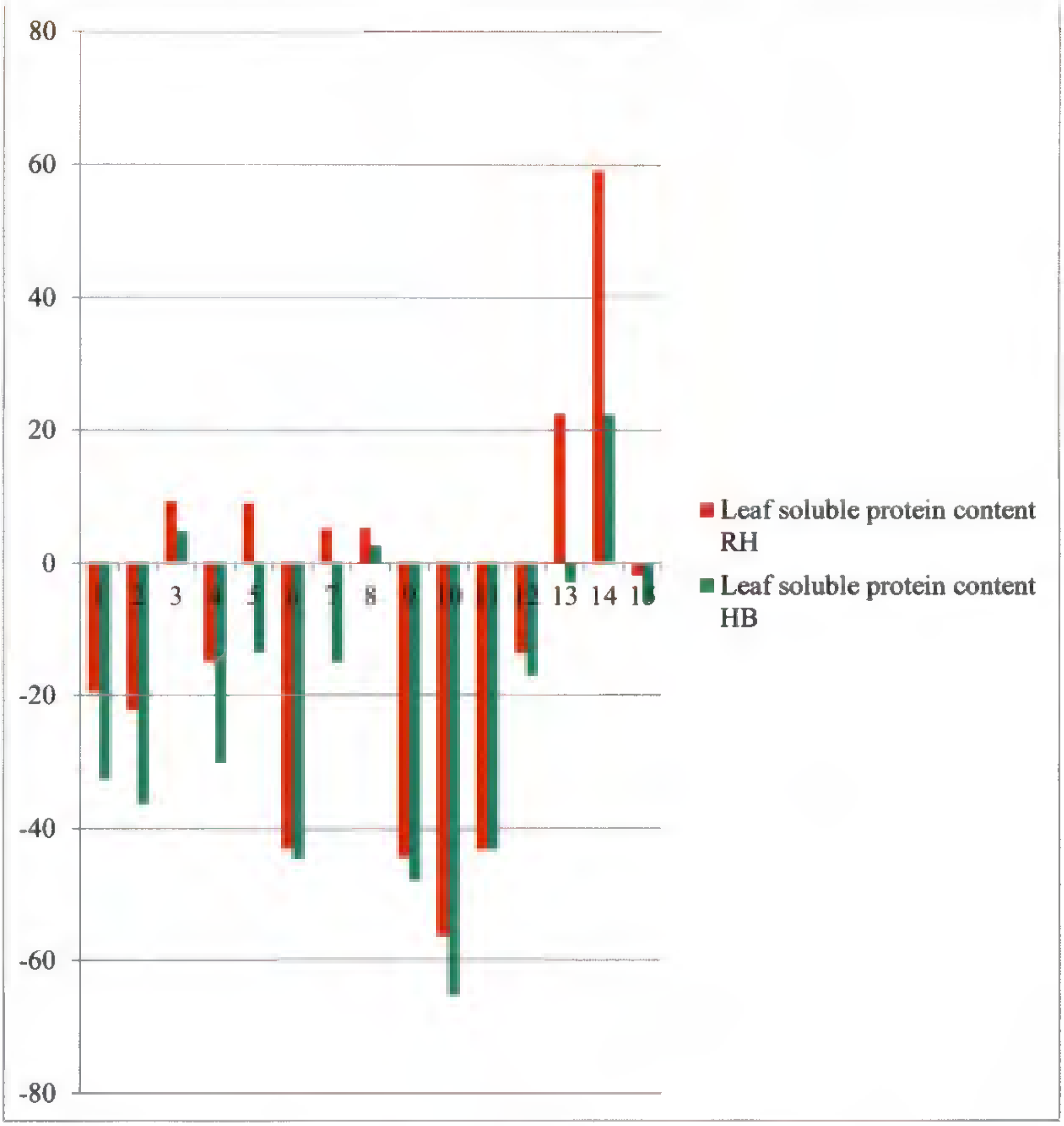
1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 40. Heterosis (%) for transpiration rate in upland rice



1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 41. Heterosis (%) for stomatal conductance in upland rice



1.Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12 . Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 42. Heterosis (%) for leaf soluble protein content in upland rice

desirable heterosis over mid parent in positive direction. Vyttila 6 x Swarnaprabha (PTB 43) (22.31%) recorded significant positive heterosis over the better parent.

4.19.14 Radiation Use Efficiency

The magnitude of heterosis ranged from 17.36 (Harsha x Swarnaprabha) to 164.23% (Thottacheera x Swarnaprabha) and 8.72 (Harsha (PTB 55) x Swarnaprabha) to 159.70 %(Thottacheera x Swarnaprabha (PTB 43)) over mid and better parents respectively. None of the hybrids were significant over mid and better parents for radiation use efficiency (Table 82).

4.19.15 Chlorophyll Meter Reading

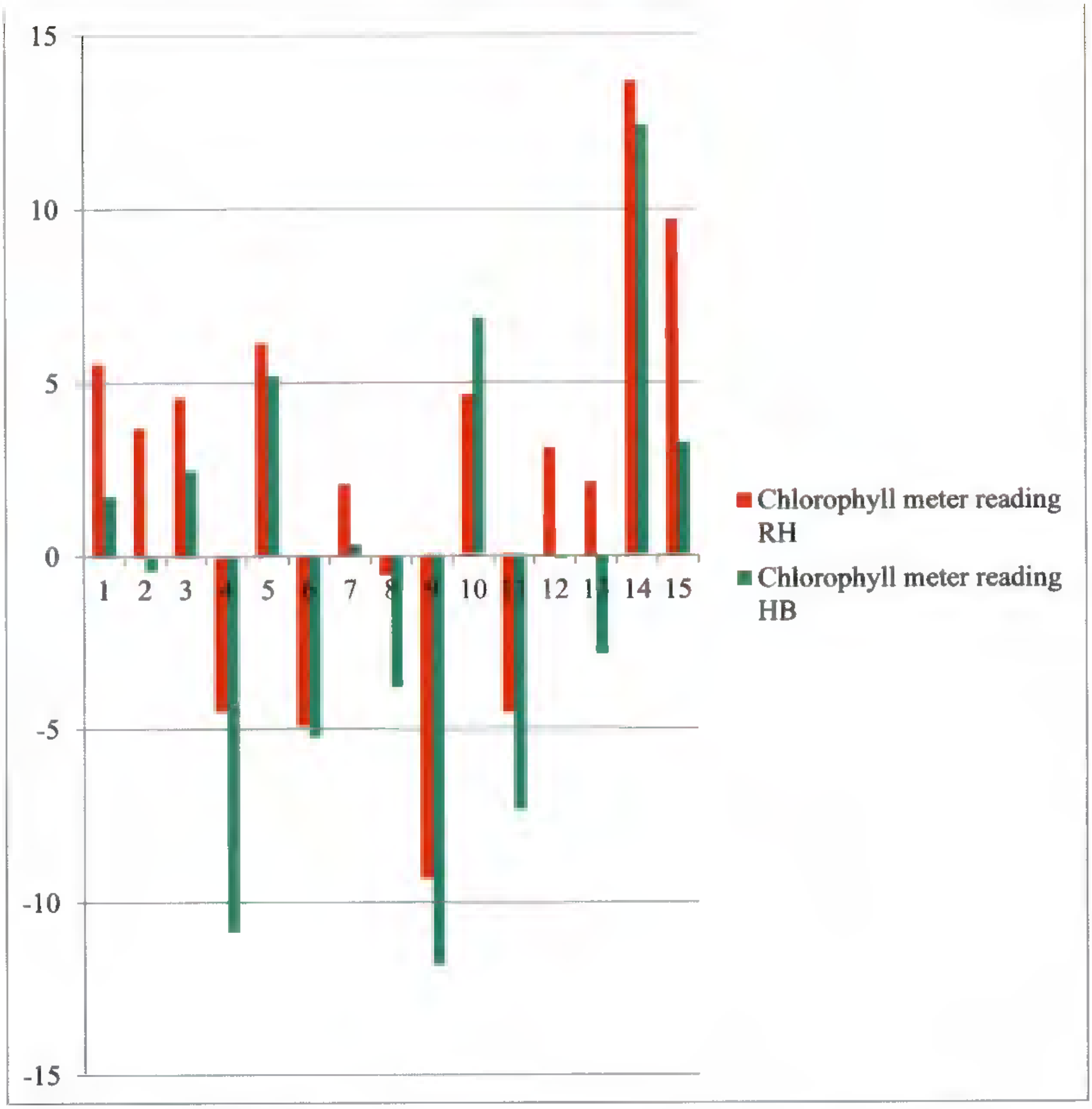
Among the hybridsVyttila 6 x Swarnaprabha (PTB 43) (13.68%),Harsha (PTB 55) x Swarnaprabha (PTB 43) (9.71%), Vaishak (PTB 60) x Swarnaprabha (PTB 43) (6.16%)andVaishak (PTB 60) x Thottacheera (5.56%), showed significant positive heterosis over mid parent (Fig.43) while the hybrids Vyttila 6 x Swarnaprabha (PTB 43) (12.41%), Kalladiaryan x Vyttila 6 (6.89%), Vaishak (PTB 60) x Thottacheera (1.71%) and Thottacheera x Vyttila 6 (0.33%) showed significant positive heterosis over better parent (Table 82).

4.19.16 Leaf Area Index (LAI)

The magnitude of heterosis over mid parent ranged between -23.11 (Thottacheera x Harsha) and 87.50% (Kalladiaryan x Swarnaprabha). Heterobeltiosis for leaf area index ranged from -28.12 (Thottacheera x Harsha) to 68.87% (Kalladiaryan x Swarnaprabha (PTB 43))(Table 83, Fig.44). Kalladiaryan x Swarnaprabha (PTB 43) showed significant positive heterosis over mid parent (87.50%) and better parent (68.87%) respectively for leaf area index.

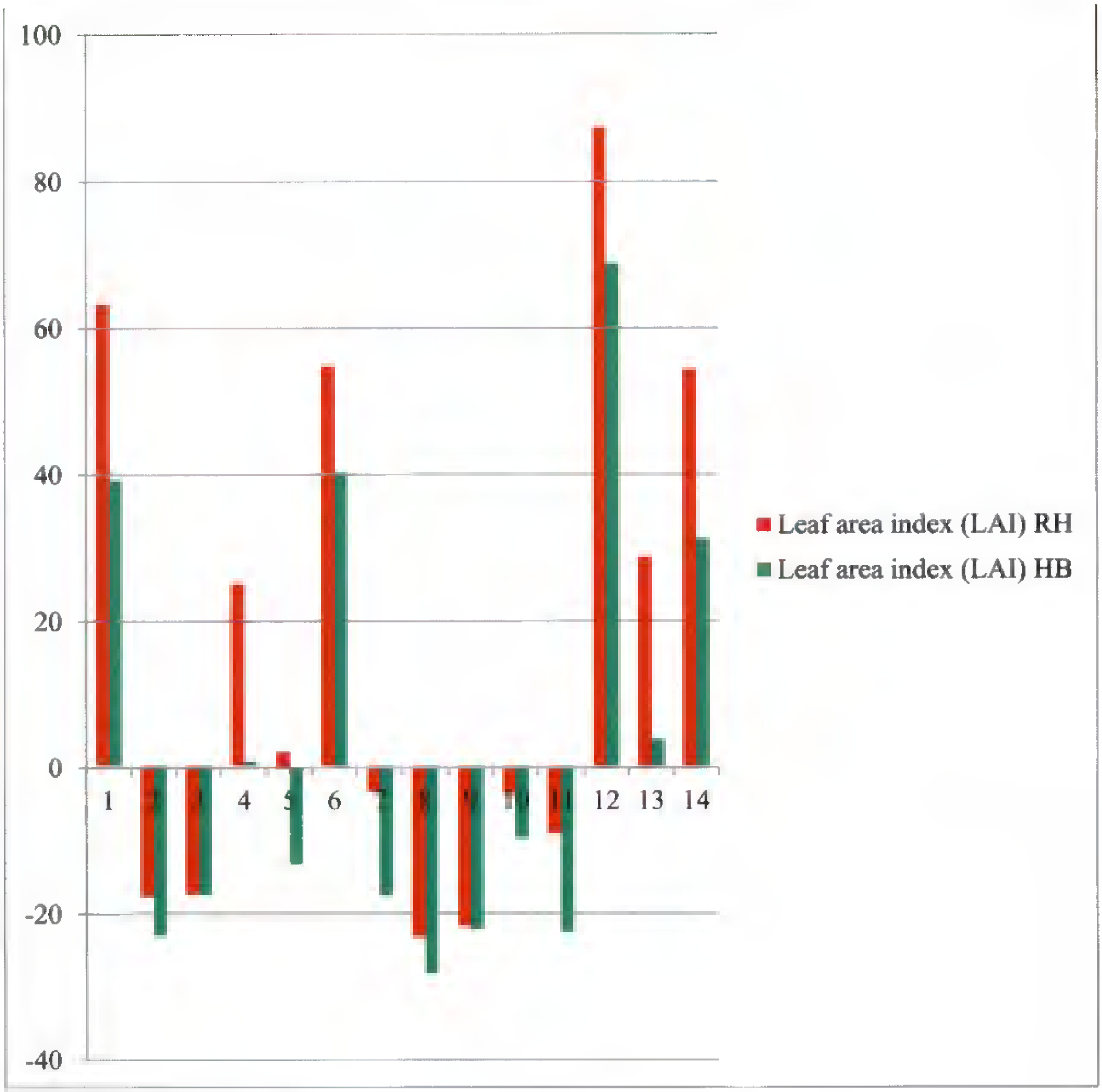
4.19.17 Relative Growth Rate (RGR) (mg/g/day)

The magnitude of heterosis ranged from -23.89 (Vaishak (PTB 60) x Kalladiaryan) to 43.59% (Thottacheera x Swarnaprabha (PTB 43)) and -32.89 (Vaishak (PTB 60) x Kalladiaryan) to 39.11% (Thottacheera x Swarnaprabha



1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 43. Heterosis (%) for chlorophyll meter reading in upland rice



1. Vaishak (PTB 60) x Thottacheera	2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6	4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)	6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6	8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)	10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)	12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)	14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)	

Fig. 44. Heterosis (%) for leaf area index in upland rice

(PTB 43) over mid and better parents respectively. None of the hybrids were significant over mid and better parents for relative growth rate (Table 83).

4.19.18 Net Assimilation Rate (NAR) (g/m2/day)

The magnitude of heterosis ranged from 17.26 (Harsha (PTB 55) x Swarnaprabha (PTB 43)) to 182.52 % (Thottacheera x Swarnaprabha (PTB 43)) and 0.08 (Harsha (PTB 55) x Swarnaprabha (PTB 43)) to 165.38 % (Thottacheera x Swarnaprabha (PTB 43)) over the mid and the better parents. Three hybrids showed significant positive heterosis over mid parent namelyThottacheera x Swarnaprabha (PTB 43) (182.52%),Vaishak (PTB 60) x Swarnaprabha (PTB 43) (169.36%) and Thottacheera x Harsha (PTB 55) (117.98%) respectively whereas Thottacheera x Swarnaprabha (PTB 43) (165.38%) and Vaishak (PTB 60) x Swarnaprabha (PTB 43) (164.01%) showed significant positive heterosis over better parent also (Table 83).

4.19.19 Carbon Isotope Discrimination (per mil)

Among the hybrids Vaishak (PTB 60) x Thottacheera (5.37%), Vaishak (PTB 60) x Vyttila 6 (5.30%), Thottacheera x Swarnaprabha (PTB 43) (4.26%), Thottacheera x Vyttila 6 (3.56%) and Vyttila 6 x Harsha (PTB 55) (-2.29%) showed significant heterosis over mid parent (Fig.45) whereas Vaishak (PTB 60) x Thottacheera (5.57%), Vaishak (PTB 60) x Vyttila 6 (4.94%), Thottacheera x Vyttila 6 (3.10%), Thottacheera x Kalladiaryan (3.03%) and Vyttila 6 x Harsha (PTB 55) (-4.36%) showed significant heterosis over better parent (Table 84).

4.19.20 Number of Days Taken for Reaching Critical Stress Level

Relative and better parent heterosis ranged from-23.40 (Thottacheera x Swarnaprabha) to 41.54% (Vaishak (PTB 60) x Thottacheera) and -34.78 (Thottacheera x Swarnaprabha) to 40.82% (Vaishak (PTB 60) x Thottacheera and Vaishak (PTB 60) x Harsha (PTB 55) respectively (Fig.46).The highest better parent heterosis of 40.82% were recorded in the two hybrids Vaishak (PTB 60) x Thottacheera and Vaishak (PTB 60) x Harsha (PTB 55) (Table 84).

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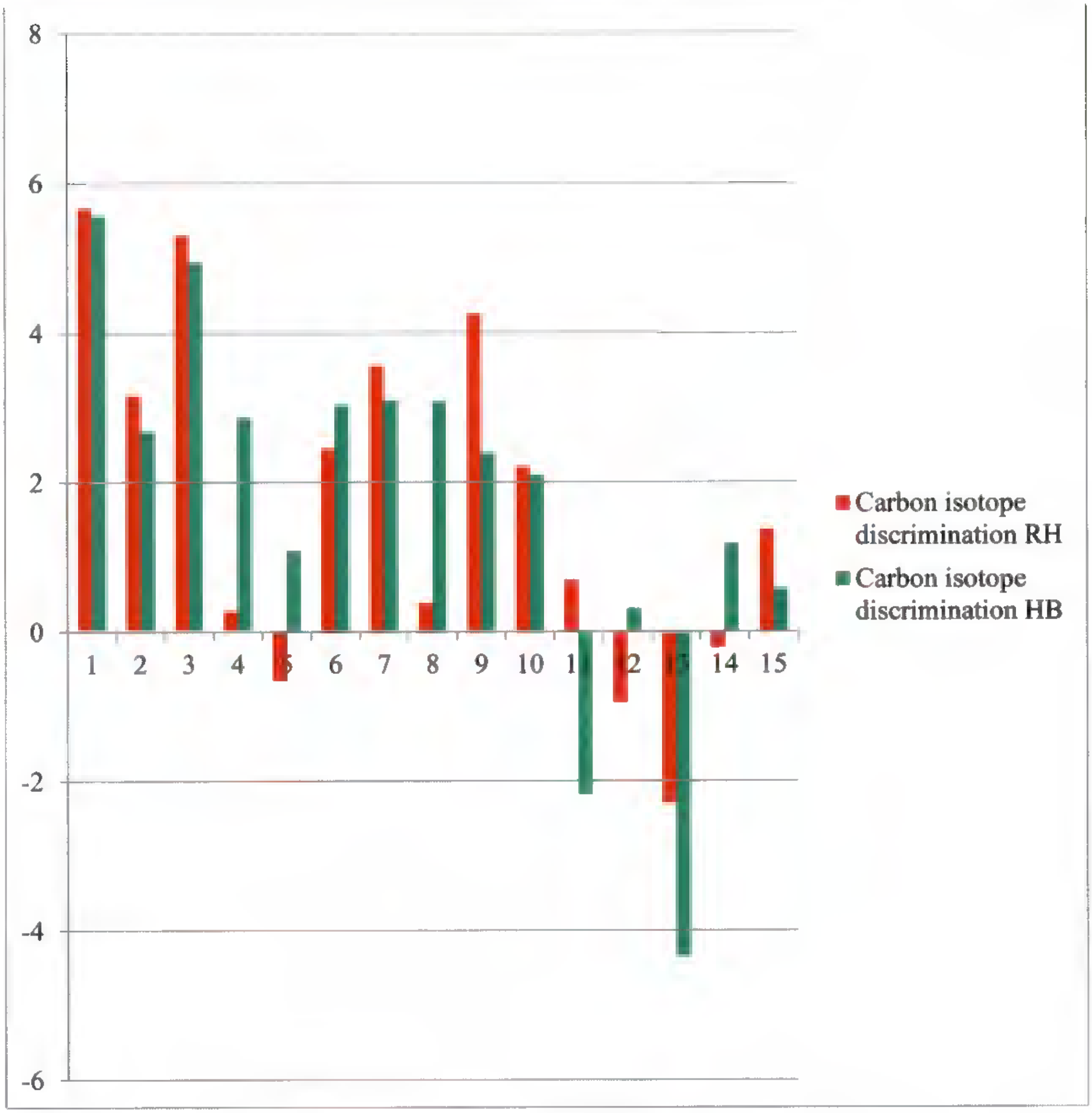


1. Vaishak (PTB 60) x Thottacheera

2. Vaishak (PTB 60) x Kalladiaryan

3. Vaishak (PTB 60) x Vyttila 6

4. Vaishak (PTB 60) x Harsha (PTB 55)

5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)

6. Thottacheera x Kalladiaryan

7. Thottacheera x Vyttila 6

8. Thottacheera x Harsha (PTB 55)

9. Thottacheera x Swarnaprabha (PTB 43)

10. Kalladiaryan x Vyttila 6

11. Kalladiaryan x Harsha (PTB 55)

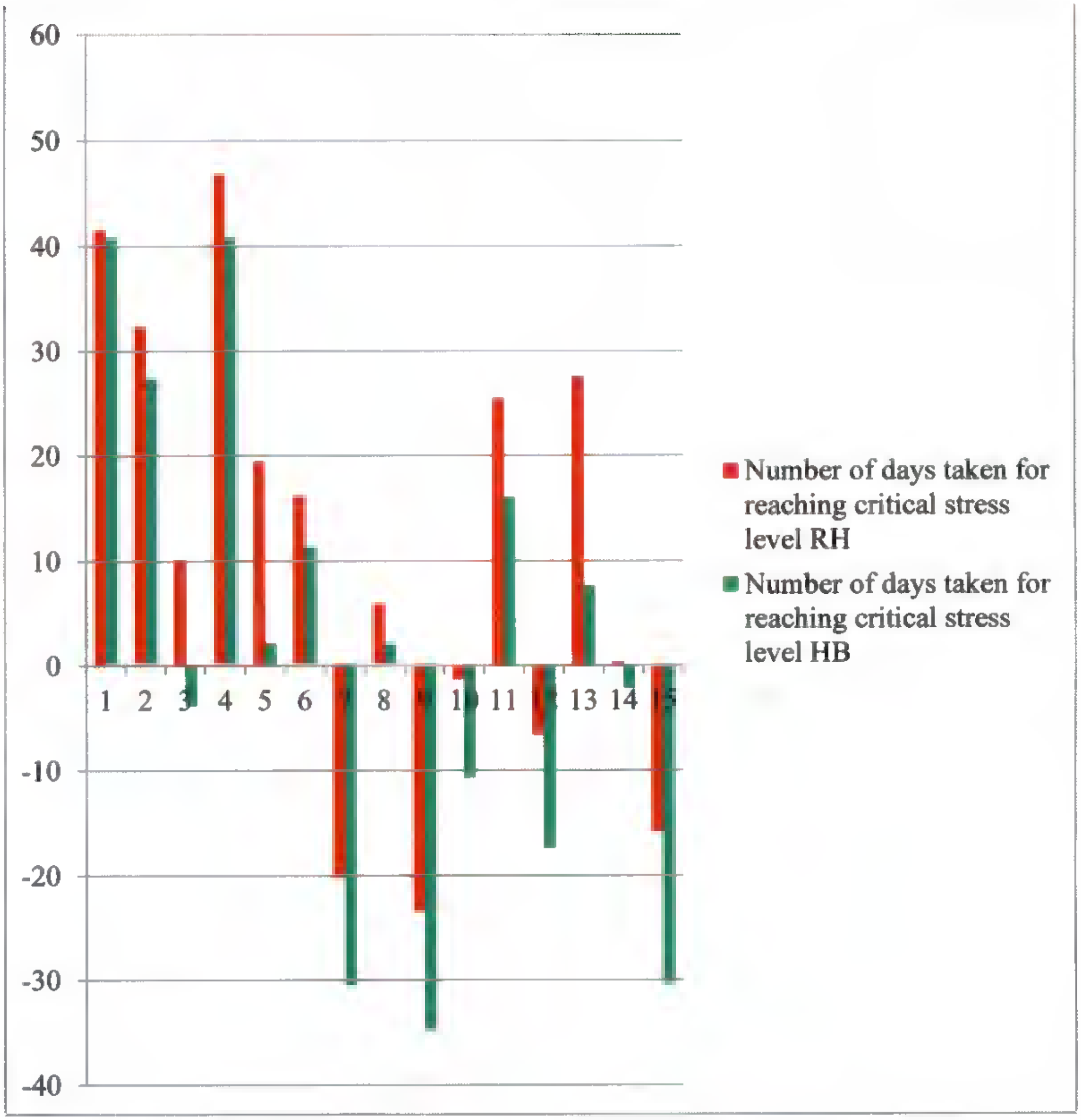
12. Kalladiaryan x Swarnaprabha (PTB 43)

13. Vyttila 6 x Harsha (PTB 55)

14. Vyttila 6 x Swarnaprabha (PTB 43)

15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 45. Heterosis (%) for carbon isotope discrimination in upland rice



1. Vaishak (PTB 60) x Thottacheera
2. Vaishak (PTB 60) x Kalladiaryan
3. Vaishak (PTB 60) x Vyttila 6
4. Vaishak (PTB 60) x Harsha (PTB 55)
5. Vaishak (PTB 60) x Swarnaprabha (PTB 43)
6. Thottacheera x Kalladiaryan
7. Thottacheera x Vyttila 6
8. Thottacheera x Harsha (PTB 55)
9. Thottacheera x Swarnaprabha (PTB 43)
10. Kalladiaryan x Vyttila 6
11. Kalladiaryan x Harsha (PTB 55)
12. Kalladiaryan x Swarnaprabha (PTB 43)
13. Vyttila 6 x Harsha (PTB 55)
14. Vyttila 6 x Swarnaprabha (PTB 43)
15. Harsha (PTB 55) x Swarnaprabha (PTB 43)

Fig. 46. Heterosis (%) for number of days taken for reaching critical stress level in upland rice

Plate 14. Vaishak x Thottacheera (7)

Plate 15. Vaishak x Kalladiaryan (8)

Plate 16. Vaishak x Swarnaprabha (11)

Plate 17. Vyttila 6 x Harsha (19)

Plate 18. Vyttila 6 x Swarnaprabha (20)

Plate 19. Crushed leaf sample for carbon isotope discrimination

4.20 SELECTION OF FIVE SUPERIOR HYBRIDS OUT OF FIFTEEN

Five superior hybrids were selected for carrying forward to further generation based on yield attributes and drought tolerance parameters (Plate 14 to 18). The five hybrids are Vaishak x Thottacheera,Vaishak x Kalladiaryan,Vaishak x Vyttila 6,Vyttila 6 x Harsha (PTB 55)and Vyttila 6 x Swarnaprabha.

