IDENTIFICATION OF PHYSIOLOGICAL AND BIOCHEMICAL PUTATIVE TRAITS AND MANAGEMENT OPTIONS RELATED TO DROUGHT RESISTANCE IN RICE

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(PLANT PHYSIOLOGY)

By

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THESIS ADVISOR: **Dr. M. KAR**

Dedicated
To my
Beloved Parents

DEPARTMENT OF PLANT PHYSIOLOGY
COLLEGE OF AGRICULTURE
ORISSA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

Dr. M. Kar, Ph.D., IARI
Professor.

Bhubaneswar
Dated:

CERTIFICATE - I

This is to certify that the thesis entitled **"IDENTIFICATION OF PHYSIOLOGICAL AND BIOCHEMICAL PUTATIVE TRAITS AND MANAGEMENT OPTIONS RELATED TO DROUGHT RESISTANCE IN RICE"** submitted by **BAIDYANATH PATRA** to the Orissa University of Agriculture and Technology, Bhubaneswar in partial fulfillment of the requirements for the award of the degree of **MASTER OF SCIENCE IN AGRICULTURE (PLANT PHYSIOLOGY)** is a faithful record of *bona fide* research work carried out under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma or published in any other form. The assistance and help received during the course of investigation have been duly acknowledged.

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(Dr. M. Kar)
Chairman
Advisory Committee

CERTIFICATE - II

This is to certify that the thesis entitled **“IDENTIFICATION OF PHYSIOLOGICAL AND BIOCHEMICAL PUTATIVE TRAITS AND MANAGEMENT OPTIONS RELATED TO DROUGHT RESISTANCE IN RICE”** submitted by **BAIDYANATH PATRA** to the Orissa University of Agriculture and Technology, Bhubaneswar in partial fulfillment of the requirements for degree of **MASTER OF SCIENCE IN AGRICULTURE (PLANT PHYSIOLOGY),** has been approved by the Student’s Advisory Committee after oral examination on the same in collaboration with an External Examiner.

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ABSTRACT

A series of experiments were conducted during *Rabi* season of 2010-11 in the Central Farm, Orissa University of Agriculture and Technology, Bhubaneswar to identify the physiological and biochemical putative traits and management options related to drought resistance in rice. The present study was attempted to screen 6 number of rice varieties for their higher productivity under moisture stress conditions using drought mitigating chemicals. Six varieties namely, Parijat, Sidhanta, Mandakini, Lalat, Manaswini, and Konark were grown in randomised block design replicated thrice with three treatments such as S_0 (Control), S_1 (Stress at PI stage) and S_2 (stress with application of salicylic acid @ 100 ppm at PI).

It was revealed from the experiment that significant reduction was observed in plant height (29 %), tillers hill^{-1} (35 %) and leaf area (35 %) in response to moisture stress at PI stage. Application of salicylic acid reduced the impact of drought on plant height, tillers hill^{-1} and leaf area. Resistance varieties namely Lalat, Mandakini and Parijat exhibited less reduction of such above character in comparison to other varieties in stress condition. Significant decrease in accumulated biomass was observed on account of moisture deficit .The decrease was more pronounced in Sidhanta compared to tolerant variety Mandakini. Significant reduction in LMRI was recorded by imposing water stress but application of salicylic acid reduced the impact of stress.

Total chlorophyll and chlorophyll stability index decreased on account of drought stress. The decrease was lower in Lalat and Parijat than other varieties.MSI % was highest in variety Lalat followed by Parijat, Mandakini and Konark the least (20.7%). Proline accumulation increased when the plants were exposed to moisture stress. Among the varieties proline accumulation was highest (436.4 μg) in Lalat followed by Parijat (430.8 μg) and minimum with Sidhant (456 μg).Catalase and SOD activities increased with severity of stress .The yield attributing characters such as number of effective tillers per hill, number of matured grains per panicle, 1000-grain weight, fertility %, harvesting index, significantly decreased due to moisture stress. The reduction of yield due to stress was 33 % and stress + SA 21.4 % as compared to control. In view of the present findings, varieties like Lalat followed by Mandakini were found to be more resistant to drought and Konark was most susceptible one.

CONTENTS

CHAPTER - I

Introduction

INTRODUCTION

Rice is the world's most important staple food crop, which not only provides food but also influences traditions, religions, culture and life style since Vedic period. 'Rice is life' truly lives up to its meaning in India, where its origin dates back to as long ago as 2500BC.In this vast country, rice is a staple food for more than half of its billion plus population and a source of livelihood for more than 50 million households.Apart from its economic and strategic importance,rice is deeply engraved in the rich Indian tradition and culture(Mohanty 2009). Especially in Asian subcontinent 90 per cent of world's rice is grown and consumed with 60 per cent of population and where, about two-thirds of world's poor live (Khush and Virk, 2000). Only 4-5 per cent of world rice production enters the global market. Hence, any shortfall in rice production in the major rice growing countries could be disaster for food security.

Rice is grown over an area of 161.4 m. ha with production of 678.7 m.t. in the world (Anon, 2010).Out of the total rice grown area about 130 m.ha belongs to Asian subcontinent with a production of 533m.tons (Anon,2010;FAO stat.). About 45 per cent of rice area is under rainfed environment, which is mainly distributed in South and South-east Asia (Wade, 1999). But, it accounts for only 25 per cent of rice production. Drought stress is the major constraint to rice production and yield stability in the rainfed regions, affecting 19 m ha of upland and over 14 m ha of rainfed lowland rice (Pandey *et al*., 2000).

In India, rice is cultivated on an area of 41.8 m. ha with production of 89.1 m. tons. (Anon, 2010; Agril.stat at a glance), where in state Orissa contributes 4.45 m. t. of rice production grown over an area of 1.31 m. ha with an average yield of 2.7 t/ha (Anon., 2009). Rice occupies pivotal role in Indian agriculture. It is the staple food for more than 70 per cent Indians and source of livelihood for 120-150 million rural households. It contributes 43 per cent to the total food grain and 53 per cent to the cereal production, and thus holds the key to sustain food sufficiency in the country (Siddiq *et al.,* 2004). Fifty four per cent of total rice area in India is under rainfed condition distributed mainly in North-East India, North India, Central-Western India, and Eastern India and partly in other regions. Average productivity of rainfed rice is 0.8 to 1.2 t/ha under different situations which is much lower compared to irrigated rice (2.9 t/ha) (Das, 2006). Rice yields are poor in rainfed situations mainly due to erratic rainfall and drought stress (Singh, 2006).

Constraints to rice production are many, but predominant is moisture stress, as more than 70 % of the rice grown in India is rainfed and such rainfed dryland occupying 6.0 million hectares. Productivity of rice is as low as around 60-75 % lower than in irrigated conditions (Rao and Venkateswarlu, 1998). The rainfed rice is most prone to water stress. Rains during the growing season are often erratic and its distribution is highly uneven, as a result the crop faces moisture stress of different types and intensities. Moisture stress frequently occurs, either at one or more phenological stage of the upland rice crop raised under rainfed condition. From the meteorological study of India, it is imminent that the country faces a drought almost every three years and the most affected is the rice crop, owing to its requirement of wetland ecosystem in general.

Rainfed rice is practically affected by drought in every aspects of its ontogeny modifying the anatomy, morphology, physiology and biochemistry. Drought tolerance is a complex trait involving several interacting physiological, phenological and morphological mechanisms for escape, avoidance, resistance and recovery. The ability to design a plant ideotype for drought prone environments depends on the available database on the physiology of crop plant, the nature of its environment and the interaction between the plant and the environment (Fukai and Cooper, 1995).

There are large numbers of morphological, physiological biochemical traits associated with plants growing naturally in arid environment, that it is believed to confer drought resistance on these plants. Identification of these traits is necessary to incorporate such desirable traits in the breeding programme (Baruah *et al.,* 1998). Although the ability to tolerate drought and have acceptable yields is limited among cultivars within a species, there are considerable differences among cultivars that allow them to avoid drought. Drought may be avoided by matching crop phenology with periods during the cropping season when water supply is abundant. This approach has been an effective tool for crops grown in monsoonal climates where they are sown at the beginning of wet season and mature before dry season (Purcell *et al.,* 2003). But the strategy often fails owing to the erratic monsoon during these days.

Adaptation or acclimation to adverse habitat, edaphic or environmental, is a common feature of plant. These adaptations are achieved through varied molecular, cellular, biochemical, physiological, anatomical and morphological modifications in plants (Paleg and Aspinall, 1981; Bohnert *et al*., 1995). The rice plant responds to the moisture deficit conditions in various ways. Although drought is a major problem for rice grown under rainfed lowland

and upland conditions, progress in breeding to improve drought resistance has been slow. To provide a basis for integrating physiological research with plant breeding objectives, drought resistance is defined in terms of relative yield of genotypes. Thus, a drought resistant genotype will be one, which has a higher grain yield than others, when all genotypes are exposed to the same level of water stress. A major reason for the slow progress in breeding for drought resistance is the complexity of the drought environment, which often results in the lack of clear identification of the target environment(s). Several drought resistance mechanisms and putative traits that contribute to them have been identified, including drought escape *via* appropriate phenology, root characteristics, specific dehydration avoidance and tolerance mechanisms, and drought recovery. Some of these traits have been shown to confer drought resistance and others show potential to do so. The most important is the appropriate phenology, which matches crop growth and development with the water environment. A deep root system with high root length density at depth is useful in extracting water thoroughly in upland conditions, but does not appear to offer much scope for improving drought resistance in rainfed lowland rice where the development of a hard pan may prevent deep root penetration. Under water-limiting environments, genotypes that maintain the highest leaf water potential generally grow best, but it is not known if genotypic variation in leaf water potential is solely caused by root factors. Osmotic adjustment is promising because it can potentially counteract the effects of a rapid decline in tissue water potential and there is a large genetic variation for this trait. There is genotypic variation in expression of green leaf retention which appears to be a ideal character for prolonged droughts, but it is affected by plant size which complicates its use as a selection criterion for drought resistance. It has been contemplated that the general lack of drought related research for rice in rainfed lowland conditions needs to be rectified, particularly considering their importance relative to upland conditions in Asian countries. Accordingly, the focus should be on physiological-genetic research efforts in clearly defined, major target environments (Fukai and Cooper, 1995).

Though attempts have been made by different scientists to study how the plants overcome the impact of stress (on growth and yield reduction) on account of drought or moisture deficit, never the less, there is lot to be understood as to the physiological and biochemical basis of drought tolerance in plants, rice in particular. This study has been taken up with the main objective to have a greater insight into this physiological and biochemical basis of drought tolerance in rice which would come in handy in designing the crop ideotypes for drought prone environments and formulating a strategy to ameliorate the effect of stress suitably so as to minimise the yield loss at times of water deficit.

The present study aims to ransack the response of rice plants to drought with all following objectives.

i) To find out the variation in morpho-physiological and biochemical traits in response to stress.

ii) To screen rice variety for their drought resistance on the basis of photosynthetic efficiency.

iii) To screen the variety on the basis of yield attributing traits.

iv) To assess the effect of some chemicals reducing the impact of drought injury.

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CHAPTER - II

Review of Literature

REVIEW OF LITERATURE

Water scarcity is a severe environmental limitation to crop productivity. Drought induced loss in crop yield may exceeds loses from all other causes, since both the severity and duration of the stress are critical (Farooq *et al.*,2008).A slow pace in revealing drought tolerance mechanism has hampered both traditional breeding efforts and the use of modern genetics approaches in the improvement of drought tolerance of crop plant.

Reviewing the genotypic variation of stress-related traits in rice, described how stress physiology could contribute to breeding programmes that aims to improve yield under drought condition. Fukai and Cooper (1995) listed the traits of rice under following categories; drought escape, drought avoidance and drought tolerance. Several putative traits which confer drought tolerance in rice include Morphological, Physiological, and Biochemical mechanisms.

In retrospect, these features may also cause detrimental effect for yield. So, foliar application of various chemical ameliorant required to nullify the ill effects of water stress on growth and yield of crop.

In this regard, the contributions of earlier researchers on the morpho-physiological and biochemical putative traits of rice during water stress are reviewed and presented under relevant heads as follows.

2.1 MORPHOLOGICAL PARAMETERS

2.1.1 Plant height

It was reported that water deficit significantly reduced plant height (Chauhan *et al.*, 1999) at booting stage coupled with leaf area index. Cultivars with bigger plant size suffered much due to drought more than cultivars with smaller plant size. Significant cultivar variations were observed in terms of capacity to maintain water status, leaf rolling and yield stability under drought (Kumar, 2002). Drought-tolerant genotypes in general were dwarf and had reduced leaf size and reduced number of nodes and internodes (Aswasthi *et al.*, 2001). Pradhan *et al.* (2006) found that plant height decreased remarkably with decrease of irrigation regimes in upland rice varieties. The plant height was observed to be significantly higher in irrigated than dry environments by 22.34 % at tillering, 2.88 % at anthesis, 2.50 % at milk ripe and 4.42 % at harvesting stage (Chandra *et al.*, 2005).

2.1.2 Number of tillers per hill

Tiller production was observed to be sensitive to moisture stress, but not all the tillers produced survived to bear ears, and the tiller death phase was reported to be sensitive to water stress. (Day, 1981). Number of ear bearing tillers and spikelets per spike were higher by 11.59 and 6.97 % in wet than dry environment (Chandra *et al.*, 2005). Cultivars that produced a fewer number of tillers under well-watered conditions were less susceptible to drought than cultivars producing a higher number of tillers (Ichwantoari *et al.*, 1989). In a study conducted on response of some upland rice varieties to varrying soil moisture levels, it was evident that drought tolerant rice cultivar (CR 143-2-2) possessed less number of tillers. While, the less tolerant varieties like Cauvery and Annada produced more number of tillers with the decrease of irrigation regime probably due to restriction of reproductive growth under higher stress conditions (Pradhan *et al.*, 2006).

2.1.3 Leaf drying scores (LDS) and leaf rolling scores (LRS)

Plants subjected to moisture stress at the reproductive and ripening stages showed various stress symptoms. Older leaves died prematurely and the younger leaves and flag leaves wilted.Chang *et al.* (1974) used leaf rolling and leaf death for assessing levels of field tolerance for drought, while O'Toole and Cruz (1979) found that, it could be sufficiently reliable to 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. 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 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). Leaf rolling rate (LRR) differed among rice ecotypes. Under upland conditions, leaves of the japonica types rolled more adaxially and those of *indica* and *Japanese* upland cultivars rolled more abaxially under lowland conditions. The greater the LRR the lower the values of photosynthesis, transpiration and stomatal conductance and the degree of decline differed depending on whether the leaves rolled adaxially or abaxially. The genotypes whose leaves roll abaxially maintain transpiration by the decreased boundary layer resistance under stress. Significant cultivar variations were observed in terms of capacity to maintain water status, leaf rolling and yield stability under drought (Kumar, 2002). An increase in Leaf Rolling Index decreased stomatal conductance and transpiration rate also decreased. Moderate leaf rolling index increased water use efficiency (Jin *et al.*, 2003).

2.1.4 Leaf length & leaf thickness

Das and Kalita.(2010) reported that moisture stress significantly reduce leaf thickness. The lowest leaf thickness was observed in less tolerant one and highest was observed in tolerant genotypes.

2.1.5 Maximum root length & root thickness

Chang ***et al.*** *(1972)* compared root features of several upland and lowland varieties, and determined the relationships of rooting patterns to field reactions to drought. The drought resistant varieties generally had predominantly thick roots, densely formed at the crown, and many deep roots. Moreover, the drought-resistant upland varieties responded to water stress by producing proportionally more thick and long roots.Maximum root length and maximum diameter of thick roots were not always found in the same variety. Dry weight of roots per unit length of row obtained in the wet season did not appear to be associated with drought resistance (Chang *et al.*, 1972)

During stress, water uptake and its use is primarily determined by root density and depth. Thick roots confer drought resistance to water flux and hence, greater capacity of water uptake from deeper soil layers. Constitutively thick and deep roots and production of more root length in response to water stress are drought resistance traits in rice (Sadasivam *et al.*, 2000).

2.1.6 Root volume (cc)/plant

Root volume was negatively associated with damage caused by drought in the reproductive phase (r = -0.85). Root volume was significantly and positively correlated with both root and shoot length (r = 0.87 and 0.68, respectively) and it was suggested that plant height could be a useful selection criterion for drought resistance (IRRI,1990)

2.1.7 Root dry weight

Root dry weight of rice varied significantly across varieties with respect to level of stress. Root weight increased almost linearly with the advancement of plant age in all the varieties. The root dry matter of tolerant variety was increased rapidly from 50 to 75 DAT in mild stress condition in comparison with less tolerant rice variety (Alam *et al.*, 2009)

2.2 PHYSIOLOGICAL PARAMETERS

2.2.1 Total dry matter accumulation per hill (g)

The total dry matter and panicle weight were significantly lower under stressed conditions than well-watered condition, irrespective of the cultivar and the stage at which stress was applied (Chauhan *et al.*, 1999). Relative sink-source ratios, export and transformation percentages of stem and sheath dry matter were higher in the more drought resistant lines (Yang^1 *et al.*, 1995). Drought for two weeks significantly reduced grain yield, grain test weight, nitrogen uptake, and shoot dry matter. Higher root dry matter was observed under drought conditions. The average root dry matter production, however, was similar under both conditions. Drought tolerance was expressed as leaf water potential, wherein dry matter production declined to 50 or 20% of that under flooded conditions. In the experiment, differences in dry matter production were closely correlated with differences in drought avoidance. Yield and dry weight at harvest under continuous drought conditions were closely related (Fujii and Horie, 2001).

Rice varieties with different drought resistance rankings (from susceptible to resistant) were grown in upland field conditions and subjected to drought conditions during the reproductive stage. Dry matter production of the shoot was higher in drought resistant cultivars and lower in sensitive cultivars.

It was suggested that the high dry matter production of those rice cultivars known to be drought resistant under field conditions may be related to an ability to maintain transpiration rate, which is supported by deep root systems (Kobata *et al.*, 1996). Another study revealed that the total dry matter and panicle weight were significantly lower under stressed conditions than that of well watered condition, irrespective of the cultivar and stage at which stress was imposed (Chauhan *et al.*, 1999).

Reduced photosynthetic carbon assimilation vis-a-vis reduced crop dry matter accumulation is a principal effect of soil water deficit in cotton and other crops. In the cotton crop subjected to various levels of water stress Ennahli and Earl (2005) observed that the net CO_2 assimilation rate was significantly decreased with the increase in water deficit.

2.2.2 Root shoot weight ratio

High ratio of root development to shoot growth is essential to total drought resistance under field conditions (Levitt 1980). Such a high ratio of roots to shoots was found in the drought-resistant traditional upland varieties (Chang ***et al.*** 1972)

2.2.3 Root length density

Genotypes showed differences in root-mass density and root-length density at 10-30 cm depths. While those differences were rather small, they were associated with genotypic differences in water extraction from the subsoil, and also with visual estimation of retention of green leaves during a dry period (Pantuwan *et al.*, 1997)Tolerant varieties had thicker roots and higher relative RLD (ratio of RLD in drought-stressed plants to that in control plants) than susceptible under drought stress, and significantly higher root growth recovery after rewatering (Trillana *et al.*, 2001). The extraction rate in the subsoil was positively correlated with the average root length density at the corresponding depth during the latter half of the drought period (Kamoshita *et al.*, 2000). Genotypes with well-developed root systems extracted water too rapidly and experienced severe water stress at flowering. Root pulling resistance, which showed smaller coefficient of variation, was more useful than root mass density in identifying genotypes with large root system (Pantuwan *et al.*, 2002).

The higher yield of dry-sown rice under stress could be related to its significantly higher root length density, higher root-shoot ratio, and more uniform root distribution with respect to soil depth and higher available soil moisture in the root zone during the stress period (Tuong *et al.*, 2002).

2.2.4 Net assimilation rate (NAR)

Ichwantoari *et al.* (1989) stated that NAR in rice crop was found to decrease, when the plants were exposed to moisture stress. Similar results have been obtained by Sahoo. (2007). Higher NAR concomitantly enhanced the carbohydrate status of the plant, which is an adaptive feature of drought resistance ability in rice plants as suggested by Chaturvedi *et al.* (1996).

2.2.5 Crop growth rate (CGR)

Sahoo. (2007) reported that CGR decreases significantly due to moisture stress in all the rice varieties. The earlier stages did not respond significantly but stress at panicle initiation stage resulted in a significant decrease (44-50 %) in the CGR. This corroborates with the results of Chandra *et al.* (2005), who observed reductions to the tune of 24% in CGR at later stages in wheat crop.

2.2.6 Leaf area per hill

Plant and organ size exercises a major control over plant and crop water use. Thus small plants of small leaf area and leaf area index (LAI) use relatively less water and are expected to enter a state of plant water deficit later than large plants of greater LAI. On being subjected to water stress, plants reduce their size and leaf area through stress responsive systems that are not within the domain of the basic genetic control of plant size (Blum, 2000). Leaf expansion is particularly sensitive to water stress. In the experiment there was a reduction in the area of photosynthetic tissue as well as the photosynthesis (Day, 1981). Leaf shedding or production of less leaf area is a common way of reducing water loss. Reduction in total plant leaf surface has been considered one of the most important factors in the survival of some desert plants (Parsons, 1980). Turner and Begg (1978) emphasized that in pasture plants, morphological responses such as the reduction in leaf area, tillering, and root growth were more sensitive to water stress than physiological responses. Green leaf retention is another useful character during prolonged drought. Chaturvedi and Ingram (1988) visualized that drought at flowering reduces effective leaf area and photosynthesis, thus plants have to depend on pre-anthesis reserves which may impart tolerance against internal water deficits.

The leaf area index declined in dryland conditions than irrigated conditions by 54 and 66 %, respectively for dry and wet seasons. This decline in LAI under dryland conditions was due to occurrence of moisture stress especially from flowering onwards in both the seasons (Rao and Venkateswarlu, 1998). Similar reductions in LAI was also recorded in rice crop under moisture stress (Chandra *et al.*, 2005).

In an experiment conducted by Chauhan *et al.* (1999) implicated that water deficit at booting and anthesis significantly decreased effective leaf area. Deka and Baruah (2000) have observed similar reductions in leaf area. The decrease was due to stress induced leaf drying besides leaf senescence. The extent to which water deficit decreases the growth and yield by reducing leaf area depends upon the relationship between expansion rate and tissue water status (Kumar *et al.*, 1994). The mean leaf area of the reduced significantly only at very low soil moisture content in wheat varieties tested (Nagarajan and Rane 2000) and due to drought in *Hippophae rhamnoides* L. (Yang *et al.*, 2005).

Leaf area, relative leaf water content (RLWC) and root and shoot dry weight decreased significantly under stress. Cultivars Iharsal ahu and Maibee II maintained higher RLWC and recorded lower reduction in leaf area and root and shoot dry weight than the other cultivars (Deka, 2000).

Reduction in leaf area by water stress is an important cause of reduced crop yield through reduction in photosynthesis (Rane *et al.*, 2001; Kramer, 1983). The photosynthetic surface of flag leaf area at anthesis was lower under moisture stress (30% ASW) as compared to normally irrigated (60% ASW) controls (Yadav *et al.*, 2001). Leaf growth is frequently found to be sensitive to water deficits. Water deficits may reduce leaf growth to a sufficiently great extent that leaf assimilation rate is hard to maintain. Thus growth decreases as water deficits develop (Sahoo., 2007).

2.2.7 Leaf area duration (LAD)

Leaf area duration (LAD) increased at a faster rate from tillering to anthesis and then it declined towards maturity. The LAD was observed to be significantly lower for the crop in dry environments than in wet environments (Chandra *et al.*, 2005).

2.2.8 Leaf moisture retention index (LMRI)

The rate at which an excised leaf looses water has been related to its ability to lose water under water stress condition in the field.LMRI is an easily measurable physiological traits reflecting leaf turgor maintenance under stress and hence, may be related to drought tolerance of genotypes. This technique is attractive because of its low technological input & simplicity of operation and allows screening large number of genotype in short time.

Sandhu & Lauda (1958) observed that excised plants of drought resistant winter wheat genotype lost water more slowly than less resistant cultivars.

This trait was also found to be heritable and is positively related to yield and drought tolerance (Clark, 1987)

Higher LMRI along with higher relative water content and lower membrane injury under stress appeared to impart drought tolerance in Rice genotype which probably resulted in better survival of these genotype under water stress conditions (Gupta & sharma, 2006).

