

Effects of Water Deficit Stress at Tillering Stage of Direct Seeded Rice (Oryza sativa L.)

Abstract

The ten rice varieties viz. NAUR-1, Purna, GNR-6, NVSR-2227, NVSR-3093, NVSR-2285, NVSR-2278, NVSR-2852, NVSR-2601 and NVSR-2927 were grown in *kharif* season for observing their efficiency in terms of yield under deficit of water at tillering stage. The effects of short term water stress on various morpho-physiological and biochemical traits viz. leaf area index, number of panicles, chlorophyll content, number of stomata, relative water content, abscisic acid, proline, glycine betaine, ascorbic acid and harvest index content were studied and they were observed higher in Purna as compared to other nine varieties. However, Plant height and Ionic leakage were recorded lower in Purna as compared to other varieties. The abscisic acid as well as proline and glycine betaine content recorded maximum in Purna which might help in keeping hydration in cell during water deficit stress. Thus, Short term water deficit stress at tillering stage, the variety Purna would be better in terms of breeding for tolerant variety as well as yield among ten rice varieties.

Keywords: Water, Stress, Rice, Tillers, Varieties

Introduction

The cereals have a major role in feeding the billions of people and 50% to 80% of daily calorie intake provided by rice especially in Asian countries. Among cereals rice consumes almost 80% of the total irrigation freshwater resources and its roots being submerged during vegetative and reproductive stage. The aerenchymatous tissue a specialized structure in rice which makes its growth and development during submerged condition (Henry et al., 2016). The direct seeded rice generally grow on upland/low water regime face water deficit stress and changes its structure and develops deep and thick roots results in improvement of hydraulic properties of roots thereby extract water from deeper soil profiles (K. Ji et al., 2012). These develop anatomy under drought stress support higher yield in upland rice than lowland rice. Many developmental processes of plant such as number of tillers, panicle initiation and anthesis adversely affected by drought stress (R. Serraj et al., 2011). Drought severity activate the production of Reactive Oxygen Species (ROS) mainly in chloroplasts and mitochondria which reduce the membrane stability index and promote leakage of ions due to membrane disruption (Pandey and Shukla,

2015). The ROS viz. Singlet oxygen, superoxide anion radicals, hydroxyl radicals, and hydrogen peroxide (H_2O_2) are produced and initiate indirect disruption of metabolism (Kant, 2020). The defense mechanism for ROS scavenging developed in plant for detoxify and suppress the production of ROS by synthesis of different enzymatic and non-enzymatic antioxidants. The drought tolerant genotype of rice dramatically increases antioxidant enzymes viz. superoxide dismutase, peroxidase and catalase which suppress the production of ROS in the cell (Mishra and Panda, 2027; Kant, 2023). The adverse effects of ROS reduced by synthesis of compatible solutes/osmolytes such as proline, glycine betaine, sugars (trehalose), polyols (sorbitol, mannitol, myo-inositol, and pinitol) which exalted hydration in the cell. These osmolytes retain water molecule in their structure and they become shield of the osmoprotectants in plant during severe water/salinity stress (Anjum, S. A. et al., 2017).

Proline one of the best osmolyte which support vitality of the plant during water deficit. It is a neutral imino acid at pH-7, having rigid structure and highly soluble in water. It stabilizes protein structures and inhibits protein unfolding during water stress (Szabados, L. & Savoure A. 2010). The enzymes of metabolic pathway alleviated by proline particularly ribulose 1, 5 bisphosphate carboxylase that initiate Calvin cycle (Kaur and Asthir, 2015). The oxidative stress is the main factor for membrane disruption and ionic leakage, and this occurs when synthesis of reactive oxygen species (ROS) exceeds their scavenging in the cell. Proline considered as an effective hydroxyl radical scavenger and promoter of enzymatic antioxidants and its biosynthesis in chloroplasts reached upto 80% during stress as compare to 5% in normal which facilitate the electron flow between photosynthetic excitation centers and maintains a low NADPH:NADP ratio in cell. Thus, it protects the plant from photoinhibition and damage to the photosynthetic apparatus because extra electron in the cell is root cause of ROS production (Bandurska et al. 2017). Proline accumulation increases cellular osmolarity that drives influx of water or reduces its efflux resulting in increase of pressure potential for cell expansion (Bhaskara et al., 2015). Another biomolecule which protect plant during water stress is glycine betaine which acts as compatible solute and improves the tissue water status. It synthesized from choline and glycine when plant exposed to drought and salinity. It improves Ca^{2+} -ATPase and Hill reaction activities in thylakoid membrane thereby promote photosynthesis and translocation of sucrose. It is a quaternary amine with zwitterionic nature and can protect biological membranes from ROS as well as improving antioxidants defense system under stress (Nawaz and Wang, 2020). The