Vaishak x Thottacheera performed well for number of spikelets panicle^{-1} (115.46), number of filled grains panicle^{-1} (72.06) and harvest index (42.66).

Vaishak x Kalladiaryan performed well for number of productive tillers plant^{-1}(19.20),panicle length (23.61), number of spikelets panicle^{-1} (102.05), straw yield plant^{-1} (28.07) and also for proline content.

Vaishak x Vyttila 6 performed well for panicle length (22.78) and number of filled grains panicle^{-1} (61.20).

Vyttila 6 x Harsha (PTB 55) was superior for grain yield plant^{-1} (30.83), harvest index (51.25), number of spikelets panicle^{-1} (120.92) and number of filled grains panicle^{-1} (98.94).

The hybrid Vyttila 6 x Swarnaprabha performed well for the traitsgrain yield plant^{-1}(24.57) and harvest index (45.50%).

Experiment V

4.21 GENETIC PARAMETERS

4.21.1 Genetic Variability

Mean performance of six parents and fivebest F$_2$populationis given in Table 85. The analysis of variance is furnished in Table 86.

Parents and F$_2$ populations showed significant differences among themselves for days to 50 per cent flowering. Kalladiaryan (80.67 days) was the earliest flowering type among parents whereas Vyttila 6 (97.33 days) took the maximum time for flowering. In the F$_2$ populations the duration varied from 77.67 (Vaishak x Swarnaprabha) to 93.33 days (Vyttila 6 x Harsha and Vyttila 6 x Swarnaprabha).

All hybrids showed significant increase over the best parents for number of productive tillers plant^{-1}. Among parents productive tillers plant^{-1} ranged from 7.27 (Thottacheera) to 11.30 (Kalladiaryan), parents Vaishak, Harsha and Swarnaprabha being on par with Thottacheera. The F_2Vyttila 6 x Swarnaprabha (19.67) recorded the highest number of tillers plant^{-1} with the value of 19.67. Vyttila 6 x Harsha and Vaishak x Thottacheera were on par with the highest value.The lowest mean value was recorded by Vaishak x Swarnaprabha (14.67) which was significantly superior to the best parent.

Significant wide range variation was observed for plant height among the parents with a range from 81.33 cm in Harsha to 119.37cm in Swarnaprabha. Vaishak (119.30cm) was on par with the tallest entry. The F_2populations were intermediate between the parents for plant height showing a range from 87.10 (Vyttila 6 x Swarnaprabha) to 108.27 (Vaishak x Thottacheera).

Panicle length was significantly higher in the F_2 populations than the parents. Among the parental varieties Vyttila 6 (19.21cm) recorded the highest mean whereas the lowest mean was recorded by Harsha (16.76cm). Kalladiaryan and Swarnaprabha were on par with Harsha. Among the F_2 segregants this trait ranged from 22.01cm in Vyttila 6 x Harsha to 22.81 cm in Vaishak x Thottacheera with all the five F_2 populations being on par with each other.

Number of spikelets panicle^{-1} was significantly high among the F_2 populations as compared to the parents. Vyttila 6 (81.03) scored the highest number of spikelets panicle^{-1} among parents whereas Thottacheera (62.20) scored the lowest. Kalladiaryan (63.83) and Harsha (67.35) were on par with Thottacheera. The F_2 populations showed highly significant differences than the parents. The F_2 segregants of Vaishak x Kalladiaryan (76.43) bore the lowest number of spikelets and Vyttila 6 x Harsha (111.30) bore the highest number.

Filled grains panicle^{-1}varied widely among the F_2 populationsas compared to parents. For the varieties the range was from 57.83 (Thottacheera) to 73.98

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(Vyttila 6). In the F_2 generation the range was from Vaishak x Kalladiaryan (52.33) to Vyttila 6 x Harsha (97.67).

Spikelet sterility percentage was significantly high among the F_2 as compared to the parents which were on par with each other. It ranged from 7.03% in Thottacheera to 10.02% in Harsha among the parents and whereas in F_2 it varied from Vyttila 6 x Harsha (12.12%) to Vaishak x Thottacheera (31.44 %).

The parents and hybrids were significantly different from each other for the trait grain weight panicle^{-1}. The F_2 segregants showed much variation among each other for the trait whereas the parental varieties were more stable for the trait. Among the parents Vaishak exhibited heaviest panicle weight (1.34g) whereas Thottacheera (0.98g) showed the lightest. Considering parents and F_2 populations together the lightest grain weight panicle^{-1} was recorded for Vaishak x Kalladiaryan (0.58g) whereas heaviest panicles were in the F_2 population of the cross Vyttila 6 x Swarnaprabha (1.66g).

1000 grain weight ranged from 17.16 g in Thottacheera to 21.07 g in Vaishak among the parents. Kalladiaryan (17.75g) and Swarnaprabha (17.61g) were on par with Thottacheera. Among the F_2 populations, the highest mean was recorded by Vyttila 6 x Harsha (20.08g).The lowest value was obtained for Vaishak x Kalladiaryan (15.38g) which was on par with Vaishak x Swarnaprabha (15.58g).

The F_2 progenies were significantly superior to their parents for grain yield per plant. Among the parents Vyttila 6 (14.40g) recorded the highest mean value followed by Kalladiaryan (12.46g) whereas the lowest mean value was obtained for Thottacheera (7.14g).In the F_2 populations, grain yield varied from 9.85g in Vaishak x Kalladiaryan to 30.51g in Vyttila 6 x Harsha. Grain yield of Vaishak x Swarnaprabha (13.67g) was on par with Vaishak x Kalladiaryan.

Straw yield plant^{-1} was generally high in the F_2 as compared to the parents. It ranged from 16 g in Thottacheera to 24.07 g in Vyttila 6 among the parents. Kalladiaryan (21.93g) was on par with Vyttila 6. Among the F_2 populations, the highest mean was recorded by Vyttila 6 x Swarnaprabha (30 g) which was on par

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with Vyttila 6 x Harsha (29.00g) and Vaishak x Kalladiaryan (27.83g).The lowest value for straw yield was obtained for Vaishak x Swarnaprabha (21.66g).

Among the parental varieties Vyttila 6 (37.40 per cent) recorded the highest mean for harvest index closely followed by Kalladiaryan (36.17 percent) whereas the lowest harvest index was obtained for Thottacheera (30.83percent). In the F_2 populations highest mean was recorded by Vyttila 6 x Harsha (50.88 percent) which was significantly superior to all other hybrids and parents. Vyttila 6 x Swarnaprabha (43.24%) came second for this trait, while the lowest mean value was recorded by Vaishak x Kalladiaryan (25.60%) (Plate 20).

4.21.2 Nature of panicle exsertion

Nature of panicle exertion is presented in Table 87. The varieties *viz.*, Vyttila 6, Harsha and Swarnaprabha and the F_2 population Vyttila 6 x Swarnaprabha and Vaishak x Swarnaprabha had their panicles partly exserted from the flag leaf.Vaishak and Vyttila 6 x Harsha had their panicles mostly exserted and Thottacheera, Kalladiaryan, Vaishak x Thottacheera and Vaishak x Kalladiaryan had well exserted panicles.

4.21.3 Leaf rolling

Mean values of leaf rolling score are presented in Table 88. The varietyKalladiaryan showed less pronounced leaf rolling under dry spell whereas all theremaining varieties were prone to leaf rolling under natural stress.

4.21.4 Percentage soil moisture content

Percentage soil moisturecontent is presented in Table 89.Soil moisture content varied from 11.56% (at seedling stage) to 10.06 % (at reproductive stage) and 6.87%(at harvesting stage).

Plate 20. Expt. V. General field view- Parents and F_2 lines

4.22 PHENOTYPIC AND GENOTYPIC COEFFICIENTS OF VARIATION OF SIX PARENTS AND BEST FIVE F_2 POPULATIONS IN RAINFED UPLAND RICE

Phenotypic variance, genotypic variance and coefficients of variation, heritability and genetic advance for 12 traits in six parents and best five F_2populations in rice are presented in Tables 90 and 91.

Among the different characters studied, the highest genotypic and phenotypic coefficients of variation was observed for spikelet sterility percent (GCV=54.62; PCV=59.33) followed by grain yield plant^{-1}(GCV= 49.20; PCV =51.98) number of productive tillers plant^{-1} (GCV=38.85; PCV=39.65), straw yield plant^{-1} (GCV=22.41; PCV=23.63) and grain weight^{-1} panicle (GCV=22.12;PCV=25.55). Moderate levels of coefficients of variation were observed for number of spikelets panicle^{-1} (GCV=19.94; PCV=20.46), filled grains panicle^{-1} (GCV=19.93;PCV=20.21), harvest index (GCV=17.17; PCV=18.85), panicle length (GCV=13.27;PCV=13.63) and plant height at maturity (GCV=12.98;PCV=13.29). The lowest genotypic and phenotypic coefficients of variation were observed for days to 50 percent flowering (GCV=7.85; PCV=7.92) and 1000 grain weight (GCV=9.65; PCV=10.43).

The difference between genotypic and phenotypic coefficient of variation was minimum for days to 50% flowering (0.07), number of filled grains panicle^{-1} (0.28), plant height at maturity (0.31) and panicle length (0.36) and maximum for spikelet sterility (4.71), grain weight panicle^{-1} (3.43), grain yield plant^{-1} (2.78), straw yield plant^{-1} (1.22) and harvest index (1.08).

4.23HERITABILITY (H^2) AND GENETIC ADVANCE (GA)

The estimates of heritability and genetic advance are furnished in Table 91. High heritability in the broad sense was observed for all the charactersunder study *viz.,*days to 50 % flowering (98%), number of productive tillers plant^{-1} (96%), plant height at maturity (95 %), panicle length (95 %), number of spikelets panicle^{-1} (95 %), number of filled grains panicle^{-1} (97%), spikelet sterility (85.00%), grain weight panicle^{-1} (75.00%), 1000 grain weight (86.00%), grain

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yield plant^{-1} (90.68%), straw yield plant^{-1} (90.00%) , biological yield plant $^{-1}$ (90.00%) and harvest index (89.00%). Heritability estimates ranged from 75.00% to 98.00%.

High heritability coupled with high genetic advance was recorded fornumber of spikelets panicle^{-1} (95.00 and 31.56) number of filled grains panicle^{-1} (97.00 and 27.20) and plant height at maturity (95 and 25.93).Moderate level of genetic advance was recorded for the traits *viz.,* spikelet sterility (14.87) were days to 50 percent flowering (13.87), grain yield plant^{-1} (13.65) harvest index (12.81)and number of productive tillers plant^{-1} (10.08).Genetic advance for the traitsgrain weight panicle^{-1} (0.44), 1000 grain weight (3.30), panicle length (5.28) and straw yield plant^{-1} (9.84) was found to be low even through their heritability estimates were high.

4.24 SELECTION INDEX

Discriminant function technique was adopted for the construction of a selection index using grain yield and morphological characters for the five best F$_2$segregants and their six parents. Characters of importance from the breeding point of view viz., number of productive tillers plant^{-1}, panicle length, number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, grain weight panicle $^{-1}$, 1000 grain weight, and straw yield plant^{-1} and harvest index were considered for the construction of the index.

The index score was computed and the parents and F$_2$ populations of their crosses were ranked accordingly. Index scores are presented in Table 92along with ranking. The highest value was recorded by the F$_2$ population. Vyttila 6 x Harsha (477.30) followed by the F$_2$ populations Vyttila 6 x Swarnaprabha (439.37), Vaishak (PTB 60) x Thottacheera (391.55) and Vaishak (PTB 60) x Swarnaprabha (PTB 43) (368.94). The fifth and the sixth positions were held by their parents *viz.*, Vyttila 6 (372.46) and Vaishak (342.67).Vaishak (PTB 60) x Kalladiaryan (342.32) ranked seventh. The parents Kalladiaryan (335.44), Harsha (PTB 55) (327.12),Swarnaprabha (PTB 43) (32.321) and Thottacheera (317.02) in that order filled the last four positions.

Table 85. Mean performance of six parents and bestfive F_2 populations in rice under rainfed upland condition

Sl.No	Parents and F2 segregants/ Character	Days to 50 % flowering	Productive tillers plant^{-1}	Plant height at maturity (cm)	Panicle length (cm)	Number of spikelets panicle^{-1}	Filled grains panicle^{-1}	Spikelet sterility (%)	Grain weight panicle^{-1} (g)	1000 Grain weight (g)	Grain yield plant^{-1} (g)	Straw yield plant^{-1} (g)	Harvest index (%)
1	Vaishak	93.33	8.00	119.30	18.07	69.60	63.90	8.19	1.34	21.07	10.75	19.27	35.78
2	Thottacheera	81.00	7.27	102.73	17.84	62.20	57.83	7.03	0.98	17.16	7.14	16.00	30.83
3	Kalladiaryan	80.67	11.30	93.40	16.80	63.83	58.10	9.00	1.10	18.93	12.46	21.93	36.17
4	Vyttila 6	97.33	11.20	87.73	19.21	81.03	73.98	8.56	1.29	17.75	14.40	24.07	37.40
5	Harsha	83.33	7.33	81.33	16.76	67.35	60.60	10.02	1.18	19.33	8.64	16.37	34.54
6	Swarnaprabha	93.33	7.70	119.37	16.88	66.57	60.20	9.57	1.06	17.61	8.06	16.40	33.08
7	Vyttila 6 x Swarnaprabha (selfed)	91.33	19.67	87.10	22.55	101.98	85.00	16.65	1.16	16.77	22.82	30.00	43.24
8	Vyttila 6 x Harsha (selfed)	91.33	19.27	87.93	22.01	111.30	97.67	12.12	1.60	20.08	30.51	29.00	50.88
9	Vaishak x Swarnaprabha (selfed)	77.67	14.47	102.24	22.49	84.10	62.50	25.50	0.94	15.58	13.67	21.66	38.74
10	Vaishak x Thottacheera(selfed)	80.67	18.20	103.43	22.81	83.17	66.60	19.79	1.00	17.68	18.21	24.83	42.22
11	Vaishak x Kalladiaryan (selfed)	82.00	17.00	108.27	22.59	76.43	52.33	31.44	0.58	15.38	9.85	27.83	25.60
	General mean	86.55	12.85	99.35	19.82	78.87	67.16	14.35	1.11	17.94	14.23	22.49	37.13
	CD(0.05)	1.532	1.729	4.874	1.040	6.187	3.794	5.665	0.242	1.208	4.065	2.880	3.978

Table 86. Analysis of variance for six parents andbestfive F_2 populations in rice under rainfed upland condition

Sl.No	Traits	MSS Treatment D.F =10	MSS Replication D.F =2	MSS Error D.F =20	F value
1	Days to 50 % flowering	139.22^{**}	1.91	0.81	172.07
2	Number of productive tillers per plant	75.86^{**}	0.31	1.03	73.62
3	Plant height at maturity (cm)	507.00^{**}	4.29	8.19	61.90
4	Panicle length (cm)	21.14^{**}	0.10	0.37	56.63
5	Number of spickelets panicle^{-1}	754.91^{**}	0.64	13.20	57.21
6	Number of filled grains panicle^{-1}	542.55^{**}	0.49	4.96	109.34
7	Spikelet sterility (%)	195.41^{**}	0.15	11.06	17.66
8	Grain weight panicle^{-1} (g)	0.20^{**}	0.02	0.02	9.98
9	1000 grain weight (g)	9.50^{**}	0.87	0.50	18.87
10	Grain yield plant^{-1} (g)	152.70^{**}	7.14	5.70	26.80
11	Straw yield plant^{-1} (g)	79.02^{**}	1.48	2.86	27.63
12	Harvest index (%)	136.03^{**}	5.42	5.45	24.94

** Significant at 1% level
*Significant at 5% level

Table 87. Nature of panicle exsertion in six parents and five F_2 populationsin rainfed upland rice

Sl. No	Variety/F_2segregants	Panicle exsertion
1	Vaishak	Mostly exserted
2	Thottacheera	Well exserted
3	Kalladiaryan	Well exserted
4	Vyttila 6	Partly exserted
5	Harsha	Partly exserted
6	Swarnaprabha	Partly exserted
7	Vyttila 6 x Swarnaprabha (selfed)	Partly exserted
8	Vyttila 6 x Harsha (selfed)	Mostly exserted
9	Vaishak x Swarnaprabha (selfed)	Partly exserted
10	Vaishak x Thottacheera(selfed)	Well exserted
11	Vaishak x Kalladiaryan (selfed)	Well exserted

Table 88. Leaf rolling score in F_2 populations under upland condition in rice

Sl. No.	Variety/ F_2	Decimal score	Description
1	Vaishak (PTB 60)	3	Leaves folding (deep V shape)
2	Thottacheera	3	Leaves folding (deep V shape)
3	Kalladiaryan	1	Leaves start to fold (Shallow V shape)
4	Vyttila 6	3	Leaves folding (deep V shape)
5	Harsha (PTB 55)	3	Leaves folding (deep V shape)
6	Swarnaprabha (PTB 43)	3	Leaves folding (deep V shape)
7	Vyttila 6 x Swarnaprabha (PTB 43)	5	Leaves folding (deep U shape)
8	Vyttila 6 x Harsha (PTB 55)	3	Leaves folding (deep V shape)
9	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	3	Leaves folding (deep V shape)
10	Vaishak (PTB 60) x Thottacheera	3	Leaves folding (deep V shape)
11	Vaishak (PTB 60) x Kalladiaryan	3	Leaves folding (deep V shape)

Table 89. Percentage soil moisture content under rainfed upland condition (Experiment V)

Sl. No.	Soil moisture content (%)	Stage of crop
1	11.56	Seedling stage
2	10.06	Reproductive stage
3	6.87	Harvesting stage

Table 90. Phenotypic and genotypic coefficients of variation of six parents and best five F_2 populations for 12 traits in rainfed upland rice

Sl. No	Traits	Genotypic variation	Phenotypic variation	Coefficient of variation	
				GCV	PCV
1	Days to 50% flowering	46.14	46.95	7.85	7.92
2	Number of productive tillers per plant	24.94	25.97	38.85	39.65
3	Plant height at maturity (cm)	166.27	174.46	12.98	13.29
4	Panicle length (cm)	6.92	7.29	13.27	13.63
5	Number of spikelets panicles-1	247.24	260.43	19.94	20.46
6	Number of filled grains panicle^{-1}	179.20	184.16	19.93	20.21
7	Spikelet sterility (%)	61.45	72.51	54.62	59.33
8	Grain weight panicle^{-1}(g)	0.06	0.08	22.12	25.55
9	1000 grain weight (g)	3.00	3.50	9.65	10.43
10	Grain yield plant^{-1} (g)	49.00	54.70	49.20	51.98
11	Straw yield plant^{-1} (g)	25.39	28.25	22.41	23.63
12	Harvest index (%)	43.53	48.98	17.77	18.85

Table 91. Broad sense heritability and genetic advance of six parents and five best F_2 populations for 12 traits in rainfed upland rice

Sl.No.	Traits	Heritability%	Genetic Advance
1	Days to 50% flowering	98	13.87
2	Number of productive tillers per plant	96	10.08
3	Plant height at maturity (cm)	95	25.93
4	Panicle length (cm)	95	5.28
5	Number of spickelets panicles^{-1}	95	31.56
6	Number of filled grains panicle^{-1}	97	27.20
7	Spikelet sterility(%)	85	14.87
8	Grain weight panicle^{-1}(g)	75	0.44
9	1000 seed weight (g)	86	3.30
10	Grain yield plant^{-1} (g)	90	13.65
11	Straw yield plant^{-1} (g)	90	9.84
12	Harvest index (%)	89	12.81

Table 92. Selection Index score and its rank number in upland rice

Sl.No.	Name of parents/F_2segregants	Selection index score	Rank number
1	Vaishak (PTB 60)	342.67	6
2	Thottacheera	317.02	11
3	Kalladiaryan	335.44	8
4	Vyttila 6	372.46	5
5	Harsha (PTB 55)	327.12	9
6	Swarnaprabha (PTB 43)	323.21	10
7	Vyttila 6 x Swarnaprabha (PTB 43)	439.37	2
8	Vyttila 6 x Harsha (PTB 55)	477.30	1
9	Vaishak (PTB 60) x Swarnaprabha (PTB 43)	368.94	4
10	Vaishak (PTB 60) x Thottacheera	391.55	3
11	Vaishak (PTB 60) x Kalladiaryan	342.32	7

Experiment VI

4.25MOLECULAR ANALYSIS STUDIES

Six parents and five hybrids were subjected to molecular analysis as with three trait specific marker. Details of markers and size given in Table 93.

Good quality DNA was isolated from the varieties and hybrids quality was checked using agrose gel electrophoresis (Plate 21). PCR was conducted using all the three primers.

Simple sequence Repeat

The polymerase chain reaction of six parents and their five best progenies was carried out with three SSR primers linked with respective quantitative traits.

PCR products by the primer RM 201 (Plate 22) shows that all the genotypes under study i.e. six parents and five hybrids produced a product of size 158 bp which is linked to the trait root length.

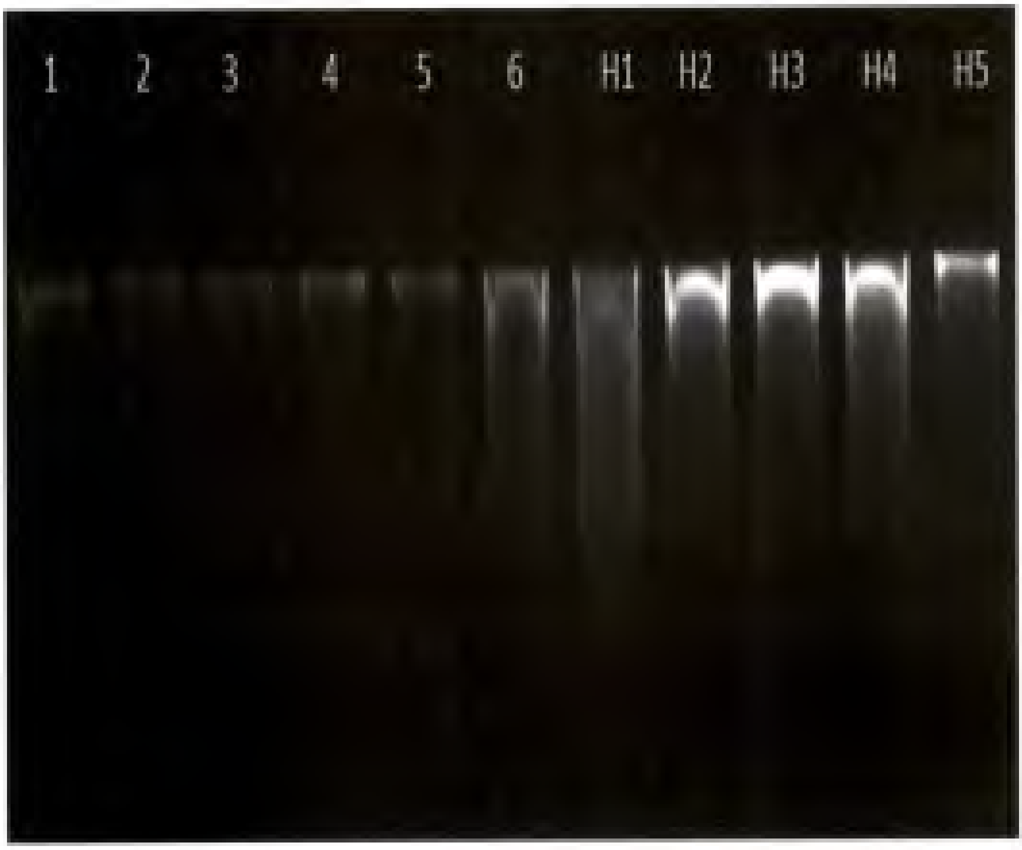
Primer RM 263 (Plate 23) produced product at 199 bp linked to the trait osmotic adjustment in parents Vaishak (1), Kalladiaryan (3), Vyttila 6 (4), Harsha (5) and also in hybrids Vyttila 6 x Swarnaprabha (H_1) and Vyttila 6 x Harsha (H_2).

Primer RM 451produced PCR product at 207 bp linked to various morphological traits through grain yield in all the accessions i.e. six parents and five hybrids (Plate 24).

