MITIGATING THE ADVERSE EFFECT OF SALINITY STRESS ON RICE (*Oryza sativa* L.) THROUGH OSMOPROTECTANTS

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BY
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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Science (Agriculture)

(PLANT PHYSIOLOGY)

JULY, 2025

CERTIFICATE-I

This is to certify that the thesis entitled **"Mitigating the adverse effect of salinity stress on rice (*Oryza sativa* L.) through osmoprotectants"** submitted in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture)** with major in **Plant Physiology** of the college of **Agriculture** Post Graduate Studies, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya is a record of *bonafide* research carried out by **Ms. Anushka Singh, ID. No.: A-14643/23,** under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been acknowledged.

Kumarganj, Ayodhya
July, 2025

Dr. A. K. Singh
Professor, Plant Physiology
Chairman
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CERTIFICATE-II

We, the undersigned, member of Advisory Committee of **Ms. Anushka Singh**, ID. No.: **A-14643/23** a candidate for the degree of **'Master of Science' in Agriculture** with major in Plant Physiology agree that the thesis entitled **"Mitigating the adverse effect of salinity stress on rice (*Oryza sativa* L.) through osmoprotectants"** may be submitted in partial fulfilment of the requirements for the degree.

20/08/2025

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Head of the Department
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CERTIFICATE-III

DECLARATION OF ANTI-PLAGIARISM

I, **Anushka Singh** , ID. No.: **A-14643/23**, certify that the thesis entitled **"Mitigating the adverse effect of salinity stress on rice (*Oryza sativa* L.) through osmoprotectants"** submitted in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture)** in **Plant Physiology** to the College of Agriculture, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.) is original work and has similarities with published work not more than minor similarities as per the UGC (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulations, 2018, adopted by the university.

I declare that I have faithfully acknowledged, given credit to and referred to the research workers wherever their works have been cited in the text and body of the thesis. I further certify that I have not wilfully lifted up some others' work, para, text, data, results etc. reported in the journals, books, magazines, reports, dissertations, thesis etc., or available at web-sites and included them in this thesis and cited as my own work.

Place: Kumarganj, Ayodhya **(Signature of the candidate)**

Date: 20/08/25

CERTIFICATE FROM THE MAJOR ADVISOR

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(Major Advisor)

20.08.2025

Head of the Department

Dean, PGS **Dean**

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Kumarganj, Ayodhya
July, 2025

(Anushka Singh)
Author

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ABBREVIATIONS USED

%	:	percentage
&	:	Ampersand (and)
@	:	At the rate
^{0}C	:	Degree Celsius
CD	:	Critical difference
cm	:	Centimeter
DW	:	Dry weight
Fig.	:	Figure
g	:	gram
ha	:	Hectare
hr.	:	Hours
i.e.	:	Id east (that is)
K	:	Potassium
EC	:	Electrical Conductivity
M	:	Molar
mg	:	milligram
ml	:	Milliliter
L	:	Litre

mt	:	Million tonnes
Na	:	Sodium
nm	:	Nano mole
NS	:	Non-significant
OD	:	Optical density
PH	:	Plant height
S	:	Significant
S. No.	:	Serial number
SEm±	:	Standard error of mean
Wt.	:	Weight
DAT	:	Day After Transplanting
et al.	:	Et allili (co-authors)
i.e.	:	Id est (that is)
J	:	Journal
kg	:	Kilogram
N	:	Nitrogen
P	:	Phosphorus
K	:	Potassium
q	:	Quintal

viz	:	Videlicet (namely)
HI	:	Harvest Index
ppm	:	Parts per million
RH	:	Relative Humidity
RPM	:	Revolution Per Minute
TSC	:	Total Soluble Carbohydrate
NR	:	Nitrate Reductase
Chl.	:	Chlorophyll
SOD	:	Superoxide Dismutase
PBT	:	Panicle Bearing Tiller
SP	:	Sterility Percentage
^{0}F	:	Degree of Fahrenheit
TW	:	Turgid Weight

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Chapter I

INTRODUCTION

Rice (*Oryza sativa* L.) is a self-pollinating, monocotyledonous plant, classified as a short-day, C3-type cereal grain, and is a member of the Gramineae (Poaceae) family. The genus *Oryza* comprises 24 acknowledged species, including 22 wild species and two cultivated species, namely *Oryza sativa* and *Oryza glaberrima* (Fang X *et al*., 2024). Rice possesses 12 chromosomes, corresponding to a diploid chromosome number of 2n = 24 (Reuscher *et al*., 2018). It is among the three primary food crops globally and serves as the staple diet for approximately half of the world's population. Asia dominates global rice production, contributing approximately 90% to the world's total output (Geng Y *et al*., 2025).

Rice is cultivated in approximately 150 million ha area in the world and 135 million ha area in Asia (IAEA/FAO, 2024). Whereas, it is cultivated in approximately 44 million ha area in India. In Uttar Pradesh, it is cultivated in 5.9 million ha area in different conditions such as irrigated, non-irrigated, water logged, non-irrigated usher land and flood affected area (Agriculture Department Uttar Pradesh, 2023). Rice is cultivated in 70 districts of Uttar Pradesh. Out of which 7 districts are under high productivity group, 29 districts are under medium productivity group, 26 districts are under medium-low productivity group, 5 districts are under low productivity group and 3 districts are under very low productivity group (Directorate of rice development, 2024).

As reported by the FAO (STAT 2023/24), global rice production for the year 2023-2024 is 523.9 million tonnes on a milled basis. Whereas, India's rice production for the 2023-2024 financial year is 128 million metric tonnes (USDA, 2024). The rice production in India for 2024-25 is projected to reach 147 million metric tons (USDA, 2024). As reported by IREF (2024), West Bengal ranks as the leading rice-producing state in India in 2024, with a production of 15.75 million tons, followed by Uttar Pradesh with 12.5 million tons and Punjab with 11.82 million tons.

Hamid A. *et al*., (2021), emphasized that rice is a rich source of energy and it contains the following nutrients: Niacin (1.9 mg), Protein (6.8 g), Carbohydrate (78.2 g), Fat (0.5 g),

Fiber (0.2 g), Minerals (0.6 g), and Riboflavin (0.06 mg). In humid and sub-humid Asia, it has been regarded as a significant source of employment for rural residents.

According to Asati R *et al*., (2023), it supplies roughly 50–80% of the calories consumed. With a threshold of 3 ds/m for the majority of grown varieties, rice is currently the most salt-sensitive cereal crop and is extremely sensitive to salinity stress (USDA, 2013).

The global map of salt affected soils (FAO, 2024), estimates that there is more than 1.4 billion ha area (Sodicity: 280-420 million ha and Salinity: 840 to 980 million ha approximately) of salt-affected soil. Most of them can be found in naturally arid or semi-arid environments. According to CSSRI (2024), an estimated area of 6.74 million ha in India suffers from salt accumulation (Sodicity: 3.78 million ha and Salinity: 2.96 million ha).

The CSSRI (2023), reported that in Uttar Pradesh, the salt affected soils accounts for about 1.37 million ha area. The majority of these soils are having pHs > 10, Exchangeable Sodium Percentage (ESP) >15 and varying Electrical Conductivity (EC). About, 11.7 million ha could be affected by salinity and alkalinity in India by 2025. With 71.2% of India's total saline soil, Uttar Pradesh has the highest area of saline soil in the nation (Frontiers, 2023). Eventually, more than 72% of the coastal saline soil occurs in West Bengal and Gujarat altogether.

With detrimental effects on germination, plant vigour, and crop yield, salinity is one of the most significant factors limiting agricultural crop productivity (Li Q *et al*., 2024). "Soil having an electrical conductivity of solution extracted from the water-saturated soil paste ECe (Electrical Conductivity of the extract) of 4 ds/m" is the USDA salinity laboratory's definition of saline soil.

Water stress, ion toxicity, nutritional problems, oxidative stress, changes in metabolic processes, membrane disarray, decreased cell division and expansion, and genotoxicity are some of the ways that high salinity impacts plants (Arif Y *et al*., 2020). All of a plant's primary functions, including photosynthesis, protein synthesis, and energy and lipid metabolism, are impacted when salt stress first appears and progresses (Hao S *et al*., 2021). The number of tillers per plant, flowering stage, panicle number, percentage of sterile florets, leaf size, shoot growth, shoot and root length, seed germination, seedling growth, and productivity are all impacted by salinity stress (Yao D *et al*., 2022).

Soil salinity is a significant environmental obstacle to agricultural development and is expected to worsen due to shifting irrigation practices and the changing climate. The primary cause of this severe abiotic stress is an accumulation of sodium chloride, which can occur naturally or as a result of irrigation (Majeed A *et al*., 2019). When sodium chloride levels are too high, stomatal closure occurs, increasing leaf temperatures and preventing shoot elongation (Ma Y *et al*., 2021). These reactions are known as the "osmotic phase" and occur separately from shoot salt accumulation (Chen, J. T *et al*., 2021). This "ionic phase" is the term used to describe the growth inhibition and early senescence of older leaves caused by prolonged exposure to salinity (Malakar P *et al*., 2021).

Excessive soil salinity causes uneven and stunted development, poor and patchy crop stands, and decreased yields; the severity of these effects depends on the salt level. The main effect of high salinity is the decreased accessibility of water to plants, even when the root zone still has some water (Balasubramaniam T *et al*., 2023) This happens as a result of the soil solution's osmotic pressure increasing as the concentration of salt increases. In addition to places with poor drainage, marshy areas, and waterlogged conditions, saline soil is common in arid and semi-arid regions. Ion toxicity, osmotic stress, oxidative stress, and deficiencies in vital minerals like N, Ca^{2+}, K^{+}, P, Fe^{2+}, and Zn^{2+} are all brought on by salinity stress, which limits plants' ability to absorb water from the soil (Joshi S *et al*., 2022).

A notable contributing factor to the reduction in growth and production of a variety of crops is salinity. Salinity in the soil negatively impacts a number of plant physiological functions, which inhibits growth (Shabala S *et al*.,2017). In order to maintain food production in areas that are prone to salinity, it is therefore essential to improve the salt tolerance of crops (Santosh Kumar *et al*., 2020). Salinity affects soil in a variety of ways, including chemical, physical, and biological. The main physical influence is on soil permeability, whereas chemical effects involve salt exchanges and interactions. Changes in protoplasm and cell membrane permeability, as well as variations in osmotic pressure, are examples of biological impacts (Wang, Z *et al*., 2021).

Improving crop resistance to salt becomes an imperative global priority, considering the need to produce enough food to fulfil the expanding demands of the world's population (Ma *et al*., 2022). There are two primary phases that govern how salinity influences plant growth: osmotic stress initially, followed by ion-specific stress and the production of Reactive Oxygen Species (ROS) and free radicals (Wahab *et al*., 2022). The accumulation

of compatible solutes in the cytosol during the first phase aids in osmotic adjustment in plant cells and maintains the pressure potential necessary for normal cell function and plant species growth (Johnson *et al*., 2022).

Numerous defense mechanisms, including osmoregulation, ion homeostasis, antioxidant, and hormonal systems, are present in tolerant plants and aid in their survival and development before they reach the reproductive stages (Hasanuzzaman M *et al*., 2022). Plants have evolved a number of defense mechanisms against osmotic stressors, including the synthesis of Na+/H+ antiporters for ion sequestration and the production of osmolytes for osmotic adjustment. The osmolality balance between xylem vessels and xylem parenchyma cells is mediated by the Na^+ transporter HKT1 (Venkataraman G *et al*., 2021). Three steps are typically needed for these responses to function: signal transduction, osmotic stress recognition, and the synthesis of physiological response components (Yu B *et al*., 2024).

Sugars are the most crucial regulators that support a variety of physiological functions, including photosynthesis, seed germination, flowering, senescence, etc. under different abiotic conditions. Low concentrations of sugars applied exogenously encourage seed germination, increase photosynthesis, encourage flowering, and postpone senescence in a variety of unfavourable environmental circumstances. Plant growth and general structure are maintained largely by soluble sugars (Afzal S *et al*., 2021). Its site specificity allows it to regulate in plants in a very complicated way. As a result, they require long-distance signals in order to synchronize with changes in the environment, development, and physiology (Jeandet P *et al*., 2022).

From embryogenesis to senescence, sugar molecules regulate metabolism, growth, stress reactions, and development in addition to serving as nutrients (Gangola *et al*., 2018). Additionally, sugars actively regulate growth, photosynthesis, carbon partitioning, lipid and carbohydrate metabolism, osmotic homeostasis, protein synthesis, gene expression, and membrane stabilization under a variety of abiotic conditions (N Khan *et al*., 2020). Furthermore, a higher concentration of soluble sugars increases a plant's resistance to a number of abiotic stresses, including cold, salinity, and drought (Saddhe A. A. *et al*., 2021).

The ROS accumulation is directly correlated with sugar accumulation to acclimatize the ill-effects of environmental stress. Moreover, sugars play a dual function as they are

associated to both ROS anabolism and catabolism, such as oxidative pentose phosphate pathway involved in NADPH production is involved in scavenging of ROS (Khanna K *et al*., 2024). ROS accumulation enhances membrane damage by producing substances involved in lipid peroxidation, such as Malondialdehyde (MDA). Sugar accumulation serves as osmolytes to alleviate the negative effects of salt stress (Afzal S *et al*., 2021).

Sugar alcohols are acyclic polyols which plays an important role in the metabolism of some higher plants. Three of them are widely distributed in Angiosperms: galactitol, mannitol and sorbitol (Bhattacharya S *et al*., 2020). They are primary photosynthetic products which are also involved in response to stress. When it constitutes a major end-product of photosynthesis in a given species, it is translocated over long distance through the phloem (Barot M *et al*., 2025)

Sugar alcohols are synthesised outside the chloroplast, *via* reductases and phosphatases. They are degraded *via* dehydrogenases or oxidases. On a daily time scale, sugar alcohols are temporarily stored in mesophyll tissues. They accumulate in the light and are translocated in the dark. In mature leaves, mannitol synthesised in mesophyll cells can be temporarily stored in petiole parenchyma cells, to be remobilised during senescence. (Suzuki Y *et al*., 2015) On a seasonal time scale, sugar alcohol can be temporarily stored in the perennial parts of some tree species.

Conversely, in fruits of species where a sugar alcohol is a major translocated sugar, the main storage form of carbohydrates is starch and hexoses (Dumschott, K *et al*., 2017). Several studies suggests that it plays a crucial role in tolerance to salt-stress. However, it is not always clear whether this role may be related to osmotic adjustment, accumulation of a compatible solute or the transitory storage of carbon reserves. Sugar alcohols may also play a role in resistance to biotic stress.

Sorbitol is a component of sugar alcohols produced by the hydrolysis of carbohydrates. It contains carbon and is produced by microorganisms and plants (Mechri *et al*., 2015). Sugar alcohols increase the growth of the microbial community because they are an easy and accessible food source of carbon for microorganisms (Hennion N *et al*., 2019). The studies show that when the plant grows under saline conditions, the concentration of sugar alcohols such as sorbitol increases in the roots of the plant (Skodra C *et al*., 2021).

Exogenous sorbitol application has positive effects on growth of salt-stressed plants and also reduce stress-induced H_2O_2 and MDA content in salt-sensitive rice seedlings (Theerakulpisut P *et al*., 2016). The humectant effect of polyols enhances the humidity on the leaf surfaces, and improve the flexibility of the guard cells stomata (Singh M *et al*., 2015). According to the research, the application of sugar alcohols in the soil increases the soil enzymes activity such as urease, catalase, and alkaline phosphatase (Yu *et al*., 2016)

A member of the sugar alcohol family, mannitol is an osmotic adjustment chemical that is used to control the osmotic potential in nutrient solutions or culture media to create a water deficit for proteomic or protein expression research (Patel T.K. *et al*., 2016). Pujni *et al*., (2007) introduced the E. coli mannitol-1-phosphate dehydrogenase gene (mt/D), a gene involved in mannitol synthesis, into Indica rice. The resultant transgenic rice plants exhibited a correlation between the increased salt tolerance and the mannitol accumulation. The species that metabolize mannitol have several advantages over those that exclusively translocate sugars. One advantage is increased tolerance to salt and osmotic stress as a result of mannitol's function as a 'compatible solute'. Therefore, the knowledge of the relevant mechanisms of specific osmolytes could be helpful in the generation of salt-tolerant crops.

Soluble sugars (such as sorbitol and mannitol) alterations in plants growing under salt stress have been generally investigated in numerous species of rice (Li Q *et al*., 2017). The parameters present in cultivated crop species during salt stresses have been evolved as effective indices for tolerance selection in breeding programs (Fang X *et al*., 2023).

With this background in mind, the following research on "**Mitigating the adverse effect of salinity stress on rice (*Oryza sativa* L.) through osmoprotectants**" is executed with the following objectives:

1. To study the effect of sorbitol and mannitol on growth parameters and biochemical changes of rice under salinity stress.

2. To find out the effect of sorbitol and mannitol on yield and yield attributes of rice under salinity stress

Chapter II

REVIEW OF LITERATURE

The literatures available on "**Mitigating the adverse effect of salinity stress on rice (*Oryza sativa* L.) through osmoprotectants**" is critically reviewed to summarize in this chapter. A brief analysis of literature on the effects of sorbitol and mannitol sugars on physiological and biochemical in cereal and other crops has been collected, evaluated and presented systematically in this part of thesis.

Sorbitol and mannitol sugars:

J Chang *et al.,* (2019) reported that salinity stress significantly impacts rice growth, particularly in sensitive cultivars like Nipponbare. In contrast, tolerant cultivars (Dendang and Fatmawati) showed enhanced metabolic responses under salt stress. Notably, mannitol accumulation in Dendang roots was significantly higher than in Nipponbare after 14 days of salt exposure, suggesting its role in conferring salt tolerance. It likely contributed to osmotic adjustment and stress mitigation, highlighting its importance in breeding salt-tolerant rice varieties.

X. Zang *et al.,* (2007) investigated rice responses to osmotic stress induced by mannitol (400 mM) using proteomic analysis. Mannitol treatment altered the expression of 15 proteins, including a stress-specific 26S proteasome regulatory subunit. Some proteins, such as HSPs and molecular chaperones, were downregulated. Importantly, several stress-responsive proteins were found in osmotic-tolerant cultivars, suggesting that mannitol-induced osmotic stress triggers a specific and coordinated protein response, aiding in plant survival under adverse conditions.

Pattnaik D *et al.,* (2021) highlighted the role of osmoprotectants such as sugar alcohols as key adaptive compounds under abiotic stress. These small, soluble molecules help maintain cellular turgor, redox balance, and reduce ROS levels. They contribute to enhanced photosynthesis, activation of antioxidant enzymes like SOD, stabilization of proteins, and regulation of stress-responsive genes. Their accumulation supports plant growth and development under stress, making them vital for stress mitigation strategies.

Chutipaijit S. (2016) evaluated drought responses in rice genotypes using mannitol (100 mM) to simulate stress. Mannitol-induced drought conditions led to differential antioxidant responses between tolerant and sensitive genotypes. Drought-tolerant seedlings showed greater increases in overall antioxidant capacity, contributing to better ROS scavenging, growth rate, and cell membrane stability. These results suggest that mannitol serves as an effective osmotic agent in enhancing drought tolerance mechanisms in rice.

P. Theerakulpisut *et al.,* (2012) studied the effect of sorbitol on rice cultivars under salt stress. In the salt-sensitive KDML105, exogenous sorbitol significantly improved growth and reduced oxidative damage by lowering H□O□, MDA content, and electrolyte leakage. However, no beneficial effects were observed in the salt-tolerant Pokkali (PK), and in some cases, sorbitol exacerbated stress responses. These results suggest that sorbitol can act as an effective osmoprotectant in salt-sensitive genotypes, aiding in stress mitigation.

Khaliq M *et al.,* (2023) demonstrated that foliar application of sorbitol effectively mitigated the adverse effects of 150 mM NaCl stress in rice. When applied at 50-, 75-, and 100-mM concentrations, sorbitol significantly enhanced morphological, physiological, and yield traits under both stress and normal conditions. The most effective concentrations were 50 mM and 75 mM, which led to notable improvements in plant growth. These results confirm that sorbitol serves as a potent foliar osmoprotectant, promoting stress resilience and overall plant performance.

Hasanuzzaman M *et al.,* (2019) reported that rice, being highly stress-sensitive, responds to abiotic stresses by accumulating osmolytes such as sorbitol, mannitol, etc. These compounds facilitate osmotic adjustment, stabilize proteins and membranes, mitigate ionic toxicity, scavenge ROS, and support redox balance. While not all plants naturally accumulate sufficient osmolytes, biotechnological interventions enhancing sugar alcohol biosynthesis or their exogenous application have shown promising results in improving stress tolerance and rice productivity.

Will *et al.,* (2011), highlighted the humectant property of sorbitol, which increases leaf surface humidity and enhances stomatal flexibility, thereby supporting efficient gas exchange. Additionally, sorbitol forms stable complexes with calcium, facilitating its uptake and transport, ultimately leading to improved calcium accumulation in rice tissues.

Pamuru R.R *et al.,* (2021) explained that sugar alcohols (polyols) such as mannitol, sorbitol, and others accumulate in rice under salt and drought stress. These compounds play a vital role in osmoregulation by maintaining cellular osmotic balance during water loss caused by abiotic stresses. Sugar alcohols contribute significantly to plant tolerance against salinity and drought, making them key targets for crop improvement and biotechnological research.

GROWTH PARAMETERS

El-Sherpiny *et al.,* (2023) conducted a trial involved the foliar application of sorbitol at different rates (0-, 5-, 10- and 15-ml L^{-1}). In terms of foliar application, all rates of sorbitol were found to enhance plant growth performance and productivity, in comparison to the control treatment (without sorbitol). The growth and productivity parameters improved with increasing rates of added sorbitol.