biosynthetic genes of proline and glycine betaine have been widely used in transgenic production to improve abiotic stress tolerance in plants (Schafleitner et al. 2007, Swamy and Kumar, 2013). Therefore, present study has been focused on creating short term water deficit stress at tillering stage of rice for determination of better yield among different varieties.

Materials and Methods

The experiment was carried out at the greenhouse located at N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat, India. The Navsari Agricultural University, Navsari campus is geographically located at 20° 57' N latitude and 72° 54' E longitude at an altitude of 16 m above the mean sea level. The average temperature and relative humidity recorded 31±1°C and 80%, respectively. Theseeds of ten rice varieties (NAUR-1, Purna, GNR-6, NVSR-2227, NVSR-3093, NVSR-2285, NVSR-2278, NVSR-2852, NVSR-2601, NVSR-2927) subspecies *Indica* groupsown in the pot filled with soil and FYM in the ratio of 2:1 in each pot after soaking in water for 12 hours and treatment with carbendazim 50% WP by immersing for 10 minutes. Both mixtures of soil and FYM were weighed and it was 7.5 Kg per pot. Fertilizer application to the test crop was done adopting the recommended fertilizer dose (RDF) for the Navsari region *i.e.*, N - P₂O₅ - K₂O (100-30-00 kg ha⁻¹). The water deficit stress created at tillering stage having the field capacity of 60%. The morphophysiological and biochemical traits were studied after creation of stress. Plants height was measured in centimetre from ground level to the tallest leaf of the plant at different stages of crop growth and average mean of height was recorded. The leaf area index (LAI) was calculated by dividing the leaf area per plant by land area occupied by the plant. The number of panicles per plant was counted and the average was worked out. Stomatal Frequency was measured with microscope and expressed as number of stomata per micrometer square. Chlorophyll content was measured with SPAD meter. Ionic leakage measured following the method of R. Sivakumar *etal.* (2015). Weighed two sets of 200 mg of leaf samples and put into two test tubes containing 10 ml double distilled water. Kept one test tube at 40°C in a water bath for 30 minutes. Thereafter measured the electrical conductivity (EC) of water containing the sample using Conductivity Bridge and noted. The other test tube incubated at 100°C in the boiling water bath for 15 minutes and measured the EC (C2). Relative Water Content (RWC) calculated following the method described by R. K. Sairam (1994). Third leaf (physiologically functional) from the top is selected for RWC estimation. Floated the leaf discs in water for four hours to attain full turgid and after taken out the leaf discs from water and

wipe out the water droplets sticking on the leaf surface by using filter paper. Immediately recorded the turgid weight (Tw) after an hour of floating. Transferred the leaf discs to a butter paper cover and then keeps the cover in hot air oven at 80°C for 48 hours. Recorded the dry weight (Dw) after removing from the Oven. $RWC = \frac{Fw - Dw}{Tw - Dw} \times 100$. Harvest index measured in percentage. Harvest index (%) = Economic yield/Biological yield × 100. (Biological yield = Grain yield + Straw yield).

The proline content in the leaves was estimated following the method described by Shivkumar et al. (2015). The 0.1 g of rice leaves was ground with 5 ml of 3% sulfosalicylic acid, and the mixture was then filtered. To 2 ml of the filtered mixture in a test tube, 2 ml of acid-ninhydrin and 2 ml of glacial acetic acid were added. The mixture was mixed with a Vortex mixer and boiled at 100°C for 1 h. The mixture was then frozen in ice and combined with 4 ml of toluene, mixed, and then left to stand for 5-10 min. Absorbance of the reddish pink upper phase was recorded at 520 nm against a toluene blank.