Table 93. List of Three trait specific SSR markers and sequence information of forward and reverse primers used in this study

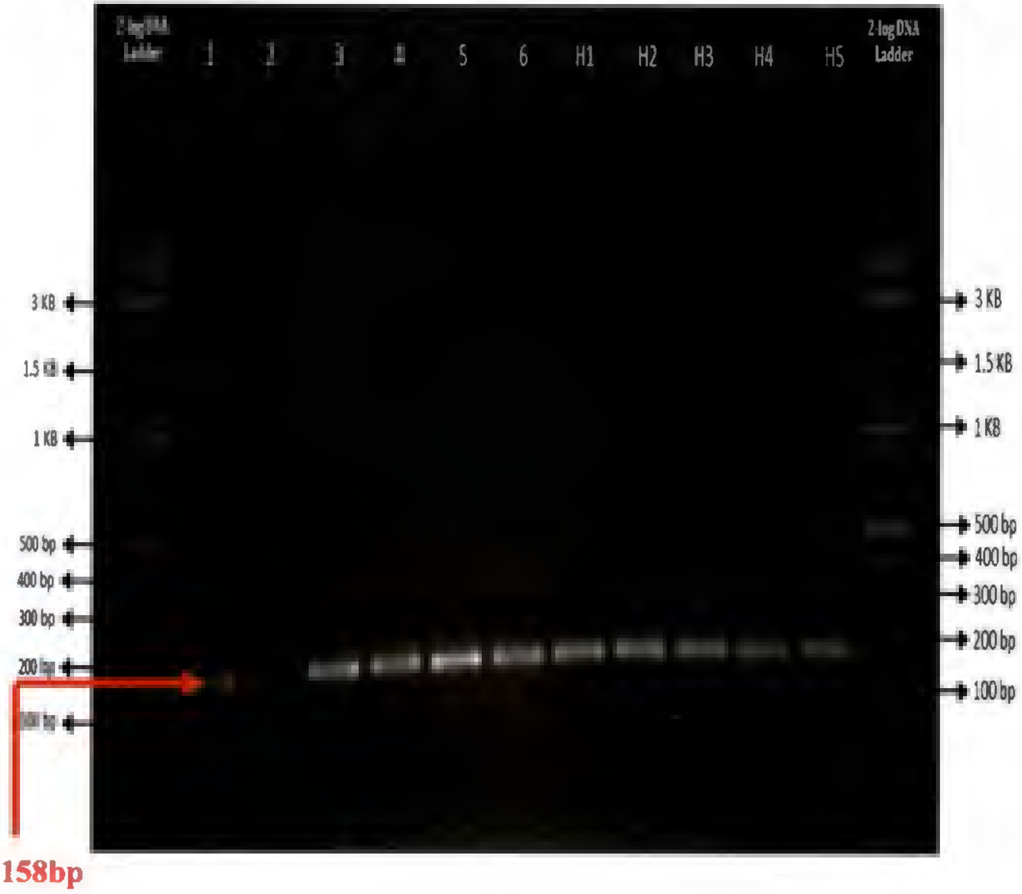
Sl. No.	Primer Name	Specific traits	Forward sequence 5'→ 3'	Reverse sequence5'→ 3'	Annealing Temp.	Specific allele size (bp)	References
1	RM201	Root length	CTCGTTTATTACCTACAGTACC	CTACCTCCTTTCTAGACCGATA	55	158	Chaitra *et al.*2005
2	RM263	Osmotic adjustment	CCCAGGCTAGCTCATGAACC	GCTACGTTTGAGCTACCACG	55	199	Srividhya *et al.* 2011 ; Zhang *et al*. 2001
3	RM451	Grain yield through various morphological traits	GATCCCCTCCGTCAAACAC	CCCTTCTCCTTTCCTCAACC	55	207	Kamoshita *et al.* 2008 (Aboulila, 2015)

Plate 21. DNA



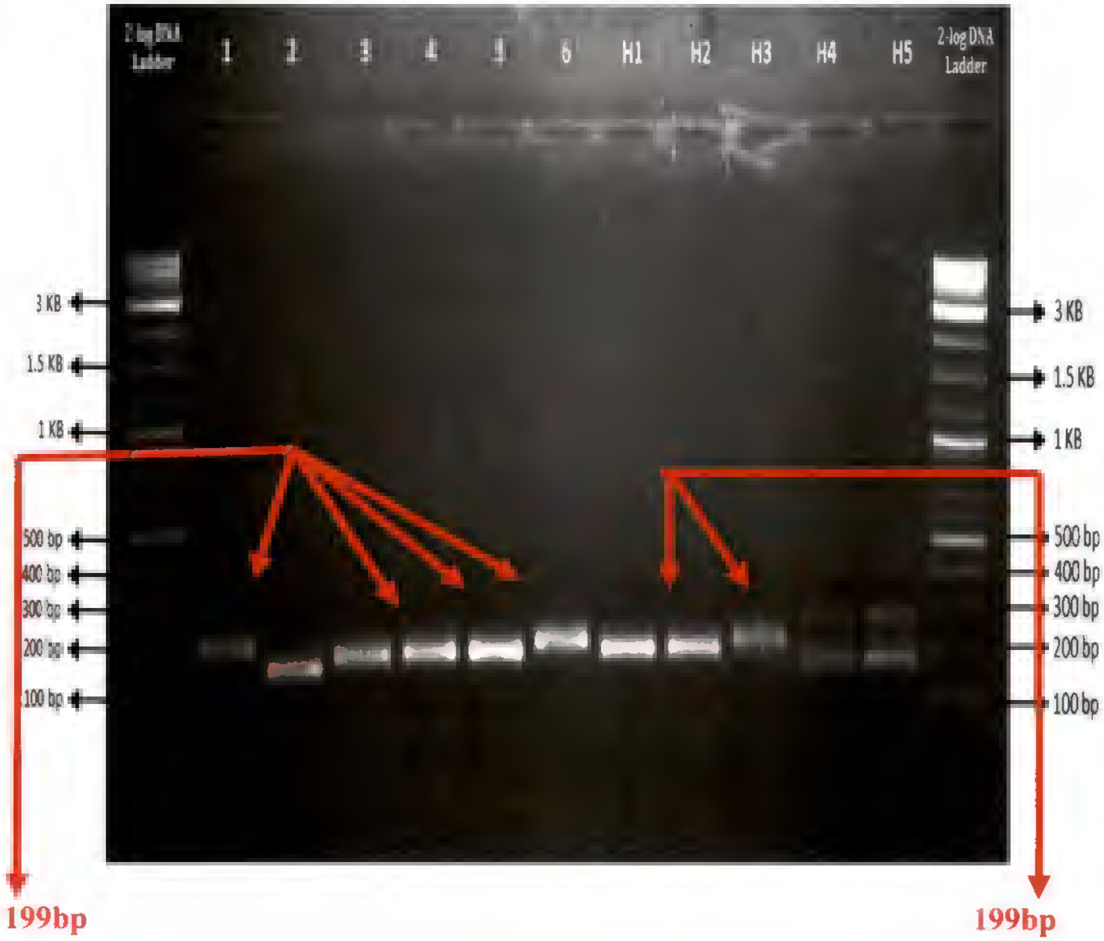
1	Vaishak	2	Thottacheera
3	Kalladiaryan	4	Vyttila 6
5	Harsha	6	Swarnaprabha
H_1	Vyttila 6 x Swarnaprabha	H_2	Vyttila 6 x Swarnaprabha
H_3	Vaishak x Swarnaprabha	H_4	Vaishak x Thottacheera
H_5	Vaishak x Kalladiaryan	bp	Base pairs

Plate 22. PCR products of six parents and five progeny by using marker RM 201



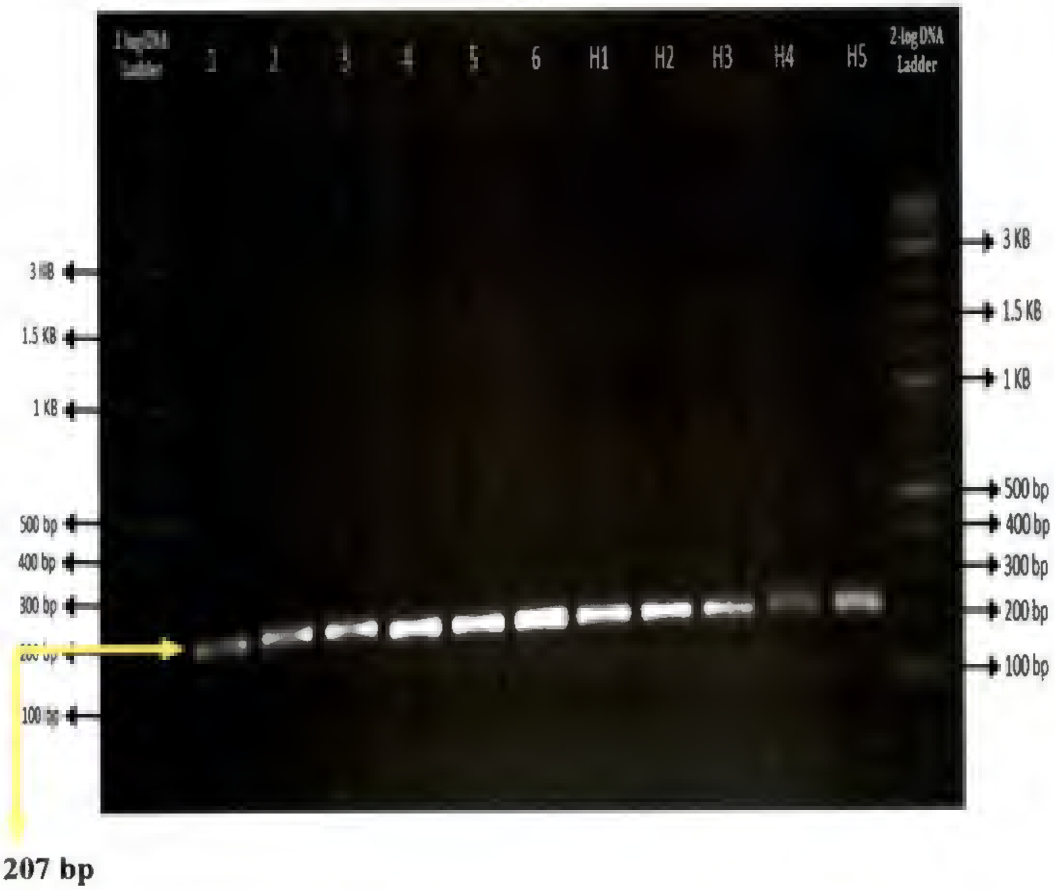
1	Vaishak (high grain yield)	2	Thottacheera (drought resistance)
3	Kalladiaryan(drought resistance)	4	Vyttila 6 (High grain yield)
5	Harsha (drought resistance)	6	Swarnaprabha (High grain yield)
H_1	Vyttila 6 x Swarnaprabha	H_2	Vyttila 6 x Swarnaprabha
H_3	Vaishak x Swarnaprabha	H_4	Vaishak x Thottacheera
H_5	Vaishak x Kalladiaryan	bp	Base pairs

Plate 23. PCR products of six parents and five progeny by using marker RM263



1	Vaishak (high grain yield)	2	Thottacheera (drought resistance)
3	Kalladiaryan(drought resistance)	4	Vyttila 6 (High grain yield)
5	Harsha (drought resistance)	6	Swarnaprabha (High grain yield)
H_1	Vyttila 6 x Swarnaprabha	H_2	Vyttila 6 x Swarnaprabha
H_3	Vaishak x Swarnaprabha	H_4	Vaishak x Thottacheera
H_5	Vaishak x Kalladiaryan	bp	Base pairs

Plate 24. PCR products of six parents and five progeny by using marker RM451



1	Vaishak (high grain yield)	2	Thottacheera (drought resistance)
3	Kalladiaryan(drought resistance)	4	Vyttila 6 (High grain yield)
5	Harsha (drought resistance)	6	Swarnaprabha (High grain yield)
H_1	Vyttila 6 x Swarnaprabha	H_2	Vyttila 6 x Swarnaprabha
H_3	Vaishak x Swarnaprabha	H_4	Vaishak x Thottacheera
H_5	Vaishak x Kalladiaryan	bp	Base pairs

DISCUSSION

5. DISCUSSION

Rice (*Oryza sativa* L.) is the staple food of more than half of the world human population (Gross and Zhao, 2013). It has the evolutionary particularity of being semi-aquatic. So irrigated or lowland rice is the most common ecosystem comprising 55% of the global rice area and accounting for 75% of global rice production (Khush, 2005). Acute water scarcity which is on the increase has threatened this ecosystem making a switchover to upland rice ecosystem essential. Upland rice encompasses 12% of global rice production area and is generally the lowest yielding ecosystem. Drought stress is the most severe abiotic stress in upland situations. Rice has relatively few adaptations to drought conditions and is extremely sensitive to drought stress.

Upland rice encompasses 12% of global rice production area and is generally the lowest yielding ecosystem. The major drought years in India were 1877, 1899, 1918, 1972, 1987 and 2002. 68 per cent of our land area is vulnerable to drought. Out of these around 33% receives less than 750mm rainfall is classified as chronically drought prone area includes 35% receives 750-1125 mm rainfall and is classified as drought prone area. The 1987 drought are one of the worst droughts of the century, with an overall rainfall deficiency of 19 percent.

Drought and high temperature (heat) stress are considered to be the two major environmental factors limiting crop growth and yield. These two stresses induce many biochemical, molecular, and physiological changes and responses that influence various cellular and whole plant processes that affect crop yield and quality. The impacts of environmental stress, particularly those of drought and heat, have been studied independently. However, under field conditions, both of these stresses often occur in combination. The interactive effects of various stresses on crop plants have received far less attention. Simultaneous occurrence of multiple stresses increases the deleterious effects such that the effect considerably exceeds the simple additive effects of the concerned action alone (cross-synergism). Similarly, a plant subjected to a single stress can be capable of increasing its resistance to subsequent or other stresses (cross-adaptation). Crop performance in terms of growth, development, biomass accumulation, and yield depends on the crop's ability to withstand, acclimate, or recover from the stress. Drought is a more complex phenomenon than most other stresses such as salinity, submergence, pests and diseases and it can occur at any point of time during crop production. Drought may affect a large array of physiological, molecular and biochemical processes of plants and thus may reduce the production potential of the rice crop. Drought resistance in rice is a complex trait controlled by polygenes. It remains the most difficult trait to study and characterise since genetic mechanisms that condition the expression of drought resistance in crops especially rice are poorly understood.

Rice is particularly susceptible to water deficit compared to other crop species, and this sensitivity is severe around flowering. Rice must be made more drought resistant and this is a somewhat contradictory objective considering that rice is preferably grown under flooded condition. Drought resistance is generally based on the relative yield or survival of the genotypes subjected to the drought environment (Hall, 1993).

Breeding for drought resistance is a challenging task because of the complexity of drought responses, environmental factors and their interactions. Conventional breeding approaches have been successful but progress has been slow. Recent advances in genome mapping and functional genomics provides new powerful tools for the genetic dissection of drought resistance components. It is anticipated that molecular genetic research will provide high throughput DNA marker systems for marker assisted selection which will be more efficient and effective in combining favourable drought resistant traits in breeding program and, will also lead to a better understanding of the molecular basis of the genes underlying drought resistance which can be used to improve the drought resistance in rice through genetic engineering.

The results obtained in the present investigation are discussed under the following heads:

5.1 Genetic variability under upland condition
5.2 Phenotypic and genotypic coefficients of variation
5.3 Heritability and genetic advance
5.4 Character association
5.5 Path coefficient analysis
5.6 Selection index
5.7 Genetic variability under protected condition
5.8 Performance of parents and hybrids
5.9 Half diallel analysis
5.10 Combining ability, gene action and heterosis
5.11 Five superior hybrids identified
5.12 Genetic parameters of F_2 populations
5.13. Molecular analysis studies

5.1 GENETIC VARIABILITY UNDER UPLAND CONDITION

In the process of crop improvement, desirable plants are continuously being selected from genetically variable populations. Genetic improvement thus depends on the existence of genetic variability. Therefore an insight into the magnitude of variability present in the crop is of utmost importance as it is a key factor which determines the amount of progress expected from selection. In the present study twenty genotypes were evaluated for morphological characters *viz.*, days to 50 % flowering, plant height at tip of longest leaf of plant, plant height at maturity, panicle length, number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, spikelet sterility, grain weight panicle^{-1}, 1000 grain weight, grain yield plant^{-1}, straw yield plant^{-1} and harvest index in rainfed upland condition during May to October, 2014.

The results revealed a wide range of variability among the genotypes for most of the traits studied. The range and analysis of variance indicated potential genetic variability and diversity in the material under consideration. These results indicated better scope for genetic improvement through conventional breeding.

The early flowering and maturing genotypes were Karutha Modan, Arimodan and Harsha. Earliness in flowering is important because a close association between this trait and drought tolerance was observed in upland evaluation of parents (Laffitte and Curtosis, 2002). The late flowering and maturing genotypes were Uma, Aathira and Kanakom. The range in number of productive tillers plant^{-1} was from 3.4 to 6.96 with variety Kanakom recording the lowest value and variety Vyttila 2 recording the highest value. The higher the number of productive tillers the greater is the yield. Similar results were reported by Valarmathi and Leenakumary (1998) that grain yield increased when number of productive tillers increased. They also observed a reduction in time to maturity in rice cultivars under upland situation compared to lowland transplanted condition.

The range for plant height was from 73.06 to139.13 cm with variety Chuvanna Modan being the tallest and variety Kanchana being the shortest. In general, moisture stress resulted in reduced plant height and the susceptible types were more sensitive to height reduction than the rice varieties specifically suited for uplands (Salisbarry and Ross,1992). The variety Swarnaprabha had the highest harvest index of 41.74. Shanmugasundaram *et al.* (2002) suggested that while selecting superior genotypes for cultivation under rainfed situations harvest index and straw yield forms on important selection criterion.

The variety Vaishak showed the highest mean of 11.66g for the trait grain yield plant^{-1}. Vaishak had appreciably high harvest index also. This is in line with the reports of Atlin *et al.* (2008) that grain yield under moisture stress is a function of biomass production and harvest index. The variety Uma which is very popular in Kerala in terms of performance and yield showed good performance during vegetative stage. The variety being late maturing and since a dry spell in kharif 2014 unfortunately coincided exactly with the early reproductive phase of this strictly rainfed upland crop, performance was severely affected. Uma scored lowest number of filled grains panicle^{-1}, grain weight panicle^{-1}, 1000 grain weight, grain yield plant^{-1}, biological yield plant^{-1}, harvest index and highest spikelet sterility. This is supported by Liu *et al.* (1993) and Wopereis *et al.* (1996) who observed that water stress at booting and heading to flowering stages reduced the

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number of filled grains panicle^{-1}, 1000 grain weight and grain yield plant^{-1} and increased spikelet sterility.

The variety Kalladiaryan had the lowest spikelet sterility and the highest grain weight panicle^{-1}, 1000 grain weight, straw yield plant^{-1} and biological yield. Adequate number of fertile grains panicle^{-1} and heavy grains are important traits, which should be considered in selection for high yield (Prasad *et al.,* 2001; Sürek and Beser, 2003). These results showed that increasing the number of spikelets panicle^{-1} does not always result in higher grain yield, but with increased filled grains percentage it increases yield. The highest yielding genotypes were Vaishak, Kalladiaryan and Vyttila 6 with grain yields of 11.66, 10.7 and 9.72 g per plant respectively and percentage filled grains of 63.17, 61.87 and 68.94 respectively. Similar findings were reported by Cruz and O'Toole (1984) and Pantuwan *et al.,* 2002 that in rice, during drought situations a lot of factors cause spikelet sterility which eventually result in yield reduction.

5.2 PHENOTYPIC AND GENOTYPIC COEFFICIENT OF VARIATION

Genotypic variation, is very essential for selection, but it cannot be measured directly. Only the external expression *i.e.* genetic variance modified by the environment is measurable as phenotypic variance. The variability available in a population can be partitioned into heritable and non-heritable components with the aid of genetic parameters like genotypic coefficient of variation, heritability and genetic advance which serve as useful guidelines for selection.

High PCV and GCV were observed for many characters such as number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, spikelet sterility, grain weight panicle^{-1}, grain yield plant^{-1}, straw yield plant $^{-1}$, biological yield plant^{-1} and harvest index. Similar findings were reported by Panwar *et al.* (2002) and Panwar and Gupta (2000) for total biological yield, straw yield plant $^{-1}$, number of fertile florets panicle^{-1} and grain number in rice. Nayudu *et al.* (2007) reported high PCV and GCV for number of filled grains panicle^{-1} in rice. Khare *et al.* (2014) and Singh *et al.* (2014) had also observed high phenotypic and genotypic coefficients of variation for grain yield plant^{-1}, spikelets panicle^{-1} and grains

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panicle^{-1}. Patel *et al.* (2014) reported high PCV and GCV for straw yield plant^{-1} which corroborates the results obtained in the present study.

The characters *viz.,* number of productive tillers plant^{-1} (19.50), plant height at tip of longest leaf of plant, plant height at maturity, panicle length and 1000 grain weight showed moderate estimates of PCV and GCV. Similar findings were reported by Nayak *et al.* (2002) and Soni *et al.* (2013) for plant height, panicle length and 1000 grain weight.

Low level of PCV value was observed for days to 50% flowering (8.56). The reports of Nayak *et al.* (2002), Patil *et al.* (2003), Sinha *et al.* (2004) and Vijayalakshmi *et al.* (2008) support these results.

Genotypic coefficient of variation measures the variability of any trait. The extent of environmental influence on a trait is indicated by the magnitude of the differences between the genotypic and phenotypic coefficients of variation. Large differences reflect high environmental influence, while small differences reveal high genetic influence. Phenotypic coefficients of variation were slightly higher than the genotypic coefficients of variation for all the traits studied. This indicated the presence of environmental influence to some degree in the phenotypic expression of characters. Similar results were observed by Rama Bai *et al.* (1992) while studying in 58 medium duration rice varieties. Akinwale *et al.* (2011) observed considerable environmental influence on character expression whereas Ramalingam *et al.* (1994) observed very low environmental influence for panicle characters in 20 rice varieties studied.

5.3 HERITABILITY AND GENETIC ADVANCE

Heritability in the broad sense is the relative magnitude of genotypic and phenotypic variances for the traits and it has a predictive role in selection procedures. This gives an idea of the total variation ascribable to genotypic effects, which is the exploitable portion of variation. Higher heritability estimates in broad sense were exhibited by all the traits. Sravan *et al.* (2012) observed high heritability coupled with high genetic advance for harvest index and grain yield in a study of 36 rice genotypes under rainfed upland condition which is in accordance with the present results. Yield is a complex trait and is controlled by many genes. Since high heritability does not always indicate high genetic gain, heritability with genetic advance considered together should be used in predicting the ultimate effect for selecting superior varieties (Ali *et al.,* 2002). High heritability coupled with high genetic advance was recorded for plant height at tip of longest leaf, plant height at maturity, spikelet sterility, number of filled grains panicle^{-1}, number of spikelets panicle^{-1} and harvest index. Results suggest that these traits are primarily under genetic control and selection for these traits can be achieved through their phenotypic performance. Khare *et al.* (2014) and Singh *et al.* (2014) reported high heritability and high genetic advance as percent of mean for number of grains panicle^{-1} and for number of spikelets panicle^{-1}.

High heritability estimates with low genetic advance observed for grain weight panicle^{-1}, total number of tillers plant^{-1}, number of productive tillers plant^{-1}, panicle length, grain yield plant^{-1}, straw yield plant^{-1} and 1000 grain weight indicated non additive type of gene action and denoted that genotype × environment interaction played a significant role in the expression of these traits. Singh *et al.* (2014) reported high heritability with low genetic advance for panicle length.

The expected genetic advance expressed as percentage of mean varied from 17.16 to 124.37. In this study, traits that exhibited high genotypic coefficient of variation like spikelet sterility (%) and grain yield plant^{-1} also gave high genetic advance as percentage of mean (GA %) in kharif season, 2014. This specified the possibility of their use as selection criteria for high grain yield. Similar results were reported by Ramalingam *et al.* (1994) for number of filled grains panicle^{-1} and spikelet sterility in 20 rice genotypes studied.

5.4 CHARACTER ASSOCIATION

Most of the traits showed high genotypic correlation coefficient than phenotypic correlation coefficient. Similar results were reported by Singh (1980) and Sarawgi *et al.* (1997) due to masking and modifying genetic effect of environment on character association at the genetic level. Grain yield was

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significantly and positively correlated with grain weight panicle^{-1}, 1000 grain weight, straw yield plant^{-1}, panicle length, plant height, number of spikelets panicle^{-1} and plant height at maturity. Biological yield plant^{-1} also had positively significant correlation with straw yield plant^{-1}, grain yield plant^{-1}, grain weight panicle^{-1}, number of filled grains panicle^{-1}, 1000 grain weight, panicle length, harvest index (%), plant height upto tip of longest leaf of plant, number of spikelets panicle^{-1} and plant height at maturity. Biological yield plant^{-1} was negatively and significantly correlated with spikelet sterility (%) and days to 50% flowering in upland kharif season indicating the importance of these components in rainfed rice ecosystem. These results were in agreement with that of Sadeghi (2011) and Ullah *et al.* 2011who noted that grain yield was positively and significantly associated with panicle length.