2.2.9 Photosynthesis and ancillary parameters

(I) Photosynthesis Rate(Pn)

Photosynthesis is the primary source of biomass and grain yield in rice (Teng *et al.*,2004). Photosynthesis has two major components; the stomatal and the non-stomatal. Nonstomatal components include activities of the photosynthetic enzymes and light reactions. Water stress affects both the stomatal and non stomatal components of photosynthesis (Sinha *et al.*, 1982). Initial photosynthetic reduction is due to an increase in plant moisture stress arising from a decrease in the conductance of carbon dioxide through the stomata. It is suggested to relate stomatal conductance to leaf turgor than leaf water potential. The threshold for stomatal closure varies in different field

2.2.8 Leaf moisture retention index (LMRI)

the primary photochemical events in sunflower and soybean (Mohanty and Boyer, 1976). Quantum yield in sunflower was reduced from 0.076 to 0.020, as LWP dropped from -4 to -15 bars. After recovery to a LWP of -5 bars, quantum yield also rose to 0.060. This is followed by a decrease in the activities of enzymes such as RuBPcase and the photochemical activity of the chloroplast. Relief of stress would change the revival capacity of the components determining net photosynthate availability. Moisture stress restricted gas exchange through leaf rolling, reduced stomatal conductance and non stomatal inhibition which became evident only at severe stress levels, leading to reduced assimilation rate (Dingkuhn *et al*., 1989). Son *et al*., (1996) studied photosynthesis as affected by drought injury in rice wherein they reported reduced stomatal conductance of 0.1 sec/cm at -14 bars soil water potential and further concluded that; drought spell affects the transpiration and photosynthetic rate. Few other scientists also reported inhibition of photosynthesis in rice due to moisture stress (Hirasawa *et al*., 1999; Stiller *et al*., 2003). The difference in leaf photosynthesis has been reported in *Oryza* species, wherein *O. glaberrimma* maintained leaf photosynthesis above zero when LWP decreased to -2 Mpa, while in *O. sativa* leaf photosynthesis ceased at -1.6 Mpa indicating *O. sativa* is more sensitive to drought (Furuya *et al*., 1994). However, Yeo *et al*. (1997) reported that, although there were significant differences in gas exchange amongst different species, the advantages that were observed over *O. sativa* were not of a magnitude likely to justify wide hybridization. Varietal differences for photosynthetic rate under drought stress have been reported. (Wada *et al*., 2001; Ravindrakumar *et al.*, 2003; Jin *et al.*, 2003). Genotypic differences for photosynthesis have been reported in rice under other abiotic stress like heat (Cao *et al.*, 2003); acid soil (Kang and Ishii, 2003); low phosphorous stress (Pan *et al.*, 2003) and in cultivars of different panicle weight (Ma *et al.*, 2003). The drought tolerant genotypes have the ability to maintain photosynthesis for longer duration under drought conditions. Photosynthetic stability and dry matter partitioning is important for yield stability of rice under reproductive stage drought (Ravindrakumar *et al.*, 2002). Photosynthetic rate decreased with decreased in stomatal conductance under drought in wheat, but a weak relationship between them implied that non-stomatal limitations to photosynthesis might have been in operation (Siddique *et al.*, 1999).

(II) Stomatal conductance(Gs)

Another mechanism of drought avoidance in the rice shoot 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.

(III) Transpiration rate (E)

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 reduced markedly by water stress (Dingkuhn *et al.*, 1989; Kobata *et al.*, 1996; Cabuslay *et al.*,1999; Wade *et al.*, 2000; Ravindrakumar *et al.*, 2003). Cultivar differences were reported by many authors (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.

2.2.10 Canopy Temperature depression(CTD°C)

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).

2.3 BIOCHEMICAL PARAMETERS

2.3.1 Total Chlorophyll Content

Chlorophyll content decreased significantly under moisture stress conditions in all the rice cultivars (Baruah *et al.*, 1998). Also such a decrease in chlorophyll content recorded when the rice cultivars were subjected to water stress at various stages (Das *et al.*, 2000; Deka, 2000).Similar results were reported by Reddy *et al.*, (2007) in rice genotypes, they opined that this may be due to low rate synthesis of chlorophyll which may be casually related to lesser absorption of nitrogen under moisture stress condition. The reduction was drastic when stress was imposed at grain filling stage (Das *et al.*, 2005). The rate of decline in chlorophyll content in the flag leaves increased after the plants were exposed to water deficits. The greater the water deficit, the faster the chlorophyll content decreased, indicating that water deficits enhanced leaf senescence (Yang *et al.*, 2003) with progressing increase in drought stress.

2.3.2 Chlorophyll stability index (CSI,%)

Premachandra *et al.*, (1990) has reported that cell membrane stability is an indicator of drought tolerance. In a study rice cv. Koshihikari plants were grown in hydroponic culture and exposed to water stress by adding mannitol to the Yoshida nutrient solution until the leaf water potential reached about 70% of that in controls. Leaf discs from these plants were floated in polyethylene glycol (PEG) 6000 solutions (20, 30, 40 or 60%) for up to 24 h to induce increasing levels of water stress. Electrolyte leakage increased from 10% to 80% from the lowest to highest level of PEG used to induce water stress and it increased with duration of PEG treatment. They concluded that this technique could be used to assess drought tolerance of rice (Agarie *et al.*, 1995). Membrane stability index did not change very much under irrigated condition in different genotypes. However, under water stress it was the highest in tolerant genotypes (Tyagi *et al.*, 1999).

The ultrastructural changes of chloroplasts in bundle sheath cells were more prominent than those in mesophyll cells under both drought stress treatments. Ribulose-1,5-bisphosphate carboxylase/ oxygenase (*rubisco*) content in bundle sheath chloroplasts was reduced more dramatically than in mesophyll chloroplasts by drought stress. Although a slight swelling of thylakoids was sometimes observed in bundle sheath chloroplasts in moderate stress for 1 month, the thylakoids were less affected by drought stress than the chloroplast envelope. These results suggest that chloroplasts in bundle sheath cells were more sensitive to drought stress than those in mesophyll cells and the thylakoids were less damaged by drought stress compared with the chloroplast envelope (Yamane *et al.*, 2003).

2.3.3 Cell Membrane Stability Index (CMSI, %)

The cell membrane stability index (CMSI) in leaf discs under control conditions did not differ significantly. In contrast, the water-stressed plants showed significant difference. MSI in non-stressed plant was 78.08% whereas it was 23.08% in stressed plant (Das & Kalita., 2010)

Sairam *et al.* (2008) reported existence of variation among wheat cultivars MSI and CSI. They observed that the genotype that showed higher MSI and CSI under water stress also possessed higher glutathione reductase and peroxidase activity. Also reported that the loss in MSI is related to production of reactive oxygen species which causes damage to membrane lipid and protein.

2.3.4 Relative Injury (RI)

Relative injury(RI) to cell membrane(electrolyte leakage) was greater under water stress condition than control condition.Higher ambient air temperature and vapor pressure deficit increased plant water deficit, which reduced RWC causing dehydration of cellular membranes and their by increasing RI in stress condition.

In a study with wheat genotypes Kumar *et al.*(2008) reported that lowest RI indicating greater tolerance to high temperature and water stress.

Das and Kalita. (2010) reported that RI increases with severity stress and lowest RI was reported in tolerant genotypes and *vice-versa.*

2.3.5 Proline Content

Among various compatible solutes, proline is one of the important molecules that has been shown to protect plant against singlet oxygen and free radical induced damages.

Dingkuhn *et al* (1991) reported that Water deficit induces change in free proline contents in leaves of rice plant. The extent of proline accumulation is proportional to the rate of plant water deficit; genotypic differences in proline accumulation may be simply a reflection of respective differences in LWP. Though the precise role of proline accumulation during moisture stress has not clearly been understood, yet, many researchers have proposed that the accumulated proline acts as an osmoticum and this may be the reason for greater RWC and LWP in tolerant rice varieties (Baruah *et al.*, 1998). Proline accumulation occurred in all cultivars under all stresses, and increased with increasing duration of stress. Sensitive cultivars accumulated more proline than tolerant ones (Liu *et al.*, 2000). Free proline accumulates in the attached and detached leaves of almost all crop species when they are subjected to moderate drought stress in laboratory experiments. Field-grown crops also accumulate proline in their leaves under drought conditions. Characteristically, free proline accumulates in stressed leaves 10-100 times (or even more) the level found in the leaves of well watered plants (Hanson and Nelsen, 1980).

Choudhury (2005) reported that water stress induces proline content in leaves of rice plant which may possibly play an important role in osmoregulation.Similar result has been reported by Kale (2006).

Das *et al.* (2005) observed an increase in the proline content in leaves of rice plant under stress at different stages of growth. Free proline accumulated in all genotypes of soybean during the withholding of water, but the levels decreased after recovery (Kocsy *et al.*, 2005) and also in the plants of sea buckthorn (Yang *et al.*, 2005). The free proline content, and seed set of the drought tolerant cultivars were higher than those of the others (Das *et al.*, 2001). Similar such accumulation of free proline has been observed in vegetative tissues of drought stressed cereals. This could be due to simulated synthesis of precursors and low rates of proline oxidation, slow incorporation into protein due to impaired protein synthesis or accelerated protein breakdown resulting in the increase of free aminoacids including proline (Mishra *et al.*, 2002). Results showed that moderate nitrogen nutrition could promote the accumulation of free proline and total free amino acid in leaves of drought resistant varieties, although it had no significant effect on conventional rice varieties (Zhu *et al.*, 2003). Proline accumulation in roots of tolerant cultivars starts earlier after the initiation of the stress treatment than that of the osmotic stress sensitive cultivar and also reaches a higher level. Proline accumulation was not related to proteolysis and so could be the result from induction of proline biosynthesis by osmotic stress (Do *et al.*, 2003). Drought tolerant genotypes showed better germinability and high proline content in axis compared to susceptible genotypes (Sahoo, 2007).

Roy *et al.* (2009) reported that high proline content is a good index for moisture resistance in rice genotypes. Under moisture stress condition the protein degrades and consequently the proline content increases.

Majeed *et al.* (2011) reported that drought stress increases the accumulation of proline significantly both in leaves and in grains but the increase was more marked at the soft dough stage. Also demonstrated that proline accumulation increases the stress tolerance of plants.

2.3.6 Superoxide dismutase activity

Superoxide dismutase catalyses the dismutation of superoxide radicals to H_2O_2 and decreases the risk of hydroxyl radical formation from superoxide. The combine action of SOD & CAT converts the toxic superoxide radical ($O^{2\cdot}$) and hydrogen peroxide (H_2O_2) to water and molecular oxygen (O_2).Thus averting the cellular damage (Reddy *et al.*, 2000).

Drought stress induces increase in H_2O_2 due to decrease in antioxidative enzyme activity.Antioxidative enzymes aid cells in removing harmful oxygen species.SOD is an important antioxidant enzyme that detoxify active oxygen species.

High levels of total catalase and SOD activities have been reported in resistant varieties by number of investigators in cotton(Bhaskaran *et al.*,1975), brinjal (Kalra *et al.*,1986), indicating the roles of these enzymes in imparting certain degree of tolerance. It is done by detoxification of enzymes such as catalase, SOD, polyphenol oxidase, ascorbate peroxidase that are known to offer protection from reactive singlet oxygen species.

2.3.7 Catalase activity

Kar and Mishra (1976) noticed that catalase activity decreased while peroxidase activity increased during senescence of detached rice leaves.It decreased during senescence of both attached and detached leaves of rice;apparently the trend of changes in catalase activity during senescence is species specific.

Catalase scavenges H_2O_2 by breaking down directly to form water and oxygen and an increase in its activity is related with increase in stress tolerance (Kraus *et al.*, 1995). Catalase is indispensable for ROS detoxification during stress (Willekens *et al.*, 1997).

Roy *et al.* (2009), reported that Catalase detoxifies H_2O_2, formed under moisture stress regime, to form water and oxygen. Increased catalase (CAT) activity is related to increased level of drought resistance in rice genotypes.

2.4 YIELD PARAMETERS AND YIELD

2.4.1 Panicle length

In rice, panicle length, panicle grain number, and panicle grain sterility are crucial determinants of grain yield together with plant panicle number (Matsushima 1995). Genetic improvement of panicle length, grain number, and grain sterility are therefore a major concern for rice breeders to attain high yields (Yonezawa 1997).Panicle length is a genetical character and controlled by gene. The identification and location of the genes controlling this trait is extremely difficult because of the large influence of environmental factors including the depth of flooding water, plant density, and weather conditions such as light, temperature & soil moisture. (Ahamadi *et al.*, 2008)

2.4.2 Productive Tiller Number per hill

Moisture stress in early reproductive stage (panicle initiation to heading) resulted in a decreased grain yield through reduction in number of spikelets (Budi and Suprihanto, 1996). However, tolerant varieties had significantly high number of productive panicles per plant and higher no. of filled grains per panicle (Reddy *et al.,* 2000).

2.4.3 Panicle number and panicle weight

Studies in Japan suggest that the "panicle weight" types, which have long and heavy panicles but rather few of them, have deeper and thicker roots and higher rates of root activity than do the heavy tillering "panicle number" types (Lee and Ota 1973)

2.4.4 Number of spikelet per panicle

The number of spikelets per panicle was shown to be reduced by reproductive phase drought (De Datta, 1981). Similar experiments on wheat revealed that, the number of spikelets per spike, number of grains per spike grain weight per spike, 1000-grain weight were significantly higher in irrigated environments than in dry environments (Chandra *et al.*, 2005).

Drought decreased numbers of spikelets and secondary rachis branches and increased the sterility ratio. The size of both hulled and un-hulled grains was decreased with a marked effect on grain thickness and a smaller effect at the reduction division stage than at panicle formation. Correlations were found between sterility, grain filling and degeneration of spikelets and rachis branches. (Hwang *et al.,* 1989). There was about 15 % decrease in the number of grains per panicle on account of water stress (Babu *et al.,* 2003). Genotypes (IET 11677 and Annada) which had a higher number of grains and grain weight/panicle, grain yield/plant, harvest index and grain productivity per plant under stress showed greater tolerance of water stress under drought conditions at both growth stages (Sahoo.,2007).

2.4.5 Grain number per panicle and test weight

Male reproductive development of rice (*Oryza sativa*) is very sensitive to drought. Water stress during meiosis of rice plant grown under controlled environmental conditions induced pollen sterility. Anthers containing sterile pollen were smaller, thinner and often deformed compared to normal anthers of well-watered plants. Only about 20% of the fully developed florets in stressed plants produced grains, compared to 90% in well-watered controls. Water stress treatments after meiosis were progressively less damaging. Levels of starch and sugars and activities of key enzymes involved in sucrose cleavage and starch synthesis were analysed in anthers collected at various developmental stages from plants briefly stressed during meiosis and then re-watered. Normal starch accumulation during pollen development was strongly inhibited in stress-revealed that, the number of spikelets per spike, number of grains per spike grain weight per spike, 1000-grain weight were significantly higher in irrigated environments than in dry environments (Chandra *et al.*, 2005).

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Number of grains per ear and the grain filling process was very much affected by stress (Day, 1981). The number of grains per plant and grain size were significantly reduced in moisture stressed plants of wheat (Yadav *et al.*, 2001).

The grain volume increased with grain length and grain weight under drought treatments. After drought stress, the relative change ratios of grain length, grain weight and grain texture affected its grain volume significantly. The effects were the largest for the relative change ratio of grain width to grain volume, and smallest for grain thickness to grain volume. Significant positive correlation between the grain volume and 1000-grain weight was recorded under the control treatment, but the correlation between them was insignificant after drought stress (Zhou *et al.,* 2003).

2.4.6 Spikelet fertility percentage

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 spikelets fertility. Studies on panicle water relations (Garrity and O'Toole, 1995; Tsuda, 1997; Pantuwan *et al.*, 2002), abnormalities of gamete formation and panicle excersion (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. Yue *et al.*(2005) reported that spikelet fertility in control condition were higher than that in stress condition for both parents.Spikelet fertility is related to assimilation during anthesis and lots of genetic variations have been reported (Pantuwan *et al.*, 2002; Babu *et al.*, 2003).Drought at flowering stage mainly hampers anthesis and seed setting leading to higher spikelet sterility and lower yields (Das and Kar, 2005). Under water-limited conditions around flowering, grain yield reduction was mainly due to increase in spikelet sterility.

2.4.7 Grain Yield

Grain yield and its components and DM yield declined with increasing drought duration (Stone *et al.*, 1986). A significant positive correlation ($r = 0.727$) was obtained between prolongation of maturation and yield reduction under drought conditions (Dikshit *et al.*, 1987). Water deficit during the vegetative stage did not significantly affect grain yield. Stress imposed for 5 or 10 days during the reproductive phase (45-80 DAS) reduced yield by 25-40%. Stress imposed for 15 days at panicle initiation (50 DAS), flowering (70 DAS) and early grain filling (85 DAS) reduced yields by 70, 88 and 52%, respectively (Yambao and Ingram, 1988). Rice yields were found to be more susceptible to water deficit at flowering than at vegetative stage (Ram *et al.*, 1998). Stress at tillering induced irreparable loss in total biomass of all the genotypes but the grain yield was reduced more due to water deficit at booting stage.

Post-anthesis water stress is critical for grain growth and affects grain weight adversely as the current photosynthesis is reduced drastically. But this loss is compensated partially by the mobilization of carbohydrates stored in the vegetative parts, which contributed up to 30% of the final grain yield when water deficits develop during grain filling (Turner and Begg, 1981; Turner, 1997).

Yield differences between plants that were transiently stressed in the early vegetative phase and well-watered plants were not significant. However, flowering and maturity were delayed. Severe drought in the reproductive phase resulted in large yield reductions, mainly caused by an increase in the percentage of unfilled grains and also in grain weight (Wopereis *et al.,* 1996). In consonance, Sharma *et al.*, 2003 and Chandra *et al.*, 2005 reported similar results in wheat subjected to either mild or severely stressed environments. Further Pradhan *et al.* (2006) corroborated the views of above workers by suggesting the decrease in yield attributing characters with decrease in irrigation regime.

In general genotypes produce significantly higher grain yield per plant in normally irrigated control than moisture stress conditions (Kumar *et al.*, 2008). The reduction might be due to harmful effect of moisture stress on pollination (Yadav *et al.*, 2001; Sahoo, 2007). Moinuddin *et al.*, (2005) reported that grain yield usually decreased with the increase in water stress irrespective of cultivars.

2.4.8 Harvesting index (HI)

The harvest index is the fraction of total dry matter that is in the grain: for cereals in general, rice in particular, when the grain fills only at the end of the crop's life it is expected that late stress will decrease the harvest index more than early stress. But the effect of stress on grain filling in the experiment was not great (Day, 1981). Moderate drought stresses did not result a change in the harvest index of the crop but severe drought stresses, where accumulated biomass was less than 1100g m^{-2}, caused harvest index to decrease (Sinclair *et al.,* 1990). Genotypes that are adapted to areas of late-season drought should also have high harvest index, intermediate height and rather small total dry matter compared to existing traditional cultivars, under well-watered conditions. This combination of characters would ensure high potential yield under favourable conditions and also contribute to resistance against late-season drought (Fukai *et al.*, 1999). Harvest Index was appreciably reduced (from 93.1% to 41.4%) on account of water stress in rice (Chauhan *et al.,* 1999). However, Babu *et al.* (2003) reported only about 10% reduction in Harvest Index under water stress in rice.

In all cultivars, the pre anthesis stress did not change the harvest index significantly indicating that dry matter conversion was more stable across moisture differences imposed at pre-anthesis stage in controlled and water stressed conditions in wheat (Rane *et al.,* 2001). Yield under stress was consistently greater in early cultivars The Harvest Index was observed to be consistently greater in early varieties than in late varieties as they were supposed to be more drought tolerant (Lafitte and Courtois, 2002).

2.4.9 Drought respond index (DRI)

Yue *et al.*(2005) reported that DRI, relative yield and relative spikelet fertility in control condition were higher than that in stress condition for both parents. In general DRI, relative yield and relative spikelet fertility had no correlation (only a few marginally negatively correlation) with root traits under stress condition. In control condition, however, significant and positive correlations were detected between drought resistance indexes and root thickness, deep root traits (including maximum root depth, root growth rate in depth and drought induced root growth in depth). Drought resistance index was negatively correlated with root size (including the traits of root volume, root growth rate in volume) both under control and stress conditions.

Mall *et al.*(2011) reported that drought tolerant genotypes shows low DRI value for seed yield in rice but higher DRI indicating the importance of ability to grow during the prolonged stress period.

Recent research findings at IRRI have demonstrated the feasibility of direct selection for yield under drought (Kumar *et al.*, 2008). Since yield under stress is a function of yield potential, escape, and drought response, the use of the Drought Response Index (DRI) can help to distinguish drought resistance from escape and yield potential (Ouk *et al.*, 2006) and therefore further enhance the precision and reproducibility of drought screening.

Ameliorating effects of exogenously applied Salicylic acid in rice under water stress:

Salicylic acid (SA) plays an important role in abiotic stress tolerance and considerable interests have been focused on SA due to its ability to induce a protective effect on plants under stress. Many studies support the SA-induced increases in the resistance of wheat to salinity (Sakhabutdinova *et al*; Shakirova *et al.*, 2003) and of maize on salinity stress and of rice on heavy metal stress (Mishra And Choudhuri, 1999) and in sunflower plants (Tayeb *et al.*, 2006) and in barley plants (Tayeb., 2005) Numerous physiological and biochemical effects of salicylic acid (SA) on plant system have been documented (Raskin., 1992). These include effects on ion uptake, membrane permeability, mitochondrial respiration etc. It is also an important signal molecule for modulating plant response to stress (Senaratna *et al.*,2000).

Stressful environments induce the generation of reactive oxygen species (ROS) such as superoxide radicals (O^{2-}), hydrogen peroxide (H_2O_2), hydroxyl radicals (OH^-) etc. in plants thereby creating a state of oxidative stress in them (Asada, 1994; Gille and Singler, 1995; Monk *et al.*, 1989; Prasad *et al.*, 1999; Panda *et al.*, 2003). This increased ROS level in plants cause oxidative damage to biomolecules such as lipids, proteins and nucleic acids, thus altering the redox homeostasis (Smirnoff, 1993; Gille and Singler, 1995). When applied exogenously at suitable concentrations, SA was found to enhance the efficiency of antioxidant system in plants (Knorzer *et al.*, 1999). Further, the treatment with salicylic acid resulted in temporary reduction of catalase (CAT) activity and increased H2O2 level (Janda *et al.*, 2003) which possibly played a key role in providing the SAR (Chen *et al.*, 1993) and tolerance against the oxidative stress (Gechev *et al.*, 2002) in plants. SA was found to enhance the activities of antioxidant enzymes, CAT and superoxide dismutase (SOD), when sprayed exogenously to the drought stressed plants of *L. esculentum* (Hayat *et al.*, 2008) or to the salinity stressed plants of *B. juncea* (Yusuf *et al.*, 2008). Krantev *et al.* (2008) reported the exogenous application of salicylic acid enhanced the activities of antioxidant enzymes ascorbate peroxidase (APX) and SOD with a concomitant decline in the activity of CAT in maize plants. The priming of seeds with lower concentrations of SA, before sowing, lowered the elevated levels of ROS due to cadmium exposure and also enhanced the activities of various antioxidant enzymes (CAT, guaiacol peroxidase, glutathione reductase and SOD) in *Oryza sativa*, thereby protecting the plants from oxidative burst (Panda and Patra, 2007).

Gomez *et al.* (1993), observed greater economic yield of wheat genotypes grown under water stress, when treated with SA. Plants respond to stress by the synthesis of signaling molecules. These activate a range of signal transduction pathways. The role of SA as a defense signal has been well established in plants (Ganesan And Thomas, 2001; Klessig and Malamy, 1994). SA has qualified as a plant hormone due to its physiological and biochemical roles in plants (Raskin, 1992). SA has been suggested as signal transducer or messenger under stress conditions (Klessig and Malamy, 1994).

Ameliorating effects of exogenously applied brassinosteroid in rice under water stress:

Brassinolide (Bs) is a new type of plant growth regulator, which is considered to be the 6th plant hormone. BR has a high bioactivity on the growth and development of plant, such as promoting growth, delaying senescence and accelerating cell redifferentiation and so on (Zhao *et al* 2001 and Yang.,2006) . All these physiological effects are regulated by gene expression. Many reports indicate that BR can make the plants produce response and regulation to high temperature stress, increase the heat tolerance in upland crops or economic crops such as *Brassica napus*, tomato, orange and tobacco (Hu *et al.*,1996), however there is few reports about rice.

Reactive oxygen species (ROS) play a key role in plant growth, development, and interaction with biotic and abiotic stresses. ROS have also been implicated as important regulatory and signaling elements in a variety of cellular processes. ROS are constantly produced during the course of photosynthesis and respiration, whereas redox homeostasis in the cell is tightly controlled by redundant protective mechanisms. Disruption of these protective mechanisms can cause oxidative stress, leading to oxidative damage and death of cell. Although, under normal growth conditions, the production of ROS in cells is very low, many stresses that disrupt the cellular homeostasis of cells enhance the production of ROS. These stresses include drought stress and desiccation, salt stress, chilling, heat shock, heavy metals, ultraviolet radiation, ozone, mechanical stress, nutrient deprivation, pathogen attack and high light stress. When plants are subjected to stresses, a variety of ROS are generated, such as superoxide radical (O^{2-}), hydrogen peroxide (H_2O_2) and hydroxyl radical (OH^-) (Gapper and Dolan, 2006). BRs, which play an essential role in plant growth and development, have been implicated in many physiological responses (Sasse. 2003). However, little is known about the role of BRs in the plant response to oxidative stress. It was shown that exogenous application of BRs modified antioxidant enzymes such as superoxide dismutase, catalase, glutathione peroxidase and ascorbate peroxidase and non enzymatic antioxidants, such as ascorbic acid, tocopherols, carotenoids, glutathione, etc. in plants under different stress conditions.