The glycine betaine (GB) content was determined following the method of Bates et al. (1973) with minor modifications. Finely ground dry material (0.5 g) was mixed with 20 ml of deionized water and maintained with mechanical agitation for 48 h at 25°C; subsequently, the mixture was centrifuged at 10,000 rpm for 10 min using a refrigerated centrifuge. The supernatant was collected and stored in the freezer until the analysis. Samples were thawed and diluted (1:1 v/v) with 2N of sulphuric acid (H₂SO₄). An aliquot of 0.5 ml was collected and incubated for 1 h in ice; after which, 0.2 mL of cold potassium iodide-iodine (KI-I₂) was added and mixed gently. The samples were stored at 0 to 4°C for 16 h; after which, they were centrifuged at 10,000 rpm for 15 min at 0°C. The supernatant was discarded while ensuring not to shake it; during this time, the samples were maintained in ice to allow separation of the periodide complexes from the acid medium. The periodide crystals that formed were dissolved in 9 ml of 1,2-dichloroethane, and the mixture was left to sit for 2 h; after which, the absorbance was read at 365 nm. For the standard GB curve, a stock comprising 1 mg/ml diluted in 1 N H₂SO₄ was prepared; concentrations of 50-200 mg/ml were used.

Abscisic acid (ABA) content determined by following the method described by Plessis et al. (2011). 100 mg of the leaves grinded and mixed with 2 ml of extraction solvent (acetone, water, acetic acid, 80/19/1, v/v/v). The supernatant was recovered by centrifugation and the pellet was rinsed with 1 ml of extraction solvent. The extraction solvent was evaporated and the residue was

resuspended in 0.5 ml of HPLC solvent (acetonitrile, water, acetic acid, 50/50/0.05, v/v/v) and ABA was quantified.

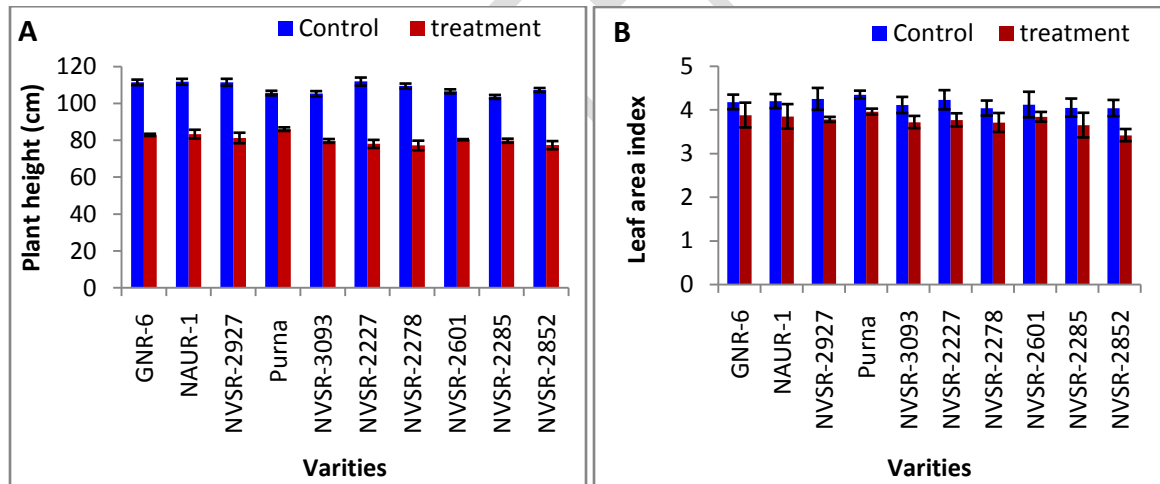
The Ascorbic acid content in the leaves was estimated following the method described by Shivkumar et al. (2015).

Statistical analysis

The data obtained were converted to mean value for each parameter with three repetitions under complete randomized design with factorial concept and statistically analyzed as described by Pans and Sukahtme (1978) factorial concept of the experiment.