5.5 PATH COEFFICIENT ANALYSIS

Among all the characters, biological yield plant^{-1} (1.0771) had the highest positive direct effect on grain yield followed by harvest index (0.3639), 1000 grain weight (0.2624), number of spikelets panicle^{-1} (0.2495), days to 50% flowering (0.1201), plant height upto tip of longest leaf (0.0361) and filled grain panicle^{-1} (0.0055). Positive direct effects of these traits on grain yield indicated their importance in determining this complex character and therefore, should be kept in mind while practicing selection aimed at the improvement of grain yield. These findings were also corroborated by Kole *et al.* (2008) and Sarawgi *et al.* (2000) that direct selection for number of fertile spikelets panicle^{-1} and harvest index would be effective for increasing grain yield in rice. Days to 50% flowering had negative indirect effect which was contributed to grain yield through 1000 grain weight (-0.0589). The highest indirect effect which was contributed to grain yield through biological yield was through plant height upto tip of longest leaf (0.6007), plant height at maturity (0.3199), panicle length (0.8349), number of spiklets panicle^{-1} (0.5950), filled spikelets panicle^{-1} (0.9716), spikelet sterility (0.6977), grain weight panicle^{-1} (1.1311), 1000 grain weight (0.9243), straw yield plant^{-1} (1.1679), harvest index (0.8238) and total number of tillers (0.3432). Similar results were reported by Patel *et al.* (2014) that path analysis revealed that straw yield plant^{-1} had the highest positive direct effect on grain yield followed by grain length, harvest index, days to maturity, protein content, number of total tillers plant^{-1} and number of grains panicle^{-1}. Based on the studies on correlation and path-coefficient analysis, it may be concluded that biological yield plant^{-1}, harvest index and panicle length exhibited maximum positive direct effect on grain yield and seem to be the primary yield contributing characters which could be relied upon for selection of genotypes to improve genetic yield potential of rice. Reddy *et al.* (2013) reported results supporting the present findings that biological yield was the major contributor to grain yield plant^{-1} followed by number of spikelets panicle^{-1} and test weight as per path analysis.

It can be concluded that higher biological yield, number of spikelets panicle^{-1} and test weight are important plant traits which should be considered when any breeding program for higher yield in rice is to be planned. Selection of plants on the basis of these traits would certainly lead to improvement in grain yield.

5.6 SELECTION INDEX

The use of selection index offers ample scope for the breeder for effective selection based on component characters rather than direct selection based on yield alone. Superior genotypes can be selected from a collection of germplasm using a selection index employing the discriminant function for characters with favourable association. The selection indices were worked out for the twenty genotypes on the basis of yield and eight component characters *viz*., panicle length, number of spikelets panicle^{-1}, grain weight panicle^{-1}, 1000 grain weight, straw yield plant^{-1}, biological yield plant^{-1} and harvest index. The genotypes Vaishak, Thottacheera, Kalladiaryan, Vyttila 6, Harsha and Swarnaprabha were selected as parents for hybridization programme based on the selection index developed. The use of selection index was important for selecting best genotypes from a group of varieties was confirmed by Singh *et al.* 2013 and he observed that the relative efficiency of selection indices ranged from 0.13 to 33.23 per cent in upland rice.

5.7 GENETIC VARIABILITY UNDER PROTECTED CONDITION

Drought resistance is a complex phenomenon conditioned by a number of internal and external factors and their interaction. Plants respond to drought in a variety of ways thereby adapting to it or resisting its adverse effect. These interactions always lead to change in the vegetative as well as reproductive performance of the crop.

Moisture stress during the crop ontogeny has been one of the main constraints for sustainable rice productivity, especially in uplands. Crop losses vary depending upon the intensity and duration of drought and the growth stages at which it strikes. The solution to this problem lies in either making water available for crop growth or breeding for drought resistant cultivars. Increased irrigation inputs are not a viable option either because the water resources are unavailable or they are too expensive to implement in drought affected uplands. Water is a limited resource today. Improvements in crop through plant breeding for developing drought tolerant varieties is the only solution. Cultivars with better ability to access soil water and with improved water use efficiency could increase yields in an economic and environmentally sustainable way.

In the present study, all the physiological and biochemical traits were significant under control/drought condition except the traits chlorophyll *a* and carbon isotope discrimination. Factor B (varieties) showed significant differences in all the traits except chlorophyll *a* content. A x B interaction effects (condition x varieties) were significant for all the traits except total chlorophyll content, carotenoides and leaf soluble protein content.

Analysis of variance for factor A (control/ drought condition) and factor B (varieties) revealed significant differences for all the morphological characters studied. The interaction effects *i.e* (condition x variety) were significant for the traits days to 50 % flowering, plant height at maturity, number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, spikelet sterility, grain weight panicle^{-1}

1000 grain weight, grain yield plant^{-1}, straw yield plant^{-1} and harvest index and non-significant for number of productive tillers plant^{-1} and panicle length.

5.7.1 Morphological characters

5.7.1.1 Days to 50% Flowering

Days to 50% flowering is an important reproductive trait adversely affected by moisture stress given at panicle initiation stage and heading stage of crop. Considerable delay in flowering was observed in all varieties evaluated. The late flowering types under control were Aathira, Uma and Kanakom whereas Vyttila 2, Kanchana and Aathira flowered late under induced drought condition. Flowering was most delayed in Kanchana, Vyttila 2 and Harsha.

The increase in number of days to 50% flowering under imposed drought was less prominent in Jyothi and Kanakom as well as in the local upland varieties *viz*., Kalladiaryan, Karuthadukkan, Parambuvattan (9.03%) and Thottacheera. These varieties were drought tolerant through ontogenetic characters correlated with appropriate flowering time. This was in accordance with the reports of Pantuwan *et al*. (2002) and Fukai *et al*. (1999) in relation to drought avoidance in rainfed lowland rice. Fukai *et al*. (1999) further reported that the timing and intensity of the occurrence of water deficit has essentially been associated with the delay in flowering.

5.7.1.2 Number of Productive Tillers Plant $^{-1}$

The reduction in number of productive tillers plant^{-1} at reproductive stage was the highest in Aathira in the present study. Reduction in tiller production was absent in Thottacheera and marginal in Kalladiaryan under drought situations as compared to other varieties. Thottacheera and Kalladiaryan were relatively resistant to the adverse effects of moisture stress. Similar findings were reported by Vijayalakhsmi and Nagarajan (1994) that the reduction in tiller production of drought resistant varieties was marginal under drought situations as compared to susceptible varieties. Reduction in productive tillers plant^{-1} under moisture stress was reported by Cutler *et al.,* 1980; Hsiao *et al.,*1984; Turner *et al.,*1986 and Liu *et al.* (1993) and Abarshahr *et al.* (2011).

5.7.1.3 Plant Height at Maturity (cm)

Plant height is an important vegetative component influenced adversely by moisture stress. Considerable reduction in plant height was observed in all varieties. Highest reduction in plant height was observed in Thottacheera (21.69%) with less reduction in grain yield plant^{-1}. Increased plant height may increase transpirational loss of water as well as water requirement of the plant due to increased vegetative growth thereby hindering the reproductive growth and ultimately reducing yield. Semi-dwarf nature of plant under drought condition had pleiotropic effects on yield-related traits such as sink size. In addition, the semi-dwarf habit is often seen associated with characteristics like high tillering and shallow rooting, due either to pleiotropic effects or indirectly influencing the traits (Lafitte *et al*., 2006). The variety Vaishak and Vyttila 6 had less pronounced reduction for plant height under drought but got maximum grain yield plant^{-1}. Similar findings were reported by Vijayalakshmi and Nagarajan (1994) that a marginal reduction in plant height was observed in drought resistant rice varieties with well developed root system.

5.7.1.4 Panicle Length (cm)

No prominent differences were observed for panicle length due to reproductive stage moisture stress. A general reduction in panicle length was noted due to drought with Aiswarya (24.69) being the most affected and Swarnaprabha (-6.45%) and the three modan varieties (-7.92,-6.72 and -9.53) being the least affected. Reduction in panicle length under moisture stress was also reported by Kuixian *et al.* (2012) in *Zhenshan* 97B. The rate of reduction observed in the cultivar IRAT109 was upto 8%.

5.7.1.5 Number of Spikelets Panicle^{-1}

Drought condition was found to reduce the number of spikelets panicle^{-1} in the present study. The varieties Kanchana (-19.68%), Aiswarya (-24.70%) and Harsha (-20.44) were considerably affected by drought whereas the varieties Katta Modan (-7.91%) and Chuvanna Modan (-7.85%) were less affected, as is evidenced from the percentage reduction for the character. Similar findings were reported by Abarshahr *et al.* (2011). They observed that Nemat cultivar had the highest spikelet number of 209.33 under optimum irrigation regimes which was reduced to 104 under drought condition (50.23 per cent reduction).

5.7.1.6 Number of Filled Grains Panicle^{-1}

Water stress influenced grain yield plant^{-1} by reducing the number of filled grains panicle^{-1}. In the present study number of filled spikelets panicle^{-1}decreased drastically due to water stress at reproductive stage in all the varieties. The varieties Kanchana (-72.79), Aathira (-72.86) and Uma (-71.18) were more affected by drought as compared to Thottacheera (-36.71%), Kalladiaryan (-39.46%) and Swarnaprabha (-40.85%). Similar results showing reduction in number of filled grains due to drought was reported by Neog *et al.* 2002 and O'Toole and Chang, (1979). Sarvasthani *et al.* (2008) reported that water stress at reproductive stage resulted in poor grain filling of panicles which finally led upto 50 percent reduction in grain yield.

5.7.1.7 Spikelet Sterility (%)

Stress soon after panicle initiation reduces the number of spikelet primordia that develop. When drought stress occurs later during meiotic division or at anthesis, sterility of florets is increased and consequently there is a lower percentage of filled grains. In the present study spikelet sterility (%) increased tremendously under drought condition. Significant differences in spikelet sterility (%) were recorded in all varieties due to water stress at reproductive stage. In general, the local upland varieties were less affected by induced stress as is revealed by their low percentage variation *viz.*,

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28.02% for Thottacheera, 30.60% for Kalladiaryan, 33.03 for Karuthadukkan and 49.23% for Parambuvattan. This percentage change was high in Kanchana (72.79%), Aathira (72.86), Uma (71.18%) and Harsha (69.31%) showing that they were seriously affected by moisture stress. Similar findings were reported by O'Toole and Chang, (1979). Cruz and O'Toole (1984) observed a high spikelet sterility of 73% when drought stress developed during the flowering stage. Sheoran and Saini (1996) reported that changes in carbohydrate levels and enzyme activities, associated with inhibition of starch accumulation in pollen are potential causes of spikelet sterility. Jongdee *et al*. (2002) observed a yield reduction of 40% due to the increment spikelet sterility when drought occurred during grain filling period.

5.7.1.8 Grain Weight Panicle^{-1} (g)

The percentage reduction due to moisture stress was less pronounced for varieties Swarnaprabha (18.92%), Thottacheera (36.78%) and Kalladiaryan (39.37%) whereas it was more pronounced for Uma (74.14%), Kanchana (72.12%) and Aathira (72.45%) for grain weight panicle^{-1}. This is in accordance with the reports of Allah *et al.* (2010) in rice under drought.

5.7.1.9 1000 Grain Weight (g)

Drought stress occurring during the period of flowering can increase embryo abortion and/or reduce single grain weight. Mild stress at vegetative stage resulted in linear decrease in 1000 grain weight in rice. Grain number is determined by the number of spikelets at anthesis and the proportion of spikelets which produce grains (filled-grain percentage). The number of spikelets is directly related to the rate of assimilation between panicle initiation and anthesis, regardless of whether the assimilate production is altered by water stress.

The percentage decrease in 1000 grain weight under moisture stress was exorbitantly high for Swarnaprabha (34.16%) and Uma (10.21%) whereas it was considerably low for Thottacheera (0.03%), Aiswarya (0.25%), Kalladiaryan (-0.25%) and Parambuvattan (-0.30%). Similar findings were collabarately

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reported by Cruz *et al*. (1986), O'Toole and Chang (1979) and Rahman and Yoshida (1985). Liu *et al.* (1993) reported that water stress at booting and heading to flowering stages reduced 1000 grain weight in rice.

5.7.1.10 Grain Yield Plant^{-1} (g)

Grain yield plant^{-1} exhibited significant reduction under water stress condition. Grain yield plant^{-1} was highest in Vaishak followed by Jyothi and Kalladiaryan whereas it was the lowest in Aathira under control. The varieties Vaishak, Thottacheera and Kalladiaryan were the highest grain yielders under drought. The greatest yield reduction was observed in Aathira, Uma, Kanchana and Aiswarya under drought whereas the reduction was less pronounced in Thottacheera and Kalladiaryan.

The productivity of cereals depend not only on the accumulation of dry matter, but also on its effective partitioning to plant parts of economic importance and this is a key to yield stability particularly under drought stress. Remobilization of reserves to grain is critical for grain yield if the plants are subjected to water stress during grain filling (Nicolas *et al*., 1985; Palta *et al*., 1994 and Ehdaie and Waines, 1996). In rice, available carbon assimilates for grain production is determined by carbon assimilation during the grain-filling period plus assimilate reserves stored in the straw (Cook and Yoshida, 1972). Pre-anthesis storage may contribute to 20–40% of the final crop yield depending on cultivar, reflecting its importance for attaining higher grain yields (Yoshida, 1972; Murata and Matsushima, 1975). Boonjung and Fukai (1996) reported that stress developed during panicle development stage reduces the yield by around 30% due to the reduction in number of spikelets panicle^{-1}. Pantuwan *et al*. (2002) suggested that a drought intensity that causes a 50% yield reduction is considered a critical point for the expression of drought tolerance mechanisms in rice. Jongdee *et al*. (2002) reported an yield reduction of 40% due to the increase in spikelet sterility when drought occurred during grain filling period. Grain yield under drought has been reported to be a function of biomass production and harvest index at the vegetative and reproductive stages. (Atlin *et al*., 2008).

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5.7.1.11 Straw Yield Plant^{-1} (g)

Drought brought about drastic reduction in straw yield in Karutha Modan, Chuvanna Modan and Aiswarya whereas Vaishak and Vyttila 6 were less affected by drought condition. Biomass production declines under water stress. Similar findings were reported by Lilley and Fukai (1994a) that water stress reduces biomass production in rice and the degree of reduction depended upon the severity of moisture stress. Yang *et al.* (1995) also reported that dry matter yield in rice genotypes were reduced by 11 to 37 percent and 30 to 65 percent under mild and severe stress conditions which is line with the present results.

5.7.1.12 Harvest Index (%)

Harvest index indicates the efficiency of translocation of food assimilates from the vegetative tissue to the reproductive tissue and it serves as a means to predict grain yield in many crops. Harvest index is the ratio between economic yield and biological yield and it is a measure of production efficiency of the plant to partition its total photosynthate into economic and non-economic sinks. Tremendous reduction in harvest index was observed in Prathyasha, Uma and Kanchana under drought whereas the upland local and improved varieties *viz.*, Kalladiaryan, Chuvanna Modan, Katta Modan and Thottacheera showed less prominent reduction coupled with less prominent yield reduction. This shows that harvest index had a close association with grain yield plant^{-1} as was reported by Reuben *et al.* (1990) and Yamauchi *et al.* (1994) which is in accordance with the results of the present investigation.

5.7.1.13 Leaf Rolling Score

The varieties Vyttila 6, Jyothi, Harsha, Kanakom and Kalladiaryan showed less pronounced leaf rolling under reproductive stage moisture stress whereas all the other varieties remained more prone to leaf rolling.

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5.7.2 Physiological and biochemical characters

5.7.2.1. Water Use Efficiency (WUE)(g/l)

Crop breeders interested in developing cultivars that can perform well under water limited conditions would like to increase whole crop WUE. Over the last few decades, evidence has accumulated that there is substantial variability for WUE within species, suggesting that WUE is a factor that can be improved through selection. However maximum single leaf WUE tends to occur at very low stomatal conductance, where photosynthetic CO_2 assimilation is also very low. Obviously, this is not an ideal characteristic for a commercial cultivar. Thus, selecting for maximum WUE *per se* is not a promising strategy for breeders. Instead, they must select for both high WUE and high crop growth rates. Such a combination would arise from: appropriate stomatal regulation (no "luxury" water consumption, but enough conductance to support high rates of photosynthesis); high leaf photosynthetic response to CO_2 (thus maintaining low ci) with low rates of maintenance respiration. In this study Kalladiaryan, Vyttila 2 and Thottacheera along with Vyttila 6, Kanakom and Swarnaprabha showed consistently efficient water use under both control and moisture stress. Water use efficiency in Karutha Modan was affected due to drought. Dingkuhn *et al*. (1991) and Scartazza *et al*. (1998) have reported on the genotypic differences for WUE. Latter author reported that decreased carbon isotope discrimination in upper internodes and high WUE during flowering showed low spikelet sterility and high yield stability. Similar results were reported by Farshadfar (2012) that significant differences were found for water use efficiency (WUE) and evapotranspiration efficiency (ETE) in wheat under moisture stress which is in line with the results of the present investigation.

5.7.2.2 Relative Leaf Water Content (RLWC)(%)

High relative leaf water content during reproductive stage moisture stress is considered to be an adaptive mechanism for drought avoidance. Relative water content in leaf tissue decreased in all the rice genotypes under moisture stress. Plant water status, measured as leaf water potential, leaf rolling or drying score or

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leaf relative water content can differ significantly among cultivars exposed to same period of water exclusion. The maintenance of plant water status more than plant functions, controls crop performance under drought. Leaf water potential is closely related to leaf relative water content, but it is confounded by osmotic adjustment and stronger correlations might be found between yield and RLWC under water stress.

The variety Karuthadukkan consistently showed high relative leaf water content in both the conditions i.e. under control (94.21%) and under drought (71.14%). Percentage decrease in RLWC due to moisture stress was less pronounced in Chuvanna Modan (16.81 percent), Arimodan (16.93 percent), Uma (19.09 per cent) and Karutha Modan (19.19 percent). Katta Modan (38.68 per cent) was the variety most affected due to reproductive stage moisture stress. Similar findings of variation in relative leaf water content under control and drought were reported by Laffitte (2002) Blum (2002), and Biswas and Choudhari (1984). Kumar *et al.* (2014) observed 31.57 per cent reduction in RLWC under reproductive stage moisture stress in rice. El-Shouny (2015) reported that RLWC was significantly decreased (30.67%) in barley, when plants were subjected to drought stress.

5.7.2.3 ***Proline Content(mg/g)***

Accumulation of proline during stress is considered to be an adaptive mechanism for drought tolerance. Proline considerably increases the amount of strongly bound water in the leaves thereby enhancing the leaf water potential. Thus the varieties showing accumulation of proline during stress will be drought tolerant and high yielding. In the present study maximum increase in proline accumulation was observed in Thottacheera (227.73 %), Karuthadukkan (82.99%) Aathira and Kanakom (75.23% each) which showed osmotic adjustment and low leaf rolling score which is in conformity with the results of Tatar and Gevrek (2008) who reported on stress enhanced proline content in leaves. It may possibly play an important role in the osmoregulation under moisture stress condition. Mostajeran and Rahimi Eichi (2009) suggested that the production of proline is a

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common response of plants exposed to drought conditions. High proline content is a good index for moisture stress resistance in genotypes which is in accordance with the findings of the present study. Under moisture stress condition the protein degrades and consequently the proline content increases (Roy *et al*., 2009). Both free proline and ABA generally showed an increase under water stress conditions and the varietal differences in the accumulation of these osmolytes were also reported (Abdellah *et al*., 2011). Similar results were reported by Vajrabhaya *et al.* (2001) who observed that after drought treatment, 9-15 fold increase in proline content was detected in the drought tolerant lines. Increase in proline content by 55.9 % under reproductive stage moisture stress was reported by Kumar *et al* 2014. Preethy *et al.* (2016) reported similar results on the accumulation of proline in high quantities in water stress and saline conditions. The plants with high proline content showed better tolerance capacity in water stress condition. It was indicated that the genotype CO 47 recorded lower proline accumulation and hence was a poor yielder under aerobic condition (Sritharan and Vijayalakshmi, 2007) and cultivar PMK 3 showed high proline accumulation than other genotypes in the aerobic condition. El-Shouny (2015) reported that proline content was significantly increased (73.39%) in barley when plants were subjected to drought stress. Ushakumari *et al.* (2014) reported that high proline content which is an index for drought tolerance was recorded in hybrid Kuruvaikalangiam / ADT36.

5.7.2.4 Cell Membrane Stability Index(%)

Cell membrane stability index was less affected by moisture stress in Karuthadukkan, Parambuvattan, Vyttila 2, Harsha and Vaishak whereas it was greatly affected in Chuvanna Modan, Arimodan and Prathyasha. The maintenance of membrane stability during severe desiccation is important for normal physiological metabolism to continue under low water potential. Phenotype selection for cell membrane stability index may not always yield accurate results for breeding purposes because of its complex nature and its strong interaction with the environment (Nir *et al.* 1969; Buttrose and Swift 1975).

5.7.2.5 Chlorophyll Content(mg/g)

Reduction in chlorophyll content under drought condition was more pronounced in Vaishak, Harsha and Vyttila 2 for chlorophyll a whereas it was less pronounced in Vyttila 6. Vaishak and Harsha exhibited drastic reduction in chlorophyll b content also. Karuthadukkan recorded the highest chlorophyll a, chlorophyll b and total chlorophyll content in all conditions. Tremendous reduction was recorded for total chlorophyll content in Vaishak and Uma under moisture stress condition. Similar findings were reported by Anjum *et al* (2003) and Farooq *et al.* (2009) that drought in several plant species can cause a change in the chlorophyll a/b ratio and carotenoid content. They observed a high chlorophyll a/b ratio in Silugonggo, followed by IPB 3S. Gowri (2005) reported reduction in chlorophyll content under moisture stress in rice. Maisura *et al* (2014) reported that physiological characters of rice varieties differed in their response to drought stress. However, drought reduced chlorophyll *a*, chlorophyll *a/b* ratio, and grain yield.

5.7.2.6 Chlorophyll Stability Index(%)

Karuthadukkan followed by Karutha Modan, Jyothi and Vyttila 6 recorded the highest chlorophyll stability index. Vaishak exhibited the lowest chlorophyll stability index value. Similar findings were reported by Ananthi *et al* (2013) in cotton. In the cross KC 2 X MCU 13 in both F_1 and F_2 generations higher values (68.36 and 74.47 respectively) of chlorophyll stability index were recorded at boll development stage indicating that this combination possesses drought tolerance characteristics.

5.7.2.7 Leaf Temperature (^0C)

Percentage change in leaf temperature under drought condition was the highest in Vyttila 2. Leaf temperature increased with increasing water stress and was generally low in Kanakom followed by Harsha and Vaishak. Similar results that leaf temperature increased with increasing water stress and was generally low in drought tolerant cultivars was reported by Ravindrakumar *et al.* (2002)

5.7.2.8 Transpiration Rate (TR)(mmol m^2s^{-1})

Transpiration is a vital process in the life cycle of plants, which gives cooling effect besides promoting water and nutrient absorption (O'Toole and De Datta, 1986). Vyttila 6 had the highest transpiration rate and stomatal conductance under water stress condition. A high transpiration rate under conditions of water deficit also implies high stomatal conductance, which is associated with continued water extraction (Cabuslay *et al.*, 1999 and Kamoshita *et al.*, 2000).

Percentage decrease in transpiration rate due to moisture stress was less pronounced in Swarnaprabha and Kalladiaryan which appeared to be drought tolerant in the present study. Similar results were reported by Dingkuhn *et al.*, 1989 b; Kobata *et al.*, 1996; Cabuslay *et al.*, 1999; Wade *et al.*, 2000 and Ravindrakumar *et al.*, 2003 that transpiration rate was reduced markedly by water stress.

5.7.2.9 Stomatal Conductance (SC) (mmol $mol^{-2}s^{-1}$)

Stomatal conductance is the speed at which water evaporates from pores in a plant, and is directly related to relative size of the stomatal aperture. Basically, the higher the evaporation rate the higher the conductance of the leaf. When the available water is limiting, plants tend to close their stomata (Cornic and Massacci, 1996), resulting in reduced inflow of CO_2 into the leaves for fixation. In the present study stomatal conductance was drastically reduced under water stress condition. Vyttila 6 had the highest transpiration rate and stomatal conductance under water stress condition. A high transpiration rate under conditions of water deficit also implies high stomatal conductance, which is associated with continued water extraction (Cabuslay *et al.*, 1999 and Kamoshita *et al.*, 2000).

Percentage decrease in stomatal conductance due to moisture stress was less pronounced in Kalladiaryan so that this variety emerged as drought tolerant under moisture stress condition. It was more pronounced in Harsha, Karutha Modan and Parambuvattan. Percentage change in transpiration rate also followed the same trend in Harsha, Karutha Modan and Parambuvattan. Similar findings were reported by Fisher *et al*. (1998) that stomatal conductance was closely and positively correlated with yield in spring wheat.

5.7.2.10 Leaf Soluble Protein Content (mg/g)

Leaf soluble protein was generally reduced under moisture stress condition. In the present study Harsha recorded the highest protein content under moisture stress condition. Low percentage reduction was recorded in Kalladiaryan and Vaishak. High reduction in leaf soluble protein content in Kanchana suggest it to be a susceptible genotype for protein content under moisture stress condition. Similar results of higher reduction in protein content in susceptible genotypes and less reduction in drought tolerant genotypes was reported by Beena *et al* 2012. Kumar *et al* (2014) reported that under drought stress condition, the genotypes IR83387-B-B-40-1, IR83376-B-B-24-2 and IR84895-B-127-CRA-5-1-1 showed less reduction in total soluble protein content compared to other genotypes and check varieties.

5.7.2.11 Radiation Use Efficiency (RUE)(MJ/g)

Radiation use efficiency is an important attribute influenced adversely by moisture stress. Under moisture stress condition cell division was restricted leading to reduction in growth of plant parts so that leaf area index was reduced which has direct bearing on radiation use efficiency. Radiation use efficiency was drastically reduced in all varieties due to moisture stress. Percentage decrease in radiation use efficiency due to moisture stress was less pronounced in Thottacheera, Kalladiaryan and Vyttila 6 which survived well under moisture stress condition. Similar findings were reported by Ahmad *et al.* (2009) that RUE was reduced under drought through reduced leaf area index.