When maize (Zea mays) seedlings treated with BL were subjected to water stress, the activities of superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), as well as ascorbic acid and carotenoids contents increased. On the other hand, BRs enhanced the activity of CAT and reduced the activities of peroxidase and ascorbic acid oxidase under osmotic stress conditions in sorghum (Sorghum vulgare) reported by Bardhini and Rao.(2003).

Rice seedlings exposed to saline stress and treated with BR showed a significant increase in the activities of CAT, SOD and glutathione reductase (GR) and a slight increase in APX (Nunez *et al.*,2003)

Ameliorating effects of exogenously applied Ascorbic Acid on rice under water stress condition:

Ascorbic acid (Vitamin C) has been proposed for long time as a biological antioxidant protecting plants from the oxidative stress resulting from biotic and abiotic stresses(Smirnoff 1996 and 2005).Shalata& Neumann(2001) reported that stress increased the accumulation of lipid peroxidation products produced by interactions with damaging reactive oxygen species;additional ascorbic acid inhibited this response.It also enhances the photosynthesis and accumulamulation of dry matter.Thus,high endogenous ascorbic acid in plants is necessary to counteract water stress and regulating processes of plant metabolism.Endogenous ascorbic acid can be increased by exogenous application of ascorbic acid through foliar spray(Heikal *et al.* 2000),seed presoaking (Khan *et al.*, 2006).

Ameliorating effects of exogenously applied cytokinin on rice under stress condition:

The plant growth regulators have been observed to influence plant responses to moisture stress by many workers. In an experiment conducted on effect of cytokinin on photosynthesis in pearl millet under water stress it was observed that water stress reduced net photosynthesis by reducing green leaf area, chlorophyll, total soluble protein and by decreasing diffusive resistance to some extent. Revival in photosynthesis was earlier than compensation in leaf area when water stress was relieved. Cytokinin affected functional sites of chloroplast under water stress (Kumari and Nath, 2003). Battal and Guller (2003) found that water stress caused a decrease in cytokinin levels in the stem of all plants used in the experiment. In another such study observations recorded at boot and anthesis stages revealed that cytokinin application increased the rate of transpiration and leaf water potential in all the genotypes at boot as well as anthesis stages. Reduction in leaf osmotic potential and increase in leaf turgour potential were also recorded at both stages. A significant increase in test weight, grain number and yield on account of cytokinin has also been recorded in all the genotypes (Gupta *et al.,* 2003).

The aim of this paper is, to study the interaction effects of drought stress with SA on some morpho-physiological and biochemical parameters of rice cultivars in general and various chemicals in particular.

Rice is one of the most important crops in the world. At present, the growth of rice has been seriously influenced by drought in many regions. The present study was conducted to asses whether exogenous application of chemicals could ameliorate the adverse effects of water stress on rice plants.

◆

CHAPTER - III

Materials and Methods

MATERIALS AND METHODS

A field experiment entitled "Identification of Physiological and Biochemical Putative traits and management option related to drought resistant in Rice (*Oryza sativa* L.) was conducted during *rabi* 2010-11.The experiment was conducted in Central farm , OUAT, Bhubaneswar .Six varieties of rice, viz., Parijat, Sidhanta,Mandakini ,Lalat,Manaswini,Konark were taken for the study. Required quantities of breeder seeds were collected from EB-I, Department of PBG for the purpose.

The varietal characteristics of the varieties chosen for the experiment have been elucidated in Table 3.1.

Table: 3.1 Salient characteristics of rice varieties used in the investigation

Variety	**Parentage**	**Duration (days)**	**Plant Height**	**Eco-system**	**General characteristics**
Parijat (IET-2684)	TKM-6 x T(N)1	95-115	Dwarf (85 cm)	High and Medium Lands	Grains: MS, moderately resistant to SB, GLH, Blast, BLB & Helminthosporium, Drought escape mechanism, Yield: 30-40 q/ha.
Sidhanta (ORS 102-4) (IET-15296)	Jajati/Annapurna	96	103 (cm)	Rainfed / irrigated uplands	Grains: SB; resistant to BS, neck blast, mod. rest. to neck BLB, RTV, and Sh.R; Yield: 34.32 q/ha
Mandakini (OR-2077-4,IET-17847)	Ghanteswari x IR27069	100-105		Rainfed upland	Grian:MS; resistant to blast, Sh.B,Drought.tolerant;replces Vandana,Yield: 45q/h.
Lalat (IET-9947)	Obs.677 x IR-207 x Vikram Complex cross	125-130	Dwarf (85-90 cm)	Irrigated medium	Grains: LS, resistant to Sh.R, GM, BPH, GLH, moderately resistant to blast, Sh.B, BS, RTV, BLB & SB; Yield: 40 q/ha.
Manaswini (IET 19005)	-	125	90 (cm)	Irrigated	Grains:LS R-BS, GM1, LF, BPH, Sh.Bl, RTD;35q/ha
Konark (IET 1009)	Lalat x OR 135-3-4	125	Semi dwarf	Irrigated medium	Grains - MS , white, tolerant to BPH ; Yield: 35-50 q/ha.

FIELD EXPERIMENT

Experimental site

The field experiments was conducted during *rabi* season 2010-11 at the experimental farm, Orissa University of Agriculture and Technology, Bhubaneswar, situated at 20^0 15` N parallel and $85^0$ 52` E longitude and 46m MSL.

WEATHER CONDITIONS

During the growth period of Rice, the weekly mean maximum & minimum temperature ranged from 29.2^0C to 42.6^0C and 13.5 to 28.5^0C respectively(Fig 1). The mean RH Range is from 63% to 82.4% and total rain fall is very less during the season.

Table-3.2 Weekly mean of weather parameters during *rabi*-2011 recorded at Central farm, OUAT, Bhubaneswar

Period	Standard Week	Temp(°C)		Mean RH (%)	Rainfall (mm)
		Max	Min		
18.01.11 to 24.01.11	3	29.2	13.5	67.3	0
25.01.11 to 31.01.11	4	31.5	16.7	69.8	0
01.02.11 to 07.02.11	5	31.1	17.1	63.6	0
08.02.11 to 14.02.11	6	30.4	21.1	65.4	0
15.02.11 to 21.02.11	7	31.2	21.4	67.9	37.8
22.02.11 to 28.02.11	8	32.6	19.8	67.8	0
01.03.11 to 07.03.11	9	36.2	19.7	63.0	0
08.03.11 to 14.03.11	10	38.4	21.8	66.2	0
15.03.11 to 21.03.11	11	35.5	22.3	69.4	0
22.03.11 to 28.03.11	12	35.7	23.2	72.1	0
29.03.11 to 04.04.11	13	36.7	25.4	75.3	0
05.04.11 to 11.04.11	14	37.6	24.5	65.8	3.1
12.04.11 to 18.04.11	15	38.4	25.2	72.3	6.1
19.04.11 to 25.04.11	16	34.5	23.4	71.1	4.1
26.04.11 to 02.05.11	17	38.1	25.3	74.2	14.7
03.05.11 to 09.05.11	18	39.2	24.8	77.0	22.5
10.05.11 to 16.05.11	19	42.6	28.5	75.1	0
17.05.11 to 23.05.11	20	36.3	23.6	82.4	80.1

DOS:18.01.2011(3rd standard week)
DOH:26.04.2011&20.05.2011(17th &20th standard week)

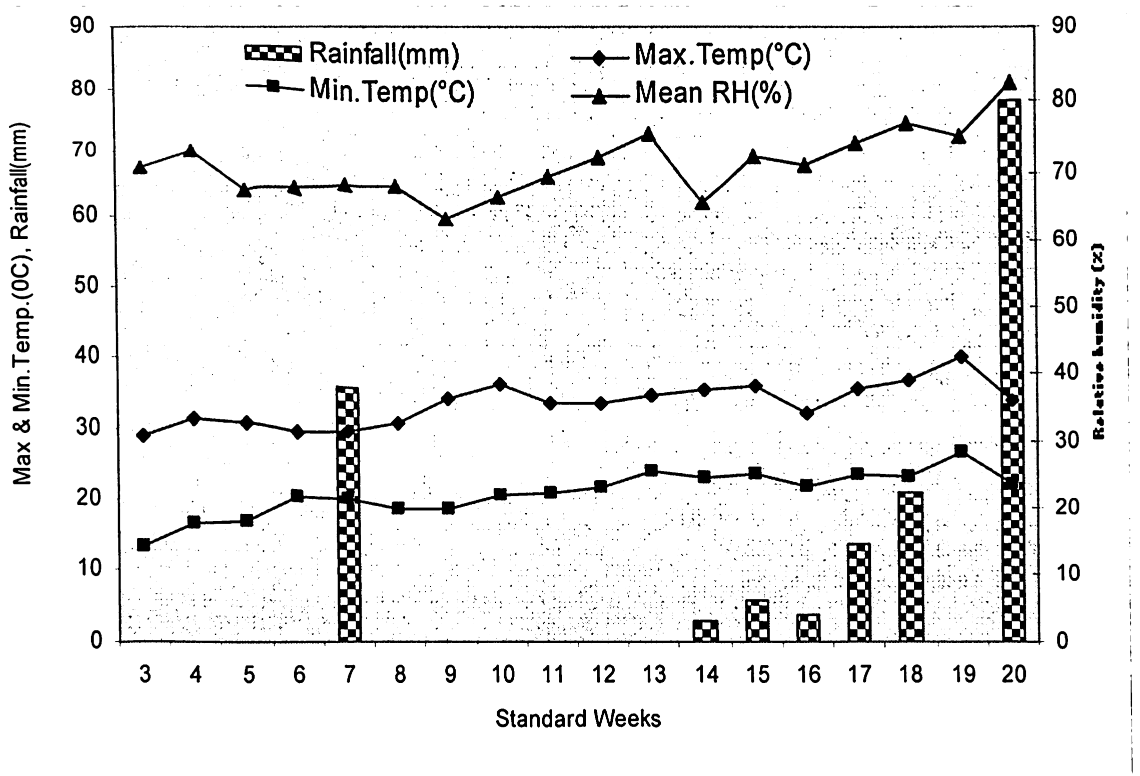


Fig. 3.1 Mean weekly weather parameters during *rabi*, 2011 recorded at Central Farm, OUAT, Bhubaneswar

EXPERIMENTAL FIELD:

The field experiment was conducted in the Central Farm OUAT during *rabi* 2010-11.Prior to preparatory cultivation of the experimental field, soil samples were collected at random from the field and soil samples were analyzed for different physico-chemical properties following the standard methods (Table-3).The result of the soil analysis indicated that the experimental soil was sandy loam in texture, slightly acidic in reaction and minimal availability of nutrient.

Table -3.3 Physico-chemical properties of the experimental field

I. Mechanical analysis

Sl. No.	Particular	Percentage of composition	Method of analysis
1	Sand	76.8	Boyuoucos Hydrometer method (Piper,1950)
2	Silt	9.7	
3	Clay	6.6	
4	Texture class	Sandy loam	

II. Chemical analysis

Sl. No.	Particular	Percentage of composition	Method of analysis
1	pH	5.8	Glass electrode(Jackson,1973)
2	Organic Carbon (%)	0.34	Walkley and Black's modified method.(Walkley & Black,1934
3	Available N(kg ha^{-1})	544	Alkaline permanganate(Subbiah and Asija,1956)
4	Available P_2O_5(kgha^{-1})	18.5	Modified Olsen's(Olsen *et al.*,1954)
5	Available K_2O(kg ha^{-1})	127.1	Neutral normal ammonium acetate(Jackson,1973)
6	Permanent wilting Point	3.45	-
7	Bulk Density(mg/m^3)	1.75	Field Method
8	Particle Density (mg/$m^{3)}$	2.66	Pycnometer Method

EXPERIMENTAL DETAILS

Crop: Rice (*Oryza sativa* L.)
Variety: Parijat, Sidhant, Mandakini, Lalat, Manaswini, Konark
Design: Randomized Block Design.
Treatment: 3

S_0: No stress (Water is given as and when required)

S_1: Water stress at PI stage.

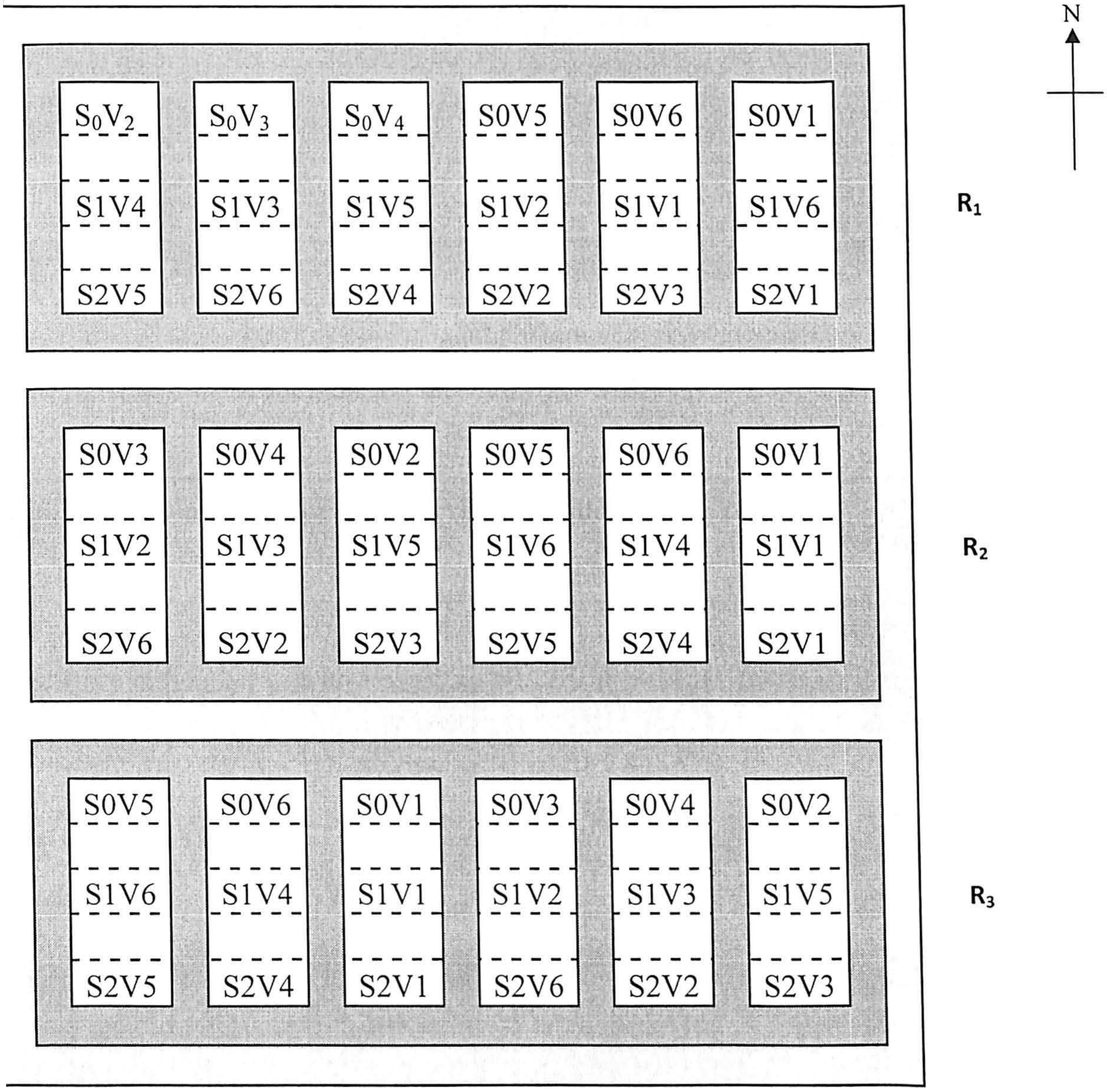
S_2: Water stress with SA treatment.

Replication: 3
Spacing : 15cm X 15cm
Plot size : 3 m X 5 m

Table 3.4 List of varieties and their symbols

S.L.No	Varieties	Symbol
1	Parijata	V_1
2	Sidhant	V_2
3	Mandakini	V_3
4	Lalat	V_4
5	Manaswini	V_5
6	Konarka	V_6

Fig. 3.2: Lay out plan of the experimental plots (*Rabi* 2011)



R₁	S_0V_2	S_0V_3	S_0V_4	SOV5	SOV6	SOV1
	S1V4	S1V3	S1V5	S1V2	S1V1	S1V6
	S2V5	S2V6	S2V4	S2V2	S2V3	S2V1
R₂	SOV3	SOV4	SOV2	SOV5	SOV6	SOV1
	S1V2	S1V3	S1V5	S1V6	S1V4	S1V1
	S2V6	S2V2	S2V3	S2V5	S2V4	S2V1
R₃	SOV5	SOV6	SOV1	SOV3	SOV4	SOV2
	S1V6	S1V4	S1V1	S1V2	S1V3	S1V5
	S2V5	S2V4	S2V1	S2V6	S2V2	S2V3

CULTIVATION DETAILS

The experimental field was ploughed thoroughly,leveled uniformly and prepared with all the recommended doses of fertilizers (@ 20-40-20 kg N-P-K hectare^{-1}) as basal and 30 days old seedlings were planted @ 2-3 seedlings per hill with a spacing of 15 X 15 cm^2. Then standing water was maintained up to a depth of 5 cm 7 days after transplanting. Rest of the recommended fertilizers were top dressed in two splits at 20 days after transplanting (@ 40

OVERALL VIEW OF EXPERIMENTAL FIELD

kg N hectare^{-1}) and at panicle initiation stage (@ 20-20 kg N-K hectare^{-1}). Stress was imposed by withholding irrigation to the required experimental plots before 5 days of the targeted crop. The stress period continued till appearance of incipient wilting/ leaf rolling and thereafter irrigation was provided to relieve the crop from stress. Stress was imposed at panicle initiation (PI) stage. SA treatment given after stress imposition from each replication and varieties. Separate pot culture experiment was done to record the photosynthesis and ancillary parameters by applying following chemicals *viz.* Urea (2%), K_2SO_4 (2%), SA (100ppm), AA (100ppm), Cytokinin (10ppm) and Brassinosteroid (1ppm) at the beginning of the stress period. The experiment was carried out in randomized block design with 3 replication.

OBSERVATION RECORDED

Observations were taken from each variety and replication at the end of the stress period before relieving the crop off the imposed stress. Then representative samples were selected from each treatment for study of Morphological, Physiological & Biochemical parameters.

3.1 MORPHOLOGICAL PARAMETERS:

3.1.1 Plant height

Plant height was measured (cm) at harvesting stage for all the treatment combinations. The height from the bass of the stem up to the collar region of the top most leaf was taken.

3.1.2 Tiller Number per hill

Number of tillers per plant was counted at the end of stress at harvesting stage.

3.1.3 Leaf drying scores (LDS)

Leaf drying score was recorded based on visual observations as per the standard Evaluation system (IRRI, 1996) under stress. It was scored with a scale from "0" to "4" just before re-irrigation. Score of "0" indicates no symptoms of drying & "4" indicates susceptible type (About half of the leaf areas dried)

3.1.4 Leaf rolling scores (LRS)

Leaf rolling score was assessed visually in each variety & replication in each plot in all treatments. Several plants were assessed and the variety were given a mean rolling score ranging from "0' to "4" with "0" being flat & "4" indicates complete leaf rolling (Turner, 1997).These rating were made during midday, i.e. about twice per week during the period of water deficit of all treatments.

3.1.5 Leaf length & leaf thickness

After destructive sampling of plant from each variety leaf length were measured by scale from the third leaf of each sample and expressed in (cm) .Leaf thickness was measured by screw gauge and expressed in (mm)

3.1.6 Maximum root length and Root Thickness

After destructive sampling of each variety from control, stress and stress+treatment at PI stage root length and Root thickness were measured by scale and screw gauge respectively.

3.1.7 Root volume (cc)/plant

The samples were excavated with minimum root damage, washed thoroughly with tap water and root system was separated from the plant. All the roots were shade dried or (soaked with muslin cloth) and dipped in measuring cylinder containing known volume of water. After dipping the total roots, the enhancement in the volume of the water was recorded as root volume.

3.1.8 Root Dry Weight:

The root dry weight of the concerned variety in the respective treatment were taken after proper washing & weighing by the balance.

3.2 PHYSIOLOGICAL PARAMETERS

Various Physiological parameters were recorded at different growth stages, which have been outlined below.

3.2.1 Total Dry Matter Accumulation Per Hill (g)

The total dry matter accumulation and its partitioning was estimated at harvesting stages from plant sample/hill in each treatment and then separated into root, stem, leaf & panicles. The plant parts were dried to a constant weight in hot air Oven at 80^0C for two days and dry weights were recorded and expressed in g/hill.

3.2.2 Root Shoot Weight Ratio

After destructive sampling of plants the root & stem were separated and kept in an oven for 48 hours at 80^0C.After 48 hour they were weighted for their dry weight. Root shoot Ratio was recorded with the following formula.

$$\text{Root: Shoot ratio} = \frac{\text{Root dry weight (g)}}{\text{Shoot dry weight (g)}}$$

3.2.3 Root Length Density

It was worked out as follow (Anbumalarmathi *et.al*, 2008) and expressed in (cm/cc).

$$\text{Root length density} = \frac{\text{Root length(cm)}}{\text{Root Volume(cc)}}$$

3.2.4 Net Assimilation Rate (NAR)

The net assimilation rate is the rate of plant dry weight increase per unit leaf area per unit time. It was determined at 15 days interval and calculated according to the formula (Gregory, 1926) given below and expressed as g cm $^{-2}$ week $^{-1}$.

$$\text{NAR} = \frac{W_2 - W_1}{(t_2 - t_1)} \times \frac{\ln A_2 - \ln A_1}{(A_2 - A_1)}$$

Where,

W_1 = Dry weight of the whole plant at the start of the period

W_2 = Dry weight of the whole plant at the end of the period

A_1 = Total leaf area of the whole plant at the start of the period

A_2 = Total leaf area of the whole plant at the end of the period

$(t_2 - t_1)$ = Period in week between initial and final observations

3.2.5 Crop Growth Rate (CGR)

CGR is the gain in weight of a community of plant on unit piece of land per unit time per week. It was determined by using the formula given below (Gregory, 1926).

$$\text{CGR} = \frac{1}{P}\ (W_2 - W_1)/(t_2 - t_1)$$

Where,

W_1 = Dry weight of the community of plant at the start of the period

W_2 = Dry weight of the community of plant at the end of the period

P = Ground area

$(t_2 - t_1)$ = Period in week between initial and final observations

3.2.6 Leaf area per hill

The leaf area was measured by leaf area mater and also manually by measuring maximum length and maximum breadth of the leaf and factor "K".

$$K = \frac{\text{Actual leaf area in cm}^2}{(\text{Length (L)} \times \text{Max. Breadth of leaf) in cm}^2}$$

Then the factor "Y" was found for the known sample and multiplied with the bulk leaf dry weights for obtaining the leaf area and expressed in cm^2.

$$Y = \frac{\text{Actual leaf area in cm}^2}{\text{Leaf dry weight in g}}$$

3.2.7 Leaf Area Duration (LAD)

The LAD represents the persistence of greenness of leaf & a measure of duration of assimilatory surface. It was calculated using the following formula.

$$\text{LAD} = \frac{A_2 + A_1}{2} \times (t_2 - t_1)$$

Where,

A_1 = Leaf Area Index at the start of the period

A_2 = Leaf Area Index at the end of the period

$(t_2 - t_1)$ = Period in week between initial and final observations

3.2.8 Leaf Moisture Retention Index (LMRI, %)

Single leaf was separated from the destructive samples and fresh weight (Fw) was recorded for the leaf. The leaf was kept in the field at ambient temperature for 5 hrs.After 5hrs, its weight was recorded as Ambient Weight(Aw).Then the leaf was kept in hot air Oven at 80^{0}Cfor two days to attain its constant dry weight (Dw).Leaf moisture retention index was calculated using the formula of Gupta& Sharma(2006).

$$\text{LMRI} = \frac{\text{Aw} - \text{Dw}}{\text{Fw} - \text{Dw}}$$

3.2.9 Soil Moisture Content (SMC, %)

Soil moisture was measured by gravimetric method (Richards 1959).It was dried in oven at 800C for 48 hrs dry weight was recorded.

$$\text{SMC \%} = \frac{\text{Fresh Weight} - \text{Dry Weight}}{\text{Dry Weight}} \text{X100}$$

3.2.10 Photosynthesis and ancillary parameters

Photosynthetic rate and other gas exchange parameters were measured on the second fully expanded leaf of three representative plants per genotype with a portable photosynthesis system (CIRAS-2 of version 2.02, USA). The measurements were made between 10.00 AM to 12.00 noon from all control, stressed and stressed + treatment field. The measured parameters were: viz., photosynthetic rate (Pr), stomatal conductance (Gs) and Transpiration rate (E).