Al-Dulaimi H.S. *et al.,* (2024) found that spraying with sorbitol has an effective role in all aspects of vegetative growth and yield. The reason for this is its role in improving the process of nutrient absorption and their transfer to the inside of the xylem and phloem vessels, and the plant's apical meristem. This leads to an increase in leaf area, volume of the vegetative system, and superiority of the yield in terms of quantity and quality due to increased cell division and elongation and regulation of the vital processes that occur in the plant.

Ghosh U.K. *et al.,* (2021) emphasized the crucial role of osmolytes, including sugar alcohols, in helping rice adapt to abiotic stresses by maintaining cellular homeostasis, osmotic adjustment, and redox balance. Osmolytes protect cellular components from osmotic and oxidative damage, supporting stress tolerance. Studies show that higher osmolyte accumulation correlates with enhanced stress resilience, and genetically engineered plants overexpressing osmolyte biosynthesis genes exhibit improved tolerance. Understanding osmolyte functions is vital for developing stress-tolerant crops.

Saxena R. *et al.,* (2019) reviewed rice adaptive responses to drought and salinity stress, highlighting osmolytes including sugar alcohols as key compounds for osmotic adjustment and cellular protection. These low molecular weight solutes help maintain water balance, activate antioxidant enzymes, and support free radical scavenging. Together with

physiological, biochemical, and molecular changes, osmolyte accumulation is a critical defence mechanism enhancing plant resilience under abiotic stress.

Xie Z *et al.*, (2020) investigated metabolic responses of rice lines with varying salt tolerance. Theu found that sorbitol, significantly increased under salt stress across all lines. The sugar alcohols contribute to rice's adaptive response to salinity, with tolerant and sensitive lines showing similar metabolic patterns but differing in the magnitude of response. The sensitive lines had more pronounced increases during the early stages of the stress treatment than the tolerant lines. The study highlights the importance of sorbitol in rice salt stress tolerance at the molecular level.

Singh *et al.*, (2022) reviewed plant adaptations to salinity stress, highlighting the role of osmolytes in stabilizing cellular osmotic balance, regulating protein folding, and facilitating stress signalling. Osmolytes, together with phytohormones, coordinate stress responses by modulating gene expression related to biosynthesis and antioxidative defence. These phytohormones modulate the level of osmolytes through alteration in the gene expression pattern of key biosynthetic enzymes and antioxidative enzymes along with their role as signalling molecules. Understanding this interplay is crucial for improving plant tolerance to salinity and safeguarding crop productivity under adverse conditions.

Li Q. *et al.*, (2017) investigated moderate salt stress tolerance in two rice genotypes, Dongdao-4 (tolerant) and Jigeng-88 (sensitive). Dongdao-4 exhibited higher biomass, chlorophyll content, and photosynthesis under stress, with no significant differences in Na^+ or K^+ ion accumulation between the genotypes. Importantly, Dongdao-4 accumulated more soluble sugars and proline, aiding osmotic adjustment, and showed higher catalase activity to reduce oxidative damage. These findings suggest that osmolyte accumulation, including soluble sugars, plays a key role in salt stress tolerance, rather than ion toxicity.

Wani S.H. *et al.*, (2016) reviewed biotechnological advances in developing abiotic stress-tolerant crops. Thus, highlighting genetic engineering strategies that enhance the biosynthesis and accumulation of compatible osmolytes such as polyols (sugar alcohols), proline, and glycine betaine. These osmolytes aid in osmotic adjustment and ROS detoxification under drought, salinity, and cold stress. Transgenic approaches using single

or multiple genes and transcription factors have been successfully applied in various crops, including rice, to improve stress tolerance.

Patel, M.K. *et al.,* (2020) discussed how rice under salinity stress produce endogenous metabolites, including sugar alcohols, to maintain cellular homeostasis and mitigate stress effects. Seed or plant priming with exogenous metabolites is a promising non-genetic approach to enhance salt tolerance. Additionally, genetic engineering of metabolic genes involved in stress responses has advanced the development of salt-tolerant crops. This highlights the importance of metabolic regulation and biotechnological interventions in improving plant resilience to salinity.

Al Mahmud *et al.,* (2017) reviewed the impact of salinity on rice, a salt-sensitive crop whose growth and yield are severely affected by ionic and osmotic stresses. Salinity reduces photosynthesis and overall growth, leading to yield loss. The use of Phyto protectants, including sugar alcohols, has shown promise in enhancing salt tolerance in rice. Various strategies involving these compounds are being explored to develop salt-tolerant rice varieties.

Chutipaijit S (2016) examined drought responses in rice genotypes using 100 mM mannitol to induce stress. Drought-tolerant genotypes showed higher increases in catalase (CAT), peroxidase (POD), and total antioxidant capacity compared to sensitive ones, indicating enhanced free radical scavenging. The strong correlation between antioxidant enzyme activity and growth parameters suggests that mannitol-induced osmotic stress triggers antioxidant defences crucial for drought tolerance.

PHYSIOLOGICAL PARAMETER

Relative Water Content (RWC):

Reddy I.N.B.L. *et al.,* (2017) reviewed salt tolerance mechanisms in rice, emphasizing the role of multiple stress-responsive genes in breeding salt-tolerant varieties. They highlighted the biosynthesis of sugar alcohols which help maintain cellular turgor and osmotic adjustment under salinity. Integrating genomics, phenomics, and metabolic profiling with transgenic and breeding approaches is essential for developing high-yielding, salt-tolerant rice cultivars.

Hoang, T.M.L *et al.,* (2016) investigated that rice (*Oryza sativa* L.) is an important staple crop that feeds more than one half of the world's population and is the model system for monocotyledonous plants. However, rice is very sensitive to salinity and is the most salt sensitive cereal crop with a threshold of 3 ds/m for most cultivated varieties. Despite many attempts using different strategies to improve salinity tolerance in rice, the achievements so far are quite modest. Thus, in such situation the sugar alcohols can be a promising compound for the improvement of salinity stress tolerance in rice as well as potential opportunities for enhancing salinity stress tolerance in this important crop.

Choudhary S *et al.,* (2023) reviewed rice plant mechanisms to combat salinity stress, highlighting the key roles of osmolytes, including sugar alcohols, in osmotic regulation (turgor maintenance) and free radical scavenging. These compounds, along with ion pumps, represent promising targets for enhancing salt tolerance through physiological and molecular approaches.

PHENOLOGICAL PARAMETERS

Days taken 50% flowering:

Godoy F *et al.,* (2021) This review discusses various plant metabolites, including sorbitol and mannitol, and their role in enhancing stress tolerance in rice crop. It highlights how mannitol application can improve growth parameters under stress conditions, which may indirectly affect flowering time.

Yang X *et al.,* (2021) highlighted the vital role of sugars in plant metabolism and stress response. Accumulation of these sugars lowers cellular water potential, enhancing water uptake and retention under drought and salinity stress. Unlike many osmolytes, soluble sugars uniquely stabilize proteins and biofilms by forming hydrogen bonds, maintaining their structure and function during water deficit. This protective mechanism helps sustain vital physiological processes and reproductive ability of the plant. Thus, it may indirectly contribute to maintaining normal flowering time in rice under stress conditions, thereby reducing delays in days taken 50% flowering.

Days taken physiological maturity:

Bhattacharya and Kundu (2020) emphasized that sugars and sugar alcohols function as key osmolytes and stress-responsive molecules, helping plants adapt to environmental stress by stabilizing membranes, protecting proteins, and supporting redox homeostasis. Their accumulation enables osmotic adjustment and aids in recovery from stress at cellular, molecular, and physiological levels. These protective and regulatory functions contribute to sustained metabolic activity during stress, which can help prevent developmental delays. Ultimately. supporting timely progression to physiological maturity in crops such as rice under salinity and drought stress.

Xiao F. and Zhou H. (2023) reported that non-structural carbohydrates such as polyols accumulate in plants under salt stress, contributing to osmotic adjustment and enhanced salt tolerance. Beyond their osmoprotective role, they also act as signalling molecules, regulating plant responses to environmental stress. This dual function helps maintain physiological processes and developmental progression under stress, potentially minimizing delays and supporting timely attainment of physiological maturity in rice.

BIOCHEMICAL PARAMETERS

Chlorophyll content:

Vineeth *et al.,* (2023) highlighted that rice plants accumulate organic osmoprotectants such as sugar alcohols to combat salinity-induced osmotic stress. These compatible solutes enhance cellular water retention without disrupting enzyme function. By stabilizing cellular structures and mitigating oxidative damage, their accumulation under stress contributes to the protection of chloroplast integrity and chlorophyll retention, thereby supporting continued photosynthetic activity during salinity stress.

Suo J *et al.,* (2017) investigated that for mitigating the salinity-induced osmotic stress, rice plants accumulate sugar alcohols like sorbitol and mannitol. These compounds enhance cellular osmolality and water retention, thereby stabilizing membranes and protecting chlorophyll from degradation under stress conditions.

Ahmad F *et al.,* (2020) reported that soluble sugars like sugar alcohols act as osmoprotectants under stress. These compounds help maintain cellular structure, regulate antioxidant activity, strengthening membrane integrity, photosynthetic proficiency and

support water balance. By stabilizing chloroplast membranes and mitigating oxidative damage, they play a vital role in preserving chlorophyll content and sustaining photosynthetic efficiency during abiotic stress.

Al Mahmud *et al.,* (2017) demonstrated that sorbitol (5 and 10 mM) supplementation enhanced oxidative stress tolerance in salt-stressed rice (170 mM NaCl) by reducing H□O□ accumulation, lipid peroxidation, and membrane leakage. Ultimately, protecting the photosynthetic machinery and chlorophyll integration in plants.

Abdallah M. M. S. *et al.,* (2016) showed that soluble sugars mitigated salt damage (30–60 mM NaCl) and improved physiological traits. These included increased levels of photosynthetic pigments such as chlorophyll a, chlorophyll b, and carotenoids, highlighting its role in chlorophyll retention under salt stress.

Ahmad *et al.,* (2018) concluded that the organic osmolytes, are considered the most important solutes during salt stress. They not only function in osmotic adjustment, but also protect photosynthetic apparatus. They are synthesized in which can stabilize the protein complexes and protect the integrity of membranes, and accelerate the PSII repair under salt stress, thereby improving photosynthesis and salt tolerance.

Total Soluble Carbohydrates (TSC):

Nadwodnik J *et al.,* (2008) conducted research which analysed the distribution of sorbitol and other sugars within rice plant cells. It was found that sorbitol constituted a significant portion of the total soluble carbohydrates in leaves, indicating its substantial role in the overall sugar content and its potential impact on photosynthetic processes.

Nagarajan S *et al.,* (2022) reported that under salinity stress, rice plants increase soluble sugar levels in shoots and starch accumulation in roots which act as a reservoir for the primary metabolism. The elevated total soluble carbohydrates function as osmolytes and metabolic reserves, aiding in stress adaptation.

Al Mahmud *et al.,* (2019) reported that transgenic rice accumulated higher sugars under salt stress, exhibiting reduced osmotic stress compared to non-transgenic plants. Under 100 mM NaCl, the salt-tolerant cultivar IR651 showed greater total soluble sugar

accumulation in shoots than the salt-sensitive IR29. This increase in total soluble carbohydrates is linked to improved osmotic regulation and water uptake during salt stress.

Li Q *et al.,* (2017) reported that Dongdao-4 rice seedlings accumulated higher levels of soluble sugars than Jigeng-88 under moderate salt stress. This enhanced accumulation supports effective osmoregulation, up-regulation of ROS detoxifying systems and water potential maintenance, contributing to Dongdao-4's superior salt tolerance. Dongdao-4 showed some specific biological processes which may underlie the mechanism by which it was able to maintain the TSC levels during salt stress.

Nitrate Reductase (NR) activity:

Nadeem *et al.,* (2020) reported that osmoprotectants such as mannitol protect plants from dehydration and maintain osmotic balance during salt and heat stress by stabilizing membranes and proteins. Their synthesis, induced under stress, not only aids cellular protection but also supports enhanced nitrate reductase activity, as sugars act as metabolic signals that stimulate nitrogen assimilation and enzyme regulation under adverse conditions.

Singh P *et al.,* (2022) explained that osmoprotectants primarily maintain cell turgor and reduce ionic toxicity under salt stress via osmoregulation. By scavenging reactive oxygen species and preserving antioxidative enzymes, they enhance the plant's defence system. Additionally, osmolytes activate stress-responsive genes, including those regulating nitrate reductase activity. thereby supporting nitrogen metabolism and overall stress tolerance.

Na^+ and K^+ (ppm):

Hameed *et al.,* (2021) reported that sugar alcohols such as mannitol and sorbitol help regulate ionic homeostasis under salt stress by lowering the Na□ accumulation and enhancing K□ uptake, thereby maintaining a favourable K□/Na□ ratio. This ionic balance protects cellular membranes and supports higher photosynthetic efficiency during stress.

Alkahtani J *et al.,* (2023) emphasized that evaluating correlations among various traits provides deeper insight into salinity tolerance in Asian rice cultivars. Beyond morphological traits like plant height, biomass, and chlorophyll content, physiological and

biochemical parameters such as the Na□/K□ ratio, cell membrane stability, proline, MDA, H□O□, and sugar levels are crucial indicators. In particular, a lower Na□/K□ ratio reflects effective ion regulation, which is key to maintaining cellular function and stress resilience.

Anjum N.A. *et al.,* (2023) highlighted that due to their immobile nature, rice plants are continuously exposed to various abiotic stresses, leading to cellular water imbalance and oxidative stress. These conditions disrupt redox homeostasis, damage organelles and macromolecules, and impair metabolism. To counteract these effects, plants synthesize and accumulate osmoprotectants that help restore redox balance. Additionally, osmolytes contribute to ionic regulation by promoting K□ retention and limiting Na□ accumulation, thereby maintaining cellular ion homeostasis under stress.

Jiménez-Arias D *et al.,* (2021) noted that mannitol, widely present in rice plants plays a key role in osmotic stress tolerance. It is synthesized in the cytoplasm from fructose-6-phosphate through a series of enzymatic steps involving phosphomannose isomerase, mannose-6-phosphate reductase, and mannitol-1-phosphate phosphatase. Beyond osmotic adjustment, mannitol also contributes to ionic balance by facilitating reduced Na□ accumulation and improved K□ retention, aiding in cellular homeostasis under salt stress.

Pamuru R.R. *et al.,* (2021) stated that sugar alcohols accumulate in high amounts under salt and drought stress, playing a central role in osmoregulation. They are derivatives of sugars produced in high amounts during stress in plants. By maintaining osmotic pressure and cellular hydration, these osmolytes help plants adapt to water-deficit conditions. Importantly, they also contribute in ionic homeostasis by reducing Na□ accumulation and enhancing K□ retention, thereby supporting cellular function and improving stress tolerance.

Superoxide Dismutase (SOD) activity:

Kiani *et al.,* (2018) reported that 176 mM mannitol application significantly enhanced total phenolic, flavonoid, and anthocyanin contents, along with increased DPPH radical scavenging activity and enzymatic antioxidant responses. Notably, mannitol stress also elevated sulforaphane levels under both normal and stress conditions. These findings suggest that mannitol enhances antioxidant defence, including upregulation of SOD activity,

which plays a key role in detoxifying superoxide radicals and mitigating oxidative damage under stress.

Pattnaik D *et al.,* (2021) highlighted that osmoprotectants significantly enhance photosynthesis and strengthen the antioxidant defence system by upregulating key enzymes such as Superoxide Dismutase (SOD). These compounds protect cellular organelles from oxidative damage and protein denaturation, contributing to improved stress resilience and regulated plant growth and development.

Suryavanshi *et al.,* (2016) reported that foliar application of mannitol 20 mM recorded higher plant height, leaf area index and dry matter accumulation proline contend and SOD activity at harvest over the unsprayed and water sprayed control. Grain yield also increased to the extent of 14.9% by mannitol during 2013-14. Injury to the plants were observed due to higher doses of osmoprotectants.

Barot M *et al.,* (2025) reported that sugar alcohols such as sorbitol and mannitol play a crucial role in plant tolerance to drought, salinity, and extreme temperatures by maintaining osmotic balance and stabilizing membrane proteins (often the first targets of stress damage). As osmoprotectants, they also scavenge reactive oxygen species, potentially enhancing antioxidant enzyme activity, including Superoxide Dismutase (SOD), which mitigates oxidative damage and supports cellular protection under stress.

Wang X *et al.,* (2019) investigated the effects of drought stress during the tillering stage in drought-sensitive and drought-tolerant rice cultivars. The study revealed that with increasing drought duration and intensity, there was a significant rise in SOD activities, alongside elevated levels of H_2O_2, soluble proteins, and soluble sugars. This suggests a coordinated antioxidant and osmotic adjustment response, where enhanced SOD activity and sugar accumulation help mitigate oxidative damage and maintain cellular homeostasis under drought stress.

Yield & yield attributing traits:

Biswas S *et al.,* (2023) found that rice seeds primed with 1%, 2%, and 3% mannitol for 48 hours at room temperature exhibited improvements in seedling dry weight and membrane stability, indicating enhanced salinity tolerance. Although the study focused on

mannitol, it underscores the potential of osmotic agents in improving rice performance under stress conditions.

Devika O.S *et al.,* (2021) highlighted the role of seed priming with osmotic agents like sorbitol and mannitol in improving germination, growth, and yield in various cereal crops like rice. The study emphasized that osmo priming could be a viable strategy to enhance crop performance under adverse conditions.

Dhakal P *et al.,* (2020) concluded that seed priming with 2% mannitol for 8 hours resulted in higher germination percentage, seedling length, dry matter production, and vigour index under water stress conditions. These improvements suggest that mannitol priming can enhance early growth stages, potentially leading to better yield performance in stress conditions.

Hassanein A. *et al.,* (2021) emphasized rice's vulnerability to drought stress, which affects over 50% of agricultural land globally. In a comparative study of two rice cultivars drought-tolerant-Gz179 and sensitive-Sk101, Gz179 exhibited superior stress resilience under 40% water holding capacity. This was attributed to its enhanced metabolic response, including greater accumulation of osmoprotectants like sugars (mannitol etc.), as well as organic acids and nonenzymatic antioxidants. These traits contributed to better osmotic adjustment and oxidative stress management. Such physiological and biochemical adaptability under stress is closely associated with high-yielding potential, making Gz179 a promising genotype for cultivation in water-limited environments.

Pamuru R.R. *et al.,* (2021) noted that polyols such as mannitol and sorbitol are produced in high amounts under salt and drought stress. They are classified as cyclic and non-cyclic polyols and function as key osmolytes that help maintain cellular osmotic balance during water loss. By supporting osmoregulation and stress tolerance, sugar alcohols enhance plant resilience, which is critical for sustaining physiological functions and contributing to stable yields under adverse conditions. Their role in stress adaptation highlights their significance in breeding and developing high-yielding, stress-tolerant crop varieties.

Geng P *et al*., (2008) This study investigated the effect of sorbitol concentration on the regeneration of embryogenic calli in upland rice varieties. The results indicated that

higher concentrations of sorbitol enhanced the regeneration process, which is crucial for improving yield-related traits through tissue culture techniques.

Saddhe A. A *et al.,* (2021) highlighted that rice plants' sessile nature has led to sophisticated defence systems involving coordinated molecular and metabolic networks. These systems regulate growth, photosynthesis, osmotic balance, and carbohydrate homeostasis under stress. Sugars play a central role in stress perception and signalling, regulating gene expression linked to osmotic adjustment, ROS scavenging, and cellular energy maintenance through carbon partitioning. Such sugar-mediated responses are crucial for sustaining growth and productivity, underpinning high-yielding potential under adverse conditions.

Khanna K. *et al.,* (2023) explained that rice plants possess complex metabolic networks, including stress-responsive genes and metabolites, to acclimate under severe environmental conditions. Sugars, integral to photosynthesis and metabolic processes, play key roles in maintaining osmotic balance and sugar homeostasis. During stress, they act as critical signals regulating osmotic adjustment, ROS scavenging, and cellular homeostasis. The identification of numerous sugar transporters highlights their role in carbohydrate partitioning and signal transduction, processes essential for sustaining growth and achieving high-yielding potential under stress.

Sachdev S *et al.,* (2023) reported that rice plants exposed to environmental stresses overproduce toxic ROS, causing oxidative damage and reducing productivity. The plants mitigate ROS damage by synthesizing osmolytes such as sugar polyols. These osmolytes regulate osmotic potential, directly scavenge ROS, modulate antioxidant enzyme activity, and chelate metal ions, collectively protecting cellular functions. Their accumulation is further enhanced by phytohormones and micronutrients, improving stress tolerance. Understanding osmolyte roles is vital for developing strategies to sustain plant growth and productivity under changing climates.

Ejaz S. *et al.,* (2020) explained that rice plants generate ROS during normal metabolism but, maintain a balance through enzymatic antioxidants like Superoxide Dismutase. Under abiotic stress, this balance shifts toward ROS excess, triggering accumulation of osmolytes including sugars and sugar alcohols (mannitol). These osmolytes

alleviate oxidative damage by directly scavenging ROS, enhancing bioactive antioxidant compound accumulation, and inducing antioxidant enzyme activities.

Pleyerová I. *et al.*, (2022) highlighted, that beyond rice plants naturally accumulating sorbitol, some species produce it in small amounts or only possess sorbitol-metabolizing enzymes. Advances in analytical methods have expanded knowledge on sorbitol's role in enhancing plant fitness under stress, particularly when balanced growth and defence trade-offs are maintained. Studies on ectopic expression of sorbitol metabolism genes reveal it's signalling potential and distinct functions compared to mannitol-producing plants. A deeper understanding of sugar alcohol metabolism is crucial for advancing plant physiology and targeted breeding of high-yielding, stress-resilient crops.