Results and Discussion

Drought stress at typical stage of rice led to reduction in maturity period and yield. Cultivation of direct seeded rice under rainfed condition usually faces water deficit during its growth stage. Growing of genotypes having the tolerance capacity of drought would be the beneficial approach for getting comparatively higher yield under short term water limitation at specific stage. Hence, 10 varieties have been grown and their performance under water deficit stress at tillering stage analysed.



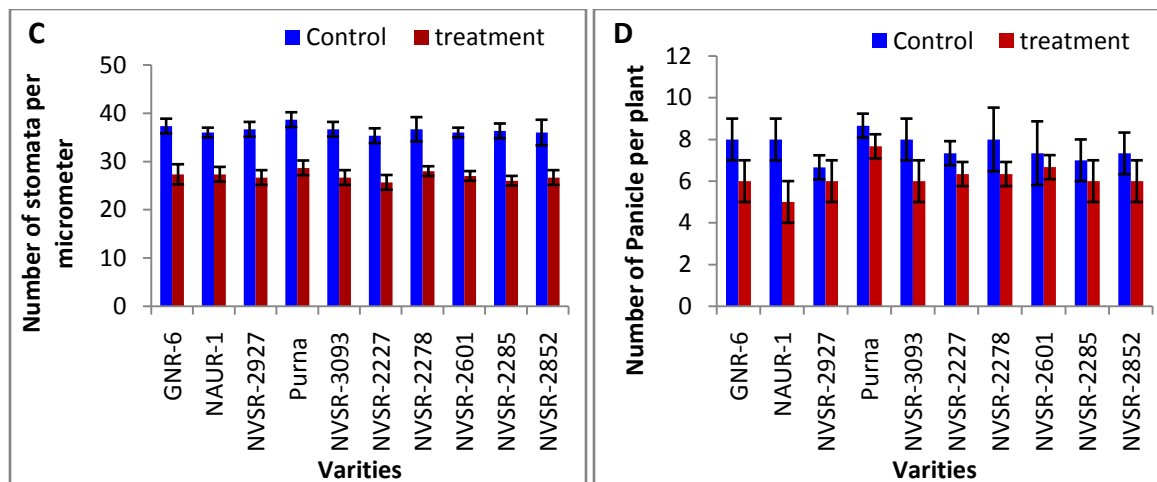
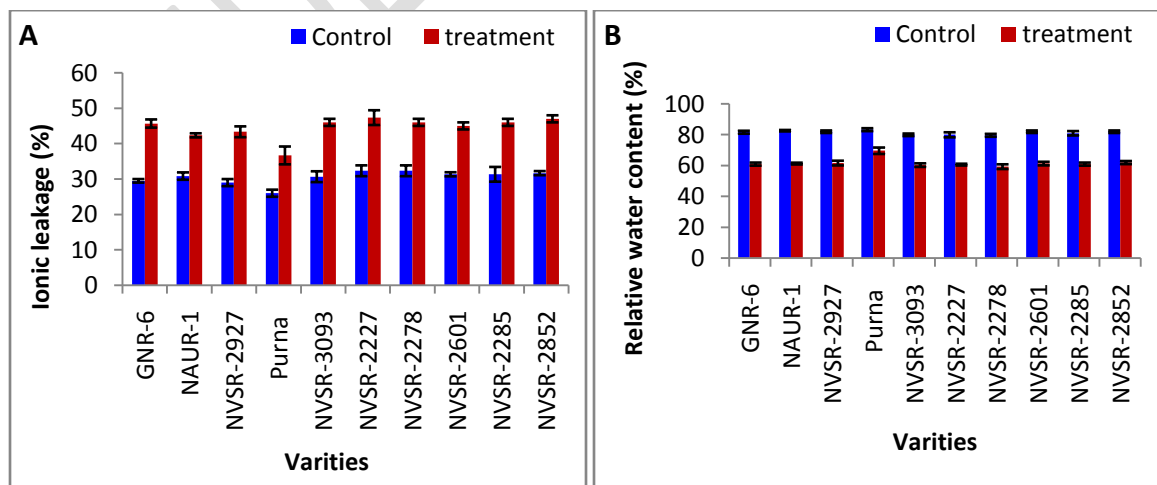