Parameters	:	Units
Photosynthetic rate (Pn)	:	µ mol of CO_2 m^{-2} s^{-1}
Transpiration rate (TR)	:	m mol m^{-2} s^{-1}
Stomatal conductance (Gs)	:	µ mol of CO_2 m^{-2} s^{-1}

3.2.11 Canopy Temperature

It was measured at noon just before re-irrigation using a hand hold infrared thermometer (Raytec corporation, CA, USA) as described by Garrity and O'Toole (1995) and Pantuwan *et* al (2002). It may be a valuable qualitative index to differences in plant water regimes. It was calculated using the following formula.

ΔT = Te - Ta

Where ΔT = Differential temperature

Te = Infrared measurement of canopy temperature

Ta = Air temperature

3.3 BIOCHEMICAL PARAMETERS

The following biochemical parameters were recorded two days after the treatment imposed (some after the crop were harvested).

3.3.1 Total Chlorophyll Content

Total chlorophyll content in the leaves were determined by using the method stated by Arnon (1949). The second leaf from the top was sampled for the purpose. The leaf samples were immediately kept in moist polythene bags to keep them turgid. 100 grams of fresh leaf was taken from the middle portion of the leaf and were cut into small pieces. The leaf discs were then put in 80 % v/v acetone solution and kept in dark for 24 hours. Then they were filtered by Whatman No.1 filter paper and the filterate was used to record the absorbance (OD) at 645 nm and 663 nm. The respective chlorophyll content was calculated using the following formulae and expressed as mg g^{-1} FW leaf.

$$\text{Chlorophyll–a} = (12.7 \text{ x } OD_{663} - 2.69 \text{ x } OD_{645}) \text{ x } \frac{V}{1000 \times W_F}$$

$$\text{Chlorophyll–b} = (22.9 \text{ x } OD_{645} - 4.68 \text{ x } OD_{663}) \text{ x } \frac{V}{1000 \times W_F}$$

$$\text{Total Chlorophyll} = (20.2 \text{ x } OD_{645} - 8.02 \text{ x } OD_{663}) \text{ x } \frac{V}{1000 \times W_F}$$

Where,

OD_{645} = OD value at 645 nm

OD_{663} = OD value at 663 nm

V = Volume of 80% acetone in ml.

W_F = Fresh weight of leaf in gram

3.3.2 Chlorophyll stability index (CSI)

Chlorophyll Stability Index (CSI) was calculated by taking leaf samples of control as untreated and those imposed with drought stress as treated and using the formula given below (Kar *et al.*, 2005).

$$\text{CSI (\%)} = \frac{\text{Total chlorophyll content (stress)}}{\text{Total chlorophyll content (non - stress)}} \times 100$$

3.3.3 Cell Membrane Stability Index (CMSI, %)

CMSI were assayed by estimating the electrolyte leakage from fresh leaf tissues into the distilled water using the method described by Sairam & Srivastava(2002).100mg leaf tissues from different samples was cut into 5mm length and placed in test tubes containg 10 ml distilled de-ionized water in two sets. One set of leaf samples were placed in a water bath maintained at a constant temperature at 40°C.After 2hr their conductivity (C1) were measured using an electrical conductivity meter (Model CMK-731,Century instruments) The second set was placed in a boiling water bath at 100°C for 20minute to completely kill the tissue and release all the electrolytes. Samples were cooled to 25°C and conductivity was measured. CMSI were calculated using the formula of Premachandran *et al.* (1989).

$$\text{CMSI} = (1 - C1/C2) \times 100$$

3.3.4 Relative Injury (RI, %)

Membrane thermostability was tested by CMSI test with pinnules obtained from plant samples following the method suggested by Tongden & Chakraborty (2007) in terms of injury. The injuries were determined as follows.

$$\text{RI} (\%) = \{1 - [1 - T1/T2]/[1 - C1/C2]\} \times 100$$

Where, T and C refers to the conductance in treatments and control tubes and subscript 1 and 2 refers to reading before and after boiling, respectively.

3.3.5 Proline Content

Proline estimation was done as per the protocol described by Sadasivam & Manickam (1996) and Gilmour *et al.*, 2005. Fresh leaves (0.5 g) were ground in mortar and pestle with 10 ml of 3% sulphosalicyclic acid and the homogenate was centrifuged at 18000 rpm. The homogenate was filtered. 2 ml of filtrate was added to 2 ml of glacial acetic acid and 2 ml of acid ninhydrin and test tubes were kept for 1 h at 100°C in water bath, followed by ice bath. The reaction mixture was vortexed with 4 ml of toluene. Toluene layer was separated and absorbance was read at 520 nm. A standard curve of proline was used for calibration and expressed as mg g^{-1}FW.

3.3.6 Superoxide dismutase activity

Superoxide dismutase (SOD,EC 1.15.1.1) activity was assayed using the method of Beauchamp and Fridovich (1971) by following the photo-reduction of nitoblue tetrazolium(NBT).0.5g of fresh leaf was ground in 20ml of potassium phosphate buffer in a pre-chilled mortar with pestle. The homogenate was filtered through filter paper and centrifuged at 15,000 rpm for 15 minute resulted extract(enzyme extract) was brought up to 25 ml with the potassium phosphate buffer.

The reaction mixture was containing $1.17x10^{-6}$M riboflavin,0.1M methionine,$2X10^{-5}$Mpotassium cyanide(KCN) and $5.6x10^{-5}$ M Nitroblue Tetrazolium salt(NBT) dissolved in 0.05 M phosphate buffer (pH 7.8).Three ml of the reaction mixture was added to one ml of enzyme extract. The reaction was initiated by placing the mixture under bright illumination was in glass test tubes of uniform thickness. The illumination was performed by two sets of 40W fluorescence tubes. The test tubes were arranged in a single row, with a set of tube lights fixed on either side. Illumination started to initiate the reaction at 30^0C for one hour. Identical solutions that were kept under dark served as blanks. The absorbance was recorded at 560nm in the spectrophotometer against blank. The reaction mixture that was not exposed to light did not develop colour and served as control

3.4.4 Grain number per panicle:

Total number of filled grains in each of 10 random panicles was counted and the mean was calculated and recorded.

3.4.5 Test weight (TW):

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

3.4.6 Spikelet fertility percentage

Total number of filled and unfilled grains was counted from 10 randomly selected panicles and mean filled and unfilled grains per panicle were calculated to estimate the percent fertile spikelets in a panicle.

3.4.7 Grain Yield per plant :

The weight of the dried and cleaned grains from 10 plants was taken in grams to work out mean grain yield per plant and recorded.

3.4.8 Harvesting index (HI)

This is being the ratio between economic yield and the biological yield (above ground part) was determined using the formula(Nichiporovic,1960) given below

$$\text{Harvest Index (HI)} = \frac{\text{Economic yield}}{\text{Biological yield}} \text{X100}$$

3.4.9 Drought Respond index (DRI)

The drought response index was calculated for each Variety using the formula suggested by Fisher and Maurer (1978).

$$\text{DRI} = \frac{1 - (\text{Ys/Yc})}{1 - (\text{mean Ys/mean Yc})}$$

Where,

YC = Yield with irrigation (Stress free environment) (potential yield)

YS = Yield under drought condition (stress environment) (stress yield)

STATISTICAL ANALYSIS

The data collected from the experiment relating to various growth and yield attributing characters, enzyme activities, biochemical observation and yield were analyzed in analysis of variance (ANOVA) technique as prescribed by Panse and sukhatme,(1995) for a randomized block design. The standard error of mean (SEm±) and critical difference (CD) at 5 % level of significance were calculated by the XLs programme and statistical package.

* * *

CHAPTER-IV

Results and discussion

RESULTS AND DISCUSSION

The present experiment was conducted during *rabi* season of 2010-11 in the Central Farm, Orissa University of Agriculture and Technology, Bhubaneswar to identify the putative traits of drought resistance in rice varieties and their management options. The various morpho-physiological and biochemical observations recorded during PI and harvesting stage of rice crops, were tabulated, analysed and presented in the following heads and subheads:

4.1 MORPHOLOGICAL PARAMETERS

4.1.1 Plant height

Data on the effect of drought on plant height of rice varieties are given in the Table 4.1 and Fig. 4.1. The plant height reduced in all the varieties with imposition of drought at panicle initiation stage and the overall reduction was 29% under stress. Foliar application of Salicylic acid in stress increased the plant height by 10% as compared to the lone stress.

Though the varieties differed in their response to drought as regards to plant height, there was a general reduction of plant height due to drought in all genotypes. Similar reduction of plant height has been reported by Pradhan *et al.* (2006) and Chandra *et al.*(2005). Among the varieties Sidhant was the tallest with mean height of 76.3 cm and variety Manaswini was shortest with a mean height 60.2 cm.

4.1.2 No. of tillers per hill

The number of tillers per hill reduced significantly when the plants were subjected to moisture stress at PI stages (Table 4.1 and Fig. 4.2.). The reduction was 35% in stress but application of salicylic acid in stress reduction was observed to the tune of 16% as compare to control. Similarly, the impact of stress caused significant reduction of number of productive tillers/hill irrespective of cultivar tested.

Application of SA on tiller production was found significant in all the genotypes. The number of productive tillers produced by the stress only 51% and stress with salicylic acid was 10% more than stress condition.

Similar reduction in number of tillers has been reported by Chandra *et al.* (2005).Maximum reduction was observed in cultivar Mandakini(45%) followed by Sidhant(43%) when exposed to stress.The variety Lalat produced the highest number of tillers followed by Parijat and Konark produced the least.It has been also reported that tiller production is much more sensitive to water stress and moreover, all the tillers survived to produce ears and tiller death phase were reported to be sensitive to dry environment Chandra *et al.*, (2005).

4.1.1 Leaf drying scores (LDS) and Leaf rolling scores (LRS)

In this study, tolerance for water stress was assessed by visual scoring based of rolling and leaf drying. Significant differences in visual score were found among the cultivars tested (Table 4.2).Leaf drying score and rolling increases with increase in level of stress. Mean leaf drying score was 2.7 with a range from 2.16 to 3.17 in stress and application of salicylic acid decreases the drying scores to 2.4(11% decrease over stress) with a range from 1.25 to 3.08. LDS was least (2.16) in cultivar Manaswini while Lalat recorded highest score among all variety in stress.

Mean rolling score in stress was 3.05 with a range from 2.17 to 3.75 in stress while SA treatment decreases the rolling to 2.88 with a range from 2.0 to 3.48

Table 4.1 Effect of water stress on plant height (cm),total number of tiller and Number of productive tiller per hill at harvesting stage of rice genotypes.

Genotypes	Plant Height(cm)				Total Number of tiller/hill				Number of Productive tiller/hill			
	S0	S1	S2	Mean	S0	S1	S2	Mean	S0	S1	S2	Mean
Parijata	82.0(100)	58.0(70)	62.6(76)	**67.5**	17.0(100)	11.7(68)	13.0(76)	**13.9**	15.3(100)	8.3(54)	11.0(71)	**11.6**
Sidhant	92.6(100)	62.3(67)	74.0(79)	**76.3**	15.7(100)	9.0(57)	15.3(97)	**13.3**	12.7(100)	6.0(47)	10.4(82)	**9.7**
Mandakini	85.0(100)	53.3(62)	65.0(76)	**67.8**	14.3(100)	8.0(55)	11.7(81)	**11.3**	11.0(100)	4.7(42)	6.3(56)	**7.3**
Lalat	86.7(100)	67.0(77)	71.3(82)	**75.0**	16.0(100)	12.3(76)	14.0(87)	**14.1**	15.0(100)	8.7(57)	10.7(71)	**11.4**
Manaswini	67.0(100)	53.6(80)	60.0(89)	**60.2**	12.7(100)	8.7(68)	10.0(78)	**10.4**	8.5(100)	3.8(44)	5.3(62)	**5.8**
Konarka	75.7(100)	56.3(74)	65.3(86)	**65.7**	12.0(100)	7.3(61)	9.0(75)	**9.4**	11.0(100)	6.3(57)	8.2(74)	**8.5**
Mean	**81.5(100)**	**58.4(71)**	**66.4(81)**	68.8	**14.6(100)**	**9.5(65)**	**12.2(84)**	**12.1**	**12.3(100)**	**6.3(51)**	**8.65(70)**	**8.7**
	V	**S**	**V x S**		**V**	**S**	**V x S**		**V**	**S**	**V x S**	
Sem(±)	0.71	0.5	1.23		0.44	0.31	0.76		0.21	0.15	0.36	
CD 5%	2.04	1.45	3.54		1.26	0.89	2.17		0.60	0.43	1.04	
CV %	3.1				10.84				7.24			

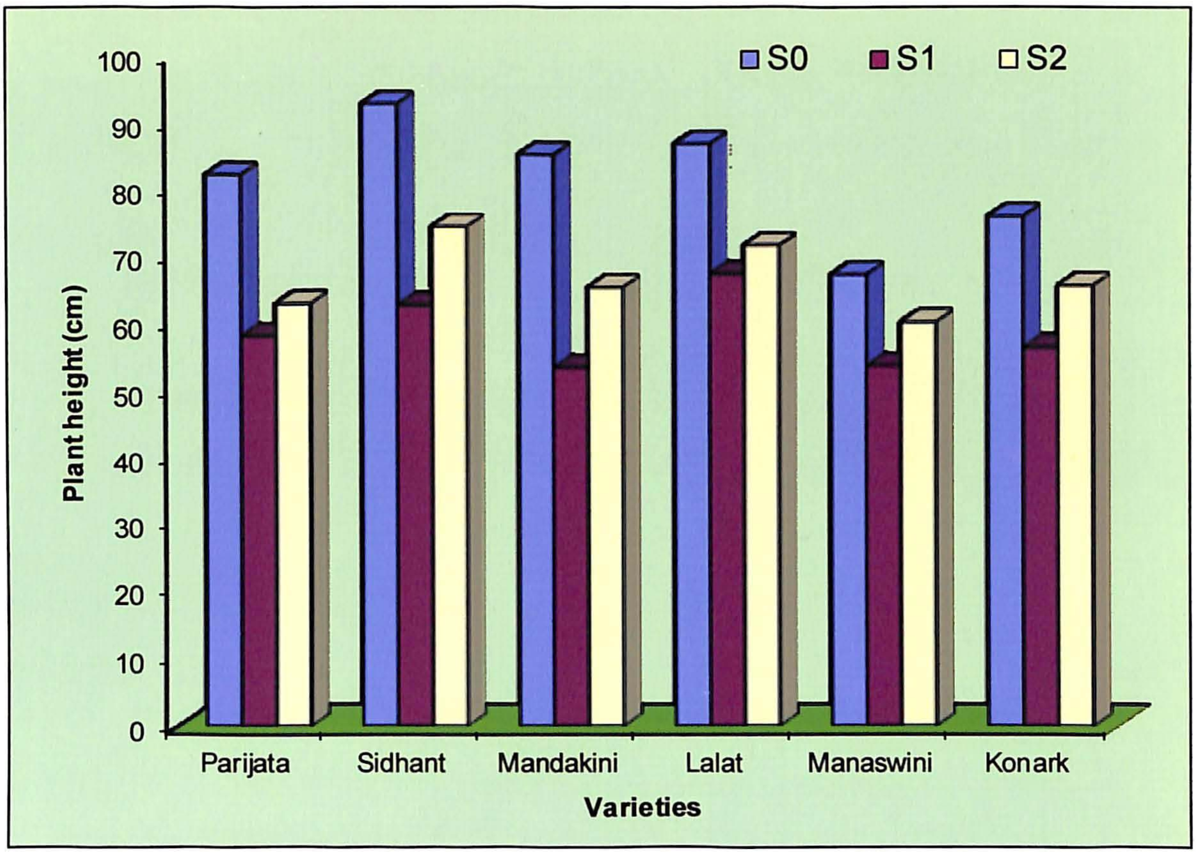


Fig. 4.1 **Effect of water stress on plant height (cm) at harvesting stage of rice varieties.**

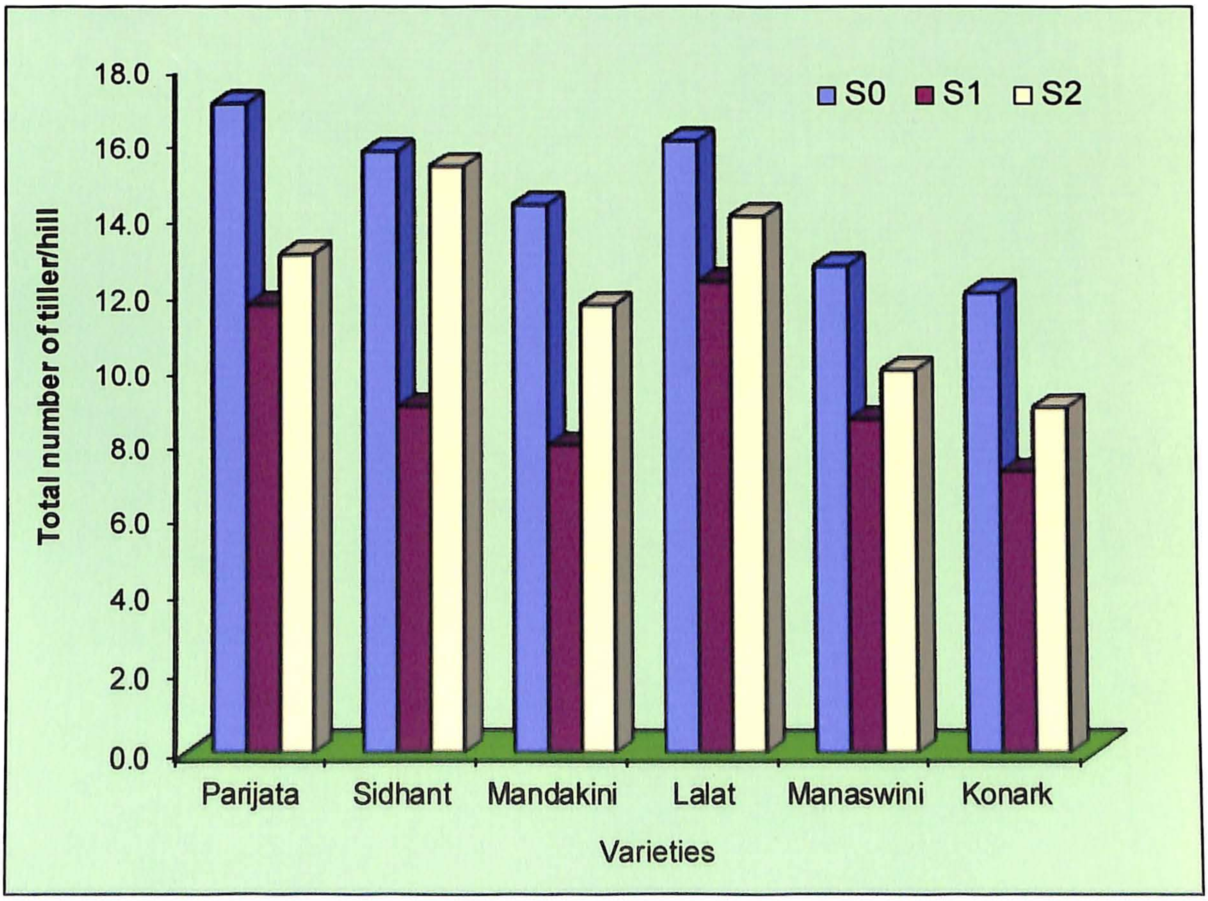


Fig. 4.2 **Effect of water stress on total number of tillers per hill at harvesting stage of rice varieties.**

among variety. LRS was highest (3.75) in both cultivar Parijat and Lalat in stress condition while Mandakini recorded lowest score (2.17).Application of Salicylic acid decreases the leaf rolling among all the variety. Lalat recorded highest and Mandakini the least score in salicylic acid treatment..

Chang *et al.* (1974) used same scoring method for leaf rolling and leaf death score to assess the levels of field tolerance for drought, while O'Toole and Cruz (1979) found that, it could be sufficiently reliable to be used as an estimate of dehydration avoidance.

Table-4.2 Effect of water stress on leaf drying Score(LDS) and Leaf rolling Score(LRS) at PI Stage of rice genotypes

Genotypes	**LDS**				**LRS**			
	S0	**S1**	**S2**	**Mean**	**S0**	**S1**	**S2**	**Mean**
Parijata	0.00	3.12	3.08	**2.07**	0.00	3.75	3.45	**2.40**
Sidhant	0.00	2.58	2.98	**1.89**	0.00	2.73	2.48	**1.74**
Mandakini	0.00	2.98	2.08	**1.68**	0.00	2.17	2.00	**1.39**
Lalat	0.00	3.17	3.00	**2.06**	0.00	3.75	3.48	**2.41**
Manaswini	0.00	2.16	2.00	**1.39**	0.00	3.17	2.43	**1.87**
Konarka	0.00	2.18	1.25	**1.14**	0.00	2.75	3.42	**2.06**
Mean	**0.00**	**2.70**	**2.39**	1.70	**0.00**	**3.05**	**2.88**	1.98
	V	S	V x S		V	S	V x S	
Sem(±)	0.061	0.043	0.105		0.090	0.066	0.162	
CD 5%	0.174	0.123	0.302		0.270	0.190	0.464	
CV %	10.100				14.150			

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. Leaf death increased linearly as the leaf water potential decreased. However, the degree of leaf death was always less in the unirrigated, osmotically adjusted rice than in the irrigated rice at a given soil moisture content.

4.1.3 Leaf length and Leaf thickness

A significant variation in leaf length was observed among the rice genotypes (table 4.3).On an average the mean reduction in leaf length was 36% in stress while application of salicylic acid in stress increased the leaf length to the tune of 16% over the stress. Konark produced significantly longer leaf than all the genotypes except Parijat similar length in stress. On the other hand Lalat and Mandakini possessed significantly longer leaf. Manaswini which had the least potential in this trait. Potentiality to long leaf is a tool of production of more photosynthetes during water stress. Possibly inefficient leaf proliferation habit of Manaswini limits its yield in drought prone area.

Table-4.3: Effect of water stress on leaf Length(cm) and Leaf Thickness(µm) at PI Stage of rice genotypes

Genotypes	**Leaf Length(cm)**				**Leaf Thickness((µm)**			
	S0	**S1**	**S2**	**Mean**	**S0**	**S1**	**S2**	**Mean**
Parijata	38.2(100)	28.1(73)	36.7(96)	**34.4**	81.3(100)	74.3(93)	79.5(97)	**78.4**
Sidhant	37.8(100)	27.6(73)	33.2(88)	**32.9**	82.0(100)	63.0(76)	70.7(86)	**71.9**
Mandakini	46.3(100)	25.8(56)	35.2(76)	**35.8**	82.3(100)	65.7(80)	73.0(88)	**73.3**
Lalat	42.7(100)	25.7(60)	33.8(79)	**34.1**	83.0(100)	75.3(99)	82.799)	**77.4**
Manaswini	37.8(100)	23.6(62)	29.3(77)	**30.2**	75.7(100)	65.0(85)	72.0(95)	**70.9**
Konarka	47.5(100)	30.1(63)	34.5(80)	**37.4**	74.2(100)	60.3(81)	65.087)	**66.7**
Mean	**41.7(100)**	**26.8(64)**	**33.8(80)**	34.1	**79.6(100)**	**67.3(85)**	**74.2(94)**	73.6
	V	S	V x S		V	S	V x S	
Sem(±)	0.478	0.338	0.829		1.504	1.064	2.606	
CD 5%	1.375	0.972	2.381		4.323	3.057	7.488	
CV %	4.210				6.160			

On being exposed to moisture stress the thickness of leaf reduced irrespective of varieties. The reduction in leaf thickness in stress was 15% but application of salicylic acid reduced the impact of drought and increases the leaf thickness to the tune of 9% over the stress. Lowest leaf thickness was observed in cultivar Konark followed by Manaswini and maximum leaf thickness was observed in cultivar Lalat followed by Parijat under moisture stress condition. Similarly, leaf thickness was highest in Lalat followed by Parijat and lowest in variety Sidhant under salicylic acid treatment. Das and Kalita.(2010) reported similar results but Hofstra and Hesketh (1975) recorded higher leaf thickness under moisture stress. This was contrary to this report.