5.7.2.12 Chlorophyll Meter Reading (SPAD)

The chlorophyll meter (SPAD 501) provides a simple, quick and non destructive method for estimating leaf chlorophyll content (Watanabe *et al.*, 1980). In the present study local upland varieties *viz.,*Thottacheera, Kalladiaryan, Karuthadukkan and Parambuvattan showed a uniform decrease of 6-7% for the character under drought. Similar results were reported by Abdellah *et al.* (2011) that chlorophyll content decreased under moderate and severe water stress situations in wheat. Similar results were reported by Maibangsa, (1998) in rice for leaf chlorophyll SPAD value.

5.7.2.13 Leaf Area Index (LAI)

Leaf area index was reduced under moisture stress condition in all the varieties. Percentage decrease in leaf area index due to moisture stress was less pronounced in Vaishak as compared to all other varieties. Reduction in leaf area index due to reproductive stage moisture stress was reported by Kumar *et al* (2014). He reported that reproductive stage moisture stress greatly influenced the performance of physiological traits including leaf area index (LAI). Significant reduction in leaf area was observed among rice genotypes under drought stress compared to non-stressed condition. The highest leaf area was observed in IR84895-B-127-CRA-5-1-1 whereas the lowest in IR64.

5.7.2.14 Relative Growth Rate (mg/g/day)

Evolution of relative growth rate was mainly dependent on net assimilation rate. In the present study varieties Aathira, Kanakom and Parambuvattan were not severely affected by drought in terms of their relative growth from panicle initiation to harvesting stage but conversion of source into sink was low. Drastic reduction was observed in Jyothi. Relative growth rate was affected by external factor like edaphic, climatic and application of fertilizer. Ali *et al.* (2011) have reported similar results that relative growth rate was affected by variations in climatic factors in rice.

5.7.2.15 Net Assimilation Rate (NAR)(g/m^2/day)

Significant differences were registered for net assimilation rate under drought condition compared to control. Highest net assimilation rate was recorded

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in Vaishak followed by Vyttila 2 due to their high leaf area index. Karuthadukkan was affected due to water stress. Similar results were reported by Yao *et al.* (1990) that a severe water stress has a negative effect on most of the growth indices (crop growth rate, CGR; relative growth rate, RGR; leaf area index, LAI; leaf area duration, LAD; net assimilation rate, NAR) in rice.

5.7.2.16 Carbon Isotope Discrimination (per mil)

Slight increase in carbon isotope discrimination was observed under moisture stress in several varieties. Carbon isotope discrimination is inversely proportional to water use efficiency. Under dryer conditions, plants growing more slowly and having a lower stomatal conductance (hence lower CID) may perform better as they achieve a larger biomass accumulation per gram of water transpired (Impha *et al.,* 2005). Percentage decrease in carbon isotope discrimination due to moisture stress was less pronounced in Vaishak, Jyothi, Prathyasha, Arimodan and Aiswarya showed good water use efficiency. Highest discrimination of carbon was recorded in Kanchana and Aathira which were less water use efficient.

5.7.2.17 Number of Days Taken for Reaching Critical Stress Level

Water stress at panicle initiation stage results in a delay in flowering. The period of delay is partly related to the extent of stress the rice genotypes experienced and those with longer delay will tend to produce less grain. The varieties Swarnaprabha (23 days), Kanakom (21days) and Jyothi (19.67 days) took maximum days to reach critical stress level. Similar findings were reported by Lafitte *et al*. (2003) for flowering date that water stress results in a delay in flowering. Ravindrakumar *et al*. (2003) reported that delay in flowering results in reduction of grain yield.

5.7.3 Root Characters

Root depth influences grain yield under stress conditions by influencing the water uptake of plant. A well developed root system is characteristic of reduced drought injury and increased yield in crop plants as reported by O'Toole and De Datta (1986). In contrast to this, in the present study the varieties with high root depth were found to give low yields. The variety Uma had maximum root depth increase in terms of percentage under drought situation but resulted in low yield. Several studies have been conducted to determine root length at different stages of crop growth. Swarnaprabha had highest rooting depth during vegetative stage, when the root growth was rapid but it declined towards the reproductive stage. Maximum root length was observed at panicle initiation stage. Similar findings were reported by Beyrouty *et al.* (1988) in rice. Growth of the rice root, in terms of total dry matter, maximum root depth, and root length density increases until flowering stage and then decreases sharply to maturity (Yoshida and Hasegawa, 1982).

Root volume was increased under moisture stress condition for most of the varieties. Chuvanna Modan recorded high root volume under moisture stress condition. Decreased root volume was observed in Uma (-61.01%) and Harsha (-54.62%) due to water stress at reproductive stage of the crop. Zuno-Altoveros *et al.* (1990) conducted an experiment to determine root volume of selected upland and low land rice varieties under drought and found variety dependent variations.

Increased root dry weight was observed under moisture stress condition. Percentage increase in root dry weight was more pronounced in Vyttila 6 (67.55%) and Chuvanna Modan (61.75%) showing that these varieties adapted well under moisture stress condition. Similar results that drought tolerant genotypes produced higher percentage increase in root dry weight under drought was reported by Vijayalakshmi and Nagarajan, (1994).

Water stress increases the proportion of plant dry matter translocated to roots compared to the leaves and stem thus increasing the root-shoot ratio. A massive increase in root–shoot ratio was observed in most of the varieties. Similar results were reported by Sorte *et al.* (1992). Cruz *et al.* (1986) that percent reduction in shoot dry mass was less than that of root dry mass, thereby decreasing root to shoot ratio under mild stress condition during vegetative stage in rice. They attributed this to a high soil strength or mechanical impedance, which decreased root length.

Significant variation was registered for deep root-shoot ratio under drought condition. Highest deep root shoot ratio was recorded in Uma (176.54) followed by Swarnaprabha, Thottacheera and Prathyasha in that order. Highest percentage increase in deep root-shoot ratio was recorded in Kanakom (15.78 times) and lowest percentage variation in Swarnaprabha (PTB 43) (0.20 times).

5.8 PERFORMANCE OF PARENTS AND HYBRIDS

Selection of superior types based on phenotypic evaluation alone may not bring about the expected improvement through hybridization. The parental attributes dictate the performance of crosses developed through hybridization. Hence the mean performance and general combining ability effects of the individuals need to be evaluated to highlight the performance of their crosses. Significant variability was noticed for most of the characters among the parents.

Parent Vaishak (P_1) exhibited high mean values for morphological traits such as plant height at maturity, grain weight panicle^{-1} and also physiological traits including leaf area index (Table 94).

Parent Thottacheera (P_2) exhibited high mean values for biochemical traits such as chlorophyll *b* content and total chlorophyll content. Lowest values were recorded for carbon isotope discrimination.

Parent Kalladiaryan (P_3) was identified as the best variety for days to 50 percent flowering, number of productive tillers plant^{-1}, 1000 grain weight, grain yield plant $^{-1}$, harvest index, and chlorophyll stability index.

Parent Vyttila 6 (P_4) was superior for panicle length, number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, straw yield plant^{-1} and also physiological traits *viz.,* water use efficiency, relative leaf water content, proline content, carotenoid content, leaf temperature, transpiration rate, stomatal conductance and leaf soluble protein content.

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Parent Harsha (P_5) was identified as the best variety for chlorophyll *a* content, radiation use efficiency, chlorophyll meter reading and net assimilation rate.

Parent Swarnaprabha (P_6) appeared superior for number of days taken for reaching critical stress level denoting that it acts as stress tolerant.

Among the crosses Vyttila 6 x Harsha was outstanding by virtue of its high mean values with respect to yield characters and drought parameters (Table 96). The cross exhibited best performance for number of spikelets panicle^{-1}, grain yield plant^{-1}, harvest index and physiological and biochemical characters such as water use efficiency, chlorophyll *b* content, total chlorophyll content, transpiration rate, stomatal conductance, leaf soluble protein content, number of days taken for reaching critical stress level and was the lowest in carbon isotope discrimination.

The hybrid Vyttila 6 x Swarnaprabha was identified as the best for the traits number of filled grains panicle^{-1} and straw yield plant^{-1}, and for physiological traits including transpiration rate and stomatal conductance.

Hybrid Vaishak x Swarnaprabha gave outstanding performance for the traits relative leaf water content, cell membrane stability index and chlorophyll stability index. Good performance for these traits denote drought tolerance in general.

Hybrid Vaishak x Thottacheera had maximum mean values for the productive and physiological and biochemical traits such as panicle length, water use efficiency (WUE), cell membrane stability index, chlorophyll stability index and number of days taken for reaching critical stress level.

Hybrid Vaishak x Kalladiaryan showed superior performance for the traits panicle length and proline content. This hybrid showed highest spikelet sterility under upland condition. The best performing hybrid for days to 50 percent flowering was Thottacheera x Harsha. Thottacheera x Kalladiaryan exhibited highest number of productive tillers plant^{-1}.The hybrid Harsha x Swarnaprabha recorded the lowest plant height, lowest leaf temperature and spikelet sterility and the highest chlorophyll meter reading at reproductive stage of crop.

Hybrid Vaishak x Harsha was identified as the best for grain weight panicle^{-1} and chlorophyll *a* content. Thottacheera x Vyttila 6 was the best for 1000 grain weight. Hybrid Thottacheera x Swarnaprabha was identified as the best for growth parameters and physiological traits such as relative growth rate and net assimilation rate as well as radiation use efficiency and carotenoide content. Highest leaf area index was exhibited by Kalladiaryan x Swarnaprabha under rainfed upland condition.

Similar results were reported by different scientists for different traits in different cross combinations. Tiwari (2015) reported that I.R. 50 x Saket 4 was superior for straw yield plant^{-1} as compared to its parents. Anyanwu and Obi 2015 reported that the cross WITA 4 x CT 7127-49 was superior for the traits panicle length, fertile spikelets and number of spikelets panicle^{-1} in rice as compared to other crosses of the same parents. Malaravizhi *et al.* (2009) Conducted crosses among a set of parents and analysed the F_1 progeny to find out combinations that performed best for specific yield related traits. The cross IR 68886 A x IR 69715-72-1-3 was superior for days to 50% flowering, IR 68886 A x PBRC 80 was the best for number of productive tillers plant^{-1}, IR 68886 A x WGL-14 was superior for panicle length, IR 68888 A x IR 55838-B2-3-2-3 was superior for number of spikelets panicle^{-1}, IR 68888 x IR 55838-B2-2-3-2-3 was superior for number of filled grains panicle^{-1}, COMS 14 A x WGL 32100 was outstanding for 1000 grain weight, IR68888 A x WCR 6 was superior for SPAD at flowering, IR 68897A x WGL 14 for relative water content at flowering, COMS 14 A x IR55838-B2-2-3-2-3 was superior for grain yield plant^{-1} and COMS14 A x IR55838-B2-2-3-2-3 was outstanding for harvest index. Manasa *et al.* (2014) claimed that the crosses MaI-105 x CML411, 1232 x CML411 and MAI-105 x CML 411 performed best for the traits grain yield, SCMR and proline content respectively in maize. The parent MAI-105 performed best for the trait SCMR while the other parent performed best for grain yield in maize. Ganapathy and Ganesh (2008) reported similar results in the cross CPMB ACM 03017 x MDU 5 which performed best for chlorophyll stability index in rice. The cross Nootripathu x IR 50 was superior for relative leaf water content. The best performed hybrid for relative leaf water content was CPMB ACM 03015 x ASD 18. Amudha (2010) reported similar results for the hybrid combinations IR 68887A x PSBRL80, IR 70369A x IR73005-23-1-3-3, IR68887A x PSBRL80, IR 67684 A x CT-6510-24-1-2 and IR 6885 A x IR73718-3-1-3-3 which performed well for the trait transpiration rate in the negative direction which as compared to the parents. Low stomatal conductance was recorded in the crosses IR 70369A x IR 73718-3-1-3-3 and IR 68885A x IR73718-3-1-3-3 under stress condition. Nayak *et al.* (2015) reported that the cross Yamini x MTU 1010 performed best as compared to the parents and other related crosses for the trait protein content in rice. Mohamad *et al.* (2007) reported that the cross CMS 983046 x CMTQ 033070 performed best for leaf area index and the cross CMT 033060 x CMS 983046 for transpiration rate and stomatal conductance in maize. Singh (1997) reported that the cross V 20 A x Narendra 80 performed best for the traits chlorophyll a, total chlorophyll content and soluble protein content in comparison with the parents and other crosses. The cross IR 46830 x Saket performed best for the trait chlorophyll a, total chlorophyll and soluble protein content whereas V 20 A x Saket I performed well for stomatal conductance as compared to other crosses in rice. John *et al.* (2011) reported that the cross JL 220 x ICGV-99029 for SPAD value and TIR-25 x JL-220 for water use efficiency in groundnut. Mohammad (2013) reported that the cross Irena x S-78-11 for chlorophyll content, Irene x Tajan performed well for the trait chlorophyll b, Chamran x Moghan 3 for cell membrane stability index, Irena x S-78-11 was superior for proline content. Tajan x Hirmand performed best for relative leaf water content, Irena x Humoon was the best for stomatal conductance and Irena x Tajan was superior for chlorophyll a content in rice as compared to other crosses. Farquhar *et al.* (1982) and Cuong *et al.* (2014) developed a theory to explain the carbon isotopic composition of plants. They have pointed out how diffusion of gaseous CO_2 can significantly affect carbon isotopic discrimination. The effects on discrimination by diffusion and carboxylation are integrated, yielding a simple relationship between discrimination and the ratio of the intercellular and atmospheric partial pressures of CO_2 in parents and cross combinations.

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5.9 HALF DIALLEL ANALYSIS

Half diallel analysis is a method put forward by (Griffing, 1956) in which the selected parents are crossed in all possible combinations excluding reciprocals. Combining ability analysis enables a plant breeder to decide the choice of parents for hybridization. It also helps to employ suitable selection procedures. Out of the four methods given by him, method two includes one way crosses and parents and is the most commonly used method of combining ability analysis from a diallel cross (Singh and Narayanan, 2000). This method helps in determining general combining ability (*gca*) effects of parents, specific combining ability (*sca*) effects of cross combinations and relative proportion of additive and non-additive genetic variance along with narrow sense heritability.

Half diallel analysis was carried out to evaluate the parents and hybrids on the basis of mean performance, general combining ability of parents and specific combining ability of hybrids. Significant variations existed for most of the characters as revealed by ANOVA.

5.10 COMBINING ABILITY, GENE ACTION AND HETEROSIS

The knowledge of combining ability is necessary for selection of appropriate parents in hybridization. It gives an idea whether a particular parent combines well in a cross and also denotes the specific performance of a cross combination against the expectations from the *gca* of the parents. The concept of general and specific combining ability (Sprague and Tatum, 1942) helps the breeder to assess the general combining ability effects of the parents and specific combining ability effects of the hybrids.

Gene action measured by *gca* and *sca* variances is particularly useful in deciding the inheritance of characters and thereby selection of a suitable breeding programme. Greater *gca* variance for a character indicates the predominance of additive gene action and if *sca* variance is greater, then non-additive gene action plays an important role in controlling that trait. Simple selection is enough for a character controlled by additive gene action as it is fixable, but if non-additive gene action which is non-fixable is predominant for a character, heterosis breeding may be rewarding.

In the present study, estimates of $\sigma^2 gca$ *and* $\sigma^2 sca$ suggest that non-additive component of heritable variation is many times larger than the additive components for all the morphological traits *viz.,* days to 50 % flowering, number of productive tillers plant^{-1}, plant height at maturity, panicle length, number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, spikelet sterility, grain weight panicle^{-1}, 1000 grain weight, grain yield plant^{-1}, straw yield plant^{-1} and harvest index. Similar findings were reported for days to 50 % flowering, plant height at maturity, productive tillers plant^{-1}, panicle length, number of grains panicle^{-1}, 100 grain weight and grain yield by Manonmani and Ranganathan (1998).

In the present investigation, non-additive gene action was exhibited by all physiological and biochemical traits *viz.*, water use efficiency, relative leaf water content, proline content, cell membrane stability index, chlorophyll a content, chlorophyll b content, total chlorophyll content (a+b), carotenoides content, leaf temperature (^{O}C), transpiration rate, stomatal conductance, leaf soluble protein content (mg/g), chlorophyll meter reading (SPAD), leaf area index, carbon isotope discrimination (per mil) and number of days taken for reaching critical stress level in rainfed upland condition. Findings supporting the current results were reported by Muthuramu *et al.* (2010) in a study of combining ability analysis through diallel cross for drought tolerance in rice. A preponderance of non additive gene action was observed for most of the traits.

Considering the preponderance of non-additive gene action for most of the characters, it can be concluded that heterosis breeding would yield better results in the improvement of these characters.

5.10.1General combining ability of parents

According to Yadav and Murthy (1966), the choice of parents especially for heterosis breeding should be based on combining ability test and their mean performance. Combining ability is a measurement of plant genotype ability to produce superior plants on crossing. Combining ability which is obtained from a

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cross between two parental lines can provide information regarding cross combinations for better heredity. Therefore, the parents chosen for the present study were assessed based on their mean performance and general combining ability effects.

The general combining ability effects represent the additive nature of gene action. A high general combiner parent is characterized by its better breeding value when crossed with a number of other parents. Based on *gca* estimates Vaishak was the best combiner for panicle length (Table 94), number of spikelets panicle^{-1}, spikelet sterility, total chlorophyll content, leaf temperature and number of days taken for reaching critical stress level and also good combiner for number of filled grains panicle^{-1}, proline content, cell membrane stability index, chlorophyll a content, chlorophyll *b* content, total chlorophyll content, leaf temperature, transpiration rate, leaf soluble protein content and number of days taken for reaching critical stress level. Thottacheera was a good general combiner for days to 50 % flowering, total chlorophyll content and leaf temperature. Kalladiaryan showed good general combining ability for number of productive tillers plant^{-1}, straw yield plant^{-1}, proline content, chlorophyll *b* content and total chlorophyll content. Frequency of superior varieties for different traits in upland rice is given in Table 95.

Vyttila 6 was the best combiner for plant height at maturity which had significant negative *gca* effects which will be helpful for the development of semi-dwarf variety. It showed best combining ability for number of filled grains panicle^{-1}, grain weight panicle^{-1} , 1000 grain weight, grain yield plant $^{-1}$and straw yield plant $^{-1}$in the desirable positive direction and was a good combiner for number of spikelets panicle^{-1}.

The parent Vyttila 6 was the best combiner for physiological and biochemical traits such as water use efficiency (WUE), relative leaf water content (RLWC) (%), proline content, cell membrane stability index, chlorophyll a content (mg/g), carotenoides content, leaf temperature, transpiration rate (TR), stomatal conductance (SC), leaf soluble protein content and good combiner for total chlorophyll content and number of days taken for reaching critical stress

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level. The parent Harsha was a good combiner for plant height at maturity, 1000 grain weight and grain weight per panicle $^{-1}$while parent Swarnaprabha showed good general combining ability for number of days taken for reaching critical stress level. Similar results were reported by John *et al* (2011) in groundnut. He reported that the *gca* effects for stomatal conductance varied from –0.41 (TCGS-584) to 0.24 (TPT-4). Positive *gca* effects were shown by Tirupati-4, ICGV-99029 and K-1375 and significant negative *gca* effects were registered by TCGS-584 in groundnut in a study conducted at Thirupati.

Vyttila 6 was the best combiner for water use efficiency, relative leaf water content, proline content, cell membrane stability index, chlorophyll a content, carotenoides content, total chlorophyll content, chlorophyll stability index, transpiration rate, stomatal conductance, leaf soluble protein content and number of days taken for reaching critical stress level in the desirable positive direction with high mean values. Kalladiaryan, Thottacheera and Vaishak were good general combiners for chlorophyll b content with high mean values. Vaishak, Vyttila 6, Kalladiaryan and Thottacheera were good general combiners for total chlorophyll content. The parents Vaishak and Thottacheera were good general combiners for leaf temperature. Vyttila 6 and Vaishak were good combiners for transpiration rate. Similar results were reported by Karyawati *et al.* (2015) that parental strains Brawijaya 1 and Brawijaya 2 had positive general combining ability and significantly different from the other strains for transpiration rate and stomatal conductance in soyabean. Shal *et al.* (2014) reported similar findings of high *gca* for transpiration rate and stomatal conductance in Egyptian wheat landraces. Vyttila 6 and Vaishak were good general combiners for leaf soluble protein content. Swarnaprabha, Vyttila 6 and Vaishak were good general combiners for number of days taken for reaching critical stress level. Findings in line with the present investigation were reported by Jayasudha and Sharma (2010) and Shal *et al.* (2014) for stomatal conductance and transpiration rate in wheat. For protein content, similar results were reported by Anyanwu and Obi (2015) in rice. Yogameenakshi *et al.* (2003) reported high *gca* in rice for relative leaf water content in ADT 36 and for proline content and

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chlorophyll stability index in Kallurundaikar. John *et al.,* (2011) reported significant *gca* for chlorophyll meter reading and water use efficiency in genotype TPT-4 in groundnut.

5.10.2 Specific combining ability, gene action and heterosis

Early flowering in rice is generally an indication of drought escaping mechanism and earliness is important in any crop improvement programme. Twelve hybrids showed significant specific combining ability for the trait days to 50 % flowering (Table 96). Out of these, nine hybrids had significant heterobeltiosis for earliness. These hybrids can be projected as the best hybrids for earliness. Heterosis for earliness has been reported by Young and Virmani (1990), Virmani and Voc (1991), Peng and Virmani (1991), Mishra and Pandey (1998) in rice. Frequency of the crosses performed superior for the different traits in upland rice are given in Table 97.

In the present study, estimates of $\sigma^2 gca$ and $\sigma^2 sca$ showed that $\sigma^2 sca$ was higher for all characters studied. Hence non-additive component of heritable variation is many times larger than the additive component for all the morphological, physiological and biochemical traits in upland rice. The preponderance of non additive gene action in the inheritance denotes that heterosis breeding will be rewarding for the improvement of these traits. Predominance of non-additive gene action for days to 50% flowering in rice was reported by Umakanta *et al.* (2002) Haripresanna *et al.* (2006), Pradhan *et al.* (2006) and Akarsh and Pathak (2008) which is in line with the present findings. Number of productive tillers plant $^{-1}$ is one of the major parameters contributing for grain yield per plant because this trait is affected by several factors such as edaphic and climatic. Five hybrids showed significant high *sca* effects and significant positive heterobeltiosis for this trait. Similar findings were reported by Pandey *et al*., (1995) that relative heterosis and heterobeltiosis showed positive estimate ranging from 12.70 percent to 170 percent over mid parent and 13.60 to 117.60 over better parent in rice hybrids. Chakraborty *et al*.(1994); Mehla *et al.*(2000) and Bisne and Motiramani (2005) observed a preponderance of non

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additive gene action for productive tillers plant $^{-1}$ which is in agreement with the present results.

Plant height is an important growth parameter from productivity and crop management point of view. Two hybrids exhibited significant negative *sca* effects and significant heterobeltiosis in the desired direction for this trait. *El-Namaky et al.* (2010) reported significant negative *sca* effects for plant height which agrees with the present findings. Similar results that non additive gene action is more important than additive gene action for plant height was reported by Chakraborty *et al*. (1994); Bisne and Motiramani (2005) and Venkatesan *et al*. (2007). Significant negative heterosis similar to the present findings was reported by Jayasudha and Sharma (2010) in rice.

Panicle length is an important parameter for increasing grain yield in rice. Four hybrids exhibited significant *sca* effects and significant heterobeltiosis in the desired direction for this character. In general the magnitude of *sca* variance was high for characters studied than their respective *gca* variances indicating the predominance of non-additive gene action. Similar results were reported by Manonmani and Ranganathan (1998) Swamy *et al*. (2003), Haripresanna *et al*. (2006), Pradhan *et al.* (2006), and Shanthi *et al.* (2003) for panicle length. Significant standard heterosis (Leenakumari, 1994) and significant relative heterosis and heterobeltiosis (Jayasudha and Sharma, 2010) reported for panicle length in rice supports the present results.

Number of spikelets panicle^{-1} is an important parameter for increasing grain yield in rice. Four hybrids exhibited significant *sca* effects and significant heterobeltiosis in the desired direction for this character. The magnitude of *sca* variance was high for characters studied than their respective *gca* variances indicating the predominance of non-additive gene action. Mehla *et al*. (2000) and Bisne and Motiramani (2005) observed a preponderance of non additive gene action for spikelets panicle^{-1}. Similar findings on heterosis for number of spikelets panicle^{-1} was reported by Chen-Shun Huei *et al.* (1997) and Tiwari *et al*. (2011).

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Spikelet sterility is mostly affected by environmental factors. Only one hybrid exhibited significant *sca* effects. None of the hybrids showed heterobeltiosis in the desired direction. Non-additive gene action was indicated by the higher magnitude of *sca* variance. Similar results of higher magnitude of *sca* variance was reported by Biswas and Haque (2007) for spikelet sterility in rice. Heterosis was studied by Radhakrishana (1992) who obtained significant negative heterobeltiosis for spikelet sterility which agrees with the present results.

Number of filled grains panicle^{-1} is a yield related trait in rice. Only one hybrid exhibited significant *sca* effects. None of the hybrids exhibited heterobeltiosis in the desired direction. Selvaraj *et al*. (2010) studied heterosis for number of filled grains panicle^{-1} obtaining similar results.