Fig. 1. (A) Plant height as affected by water deficit stress at tillering stage and control. \pm Bars indicate SD (n = 10) (B) Leaf area index as affected by water deficit stress at tillering stage and control. \pm Bars indicate SD (n = 10) (C) Number of stomata per micrometer of leaf area as affected by water deficit stress at tillering stage and control. \pm Bars indicate SD (n = 10) (D) Number of panicle per plant as affected by water deficit stress at tillering stage and control. \pm Bars indicate SD (n = 10)

The results of 10 varieties of their four morphological traits showed that the variety Purna was lower plant stature (Fig. 1A), higher leaf area index (Fig. 1B), higher number of stomata per micrometer (Fig. 1C) and higher number of panicle per plant (Fig. 1D). These are the traits which support the plants their performance under stage specific stress. Fleury et al. (2010) reported that genotypic variance in wheat increase tolerance capacity of drought. It has been indicated that breeding strategy with genotypic selection might increase the tolerance against drought (T. R. Sinclair, 2011). Morphological traits might have the greater influence on drought tolerance and phenotyping of crops in the genomic era provided higher impact on yield and ecosystem (R. Tuberosa, 2012).



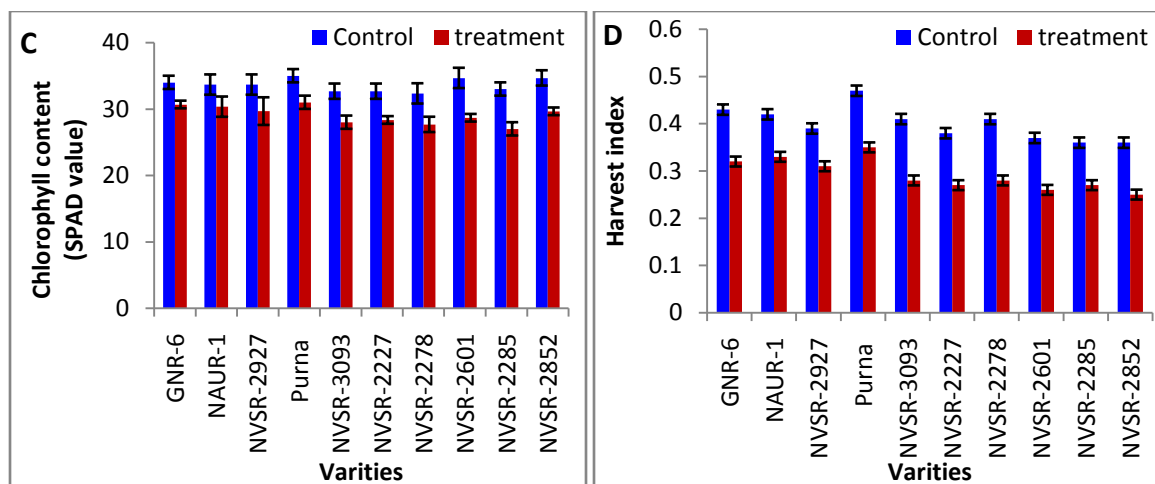
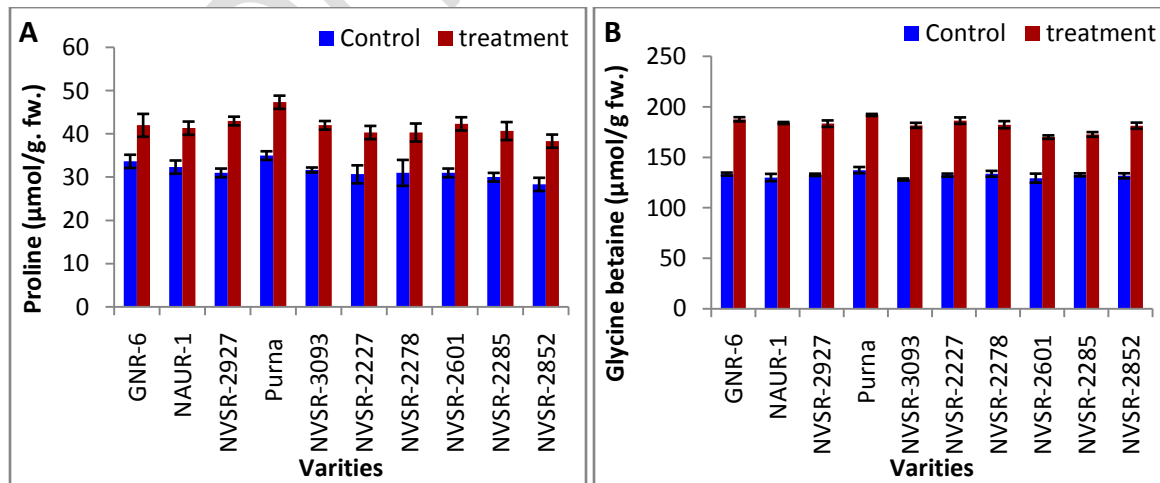