Chapter III

MATERIALS AND METHODS

The present investigation entitled "**Mitigating the adverse effect of salinity stress on rice (*Oryza sativa* L.) through osmoprotectants**" was carried out at Plant Physiology Farm and in the Laboratory of Department of Plant Physiology, Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya (U.P.) during the Kharif season of 2023-24. The following are details of the materials utilized, the experimental procedure followed, the techniques used, and the climatic and edaphic conditions that prevailed during the experiment are as follows:

3.1 Experimental Site:

The experimental site Plant Physiology Farm is located at the Acharya Narendra Deva University of Agriculture and Technology, Narendra Nagar, Kumarganj, Ayodhya (U.P.), 42 kilometres from Ayodhya city and 23 kilometres from Jagdishpur.

3.2 Agro-metrological Condition:

Geographically, Ayodhya comes under sub-tropical climatic zone of Indo-Gangetic alluvium of eastern Uttar Pradesh, India with hot summer and coldest winter. It is situated at about 24.40 to 26.560 N latitude and 82.120 to 83.980 east longitude at an altitude of 113 meter above mean sea level (MSL). The average annual rainfall of this region during rainy season is about 1280 mm. Generally, April and May are the hottest months of the year. The monsoon season, which starts from June to September, receives over 80% of the total rainfall, with only a few showers in the winter. Westerly hot winds start from the month of April and continued till the onset of the monsoon.

3.3 Weather condition during crop season:

Faizabad region comes under semi-arid zone with hot summer and cold winters. Weather condition such as maximum and minimum temperature, relative humidity (%), total rainfall (mm.), wind speed(km/hr), bright sunshine (hrs.) and total evaporation record during the crop season which is present in Table-3.1.

Meteorological data was taken from the department of Agricultural Meteorology on weekly basis.

Table 3.1: Weekly Meteorological weather data during crop period (May, 2024 to October, 2024)

Week No.	Temperature ºC		Ave. R.H. (%)	Vapour Pressure (mm)	Total Rainfall (mm)	Wind Speed (Km/hr.)	Bright Sunshine (hrs.)	Total Evaporation (mm)
	Max.	Min.						
21	27.0	40.3	60.2	24.7	0	6.4	10.0	8.6
22	28.5	42.8	54.9	25.5	0	4.5	9.2	9.3
23	25.4	40.8	58.6	27.5	9.4	4.8	9.1	8.4
24	28.5	43.6	55.7	25.8	0	5.7	10.7	10.3
25	27.0	38.7	59.2	23.0	0	6.3	7.3	9.7
26	25.2	34.7	68.3	23.1	86.6	4.6	3.6	7.5
27	25.2	31.2	82.8	24.1	91.4	4.8	0.4	4.9
28	26.2	34.8	77.2	26.3	48.2	2.9	3.8	5.0
29	27.5	35.3	77.6	27.7	0	4.9	7.1	5.9
30	27.2	34.9	78.3	27.2	49.4	5.0	7.3	6.0
31	26.3	33.3	78.7	26.2	5.4	6.2	6.9	5.6
32	24.8	31.6	81.1	23.7	127.6	2.1	1.5	4.8
33	25.0	32.4	78.9	23.9	122.0	2.3	3.7	5.1
34	25.2	32.8	76.8	23.8	3.8	3.0	3.2	5.5
35	25.3	33.2	76.2	23.4	29.2	3.8	5.3	5.2
36	25.5	33.8	76.7	24.3	16.0	2.8	7.7	5.0
37	24.9	32.6	78.2	24.8	29.6	6.3	4.2	4.6
38	24.6	32.5	74.3	23.4	2.6	3.4	6.5	4.6
39	23.5	30.4	79.1	22.2	199.6	4.0	3.5	4.0
40	24.2	33.1	72.0	23.3	0	1.8	7.6	4.6
41	22.2	32.6	74.7	21.9	0	1.2	6.3	4.4
42	19.5	32.6	71.3	18.9	0	1.2	7.4	4.6
43	19.9	32.0	72.9	19.7	0	1.6	6.5	4.1
44	18.0	32.2	69.7	17.7	0	1.5	7.5	3.7

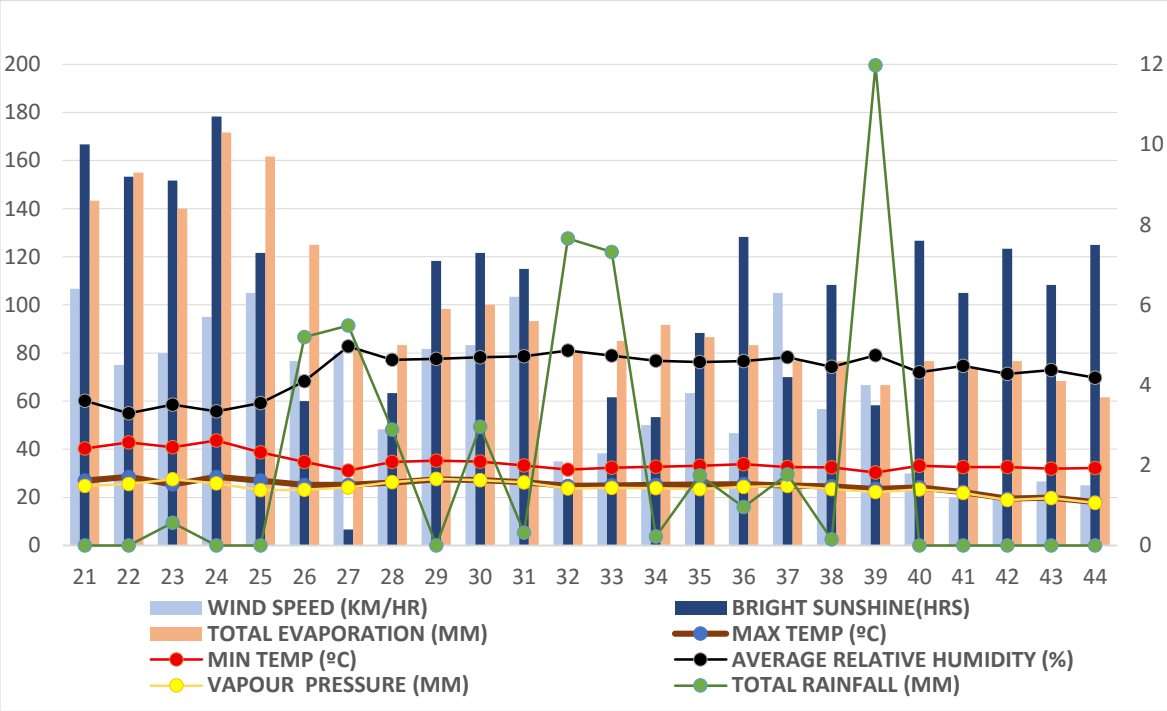


Fig. 3.1: Weekly Meteorological weather data during crop period (June, 2024 to October, 2024)

Table 3.2 Characteristics of experimental soil

The physio-chemical properties of the experimental soil are given below:

S. No.	Soil characteristics (saline soil)	Values
1.	Soil texture	Silty loam
a.	Clay (%)	23.6
b.	Silt (%)	53.3
c.	Sand (%)	23.1
2.	pH	9.2
3.	EC (ds/m)	4.5
4.	Organic carbon (%)	0.32
5.	ESP (%)	12.4

3.3. Experimental details

Design: Factorial RBD

Replication: 3 (each replication comprises of 2 varieties with 7 treatments) (as viewed in plate 1, 2 and 3)

Treatments: (as viewed in plate 7)

T1: Control – Foliar spray of distilled water at 40 DAT

T2: Sorbitol @40ppm at 40 DAT

T3: Sorbitol @60ppm at 40 DAT

T4: Sorbitol @80ppm at 40 DAT

T5: Mannitol @40ppm at 40 DAT

T6: Mannitol @60ppm at 40 DAT

T7: Mannitol @80ppm at 40 DAT

Varieties: (as viewed in plate 5 and 24)

1. CSR 23 (salt tolerant)
2. Sarju 52 (salt susceptible)

Total no of treatment: 3×14= 42

3.4. Nursery raising

Bold and healthy seeds of Sarju 52 and CSR 23 varieties of rice seeds were sterilized with 1% NaCl. Seeds were soaked with distilled water for 6 hr. and further seeds were kept in shed, little germination initiated. Further seeds of each variety spread over will saturated seed bed.

3.5. Main experimentation

3.5.1 Field preparation

The field was deep ploughed (2–3 times) to break soil clods, followed by flooding and puddling to reduce percolation losses and enhance the soil-water interface. Then, the field was levelled to ensure uniform water depth for facilitating transplantation. Finally, the layout was prepared as per measurements using ropes, and each plot was appropriately tagged according to the rice variety to be transplanted.

3.5.2 Fertilizer application

As per the recommended dose of fertilizer (RDF), NPK were applied at 120:60:40 kg/ha, respectively. Phosphorus, potassium and zinc (ZnSO□@25 kg/ha) were applied as a basal dose before transplanting. Nitrogen was applied in three equal splits: one-third at transplanting, one-third at active tillering, and the remaining one-third at panicle initiation stage to ensure optimal nutrient availability throughout the crop growth stages.

3.6. Transplanting

As per layout and design of experiment the 4 weeks (30 days) old seedlings were transplanted at the rate of one seedling hill^{-1} in the puddled field at spacing of 15 cm line to line and 10 cm plant to plant (as viewed in plate 29).

3.7. Plant protection

Suitable plant protection measures and intercultural operations were adopted in order to keep the plant free from diseases and insects (as viewed in plate 6).

3.8. Observations recorded

All the observations were recorded at 30, 45, 75 days after transplanting (DAT) and at physiological maturity. Three plants were tagged initially which were used for growth, biochemical analysis and yield measurement (as viewed in plate 27).

A. MORPHOLOGICAL TRAITS (30, 45, 75 DAT and at physiological maturity stage)

1. Plant height (cm)

2. Number of tiller plant^{-1}

3. Dry weight plant^{-1} (g)

4. Root length (cm)

B. PHENOLOGICAL TRAITS

1. Days taken 50% flowering

2. Days taken physiological maturity

C. BIOCHEMICAL ANALYSIS (30, 45, 75 DAT and at physiological maturity stage)

1. Estimation of chl. a, b and total chlorophyll content (mg g^{-1} fresh weight)

2. Estimation of Na^+ and K^+ Concentration in plant tissue (ppm)

3. Estimation of NR Activity (µg nitrate produced g^{-1} fresh weight min^{-1})

4. Estimation of Total Soluble Carbohydrate (TSC) content in plant tissue (mg g^{-1} dry weight)

5. Estimation of SOD activity (unit g^{-1} fresh weight)

D. PHYSIOLOGICAL TRAITS (30, 45, 75 DAT and at physiological maturity stage)

1. Estimation of Relative Water Content (RWC): %

E. YIELD AND YIELD ATTRIBUTING TRAITS

1. Panicle length (cm)

2. Panicle bearing tiller per plant

3. Sterility (%)

4.. Fertility %

5. Total number of grains panicle^{-1}

6. Grain yield plant^{-1} and per m^2 (gm)

7.. Straw yield plant^{-1} and per m^2 (gm)

8. Test weight (1000 seed weight)

9. Harvesting Index (%)

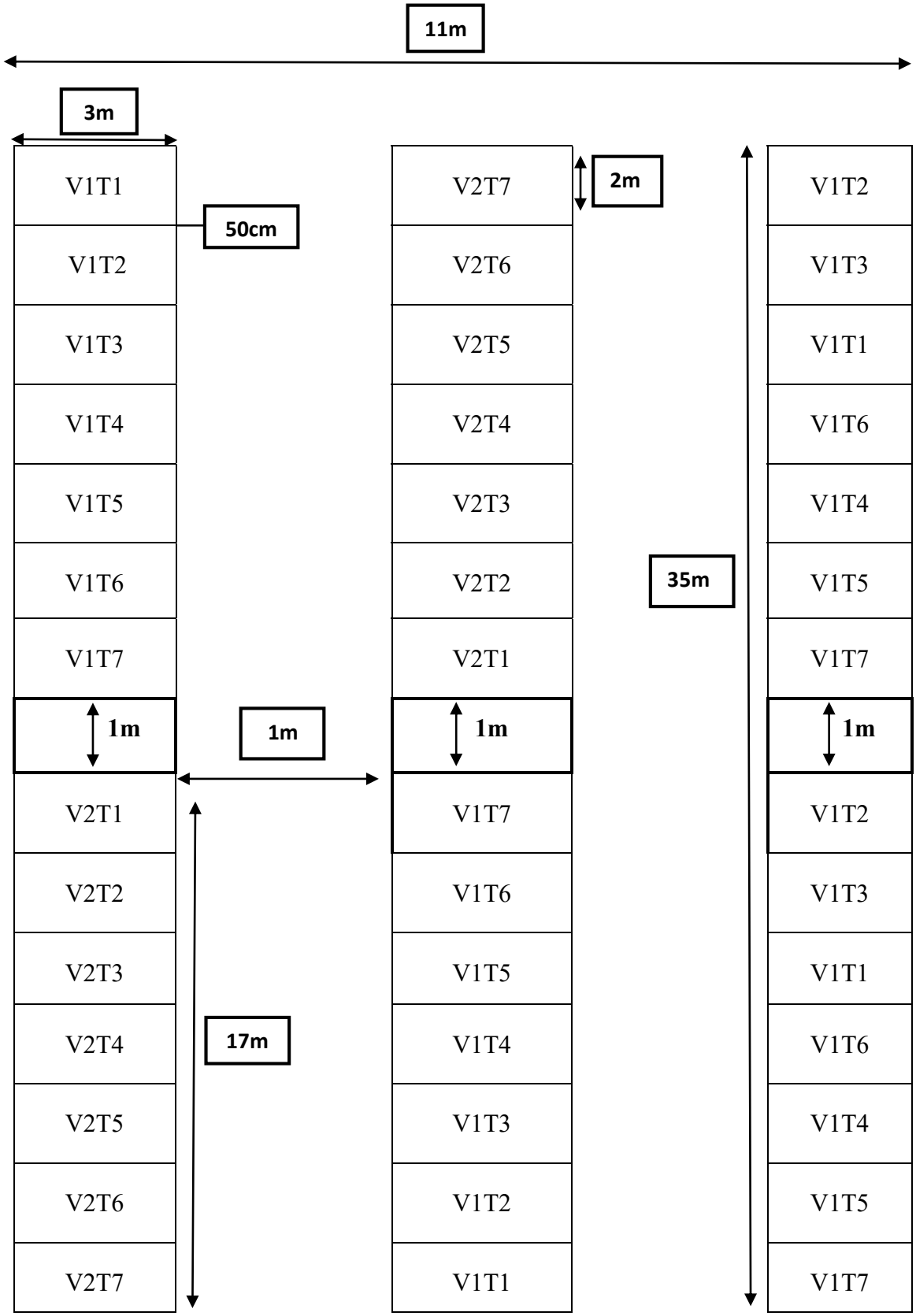


Fig.3.2: Layout plan of the experiment

3.8.1 MORPHOLOGICAL TRAITS

3.8.1.1 Plant height

The height of the plants was measured in centimetres, starting from the soil surface up to the tip of the plant, using a meter scale. Three plants from each replication, which had been previously tagged for this purpose, were selected for measurement. The average height of these three plants was then calculated to represent the plant height for that replication (as viewed in plate 8).

3.8.1.2 Root length

The length of the root was measured in centimetres, starting from the soil surface up to the tip of the root, using a meter scale. Three plants from each replication, which had been previously tagged for this purpose, were selected for measurement. The average length of the roots of these three plants was then calculated to represent the root length for that replication (as viewed in plate 23).

3.8.1.3 Number of tillers plant^{-1}

The tiller number were recorded at four different stages: 30, 45, 75 days after transplanting (DAT), and at physiological maturity. Visual scoring was employed to count the number of tillers plant^{-1} at each observation stage. Plants that had been previously tagged for this purpose were utilized, and the average tiller count plant^{-1} were calculated based on the recorded data (as viewed in plate 15).

3.8.1.4 Dry weight plant^{-1}

Three healthy and uniformly representative plants from each treatment were selected for sampling. These plants were then oven-dried at a temperature of 70±5°C until a constant weight was reached. The weight of the dried plant material was measured using a weighing machine. (as viewed in plate 13).

3.8.2 PHENOLOGICAL CHARACTERS

3.8.2.1 Days taken 50% flowering

The duration until reaching 50% flowering was documented as the number of days elapsed from the transplanting date to the emergence of 50% of the panicles in each plot (as viewed in plate 9, 30 and 31).

3.8.2.2 Days taken physiological maturity

The physiological maturity period for each treatment was evaluated based on the visual characteristics of the grains and the coloration of the leaves, specifically the flag leaf. Crop physiological maturity was considered attained when approximately half of the flag leaves exhibited a yellowish hue (as viewed in plate 4).

3.8.3 BIOCHEMICAL ANALYSIS

All the biochemical analysis were done in leaves at 30, 45 and 75 days after transplanting (DAT) and at physiological maturity.

3.8.3.1. Estimation of chl. a, b and total chlorophyll content (mg g^{-1} fresh weight)

The chl. a, b, and total chlorophyll content were calculated using Arnon's (1949) method and reported as milligrams per gram of fresh leaf weight. Method: After homogenizing 200 mg of fresh leaves in 10 ml of an 80% aqueous acetone solution, the mixture was centrifuged for 20 minutes at 4000 rpm. After collecting the supernatant, the leftovers were extracted again using 10 milliliters of 80% acetone and centrifuged. After mixing the supernatant, 20 milliliters of 80% acetone were added. The optical density (O. D.) was measured using a spectrophotometer with a blank of 80% acetone at 645 and 663 nm. (as viewed in plate 12 and 16). The amount of total chlorophyll was calculated as follows:

$$\textbf{Chlorophyll A} = 12.7\,(\text{O.D. } 663\text{nm}) - 2.69\,(\text{O.D. } 645\text{nm}) \times \frac{V}{1000 \times W}$$

$$\textbf{Chlorophyll B} = 22.9\,(\text{O.D. } 645\text{nm}) - 4.68\,(\text{O.D. } 663\text{nm}) \times \frac{V}{1000 \times W}$$

$$\textbf{Total Chlorophyll} = 20.2\,(\text{O.D. } 645\text{nm}) + 8.02\,(\text{O.D. } 663\text{nm}) \times \frac{V}{1000 \times W}$$

Where,

W = weight of sample

V = final volume

O.D. = optical density

3.8.3.2 Estimation of Total Soluble Carbohydrates (TSC) in plant tissue (mg g^{-1} dry weight)

Principle

Carbohydrates are first hydrolysed into simple sugars using dilute hydrochloric acid. In hot acidic medium glucose is dehydrated to hydroxymethyl furfural. This compound condenses with anthrone to form blue-green coloured product that is measured at 630 nm Yemn and Willis (1994).

Chemicals required

Hydrochloric acid (HCl)

Sulfuric acid (H_2SO_4)

Anthrone

Glucose

Preparation of reagents

2.5 N hydrochloric acid (HCl): 20.83 ml of 35% HCl make up to 100 ml of D.D.H_2O.

Anthrone reagent: dissolve 200 mg anthrone in 100 ml of ice cold 95% H_2SO_4. Prepare fresh before use.

Extraction

Weigh 100 mg of sample into a test tube, add 5 ml of 2.5 N HCl. The test tube is then kept in hot water bath for 3 h and cool to room temperature, add solid sodium carbonate until the effervescence ceases to neutralize it. Make up the volume to 50 ml with distilled water. Centrifuge for 20 min at 2000 rpm and collect the supernatant (as viewed in plate 21 and 26).

Estimation

Take one milliliter of the aliquot for analysis, cool it on ice, and then add four milliliters of ice cold anthrone reagent. Let it sit in a hot water bath for eight minutes, then quickly cool it down. Then, use the spectrophotometer at 630 nm to measure the green color intensity.

As previously mentioned, make the reagent blank by substituting 1 milliliter of distilled water for the extract, dissolving 100 milligrams of glucose in 100 milliliters of distilled water in a volumetric flask, and then taking 10 milliliters of this stock standard and diluting it to 100 milliliters in a different volumetric flask for their working standard solution.

A concentration range of 10–100 mg is obtained by varying the volumes of this standard solution from 0.0 to 1.0 ml. Then, proceed with the samples and read the color.

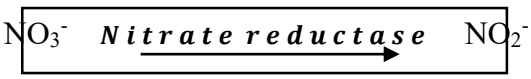
Calculation:

Draw a standard curve using absorbance versus concentration. Find out the concentration of the total carbohydrates in the sample using standard regression equation and express as mg per gram dry weight.

3.8.3.3 Estimation of Nitrate Reductase (NR) activity (µg nitrate produced g^{-1} fresh weight min^{-1})

NR activity was measured with colorimetric method given by Jaworski (1971).

Nitrate reductase reduces nitrate to nitrite:



The nitrate produced were allowed to react with sulphanilamide and NEDH. This produced a pink-coloured complex absorbing maximally at 540nm (Jaworski, 1971). The enzyme activity was expressed as µg nitrate produced g^{-1} fresh weight min^{-1}. Sodium nitrite ($NaNO_2$) was used to prepare a standard curve (10-70 n moles).

Reagents

Phosphate Buffer 0.1M pH 7.5

Potassium nitrate (KNO_3) as substrate 0.1M (1.0 g/ 100 ml Distilled water)

Propanol 5%

Sulphanilamide 1% in 3N HCL

N-1, Naphthyl ethylene diamine di-hydrochloride (NEDH) 0.02% (10 mg in 50 ml distilled water)

Sodium nitrite standard 6.9 mg dissolved in 1000 ml of distilled water.