4.1.4 Maximum root length and thickness

Data on root length and thickness have been depicted in Table 4.4. Results pertaining to root length revealed that there was significant variation in root length was observed among the rice genotypes. On an average stress reduced the root length 23% as compare to control while application of Salicylic acid during stress reduced the reduction percentage to 9% in comparison to nonstress. Sidhant produced significantly longer mean roots

Table 4.4 Effect of water stress on Root Length(cm) and Root Thickness(mm) at PI Stage of rice genotypes

Genotypes	Root Length(cm)				Root Thickness((mm)			
	S0	S1	S2	Mean	S0	S1	S2	Mean
Parijata	17.1(100)	11.8(69)	13.0(80)	**14.2**	1.75(100)	1.50(86)	1.70(97)	**1.65**
Sidhant	17.9(100)	12.2(68)	16.6(93)	**15.6**	1.72(100)	1.32(78)	1.41(83)	**1.48**
Mandakini	15.4(100)	12.3(80)	13.7(88)	**13.8**	1.52(100)	1.24(82)	1.42(94)	**1.39**
Lalat	15.1(100)	12.1(80)	14.1(93)	**13.8**	1.57(100)	1.48(94)	1.52(96)	**1.62**
Manaswini	14.2(100)	10.2(71)	12.8(90)	**12.4**	1.73(100)	1.52(89)	1.63(94)	**1.63**
Konarka	12.6(100)	12.3(98)	12.4(98)	**12.8**	1.46(100)	1.17(80)	1.35(92)	**1.33**
Mean	**15.4(100)**	**11.8(77)**	**14.1(91)**	13.8	**1.62(100)**	**1.37(85)**	**1.56(96)**	1.52
	V	S	V x S		V	S	V x S	
Sem(±)	0.431	0.305	0.747		0.029	0.021	0.05	
CD 5%	1.24	0.877	2.148		0.084	0.059	0.145	
CV %	9.402				5.75			

observed in cultivar Konark followed by Manaswini and maximum leaf thickness was observed in cultivar Lalat followed by Parijat under moisture stress condition. Similarly, leaf thickness was highest in Lalat followed by Parijat and lowest in variety Sidhant under salicylic acid treatment. Das and Kalita.(2010) reported similar results but Hofstra and Hesketh (1975) recorded higher leaf thickness under moisture stress. This was contrary to this report.

4.1.4 Maximum root length and thickness

Data on root length and thickness have been depicted in Table 4.4. Results pertaining to root length revealed that there was significant variation in root length was observed among the rice genotypes. On an average stress reduced the root length 23% as compare to control while application of Salicylic acid during stress reduced the reduction percentage to 9% in comparison to nonstress. Sidhant produced significantly longer mean roots

Table 4.4 Effect of water stress on Root Length(cm) and Root Thickness(mm) at PI Stage of rice genotypes

Genotypes	Root Length(cm)				Root Thickness((mm)			
	S0	S1	S2	Mean	S0	S1	S2	Mean
Parijata	17.1(100)	11.8(69)	13.0(80)	**14.2**	1.75(100)	1.50(86)	1.70(97)	**1.65**
Sidhant	17.9(100)	12.2(68)	16.6(93)	**15.6**	1.72(100)	1.32(78)	1.41(83)	**1.48**
Mandakini	15.4(100)	12.3(80)	13.7(88)	**13.8**	1.52(100)	1.24(82)	1.42(94)	**1.39**
Lalat	15.1(100)	12.1(80)	14.1(93)	**13.8**	1.57(100)	1.48(94)	1.52(96)	**1.62**
Manaswini	14.2(100)	10.2(71)	12.8(90)	**12.4**	1.73(100)	1.52(89)	1.63(94)	**1.63**
Konarka	12.6(100)	12.3(98)	12.4(98)	**12.8**	1.46(100)	1.17(80)	1.35(92)	**1.33**
Mean	**15.4(100)**	**11.8(77)**	**14.1(91)**	13.8	**1.62(100)**	**1.37(85)**	**1.56(96)**	1.52
	V	S	V x S		V	S	V x S	
Sem(±)	0.431	0.305	0.747		0.029	0.021	0.05	
CD 5%	1.24	0.877	2.148		0.084	0.059	0.145	
CV %	9.402				5.75			

length than all the genotypes. On the other hand Parijat all most at par with Mandakini & Lalat. Manaswini which had the least potential in this trait. Similar reduction has been reported by Chang ***et al.*** *(1972)*. Potentiality to long rooting is a tool of exploring water from deeper soil layer during water stress. Thus root lengths can be good indicators of stress tolerance in rice (Gracia and Gonzalez, 1997; Reddy and Vanaja, 2006) so far as the extraction of moisture from deeper zones was concerned. Possibly inefficient rooting habit of Manaswini limit its cultivation in drought prone Zone.Morever increase in root length potential in Sidhant & Konark would be an important improvement over Check variety in both duration.

Root thickness reduced when plant exposed to drought stress as compared to irrigated condition. There was 15% reduction in root thickness have been observed under stress however application of SA decreases the thickness 4% as compared to control condition. Variety Parijat,Lalat & Manaswini have significantly higher mean value for this trait and these variety are statistically at par.Konark recorded lowest mean thickness. Sadasivam *et al.*(2000) reported similar results in rice genotypes. Generally, thick roots confer drought resistance to water flux and hence, greater capacity of water uptake from deeper soil layers. Constitutively thick and deep roots and production of more root length in response to water stress are drought resistance traits in rice.

4.1.5 Root volume (cc)/plant

Data on effect of moisture stress on root volume were presented in Table 4.5 and Fig. 4.5. The pattern of root development was studied by measuring volume per hill after imposition of drought at panicle initiation stage.

It was observed that the root volume decreased in all the genotypes in general (47 % on an average) when stress was imposed. Foliar application of

SA (100ppm) significantly increases the root volume irrespective of genotypes. Root volume of Lalat had significantly highest mean value (7.03cc).Parijat and Mandakini had lowest mean value for this trait. Except Lalat, all the varieties were at par to each other. Similar results have been documented by IRRI in 1990.

Table-4.5 Effect of water stress on Root dry weight(g) and Root volume(cc) per hill at PI Stage of rice genotypes

Genotypes	**Root dry weight(g)**				**Root volume(cc)**			
	S0	**S1**	**S2**	**Mean**	**S0**	**S1**	**S2**	**Mean**
Parijata	7.67(100)	2.84(37)	3.60(47)	**4.7**	4.57(100)	2.50(55)	2.87(63)	**3.31**
Sidhant	6.06(100)	2.61(43)	3.12(57)	**3.93**	4.90(100)	2.50(51)	3.42(70)	**3.61**
Mandakini	5.25(100)	1.81(34)	2.78(51)	**3.28**	4.95(100)	2.40(48)	2.75(56)	**3.37**
Lalat	10.77(100)	2.40(22)	2.96(27)	**5.37**	8.33(100)	5.07(61)	7.70(92)	**7.03**
Manaswini	4.92(100)	1.63(33)	2.47(50)	**3.01**	4.27(100)	2.53(59)	3.40(80)	**3.4**
Konarka	4.29(100)	1.50(35)	2.43(57)	**2.74**	6.03(100)	2.50(41)	2.93(49)	**3.82**
Mean	**6.49(100)**	**2.13(33)**	**2.89(45)**	3.84	**5.51(100)**	**2.92(53)**	**3.84(70)**	4.09
	V	S	V x S		V	S	V x S	
Sem(±)	0.115	0.081	0.199		0.181	0.128	0.314	
CD 5%	0.33	0.233	0.571		0.521	0.368	0.902	
CV %	8.96				13.29			

4.1.6 Root dry weight

Data on root dry weight have been depicted in Table 4.5. Results pertaining to root dry weight revealed that the root dry weights decreased on imposition of stress. Application of Salicylic acid (100ppm) in moisture stress results significant increased in root dry weight. The reduction of root dry weight was 77% in stress but SA application in stress the reduction was reduced to 55%.The Maximum root dry weight was recorded in case of Lalat (2.84 g) followed by Sidhant (2.61 g) and Konark (1.5 g), which were significantly lower than that of control. Fugi and Horie (2001) also observed similar decrease. Houkue and Kobata (1998) observed root dry weights to increase in tolerant genotypes compared to susceptible one.

4.2 PHYSIOLOGICAL PARAMETERS

4.2.1 Total dry matter accumulation

Data on total plant biomass have been presented in Table 4.6 and Fig. 4.3.Total dry matter or total plant biomass studies revealed that as the plants were exposed to moisture stress the total dry matter decreased as compared to the control. Application of SA (100ppm) to stress significantly increases total plant dry matter by reducing the impact of stress. The reduction of TDM on an average values due to imposition of stress was 28% and to that of 16% in SA treatment in stressed plants irrespective of variety. Lalat recorded the highest mean dry matter of 51.78 g hill^{-1} followed by Parijat with 39.91 g hill^{-1} and Manaswini had the least of 29.54 g hill^{-1}. Konark had the highest decrease of 38 % in stress followed by Lalat and Mandakini registering a decrease of 34 and 31 % respectively.

Total plant biomass decreased significantly when the plants were exposed to moisture stress . Similar decreases was also observed by Kobata et al., (1996), Chauhan *et al.* (1999), Deka and Baurah (2000), Fuji and Horie (2001).

4.2.2 Root shoot weight ratio

Moisture stress was found to significantly change the root: shoot ratio in rice (Table 4.6) On an average root: shoot ratio was decreased by 47% due to the moisture stress but application of SA the reduction was minimized to18%. Among the cultivars, the root: shoot ratio was more in cultivar Parijat and less in cultivar Konark,Manaswini and Sidhant. Acceleration of root growth in cultivar Parijat and Mandakini and Lalat under moisture stress condition could also result in the establishment of seedlings more rapidly and avoidance of moisture stress. Which corroborates with the results of Chang *et al.*(1972), Levitt (1980)

Table-4.6 Effect of water stress on total dry matter(g/hill),root shoot weight ratio and root length density(cm/cc) at harvesting stage

Genotypes	**Total Dry matter(g/hill)**				**Root shoot Weight Ratio**				**Root Length Density(cm/cc)**			
	S0	**S1**	**S2**	**Mean**	**S0**	**S1**	**S2**	**Mean**	**S0**	**S1**	**S2**	**Mean**
Parijata	45.17(100)	34.67(77)	39.91(88)	**39.91**	0.46(100)	0.31(67)	0.45(98)	**0.41**	3.72	4.73	4.52	**4.32**
Sidhant	42.69(100)	34.37(81)	37.80(89)	**38.29**	0.49(100)	0.21(43)	0.32(65)	**0.34**	3.65	4.86	4.84	**4.45**
Mandakini	43.46(100)	29.85(69)	35.40(81)	**36.24**	0.41(100)	0.26(63)	0.38(93)	**0.35**	3.08	5.00	4.96	**4.22**
Lalat	65.05(100)	42.62(66)	47.67(73)	**51.78**	0.47(100)	0.25(53)	0.38(81)	**0.37**	1.82	2.42	1.82	**2.02**
Manaswini	32.19(100)	25.89(80)	30.52(95)	**29.54**	0.44(100)	0.21(48)	0.32(73)	**0.33**	3.34	4.01	3.78	**3.71**
Konarka	40.14(100)	24.99(62)	35.19(88)	**33.44**	0.43(100)	0.20(49)	0.34(79)	**0.33**	2.08	4.82	4.58	**3.82**
Mean	**44.79(100)**	**32.06(72)**	**37.75**	38.2	**0.45(100)**	**0.24(53)**	**0.37(82)**	0.35	**2.94**	**4.32**	**4.08**	3.75
	V	**S**	**V x S**		**V**	**S**	**V x S**		**V**	**S**	**V x S**	
Sem(±)	0.754	0.533	1.306		0.012	0.008	0.021		0.196	0.139	0.34	
CD 5%	2.167	1.533	3.754		0.034	0.024	0.059		0.564	0.399	0.977	
CV %	5.92				10.09				11.96			

4.2.3 Root Length Density:

The root mass density was studied for its response to imposition of stress at PI stage and depicted in Table 4.6. The study revealed that the root length density increased with the increase in moisture stress.

When stress was applied at panicle initiation stage the root length density on an average increased compared to control. Application of SA did not yield any spectacular results however a decreasing trend was observed. Mandakini had the highest root length density of 5.1 cm cc^{-1} followed by Sidhant (4.86 cm cc^{-1}) and Konark (6.07 cm cc^{-1}) in stress.

Root length studies revealed that the root length densities on an average increased compared to control. The differences among the varieties were significant. The treatments with SA application registered 5% over the stress.which corroborates with the results of Kamoshita *et al.*, 2000 and Tuong *et al.*, 2002.

4.2.4 Net assimilation rate (NAR)

The studies revealed that(Table:4.7) in general moisture stress at panicle initiation stage resulted in a decrease in NAR. The stress treatments applied with SA registered a significant increases in NAR compared to their stress treated counterparts.On overall mean values there was a reduction of 41% due to imposition of stress but application of SA in stressed plants the reduction was 27% as compare to nonstress. The highest mean NAR of 0.492 g cm^{-2} day^{-1} was recorded in case of cultivar Lalat followed by Parijat(0.484 g cm^{-2} day^{-1}),Mandakini(0.449 g cm^{-2} day^{-1}) during panicle initiation.

The highest reduction was also recorded for variety Manaswini(49%) followed by Lalat and Konark in stress as compare to control. Similar results have been obtained by Ichwantoari *et al.* (1989). Higher NAR concomitantly enhanced the carbohydrate status of the plant, which is an adaptive feature of drought resistance ability in rice plants as suggested by Chaturvedi *et al.* (1996).

Table-4.7 Effect of water stress on Net Assimilation Rate(NAR) & Crop Growth Rate(CGR,g m^2 d^{-1}) at PI stage

Genotypes	**Net Assimilation Rate(NAR)**				**Crop Growth Rate(CGR,g m^2 d^{-1})**			
	S0	S1	S2	Mean	S0	S1	S2	Mean
Parijata	0.63(100)	0.37(59)	0.45(72)	**0.48**	14.78(100)	11.47(77)	12.8787)	**13.04**
Sidhant	0.52(100)	0.34(65)	0.44(84)	**0.44**	15.63(100)	8.90(57)	12.19(78)	**12.24**
Mandakini	0.58(100)	0.35(60)	0.40(68)	**0.45**	15.18(100)	10.32(67)	13.18(86)	**12.89**
Lalat	0.62(100)	0.36(58)	0.49(80)	**0.49**	14.5(100)	11.43(78)	13.45(93)	**13.13**
Manaswini	0.55(100)	0.29(51)	0.35(64)	**0.40**	14.74(100)	9.49(64)	11.30(76)	**11.84**
Konarka	0.48(100)	0.28(58)	0.34(71)	**0.37**	13.56(100)	8.78(66)	10.12(74)	**10.82**
Mean	**0.56(100)**	**0.33(59)**	**0.41(73)**	0.44	**14.73(100)**	**10.06(68)**	**12.18(83)**	12.33
	V	S	V x S		V	S	V x S	
Sem(±)	0.008	0.005	0.013		0.269	0.19	0.466	
CD 5%	0.022	0.016	0.038		0.774	0.547	1.34	
CV %	5.28				6.55			

4.2.5 Crop Growth Rate (CGR)

Data on crop growth rates have been presented in Table 4.7 and Fig. 4.4. When stress was applied at panicle initiation stage, the CGR reduced in all the varieties. Stress treatments applied with SA recorded significantly higher CGRs as compared to stress. There was a general reduction of 32% in stress as compare to nonstress but application of SA the reduction was minimized to 18%. The highest mean CGR of 13.13 g m^{-2} day^{-1} was recorded for Lalat followed by Parijat with 13.04 g m^{-2} day^{-1} and Konark the least with 10.82 g m^{-2} day^{-1}. Sidhant registered the highest reductions (43 %) in CGR followed by

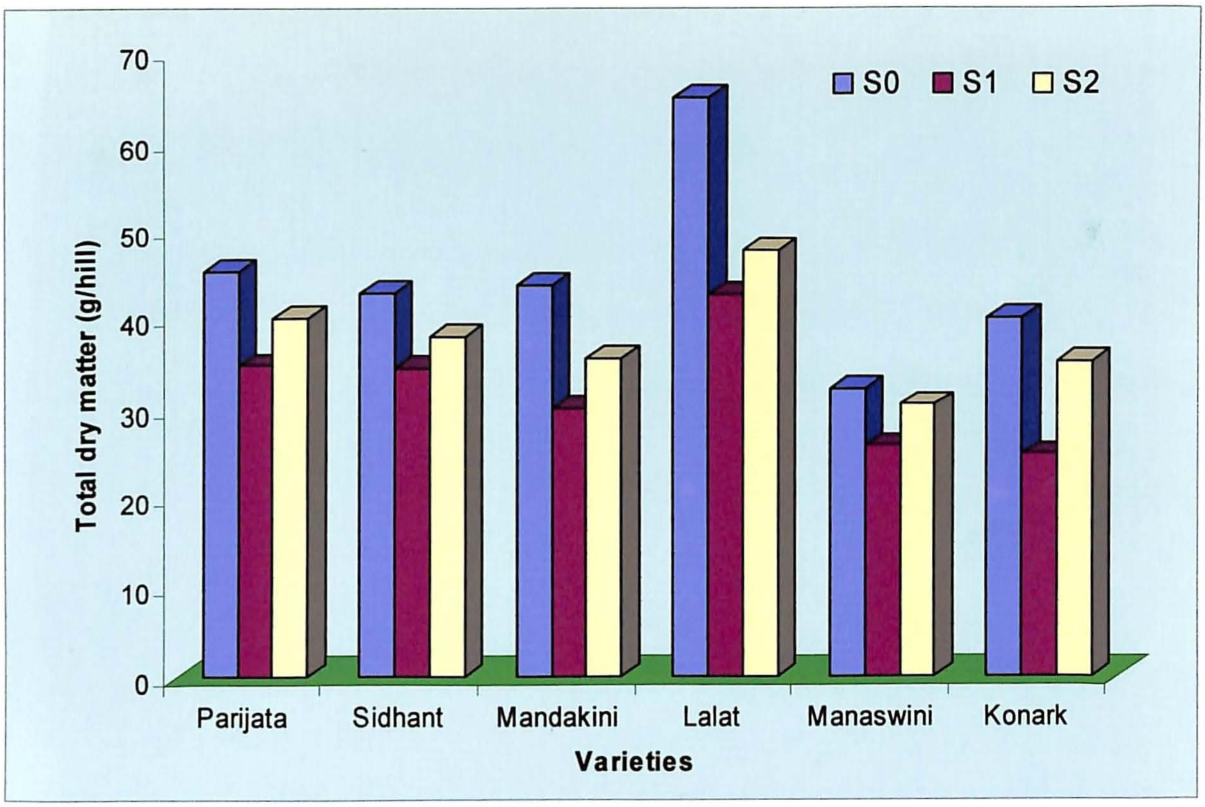


Fig. 4.3 **Effect of water stress on total dry matter(g/hill at harvesting stage of rice varieties.**

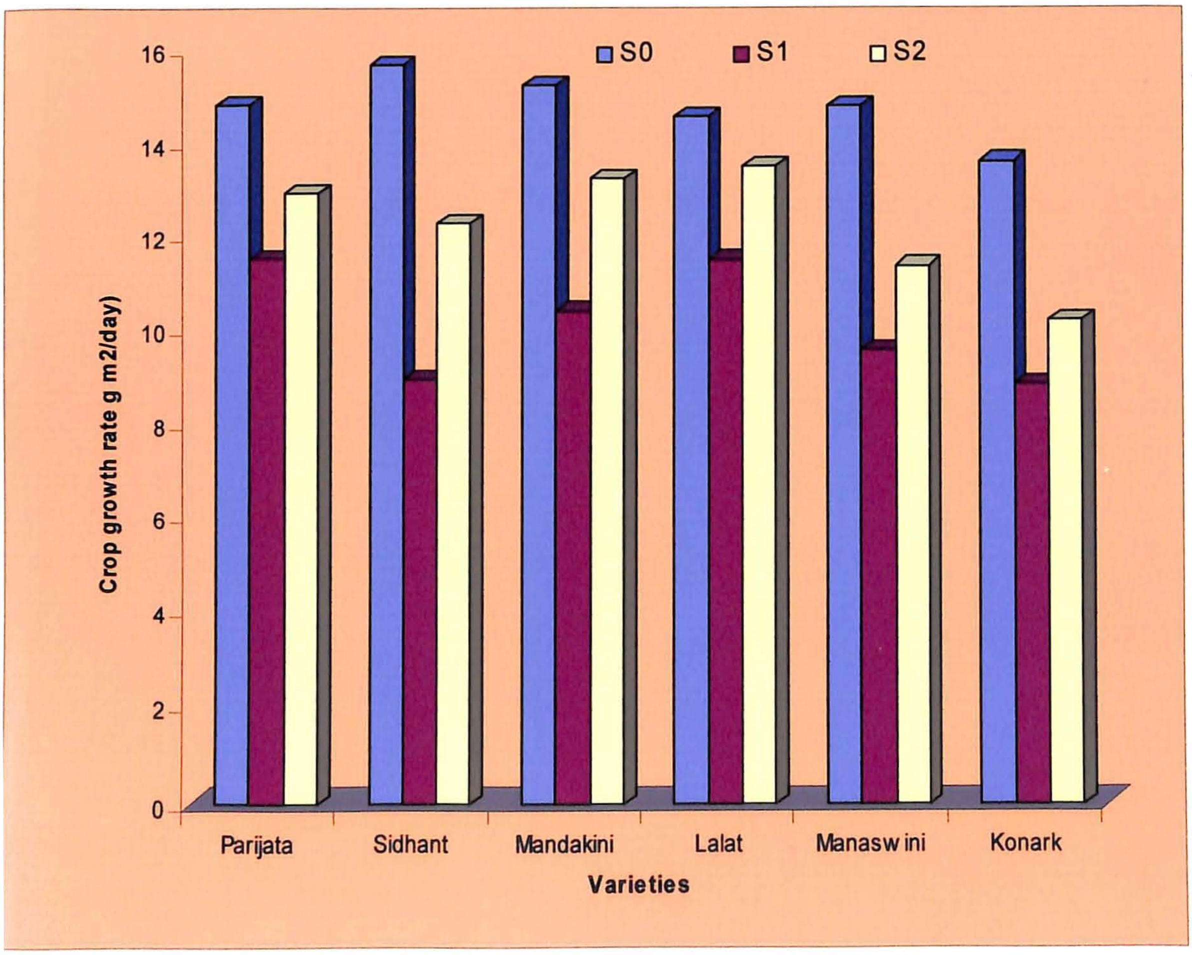


Fig. 4.4 **Effect of water stress on crop growth rate(CGR,g m^2 d^{-1}) at PI stage of rice varieties.**

Manaswini(36%),Konark(35%) and lowest reduction was observed in Parijat(23%) & Lalat(22%) in moisture stress condition.

SA application significantly increases CGR in water stress and the increased was to the tune of 15 % over stress. Konark recorded the lowest CGR of 10.12 g m^{-2} day^{-1} and Lalat the highest with a CGR of 13.45 g m^{-2} day^{-1}.in SA treatment.

This corroborates with the results of Chandra *et al.* (2005), who observed reductions to the tune of 24% in CGR at later stages in wheat crop.

4.2.6 Leaf area per hill

Data on effect of moisture stress on leaf area were depicted in Table 4.8. The pattern of leaf area development was studied by measuring leaf area per hill after imposition of stress PI stage.

It was observed that the leaf area decreased in all the genotypes in general (35 % on an average) when moisture stress was imposed. Among the stress treatments, plants sprayed with SA (100ppm) had significant increased(20% over the stress) on leaf area was noticed. Leaf area decreased significantly in variety Manaswini(41%),Konark(39%) and Sidhant the least as compared to control. Parijata recorded the largest leaf area of 579 cm^2& lowest leaf area of 444.6 cm^2 was recorded for Konark. Variety Parijat was at par with variety Lalat and Sidhant. The interaction effect on leaf area between varieties and treatments was noticed to be significant.

This corroborates with result of (Day, 1981), Blum, (2000), Chauhan *et al.*, (1999), (Deka and Baurah, 2000), Similar leaf area reduction was also reported in wheat by Nagarajan and Rane, 2000.