Fig. 2. (A) Ionic leakage as affected by water deficit stress at tillering stage and control. \pm Bars indicate SD (n = 10) (B) Relative water content as affected by water deficit stress at tillering stage and control. \pm Bars indicate SD (n = 10) (C) Chlorophyll content as affected by water deficit stress at tillering stage and control. \pm Bars indicate SD (n = 10) (D) harvest index as affected by water deficit stress at tillering stage and control. \pm Bars indicate SD (n = 10)

The ionic leakage was observed lower in Purna among 10 treated varieties under water deficit condition in comparison to control (Fig. 2 A) and relative water content (Fig. 2 B) Chlorophyll content (Fig. 2 C) were recorded (69.66%) and (31 SPAD value) respectively, in Purna and they were higher among 10 treated varieties while in control relative water content (RWC) maintained at >80% and chlorophyll content was higher in all 10 varieties compared to treated plants. The percentage harvest index showed that Purna performed better under stage specific water stress among 10 varieties while in control harvest index were higher in all cases compared to treated plants (Fig. 2 D). The water deficit stress delayed panicle initiation and increased ionic leakage led to membrane damage, decreased respiration as well as ATP production in rice (Kadam et al., 2017). Low water potential under drought is the common phenomena and is genotypically regulated as per tolerance of the plant. It affects the anatomy of leaves and their ultrastructure highly influenced under low relative water content led to lower number of stomata per micrometer of leaf (Upadhyaya and Panda, 2019). Reduced leaf area and chlorophyll content, leaf rolling, stomatal closure, and cutinized layer on the leaf surface induce early flowering and decline harvest index (Singh et al., 2012). It has been reported that short period of drought in rice reduced panicle length and grain filling duration resulted in loss in grain yield as well as harvest index. Reduced number of stomata and higher ionic leakage followed by lower stomatal conductance hinders the exchange of gases, resulting in poor seed setting and reduced grain size (Wei et al., 2017). Water deficit at short term negatively affected the RWC which created

osmotic imbalance, lipid peroxidation, membrane damage, and in severe cases necrosis spot has been also reported in rice (Zhu et al., 2020; Panda et al., 2021).

Osmotic imbalance under low RWC is genotypically regulated in plant. Some plants have their physiological and biochemical mechanism to synthesize osmolytes and protect from water stress. The simultaneous processes of photosynthesis and transpiration continued with lower stomatal resistance and higher osmoprotectant under water limited condition are one of the most important traits to select genotype for different environmental conditions (Kamoshita et al., 2008). The acclimatization of genotypes in response to the changing environments is the Genotype-environment interactions ($G \times E$). These two sources of variation might be considered for varietal evaluation for breeding and cultivation across environments (Yan et al., 2003). In the present study, Purna showed better among 10 varieties in the synthesis of Proline, Glycine betaine which induced by increased amount of abscisic acid (Fig. 3). The increased amount of ascorbic acid was significant impact on stress mitigation in case of selected 10 varieties (Fig. 3D). The content of Proline, Glycine betaine, abscisic acid and ascorbic acid were higher in Purna compared to other nine varieties while ascorbic acid was higher in all 10 varieties under control. These two osmolytes-Proline, and Glycine betaine have greater impact on hydration capacity of cell which led to higher yield under greenhouse conditions in comparison to other nine varieties. Accumulating osmolytes maintain turgidity and exposed the leaves for getting photosynthetic active radiation and assimilate translocation. Proline a well known vital osmoprotectant increased in rice under water deficit conditions and it helps the plant to continue stomatal conductance and maintain leaf turgidity (Kumar et al., 2016).