Procedure

250 mg leaf tissue was suspended in screw cap vials having 4.5 ml medium containing phosphate buffer 0.1M ph 7.5, 2 ml and 2 ml of KNO_3 0.1M and 0.5 ml 5% Propanol.

The vials were capped and kept in dark at 30ºC for 3 hr. incubation period. Nitrite released into medium was determined by treating 0.4 ml aliquot with 0.3 ml each of sulphanilamide and NEDH dye. A pink colour complex was formed (as viewed in plate 20 and 28).

After 20 minutes the solution was diluted with distilled water to make the volume up to 5ml and the absorbance was measured at 540 nm in a spectrophotometer.

The leaves suspended in phosphate buffer were kept in boiling water bath inactivate the enzyme and this was used as blank.

3.8.3.4 Estimation of Na^+ and K^+ concentration in plant tissue (ppm)

Sodium content (ppm)

The sodium content in leaves was determined by flame photometer.

Digestion

50 mg dried and well grinded plant material was taken in a 50 ml conical flask and 3 ml of 9:1 H□SO□ and HCl, mixture was added. The flasks were heated gently over a hot plate for 5-10 minutes and thereafter, the heating temperature was raised when the frothing in the mixture was ceased. Digestion was continued until the solution became colourless. The digest was cooled and diluted to 100 ml with distilled water (as viewed in plate 11 and 19).

Estimation

The digest is diluted to suitable concentration so that the sodium content lies between 0 to 10 ppm. The flame photometer was calibrated with graded concentration of sodium between 0 ppm (Distilled water) to 100 ppm (highest sodium concentration i.e. 40 or 50 ppm). Once the photometer displays stable values, the digested samples are fed for the actual measurement and the display value is in ppm (as viewed in plate 18 and 19).

Potassium content (ppm)

The potassium content in leaves was determined separately using flame photometer method given by Linder (1944) as described below.

Digestion

Three millilitres of a 9:1 H2SO4 and HCl mixture were added to 50 milligrams of dried and well-ground plant material in a 50-ml conical flask. For five to ten minutes, the flasks were slowly heated over a hot plate. When the mixture stopped foaming, the heating temperature was increased. The process of digestion was maintained until the solution lost its colour. After cooling, the digest was diluted with 100 ml of distilled water. (as viewed in plate 17 and 18).

Standard 'K' solution

Prepare solution containing 100 mg (K) L^{-1} by dissolving 0.191g of dried KCl in water and making the volume to 1 L.

3.8.3.5 Estimation of Superoxide Dismutase (SOD) activity (unit g^{-1} fresh weight):

Numerous molecules are produced by the cell as a result of its metabolic activities. Excessive production of active species like superoxide, hydrogen peroxide, and hydroxyl radicals is caused by environmental stressors like high or low temperatures, water stress, air pollution, ultraviolet light, and chemicals. Damage to macromolecules like DNA and tissue is imminent if these harmful molecules are not removed. A slightly altered method makes it convenient to assay SOD (Madamanchi *et al*.,1994). Beauchamp and Fridovich (1971) were the first to describe it.

Principle:

Superoxide Dismutase (SOD), a metal-containing enzyme, plays a vital role in scavenging superoxide ($O2^{-}$) radical. Hydrogen peroxide is eliminated by peroxidases and catalases. Superoxide Dismutase activity was determined by measuring its ability to inhibit the photochemical reduction of Nitro Blue Tetrazolium (NBT).

The reaction mixture lacking enzyme develop maximum colour and colour intensity decreased with increase in the enzyme activity.

Chemicals required:

Potassium monohydrogen phosphate (K_2HPO_4)

Potassium dihydrogen phosphate (KH_2PO_4)

Methionine

Riboflavin

EDTA

Nitro Blue Tetrazolium (NBT)

Preparation of reagents:

Potassium phosphate buffer stock:

Solution A: potassium monohydrogen phosphate (250 mM): 4.37 g in 100 ml.

Solution B: potassium dihydrogen phosphate (250 mM): 3.402 g in 100 ml.

Add solution A to solution B with constant stirring and pH 7.8 is maintained using sodium hydroxide.

Potassium phosphate buffer (50 mM), ph:7.8: 100 ml of stock in 400 ml of distilled water

Methionine (100 mM): 298 mg in 20 ml of D.D. H_2O

Riboflavin (10 mM): 37.6 mg in 10 ml of D.D. H_2O

EDTA (5 mM): 93 mg in 100 ml of D.D.H_2O

NBT (750 mM): 6.1 mg in 10 ml of D.D. H_2O

Extraction:

Fresh sample of 1 g is grinded with 10 ml of 50 mM potassium phosphate buffer (pH:7.8) in pre-cold mortar using pestle at 4ºC.

Then the sample is centrifuged at 10,000 rpm for 10 min.

Collect the supernatant and store it in deep freezer.

Estimation:

Preparation of 3 mL cocktail solution:

0.6 ml of 250 mM potassium phosphate buffer, 0.39 ml of 100 mM Methionine, 0.0006 ml of 10 mM riboflavin, 0.06 ml of 5 mM EDTA, 0.3 ml of 750 mM NBT, and 50 ml of enzyme extract were taken into a test tube and make up to 3 ml with distilled water.

Prepare cocktail solution freshly and keep under fluorescent bulb for 15 min.

Then read absorbance (OD) at 560 nm by UV–VIS spectrophotometer using kinetics method. Preparation without enzyme extract and NBT serve as a blank to calibrate the spectrophotometer (as viewed in plate 25).

Set another control having NBT but no enzyme extract as reference control. Calculate the % inhibition.

The 50% inhibition of the reaction between riboflavin and NBT in the presence of methionine is taken as one unit of SOD activity.

The enzyme activity is expressed as **unit g^{-1} fresh weight**

Calculation:

SOD Activity = (Maximum absorbance – Minimum absorbance) × 60 × 2

3.9 PHYSIOLOGICAL TRAITS

3.9.1 Estimation of Relative water content (%):

Turner and Beg's (1981) method were used to calculate the Relative Water Content (RWC). Leaf discs were separated from the leaves, weighed, and then submerged for four hours in petri dishes with distilled water. After surface drying, the discs were weighed. Discs were then stored in an oven set to 80 degrees Celsius for a full day. Using an electronic balance, the discs' weight was determined after they had dried.

$$\textbf{RWC (\%)} = \frac{\text{Fresh weight (F.W.)} - \text{Dry weight(D.W.)}}{\text{Turgid weight (T.W.)} - \text{Dry weight(D.W.)}} \text{ x } 100$$

3.10 YIELD AND YIELD ATTRIBUTING TRAITS

3.10.1 Panicle length

The length of three panicles per replication was measured with meter scale from neck node to the tip of the panicle and finally the average was calculated and expressed in cm.

3.10.2 Panicle bearing tiller plant^{-1}

The panicle bearing tillers plant^{-1} was counted at maturity.

3.10.3 Total number of grains panicle^{-1}

Total number of grains were worked out by taking 3 randomly selected panicles from each tagged plants and expresses as average number of grains panicle^{-1} (as viewed in plate 22).

3.10.4 Grain yield plant^{-1} and per m^2(g)

All panicles of individual selected plants were threshed manually and weighted using electric balance (Compax- Cx- 600). Average grain yield per plant was worked out for each genotype in each replication.

3.10.5 Straw yield plant^{-1} and per m^2 (g)

Straw yield plant^{-1} was recorded by weighing the total harvested produce (after removing the panicles) of individual selected plants from each treatment and replication.

3.10.6 Sterility%

$$\textbf{Sterility \%} = \frac{Number\ of\ sterile\ grains\ per\ panicle}{Total\ number\ of\ grains\ per\ panicle} \times 100$$

3.10.7 Fertility%

$$\textbf{Fertility \%} = \frac{Number\ of\ fertile\ grains\ per\ panicle}{Total\ number\ of\ grains\ per\ panicle} \times 100$$

3.10.8 Test weight

1000 grains were counted from the samples of each treatment. These counted grains were weighed and recorded as test weight at 15% moisture level.

3.10.9 Harvest Index (%)

The Harvest Index (HI) was calculated as per the formula of Donald and Hamblin (1976) as follows:

$$\textbf{HI\%} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

3.10 Statistical analysis

Data recorded on various growth and yield attributes were subjected to statistical analysis by Fisher method of analysis of variance (Fisher and Yates,1949).

The significance of various treatments was judged by comparing calculated, F' value with Fisher's, F' value at 5 percent level, incorporate in tables, were also calculated to compare

The relative performance of various treatments by using the follow formula:

$$\textbf{SEm}\pm = \frac{\sqrt{EMS}}{N}$$

Where,

EMS = mean sum of square of error

N = total number of experimental units

Level of factors

$$\textbf{CD} = \frac{\sqrt{2EMS}}{N} \text{ x t}$$

Where,

Value of ‘t' from Fisher's table at error degree of freedom on 5% level of significance.

Plate 1: Rice Field at 30 DAT

Plate 2: Rice Field at 45 DAT

Plate 3: Rice Field at 75 DAT

Plate 4: Rice Field at physiological maturity

Plate 5: Varietal comparison at 30 DAT

Plate 6: Intercultural operation on the rice field

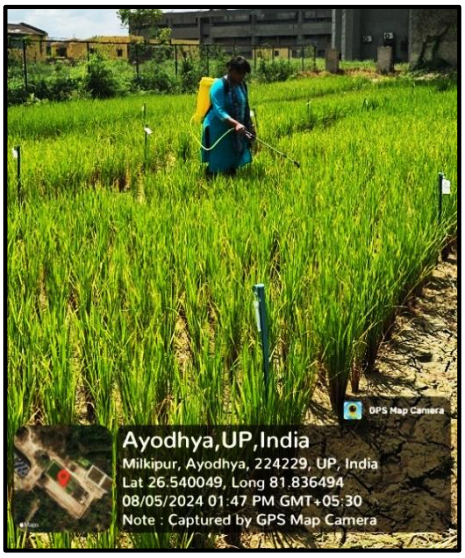


Plate 7: Osmoprotectants spray at 40 DAT

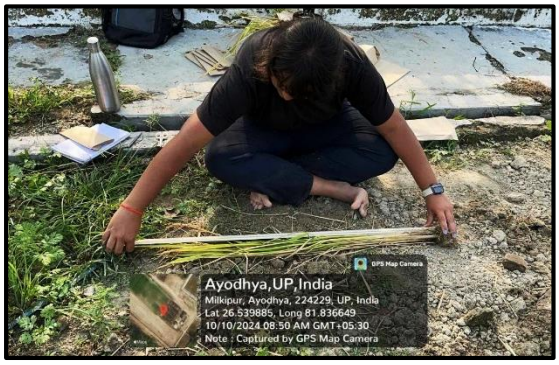


Plate 8: Plant height measurement at 75 DAT

Plate 9: Rice field at 70 DAT

Plate 10: Laboratory work during analysis

Plate 11: Laboratory work during analysis (Na^+/K^+)

Plate 12: Laboratory work during chlorophyll estimation

Plate 13,14,15: Laboratory work during analysis

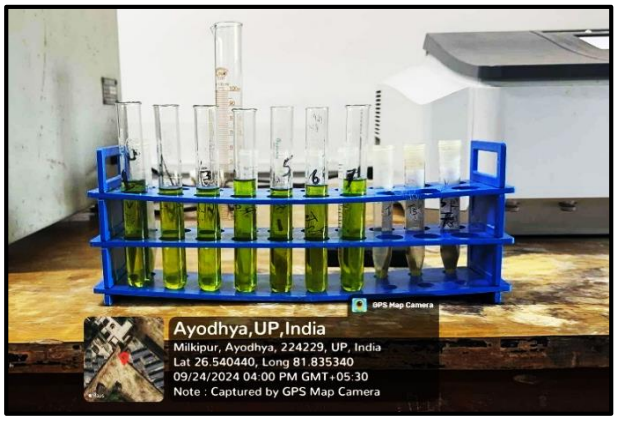


Plate 16: Estimation of chlorophyll

Plate 17: Flame view of K^+

Plate 18: Digestion for Na^+/K^+ estimation

Plate 19: Flame view of Na^+

Plate 20: Estimation of NR activity

Plate 21: Estimation of TSC

Plate 22: Counting total grains panicle^{-1}

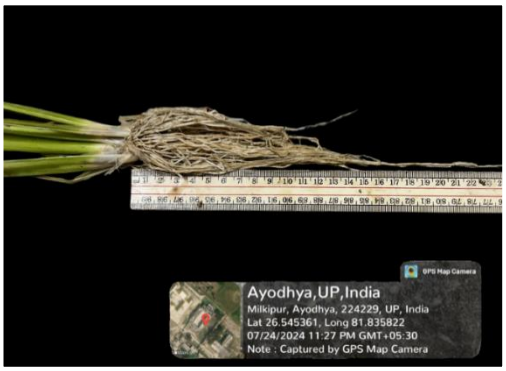


Plate 23: Measurement of root length at 30 DAT

Plate 24: Effect of salinity stress on Sarju 52 rice variety

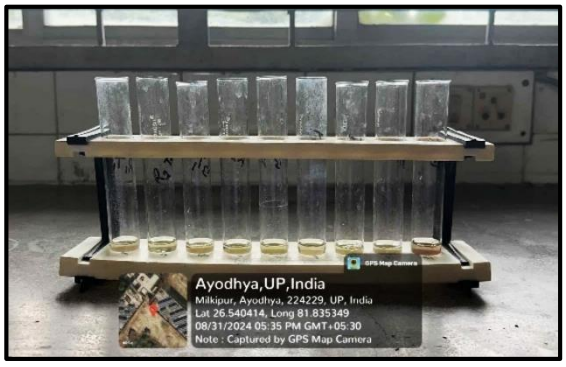


Plate 25: Estimation of SOD activity

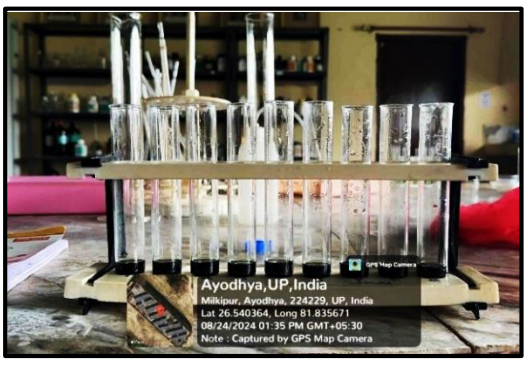


Plate 26: Estimation of TSC content

Plate 27: Collection of plant samples

Plate 28: Estimation of NR activity

Plate 29: Rice field after transplanting

Plate 30: Panicles of CSR 23 rice variety

Plate 31: Panicles of Sarju 52 rice variety

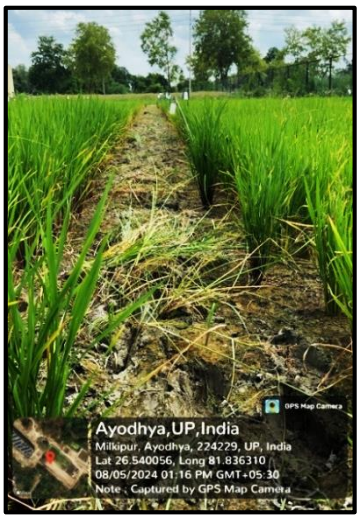


Plate 32: Rice field at 45 DAT

Chapter IV

RESULTS AND DISCUSSION

The present investigation entitled "**Mitigating the adverse effect of salinity stress on rice (*Oryza sativa* L.) through osmoprotectants**" was conducted at Plant Physiology Farm, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.), India during Kharif season of 2023-24. A Comprehensive statistical analysis of data was done to compare the effect of treatments and results have been presented in form of tables and figures. The overall findings have been categorized and presented under following sub heads.

4.1 Growth characters

4.2 Phenological characters

4.3 Biochemical characters

4.4 Physiological characters

4.5 Yield and yield attributes

GENERAL

Salinity stress exerts a profound influence on rice growth and development, affecting all phenological stages from germination to senescence. During germination, elevated salt concentrations reduce osmotic potential. Thereby, inhibiting water uptake, impairing germination percentage, rate, and radicle elongation (Win K.T. *et al*., 2022). During the early seedling stage, shoot and root elongation, along with total dry matter accumulation, are significantly suppressed under saline conditions (Ologundudu A.F. *et al*., 2014). Progressing into the vegetative phase, salinity significantly restricts plant height, tiller formation, and biomass accumulation, with recorded declines of 9% in plant stature and 15% in tillering (Quan R. *et al*., 2024). During the reproductive stage, ionic disequilibrium particularly Na□ toxicity and disrupted K□ homeostasis leads to yield loss, with grain yield reductions of 42.9% in tolerant and 58.3% in sensitive genotypes. The regulation of Na□/K□ transport

via HKT-type transporters plays a pivotal role in maintaining ion balance (Atta K. *et al*., 2023). During the senescence phase, salinity-induced oxidative stress accelerates chlorophyll catabolism, accompanied by upregulation of senescence-associated genes such as OsNAP and SGR (Sakuraba Y. *et al*., 2015). Additionally, reduced SPAD values and enhanced chlorophyll degradation in flag leaves during maximum tillering, signal premature senescence (Hasanuzzaman M. *et al*., 2009). Collectively, these physiological disruptions underscore the deleterious impact of salinity stress on rice growth, productivity, and longevity.

4.1 GROWTH CHARACTERS

4.1.1 Plant height (cm):

Plant height data were recorded at 30, 45, and 75 days after transplanting (DAT), and at physiological maturity under salinity stress. The effect of various concentrations of sorbitol and mannitol, are summarized in Table 4.1.1 and depicted in Figure 4.1.1. Salinity significantly suppressed plant height across all growth stages, reflecting its inhibitory effects on cellular expansion and internodal elongation (Hu Y *et al*., 2008).

However, foliar application of sorbitol@80 ppm (T4) elicited the highest plant heights i.e., 87.85 cm (45 DAT), 107.01 cm (75 DAT), and 110.82 cm (physiological maturity) indicating improved vegetative growth under ionic stress. The untreated control treatment-T1 exhibited the lowest growth metrics, underscoring the severity of salinity-induced osmotic imbalance and growth retardation.

Application of both osmoprotectants significantly mitigated salinity stress, presumably through enhanced osmotic adjustment, preservation of turgor, and stabilization of cellular structures. Among genotypes, the salt tolerant variety, V1-CSR23 (93.32, 111.16, and 115.84 cm) consistently outperformed the salt susceptible variety, V2-Sarju 52 (82.38, 102.85, 105.80 cm), registering greater plant heights at 45, 75 DAT, and at physiological maturity respectively.

Overall, T4 (sorbitol@80ppm) was the most effective treatment, followed by T7 (mannitol@80ppm), suggesting both polyols confer growth advantages, likely *via* modulation of osmotic potential and upregulation of stress-responsive pathways.

These outcomes corroborate prior findings by El-Sherpiny *et al.,* (2023), who reported enhanced shoot elongation and growth recovery under salinity with sorbitol and mannitol supplementation.

Analysis of variance indicated a significant beneficial effect (5–6%) with foliar application of osmoprotectants. At 45 DAT, V2- Sarju 52 showed a 5.94% increase, while V1-CSR-23 recorded a 5.71% increase following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V2 (Sarju-52) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7). This differential response implies genotype-specific variations in osmoprotectants uptake, translocation, or metabolic utilization under saline stress. The present findings align with previous reports by Al-Dulaimi H.S. *et al.,* (2024) and Ghosh U.K. *et al*., (2021) who demonstrated that polyols such as sorbitol and mannitol enhance biomass accumulation and maintain membrane integrity by modulating antioxidative defence systems under salinity stress.