Grain weight panicle^{-1} is a yield related trait. Only one hybrid exhibited significant *sca* effects. None of the hybrids exhibited heterobeltiosis in the desired direction. Non additive gene action was found to be more important as per the present results. Similar results were reported by Bisne and Motiramani (2005), Predeep Kumar and Reddy (2011), Vani and Rani (2003), Akarsh and Pathak (2008), Haripresanna *et al*. (2006), Pradhan *et al*. (2006), Umakanta *et al*. (2002) and Mehla *et al*. (2000) for gene action. Selvaraj *et al*., (2010) studied heterosis for grain weight panicle^{-1} in 64 selected crosses and found negative heterosis to be more prevalent.

For the character 1000 grain weight, four hybrids exhibited significant *sca* effects and two hybrids exhibited significant heterobeltiosis. The *sca* effects were more pronounced and non additive gene action was more important. Similar results on the relative importance of *sca* effects were reported by Bisne and Motiramani (2005) Predeep Kumar and Reddy (2011), Vani and Rani (2003), Akarsh and Pathak (2008), Haripresanna *et al*. (2006), Pradhan *et al*. (2006), Umakanta *et al*. (2002) and Mehla *et al*. (2000) for 1000 grain weight in rice. Selvaraj *et al*. (2010) studied heterosis for 1000 grain weight reporting more of negative heterosis.

For grain yield plant^{-1}, two hybrids exhibited significant *sca* effects and four hybrids exhibited heterobeltiosis. The magnitude of *sca* variance was high for the

Table 94. Evaluation of parents based on *gca* effects and mean performance.

Sl.No	Morphological traits	Superior mean performance	High *gca* effects	Superior mean performance and *gca* effects
1	Days to 50 % flowering	P_3, P_2, P_5	P_2, P_3, P_5	P_2, P_3, P_5
2	Number of productive tillers per plant	P_3, P_4, P_1	P_3	P_3
3	Plant height at maturity (cm)	P_1, P_4	P_4, P_5	P_4
4	Panicle length (cm)	P_4, P_1	P_1	P_1
5	Number of spikelets per panicle	P_4, P_2, P_1	P_1, P_4	P_4, P_1
6	Number of filled grains per panicle	P_4, P_6, P_2	$P_4 P_1$	P_4
7	Spikelet sterility (%)	P_2, P_3, P_6, P_4	P_1	P_1
8	Grain weight per panicle(g)	P_1, P_4, P_6, P_5	P_4, P_5	P_4, P_5
9	1000 grain weight (g)	P_3, P_5, P_1, P_2, P_4	P_4, P_5	P_5
10	Grain yield per plant (g)	P_3, P_4, P_1	P_4	P_4
11	Straw yield per plant (g)	P_4, P_1, P_6	P_4, P_3	P_4
12	Harvest index (%)	P_3, P_1, P_4	-	-
Physiological and biochemical traits				
1	Water use efficiency (WUE) (g/l)	P_4, P_3, P_1	P_4	P_4
2	Relative leaf water content (RLWC) (%)	P_4, P_2, P_5	P_4	P_4
3	Proline content	P_4, P_6, P_2	P_4, P_3, P_1	P_4
4	Cell membrane stability index	P_4, P_2	P_4, P_1	P_4
5	Chlorophyll a content (mg/g)	P_5, P_4, P_6	P_4, P_1	P_4
6	Chlorophyll b	P_2, P_3, P_6, P_1	P_3, P_2, P_1	P_3, P_2, P_1
7	carotenoides	P_4, P_5, P_2, P_3	P_4	P_4
8	Total chlorophyll content	$P_2, P_3, P_4. P_1$	P_1, P_4, P_3, P_2	P_1, P_4, P_3, P_2
9	Chlorophyll stability index	P_3, P_5, P_4	P_4	P_4
10	Leaf temperature (0C)	P_4, P_2, P_1	P_1, P_2	P_1, P_2
11	Transpiration rate (TR)	P_4, P_1, P_5	P_4, P_1	P_4, P_1
12	Stomatal conductance (SC)	P_4, P_1, P_3	P_4	P_4

13	Leaf soluble protein content(mg/g)	P_4,P_1	P_4,P_1	P_4, P_1
14	Radiation use efficiency	P_5,P_4,P_3	-	-
15	Chlorophyll meter reading (SPAD)	P_5,P_3,P_2	-	-
16	Leaf area index (LAI)	P_1,P_4,P_3	-	-
17	Relative growth rate (RGR) (mg/g/day)	P_3,P_5,P_4,P_6	-	-
18	Net assimilation rate (NAR) (g/m2/day)	P_5,P_4,P_3	-	-
19	Carbon isotope discrimination (per mil)	P_2,P_1,P_4,P_3	-	-
20	Number of days taken for reaching critical stress level	P_6,P_4,P_3,P_1	P_1,P_4,P_6	P_6,P_4,P_1

P_1: Vashak

P_2: Thottacheera

P_3: Kalladiaryan

P_4: Vyttila6

P_5: Harsha

P_6:Swarnaprabha

Table 95. Frequency of superior varieties for different traits in upland rice

Sl.No	Variety	Number of times for morphological traits	Number of times for physiological and biochemical traits	Total
1	Vaishak	3	5	8
2	Thottacheera	1	3	4
3	Kalladiaryan	2	2	4
4	Vyttila 6	6	11	17
5	Harsha	3	0	3
6	Swarnaprabha	0	1	1

Table 96. Evaluation of hybrids on the basis of mean performance, *sca* effects and heterobeltiosis

Sl.No	Morphological traits	Superior mean performance	High *sca* effects	Heterobeltiosis	Superior hybrids
1	Days to 50 % flowering	P_2 x P_5, P_2 x P_4, P_2 x P_6, P_3XP_5, P_1XP_6,P_5XP_6,P_2xP_3,P_1xP_5,P_1xP_2,P_3xP_4,P_3xP_6,P_1xP_4,P_1xP_3	P_2xP_4,P_2xP_6,P_2xP_5,P_3xP_4,P_1xP_6,P_1xP_4,P_4xP_5 ,P_2xP_3,P_4xP_6,P_5xP_6,P_1xP_5,P_3xP_5 Akarsh and Pathak (2008), Haripresanna *et al.* (2006), Pradhan *et al.* (2006) and Umakanta *et al.* (2002)	P_1xP_6,P_1xP_4,P_2xP_5,P_2xP_4,P_2xP_6,P_5xP_6,P_3xP_5,P_1xP_5,P_1xP_2 Young and Virmani (1990), Mishra and Pandey (1998), Peng and Virmani (1991)	P_1xP_6, P_1xP_4,P_2xP_5,P_2xP_4, P_2xP_6,P_5x P_6,P_3xP_5,P_1xP_5
2	Number of productive tillers per plant	P_2xP_3,P_1xP_2,P_4xP_5,P_3xP_5, P_1xP_3,P_4xP_6,P_2xP_3,P_1xP_6,P_1xP_2	P_1xP_2,P_4xP_5,P_4xP_6, P_3xP_5,P_2xP_3 Bisne and Motiramani (2005), Chakraborty *et al.* (1994), Mehla *et al.* (2000)	P_1xP_2,P_4xP_5,P_2xP_5,P_2xP_4, P_4xP_6,P_1xP_6,P_2xP_3,P_3xP_5,P_1xP_3, P_3xP_4,P_3xP_6 Pandey *et al.*, (1995)	P_1xP_2,P_4xP_5,P_4xP_6, P_3 xP_5,P_2xP_3
3	Plant height at maturity (cm)	P_5xP_6, P_2xP_6,P_2xP_5,P_4xP_6,P_4xP_5	P_5xP_6, P_2xP_6 Chakraborty *et al.* (1994), Bisne and Motiramani (2005) and Venkatesan *et al.* (2007)	P_5xP_6, P_2xP_6, P_4xP_6, P_2xP_5, P_1xP_2, P_2 x P_4 Jayasudha and Sharma (2010)	P_5xP_6, P_2xP_6
4	Panicle length (cm)	P_4xP_3,P_4xP_6,P_1xP_5,P_2xP_3,P_4xP_5,P_1xP_2	P_4xP_6,P_1xP_3,P_4xP_5, P_1xP_5,P_2xP_3, P_1xP_2 Manonmani and Ranganathan (1998) Swamy *et al.* (2003), Haripresanna *et al.* (2006), Pradhan *et al.* (2006), and Shanthi *et al.* (2003).	P_1xP_5,P_1xP_3,P_1xP_2,P_1xP_6,P_4xP_6,P_1xP_4,P_2xP_3 Leenakumari (1994), Jayasudha (2010)	P_4xP_6,P_1xP_3,P_4xP_5, P_1xP_5,P_2xP_3, P_1xP_2
5	Number of spikelets per panicle	P_4xP_5,P_1xP_5,P_1xP_4,P_4xP_6, P_1xP_3, P_1xP_6	P_1xP_3,P_4xP_5, P_4xP_6, P_1 x P_2 Bisne and Motiramani (2005) Mehla *et al.* (2000)	P_1xP_2,P_1xP_3,P_1xP_5,P_4xP_5, Chen-Shun Huei *et al.* (1997) Tiwari *et al.* (2011)	P_1xP_3,P_4xP_5,
6	Number of filled grains per panicle	P_4xP_6,P_4xP_5,P_1xP_4,P_1xP_2,	P_4xP_5,P_4xP_6 Akter, *et al.* (2010)	P_4xP_5 Selvaraj *et al.* (2010)	P_4xP_5
7	Spikelet sterility (%)	P_5xP_6,P_4xP_6,P_2xP_6, P_4xP_6,P_3xP_5,P_2xP_5	P_2xP_3 Biswas and Haque (2007)	--	--
8	Grain weight per panicle(g)	P_1xP_5,P_4xP_5,P_4xP_6,P_2xP_6,P_2xP_4	P_1xP_5 Bisne and Motiramani (2005)	--	--

9	1000 grain weight (g)	$P_2xP_4,P_2xP_6,P_4xP_5,P_3xP_5,P_2xP_5$	$P_2 xP_4,P_2xP_6,P_3xP_5,P_4xP_5$ Bisne and Motiramani (2005)	P_2xP_4,P_2xP_6 Predeep Kumar and Reddy (2011), Vani and Rani (2003), Akarsh and Pathak (2008), Haripresanna *et al.*(2006), Pradhan *et al.* (2006), Umakanta *et al.* (2002) and Mehla *et al.*(2000), Selvaraj *et al.* (2010)	P_2xP_4,P_2xP_6
10	Grain yield per plant (g)	$P_4xP_5,P_4xP_6,P_1xP_2,P_2xP_4,P_2xP_3,P_1xP_5$	P_4xP_5,P_4xP_6 Akarsh and Pathak (2008), Haripresanna *et al.* (2006), Pradhan *et al.* (2006), Umakanta *et al.* (2002), Predeep Kumar and Reddy (2011), Shanthi *et al.*(2003) Vanaja *et al.* (2003), Chakraborty *et al.* (1994) and Mehla *et al.* (2000) Anand *et al.* (1999)	$P_4xP_5,P_4xP_6,P_2xP_5,P_1xP_2$ Virmani and Voc (1991), Nadali and Nadali (2010) and Veeresha *et al.* (2013)	P_4xP_5,P_4xP_6
11	Straw yield per plant (g)	$P_4xP_6,P_3xP_4,P_4xP_5,P_1xP_3,P_2xP_3,P_2xP_4$	P_2xP_3,P_4xP_6,P_4xP_5 Chandra *et al.* 2014	P_2xP_3 Tiwari (2015)	P_2xP_3
12	Harvest index (%)	$P_4xP_5,P_3xP_6,P_2xP_5,P_3xP_5,P_4xP_6$	-	P_2xP_6,P_4xP_5,P_2xP_5 Patel *et al.* (1994) and Tiwari *et al.* (2011)	–
Physiological and biochemical traits					
1	Water use efficiency (WUE) (g/l)	$P_4xP_5,P_4xP_6,P_2xP_4,P_2xP_3,P_1xP_2,P_3xP_4,P_1xP_4$	$P_4xP_5,P_4xP_6, P_1xP_2, P_2xP_3$	$P_4xP_5,P_4xP_6,P_1xP_2,P_2xP_3,P_2xP_4,P_3xP_4,P_3xP_5$ John *et al.*(2011)	$P_4xP_5,P_4xP_6, P_1xP_2, P_2xP_3$
2	Relative leaf water content (RLWC) (%)	$P_1xP_6,P_1xP_4,P_3xP_4,P_2xP_4$	-	-- Yogameenakshi *et al.* (2003), Ganapathy and Ganesh (2008)	–
3	Proline content	$P_1xP_3,P_1xP_4,P_4xP_6.P_3xP_6,P_4xP_5$	$P_1 x P_3. P_1XP_4, P_4 XP_5, P_2XP_5$ Gopikannan and Ganesh (2013) Mohammad *et al.* (2013), Manasa *et al.* (2014)	P_1xP_3 Giancarla *et al.* (2015)	P_1xP_3

4	Cell membrane stability index	$P_1xP_6,P_1xP_2,P_1xP_4,P_3xP_4,P_1xP_5$	$P_1xP_6,P_1xP_5,P_2xP_5,P_1xP_2,P_3xP_4$ Mohammad *et al.* (2013), Amudha *et al.* (2010)	P_1xP_5,P_1xP_6,P_1xP_2 Singh *et al* (2015)	P_1xP_5,P_1xP_6,P_1xP_2
5	Chlorophyll a content (mg/g)	$P_1xP_5,P_3xP_4,P_2xP_6,P_1xP_6,P_4xP_5,P_4xP_6,P_1xP_4,P_1xP_2,P_2xP_3$	$P_1xP_5,P_3xP_4,P_3xP_6,P_4xP_5,P_2xP_4,P_1xP_6, P_2xP_3$ Mohammad *et al.* (2013)	-- Singh, (1997), and Amudha *et al.* (2010)	--
6	Chlorophyll b content	$P_4xP_5,P_1xP_3,P_1xP_2,P_2xP_3,P_1xP_4$	$P_4xP_5,P_1xP_3,P_1xP_2,P_1xP_4,P_2xP_3,P_3xP_6$ Mohammad *et al.*(2013), Amiribehzadi *et al.* (2012)	P_4xP_6, P_1xP_4	P_1xP_4
7	carotenoides content	$P_2xP_6,P_3xP_5,P_4xP_6,P_1xP_5,P_1xP_6,P_2xP_5,P_4xP_5,P_4xP_5$	$P_2xP_6,P_1xP_5,P_3xP_5,P_4xP_6,P_1xP_6$ Mohammad *et al.*(2013)	P_2xP_6, P_1xP_5	P_2xP_6, P_1xP_5
8	Total chlorophyll content	$P_4xP_5,P_1xP_3,P_4xP_6,P_1xP_2,P_2xP_3,P_1xP_4,$	$P_4xP_5,P_4xP_6,P_2xP_3,P_1xP_3,P_3xP_6,P_1xP_2$	$P_4xP_5,P_1xP_4,P_4xP_6,$ Gopikannan and Ganesh (2013), Singh (1997)	P_4xP_5,P_4xP_6
9	Chlorophyll stability index	$P_1xP_6,P_1xP_2,P_4xP_5,P_1xP_4,P_2xP_4,P_2xP_4$	$P_1xP_6,P_1xP_2,P_4xP_5,P_2xP_3,P_1xP_4,P_1xP_5,P_2xP_4,P_3xP_6,P_5xP_6$	P_1xP_6, P_1xP_2 Ganapathy and Ganesh (2008), Lal *et al.* (2013)	P_1xP_6, P_1xP_2
10	Leaf temperature (0C)	$P_5xP_6, P_4xP_5,P_3xP_4,P_3xP_6$	$P_5xP_6, P_4xP_5,P_4xP_6,P_3xP_6$ Azam *et al.* (2014)	P_5xP_6, P_4xP_5,P_4xP_6	$P_5xP_6. P_4xP_5,P_4xP_6$
11	Transpiration rate (TR)	$P_4xP_6,P_3xP_4,P_1xP_4,P_3xP_5,P_1xP_5,P_2xP_6$	$P_1xP_3,P_2xP_6,P_4xP_6,P_3xP_5,P_3xP_4,P_1xP_5,P_5xP_6$ Karyawati *et al.*(2015) Shal, *et al.*(2014)	$P_2xP_6,P_3xP_6,P_3xP_5,P_5xP_6,P_1xP_3,P_2xP_5,P_4xP_6,P_3xP_4,P_2xP_3,P_1xP_4,P_1xP_5,P_1xP_2, P_3 x P_6, P_1x P_2, P_1x P_4, P_2 x P_4$	$P_1xP_3,P_2xP_6,P_4xP_6,P_3xP_5,P_3xP_4, P_1xP_5$
12	Stomatal conductance (SC)	$P_4xP_6,P_2xP_4,P_3xP_4,P_3xP_6,P_4xP_5,P_3xP_5,P_1xP_5$	$P_4xP_6,P_1xP_5,P_1xP_2,P_3xP_5,P_3xP_6,P_2xP_6$	$P_1xP_5, P_3xP_6, P_4xP_6$ Mohamad *et al.* (2007)	P_1xP_5,P_3xP_6, P_4xP_6
13	Leaf soluble protein content(mg/g)	$P_4xP_6,P_1xP_4,P_4xP_5,P_2xP_4,P_1xP_6,P_1xP_5,P_2xP_5,P_2xP_4,P_1xP_6$	P_4xP_6,P_4xP_5,P_2xP_5 Anyanwu and Obi (2015), Won *et al.*(2002)	P_4xP_6	P_4xP_6
14	Radiation use efficiency	$P_2xP_6,P_4xP_5,P_3xP_4,P_2xP_5,P_2xP_4,P_1xP_6$	--	--	--

15	Chlorophyll meter reading (SPAD)	P_5xP_6,P_4xP_6,P_4xP_5,P_3xP_4,P_2xP_5	P_4xP_6,P_5xP_6 John *et al.* (2011)	P_4xP_6,P_3xP_4,P_1xP_2	P_4xP_6
16	Leaf area index (LAI)	P_3xP_6,P_1xP_2,P_4xP_6,P_2xP_3,P_4xP_5,P_1xP_5	P_3xP_6,P_1xP_2,P_4xP_6	P_3xP_6 Kindred and Gooding (2005)	P_3xP_6
17	Relative growth rate (RGR) (mg/g/day)	P_2xP_6,P_2xP_5, P_4xP_5,P_3xP_5	--	--	--
18	Net assimilation rate (NAR) (g/m2/day)	P_2xP_6,P_2xP_5,P_1xP_6,P_4xP_5,P_3xP_5	--	P_2xP_6, P_1xP_6 Akter, *et al.* (2010) and Kumar *et al.* (2014)	--
19	Carbon isotope discrimination (per mil)	P_4xP_5,P_4xP_6,P_2xP_3,P_1xP_5,P_2xP_5	P_4xP_5,P_1xP_6,	P_4xP_5 Cuong *et al.* (2014)	P_4xP_5
20	Number of days taken for reaching critical stress level	P_4xP_5,P_1xP_6,P_1xP_2,P_1xP_3,P_4xP_5,P_1xP_4,P_3xP_5	P_1xP_4,P_1xP_2,P_2xP_6,P_5 xP_6,P_1x P_3, P_2xP_4, P_3xP_4,	P_1xP_2,P_1xP_5,P_1xP_3,P_2xP_3, P_4xP_5,P_1xP_6	P_1xP_2, P_1x P_3

P_1 x P_2: Vaishak x Thottacheera

P_1 x P_3: Vaishak x Kalladiaryan

P_1 X P_4: Vaishak x Vyttila 6

P_1 X P_5:Vaishak x Harsha

P_1 X P_6: Vaishak x Swarnaprabha

P_2 xP_3: Thottacheera x Kalladiaryan

P_2 xP_4:Thottacheera x Vyttila 6

P_2 x P_5:Thottacheera x Harsha

P_2 x P_6: Thottacheera x Swarnaprabha

P_3 x P_4: Kalladiaryan x Vyttila 6

P_3 x P_5: Kalladiaryan x Harsha

P_3 x P_6: Kalladiaryan x Swarnaprabha

P_4 xP_5 : Vyttila 6 x Harsha

P_4 x P_6 : Vyttila 6 x Swarnaprabha

P_5 x P_6 : Harsha x Swarnaprabha

Table 97.Frequency of the crosses performed superior for the different traits in upland rice

Sl.No	Hybrids	Number of times for morphological traits	Number of times for physiological and biochemical traits	Total
1	Vaishak x Thottacheera	1	4	5
2	Vaishak x Kalladiaryan	2	3	5
3	Vaishak x Vyttila 6	1	1	2
4	Vaishak x Harsha	0	3	3
5	Vaishak x Swarnaprabha	1	2	3
6	Thottacheera x Kalladiaryan	2	1	3
7	Thottacheera x Vyttila 6	2	0	2
8	Thottacheera x Harsha	1	0	1
9	Thottacheera x Swarnaprabha	1	1	2
10	Kalladiaryan x Vyttila 6	0	1	1
11	Kalladiaryan x Harsha	1	2	3
12	Kalladiaryan x Swarnaprabha	0	2	2
13	Vyttila 6 x Harsha	4	3	7
14	Vyttila 6 x Swarnaprabha	2	6	8
15	Harsha x Swarnaprabha	0	1	1

character and non additive gene action was more prevalent. Venkatesan *et al.* (2007) found non additive gene action for plant height, days to fifty percent flowering and grain yield in a line x tester analysis with several rice strains. Similar results that non-additive type of gene action was governing all important yield related characters studied was reported by Chakraborty *et al.* (1994), Anand *et al.* (1999), Umakanta *et al.* (2002), Shanthi *et al.* (2003), Vanaja *et al.* (2003), Haripresanna *et al.* (2006), Pradhan *et al.* (2006), Akarsh and Pathak (2008), Predeep Kumar and Reddy (2011), and Mehla *et al.* (2000). Combining ability of eight quantitative characters related to yield was studied in rice by Anand *et al.* (1999). The study revealed non-additive type of gene action governing all eight characters which is similar to the present results. Tiwari *et al.* (2011) reported significantly superior mainifestation of heterobeltiosis for grain yield for 43 hybrids studied. This is in line with the results of the present investigation. Mishra and Pandey (1998) derived information on heterosis from data on 10 yield related traits in 36 F_1 hybrids. About 17-20% of all the hybrids manifested significant and positive heterobeltiosis for grain yield due to significant and positive heterosis for panicle length and 1000-grain weight. Punitha *et al.* (2004) worked out heterosis from a 3 line × 4 tester experiment including their 12 F_1 hybrids and reported high mid parent and better parent heterosis for yield. Significant superior relative heterosis for grain yield plant^{-1} was reported in rice hybrids by Virmani and Voc (1991), Nadali and Nadali (2010). Veeresha *et al* (2013) observed significant superior standard heterosis. All these reports support the present findings.

For straw yield plant^{-1}, three hybrids exhibited significant *sca* effects and one hybrid exhibited significant heterobeltiosis. Similar results were reported by Tiwari (2015) for a heterosis over better and mid parents ranging from -15.00 to 40.65 and -5.92 to 25.57 respectively.

Harvest index is a very important trait for improving grain yield. Three hybrids exhibited significant heterobeltiosis for harvest index. Current results were supported by Patel *et al.* (1994) and Tiwari *et al.* (2011) who studied grain yield and harvest index in rice.

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High water use efficiency is a very important trait in improving grain yield in upland rice. Four hybrids exhibited significant *sca* effects and seven hybrids exhibited heterobeltiosis for the trait. John *et al.* 2011 identified hybrid TPT-4 x TIR-25 as the specific hybrid for high water use efficiency with high relative heterosis and heterobeltiosis.

For proline content, four hybrids exhibited significant *sca* effects and one hybrid showed significant heterobeltiosis. The character showed non-additive gene action. Similar results on gene action were reported by Gopikannan and Ganesh (2013) in rice and Mohammad *et al.* (2013) in wheat. Significant mid parent heterosis for proline content was observed in maize by Manasa *et al.* (2014) in barley by Giancarla *et al.* (2015).

Cell membrane stability index is one of the important traits attributing drought avoidance mechanism. This trait is very crucial for determining the stress tolerant hybrid. Five hybrids exhibited significant *sca* effects and three hybrids exhibited significant heterobeltiosis for cell membrane stability index in rice. Singh *et al.* (2015) recorded heterosis in the range of 6.93 to 9.0% in hybrid rice for this trait. In the present study non additive gene action prevailed for the character. Similar results on gene action were reported by Amudha *et al.* (2010) in rice and Mohammad *et al.* (2013) in wheat.

For chlorophyll a content in upland rice, seven hybrids exhibited significant *sca* effects. Heterobeltiosis ranged from -52.69 to 3.51 with four hybrids showing significant negative values. Similar results for heterosis were reported by Singh (1997) in rice for chlorophyll a content with a range from -58.18 to 54.62 per cent over mid parent. Results akin to the present were reported by Mohammad *et al.* (2013) in wheat and Amiribehzadi *et al.* (2012) in pearl millet for heterobeltiosis.

For chlorophyll b content, six hybrids exhibited significant *sca* effects and two hybrids exhibited significant heterobeltiosis in the desired direction for the trait. Similar results for heterosis were reported by Mohammad *et al.* (2013) in wheat and Amiribehzadi *et al.* (2012) in pearl millet. Non-additive gene action was predominant.

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For the character carotenoide content, five hybrids exhibited significant *sca* effects and two hybrids exhibited significant positive heterobeltiosis. Similar results on significant positive heterosis were reported by Mohammad *et al.* (2013) in wheat, Cheema and Sadaqat (2004) in Canola and Amiribehzadi *et al.* (2012) in pearl millet. In the present study, *sca* effects were found to be predominant.

For total chlorophyll content, six hybrids exhibited significant *sca* effects and three hybrids exhibited significant heterobeltiosis. Non-additive effects prevailed for the character. Similar results on the prevalence of non additive gene action was reported by Gopikannan and Ganesh (2013) for the character. Singh (1997) reported values ranging from-39.70 to 53.82 percent for heterobeltiosis in total chlorophyll content.