Table 4.8 **Effect of water stress on leaf area(cm2) & leaf area index and leaf area duration per hill at PI stage of rice genotypes**

Genotypes	**Leaf Area(cm^2)**				**Leaf Area Index**				**Leaf Area Duration**			
	S0	**S1**	**S2**	**Mean**	**S0**	**S1**	**S2**	**Mean**	**S0**	**S1**	**S2**	**Mean**
Parijata	852.3(100)	579.0(68)	768.0(90)	**733.1**	4.62(100)	3.05(66)	3.91(85)	**3.86**	7.33(100)	5.63(77	7.05(96)	**6.67**
Sidhant	833.0(100)	573.3(69)	718.1(86)	**708.1**	4.41(100)	2.99(68)	4.23(96)	**3.88**	7.85(100)	5.38(67)	6.93(88)	**6.72**
Mandakini	844.6(100)	538.7(64)	732.0(87)	**705.2**	4.56(100)	2.74(60)	3.61(80)	**3.65**	7.65(100)	5.28(70)	6.49(85)	**6.47**
Lalat	860.6(100)	574.3(67)	741.3(86)	**725.5**	4.65(100)	2.87(63)	3.94(86)	**3.82**	7.74(100)	5.75(74)	7.23(93)	**6.91**
Manaswini	774.5(100)	458.5(59)	671.6(87)	**635.0**	3.89(100	2.35(61)	2.83(73)	**3.03**	6.68(100)	4.61(69)	5.20(78)	**5.50**
Konarka	727.33(100)	444.6(61)	533.4(73)	**568.4**	3.67(100)	2.28(62)	2.52(69)	**2.83**	6.50(100)	4.60(71)	4.96(76)	**5.35**
Mean	**815.44(100)**	**528.1(65)**	**694.2(85)**	679.2	**4.30(100)**	**2.71(63)**	**3.51(82)**	3.51	**7.29(100)**	**5.21(71)**	**6.31(87)**	6.27
	V	**S**	**V x S**		**V**	**S**	**V x S**		**V**	**S**	**V x S**	
Sem(±)	8.891	6.287	15.4		0.072	0.051	0.125		0.081	0.057	0.14	
CD 5%	25.55	18.067	44.254		0.208	0.147	0.36		0.233	0.165	0.403	
CV %	3.93				6.19				3.88			

4.2.7 Leaf Area Duration (LAD)

Data on leaf area duration have been presented in Table 4.8. The LAD values recorded for different varieties showed a decreasing trend with moisture stress at PI stage among all the varieties.

Moisture stress resulted in a decrease of LAD. There was about 29 % decreased LAD recorded in stress condition while stress+ treatments the decrease was only 13% as compared to stress. Lalat registered the highest mean LAD(6.91) followed by Sidhant (6.72), Parijata (6.67), Mandakini (6.47) and Konark (5.35), the least. The highest decrease was found in case of Sidhant (33%) followed by Manaswini 31% and Mandakini 30% and the least reduction was recorded in Parijata (23%) over the control. Application of SA to stress treated plants resulted an increase in LAD values by about 16 % over that of only stress treated counterparts. Variety Lalat was at par with varieties Parijat and Sidhant. Chandra *et al.*, 2005 reported similar results in rice genotypes

4.2.8 Leaf Moisture Retention Index (LMRI):

Data on Leaf moisture retention index (LMRI) have been depicted in. The LMRI was found to decrease when plants were subjected to moisture stress (Table-4.9). On application SA higher LMRI were recorded as compared to their unapplied counterparts.The LMRI was observed to decrease((60%) in stress but Stress treatments applied with SA recorded a higher LMRI(44%) as compared to stress treatments. At PI stage maximum mean LMRI of 10.26 % was recorded in leaves of Lalat closely followed by Sidhant with 10.03% and Parijata 9.62%. This corroborates with result of Sandhu and Lauda (1958) and Gupta and Sharma, (2006) in wheat and rice genotypes respectively. Maximum reduction was observed in case of Konark(67%) followed by Mandakini(60%) and Sidhant (59%) in stress condition.

Table-4.9 Effect of water stress on Leaf Moisture Retention Index (LMRI) & Canopy Temperature Depression (^{0}C) at PI stage of Rice Genotypes

Genotypes	Leaf Moisture Retention Index(LMRI,%)				Canopy Temperature Depression(^{0}C)			
	S0	S1	S2	Mean	S0	S1	S2	Mean
Parijata	12.52(100)	5.72(46)	10.61(85)	**9.62**	-3.4	-4.3	-4.1	**-3.9**
Sidhant	13.27(100)	5.21(39)	11.61(87)	**10.03**	-5.3	-4.3	-4.3	**-4.7**
Mandakini	11.95(100)	4.63(38)	10.81(90)	**9.13**	-5.7	-5.0	-5.3	**-5.3**
Lalat	13.40(100)	5.55(41)	11.82(88)	**10.26**	-4.0	-2.0	-3.0	**-3.0**
Manaswini	10.53(100)	4.31(40)	7.93(75)	**7.59**	-6.7	-5.0	-6.0	**-5.9**
Konarka	10.31(100)	3.49(34)	9.52(92)	**7.77**	-4.0	-1.0	-2.0	**-2.3**
Mean	**12.00(100)**	**4.82(40)**	**10.38(86)**	9.07	**-4.8**	**-3.6**	**-4.1**	-4.2
	V	**S**	**V x S**		**V**	**S**	**V x S**	
Sem(±)	0.01	0.01	0.01		0.18	0.13	0.31	
CD 5%	0.02	0.01	0.04		0.52	0.37	0.9	
CV %	0.24				NS			

4.2.9 Photosynthesis and ancillary parameters

i) Photosynthesis Rate(Pn)

From the data presented in Table 4.10 and Fig.4.5 indicated that due to imposition of stress there was significantly decrease in photosynthetic rate in all the varieties tested in present investigation. It was observed from the data that the photosynthetic rate, in general, was reduced to 42 % when stress was imposed but application of various drought mitigating chemicals in stress, the reduction was reduced to 32%, 31.3%, 41%, 36.3%, 34.2% & 26.08% by chemicals viz.Cytokinin,SA,Urea,K_2SO_4,ascobic acid & brassinosteroid(Bs) respectively as compared to control.

Table-4.10 Effect of drought mitigating Chemicals on Photosynthesis rate(Pn) during moisture stress on rice genotypes(PI Stage)

Genotypes	Photosynthesis rate(μmol $CO_2m^{-2}s^{-1}$)							
	Control	Stress	Cyt	SA	Urea	K_2SO_4	AA	Bs
Parijata	21.54	12.67	13.47	13.57	12.63	13.67	14.73	15.00
Sidhant	17.73	14.23	14.73	15.60	14.47	15.50	15.43	16.60
Mandakini	19.53	13.40	15.70	16.30	13.70	14.57	14.90	16.37
Lalat	23.37	13.20	14.70	15.67	13.03	13.27	13.70	16.33
Manaswini	16.73	7.53	10.13	8.70	7.97	8.73	8.33	9.67
Konarka	14.83	5.30	8.57	8.23	4.90	6.67	7.67	9.27
Mean	**18.95**	**11.06**	**12.88**	**13.01**	**11.12**	**12.07**	**12.46**	**13.87**
Sem(±)	0.568	0.454	0.354	0.267	0.137	0.295	0.215	0.267
CD 5%	1.218	0.974	0.760	0.573	0.295	0.632	0.461	0.572
CV %	3.668	5.033	3.368	2.517	1.514	2.992	2.111	2.353

The varieties like Sidhant, Mandakini and Lalat exhibited their excellence for their minimum reduction in photosynthetic rate under stress as compared to other varieties. Application of chemicals under stress increased the photosynthetic rate 16.5%, 17.5%, 0.5%, 9.1%, 12.6% & 25.4% by chemicals Cytokinin, SA, Urea, K_2SO_4, Ascobic Acid & Bs respectively as compare to stress. Variety Sidhant had higher photosynthesis (14.23) followed by Mandakini (13.4) and Lalat (13.2). The reduction of photosynthesis rate under stress and stress + chemical application was minimum in Sidhant, Mandakini, Lalat & Parijat whereas maximum reduction was noticed from Manaswini & Konark in above treatments. It was observed that the reduction on photosynthesis rate between the treatment and variety was significant. Similar results have been reported by Wada *et al.*, 2001; Ravindrakumar *et al.*, 2003; Jin *et al.*, 2003 in rice variety.

(ii) Stomatal conductance(Gs)

The data pertaining to stomatal conductance (Gs) was presented in Table 4.11 and Fig.4.5. From the data it was revealed that water stress at PI stage resulted drastic reduction of stomatal conductance in almost all the varieties. In general, stomatal conductance was decreased to the tune of 42.4 % on account of stress whereas chemical application viz .SA, Bs,Cyt & K_2SO_4 in stress the decreases 27.2%,24.5 %,36.3%,36.4% respectively over control(other chemical effect did not show any spectacular results).

Table-4.11 Effect of drought mitigating Chemicals on stomatal conductance(Gs) during moisture stress on rice genotypes.

Genotypes	**Stomatal conductance(µmol $CO_2m^{-2}s^{-1}$)**							
	Control	**Stress**	**Cyt**	**SA**	**Urea**	**K_2SO_4**	**AA**	**Bs**
Parijata	0.37	0.19	0.24	0.23	0.14	0.15	0.19	0.21
Sidhant	0.34	0.23	0.21	0.27	0.18	0.26	0.24	0.27
Mandakini	0.23	0.17	0.19	0.22	0.16	0.19	0.17	0.23
Lalat	0.41	0.26	0.26	0.34	0.23	0.32	0.27	0.30
Manaswini	0.33	0.17	0.23	0.19	0.22	0.18	0.24	0.26
Konarka	0.27	0.14	0.14	0.16	0.14	0.16	0.12	0.26
Mean	0.33	0.19	0.21	0.24	0.18	0.21	0.20	0.25
Sem(±)	**0.023**	**0.014**	**0.014**	**0.009**	**0.013**	**0.015**	**0.013**	**0.016**
CD 5%	**0.049**	**0.031**	**0.031**	**0.019**	**0.028**	**0.032**	**0.028**	**0.034**
CV %	**8.595**	**9.068**	**8.215**	**4.629**	**9.020**	**8.634**	**7.724**	**7.661**

Stomatal conductance was highest for Lalat in SA treatment (0.34 µ mol $m^{-2}s^{-1}$), followed by Bs treatment (0.30 µ mol $m^{-2}s^{-1}$) in the same variety. In stress+urea, the mean stomatal conductance was lowest(0.18 µ mol $m^{-2}s^{-1}$)among all the treatment and highest mean value 0.25 µ mol $m^{-2}s^{-1}$ was observed in BR treatment. The lowest stomatal conductance was observed in Konark (0.14µmol m^{-2} S^{-1}) followed by Mandakini & Manaswini (0.17 µmol m^{-2} s^{-1}) each in stress condition.This corroborates with result of Dingkuhn *et al.*, 1989; Dingkuhn *et al.*, 1991; Price *et al.*, 1997; Hoque and Kobata, 1998.

iii) Transpiration

From the Table 4.12 Fig. 4.5, it was revealed that imposing of water stress at PI stage there was significant reduction of transpiration rate in all the varieties. The minimum transpiration rate was observed by Konark (3.29 m mol m^{2}S^{-1}) followed by Manaswini (3.36m mol m^{2}S^{-1}) among the varieties due to imposition of stress. In general the transpiration rate was reduced to 34 % in stress and 27,28,32,26,33 and 22 % in stress + chemical application viz.Cyt, SA, Urea, K_2SO_4, Ascobic Acid & Bs respectively as compared to control.

Table-4.12 Effect of drought mitigating Chemicals on Transpiration rate during moisture stress on rice genotypes

Genotypes	Transpiration rate(mmol m^{-2}s^{-1})							
	Control	Stress	Cyt	SA	Urea	K_2SO_4	AA	Bs
Parijata	8.27(100)	4.93(59)	6.30(76)	5.90(71)	5.43(65)	6.36(77)	5.57(67)	6.03(73)
Sidhant	8.40(100)	3.67(43)	4.50(53)	4.54(54)	4.36(52)	4.57(54)	4.40(52)	4.63(55)
Mandakini	5.57(100)	3.60(57)	4.19(75)	3.63(65)	3.54(63)	4.33(76)	3.63(65)	4.40(78)
Lalat	9.46(100)	4.27(45)	6.43(67)	5.50(58)	5.40(57)	5.80(61)	5.60(59)	6.53(69)
Manaswini	5.62(100)	3.36(59)	3.53(62)	5.13(91)	4.53(80)	4.60(81)	4.60(82)	5.46(93)
Konarka	5.20(100)	3.29(63)	4.60(88)	4.28(82)	4.23(81)	4.43(85)	3.63(69)	4.67(89)
Mean	7.08(100)	3.78(53)	4.92(69)	4.86(68)	4.58(64)	5.02(71)	4.57(64)	5.29(74)
Sem(±)	**0.35**	**0.11**	**0.22**	**0.18**	**0.15**	**0.21**	**0.19**	**0.24**
CD 5%	**0.74**	**0.24**	**0.47**	**0.39**	**0.32**	**0.45**	**0.40**	**0.51**
CV %	**6.29**	**7.27**	**5.45**	**4.63**	**3.96**	**5.17**	**5.01**	**5.54**

The minimum reduction in transpiration rate was noticed by BR treatment under stress where as maximum reduction was observed in Ascorbic acid. The reduction in transpiration rate between variety and treatment was found to be significant. Transpiration rate reduced markedly by water stress (Dingkuhn *et al.*, 1989; Kobata *et al.*, 1996; Cabuslay *et al.*,1999; Wade *et al.*, 2000; Ravindrakumar *et al.*, 2003). Cultivar differences were reported by many authors (Wade *et al.*, 2000; Cabuslay *et al.*, 2002).which are in consonance with the presnt findings.

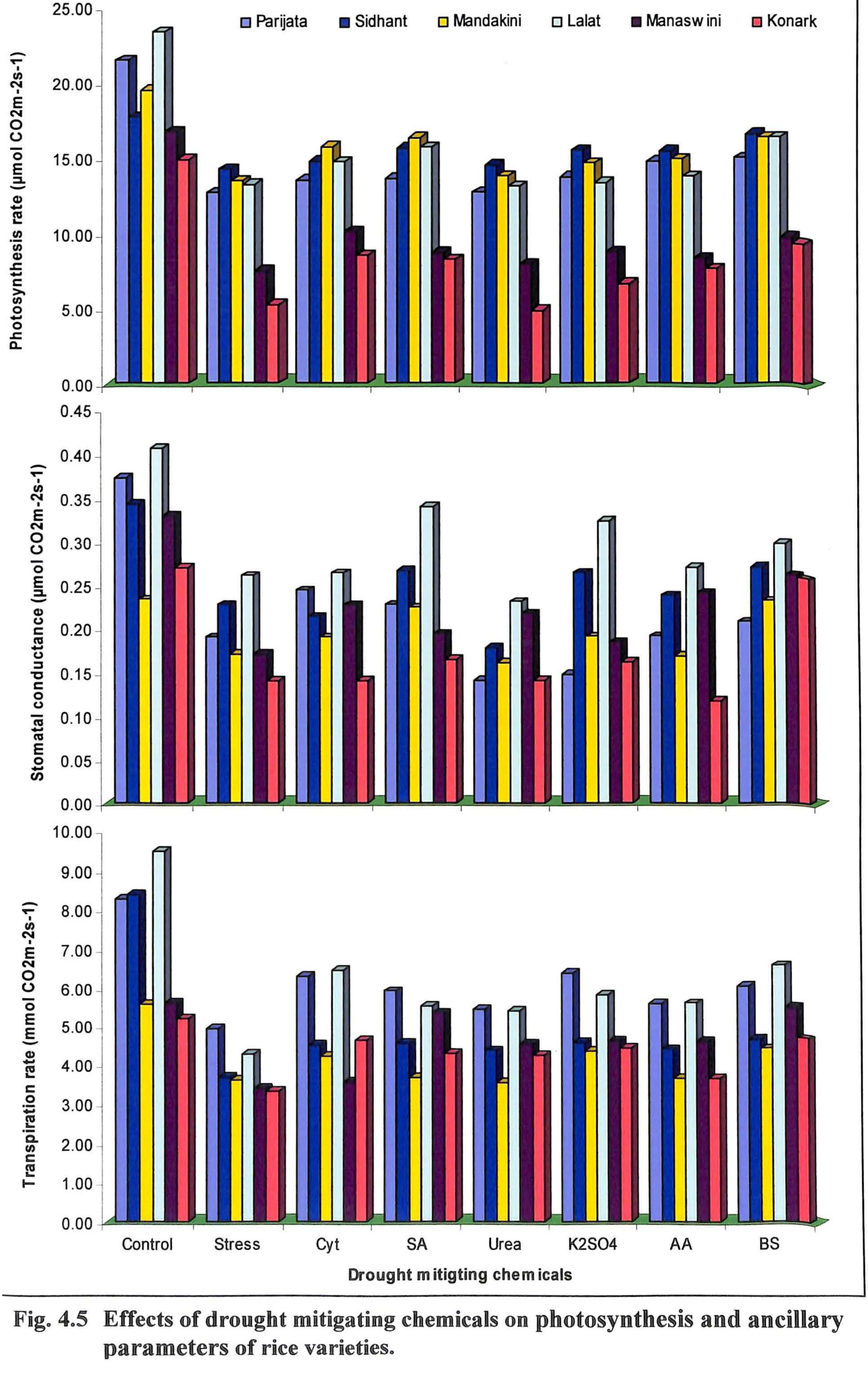


Fig. 4.5 Effects of drought mitigating chemicals on photosynthesis and ancillary parameters of rice varieties.

4.2.1 Canopy Temperature Depression(CTD)

The data reflected in Table 4.9 indicated that due to imposition of stress the canopy temperature depression decreased significantly. Overall mean values indicated that there was decrease of temperature by 14 % due to stress but application of SA in stressed plants it was reduced to 4 % as compared to non-stress. Except varieties Sidhant and Konark rest 3 varieties Lalat, Mandakini & Manaswini maintained a higher canopy temperature depression and these varieties are superior to their counterpart. Higher canopy temperature depression is related to higher cooling surface of the canopy. This corroborates with result of Ravindrakumar *et al.*, 2002; Lafitte *et al.*, 2003. A cooler canopy temperature under stress has been reported to be a measure of drought avoidance (Blum, 1988), which indicates maintenance of higher transpiration compared to susceptible ones.

4.3 BIOCHEMICAL PARAMETERS

4.3.1 Total Chlorophyll Content

The chlorophyll content of leaf was estimated at PI stage. The data have been presented in Table 4.13 & Fig. 4.6. Moisture stress resulted decrease in total chlorophyll content at PI stages. Application of SA had significant impact on total chlorophyll content in leaf. Due to imposition of stress overall mean values the reduction of chlorophyll content was 52% to that of 27% on application of SA in stress as compared to non-stress.Among the varieties Mandakini recorded the highest mean chlorophyll content(2.38 mg g^{-1} FW leaf) and was at par to Parijat & Lalat. The lowest mean value was observed in variety Sidhant followed by Konark. Reductions in chlorophyll content in rice leaves have been observed by Deka (2000), Yamane, *et al.* (2003) and Das *et al.* (2005).

Table 4.13 Effect of water stress on total chlorophyll content (mg/g FW Leaf) , chlorophyll stability index(CSI,%) and Proline content of rice genotypes at PI stage

Genotypes	**Total Chlorophyll Content (mg g^{-1} FW Leaf)**				**Chlorophyll Stability Index(CSI,%)**				**Proline Content(μg g^{-1} fw of leaf)**			
	S0	**S1**	**S2**	**Mean**	**S0**	**S1**	**S2**	**Mean**	**S0**	**S1**	**S2**	**Mean**
Parijata	3.08(100)	1.50(49)	2.50(81)	**2.36**	92.25	44.43	68.18	**68.29**	104.17	330.21	458.26	**297.54**
Sidhant	2.78(100)	1.41(51)	1.80(65)	**2.00**	91.88	40.33	62.63	**64.95**	92.67	296.5	391.08	**260.07**
Mandakini	3.07(100)	1.37(44)	2.58(84)	**2.34**	89.95	43.67	64.43	**66.02**	71.73	352.9	450.5	**291.70**
Lalat	3.18(100)	1.61(50)	2.34(73)	**2.38**	91.78	45.27	65.22	**67.42**	95.83	365.28	452.62	**304.56**
Manaswini	2.96(100)	1.43(48)	2.07(70)	**2.15**	90.04	37.33	61	**62.79**	60.25	360.17	430.29	**283.57**
Konarka	2.87(100)	1.46(51)	1.92(67)	**2.08**	89.45	42.27	64.33	**65.35**	68.3	298.15	405.2	**257.22**
Mean	**2.99(100)**	**1.46(48)**	**2.20(73)**	2.22	**90.89**	**42.22**	**64.3**	65.8	**82.14**	**333.86**	**431.32**	280.27
	V	**S**	**V x S**		**V**	**S**	**V x S**		**V**	**S**	**V x S**	
Sem(±)	0.064	0.045	0.11		1.048	0.741	1.816		6.934	4.903	12.01	
CD 5%	0.183	0.129	0.316		3.013	2.13	5.218		19.925	14.089	34.512	
CV %	8.6				4.78				5.02			

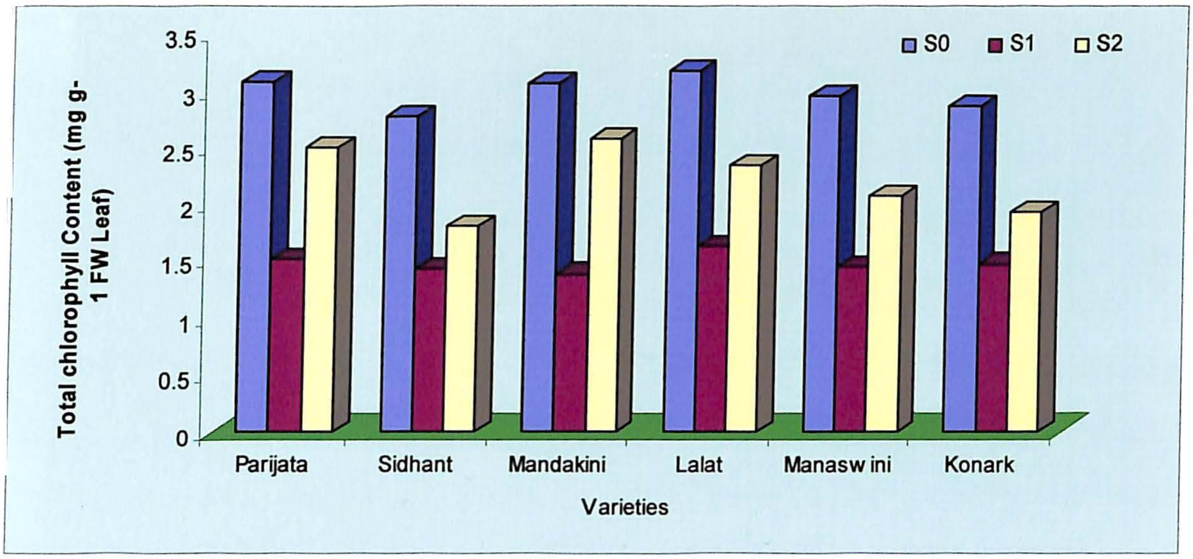


Fig. 4.6 **Effect of water stress on Total chlorophyll content (mg g^{-1} Fw Leaf) at PI stage of rice varieties.**

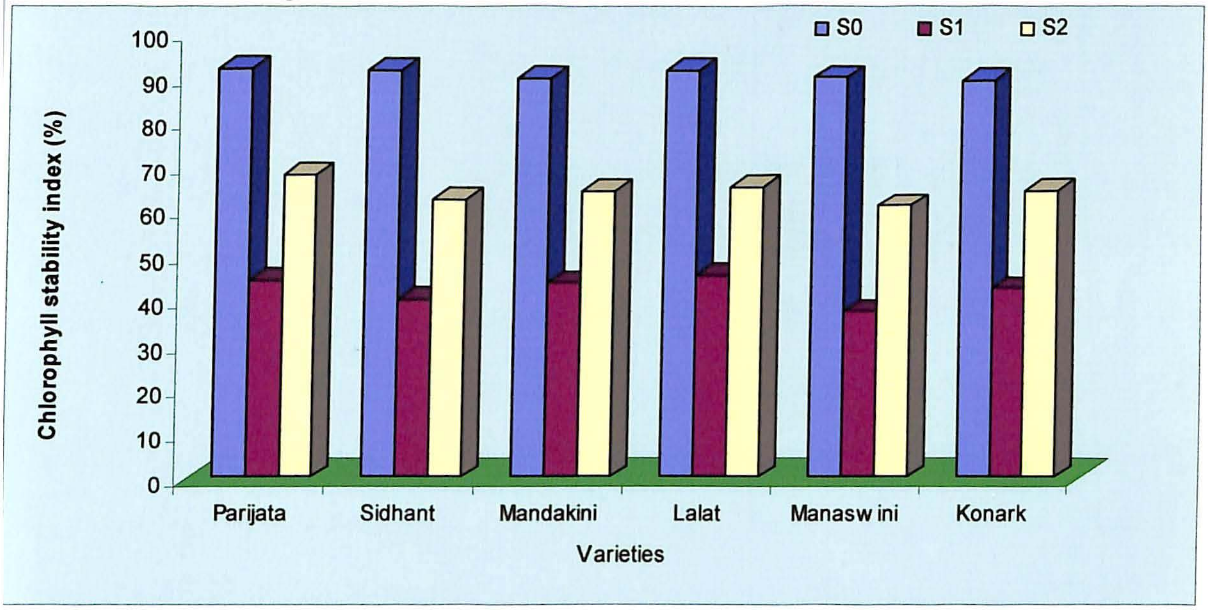


Fig. 4.7 **Effect of water stress on chlorophyll stability index(CSI,%) of rice varieties at PI stage.**

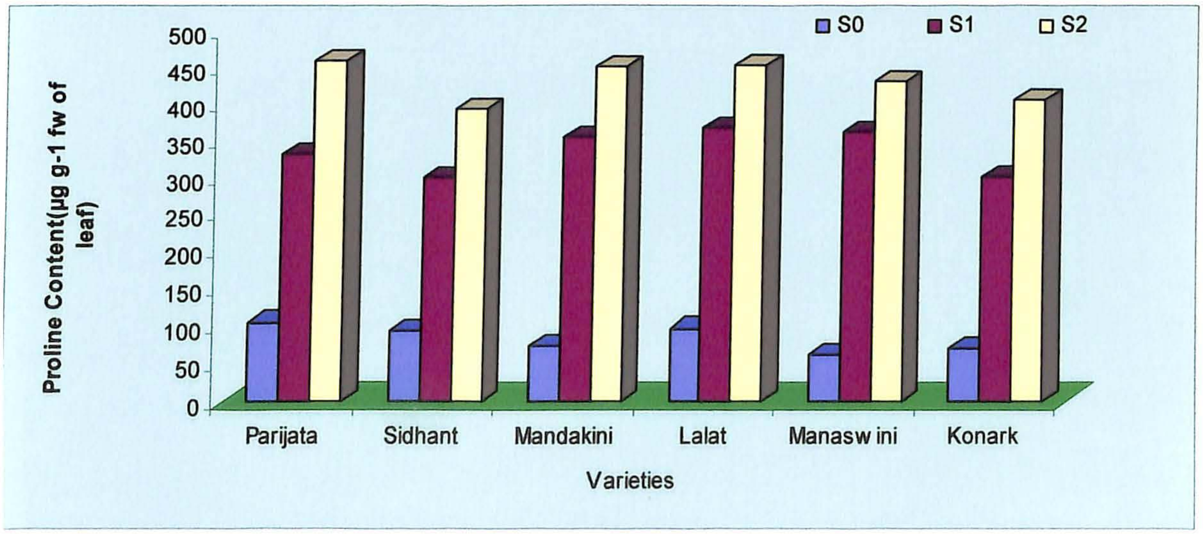


Fig. 4.8 **Effect of water stress on Proline content(mg g^{-1} fw of leaves) at PI stage of rice varieties.**

4.3.2 Chlorophyll stability index (CSI)

Data on chlorophyll stability index have been presented in table 4.13 & Fig.4.7. The study on chlorophyll stability index indicated that it significantly decreased with increase in moisture stress irrespective of varieties. The decrease was 54% in stress and 30% in SA treatment as compare to control. The highest mean CSI% was recorded in Parijat (68.29%) followed by Lalat (67.4%) and Manaswini recorded the least (62.79%).Moreover, variety Lalat was at par with varieties Sidhant, Mandakiniand Parijat. Application of SA significantly increases the chlorophyll stability index over the stressed plants. This corroborates with the results obtained by Agarie *et al.* (1995), Tyagi *et al.*, (1999).