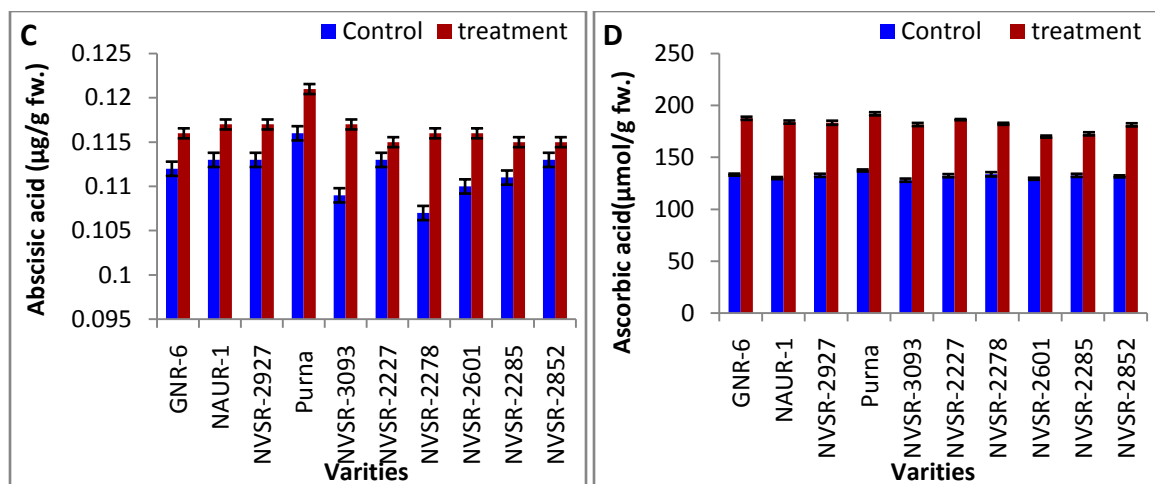


Fig. 3. (A) Proline content as affected by water deficit stress at tillering stage and control. \pm Bars indicate SD (n = 10) (B) Glycine betaine content as affected by water deficit stress at tillering stage and control. \pm Bars indicate SD (n = 10) (C) Abscisic acid content as affected by water deficit stress at tillering stage and control. \pm Bars indicate SD (n = 10) (D) Ascorbic acid content as affected by water deficit stress at tillering stage and control. \pm Bars indicate SD (n = 10)

Proline is one of the important imino acid which acts in cellular processes in two ways - component of protein and osmoprotectant under drought. Hence, content of proline would be the important tool for screening of plants under drought and might taken as a biochemical marker for analysis of rice genotypes (Mishra et al., 2019). The increased proline content in Purna resulted in hydration in cell, thus increased relative water content which continued the metabolism under short term water deficit stress (Fig 3A). The ABA and osmolytes viz. proline, glycine betaine, etc. reduced the oxidative damage and ionic leakage under drought stress in plants (Song, J.-X. et al., 2017). Water deficit stress increased ABA in all 10 varieties but it was higher in Purna which might influence the stomata closure and activate the defense mechanisms and synthesis of osmolytes in plant cell. It has been reported that increased concentration of ABA induce the synthesis of primary and secondary metabolites and enhance the biomass production (Fahad, S. et al., 2017). The Glycine betaine acts as a compatible solute and it has a major role in improving the water stress tolerance in plants. It has been well documented that Glycine betaine (GB) improved drought tolerance in various crops viz. wheat (Raza et al., 2014) sunflower (Hussain et al., 2008) etc. and increased yield compared to other GB deficient plants. The increased GB content remarkably enhances the osmotic balance, enzymes, and genes associated with drought resistance (Hussain et al., 2013). Hence, the

maintained hydration and osmoticum in cell led to survival and yield of the plant under short term water deficit stress.

Conclusion

The abiotic stress particularly water deficit in plant under rainfed condition is the major challenge for marginal farmer for production and yield of crops. Selection of drought tolerant varieties might reduce severe loss caused by water stress. The variety Purna has been found better under short term water deficit among 10 varieties of rice. Hence, drought tolerant variety can be produced through breeding program with the help of Purna.

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