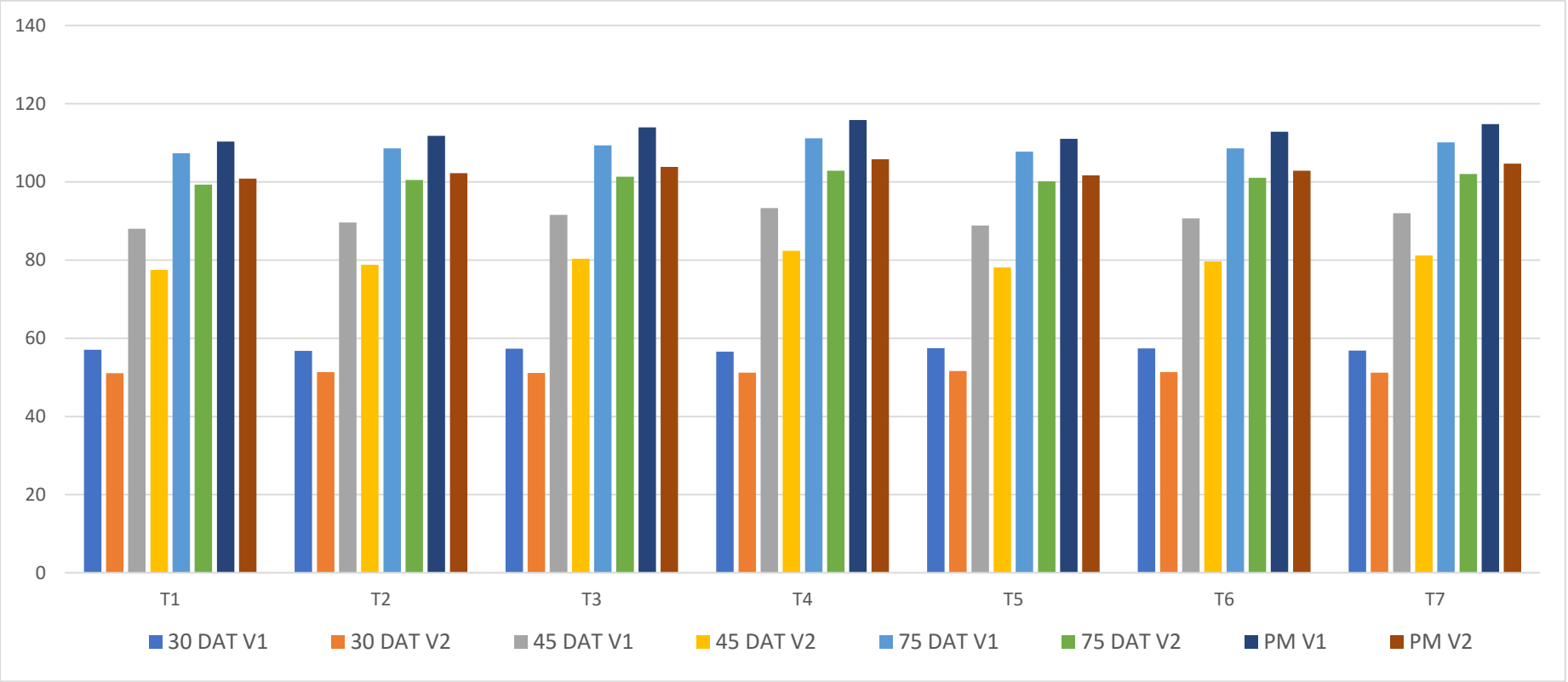
Table 4.1.1: **Effect of sorbitol and mannitol on plant height (cm) at various growth stages of rice under salinity stress**

Treatments	Plant height at 30 DAT			Plant height at 45 DAT			Plant height at 75 DAT			At Physiological maturity		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	57.09	51.09	**54.09**	87.99	77.49	**82.74**	107.33	99.34	**103.34**	110.31	100.81	**105.56**
T2	56.80	51.36	**54.08**	89.60	78.81	**84.21**	108.61	100.50	**104.56**	111.77	102.23	**107.00**
T3	57.33	51.14	**54.24**	91.59	80.35	**85.97**	109.37	101.34	**105.36**	113.97	103.81	**108.89**
T4	56.60	51.20	**53.90**	93.32	82.38	**87.85**	111.16	102.85	**107.01**	115.84	105.80	**110.82**
T5	57.49	51.60	**54.55**	88.82	78.10	**83.46**	107.74	100.11	**103.93**	111.03	101.67	**106.35**
T6	57.39	51.37	**54.38**	90.68	79.66	**85.17**	108.59	101.04	**104.82**	112.85	102.83	**107.84**
T7	56.83	51.17	**54.00**	92.02	81.18	**86.60**	110.09	102.03	**106.06**	114.76	104.70	**109.73**
MEAN	**57.08**	**51.28**		**90.57**	**79.71**		**108.98**	**101.03**		**112.93**	**103.12**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.09**	**NS**		**0.05**	**0.14**		**0.05**	**0.16**		**0.06**	**0.18**	
Treatments	**0.17**			**0.09**	**0.26**		**0.1**	**0.29**		**0.12**	**0.34**	
VxT	**0.24**			**0.13**	**0.37**		**0.14**	**0.42**		**0.17**	**0.48**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Figure 4.1.1: **Effect of sorbitol and mannitol on plant height (cm) at various growth stages of rice under salinity stress**



T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR-23

V2: Sarju 52

4.1.2 Root length (cm):

Root length data were recorded at 30, 45, and 75 days after transplanting (DAT), and at physiological maturity under salinity stress. The effect of foliar application of various concentrations of sorbitol and mannitol are summarized in Table 4.1.2 and illustrated in Figure 4.1.2. Salinity stress significantly impaired root elongation in both rice varieties, underscoring its detrimental effect on root length development (Huang, Y *et al*., 2021). However, foliar application of osmoprotectants substantially mitigated these adverse effects, enhancing root length under saline conditions.

Overall, sorbitol@80ppm (T4) application yielded the longest root lengths (34.53, 42.09, 47.06 cm) at 45, 75 DAT and at physiological maturity respectively, followed closely by mannitol@80 ppm (T7). This suggests that both osmoprotectants enhance root elongation under salinity stress. The control treatment-T1, subjected to salinity stress without osmoprotectants supplementation, exhibited a pronounced reduction in root length at all growth stages.

In contrast, the salt tolerant variety, V1-CSR23 (36.62, 43.64, and 49.46 cm) consistently outperformed the salt susceptible variety, V2-Sarju 52 (32.43, 40.53, and 44.66 cm) in root elongation at 45, 75 DAT, and physiological maturity, respectively. These results highlight V1-CSR23's superior salinity tolerance, particularly in root length development.

Analysis of variance indicated a highly significant beneficial effect (14-15%) with foliar application of osmoprotectants. At 45 DAT, V2- Sarju 52 showed a 15.23% increase, while V1-CSR-23 recorded a 14.64% increase following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V2 (Sarju-52) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7). These varietal differences are likely due to inherent variations in root architecture and osmolyte utilization efficiency. The role of osmoprotectants in ameliorating root length development under salinity stress has been well-documented by Singh *et al.,* (2022) and Ghosh U.K. *et al.,* (2021). They confirmed that sorbitol facilitates osmotic adjustment and acts as a metabolic substrate for root development. Additionally, El-Sherpiny *et al*., (2023) demonstrated that mannitol mitigates oxidative stress and promotes root biomass accumulation under salinity stress conditions.

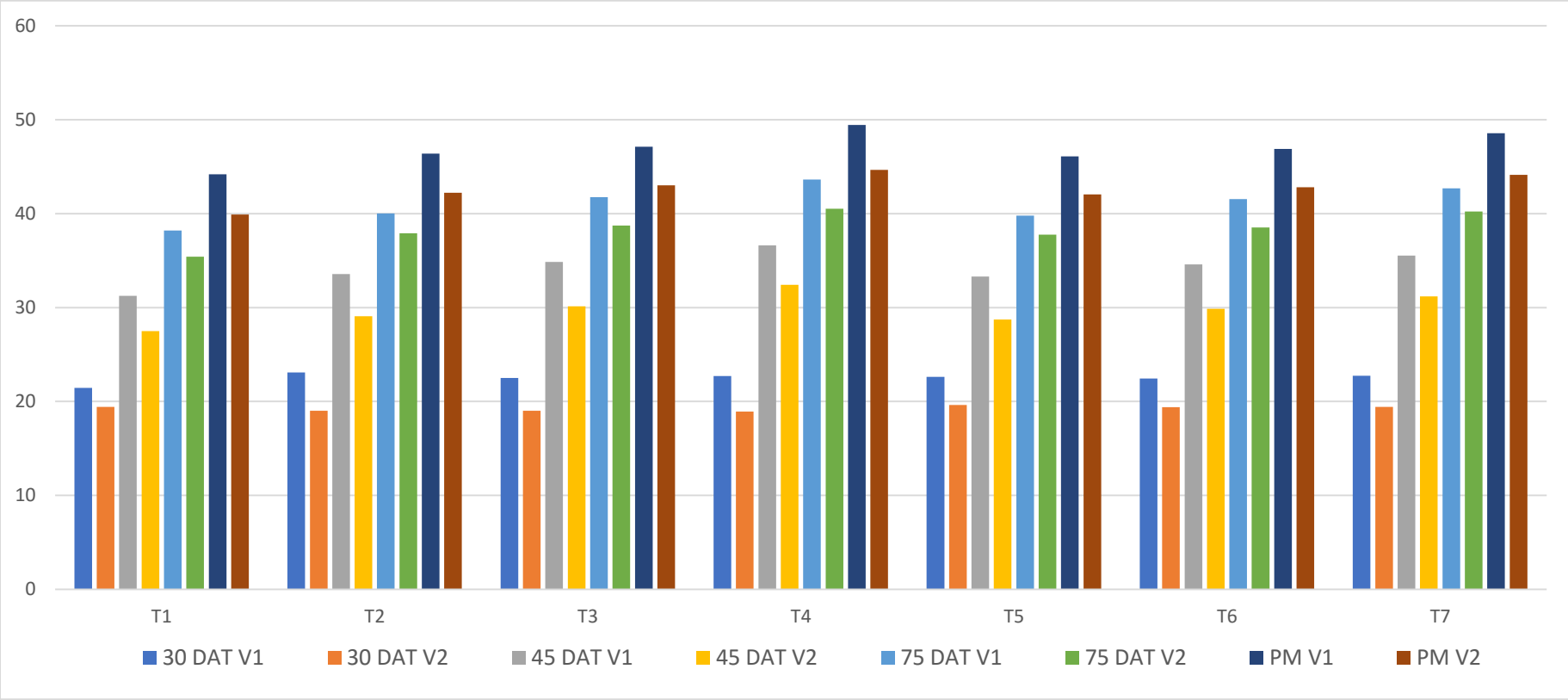
Table 4.1.2: Effect of sorbitol and mannitol on root length (cm) at various growth stages of rice under salinity stress

Treatments	Root length at 30 DAT			Root length at 45 DAT			Root length at 75 DAT			At Physiological maturity		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	21.46	19.43	**20.45**	31.26	27.49	**29.38**	38.20	35.42	**36.81**	44.18	39.90	**42.04**
T2	23.09	19.01	**21.05**	33.58	29.08	**31.33**	40.04	37.9	**38.97**	46.39	42.23	**44.31**
T3	22.51	19.03	**20.77**	34.87	30.14	**32.51**	41.75	38.73	**40.24**	47.12	43.03	**45.08**
T4	22.72	18.93	**20.83**	36.62	32.43	**34.53**	43.64	40.53	**42.09**	49.46	44.66	**47.06**
T5	22.62	19.62	**21.12**	33.32	28.74	**31.03**	39.80	37.78	**38.79**	46.11	42.04	**44.08**
T6	22.45	19.41	**20.93**	34.59	29.87	**32.23**	41.54	38.53	**40.04**	46.88	42.81	**44.85**
T7	22.75	19.42	**21.09**	35.53	31.18	**33.36**	42.71	40.22	**41.47**	48.57	44.14	**46.36**
MEAN	**22.51**	**19.26**		**34.25**	**29.85**		**41.10**	**38.44**		**46.96**	**42.69**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.1**	**NS**		**0.05**	**0.13**		**0.07**	**0.19**		**0.04**	**0.13**	
Treatments	**0.18**			**0.09**	**0.25**		**0.12**	**0.36**		**0.08**	**0.24**	
VxT	**0.26**			**0.12**	**0.36**		**0.18**	**0.51**		**0.12**	**0.34**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Figure 4.1.2: Effect of sorbitol and mannitol on root length (cm) at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR-23

V2: Sarju 52

4.1.3 Dry weight (g):

The data on dry weight accumulation were recorded at 30, 45, and 75 days after transplanting (DAT), and at physiological maturity under salinity stress. The effect of foliar application of various concentrations of sorbitol and mannitol, are presented in Table 4.1.3 and depicted in Figure 4.1.3. Salinity stress significantly hindered dry biomass accumulation across all developmental stages in both rice varieties (Santanoo S *et al*., 2023).

Among the treatments, sorbitol@80ppm (T4) resulted in the highest dry weight (7.25, 18.53, 64.16 g) at 45, 75 DAT and at physiological maturity respectively, followed closely by (T7) mannitol@80ppm. The control treatment (T1), subjected to salinity stress without osmoprotectants supplementation, exhibited a pronounced reduction in dry weight at all growth stages.

The salt tolerant variety, V1-CSR23 exhibited significantly higher dry weight values (7.86, 19.76, and 69.12 g) compared to the salt susceptible variety, V2-Sarju 52 (6.63, 17.30, and 59.2 g) at 45, 75 DAT, and physiological maturity, respectively. This indicates V1-CSR23's superior salinity tolerance and enhanced biomass retention capacity.

Analysis of variance indicated a highly significant beneficial effect (29-33%) to foliar application of osmoprotectants. At physiological maturity, V1- CSR 23 showed a 33.83% increase, while V2- Sarju 52 recorded a 29.86% increase following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V1-CSR 23 exhibiting a more pronounced response to (T4) sorbitol@80ppm followed by (T7) mannitol@80ppm. These varietal differences suggest genotype-specific mechanisms for osmotic adjustment and differential efficiencies in the uptake and utilization of exogenously applied osmolytes.

These findings align with previous studies indicating the effectiveness of sorbitol and mannitol in promoting dry matter production under salinity stress. Saxena R. *et al.,* (2019) and Xie Z *et al.,* (2020) demonstrated that osmolytes improve water retention, alleviate oxidative stress, and stabilize protein structures in salinity-stressed plants. Similarly, Wani S.H. *et al.,* (2016) reported that moderate concentrations of sorbitol stimulated dry biomass production. While, Singh *et al.,* (2022) observed increased shoot and root dry mass in rice under salinity following mannitol foliar application.

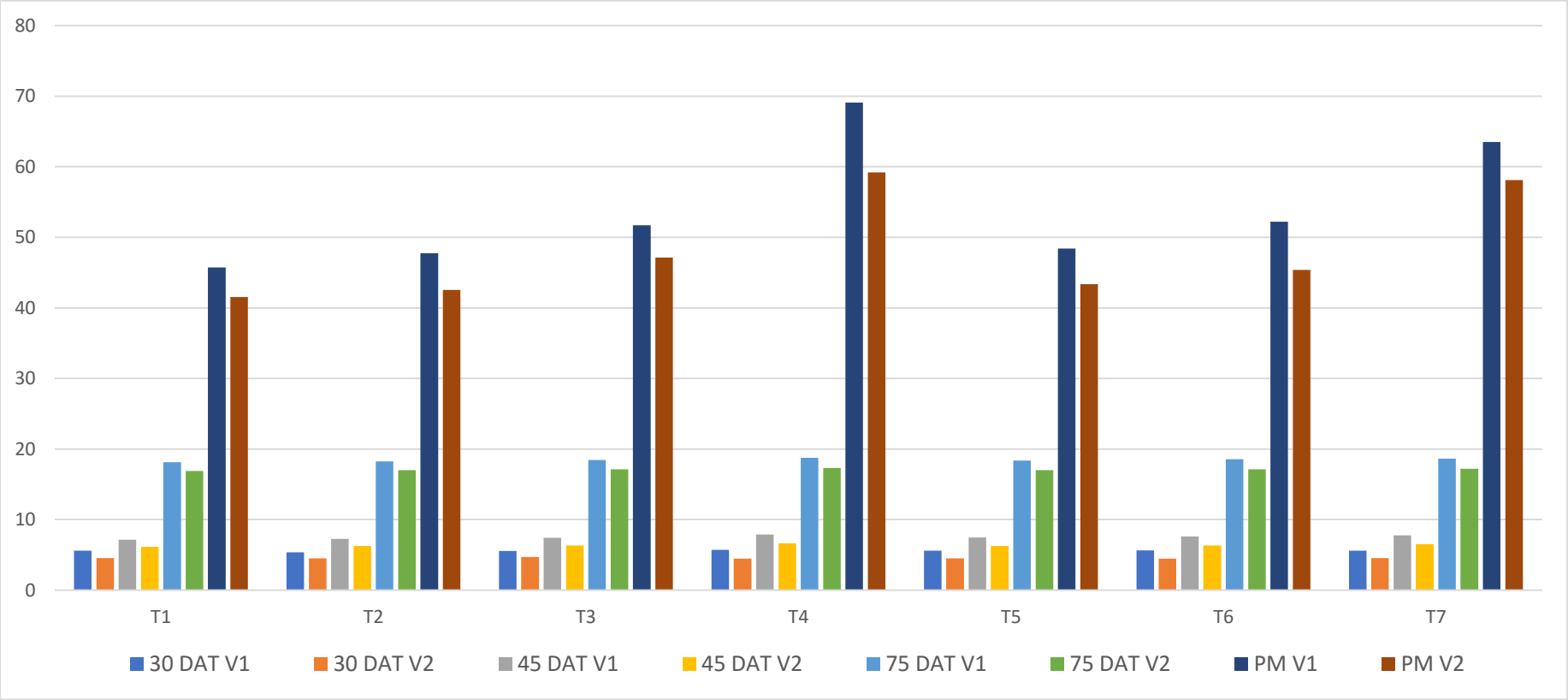
Table 4.1.3: Effect of sorbitol and mannitol on dry weight (gm) at various growth stages of rice under salinity stress

Treatments	Dry weight at 30 DAT			Dry weight at 45 DAT			Dry weight at 75 DAT			At Physiological maturity		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	5.59	4.54	**5.07**	7.14	6.13	**6.64**	18.14	16.87	**17.51**	45.74	41.52	**43.63**
T2	5.37	4.51	**4.94**	7.24	6.23	**6.74**	18.23	16.99	**17.61**	47.76	42.55	**45.16**
T3	5.54	4.68	**5.11**	7.40	6.33	**6.87**	19.44	17.10	**18.27**	51.7	47.13	**49.42**
T4	5.69	4.45	**5.07**	7.86	6.63	**7.25**	19.76	17.30	**18.53**	69.12	59.2	**64.16**
T5	5.59	4.49	**5.04**	7.43	6.24	**6.84**	18.35	17.01	**17.68**	48.41	43.38	**45.90**
T6	5.62	4.46	**5.04**	7.62	6.33	**6.98**	19.55	17.10	**18.33**	52.22	45.4	**48.81**
T7	5.6	4.55	**5.08**	7.74	6.53	**7.14**	19.64	17.19	**18.42**	63.53	58.11	**60.82**
MEAN	**5.57**	**4.53**		**7.49**	**6.35**		**19.02**	**17.08**		**54.07**	**48.18**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.03**	**NS**		**0.01**	**0.02**		**0.01**	**0.02**		**0.35**	**1.01**	
Treatments	**0.05**			**0.01**	**0.04**		**0.01**	**0.03**		**0.63**	**1.84**	
VxT	**0.08**			**0.02**	**0.06**		**0.02**	**0.05**		**0.89**	**2.57**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Figure 4.1.3: Effect of sorbitol and mannitol on dry weight (gm) at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR 23

V2: Sarju 52

4.1.4 Number of tillers plant^{-1}:

Data on number of tillers plant^{-1} were recorded at 30, 45, and 75 days after transplanting (DAT), and at physiological maturity under salinity stress. The influence of foliar application of various concentrations of sorbitol and mannitol are presented in Table 4.1.4 and illustrated in Figure 4.1.4. Salinity stress significantly reduced tiller formation in both rice varieties (Wei H.H *et al*., 2020).

Among the treatments, sorbitol@80ppm (T4) resulted in the highest tiller count (13.39, 16.73, 14.75) followed closely by mannitol@80ppm (T7), underscoring its potential in promoting vegetative growth under osmotic stress. The control treatment (T1), subjected to salinity stress without osmoprotectants supplementation, exhibited a pronounced reduction in the production of tillers at all growth stages.

The salt tolerant variety, V1-CSR 23 demonstrated significantly higher tiller counts (14, 17.67, 15.67) compared to the salt susceptible variety, V2-Sarju 52 (12.78, 15.78, 13.82) at 45, 75 DAT, and physiological maturity, respectively. This suggests a superior capacity of V1-CSR 23 for tillering under saline conditions. This aligns with the observations of El-Sherpiny *et al*., (2023) and Li Q. *et al.,* (2017), who reported improved tillering and shoot biomass in salinity-stressed plants treated with sorbitol.

Analysis of variance indicated a highly significant beneficial effect (35-39%) to foliar application of osmoprotectants. At 45 DAT and physiological maturity, V1-CSR 23 exhibited an increase of 35.71% and 39.76% respectively. Meanwhile, V2-Sarju 52 recorded a 35.67% increase at physiological maturity following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V1 (CSR 23) exhibiting a more pronounced response to (T4) sorbitol@80ppm followed by (T7) mannitol@80ppm. These varietal differences may be attributed to variations in shoot meristem activity, intrinsic stress tolerance, and differential efficiencies in osmolyte uptake and utilization. The enhancement in tiller number following osmoprotectants application supports previous studies by Wani S.H. *et al.,* (2016) and Patel, M.K. *et al.,* (2020) who demonstrated that sorbitol promotes vegetative vigour and shoot branching, Moreover, Al Mahmud et al., (2017), also noted that sugar alcohols enhance shoot development by improving metabolic efficiency and reinforcing stress tolerance mechanisms.