4.3.3 Cell Membrane Stability Index and Relative Injury (RI)

The cell membrane stability index (CMSI) in leaf discs were presented in Table 4.14.In general, the water-stressed plants showed significant decrease in MSI but it was increased due to application of SA in stress irrespective of varieties.On an average CMSI in non-stressed plants were 64% where as 23% in stressed plant . There was highest mean CMSI (44.9%) recorded in Lalat whereas it was 31.9% in Konark. Similarlly in water stress condition Lalat showed higher CMSI followed by Parijat, Mandakini and Konark the lowest(20.7%) at PI stage. Application of SA increases the stability 9.3% over the stress condition. There were significant differences in interaction observed in between variety and treatment. Similar results found by Tyagi *et al.* (1999) they reported that tolerant varieties possess the highest membrane stability index.

Complete opposite trend was observed in case of relative injury (RI %). The highest RI (76.3%) was observed in stress whereas it was (42%) in SA application. The highest mean relative injury was observed in variety Manaswini (44.1%) followed by Konark (42.6%) and Sidhant the least. Kumar et al.(2008) reported by studying the wheat, that lowest RI indicating greater tolerance to high temperature and water stress. This corroborates with results of Das and Kalita. (2010).

Table-4.14 Effect of water stress on Cell Membrane Stability Index(CMSI,%) & Relative Injury(RI,%) at PI stage of Rice Genotypes

Genotypes	**Cell Membrane Stability Index(CMSI,%)**				**Relative injury(RI,%)**			
	S0	S1	S2	Mean	S0	S1	S2	Mean
Parijata	65.90	27.70	37.70	**43.70**	0.00	71.40	35.90	**35.80**
Sidhant	64.50	22.70	34.20	**40.50**	0.00	73.20	31.60	**35.00**
Mandakini	63.00	26.00	36.20	**41.80**	0.00	71.70	45.20	**39.00**
Lalat	65.30	28.80	40.70	**44.90**	0.00	79.00	42.00	**40.30**
Manaswini	62.90	20.70	32.30	**38.60**	0.00	83.40	48.70	**44.10**
Konarka	60.00	17.70	18.20	**31.90**	0.00	79.30	48.60	**42.60**
Mean	**63.60**	**23.90**	**33.20**	40.20	**0.00**	**76.30**	**42.00**	39.40
	V	**S**	**V x S**		**V**	**S**	**V x S**	
Sem(±)	1.25	0.89	2.17		0.42	0.3	0.73	
CD 5%	3.6	2.55	6.24		1.22	0.86	2.1	
CV %	9.35				3.21			

4.3.4 Proline Content

Data on proline accumulation in response to stress have been depicted in Table 4.13 and Fig.4.8. Record of proline accumulation indicated that greater amount of free proline was found to accumulate when plant were subjected to stress irrespective of varieties. Application of SA showed significant increase of proline accumulation over the stressed plants. Lalat accumulated the greatest mean quantity 304.56 μg g^{-1} FW leaf followed by Parijata, Mandakini and Manaswini the values were 297.5,291.7 and 283.5 μg g^{-1} FW leaf respectively.These variety were statistically at par. However application of SA increases 29% proline accumulation over the stress condition. Parijat registered the highest average increase in SA treatment 38% of proline followed by Konark (35 %),Sidhant (31%) and Lalat accumulated the least increase over their respective stress (23 %). Roy *et al.* (2009) reported that high proline content is a good index for drought resistance in rice genotypes. Under moisture stress condition the protein degrades and consequently the proline content increases.This corroborates with results of Majeed *et al.* (2011)

4.3.2 Catalase and Superoxide dismutase activity

Catalase and superoxide dismutase (SOD), which offer protection to the living cell from reactive singlet oxygen species against biotic stresses, are depicted in Table 4.15(Fig.4.9 & 4.10). The variations of these two parameters in rice genotypes under examination were found significant. Impact of moisture stress significantly increased (63%) the catalase activity (Fig.4.9)on an average but SA application to stressed plant, the reduction was 37% as compared to stress. Mean catalase activity was maximum in Lalat(25.1) and minimum in Konark (14.0). Variety Parijata showed value at par with only Lalat.

In SA application in stress, Parijat revealed highest and Konark lowest activities with values 25.7 and 14.6 unit/min/g fw leaf, respectively and significant differences has been observed all other genotypes tested.This corroborates with results of Kraus et al.(1995);Willekens et al.(1997) and Roy et al. (2009).

Table-4.15 Effect of water stress on Catalase and Superoxide dismutase activity at PI Stage of rice genotypes

Genotypes	CAT(unit/min/g fw leaf)				SOD(unit/min/g fw leaf)			
	S0	S1	S2	Mean	S0	S1	S2	Mean
Parijata	13.2	34.6	25.7	**24.5**	15.2	38.5	22.6	**25.5**
Sidhant	9.2	32.3	18.5	**20.0**	12.8	25.5	16.5	**18.3**
Mandakini	15.4	32.4	20.7	**22.8**	11.1	32.5	17.0	**20.2**
Lalat	16.1	38.5	20.8	**25.1**	17.8	42.7	27.5	**29.3**
Manaswini	7.5	25.5	15.3	**16.1**	14.8	24.1	20.5	**19.8**
Konarka	6.3	21.1	14.6	**14.0**	9.3	23.7	21.8	**18.3**
Mean	**11.3**	**30.7**	**19.3**	20.4	**13.5**	**31.2**	**21.0**	21.9
	V	**S**	**V x S**		**V**	**S**	**V x S**	
Sem(±)	0.43	0.31	0.75		0.36	0.25	0.62	
CD 5%	1.24	0.88	2.15		1.03	0.73	1.78	
CV %	6.36				4.90			

Similar trend has been observed in SOD activity,Variety Lalat and Parijat revealed values of 29.3 and 25.5 unit/min/g and respectively which were found higher than other rice varieties.In both stress and treatment cases, Manaswini showed minimum activities with values of 24.1 and 20.5 unit/ min/mg, respectively.Parijat showed highest value(38.5) in stress and second highest(22.6) in SA treatment. Lalat & Parijat revealed superiority in SOD activities over other genotypes. Similar results have been reported by Reddy *et al.*, (2000) and Basudha et al.(2001).

4.3 YIELD PARAMETERS AND YIELD

4.4.1 Panicle length

The observations on panicle length (Table 4.16) revealed that it decreased in all the varieties when subjected to moisture stress. On an average

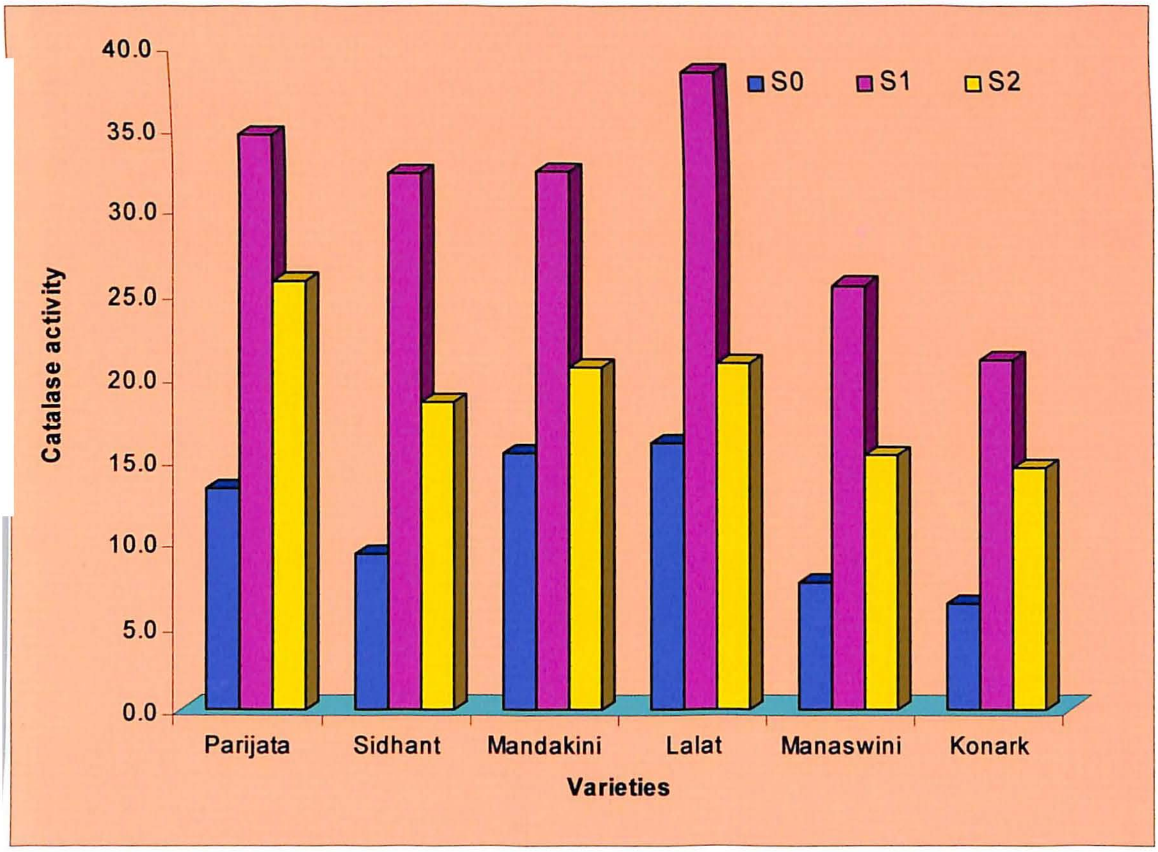


Fig. 4.9 Effect of water stress on catalase activity (units/min/g fw leaf) at PI stage of rice varieties.

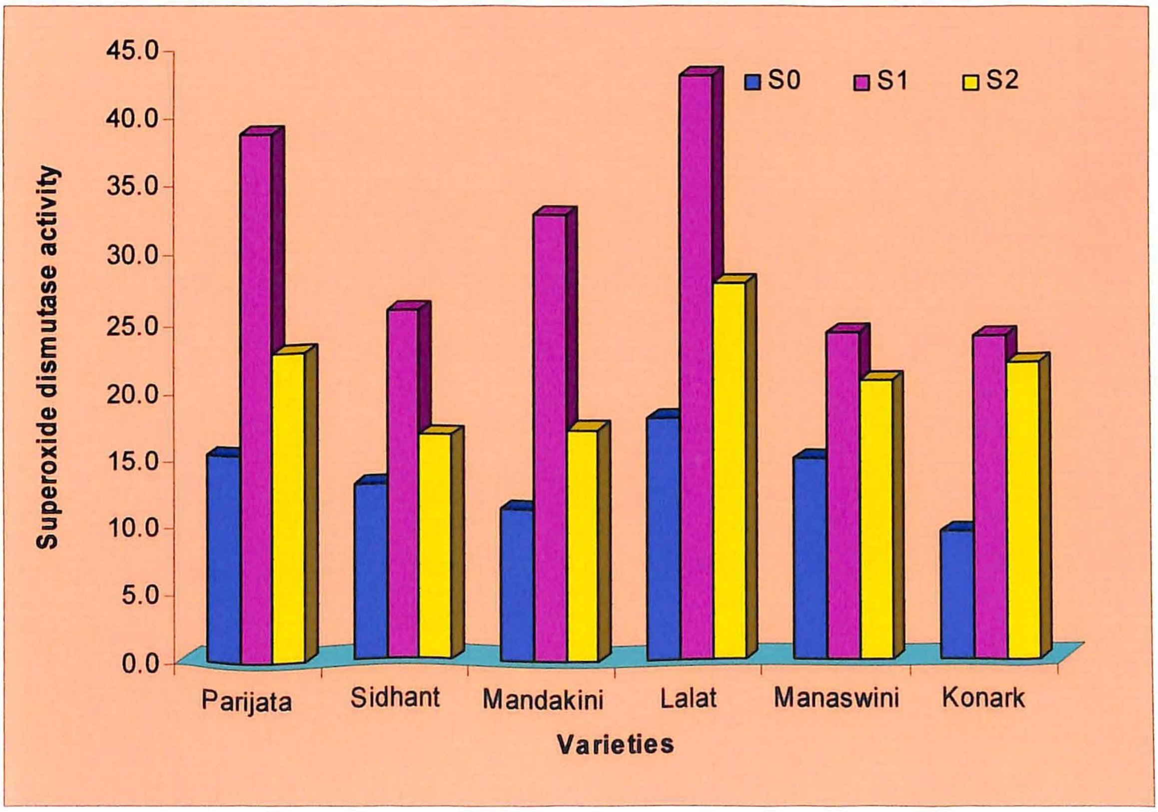


Fig.4.10 Effect of water stress on superoxide dismutase activity (unit/min/g fw leaf) at PI stage of rice varieties.

mean values the reduction of panicle length due to moisture stress was 24% which was reduced to 14% due to SA application in stress as compared to control.Among the varieties Lalat (Check) followed by Manaswini recorded maximum panicle length in stress. Mean panicle length was 22.50cm with a range from 19.13 to 25.30cm; 17.10cm with a range from 15.13 to 19.03cm;19.28cm with a range from 18.37 to 20.97 inS_0 ,S_1, and S_2 respectively.

However, application of SA reduced the impact of stress and increases the panicle length. Mandakini and Manaswini were almost at par to each other so far as the decrease in panicle length in response to moisture stress was concerned. Among the variety tested, Parijat and Konark noticed minimum decrease. This corroborates with the findings of Yonezawa .(1997) and Ahamadi *et al.*, (2008)

4.4.2 Panicle weight

Data pertaining to panicle weight per hill have been presented in Table 4.16.It was revealed from the data that panicle weight decreased with response to stress irrespective of varieties. Application of SA resulted higher panicle weight per hill as compared to moisture stress. Due to moisture stress there was reduction of 48% in weight which was reduced to 30% on application of SA during stress as compared to control. Among all the variety, Lalat recorded maximum panicle weight per hill in all the three condition. In general, mean panicle weight/hill was 27.32g with a range from 19.83 to 42.53g; 14.31g with a range from 12.13 to 17.74g and 14.31g with a range from 16.07 to 29.01g in control, stress and stress with SA respectively. Variety Manaswini recorded lowest panicle weight per hill due to stress. Reddy *et al.*(2000); Kobata and Uemuki.2004 reported same result in rice genotypes.

Table 4.16 Effect of water stress on panicle length(cm),panicle weight(g) & number of spikelet per panicle of rice genotypes at harvesting stage

Genotypes	Panicle length(cm)				Panicle weight(g)				Number of spikelet per panicle			
	S0	**S1**	**S2**	**Mean**	**S0**	**S1**	**S2**	**Mean**	**S0**	**S1**	**S2**	**Mean**
Parijata	19.13(100)	15.9(83)	18.37(96)	**17.80**	25.42(100)	12.51(49)	18.00(71)	**18.64**	30.66(100)	28.33(92)	30.36(99)	**29.77**
Sidhant	21.07(100)	15.13(72)	18.57(88)	**18.26**	26.3(100)	14.24(54)	16.61(63)	**19.05**	38.67(100)	25.00(65)	27.65(72)	**30.44**
Mandakini	25.30(100)	17.27(68)	19.17(76)	**20.58**	29.17(100)	12.9(44)	16.17(55)	**19.41**	57.68(100)	26.00(45)	34.66(60)	**39.43**
Lalat	24.57(100)	19.03(77)	20.97(85)	**21.52**	42.53(100)	17.74(42)	29.01(68)	**29.76**	35.62(100)	28.33(80)	31.50(88)	**31.89**
Manaswini	24.03(100)	17.93(75)	18.47(77)	**20.14**	19.83(100)	12.13(61)	16.07(81)	**16.01**	52.00(100)	44.67(86)	47.00(90)	**47.89**
Konarka	20.90(100)	17.33(83)	20.13(96)	**19.46**	20.67(100)	16.33(79)	18.51(90)	**18.51**	35.00(100)	25.33(72)	34.00(97)	**31.44**
Mean	**22.5(100)**	**17.1(76)**	**19.28(86)**	19.63	**27.32(100)**	**14.31(52)**	**19.06(70)**	20.23	**41.63(100)**	**29.61(71)**	**34.22(82)**	35.15
	V	**S**	**V x S**		**V**	**S**	**V x S**		**V**	**S**	**V x S**	
Sem(±)	0.22	0.16	0.38		0.5	0.36	0.87		0.29	0.2	0.49	
CD 5%	0.64	0.45	1.1		1.44	1.02	2.5		0.82	0.58	1.42	
CV %	3.38				7.45				2.43			

4.4.3 Number of spikelet Per Panicle

Data on number of spikelet per panicle have been presented in Table 4.16.The spikelet number per panicle decreased significantly with imposition of stress at PI stage .Application of SA resulted higher number of spikelet per panicle as compared to stress. In general there was reduction of 29% spikelet per panicle which was minimized to 18% on SA application in stress as compared to control. Among variety tested, Mandakini recorded maximum number of spikelet per panicle in control condition and Manaswini recorded maximum spikelet per panicle in both stress and stress + treatment condition. Mean spikelet number per panicle was 41.63 with a range from 30.66 to 57.68; 29.61 with a range from 25.00 to 44.67 and 34.22 with a range from 27.65to 47.0 in control, stress and stress + treatment respectively. This was corroborated with the results of Yadav *et al.* (2001), Chandra *et al.*, 2005 and Sahoo.,2007.

44.4 Grain number per panicle

Data on grain number have been presented in Table 4.17. Record of number of grains per panicle revealed that it decreased with imposition of moisture stress at panicle initiation stage. Application of SA resulted in a higher number of grains per panicle. On being exposed to moisture stress there was reduction of 40% and application of SA was 24% as compared to control. Among the varieties Lalat possessed the highest number (149 nos.) and Parijat the least number (99.7 nos.) of grains per panicle. The overall mean values implied that number of grains in SA treatment was 114 which declined to 90 in stressed plants.

Number of mature grains exhibited a varying trend in response to moisture stress. Application of SA to stress treatments resulted in a higher number of mature grains per panicle compared to the only stress counterparts.

Table 4.17 Effect of water stress on total number of grain/panicle,no. of chaffy grain/panicle & spikelet fertility percentage of rice genotypes at harvesting stage

Genotypes	Total number of grain/panicle				Number of chaffy grain/panicle				Spikelet fertility percentage			
	S0	S1	S2	Mean	S0	S1	S2	Mean	S0	S1	S2	Mean
Parijata	109.0(100)	89.1(81)	101.0(92)	**99.7**	11.0	46.3	26.7	**28.0**	92.6	48.5	72.5	**71.2**
Sidhant	145.3(100)	78.0(53)	87.7(60)	**103.7**	10.0	47.3	32.0	**29.8**	95.5	36.3	60.7	**64.2**
Mandakini	157.0(100)	82.5(52)	94.3(60)	**111.1**	23.0	56.7	32.3	**37.3**	83.0	26.7	68.0	**59.2**
Lalat	182.3(100)	121.0(66)	143.7(79)	**149.0**	32.3	86.7	53.0	**57.3**	81.0	25.0	60.3	**55.4**
Manaswini	132.5(100)	98.6(74)	124.6(94)	**118.6**	14.3	95.0	32.7	**47.4**	88.3	25.7	78.0	**64.0**
Konarka	173.7(100)	74.7(43)	133.0(76)	**127.1**	73.0	29.0	46.3	**49.4**	77.3	46.7	62.0	**62.0**
Mean	**149.9(100)**	**90.55(60)**	**114.1(71)**	119.4	**27.3**	**60.1**	**37.2**	42.1	**86.3**	**34.8**	**66.9**	62.7
	V	S	V x S		V	S	V x S		V	S	V x S	
Sem(±)	0.51	0.36	0.88		0.91	0.64	1.57		0.98	0.69	1.69	
CD 5%	1.45	1.03	2.52		2.61	1.85	4.52		2.8	1.98	4.86	
CV %	1.27				6.48				4.67			

Number of chaffs per panicle also observed to increase with stress in general as compared to control. Less number of chaffs was recorded for stress treatments applied with SA compared to only stress. On an average SA treatment reduced 38% chaff in stress. The greatest numbers of chaffs were observed in case of Lalat with 57.3 mean chaffs / panicle (38.4 % of total no. of grains) and the least registered with Parijat with 28 chaffs/panicle (25 %).

Budi and Suprihanto (1996) reported similar reduction in grain number when stress was imposed at panicle initiation stage. Gupta *et al.* (2003) reported that application of ameliorants increases number of grains per panicle, one of contributing traits for higher productivity. This also corroborated with the results of Chandra *et al.*, 2005 and Sahoo., 2007.

4.4.5 Test weight (TW)

Moisture stress significantly decreased the test weight of grains (Table 4.18). The observations recorded for test weight indicated that there was about 6.52% reduction in test weight due to imposition of stress and application of SA the reduction was 2.9%as compared to stress. Mandakini had the maximum mean value of 23.96 g, followed by Lalat 23.26 g and Manaswini had the minimum test weight of 19.39g.Variety Mandakini was at par with Lalat and Manaswini. Similar results have been observed by Zhou *et al.*, 2003.

4.4.6 Harvesting index (HI)

Data on harvest index have been presented in Table 4.18. The studies on harvest indices indicated that there was a significant reduction in harvest index due to moisture stress. The reduction were 11% in stress and 7% in stress applied with SA. Among all the varieties, Lalat recorded maximum HI in stress and SA treatment condition while Parijat in control .In general, mean HI was 41.72 with a range from 39.8 to 44.57; 37.32 with a range from 34.19 to 40.84 and 38.76 with a range from 35.85 to 41.93 in S_0, S_1, S_2 respectively. Variety Konark recorded lowest HI due to stress. Sinclair *et al.* (1990), Chauhan *et al.* (1999), Babu *et al.* (2003) observed similar reduction in H.I. in rice crop. This corroborates with the works of Lafitte and Courtois (2002).