With respect to chlorophyll stability index, nine hybrids exhibited significant *sca* effects and two hybrids exhibited significant heterobeltiosis. Non additive gene action was more important for the character. Similar findings were reported by Ganapathy and Ganesh (2008) on significant desirable heterosis over mid parent for chlorophyll stability index. Lal *et al.* (2013) reported that heterosis and heterobeltiosis ranged from -14.14 to 28.36 percent and 3.33 to 26.32 percent over mid and better parents for chlorophyll stability index in wheat.

For leaf temperature, four hybrids exhibited significant *sca* effects and three hybrids exhibited significant heterobeltiosis. Non additive gene action was indicated. Similar results were reported by Azam *et al.* (2014) that canopy temperature was controlled by both additive and dominant effects in sunflower.

Transpiration rate is an important trait related to drought tolerance. Eleven hybrids exhibited significant *sca* effects and twelve hybrids exhibited significant heterobeltiosis for transpiration rate. Similar results on the relative importance of sca effects on transpiration rate were reported by Karyawati *et al.* (2015) in soybean and Shal, *et al.* (2014) in wheat. Similar results of a high standard heterosis (87.50 %) for the trait was observed by Amudha *et al.* (2010) in rice.

For stomatal conductance, six hybrids exhibited significant *sca* effects and three hybrids exhibited significant heterobeltiosis. Heterosis for stomatal conductance was studied by Mohamad *et al.* (2007) in wheat. A heterosis

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estimate 40 % was reported. Amudha *et al.* (2010) reported significant standard heterosis for stomatal conductance (134.63%) for a rice hybrid under upland situations. Similar results on heterosis were reported by Karyawati *et al.* (2015) in soybean, John *et al.* (2011) in groundnut and Shal *et al* (2014) in wheat.

For protein content three hybrids exhibited significant *sca* effects and one hybrid exhibited significant heterobeltiosis. Heterosis for leaf soluble protein content was studied by Anyanwu and Obi (2015), Won *et al.* (2002) and Nayak *et al.* (2015) in rice and Lal *et al.* (2013) in wheat.

For chlorophyll meter reading, two hybrids exhibited significant *sca* effects and three hybrids exhibited significant heterobeltiosis. Similar results were reported by Won *et al.* (2002) and Anyanwu and Obi (2015) in rice. The magnitude of *sca* variance was higher for characters studied than their respective *gca* variances indicating the predominance of non-additive gene action.

For leaf area index, three hybrids exhibited significant *sca* effects and one hybrid exhibited significant heterobeltiosis. Similar results were reported by Akter, *et al.* (2010) and Kumar *et al.* 2014 for non-additive gene action in leaf area index in rice. Similar results on heterosis were reported by Mohamad *et al.* (2007) in maize and Anna Dura (2002) in rice. Akter *et al.* (2010), based on his study, suggested that to get hybrids heterotic for grain yield, LAI during maximum tillering stage should be moderate. These results support the current findings.

For the character net assimilation rate, two hybrids exhibited significant heterobeltiosis in upland rice. Kumar and Sharma (2008) reported that hybrids HPR 2047 x JD 8, VL 93-3613 x IR 57893-08 and VL 93-6052 x VL Dhan 221 in rice were identified as the best crosses on the bases of grain yield plant^{-1} along with net assimilation rate, dry matter and leaf area index. This information on the extent of heterosis would help in the choice of parents for further breeding programmes.

For carbon isotope discrimination two hybrids exhibited significant *sca* effects and one hybrid exhibited significant heterobeltiosis. Similar results on

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heterosis for water use efficiency was reported by Farquhar *et al.* (1982) and Cuong *et al.* (2014).

Seven hybrids exhibited significant *sca* effects and six hybrids exhibited significant heterobeltiosis for number of days taken for reaching critical stress level.

5.11 FIVE SUPERIOR HYBRIDS IDENTIFIED

The hybrid Vyttila 6 x Swarnaprabha exhibited good mean performance for the traits number of productive tillers plant^{-1}, number of filled grains panicle^{-1}, panicle length, grain weight panicle^{-1}, harvest index, straw yield plant^{-1} and leaf area index (Table 98). In terms of physiological and biochemical trait the hybrid exhibited good performance for osmotic potential traits such as cell membrane stability index, water use efficiency, relative leaf water content, chlorophyll stability index. This hybrid maintain leaf water potential under moisture stress. Chlorophyll meter reading, total chlorophyll content and chlorophyll stability index were high in the hybrid. The hybrid performed well for relative growth rate.

The hybrid Vyttila 6 x Harsha exhibited highest number of productive tillers plant^{-1}, straw yield plant^{-1}, grain yield plant^{-1}, grain weight panicle^{-1}, 1000 grain weight, harvest index, number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, spikelet sterility, panicle length and number of filled grains panicle^{-1}. The hybrid performed well for chlorophyll b content, total chlorophyll content, chlorophyll stability index, chlorophyll meter readings and chlorophyll a content. The hybrid showed high relative growth rate and net assimilation rate under upland condition. The hybrid exhibited least carbon isotope discrimination under upland condition. The hybrid had good conductance of CO_2 stomatal conductance under upland condition. This hybrid had good leaf soluble protein content and good radiation use efficiency under upland condition.

Vaishak x Swarnaprabha had highest panicle length, number of spikelets panicle^{-1}, number of filled grains per panicle and was good for days to 50 % flowering. This hybrid had high chlorophyll a content and remarkable, osmotic potential traits and also performed well for the hybrid and best for stomatal cond-

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Sl.No.	Table 98. Five superior F_1 hybrids identified under upland condition		
	Hybrid combinations	Characters	Rating
1	Vyttila 6 x Swarnaprabha (PTB 43) (20)	Stomatal conductance	Best
		Leaf soluble protein content	Best
		Grain yield plant^{-1}	Good
		Number of productive tillers plant^{-1}	Good
		Number of filled grains panicle^{-1}	Good
		Plant height at maturity	Good
		Panicle length	Good
		Harvest index	Good
		Grain weight panicle^{-1}	Good
		1000 grain weight	Good
		Straw yield plant^{-1}	Good
		Water use efficiency	Good
		Proline content	Good
		Transpiration rate	Good

		Chlorophyll meter reading	Good
		Leaf area index	Good
		Relative growth rate	Good
		Number of days taken for reaching critical stress level	Good
2	Vyttila 6 x Harsha (PTB 55) (19)	Number of spikelets panicle $^{-1}$	Best
		Number of filled grains panicle^{-1}	Best
		Spikelet sterility	Best
		Grain yield plant^{-1}	Best
		Harvest index	Best
		Water use efficiency	Best
		Chlorophyll b content	Best
		Total chlorophyll content	Best
		Relative growth rate	Best
		Carbon isotope discrimination	Best
		Number of days taken for reaching critical stress level	Best

		Number of productive tillers plant^{-1}	Good
		Plant height at maturity	Good
		Straw yield plant^{-1}	Good
		Grain weight panicle^{-1}	Good
		1000 grain weight	Good
		Panicle length	Good
		Chlorophyll stability index	Good
		Chlorophyll meter reading	Good
		Chlorophyll a content	Good
		Carotenoide content	Good
		Chlorophyll stability index	Good
		Stomatal conductance	Good
		Leaf soluble protein content	Good
		Radiation use efficiency	Good
		Relative growth rate	Good
		Net assimilation rate	Good

3	Vaishak (PTB 60) x Swarnaprabha (PTB 43)(11)	Panicle length	Good
		Number of spikelets panicle^{-1}	Good
		Number of filled grain panicle^{-1}	Good
		Chlorophyll a content	Good
		Relative leaf water content	Good
		Cell membrane stability index	Good
		Days to 50 % flowering	Good
		Stomatal conductance	Good
		Carbon isotope discrimination	Good
4	Vaishak (PTB 60) x Thottacheera (7)	Transpiration rate	Best
		Number of spikelets panicle^{-1}	Good
		Number of filled grains panicle^{-1}	Good
		Grain yield plant^{-1}	Good
		Harvest index	Good
		leaf temperature	Good
		Chlorophyll stability index	Good
		Leaf temperature	Good
		Number of days taken for reaching critical	Good

		stress level	
5	Vaishak (PTB 60) x Kalladiaryan (8)	Proline content	Best
		Number of productive tillers plant^{-1}	Good
		Panicle length	Good
		Number of spikelets panicle $^{-1}$	Good
		Straw yield plant^{-1}	Good
		Transpiration rate	Good
		Chlorophyll a content	Good
		Chlorophyll b content	Good
		Total chlorophyll content	Good
		Leaf temperature	Good
		Number of days taken for reaching critical stress level	Good

-uctance. Hybrid best for carbon isotope discrimination and net assimilation rate. Vaishak x Thottacheera had good number of spikelets, filled grains panicle^{-1}, grain yield plant^{-1} and harvest index. Hybrid had good physiological and biochemical traits such as leaf temperature, chlorophyll stability index, transpiration rate and maximum days taken for reaching critical stress level under upland condition.

Vaishak x Kalladiaryan exhibited high proline content under upland condition. Panicle length, number of spikelets panicle^{-1}and straw yield plant^{-1} was good and number of days taken for reaching critical stress level was the highest here. The hybrid had high chlorophyll a content, chlorophyll b content, total chlorophyll content and leaf temperature under upland condition.

5.12 GENETIC PARAMETERS OF F_2 POPULATIONS

5.12.1 Variability

Much variability along with the appearance of transgressive segregants was observed in the F_2 for all characters under study, when compared to parents. F_2 populations showed significant differences among themselves for days to 50 percent flowering, number of productive tillers plant^{-1}, plant height at maturity, number of spikelets panicle^{-1}, filled grains panicle^{-1}, spikelet sterility percentage, grain weight panicle^{-1}, grain yield plant^{-1}, straw yield plant^{-1} and harvest index. Kalladiaryan was the earliest flowering type among parents whereas Vyttila 6 took the maximum time for flowering. Majority of F_2 were early flowering. The F_2 populations were intermediate between the parents for plant height. Panicle length as well as number of spikelets panicle^{-1} were significantly high among the F_2 populations as compared to the parents. Spikelet sterility percentage was significantly high among the F_2 as compared to the parents which were on par with each other. The parental varieties were more or less stable for the characters grain weight panicle^{-1}and grain yield per plant whereas in the F_2 much variation with transgressive segregation was evident. Among the parents, Vyttila 6 recorded the highest mean grain yield per plant (14.40g) followed by Kalladiaryan (12.46g) whereas the lowest mean value was obtained for Thottacheera (7.14).

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In the F_2 populations grain yield varied from 9.85g in Vaishak x Kalladiaryan to 30.51g in Vyttila 6 x Harsha. Similar results of high phenotypic variability for grain yield per plant in F_2 population in rice in comparision to parents was reported by Unnikrishnan (1980) Venkataravana (1991) and Ganesan *et al.* (1997). Straw yield per plant was generally high in the F_2 as compared to the parents where it ranged from 16 g in Thottacheera to 24.07 g in Vyttila 6. Among the F_2 segregating populations much variability with higher frequency of positive transgressive segregants was observed. All the parents and segregants showed high significance for harvest index with more of positive segregants in the F_2.

Findings similar to the present results were reported by Pantuwan *et al.* (2002) for days to 50% flowering, Unnikrishnan (1980) and Venkataravana (1991) for productive tillers Ganesan *et al.* (1997) for grain number panicle^{-1}, Venkataravana (1991) for panicle weight and Vaithiyalingan and Nadarajan (2006) for all the characters studied.

5.12.2 Phenotypic and genotypic coefficients of variation of six parents and five best F_2 segregants in upland rice

Coefficients of variation gives a unit free comparision of characters measured in different units. Further the magnitude of the coefficients of variation dictate appropriate breeding strategy suitable for improving each character. Among the different characters studied, the highest genotypic and phenotypic coefficients of variation was observed for spikelet sterility percent followed by grain yield plant^{-1}, number of productive tillers plant^{-1}, straw yield plant^{-1}, and grain weight panicle^{-1}. Similar results were reported by Unnikrishnan (1980) who found higher phenotypic and genotypic coefficients of variation for grain yield and number of productive tillers in his study on three F_2 populations for 10 characters which was supported by Sukanya (1984) for number of ear bearing tillers, panicle weight and grain yield in all the three populations.

Similar results were obtained by Ramalingam *et al.* (1994) who studied variability, heritability and genetic advance for panicle characters in 20 rice

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genotypes and obtained high variability for the character. High phenotypic variance was observed for chaffy grains.

In the present study, moderate levels of coefficients of variation were observed for number of spikelets panicle^{-1}, filled grains panicle^{-1}, harvest index, panicle length and plant height at maturity. Similar results were reported by Kahanil and Hittalmani (2016) for straw yield and panicle length. Results inline with the present.

5.12.3 Heritability and genetic advance

High heritability in the broad sense was observed for all the characters under study *viz.,* days to 50 % flowering, number of productive tillers plant^{-1}, plant height at maturity, panicle length, number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, spikelet sterility, grain weight panicle^{-1}, 1000 grain weight, grain yield plant^{-1}, straw yield plant^{-1}, biological yield plant^{-1} and harvest index. Similar results were reported by Maurya (1982) who evaluated 49 populations (21 F_1, 21 F_2 and 7 parents) for yield attributing characters and the result indicated the presence of high heritability values in both the generations for days to heading, plant height, number of grains panicle^{-1} and test weight. Venkataravana (1991), in an F_2 population observed high heritability for plant height and days to maturity in both direct sown rainfed and irrigated conditions. Ramalingam *et al.* (1994) observed high heritability for filled grains panicle^{-1}and grain yield plant^{-1} Chauhan (1996) observed the same for number of spikelets panicle^{-1}, grain weight, grain yield plant^{-1} and harvest index. Shukla *et al.* (2005) observed high heritability for harvest index and Panwar *et al.* (2007) for 1000 grain weight.

High heritability coupled with high genetic advance was recorded for number of spikelets panicle^{-1}, number of filled grains panicle^{-1} and plant height at maturity. Similar findings were reported by Ramalingam *et al.* (1994) for filled grains panicle^{-1}, Chauhan (1996) for number of spikelets panicle^{-1} and Mahto *et al.* (2003) for plant height.

Moderate level of genetic advance was recorded for the traits *viz.,* spikelet sterility, days to 50 percent flowering, grain yield plant^{-1}, harvest index and number of productive tillers plant^{-1}. Genetic advance for the traits grain weight panicle^{-1}, 1000 grain weight, panicle length and straw yield plant^{-1} was found to be low even though their heritability estimates were high. Similar results were reported by Venkataravana (1991) that high heritability (broad sense) values were recorded for plant height and days to maturity in both direct sown rainfed and irrigated conditions. The expected genetic advance was also high for panicle weight and productive tillers.

The selection index score was computed and the parents and F_2 populations of their crosses were ranked accordingly. The highest rank value was recorded by the F_2 segregants Vyttila 6 x Harsha followed by Vyttila 6 x Swarnaprabha, Vaishak (PTB 60) x Thottacheera and Vaishak (PTB 60) x Swarnaprabha (PTB 43). Their parents *viz.,* Vyttila 6 and Vaishak and Vaishak (PTB 60) x Kalladiaryan following. The parents Kalladiaryan, Harsha (PTB 55), Swarnaprabha (PTB 43) and Thottacheera occupied the last positions. In a selection index was used in a combined manner for parents and F_2 segregants in greengram by Eberezer (1999). The segregants Vaishak x Swarnaprabha, Vaishak x Thottacheera and Vaishak x Kalladiaryan were early maturing segregants play an important mechanism for the drought escape. Drought escaping and drought tolerance mechanism attributed by these segregants.

These segregants will be very useful for the development of drought resistant variety under upland condition. The F_2 segregants Vyttila 6 x Harsha, Vyttila 6 x Swarnaprabha, Vaishak x Thottacheera, Vaishak x Swarnaprabha and Vaishak x Kalladiaryan were deviating from parental limit positive and negative direction in these segregants indicating the possibility of identifying desirable recombinants with high yield and drought tolerance which can be further utilized for developing superior varieties.

Vyttila 6 x Harsha and Vyttila 6 x Swarnaprabha exhibited superior performance for the trait grain yield plant^{-1} and water use efficiency. These hybrids adopting drought tolerance mechanism.

It can be concluded that the five superior segregants identified in this study may be carried forward by pedigree method for developing high yielding and drought resistant varieties.

5.13 MOLECULAR ANALYSIS STUDIES

Molecular analysis of the selected accessions was done using primers RM 201, RM 263 and RM 451. The accessions for molecular analysis were selected based on yield and drought resistance. Primer RM 201 is reported to be linked to root length and drought tolerance. The varieties with drought tolerance and increased root length produced PCR product at 158bp (Chaitra, *et al.,* 2006). In this study also all the selected parents and hybrids produced PCR product at 158 bp with primer RM 201. This confirms the drought tolerance of these accessions through root length.

The primer RM 263 is reported to be linked to drought tolerance through osmotic adjustment (Zhang *et al*., 2001) and was reported to produce a product at 199bp (Srividhya *et al.,* 2011). In the present study also parents Vaishak (1), Kalladiaryan (3), Vyttila 6 (4) and Harsha (5) and hybrids Vyttila 6 x Swarnaprabha (H_1) and Vyttila 6 x Harsha (H_2) produced a product at 199 bp confirming drought resistance through osmotic adjustment in these genotypes. Phenotypically also the highest relative leaf water content was observed in Vyttila 6 (95.34%) which conforms to the results of molecular analysis. Both the hybrids with Vyttila 6 as the female parent also showed drought resistance through osmotic adjustment. Cell membrane stability index is also related to osmotic adjustment. Phenotypically also the parents Vaishak, Vyttila 6 and Harsha showed high cell membrane stability index which is expected from their performance at molecular level using primer RM 263.

Vyttila 6 had saline tolerant property due to the presence of ‘saltol’ gene. Salt stress creates moisture deficit in plants by preventing plant water uptake and reduces the osmotic potential of plants. Plants need excess energy to absorb water from the soil under saline condition. This results in higher concentration of Na+ and Cl$^-$ ions producing toxic effects.

Cell organelles and their metabolism is affected leading to reduced plant growth and yield. The same condition prevails under drought stress also. Therefore plants which survive under saline condition can survive under drought condition also.

The primer RM 451 was reported to be linked to drought tolerance through various morphological traits (Aboulila, 2015).

In this study all the selected parents and the best hybrids produced PCR product at 207 bp with primer RM 451. This confirms the drought tolerance of the genotypes under study through various morphological traits. As per Liu *et al.* (2008) the primer RM 451 is linked to high grain yield under drought. The present study also supports the view that primer RM 451 is linked to high grain yield under drought Although all these parents and hybrids had suffered several dry spells under field condition the final grain yield remained comparatively high and unaffected.

SUMMARY

6. SUMMARY

Rice (*Oryza sativa* L.) as a cereal grain is the most widely consumed staple food for a large part of the world's human population, especially in Asia. It is the agricultural commodity with the third highest worldwide production, after sugarcane and maize. Being an extravangant consumer of water, rice uses around 5000 liters of fresh water to produce 1 kg of rice (Kahani and Hittalmani 2015). Rapidly depleting water resources threaten the sustainability of irrigated rice and hence the food security and livelihood of rice producers and consumers. Therefore, farmers need technology to cope with water shortage and ways must be sought to grow rice with lesser amount of available water. Keeping this scenario in view, the present investigation entitled "Genetic analysis of drought tolerance in rice (*Oryza sativa* L.)" was carried out at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India during 2014-2016, with the objective of analysing the nature and magnitude of gene effects in the inheritance of drought tolerance in rice under upland condition with molecular confirmation.

The genetic material for the study consisted of twenty diverse rice genotypes including varieties recommended for uplands and popular high yielding varieties widely cultivated in the state. Screening for drought tolerance was carried out in the target environment *i. e.* under upland virippu, 2014 adopting a randomized block design with three replications. Morphological, physiological and biochemical and aspects of the genotypes were studied. Observations were taken at appropriate plant growth stages following the Standard Evaluation System for Rice [IRRI, 1996]. The screening of genotypes was done as per the protocols of DRR (2012).

Data collected on morphological characters were subjected to analysis of variance revealing significant differences among the twenty genotypes for all characters *viz.*, days to 50 % flowering, number of productive tillers plant^{-1}, plant height at maturity, panicle length, number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, spikelet sterility, grain weight panicle^{-1}, 1000 grain weight, grain yield plant^{-1}, straw yield plant^{-1} and harvest index. Genotypic and phenotypic coefficients of variations (GCV and PCV), heritability (H^2) in the broad sense and genetic advance (GA) were estimated.

Simultaneously, the varieties were screened under protected condition imposing reproductive stage moisture stress. Single plants were grown in 20 cm wide and 100 cm long polythene tubes filled with soil in a rain shelter. The plants were irrigated upto field capacity until stress was given. Reproductive stage moisture stress was imposed at panicle initiation and at heading. At these two stages moisture were withheld till the point when plants exhibited a leaf rolling score of 7 or relative leaf water content (RLWC) of 70%. Full irrigation was resumed thereafter till harvest. Morpho-physiological, biochemical and root character aspects of the genotypes were studied.

Indirect estimation of water use efficiency (WUE) was done. Observations for relative leaf water content (RLWC) and proline content was taken immediately before giving stress and when plants reached the critical stress level.

Destructive sampling was done for relative growth rate (RGR), leaf area index (LAI), net assimilation rate (NAR) and root characters immediately before giving stress and when plants reached the critical stress level. One time observations were taken for carbon isotope discrimination and biomass studies. Observations on other morphological characters were taken at appropriate plant growth stages following the Standard Evaluation System for Rice [IRRI, 1996]. The screening of genotypes was done as per the protocols of DRR (2012).

The results revealed a wide range of variability among the genotypes for most of the traits studied. The range and analysis of variance indicated potential genetic variability and diversity in the material under consideration. Under upland condition Karutha Modan was the earliest flowering and maturing genotype. Vaishak performed best for grain yield plant^{-1}with high harvest index. Vyttila 6 performed best for the trait, number of filled grains panicle^{-1}. The variety Kalladiaryan had the lowest spikelet sterility and the highest grain weight panicle^{-1}, 1000 grain weight, straw yield plant^{-1} and biological yield plant^{-1}. Adequate number of fertile grains panicle^{-1} and heavy grains are important traits, which should be considered in selection for high yield. The variety Uma which is very popular in Kerala in terms of performance and yield showed good performance during vegetative stage. The variety being late maturing and since a dry spell in kharif 2014 unfortunately coincided exactly with the early reproductive phase of the variety in this strictly rainfed upland crop, performance was severely affected. Uma scored the lowest number of filled grains panicle^{-1}, grain weight panicle^{-1}, 1000 grain weight, grain yield plant^{-1}, biological yield plant^{-1}, harvest index and had the highest spikelet sterility.

High PCV and GCV were observed for several characters such as number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, spikelet sterility, grain weight panicle^{-1}, grain yield plant^{-1}, straw yield plant^{-1}, biological yield plant^{-1} and harvest index. The characters *viz.* , number of productive tillers plant^{-1}, plant height at tip of longest leaf of plant, plant height at maturity, panicle length and 1000 grain weight showed moderate estimates of PCV and GCV. Low level of PCV values were observed for days to 50% flowering. High heritability coupled with high genetic advance was recorded for plant height at tip of leaf, plant height at maturity, spikelet sterility, number of filled grains panicle^{-1}, number of spikelets panicle^{-1} and harvest index. Results suggest that these traits are primarily under genetic control and selection for these traits can be achieved through their phenotypic performance. High heritability estimates with low genetic advance observed for grain weight panicle^{-1}, total number of tillers plant^{-1}, number of productive tillers plant^{-1}, panicle length, grain yield plant^{-1}, straw yield plant^{-1} and 1000 grain weight indicated that genotype × environment interaction played a significant role in the expression of these traits. The expected genetic advance expressed as percentage of mean, varied from 17.16 to 124.37. In this study, traits that exhibited high genotypic coefficient of variation like spikelet sterility (%) and grain yield plant^{-1} also gave high genetic advance as percentage of mean (GA %) in kharif season 2014. Studies on correlation and path-coefficient analysis revealed that biological yield plant^{-1}, harvest index and panicle length exhibited maximum positive direct effect on grain yield. Hence, importance should be given to these characters during selection for single plant yield improvement.

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Genetic variability and percentage change for morphological, physiological, biochemical and root characters was estimated under reproductive stage moisture stress in polythene tube. Moisture stress given at reproductive stage of rice crop brings about drastic reduction in the all the yield contributing traits. Early maturity is an important drought escaping mechanism observed in the varieties Karutha Modan, Arimodan, Harsha, Thottacheeera and Kalladiaryan. Out of these Thottaacheera and Kalladiaryan were less affected by moisture stress as is evidenced by the low percentage change for the traits productive tillers plant^{-1}, panicle length, number of filled grains panicle^{-1}, number of spikelets panicle^{-1}, spikelet sterility, grain weight panicle^{-1}, 1000 grain weight, grain yield plant^{-1} and harvest index under stress. Vyttila 6 exhibited less pronounced percentage change for spikelet sterility, 1000 grain weight and straw yield plant^{-1} under imposed drought. Swarnaprabha exhibited low percentage change for panicle length, number of spikelets panicle^{-1}, number of filled grains panicle-1, grain weight panicle^{-1}, grain yield plant^{-1} and harvest index under moisture stress. Vaishak exhibited low percentage change for plant height, grain weight panicle^{-1}, spikelet sterility, 1000 grain weight, grain yield plant^{-1} and harvest index under stress. Harsha exhibited low percentage change for productive tillers plant^{-1}, 1000 grain weight and harvest index under imposed drought. The varieties *viz.* , Thottacheera, Kalladiaryan, Swarnaprabha and Vaishak exhibited drought tolerance in this study in the sense that yield reduction due to moisture stress was the least in these varieties. The varieties Kanchana, Aiswarya and Harsha were considerably affected by drought whereas the varieties Katta Modan and Chuvanna Modan were less affected. In general the local upland varieties *viz* Thottacheera, Kalladiaryan, Karuthadukkan and Parambuvattan were less affected by induced stress as is revealed by the low percentage variation in their mean values for yield attributing traits. This percentage change was high in Kanchana, Aathira, Uma and Harsha showing that they were seriously affected by moisture stress.