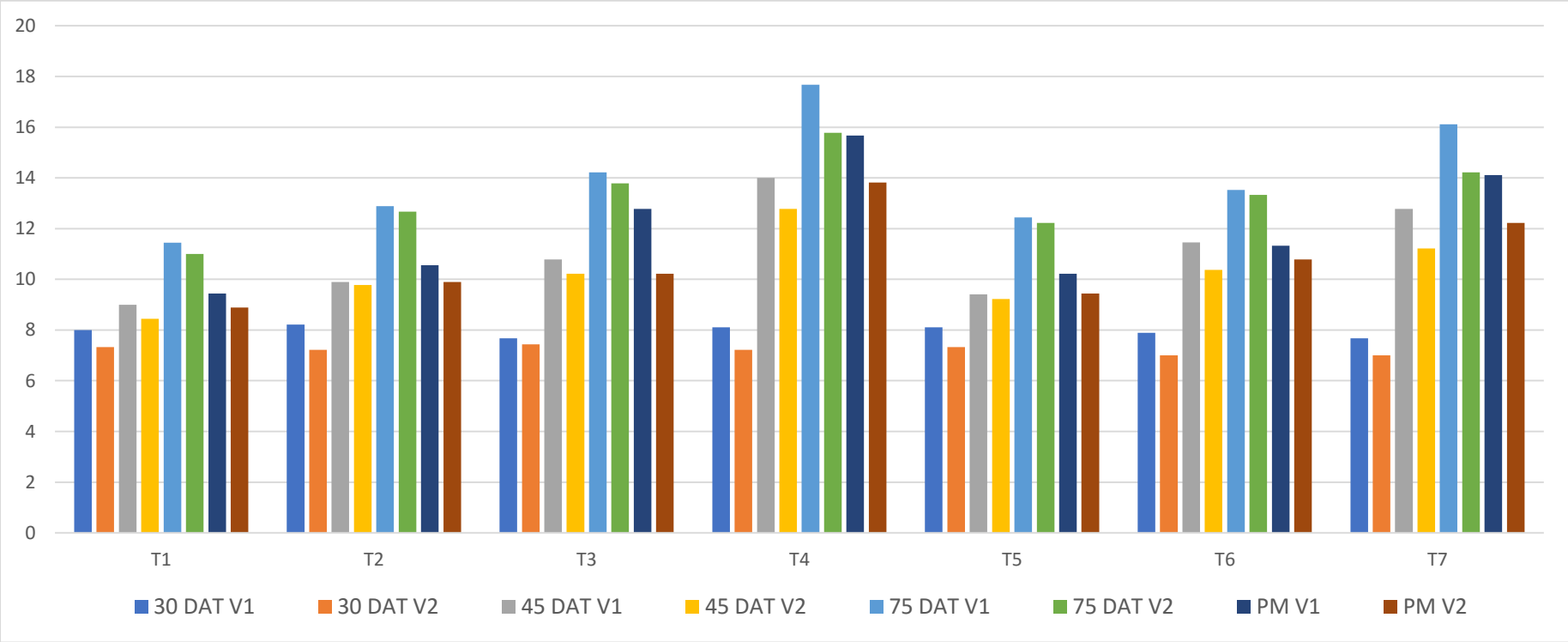
Table 4.1.4: Effect of sorbitol and mannitol on tiller per plant (count) at various growth stages of rice under salinity stress

Treatments	Tiller per plant at 30 DAT			Tiller per plant at 45 DAT			Tiller per plant at 75 DAT			At Physiological maturity		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	8.00	7.33	**7.67**	9.00	8.44	**8.72**	11.44	11.00	**11.22**	9.44	8.89	**9.17**
T2	8.22	7.22	**7.72**	9.89	9.78	**9.84**	12.89	12.67	**12.78**	10.56	9.89	**10.23**
T3	7.67	7.44	**7.56**	10.78	10.22	**10.50**	14.22	13.78	**14.00**	12.78	10.22	**11.50**
T4	8.11	7.22	**7.67**	14.00	12.78	**13.39**	17.67	15.78	**16.73**	15.67	13.82	**14.75**
T5	8.11	7.33	**7.72**	9.41	9.22	**9.32**	12.44	12.22	**12.33**	10.22	9.44	**9.83**
T6	7.89	7.00	**7.45**	11.45	10.37	**10.91**	13.52	13.33	**13.43**	11.33	10.78	**11.06**
T7	7.67	7.00	**7.34**	12.78	11.22	**12.00**	16.11	14.22	**15.17**	14.11	12.24	**13.18**
MEAN	**7.95**	**7.22**		**11.04**	**10.29**		**14.04**	**13.29**		**12.02**	**10.75**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.08**	**NS**		**0.08**	**0.23**		**0.05**	**0.14**		**0.05**	**0.15**	
Treatments	**0.14**			**0.15**	**0.43**		**0.09**	**0.27**		**0.1**	**0.29**	
VxT	**0.2**			**0.21**	**0.61**		**0.12**	**0.38**		**0.14**	**0.4**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Figure 4.1.4: Effect of sorbitol and mannitol on tiller per plant (count) at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR 23

V2: Sarju 52

4.2 PHENOLOGICAL CHARACTERS

4.2.1 Days taken 50% flowering

The data on days taken to 50% flowering and effect of various concentrations of osmoprotectants treatments under salinity stress are summarized in Table 4.2.1 and depicted in Figure 4.2.1. Foliar application of T4-sorbitol@80 ppm significantly reduced the days taken to 50% flowering (79.00 days), closely followed by T7-mannitol@80 ppm (79.22 days). Both treatments significantly accelerated flowering compared to other treatments, highlighting their efficacy in promoting early reproductive development under salinity stress (Alhudhaibi A.M *et al*., 2024). The control treatment (T1), subjected to salinity stress without osmoprotectants supplementation, exhibited a pronounced delay in days taken to 50% flowering (82.22 days).

Among the two rice varieties, the salt susceptible variety, V2-Sarju 52 exhibited a significantly delayed 50% flowering time (83.33 days) compared to the salt tolerant variety, V1-CSR23 (74.67 days), indicating greater sensitivity of V2-Sarju 52 to salinity-induced delays. Analysis of variance indicated a significant beneficial effect (3-5%) with foliar application of osmoprotectants. The salt tolerant variety, V1- CSR 23 showed a 5.05% decrease, while V2-Sarju 52 recorded a 3.20% decrease following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V1 (CSR 23) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7).

Salinity stress induced a substantial delay in flowering in both varieties, likely due to osmotic and ionic imbalances that disrupt hormonal signalling pathways essential for flower initiation (Godoy F *et al*., 2021). However, the foliar application of polyols alleviated these delays, through enhanced osmotic regulation and stress mitigation (Yang X *et al.,* 2021).

4.2.2 Days taken physiological maturity

The data on days taken to physiological maturity and effect of foliar application of osmoprotectants at various concentrations under salinity stress are presented in Table 4.2.1 and illustrated in Figure 4.2.1. Foliar application of T4-sorbitol@80ppm significantly reduced the days taken to physiological maturity, recording the shortest duration (114.00 days), followed closely by T7-mannitol@80ppm (113.95 days). These treatments were

notably more effective than others in mitigating the salinity-induced delay in physiological maturity (A Mukami *et al*., 2019). The control treatment (T1), subjected to salinity stress without osmoprotectants supplementation, exhibited a pronounced delay in days to physiological maturity (117.44 days).

Varietal analysis revealed that V2-Sarju 52 exhibited a significantly longer time in days taken to physiological maturity (118.33 days) as compared to V1-CSR23 (109.67 days), indicating greater sensitivity of V2-Sarju 52 to salinity stress in terms of delay in physiological maturity.

Analysis of variance indicated a significant beneficial effect (2-4%) to foliar application of osmoprotectants. The salt tolerant variety V1- CSR 23 showed a 3.43% decrease, while V2-Sarju 52 recorded a 2.62% decrease following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V1 (CSR 23) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80 ppm (T7).

Salinity stress extended the days taken to physiological maturity in both varieties, likely due to disruptions in physiological and biochemical processes under osmotic and ionic stress (Bhattacharya and Kundu, 2020). However, the foliar application of polyols effectively mitigated these delays, possibly through enhanced osmotic regulation, stabilization of metabolic processes, and maintenance of growth under saline conditions (Xiao F. and Zhou H., 2023).

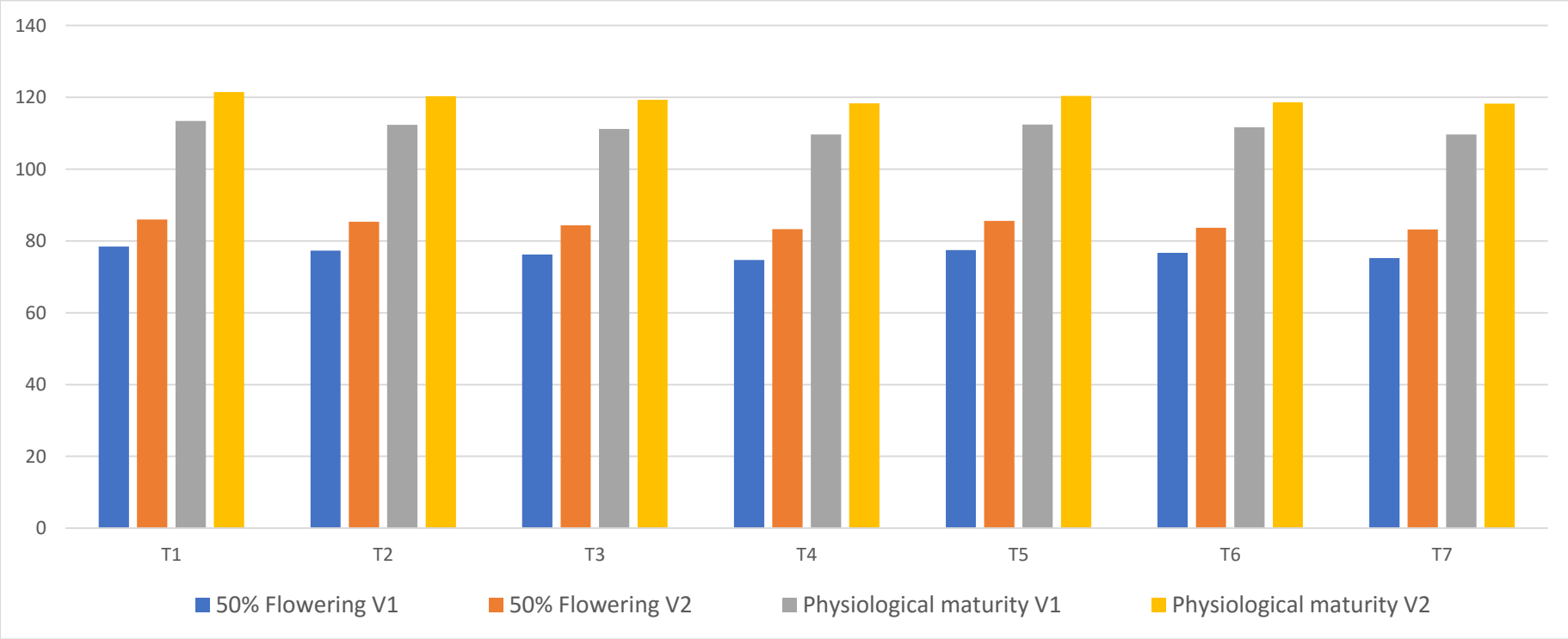
Table 4.2.1: Effect of sorbitol and mannitol on days taken 50% flowering and days taken physiological maturity under salinity stress

Treatments	Days taken 50% flowering			Days taken physiological maturity		
	V1	V2	MEAN	V1	V2	MEAN
T1	78.44	86	**82.22**	113.44	121.44	**117.44**
T2	77.33	85.33	**81.33**	112.33	120.33	**116.33**
T3	76.22	84.33	**80.28**	111.22	119.33	**115.28**
T4	74.67	83.33	**79.00**	109.67	118.33	**114.00**
T5	77.44	85.56	**81.50**	112.44	120.44	**116.44**
T6	76.67	83.67	**80.17**	111.67	118.67	**115.17**
T7	75.22	83.22	**79.22**	109.67	118.22	**113.95**
MEAN	**76.57**	**84.49**		**111.49**	**119.54**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.08**	**0.24**		**0.05**	**0.14**	
Treatments	**0.16**	**0.45**		**0.09**	**0.27**	
VxT	**0.22**	**0.64**		**0.13**	**0.38**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Figure 4.2.1: Effect of sorbitol and mannitol on days taken 50% flowering and days taken physiological maturity of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR 23

V2: Sarju 52

4.3. BIOCHEMICAL PARAMETERS

4.3.1 Estimation of chl. a, b and total chlorophyll

The data on chl. a, b, and total chlorophyll content were recorded at 30, 45, 75 DAT and at physiological maturity, under salinity stress. The effect of foliar application of sorbitol and mannitol at various concentrations, are summarized in Tables 4.3.1.1, 4.3.1.2, 4.3.1.3 and depicted in Figures 4.3.1.1, 4.3.1.2, 4.3.1.3. Salinity stress significantly reduced chlorophyll levels in both rice varieties, indicating a reduction in photosynthetic efficiency (Chandramohanan, K.T *et al*., 2014). However, foliar application of osmoprotectants, mitigated this decline, significantly enhancing chlorophyll retention and improving photosynthetic capacity under saline conditions.

4.3.1.1 Chlorophyll A content

The data on chl. a content were recorded at 30, 45, and 75 days after transplanting (DAT), and at physiological maturity under salinity stress. The effect of osmoprotectants treatments at various concentrations are presented in Table 4.3.1.1 and illustrated in Figure 4.3.1.1.

The results demonstrated that the highest chl. a content at 45, 75 DAT, and physiological maturity (2.04, 1.01, and 0.48 mg g^{-1} fresh weight respectively) were recorded with foliar application of sorbitol@80ppm (T4), followed closely by mannitol@80ppm (T7). These treatments consistently outperformed the other treatments across all growth stages. Whereas, the untreated control (T1) exhibited a progressive decline due to salinity-induced pigment degradation.

Regarding varietal differences, V1-CSR23 exhibited significantly higher chl. a level (1.58, 2.14, 1.23, and 0.64 mg g^{-1} fresh weight) compared to V2-Sarju 52 (1.42, 1.93, 0.78, and 0.32 mg g^{-1} fresh weight) at 30, 45, and 75 DAT and physiological maturity, respectively.

Analysis of variance indicated a highly significant beneficial effect (12-25%) with foliar application of osmoprotectants. At physiological maturity, V2- Sarju 52 showed a 25% increase, while V1-CSR 23 recorded a 12.5% increase following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V2 (Sarju-52) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm.

The enhanced chl. a content suggests that polyols mitigate pigment degradation by stabilizing the photosynthetic machinery and enhancing chloroplast integrity under saline conditions. These findings align with the studies of Vineeth *et al.,* (2023) and Suo J *et al.,* (2017), who reported that exogenous osmolyte application preserves pigment composition and photosynthetic efficiency in salinity-stressed plants.

4.3.1.2 Chlorophyll B content

The data on chl. b content were recorded at 30, 45, and 75 days after transplanting (DAT), and at physiological maturity under salinity stress. The mitigating effects of foliar-applied sorbitol and mannitol at various concentrations are summarized in Table 4.3.1.2 and illustrated in Figure 4.3.1.2.

The results revealed that the highest chl. b content at 45, 75 DAT, and physiological maturity (1.32, 0.72, and 0.47 mg g^{-1} fresh weight respectively) were observed with foliar application of sorbitol@80ppm(T4), followed by mannitol@80 ppm(T7). These treatments significantly improved pigment retention as compared to the other treatments across all stages of growth. Whereas, the control (T1) exhibited a progressive decline in pigment levels under salinity stress. Varietal comparisons showed that the salt tolerant variety, V1-CSR 23 consistently exhibited higher chl. b levels (1.23, 1.39, 0.85, and 0.64 mg g^{-1} fresh weight) compared to the salt susceptible variety, V2 -Sarju 52 (0.99, 1.25, 0.59, and 0.30 mg g^{-1} fresh weight) at 30, 45, 75 DAT, and physiological maturity, respectively.

Analysis of variance indicated a highly significant beneficial effect (25-50%) to foliar application of osmoprotectants. At physiological maturity, V2- Sarju 52 showed a 50% increase, while V1-CSR-23 recorded a 25% increase following sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V2 (Sarju-52) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7). The enhanced chl. b content under sorbitol and mannitol treatments suggests a protective role in stabilizing the light-harvesting pigment complex. Thereby, sustaining photosynthetic efficiency under salinity-induced oxidative stress. These findings corroborate with Ahmad F *et al.,* (2020) and Al Mahmud *et al.,* (2017), who reported that osmolytes help retain chlorophyll pigments and maintain photochemical activity in salinity-stressed plants.

4.3.1.3 Total chlorophyll content

The data on total chlorophyll content were recorded at 30, 45, and 75 days after transplanting (DAT), and at physiological maturity under salinity stress. The effects of sorbitol and mannitol treatments at various concentrations are presented in Table 4.3.1.3 and illustrated in Figure 4.3.1.3.

The results indicated that the highest total chlorophyll content at 45, 75 DAT, and physiological maturity (3.25, 3.05, and 2.81 mg g^{-1} fresh weight respectively) were observed with foliar application of sorbitol@80ppm (T4), followed by mannitol@80 ppm (T7). These treatments consistently outperformed the other treatments in preserving total chlorophyll content across all growth stages. Whereas, untreated control (T1), showed consistent degradation in the total chlorophyll content.

Varietal differences revealed that the salt tolerant variety, V1-CSR 23 exhibited significantly higher total chlorophyll content (2.79, 3.29, 3.14, and 2.85 mg g^{-1} fresh weight) compared to the salt susceptible variety, V2-Sarju 52 (3.02, 3.21, 2.96, and 2.77 mg g^{-1} fresh weight) at 30, 45, 75 DAT, and physiological maturity, respectively.

Analysis of variance indicated a significant beneficial effect (4–6%) with foliar application of osmoprotectants. At 45 and 75 DAT, V1-CSR 23 showed a 5.78% and 5.41% increase respectively. Whereas, V2- Sarju 52 recorded a 4.73% increase at 75 DAT following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V1 (CSR 23) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7). These findings confirm that polyols help sustain chlorophyll synthesis and reduce degradation under salinity stress. The stabilizing effects of sugar alcohols on chlorophyll under adverse conditions align with the results of Abdallah M. M. S. *et al.,* (2016) and Ahmad *et al.,* (2018), who highlighted the role of polyols in enhancing chlorophyll stability and photosynthetic efficiency in stressed rice plants.

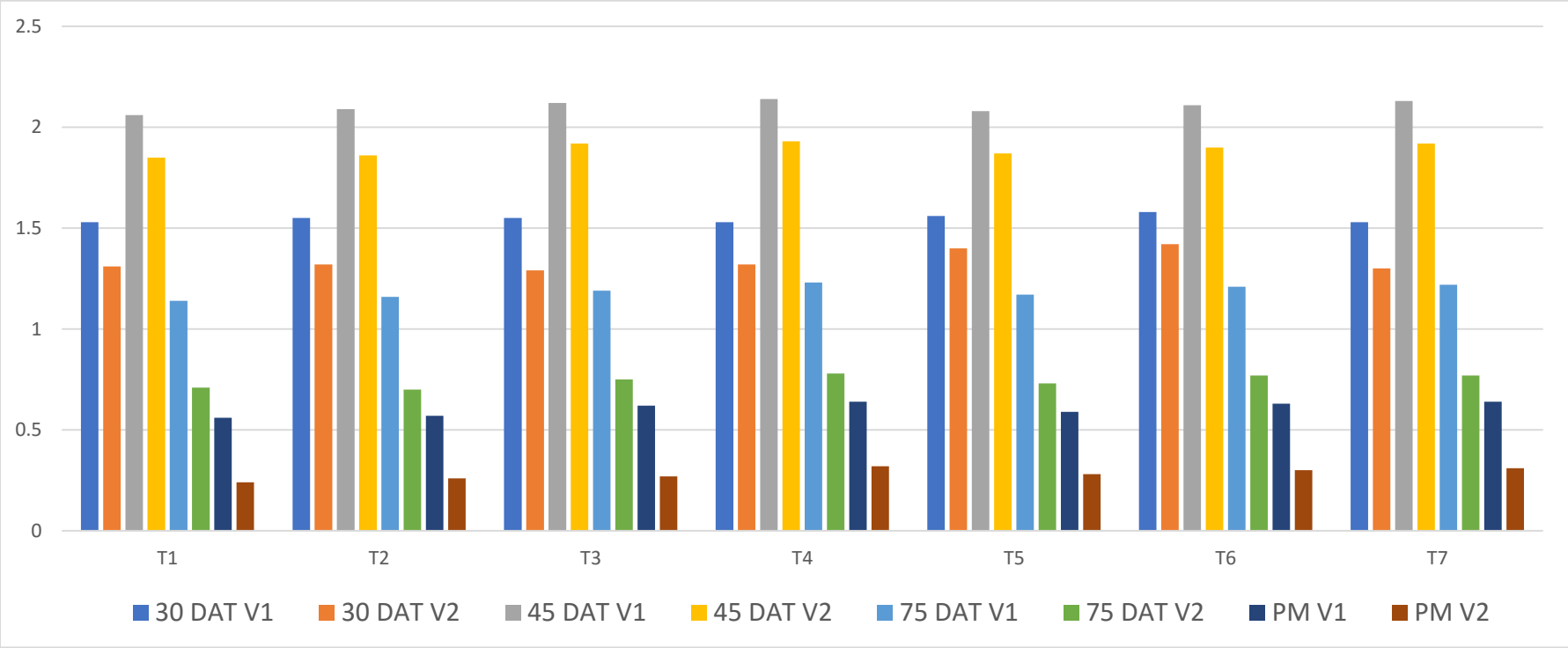
Table 4.3.1.1: Effect of sorbitol and mannitol on chl. A (mg g^{-1} fresh weight) at various growth stages of rice under salinity stress

Treatments	Chl. A at 30 DAT			Chl. A at 45 DAT			Chl. A at 75 DAT			At Physiological maturity		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	1.53	1.31	**1.42**	2.06	1.85	**1.96**	1.14	0.71	**0.93**	0.56	0.24	**0.40**
T2	1.55	1.32	**1.44**	2.09	1.86	**1.98**	1.16	0.70	**0.93**	0.57	0.26	**0.42**
T3	1.55	1.29	**1.42**	2.12	1.92	**2.02**	1.19	0.75	**0.97**	0.62	0.27	**0.45**
T4	1.53	1.32	**1.43**	2.14	1.93	**2.04**	1.23	0.78	**1.01**	0.64	0.32	**0.48**
T5	1.56	1.40	**1.48**	2.08	1.87	**1.98**	1.17	0.73	**0.95**	0.59	0.28	**0.44**
T6	1.58	1.42	**1.50**	2.11	1.90	**2.01**	1.21	0.77	**0.99**	0.63	0.30	**0.47**
T7	1.53	1.30	**1.42**	2.13	1.92	**2.03**	1.22	0.77	**1.00**	0.64	0.31	**0.48**
MEAN	**1.55**	**1.34**		**2.10**	**1.89**		**1.19**	**0.74**		**0.61**	**0.28**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.01**	**NS**		**0.01**	**0.03**		**0.01**	**0.03**		**0.01**	**0.02**	
Treatments	**0.03**			**0.02**	**0.06**		**0.01**	**0.02**		**0.01**	**0.03**	
VxT	**0.04**			**0.01**	**0.01**		**0.01**	**0.02**		**0.01**	**0.01**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Figure 4.3.1.1: Effect of sorbitol and mannitol on chl. A (mg g^{-1} fresh weight) at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR 23