Table-4.18 Effect of water stress on Test Weight & Harvest Index(HI) of Rice genotypes

Genotypes	Test Weight				Harvest Index(HI)			
	S0	**S1**	**S2**	**Mean**	**S0**	**S1**	**S2**	**Mean**
Parijata	20.73	18.84	20.05	**19.87**	44.57	40.02	41.93	**42.17**
Sidhant	19.95	18.09	18.43	**18.83**	40.70	36.31	38.60	**38.54**
Mandakini	25.12	22.27	24.49	**23.96**	41.37	36.67	38.04	**38.69**
Lalat	23.78	22.50	23.51	**23.26**	43.77	40.84	41.73	**42.11**
Manaswini	19.80	19.20	19.16	**19.39**	39.80	35.87	36.40	**37.36**
Konarka	23.22	23.08	23.11	**23.14**	40.13	34.19	35.85	**36.72**
Mean	**22.10**	**20.66**	**21.46**	21.41	**41.72**	**37.32**	**38.76**	39.27
	V	**S**	**V x S**		**V**	**S**	**V x S**	
Sem(±)	0.22	0.16	0.39		0.20	0.14	0.35	
CD 5%	0.64	0.46	1.11		0.58	0.41	1.00	
CV %	3.14				1.54			

4.4.7 Spikelet fertility percentage

Data on spikelet fertility percentage have been reflected in Table 4.17 and Fig. 4.11. It was observed that due to stress at PI stage there was significant decrease of fertility percentage per panicle in all the varieties and decrease of fertility percentage was reduced due to application of SA in stressed plants compared to control. In general, the fertility percentage in stress was 34.8 % but stress + SA it was 66.9 %. On an average of mean values the percentage of fertility was less in Lalat (55.44 %) followed by Mandakini (59.22 %) and Parijata (71.18%) the highest. Variety Sidhant recorded maximum spikelet fertility(95.4%) in control, while Konark recorded maximum spikelet fertility in stress (46.67%) and Manaswini (78%) in stress with SA treatment condition. The interaction effect on fertility percentage between stress and variety was significant. Moisture stress hampers anthesis and seed setting leading to a lower spikelet fertility and lower yields (Das and Kar, 2005).Also Similar result have been reported by Babu *et al.*, 2003.

4.4.8 Grain Yield

Grain yield in general reduced irrespective of genotypes when the plants were subjected to moisture stress (Table 4.19 & Fig.4.12).Due to stress the reduction in grain yield was 33% but application of SA to stress resulted 14% reduction over the control. Among different varieties, Parijat recorded highest yield in control, stress and stress with SA treatment condition. Application of SA to stress treatments resulted increase in yield by 19 % over those recorded for only moisture stress. Parijat had the maximum mean yield per hectare (34.69 q/ha) followed by Lalat with 33.89q/ha and Manaswini (26.53q/ha) the least. There were significant difference in yield among the genotypes.(Moinuddin *et al.* ,2005) and Pradhan *et al.*, 2006).

Table-4.19 Effect of water stress on Grain yield(q/ha) & Drought respond index(DRI) of Rice genotypes.

Genotypes	**Grain yield(q/ha)**				**Drought respond index**	
	S0	**S1**	**S2**	**Mean**	**S1**	**S2**
Parijata	40.26	28.35	35.48	**32.69**	1.04	1.06
Sidhant	33.49	22.30	28.63	**26.41**	0.98	1.01
Mandakini	35.83	25.20	32.46	**28.53**	1.03	1.07
Lalat	39.18	27.65	34.85	**32.45**	1.05	1.05
Manaswini	32.15	21.00	26.47	**26.75**	0.95	0.97
Konarka	32.90	20.16	26.82	**25.81**	0.91	0.98
Mean	**35.63**	**24.11**	**30.77**	30.17	**0.99**	**1.02**
	V	S	V x S			
Sem(±)	0.47	0.33	0.81		0.01	0.01
CD 5%	1.34	0.95	2.33		0.03	0.02
CV %	4.95				2.60	1.31

in stress (46.67%) and Manaswini (78%) in stress with SA treatment condition. The interaction effect on fertility percentage between stress and variety was significant. Moisture stress hampers anthesis and seed setting leading to a lower spikelet fertility and lower yields (Das and Kar, 2005).Also Similar result have been reported by Babu *et al.*, 2003.

4.4.8 Grain Yield

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Genotypes	**Grain yield(q/ha)**				**Drought respond index**	
	S0	**S1**	**S2**	**Mean**	**S1**	**S2**
Parijata	40.26	28.35	35.48	**32.69**	1.04	1.06
Sidhant	33.49	22.30	28.63	**26.41**	0.98	1.01
Mandakini	35.83	25.20	32.46	**28.53**	1.03	1.07
Lalat	39.18	27.65	34.85	**32.45**	1.05	1.05
Manaswini	32.15	21.00	26.47	**26.75**	0.95	0.97
Konarka	32.90	20.16	26.82	**25.81**	0.91	0.98
Mean	**35.63**	**24.11**	**30.77**	30.17	**0.99**	**1.02**
	V	S	V x S			
Sem(±)	0.47	0.33	0.81		0.01	0.01
CD 5%	1.34	0.95	2.33		0.03	0.02
CV %	4.95				2.60	1.31

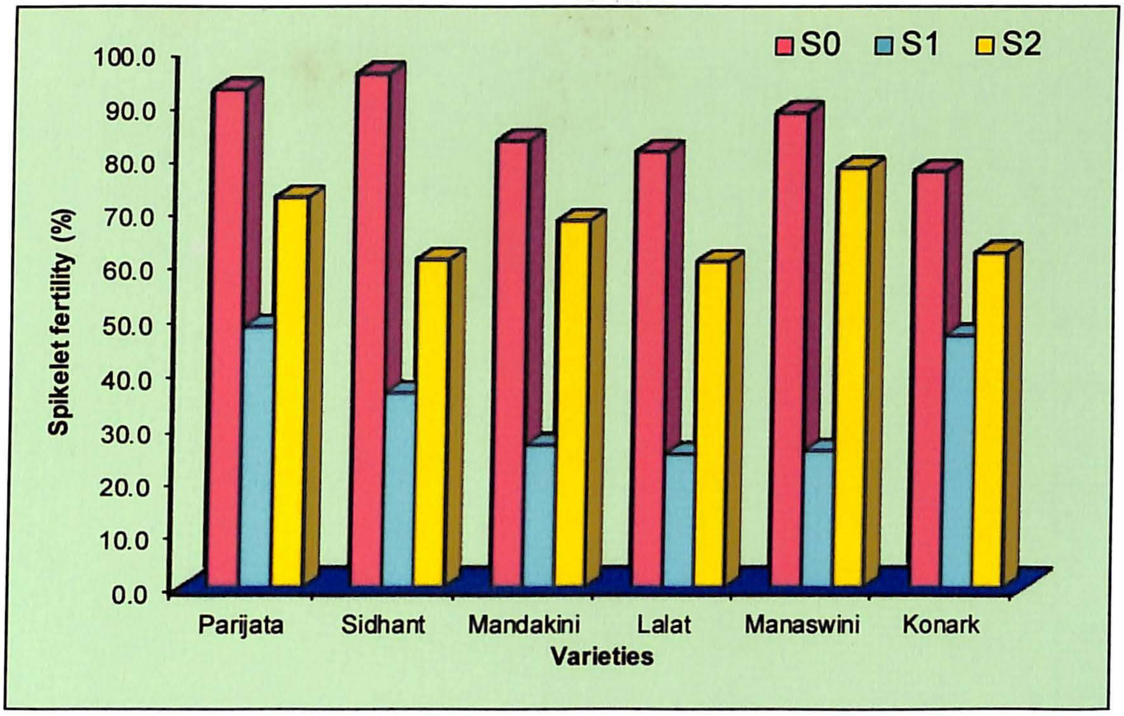

Fig. 4.11 **Effect of water stress on spikelet fertility percentage of rice varieties at harvesting stage**

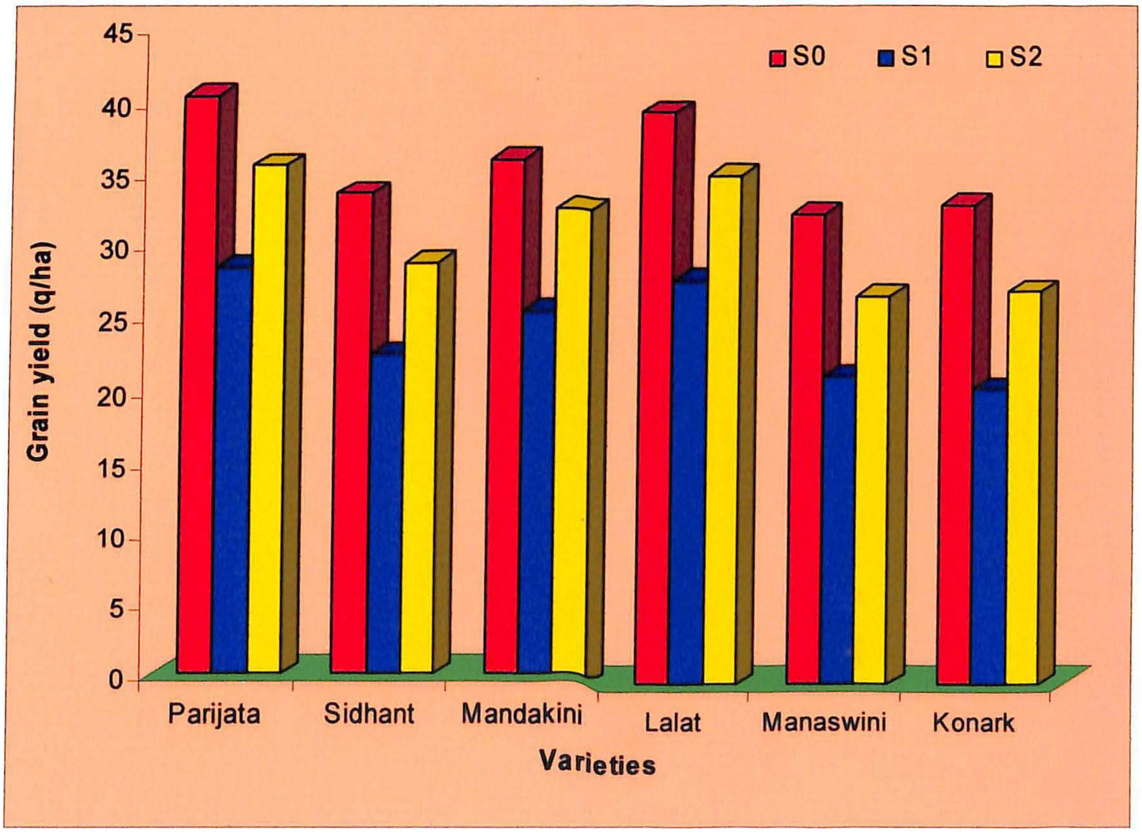

Fig. 4.12 Effect of water stress on grain yield (q/ha) of rice varieties.

4.4.9 Drought Response indices

Data on DRI (Table 4.19) revealed that under stress condition Lalat gives better response followed by Parijat as compare to other variety and least DRI was observed in variety Konark followed by Manaswini. The mean DRI observed to be 0.99 with a range from 0.91 to 1.05; 1.02 with a range from 0.97 to 1.07 in stress and stress with SA treatment respectively. Application of SA increases 3% the drought respond index over stress.

Recent research findings at IRRI have demonstrated the feasibility of direct selection for yield under drought (Kumar *et al.*, 2008). Since yield under stress is a function of yield potential, escape, and drought response, the use of the drought response index (DRI) could help to distinguish drought resistance from escape and yield potential (Ouk *et al.*, 2006) and therefore, further enhance the precision and reproducibility of drought screening.

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CHAPTER - V

Summary & Conclusion

SUMMARY AND CONCLUSION

Drought is the primary cause of poor yields in rainfed rice. Development of high yielding well adapted rice varieties is the prime requirement to increase food production and sustain livelihoods. The genetic improvement for adaptation to drought condition through the conventional approach is by selecting for yield and stability. Because of unpredictability in drought occurrence, such programmes are expensive and slow in attaining progress.

Physiological and biochemical approaches to identify complex drought tolerant traits and breeding for these traits offer prospect for drought tolerance. Ultimately the yield under drought is more important. The physiological and biochemical traits that contributes to grain yield under drought stress and its stability are also equally important. Hence, identification of these traits is important for drought tolerance in rice. .

Several studies were carried out separately,but there have been limited reports which explored on the combined effects of stress factors and various strategies have been identified/ sort listed, those can be alternatives to overcome this impact. Among them, exploitation of the inherent physiological and biochemical strengths of an species to reduce or nullify the crop loss suffered on account of drought, holds a certain promise.

5.1 Field Experiment

The series of experiment was carried out in the field located in the Central Research Station of Orissa University of Agriculture and Technology, Bhubaneswar during *Rabi* 2010-11.Six varieties of rice, viz. namely, Parijat, Sidhanta, Mandakini, Lalat, Manaswini, and Konark were taken.

Seeds were treated dry with Carbendazim 85%WP and sown in the raised bed nursery after sprouting them in controlled conditions for raising seedlings. Transplanting on main field was done using 30 days old seedlings. Recommended doses of fertilizers (@ 80-40-40 kg N-P-K hectare^{-1}) were applied in three splits; at land preparation, tillering and panicle initiation.

The field experiment conducted with randomised block design replicated thrice with three treatments viz. S_0 (Control), S_1 (Stress at PI stage) and S_2 (stress with application of salicylic acid @ 100 ppm at PI).At panicle initiation stage,stress was imposed by withholding irrigation for aperiod of 7-10 days.

Drought symptom was noticed by wilting/leaf rolling of leaves and thereafter irrigation was provided to relieve the crop from stress. At the time of wilting observations morphological, physiological and biochemical parameters were taken from each treatment. The results obtained on all these aspects in the present investigation are summarized here under:

5.1.1 Morphological Parameters

The rice varieties under test exhibited a reduction in plant height when the plants are exposed to moisture deficiency. The decrease in plant height, in general, due to stress was to the tune of 29% but application of SA in stress it was observed to be 10%, in comparison to non-stress conditions. The maximum plant height was recorded (76.3 cm) by Sidhant followed by lalat (75 cm).

Lalat produced maximum number of tillers followed by Parijat whereas the lowest number of tillers was recorded in Konark compared to other varieties when exposed to stress. Application of SA under stress condition to the plants increased the number of tillers per hill compared to stress condition. The extension of reduction due to stress was recorded 35 % which was reduced to 16 % in stress + SA.

Significant differences in visual score were found among the cultivars tested.Leaf drying score and rolling increases with increase in level of stress irrespective varieties.Mean leaf drying score was 2.7 in stress and application of salicylic acid decreases the drying scores to 2.4(11% decrease over stress). LDS was least (2.16) in cultivar Manaswini while Lalat recorded highest score among all variety in stress.Mean rolling score in stress was 3.05 in stress while SA treatment decreases the rolling to 2. among variety. LRS was highest (3.75) in both cultivar Parijat and Lalat in stress condition while Mandakini recorded lowest score (2.17).

On an average the mean reduction in leaf length was 36% in stress while application of salicylic acid in stress increased the leaf length to the tune of 16% over the stress.Konark produced significantly longer leaf than all the genotypes except Parijat similar length in stress.

Moisture stress reduced the thickness of leaf irrespective of varietis.The reduction in leaf thickness in stress was 15% but application of Salicylic acid reduced the impact of drought and increases the leaf thickness to the tune of 9% over the stress.

On an average stress reduced the root length 23% as compare to control while application of Salicylic acid during stress reduced the reduction percentage to 9% in comparison to nonstress. Sidhant produced significantly longer mean roots length than all the genotypes.

There was 15% reduction in root thickness have been observed under stress however application of SA decreases the thickness 4% as compared to control condition. Variety Parijat, Lalat & Manaswini have significantly higher mean value for this trait.

Irrespective of varieties root volume decreased in all the genotypes in general (47 % on an average) when stress was imposed. Foliar application of SA (100ppm) significantly increases the root volume. Root volume of Lalat had significantly highest mean value (7.03cc).Parijat and Mandakini had lowest mean value for this trait.

5.1.2 Physiological Parameters

The reduction of total dry matters(TDM) on an average values due to imposition of stress was 28% and to that of 16% in SA treatment in stressed plants irrespective of variety. Lalat recorded the highest mean dry matter of 51.78 g $hill^{-1}$ followed by Parijat with 39.91 g $hill^{-1}$ and Manaswini had the least of 29.54 g $hill^{-1}$.

Moisture stress significantly decreased root: shoot ratio and the decrease was to the tune of 47% but application of SA the decease was minimized to18%. Among the cultivars, the root: shoot ratio was more in cultivar Parijat and less in cultivar Konark, Manaswini and Sidhant.

The root length density increased with the increase in moisture stress. Mandakini had the highest root length density of 5.1 cm cc^{-1} followed by Sidhant (4.86 cm cc^{-1}) and Konark (6.07 cm cc^{-1}) in stress. Application of SA did not yield any spectacular results however a decreasing trend was observed.

In general moisture stress resulted in a decrease in NAR. The stress treatments applied with SA registered a significant increases in NAR compared to their stress treated counterparts.The was reduction 41% due to imposition of stress but application of SA reduction was 27% as compare to nonstress. The highest mean NAR of 0.492 g cm^{-2} day^{-1} was recorded in case of cultivar Lalat followed by Parijat(0.484 g cm^{-2} day^{-1}),Mandakini(0.449 g cm^{-2} day^{-1}) during panicle initiation.

There was a general reduction of CGR to the tune of 32% in stress as compare to nonstress but application of SA the reduction was minimized to 18%. Sidhant registered the highest reductions (43 %) in CGR followed by Manaswini (36%), Konark (35%) and lowest reduction was observed in Parijat (23%) & Lalat (22%) in moisture stress condition.

Irrespective of varieties, leaf area decreased due to imposition of stress but the impact of stress on leaf area was reduced due to application of SA in stress condition. Among the varieties the highest leaf area was recorded in Parijat followed by Lalat and Sidhant. On account of moisture stress, there was reduction of 35 % whereas application of SA in stress reduction was decreased to 20 %.

There was about 29 % decreased of LAD recorded in stress condition while stress+ treatments the decrease was only 13% as compared to stress. Lalat registered the highest mean LAD (6.91) followed by Sidhant (6.72), Parijata (6.67), Mandakini (6.47) and Konark (5.35) the least. Application of SA to stress treated plants resulted an increase in LAD values by about 16 % overall that of only stress treated counterparts.

The LMRI was observed to decrease ((60%) in stress but stress treatments applied with SA recorded a higher LMRI (44%) as compared to stress treatments. At PI stage maximum mean LMRI of 10.26 % was recorded in leaves of Lalat closely followed by Sidhant with 10.03% and Parijata 9.62%.

In general, the photosynthetic rate(Pn) was reduced to 42 % when stress was imposed but application of various drought mitigating chemicals in stress, the reduction was reduced to 32%, 31.3%, 41%, 36.3%, 34.2% & 26.08% by chemicals Cytokinin,SA,Urea,K_2SO_4,Ascobic Acid & BR in the order as compared to control. The varieties like Sidhant, Mandakini and Lalat exhibited their excellence for their minimum reduction in photosynthetic rate under stress as compared to other varieties.

There was drastic reduction in stomatal conductance(Gs) which was to the tune of 42.4 % in stress whereas chemical application viz.SA,BR,Cytokinin & K_2SO_4 in stress the decreases 27.2%,24.5 %,36.3%,36.4% repectively over control(other chemical effect did not show any spectacular results). Stomatal conductance was highest for Lalat in SA treatment (0.34 μ mol $m^{-2}s^{-1}$), followed by BR treatment (0.30 μ mol $m^{-2}s^{-1}$) in the same variety. The lowest stomatal conductance was observed in Konark (0.14μmol m^{-2} S^{-1}) followed by Mandakini & Manaswini.

There was significant reduction of transpiration rate in all the varieties. The minimum transpiration rate was observed by Konark (3.29 m mol m^2S^{-1}) followed by Manaswini (3.36m mol m^2S^{-1}) among the varieties due to imposition of stress. In general the transpiration rate was reduced to 34 % in stress and 27,28,32,26,33 and 22 % in stress + chemical application viz.Cytokinin, SA, Urea, K_2SO_4, Ascobic Acid & BR respectively as compared to control.

Due to imposition of stress the canopy temperature depression decreased significantly. Overall mean values indicated that there was decrease of temperature by 14 % due to stress but application of SA in stressed plants it was reduced to 4 % as compared to non-stress. Except varieties Sidhant and

Konark rest 3 varieties Lalat, Mandakini & Manaswini maintained a higher canopy temperature depression and these varieties are superior to their counterpart.

5.1.3 Biochemical Parameters

Total chlorophyll content of leaves recorded at PI stage decreased in response to moisture stress compared to control in all the varieties. The overall mean values indicated that decrease of chlorophyll content in response to stress was to the tune of 52% whereas it was reduced to 27% when SA was applied to stressed plants. Varieties namely Lalat, Parijat had higher chlorophyll content and lowest in Sidhant followed by Konark among the varieties under test.

The chlorophyll stability index (CSI), in general decreased in plants treated with moisture stress. Application of SA was found to have significant impact on maintenance of higher CSI. The highest mean CSI% was recorded in Parijat (68.29%) followed by Lalat (67.4%) and Manaswini recorded the least (62.79%).The overall mean value revealed that the values of CSI at PI stage was 43 per cent due to stress whereas application of SA, resulted in 64 per cent CSI.

In general, the water-stressed plants showed significant decrease in MSI which increased due to application of SA in stress irrespective of varieties.On an average MSI in non-stressed plants were 64% where as 23% in stressed plants. There was highest mean CMSI (44.9%) recored in Lalat whereas it was 31.9% in Konark.

The highest relative injury(RI) (76.3%) was observed in stress whereas it was (42%) in SA application.The highest mean ralative injury was observed in variety Manaswini (44.1%) followed by Konark (42.6%) and Sidhant the least.

Proline accumulation also exhibited an increasing trend in response to moisture stress in all the varieties at PI stage. Tolerant varieties such as Lalat,Mandakini and Parijat accumulated more proline to their counterparts in response to stress. Application of SA to stress plants resulted more accumulation in proline content compared to non-treated stressed plants.

Moisture stress significantly increased the catalase activity on an average 63% but SA application to stressed plants the reduction was 37% as compared to stress. Similar trend has been observed in SOD activity, variety Lalat and Parijat revealed values of 29.3 and 25.5 unit/min/g and respectively.

5.1.4 Yield and Yield attributes:

Length of panicle decreased in response to moisture stress, when stress was applied at PI stage. The maximum panicle length was recorded in Lalat followed by Manaswini. The over all mean value indicated that due to imposition of stress, there was a reduction of 24 % but application of SA reduced the impact of stress where the reduction was 14 %.

Total number of grain per panicle decreased under stress treatments at PI stage. Application of SA in stress resulted in higher number of grains in comparison to stress to the tune of 11 % increase. On the contrary, the fertility percentage decreased in response to imposition of stress at PI stage and application of SA increased the fertility percentage to the tune of 32 %. Among the varieties, the minimum fertility percentage was recorded with Lalat, whereas maximum in Parijat and Sidhanta.

Grain yield, test weight and harvest index were observed to decrease in response to moisture stress irrespective of varieties. Maximum reductions in these parameters were observed in Manaswini, Sidhanta and Konark, when stress was applied at PI stage. Minimum reduction was registered with Lalat,Mandakini and Parijat in stress and stress + SA treatment respectively. The maximum harvest index was recorded in case of Parijat (42.17 %) followed by Lalat(42.11%) and Mandakini (38.69 %) when stress was imposed. In general, analyzing overall mean value of the treatments and varieties, there was a reduction of 33% and 22 % when stress imposed and application of SA under stress respectively. Basing on the drought index data it was observed that the varieties such as Lalat, Mandakini, Parijat possess drought resistant characters.

CO NCLUSION

The present finding envisaged that out of the varieties tested Lalat followed by Mandakini and Parijat successfully grown under moisture deficit conditions (rainfed situations) and the varieties Manaswini and Konark are most susceptible ones, hence unsuitable for the dry environments. Physiological and biochemical traits related to drought resistance of the above mentioned varieties vis-à-vis their productivity are Lalat, Parijat, Mandakini, Sidhant, Manaswini and Konark. Similarly, the rice productivities directly related to grain number per panicle, number of productive tillers and spikelet fertility percentage under rainfed condition. Out of the chemicals tested Bs, AA performed better compared to others and could able to enhance productivity(enhancing Photosynthesis) by a margin of 40% under stressful environment.Neverthless,K_2SO_4 or SA are better alternatives of Bs/AA under drought-prone environmental situation to mitigate the drought injury.

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