Delay in flowering was observed in all the varieties under stress condition. The osmotic potential traits were severly affected under moisture stress condition.

The highest percentage decrease was found in Aiswarya and Harsha for the trait water use efficiency. All the genotypes were severly affected due to drought for water use efficiency.

Generally proline content increased tremendously under stress condition. Thottacheera exhibited tremendous production of proline under protected condition. In general a reduction in growth indices such as leaf area index, relative growth rate and net assimilation rate was observed in the varieties studied under reproductive stage moisture stress. Vyttila 6 had the highest reduction in relative growth rate under protected condition but it did not affect the yield. Kalladiaryan, Vyttila 2, Thottacheera, Vyttila 6, Kanakom and Swarnaprabha showed consistently efficient water use under both control and moisture stress. Percentage decrease in RLWC due to moisture stress was less pronounced in Arimodan, Chuvanna Modan, Karutha Modan and Uma. Increase in proline content was less pronounced for Harsha, Karutha Modan and Arimodan. The increase was pronounced in Thottacheera, Karuthadukkan Aathira and Kanakom. Cell membrane stability index was less affected by moisture stress in Karuthadukkan, Parambuvattan, Vyttila 2, Harsha and Vaishak whereas it was greatly affected in Chuvanna Modan, Arimodan and Prathyasha. Vaishak recorded the highest reduction in chlorophyll a, chlorophyll b, total chlorophyll and carotenoides content, transpiration rate and stomatal conductance under imposed moisture stress. Karuthadukkan had the highest chlorophyll content under protected condition. Karutha Modan and Vyttila 6 had high chlorophyll a contents whereas it was low in Vaishak followed by Arimodan under drought. Highest chlorophyll b content was observed in Chuvanna Modan and Jyothi and lowest in Vaishak followed by Kanakom under drought. Maximum total chlorophyll content was recorded in Karutha Modan and Jyothi and minimum was recorded in Vaishak followed by Kanakom under drought. Lowest carotenide content was recorded in Swarnaprabha under drought whereas Kanchana and Swarnaprabha recorded lowest value under imposed moisture stress condition. Significant differences were noticed for chlorophyll stability index. The highest chlorophyll stability index was recorded in Karuthadukkan followed by Karutha

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Modan, Jyothi and Vyttila 6. The lowest chlorophyll stability index was recorded in Vaishak. This percentage change was highest in Vyttila 2 and lowest in Kanakom followed by Aiswarya, Harsha and Vaishak for leaf temperature. Percentage decrease in transpiration rate due to moisture stress was less pronounced in Swarnaprabha, Kalladiaryan and Prathyasha for transpiration rate. Percentage decrease in stomatal conductance due to moisture stress was less pronounced in Kalladiaryan, Vyttila 2 and Prathyasha. Percentage decrease in stomatal conductance was the highest in Kattamodan and Harsha and low in Vyttila 2 under drought. Percentage decrease in radiation use efficiency due to moisture stress was less pronounced in Thottacheera, Kalladiaryan and Vyttila 6 and more pronounced in Kanchana and Aiswarya among varieties studied. Percentage decrease in chlorophyll meter reading due to moisture stress was less pronounced in Swarnaprabha, Chuvanna Modan and Arimodan and more pronounced in Prathyasha, Aathira and Uma. Local upland varieties showed moderate reduction in chlorophyll meter reading *viz.,* Thottacheera, Kalladiaryan, Karuthadukkan and Parambuvattan. Percentage decrease in leaf area index due to moisture stress was less pronounced in Vaishak and more pronounced in Arimodan. Percentage decrease in relative growth rate due to moisture stress was less pronounced in Harsha and Aiswarya whereas it was more pronounced in Jyothi. The varieties Aathira, Kanakom and Parambuvattan were not affected by drought in terms of their relative growth from panicle initiation to harvesting stage but conversion of source into sink was low. Percentage decrease in net assimilation rate due to moisture stress was less pronounced in Uma (MO 16), Thottacheera and Jyothi whereas it was more pronounced in Karuthadukkan. Most of the varieties showed increase in carbon isotope discrimination while decrease in carbon isotope discrimination under stress condition was observed in Jyothi, Uma, Prathyasha and Arimodan. This shows that these varieties are having high water use efficiency. Percentage decrease in carbon isotope discrimination due to moisture stress was less pronounced in Vaishak, Jyothi, Prathyasha, Arimodan and Aiswarya. The varieties Swarnaprabha, Kanakom and Jyothi took maximum days to reach critical stress level whereas Chuvanna Modan and Kanchana took minimum days to reach critical stress level.

Percentage increase in root depth due to moisture stress was more pronounced in Uma, Vaishak, Karuthadukkan, and Harsha whereas it was less pronounced in Jyothi and Swarnaprabha. Percentage increase in root volume due to moisture stress was more pronounced in Chuvanna Modan, Karuthadukkan and Prathyasha and was less pronounced in Arimodan whereas decreased root volume was observed in Uma and Harsha. Percentage increase in root dry weight was more pronounced in Vyttila 6 and Chuvanna Modan and was less pronounced in Karuthadukkan due to moisture stress at reproductive stage of crop. Highest percentage decrease in root dry weight was observed in Swarnaprabha and Jyothi due to moisture stress. Highest percentage increase in deep root-shoot ratio was recorded in Kanakom and lowest percentage variation in Swarnaprabha (PTB 43).

Selection indices were worked out for the twenty genotypes on the basis of yield and eight component characters *viz*., panicle length, number of spikelets panicle^{-1}, grain weight panicle^{-1}, 1000 grain weight, and straw yield plant^{-1}, biological yield plant^{-1} and harvest index. Final ranking was done by considering all physiological, biochemical and root characters also. Based on this ranking, the genotypes Vaishak, Thottacheera, Kalladiaryan, Vyttila 6, Harsha and Swarnaprabha were selected as parents for hybridization programme.

The six parents and their fifteen hybrids were evaluated in a Randomized Block Design with three replications during Virripu, 2015. Highly significant differences were reported among genotypes for all the morphological, physiological and biochemical characters studied. Among the parents and among the crosses there were significant differences for water use efficiency, relative leaf water content, proline content, cell membrane stability index, chlorophyll content, chlorophyll stability index, leaf temperature, transpiration rate, stomatal conductance, leaf soluble protein content, chlorophyll meter reading, leaf area index, carbon isotope discrimination and number of days taken for reaching critical stress level whereas it was non-significant for radiation use efficiency, relative growth rate and net assimilation rate. On further analysis there were no significant differences among the parents for the trait chlorophyll meter reading,

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leaf area index and carbon isotope discrimination for general combining ability while for specific combining ability all traits were significant. Estimates of σ^2*gca* and σ^2*sca* suggest that non-additive component of heritable variation is many times larger than the additive components for all the morphological, physiological and biochemical traits in rainfed upland rice. The general combining ability effects represent the additive nature of gene action. A high general combiner parent is characterized by its better breeding value when crossed with a number of other parents. Based on *gca* estimates, it was observed that parent Vaishak was the best combiner for panicle length, number of spikelets panicle^{-1}, spikelet sterility, total chlorophyll content, leaf temperature and number of days taken for reaching critical stress level and also good combiner for number of filled grains panicle^{-1}, proline content, cell membrane stability index, chlorophyll a, chlorophyll b, total chlorophyll content, leaf temperature, transpiration rate, leaf soluble protein content and number of days for reaching critical stress level. Thottacheera was a good general combiner for days to 50 % flowering, total chlorophyll content and leaf temperature. Kalladiaryan showed good general combining ability for number of productive tillers plant^{-1}, straw yield plant^{-1}, proline content, chlorophyll b content and total chlorophyll content. Vyttila 6 was the best combiner for plant height at maturity which had negative significant *gca* effects which will be helpful for the development of semi-dwarf variety. It showed best combining ability for number of filled grains panicle^{-1}, grain weight panicle^{-1}, 1000 grain weight, grain yield plant^{-1} and straw yield plant^{-1} in desirable positive direction and was also a good combiner for number of spikelets panicle. $^{-1}$ Vyttila 6 was the best general combiner for physiological and biochemical traits such as water use efficiency, relative leaf water content, proline content, cell membrane stability index, chlorophyll *a* content, carotenoides content, leaf temperature, transpiration rate, stomatal conductance, leaf soluble protein content and good combiner for total chlorophyll content and number of days taken reaching critical stress level. The parent Harsha was a good general combiner for plant height at maturity, 1000 grain weight and grain weight panicle^{-1} while

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parent Swarnaprabha showed good general combining ability for number of days taken for reaching critical stress level.

Early flowering is particularly important in drought breeding since it provides a drought escaping mechanism. Twelve hybrids showed significant specific combining ability for the trait days to 50 % flowering. Out of these, nine hybrids had significant heterobeltiosis for earliness. These hybrids can be projected as the best hybrids for earliness.

In the present study, estimates of $\sigma^2 gca$ and $\sigma^2 sca$ showed that $\sigma^2 sca$ was higher for all characters studied. Hence non-additive component of heritable variation is many times larger than the additive component for all the morphological, physiological and biochemical traits in upland rice. The preponderance of non additive gene action in the inheritance denotes that heterosis breeding will be rewarding for the improvement of these traits.

Number of productive tillers plant^{-1} is one of the major parameters contributing for grain yield plant^{-1} and this trait is affected by several factors such as edaphic and climatic. Five hybrids showed significant high *sca* effects and significant positive heterobeltiosis for this trait. Plant height is an important growth parameter from productivity and crop management point of view. Two hybrids exhibited significant negative *sca* effects and significant heterobeltiosis in the desired direction for this trait. Panicle length is an important parameter for increasing grain yield in rice. Four hybrids exhibited significant *sca* effects and significant heterobeltiosis in the desired direction for this character. Number of spikelets panicle^{-1} is an important parameter for increasing grain yield in rice. Four hybrids exhibited significant *sca* effects and significant heterobeltiosis in the desired direction for this character. Spikelet sterility is mostly affected by environmental factors. Only one hybrid exhibited significant *sca* effects. None of the hybrids showed heterobeltiosis in the desired direction. Number of filled grains panicle^{-1} is a yield related trait in rice. Only one hybrid exhibited significant *sca* effects. None of the hybrids exhibited heterobeltiosis in the desired direction. For grain weight panicle^{-1}, only one hybrid exhibited significant *sca* effects. None of the hybrids exhibited heterobeltiosis in the

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desired direction. For the character 1000 grain weight, four hybrids exhibited significant *sca* effects and two hybrids exhibited significant heterobeltiosis. For grain yield plant^{-1}, two hybrids exhibited significant *sca* effects and four hybrids exhibited heterobeltiosis. For straw yield plant^{-1}, three hybrids exhibited significant *sca* effects and one hybrid exhibited significant heterobeltiosis. Harvest index is a very important trait for improving grain yield. Three hybrids exhibited significant heterobeltiosis for harvest index. For the trait water use efficiency, four hybrids exhibited significant *sca* effects and seven hybrids exhibited heterobeltiosis. For proline content, four hybrids exhibited significant *sca* effects and one hybrid showed significant heterobeltiosis. Cell membrane stability index is one of the important traits attributing drought avoidance mechanism. This trait is very crucial for determining the stress tolerant hybrid. Five hybrids exhibited significant *sca* effects and three hybrids exhibited significant heterobeltiosis for cell membrane stability index in rice. For chlorophyll a content in upland rice, seven hybrids exhibited significant *sca* effects. For chlorophyll b content, six hybrids exhibited significant *sca* effects and two hybrids exhibited significant heterobeltiosis in the desired direction. For the character carotenoide content, five hybrids exhibited significant *sca* effects and two hybrids exhibited significant positive heterobeltiosis. For total chlorophyll content, six hybrids exhibited significant *sca* effects and three hybrids exhibited significant heterobeltiosis. With respect to chlorophyll stability index, nine hybrids exhibited significant *sca* effects and two hybrids exhibited significant heterobeltiosis. Non additive gene action was more important for the character. For leaf temperature, four hybrids exhibited significant *sca* effects and three hybrids exhibited significant heterobeltiosis. Non additive gene action was indicated. Transpiration rate is an important trait related to drought tolerance. Eleven hybrids exhibited significant *sca* effects and twelve hybrids exhibited significant heterobeltiosis for transpiration rate. For stomatal conductance, six hybrids exhibited significant *sca* effects and three hybrids exhibited significant heterobeltiosis. For protein content three hybrids exhibited significant *sca* effects and one hybrid exhibited significant heterobeltiosis. For chlorophyll meter

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reading, two hybrids exhibited significant *sca* effects and three hybrids exhibited significant heterobeltiosis. For leaf area index, three hybrids exhibited significant *sca* effects and one hybrid exhibited significant heterobeltiosis. For the character net assimilation rate, two hybrids exhibited significant heterobeltiosis in upland rice. For carbon isotope discrimination two hybrids exhibited significant *sca* effects and one hybrid exhibited significant heterobeltiosis. Seven hybrids exhibited significant *sca* effects and six hybrids exhibited significant heterobeltiosis for number of days taken for reaching critical stress level.

The polymerase chain reaction of six parents and their best five progenies was carried out with three SSR primers linked with respective quantitative traits. In the present study parents Vaishak, Kalladiaryan, Vyttila 6 and Harsha and hybrids Vyttila 6 x Swarnaprabha and Vyttila 6 x Harsha produced a product at 199 bp confirming drought resistance through osmotic adjustment in these genotypes. Phenotypically also the highest relative leaf water content was observed in Vyttila 6 which conforms to the results of molecular analysis. Both the hybrids with Vyttila 6 as the female parent also showed drought resistance through osmotic adjustment. Cell membrane stability index is also related to osmotic adjustment. Phenotypically also the parents Vaishak, Vyttila 6 and Harsha showed high cell membrane stability index which is expected from their performance at molecular level using primer RM 263. The primer RM 451 was reported to be linked to drought tolerance through various morphological traits. All the selected parents and the best hybrids produced PCR product at 207 bp with primer RM 451 and all were giving high grain yield inspite of drought. This confirms that drought tolerance of the genotypes under study is through various morphological traits.

Field evaluation of F_2 segregating populations obtained from the five best F_1 combinations along with their parents was done in the target environment. Parents and F_2 populations showed significant differences among themselves for days to 50 percent flowering. All hybrids showed significant increase over the best parents for number of productive tillers plant^{-1}. Kalladiaryan produced the

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highest number of productive tillers among parents and Vyttila 6 x Swarnaprabha among F_2.

Filled grains panicle^{-1} varied widely among the F_2 populations as compared to parents. Spikelet sterility percentage was significantly high among the F_2 as compared to the parents which were on par with each other. The parents and hybrids were significantly different from each other for the trait grain weight panicle^{-1}. The F_2 segregants showed much variation among each other for the trait whereas the parental varieties were more stable for the trait. Among the parents Vaishak exhibited heaviest panicle weight whereas Thottacheera showed the lightest. Considering parents and F_2 populations together the lightest grain weight panicle^{-1} was recorded by Vaishak x Kalladiaryan whereas heaviest grain weight was in Vyttila 6 x Swarnaprabha. 1000 grain weight ranged from Thottacheera being the lowest to Vaishak being the highest. Kalladiaryan and Swarnaprabha were on par with Thottacheera. Among the F_2 segregating populations, the highest mean was recorded by Vyttila 6 x Harsha. The lowest value was obtained for Vaishak x Kalladiaryan which was on par with Vaishak x Swarnaprabha. The F_2 progenies were significantly higher than their parents for grain yield plant^{-1}. Among the parents Vyttila 6 recorded the highest mean value followed Kalladiaryan whereas the lowest mean value was obtained for Thottacheera. In the F_2 populations grain yield varied from Vaishak x Kalladiaryan to Vyttila 6 x Harsha being the highest. Grain yield of F_2 plants of the cross Vaishak x Swarnaprabha was on par with Vaishak x Kalladiaryan. Straw yield plant^{-1} was generally high in the F_2 as compared to the parents. Among the parental varieties Vyttila 6 recorded the highest mean for harvest index closely followed by Kalladiaryan whereas the lowest harvest index was obtained for Thottacheera. In the F_2 populations highest mean was recorded by Vyttila 6 x Harsha which was significantly superior to all other hybrids and parents. The second was Vyttila 6 x Swarnaprabha for this trait, while the lowest mean value was recorded by Vaishak x Kalladiaryan.

Phenotypic variance, genotypic variance and coefficients of variation, heritability and genetic advance for 12 traits in six parents and 5 best F_2 segregants in rice were studied.

Among the different characters studied, the highest genotypic and phenotypic coefficients of variation was observed for spikelet sterility per cent followed by grain yield plant^{-1}, number of productive tillers plant^{-1}, straw yield plant^{-1} and grain weight panicle^{-1}. Moderate levels of coefficients of variation were observed for number of spikelets panicle^{-1}, filled grains panicle^{-1}, harvest index, panicle length and plant height at maturity. The lowest genotypic and phenotypic coefficients of variation was observed for days to 50 percent flowering and 1000 grain weight.

High heritability in the broad sense was observed for all the studied characters. High heritability coupled with high genetic advance was recorded for number of spikelets panicle^{-1}, number of filled grains panicle^{-1} and plant height at maturity.

Moderate level of genetic advance was recorded for the traits *viz.* , spikelet sterility, days to 50 percent flowering, grain yield plant^{-1}, harvest index and number of productive tillers per plant. Genetic advance for the traits grain weight per panicle, 1000 grain weight, panicle length and straw yield plant^{-1} was found to be low even through their heritability estimates were high.

Discriminant function technique was adopted for the construction of a selection index using grain yield and morphological characters for the 5 best F_2 segregants and their parents characters of importance from the breeding point of view *viz.,* productive tillers plant^{-1}, panicle length, number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, grain weight panicle^{-1}, 1000 grain weight, straw yield plant^{-1} and harvest index were considered in the construction of the index.

The selection index score was computed and the parents and F_2 populations of their crosses were ranked accordingly. The first position was occupied by the F_2 segregant Vyttila 6 x Harsha followed by Vyttila 6 x Swarnaprabha, Vaishak x Thottacheera and Vaishak x Swarnaprabha. The fifth and sixth positions were occupied by their parents *viz.*, Vyttila 6 and Vaishak.

Vaishak x Kalladiaryan occupied the seventh position. The parents Kalladiaryan, Harsha, Swarnaprabha and Thottacheera in that order occupied the last positions.

Future line of work

The segregants Vaishak x Swarnaprabha, Vaishak x Thottacheera and Vaishak x Kalladiaryan were early maturing segregants play an important mechanism for the drought escape. Drought escaping and drought tolerance mechanism attributed by these segregants. These segregants will be very useful for the development of drought resistant variety under upland condition. The F_2 segregants Vyttila 6 x Harsha, Vyttila 6 x Swarnaprabha, Vaishak x Thottacheera, Vaishak x Swarnaprabha and Vaishak x Kalladiaryan were deviating from parental limit positive and negative direction in these segregants indicating the possibility of identifying desirable recombinants with high yield and drought tolerance which can be further utilized for developing superior varieties. Vyttila 6 x Harsha and Vyttila 6 x Swarnaprabha exhibited superior performance for the trait grain yield plant and water use efficiency. These hybrids adopting drought tolerance mechanism.

It can be concluded that the five superior segregants identified in this study may be carried forward by pedigree method for developing high yielding and drought resistant varieties.

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*Originals not seen

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GENETIC ANALYSIS OF DROUGHT TOLERANCE IN RICE
(*Oryza sativa* L.)

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(2013 - 21 - 117)

ABSTRACT

of the thesis submitted in partial fulfilment of
the requirements for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF PLANT BREEDING AND GENETICS

COLLEGE OF AGRICULTURE

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2017

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ABSTRACT

The research work entitled "Genetic analysis of drought tolerance in rice (*Oryza sativa* L.)" was carried out in the Department of Plant Breeding and Genetics College of Agriculture,Vellayani, Thiruvananthapuram during the period 2014 – 2016. The study aimed at estimating the nature and magnitude of gene effects in the inheritance of drought tolerance in rice under upland conditions. Screening of the selected parents and superior progenies for the presence of molecular markers associated with drought tolerance was envisaged.

Twenty diverse genotypes including varieties recommended for uplands and popular high yielding varieties widely cultivated in the state were screened for drought tolerance under rainfed upland condition during May to October, 2014. Morphological observations were taken at appropriate plant growth stages following the Standard Evaluation System for Rice [IRRI, 1996]. The screening of genotypes was done as per the protocols of DRR (2012). The rice genotypes were further screened for drought tolerance imposing reproductive stage moisture stress under protected condition.

The data from rainfed and protected condition screening were utilized for the development of a selection index based on which the genotypes were ranked. The six top ranking genotypes with high yield and drought tolerance *viz.,* Vaishak, Thottacheera, Kalladiaryan, Vyttila 6, Harsha and Swarnaprabha were hybridized in half diallel pattern. The 15 F_1 hybrids were evaluated along with their parents under rainfed situation to select the top five heterotic hybrids which were carried forward to F_2.

In all populations studied, qualitative traits related to drought such as nature of panicle exsertion (DRR, 2004) and scoring for leaf rolling (IRRI, 1991) were analysed. Degree of panicle exsertion has a direct bearing on spikelet sterility. Leaf rolling is a tricky character where the breeder has to strike a balance between the onset, intensity and duration of rolling as well as the recovery from rolling when moisture is provided. This is because leaf rolling reduces transpiration loss at the expense of photosynthate production. Mild incidence of

insect pests *viz.*, gandhi bug and leaf folder and diseases *viz.*, brown spot, blast and bacterial leaf blight was observed in the field experiments. The variety Swarnaprabha had good cooking quality. Kanchana had excellent milling recovery and good cooking quality with high volume expansion on cooking and comparatively high protein content. Prathyasha had high nutrient content and good cooking quality. Aathira possessed excellent milling recovery and cooking quality. Parambuvattan had appreciable quality and is preferred for certain special preparations. The traditional upland varieties *viz.*, Katta Modan, Karutha Modan and Chuvana Modan had superior milling recovery.

High PCV and GCV values were observed for yield related characters such as filled grains panicle^{-1}, grain yield plant^{-1}, harvest index etc. Based on the studies on correlation and path coefficient analysis, biological yield plant^{-1}, harvest index and panicle length exhibited maximum positive direct effect on grain yield.

Vaishak was the best combiner for panicle length, number of spikelets panicle^{-1}, spikelet fertility, total chlorophyll content, leaf temperature and good combiner for number of filled grains panicle^{-1}, proline content, cell membrane stability index, chlorophyll a, chlorophyll b, total chlorophyll content, leaf temperature, transpiration rate, leaf soluble protein content and number of days for reaching critical stress level. Thottacheera was a good general combiner for days to 50 % flowering, total chlorophyll content and leaf temperature. Kalladiaryan showed good general combining ability for number of productive tillers plant^{-1}, straw yield plant^{-1}, proline content, chlorophyll b content and total chlorophyll content. Vyttila 6 was the best combiner for plant height at maturity and also for physiological and biochemical traits such as water use efficiency, relative leaf water content, proline content, cell membrane stability index, chlorophyll *a* content, carotenoides content, leaf temperature, transpiration rate, stomatal conductance, leaf soluble protein content and good combiner for total chlorophyll content and number of days taken for reaching critical stress level. Harsha was a good general combiner for short stature at maturity, 1000 grain weight and grain weight panicle^{-1} while parent Swarnaprabha showed good general combining ability for number of days taken for reaching critical stress level. Considering the preponderance of non additive gene action for most of the characters and *gca* and *sca* variances it can be concluded that heterosis breeding would yield better results. The hybrids Vyttila 6 x Harsha, Vyttila 6 x Swarnaprabha and Vaishak x Thottacheera exhibited highest heterosis for grain yield under upland condition.

Six parents and their best hybrids were subjected to molecular analysis using three SSR markers linked to quantitative traits. The allele linked to the respective trait was present in all the hybrids, as in the parent with resistance to drought.

Transgressive segregants for yield and yield attributing traits were observed in the F_2. The F_2 segregants Vaishak x Swarnaprabha, Vaishak x Thottacheera and Vaishak x Kalladiaryan were early maturing, playing an important role in the mechanism for drought escape. Drought tolerance mechanism can also be attributed to these segregants. These types will be valuable for the development of early maturing drought tolerant upland varieties. . The hybrids Vyttila 6 x Harsha and Vyttila 6 x Swarnaprabha ranked best for grain yield plant^{-1}. Drought resistance was conferred to these hybrids *via.* , root length and osmotic adjustment traits and the hybrids had various yield attributing traits also , which was further confirmed by trait specific SSR markers.

Desirable F_2 segregants from the combinations Vaishak x Swarnaprabha, Vaishak x Thottacheera and Vaishak x Kalladiaryan may be carried forward further for the development of drought escaping early maturing upland varieties with high grain yield. The combinations Vyttila 6 x Harsha and Vyttila 6 x Swarnaprabha can be carried forward further for the development of drought tolerant upland varieties with high grain yield.