V2: Sarju 52

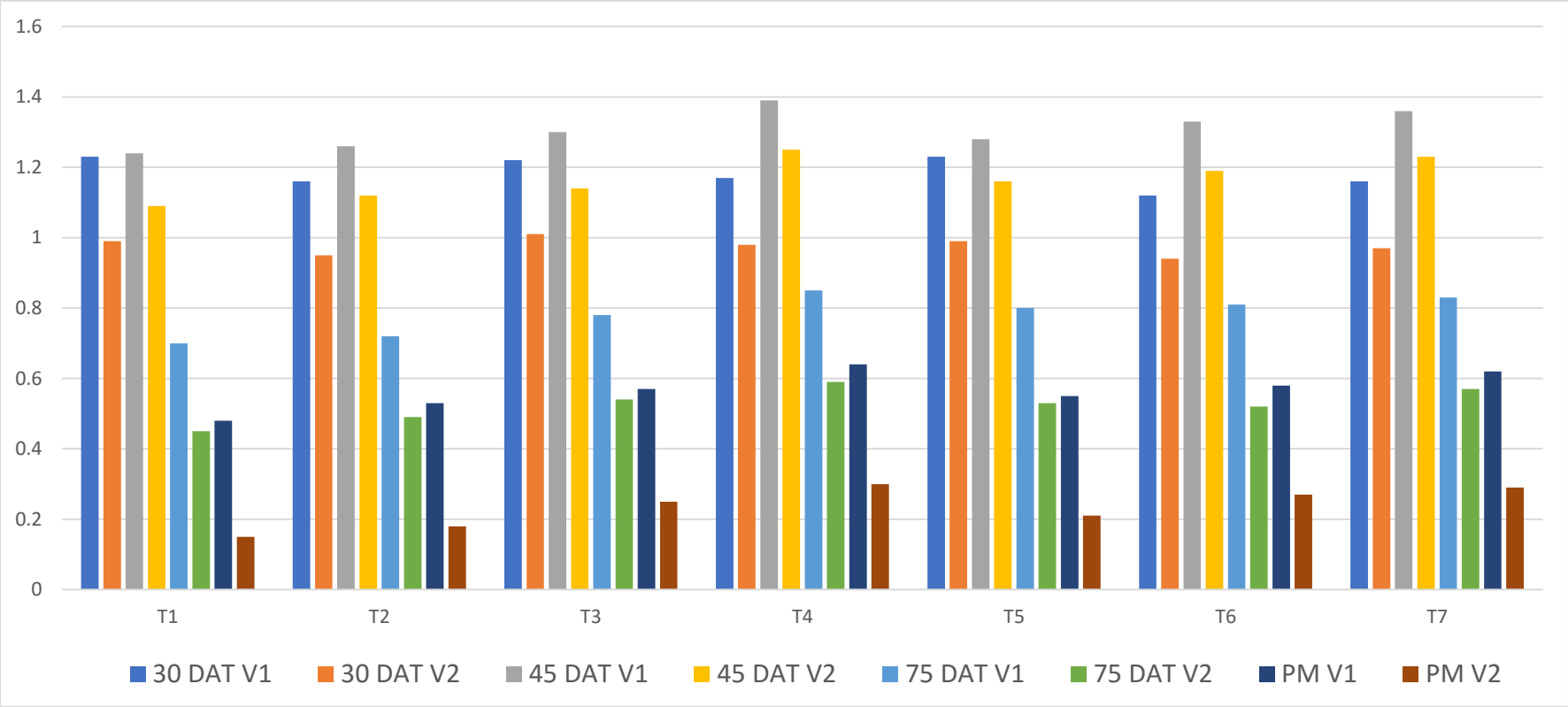
Table 4.3.1.2: Effect of sorbitol and mannitol on chl. B (mg g^{-1} fresh weight) at various growth stages of rice under salinity stress

Treatments	Chl. B at 30 DAT			Chl. B at 45 DAT			Chl. B at 75 DAT			At Physiological maturity		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	1.23	0.99	**1.11**	1.24	1.09	**1.17**	0.7	0.45	**0.58**	0.48	0.15	**0.32**
T2	1.16	0.95	**1.06**	1.26	1.12	**1.19**	0.72	0.49	**0.61**	0.53	0.18	**0.36**
T3	1.22	1.01	**1.12**	1.3	1.14	**1.22**	0.78	0.54	**0.66**	0.57	0.25	**0.41**
T4	1.17	0.98	**1.08**	1.39	1.25	**1.32**	0.85	0.59	**0.72**	0.64	0.30	**0.47**
T5	1.23	0.99	**1.11**	1.28	1.16	**1.22**	0.8	0.53	**0.67**	0.55	0.21	**0.38**
T6	1.12	0.94	**1.03**	1.33	1.19	**1.26**	0.81	0.52	**0.67**	0.58	0.27	**0.43**
T7	1.16	0.97	**1.07**	1.36	1.23	**1.30**	0.83	0.57	**0.70**	0.62	0.29	**0.46**
MEAN	**1.18**	**0.98**		**1.31**	**1.17**		**0.78**	**0.53**		**0.57**	**0.24**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.01**	**NS**		**0.01**	**0.03**		**0.01**	**0.03**		**0.01**	**0.01**	
Treatments	**0.02**			**0.01**	**0.02**		**0.01**	**0.04**		**0.01**	**0.01**	
VxT	**0.03**			**0.03**	**0.09**		**0.01**	**0.01**		**0.01**	**0.02**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Figure 4.3.1.2: Effect of sorbitol and mannitol on chl. B (mg g^{-1} fresh weight) at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR 23

V2: Sarju 52

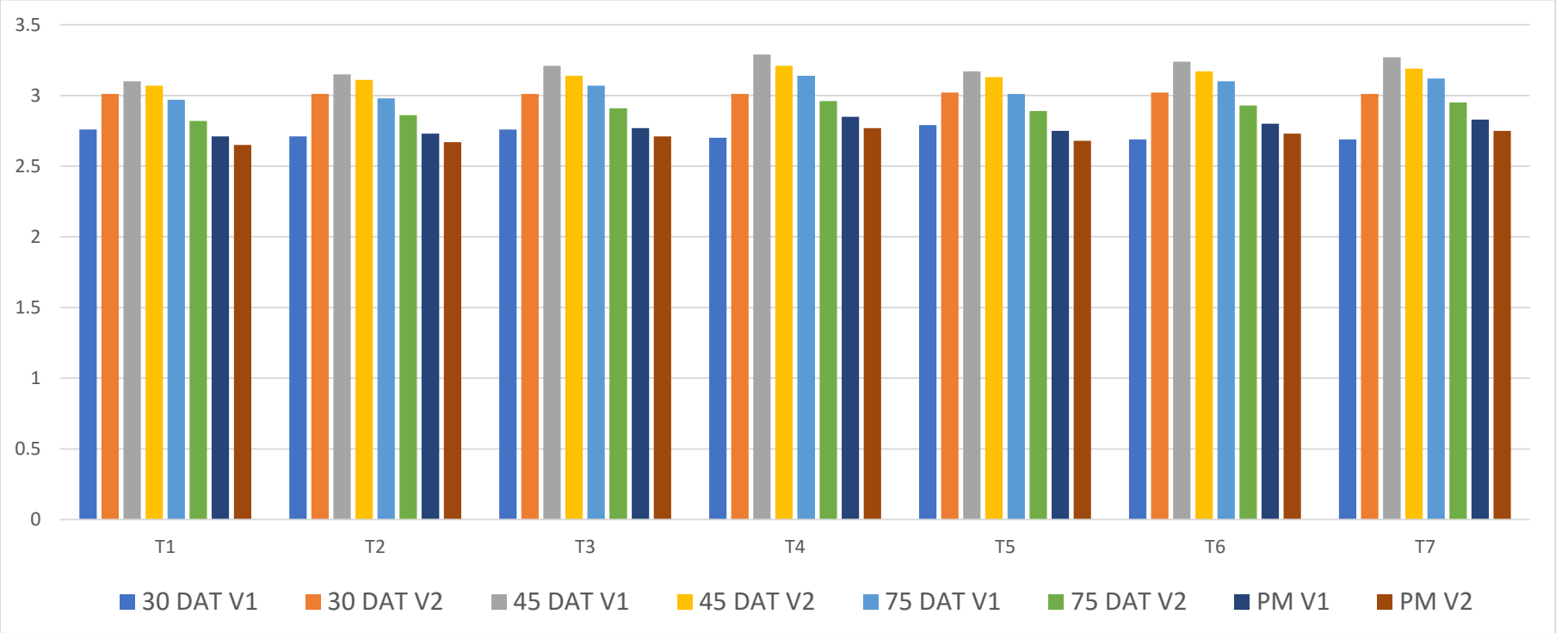
Table 4.3.1.3: Effect of sorbitol and mannitol on total chlorophyll (mg g^{-1} fresh weight) at various growth stages of rice under salinity stress

Treatments	Total chlorophyll at 30 DAT			Total chlorophyll at 45 DAT			Total chlorophyll at 75 DAT			At Physiological maturity		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	2.76	3.01	**2.89**	3.10	3.07	**3.09**	2.97	2.82	**2.90**	2.71	2.65	**2.68**
T2	2.71	3.01	**2.86**	3.15	3.11	**3.13**	2.98	2.86	**2.92**	2.73	2.67	**2.70**
T3	2.76	3.01	**2.89**	3.21	3.14	**3.18**	3.07	2.91	**2.99**	2.77	2.71	**2.74**
T4	2.70	3.01	**2.86**	3.29	3.21	**3.25**	3.14	2.96	**3.05**	2.85	2.77	**2.81**
T5	2.79	3.02	**2.91**	3.17	3.13	**3.15**	3.01	2.89	**2.95**	2.75	2.68	**2.72**
T6	2.69	3.02	**2.86**	3.24	3.17	**3.21**	3.1	2.93	**3.02**	2.80	2.73	**2.77**
T7	2.69	3.01	**2.85**	3.27	3.19	**3.23**	3.12	2.95	**3.04**	2.83	2.75	**2.79**
MEAN	**2.73**	**3.01**		**3.20**	**3.15**		**3.06**	**2.90**		**2.78**	**2.71**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.01**	**NS**		**0.01**	**0.02**		**0.01**	**0.03**		**0.02**	**0.04**	
Treatments	**0.02**			**0.01**	**0.04**		**0.01**	**0.02**		**0.01**	**0.03**	
VxT	**0.02**			**0.01**	**0.03**		**0.02**	**0.06**		**0.01**	**0.04**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Figure 4.3.1.3: Effect of sorbitol and mannitol on total chlorophyll (mg g^{-1} fresh weight) at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR 23

V2: Sarju 52

4.3.2.1 Sodium (Na^+) content (ppm)

Data regarding sodium (Na^+) content were recorded at 30, 45, and 75 days after transplanting (DAT), and at physiological maturity under salinity stress. The effects of sorbitol and mannitol treatments at various concentrations, are presented in Table 4.3.2.1 and illustrated in Figure 4.3.2.1.

Foliar application of sorbitol@80ppm (T4) resulted in the lowest sodium accumulation at 45, 75 DAT, and physiological maturity (2.23, 2.18 and 2.14 ppm respectively) closely followed by mannitol@80 ppm (T7). Whereas, the untreated control treatment (T1) consistently exhibited the highest Na□ levels at all stages, highlighting the severity of ionic stress in the absence of osmoprotective interventions (Wang H *et al*., 2012).

Varietal differences revealed that the salt tolerant variety V1-CSR 23 consistently exhibited lower sodium accumulation (1.75, 1.62, 1.56, and 1.53 ppm) compared to the salt susceptible variety V2-Sarju 52 (2.95, 2.84, 2.79, and 2.74 ppm) at 30, 45, 75 DAT, and physiological maturity, respectively. This indicates a higher intrinsic tolerance of V1-CSR23 to salinity-induced ionic stress.

Analysis of variance indicated a significant beneficial effect (2-6%) to foliar application of osmoprotectants. At 45 DAT and physiological maturity, V1-CSR 23 showed a 5.56% and 5.88% decrease respectively. Whereas, V2-Sarju 52 recorded a 2.55% decrease at physiological maturity following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V1 (CSR23) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7).

Overall, salinity stress led to increased Na□ uptake in both varieties across all stages, yet foliar application of sorbitol and mannitol significantly reduced Na□ accumulation, alleviating potential osmotic and metabolic disturbances. These results are consistent with findings by Hameed *et al.,* (2021), who demonstrated the efficacy of sorbitol in mitigating sodium-induced toxicity. Additionally, Alkahtani J *et al.,* (2023) reported that sorbitol modulates ion transport through regulation of membrane ion channels. While, Anjum N.A. *et al.,* (2023) observed that mannitol reduces Na□ content and enhances K□ uptake, thereby improving ionic balance and stress tolerance in salinity-affected plants.

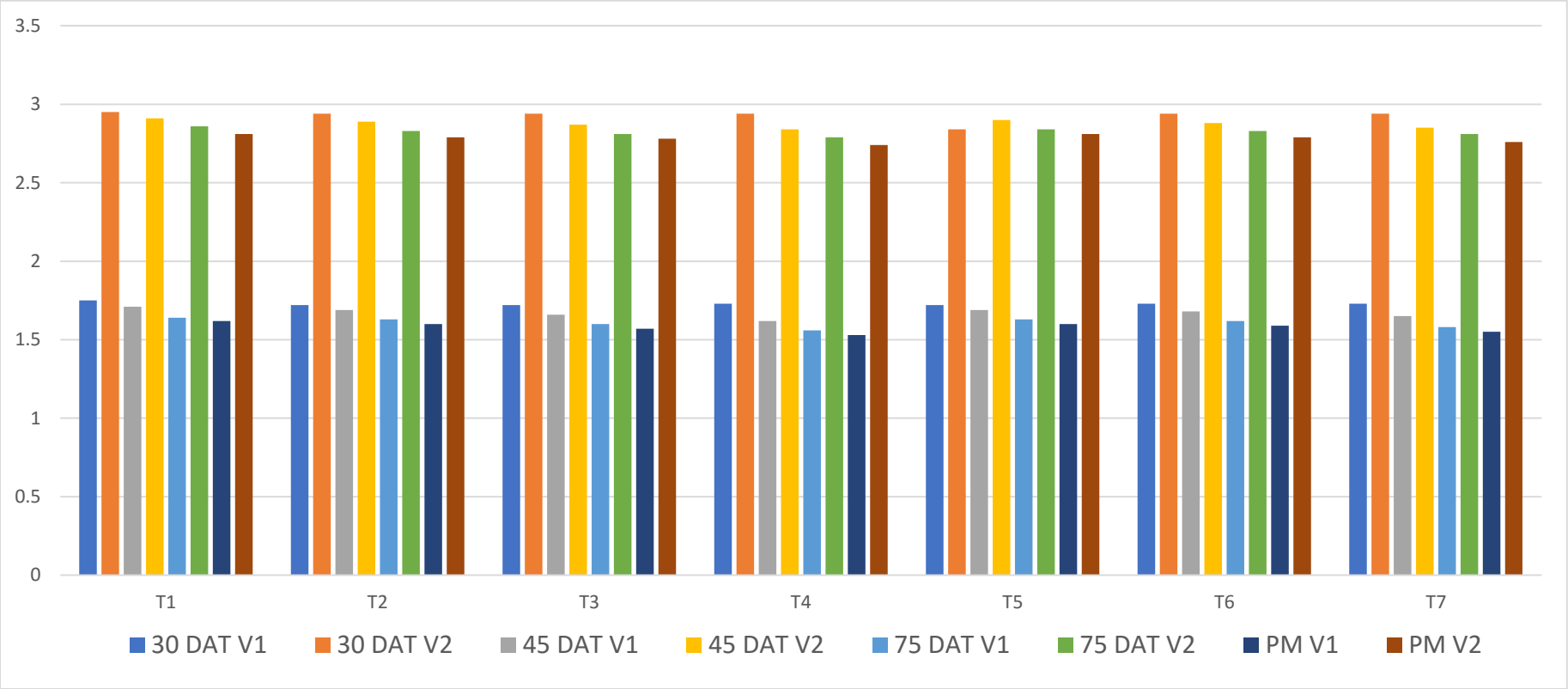
Table 4.3.2.1: Effect of sorbitol and mannitol on sodium (ppm) content at various growth stages of rice under salinity stress

Treatments	Sodium content at 30 DAT			Sodium content at 45 DAT			Sodium content at 75 DAT			At Physiological maturity		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	1.75	2.95	**2.35**	1.71	2.91	**2.31**	1.64	2.86	**2.25**	1.62	2.81	**2.22**
T2	1.72	2.94	**2.33**	1.69	2.89	**2.29**	1.63	2.83	**2.23**	1.60	2.79	**2.20**
T3	1.72	2.94	**2.33**	1.66	2.87	**2.27**	1.6	2.81	**2.21**	1.57	2.78	**2.18**
T4	1.73	2.94	**2.34**	1.62	2.84	**2.23**	1.56	2.79	**2.18**	1.53	2.74	**2.14**
T5	1.72	2.84	**2.28**	1.69	2.90	**2.30**	1.63	2.84	**2.24**	1.60	2.81	**2.21**
T6	1.73	2.94	**2.34**	1.68	2.88	**2.28**	1.62	2.83	**2.23**	1.59	2.79	**2.19**
T7	1.73	2.94	**2.34**	1.65	2.85	**2.25**	1.58	2.81	**2.20**	1.55	2.76	**2.16**
MEAN	**1.73**	**2.93**		**1.67**	**2.88**		**1.61**	**2.82**		**1.58**	**2.78**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.01**	**NS**		**0.01**	**0.02**		**0.01**	**0.03**		**0.01**	**0.02**	
Treatments	**0.02**			**0.01**	**0.01**		**0.01**	**0.01**		**0.01**	**0.01**	
VxT	**0.03**			**0.01**	**0.01**		**0.01**	**0.01**		**0.01**	**0.01**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Figure 4.3.2.1: Effect of sorbitol and mannitol on sodium (ppm) content at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR 23

V2: Sarju 52

4.3.2.2 Potassium (K^+) content (ppm)

Data on potassium content (K^+) were recorded at 30, 45, and 75 days after transplanting (DAT), and at physiological maturity under salinity stress. The effects of foliar applied sorbitol and mannitol treatments at various concentrations, are presented in Table 4.3.2.2 and illustrated in Figure 4.3.2.2.

Foliar application of sorbitol@80ppm (T4) resulted in the highest K□ concentrations (2.29, 1.86 and 1.58 ppm) at 45, 75 DAT and at physiological maturity respectively, followed by mannitol@80ppm (T7). These results indicate that both osmolytes effectively promoted K□ retention and uptake in the varieties exposed to salinity stress. The untreated control (T1) consistently exhibited the lowest K□ accumulation across all growth stages, reflecting a pronounced ionic imbalance under saline conditions (Paul P.L.C *et al*., 2024).

In varietal comparison, the salt tolerant variety V1-CSR23 consistently exhibited higher K□ accumulation (2.37, 2.55, 2.05 and 1.77 ppm) compared to the salt susceptible variety V2-Sarju 52 (1.83, 2.03, 1.67 and 1.39 ppm) at 30, 45, 75 DAT, and physiological maturity, respectively.

Analysis of variance indicated a significant beneficial effect (5-7%) with foliar application of osmoprotectants. At 75 DAT and physiological maturity, V2- Sarju 52 showed a 6.59% and 7.91% increase respectively. Meanwhile, V1-CSR 23 recorded a 5.65% increase at physiological maturity following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V2 (Sarju-52) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm(T7).

The enhanced potassium accumulation under polyols treatments underscores their role in mitigating the adverse effects of sodium stress by improving K□ uptake and minimizing Na□ interference. These findings are consistent with previous studies by Jiménez-Arias D *et al.,* (2021), who reported increased potassium, content in salinity-stressed rice plants following mannitol application. Similarly, Pamuru R.R. *et al.,* (2021) observed elevated potassium levels and enhanced sorbitol biosynthesis in rice plants under potassium-enriched environments.

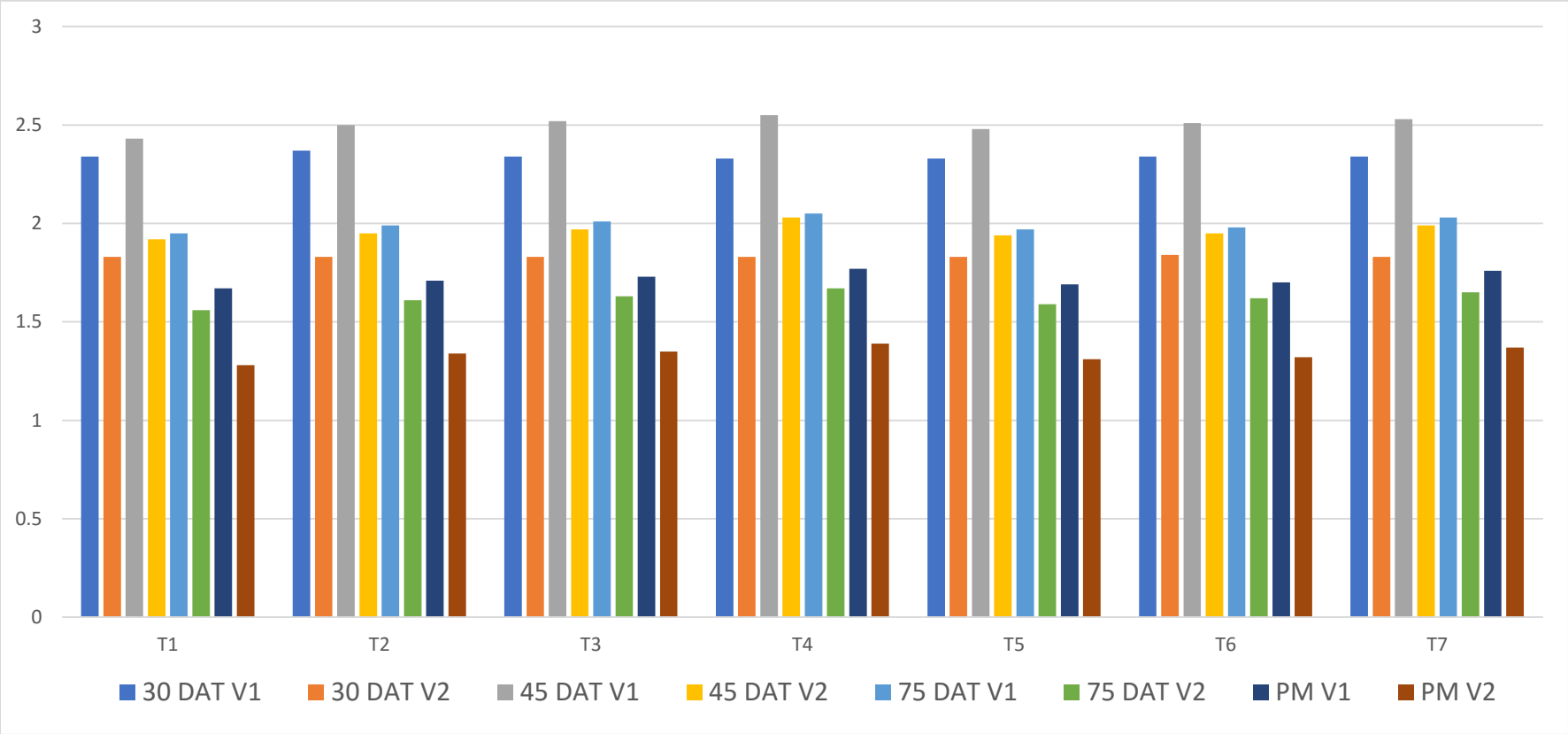
Table 4.3.2.2: Effect of sorbitol and mannitol on potassium (ppm) content at various growth stages of rice under salinity stress

Treatments	Potassium content at 30 DAT			Potassium content at 45 DAT			Potassium content at 75 DAT			At Physiological maturity		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	2.34	1.83	**2.09**	2.43	1.92	**2.18**	1.95	1.56	**1.76**	1.67	1.28	**1.48**
T2	2.37	1.81	**2.09**	2.50	1.95	**2.23**	1.99	1.61	**1.80**	1.71	1.34	**1.53**
T3	2.34	1.86	**2.10**	2.52	1.97	**2.25**	2.01	1.63	**1.82**	1.73	1.35	**1.54**
T4	2.33	1.83	**2.08**	2.55	2.03	**2.29**	2.05	1.67	**1.86**	1.77	1.39	**1.58**
T5	2.33	1.79	**2.06**	2.48	1.94	**2.21**	1.97	1.59	**1.78**	1.69	1.31	**1.50**
T6	2.34	1.84	**2.09**	2.51	1.95	**2.23**	1.98	1.62	**1.80**	1.70	1.32	**1.51**
T7	2.34	1.85	**2.10**	2.53	1.99	**2.26**	2.03	1.65	**1.84**	1.76	1.37	**1.57**
MEAN	**2.34**	**1.83**		**2.50**	**1.96**		**2.00**	**1.62**		**1.72**	**1.34**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm ±**	**CD at 5%**	
Variety	**0.01**	**NS**		**0.01**	**0.03**		**0.01**	**0.02**		**0.01**	**0.02**	
Treatments	**0.01**			**0.01**	**0.02**		**0.01**	**0.01**		**0.01**	**0.04**	
VxT	**0.01**			**0.01**	**0.02**		**0.01**	**0.01**		**0.01**	**0.01**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Figure 4.3.2.2: Effect of sorbitol and mannitol on potassium (ppm) content at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR 23

V2: Sarju 52

4.3.3 Nitrate Reductase activity (µg nitrate produced g^{-1} fresh weight min^{-1})

Data pertaining to Nitrate Reductase (NR) activity were recorded at 30, 45, and 75 days after transplanting (DAT), and at physiological maturity under salinity stress. The influence of foliar-applied sorbitol and mannitol at various concentrations are presented in Table 4.3.3 and illustrated in Figure 4.3.3.

The results showed that the highest NR activity across all growth stages was recorded with foliar application of sorbitol@80ppm-T4 (4.70, 3.96 and 0.53 µg nitrate produced g^{-1} fresh weight min^{-1}) at 45, 75 DAT and at physiological maturity followed closely by mannitol@80ppm (T7). Whereas, the untreated control (T1), consistently exhibited the lowest NR activity, indicating that salinity stress significantly inhibits nitrogen assimilation in the absence of osmoprotectants (Wang, H *et al*., 2012).

In terms of varietal performance, the salt tolerant variety V1-CSR 23 recorded significantly higher NR activity values (5.28, 4.78, and 0.71 µg nitrate produced g^{-1} fresh wt min^{-1}) at 45, 75 DAT, and physiological maturity, respectively, compared to the salt susceptible variety, V2-Sarju 52 (4.11, 3.13, and 0. µg nitrate produced g^{-1} fresh wt. min^{-1} respectively). This suggests that V1-CSR23 possesses a greater inherent capacity for nitrogen metabolism under saline conditions, which is further enhanced by osmoprotectants application.

Analysis of variance indicated a highly significant beneficial effect (23-46%) with foliar application of osmoprotectants. At physiological maturity, V2- Sarju 52 showed a 45.71% increase, while V1-CSR 23 recorded a 23.94% increase following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V2 (Sarju 52) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7).

The improved NR activity under polyols treatments highlights their role in maintaining nitrogen metabolism under osmotic and ionic stress. These results are consistent with Nadeem *et al.,* (2020), who reported enhanced NR activity in rice plants following sorbitol application, likely due to improved enzyme stability and nitrogen uptake. Similarly, Singh P *et al.,* (2022) demonstrated that mannitol enhances enzyme stabilization and activation, contributing to improved nitrogen use efficiency under salinity stress.

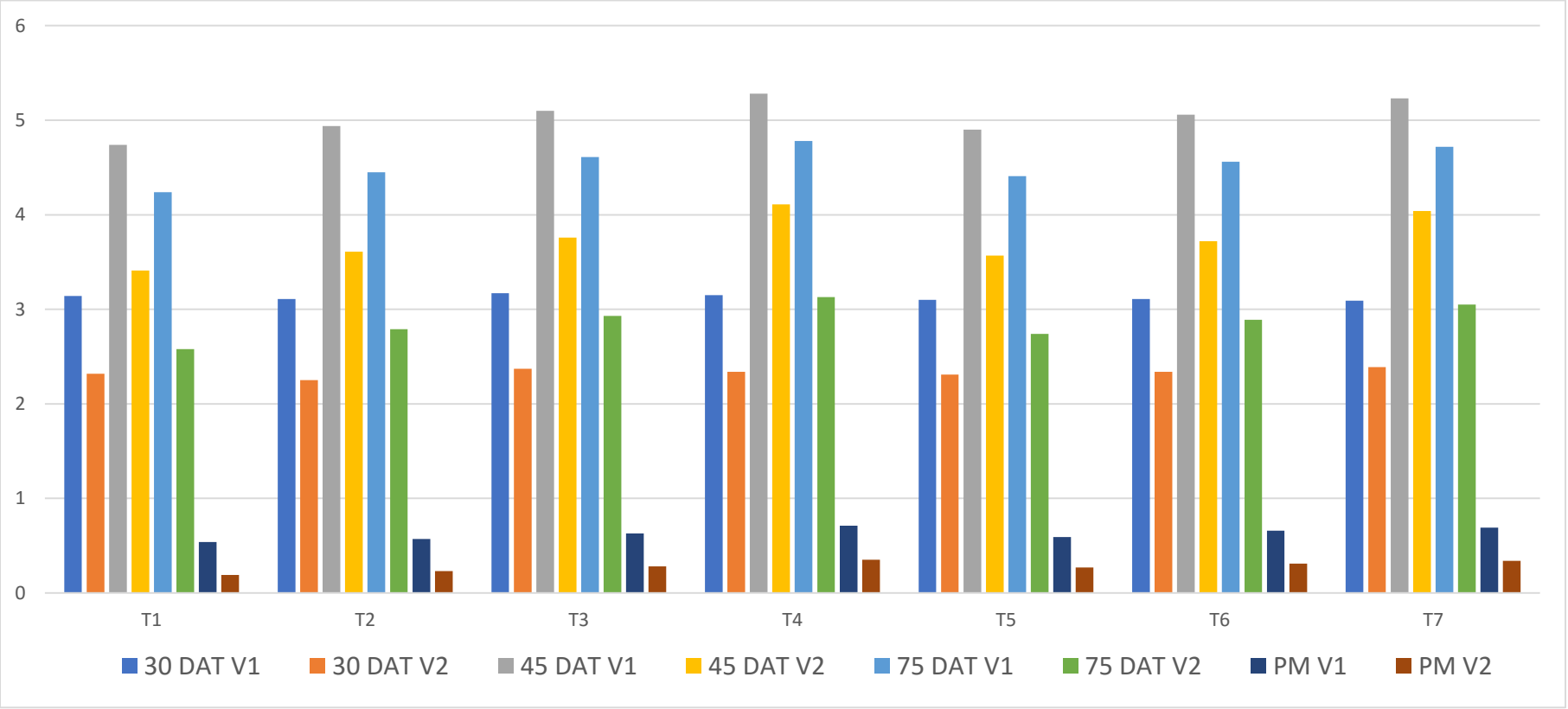
Table 4.3.3: Effect of sorbitol and mannitol on NR (µg nitrate produced g^{-1} fresh weight min^{-1}) activity at various growth stages of rice under salinity stress

Treatments	NR activity at 30 DAT			NR activity at 45 DAT			NR activity at 75 DAT			At Physiological maturity		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	3.14	2.32	**2.73**	4.74	3.41	**4.08**	4.24	2.58	**3.41**	0.54	0.19	**0.37**
T2	3.11	2.25	**2.68**	4.94	3.61	**4.28**	4.45	2.79	**3.62**	0.57	0.23	**0.40**
T3	3.17	2.37	**2.77**	5.1	3.76	**4.43**	4.61	2.93	**3.77**	0.63	0.28	**0.46**
T4	3.15	2.34	**2.75**	5.28	4.11	**4.70**	4.78	3.13	**3.96**	0.71	0.35	**0.53**
T5	3.10	2.31	**2.71**	4.9	3.57	**4.24**	4.41	2.74	**3.58**	0.59	0.27	**0.43**
T6	3.11	2.34	**2.73**	5.06	3.72	**4.39**	4.56	2.89	**3.73**	0.66	0.31	**0.49**
T7	3.09	2.39	**2.74**	5.23	4.04	**4.64**	4.72	3.05	**3.89**	0.69	0.34	**0.52**
MEAN	**3.12**	**2.33**		**5.04**	**3.75**		**4.54**	**2.87**		**0.63**	**0.28**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.01**	**NS**		**0.01**	**0.02**		**0.01**	**0.04**		**0.03**	**0.08**	
Treatments	**0.03**			**0.01**	**0.03**		**0.01**	**0.02**		**0.01**	**0.04**	
VxT	**0.04**			**0.01**	**0.04**		**0.01**	**0.03**		**0.01**	**0.03**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Figure 4.3.3: Effect of sorbitol and mannitol on NR (µg nitrate produced g^{-1} fresh weight min^{-1}) activity at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR 23

V2: Sarju 52

4.3.4. Total Soluble Carbohydrates-TSC (mg g^{-1} dry weight)

Data related to Total Soluble Carbohydrate (TSC) content of leaves were recorded at 30, 45, and 75 days after transplanting (DAT), and at physiological maturity under salinity stress. The effects of foliar applied sorbitol and mannitol application at various concentrations are presented in Table 4.3.4 and illustrated in Figure 4.3.4.

The highest TSC values at 45, 75 DAT, and physiological maturity were recorded with the foliar application of T4-sorbitol@80 ppm (292.20, 94.39, 47.71 mg g□¹ dry weight), followed by mannitol@80 ppm (T7). These treatments significantly outperformed the untreated control (T1), which exhibited the lowest TSC levels across all stages, indicating impaired carbon assimilation and compromised osmotic adjustment under saline conditions (Nemati I *et al*., 2011).

Regarding varietal response, the salt tolerant variety V1-CSR 23 consistently exhibited higher TSC content (261.20, 297.76, 100.86, and 54.48 mg g□¹ dry weight) compared to salt susceptible variety V2-Sarju 52 (242.22, 286.64, 87.91, and 40.94 mg g□¹ dry weight) at 30, 45, 75 DAT and at physiological maturity, respectively.

Analysis of variance indicated a highly significant beneficial effect (42-52%) with foliar application of osmoprotectants. At physiological maturity, V2- Sarju 52 showed a 51.51% increase, while V1-CSR 23 recorded a 42.09% increase following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V2 (Sarju-52) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7).

The elevated TSC levels suggests that polyols enhance carbohydrate retention by stabilizing cellular membranes, improving osmotic balance, and supporting continued photosynthate production under saline conditions. These findings are consistent with Nagarajan S *et al.,* (2022), who emphasized the role of sorbitol in sugar transport and osmotic regulation under salinity stress. Moreover, Al Mahmud *et al.,* (2019) similarly reported increased soluble sugar content in rice plants and sorbitol under osmotic stress. While, Li Q *et al.,* (2017) also demonstrated a positive correlation between sorbitol accumulation and enhanced carbohydrate content under abiotic stress, further affirming the protective role of sugar alcohols.

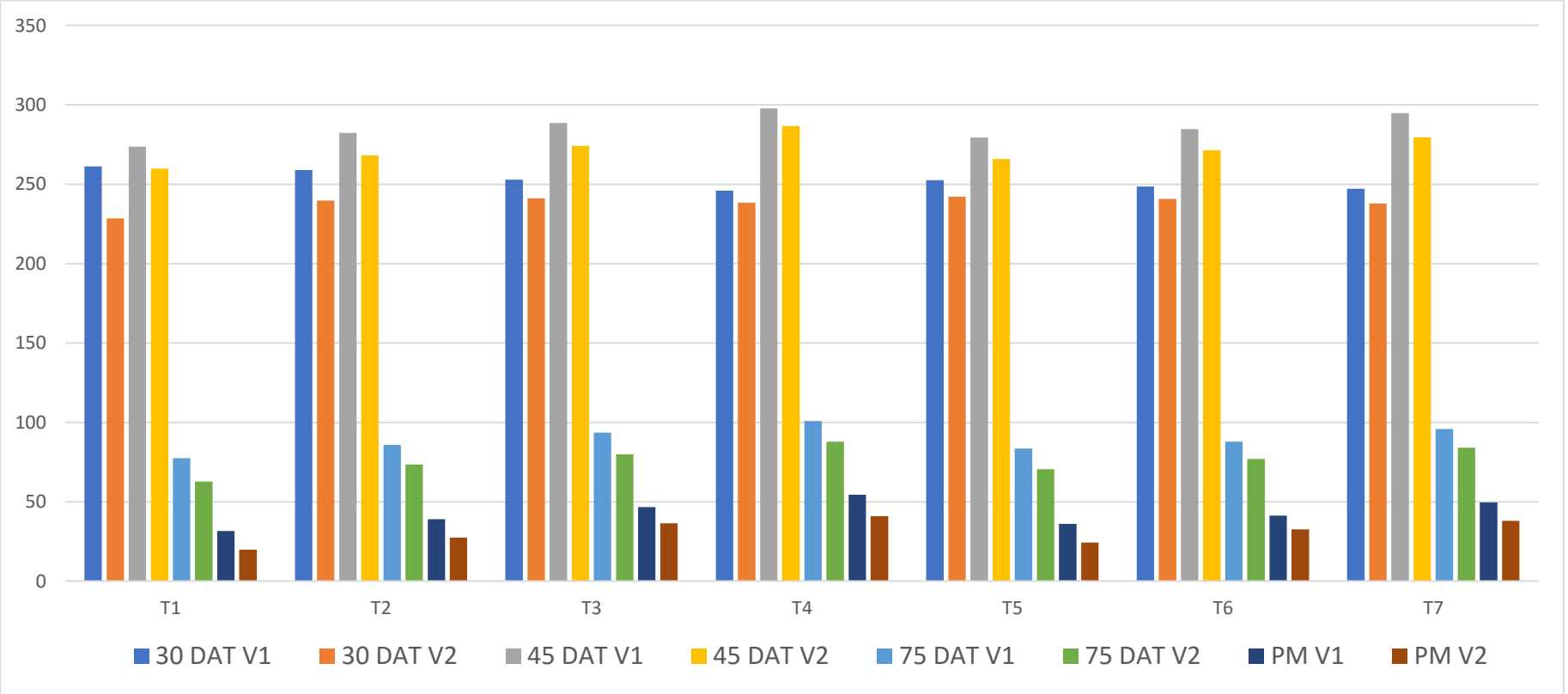
Table 4.3.4: Effect of sorbitol and mannitol on Total Soluble Carbohydrate-TSC (mg g^{-1} dry weight) at various growth stages of rice under salinity stress

Treatments	TSC at 30 DAT			TSC at 45 DAT			TSC at 75 DAT			At Physiological maturity		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	261.20	228.54	**244.87**	273.65	259.80	**266.73**	77.54	62.71	**70.13**	31.55	19.85	**25.70**
T2	258.93	239.78	**249.36**	282.39	268.24	**275.32**	85.83	73.54	**79.69**	39.10	27.44	**33.27**
T3	252.84	241.14	**246.99**	288.54	274.28	**281.41**	93.62	79.95	**86.79**	46.57	36.38	**41.48**
T4	245.95	238.36	**242.16**	297.76	286.64	**292.20**	100.86	87.91	**94.39**	54.48	40.94	**47.71**
T5	252.48	242.22	**247.35**	279.41	265.83	**272.62**	83.6	70.46	**77.03**	36.03	24.28	**30.16**
T6	248.64	240.71	**244.68**	284.84	271.37	**278.11**	87.83	76.87	**82.35**	41.27	32.56	**36.92**
T7	247.12	237.86	**242.49**	294.87	279.56	**287.22**	95.74	84.02	**89.88**	49.56	38.05	**43.81**
MEAN	**252.45**	**238.37**		**285.92**	**272.25**		**89.29**	**76.49**		**42.65**	**31.36**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**1.2**	**NS**		**0.31**	**0.89**		**0.33**	**0.95**		**0.43**	**1.24**	
Treatments	**2.25**			**0.57**	**1.67**		**0.61**	**1.78**		**0.8**	**2.33**	
VxT	**3.19**			**0.81**	**2.36**		**0.87**	**2.51**		**1.13**	**3.29**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Figure 4.3.4: Effect of sorbitol and mannitol on Total Soluble Carbohydrate-TSC (mg g^{-1} dry weight) at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR 23

V2: Sarju 52

4.3.5 Superoxide Dismutase (SOD) activity (unit g^{-1} fresh weight)

Data on Superoxide Dismutase (SOD) activity were recorded at 30, 45, and 75 days after transplanting (DAT), and at physiological maturity under salinity stress. The influence of foliar applied sorbitol and mannitol at various concentrations are presented in Table 4.3.5 and illustrated in Figure 4.3.5.

The results indicated that salinity stress substantially elevated SOD activity as part of an induced antioxidative defence response. Among the treatments, the highest SOD activity was recorded with foliar application of T4-sorbitol@80ppm (163.22, 139.60, 117.04 unit g□¹ fresh weight), followed by T7-mannitol@80ppm. This suggests that both osmolytes effectively enhanced enzymatic antioxidant responses under saline conditions. In contrast, the untreated control (T1) exhibited lowest SOD activity, reflecting heightened vulnerability to oxidative damage due to insufficient ROS-scavenging capacity (Ponce, K.S *et al*., 2021).

Varietal differences were also evident, with V1-CSR 23 consistently exhibiting significantly higher SOD activity (189.29, 165.95, and 137.92 unit g□¹ fresh weight) compared to V2-Sarju 52 (137.15, 113.25, and 96.16 unit g□¹ fresh weight) at 45, 75 DAT, and physiological maturity, respectively.

Analysis of variance indicated a highly significant beneficial effect (20-39%) with foliar application of osmoprotectants. At 75 DAT and physiological maturity, V2- Sarju 52 showed a 38.35% and 36.47% increase respectively. Whereas, V1-CSR-23 recorded a 20.09% increase at 75 DAT following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V2 (Sarju-52) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7).

The observed enhancement in SOD activity is attributable to the dual role of sorbitol and mannitol in osmotic regulation and the upregulation of antioxidative defence mechanisms. These results are supported by Kiani *et al.,* (2018) and Wang X *et al.,* (2019) who demonstrated that mannitol treatment increases SOD activity and maintains membrane stability in salinity-stressed plants. Similarly, Suryavanshi *et al.,* (2016) also reported that exogenous application of sorbitol boosts antioxidant enzyme activities, contributing to improved oxidative stress management.

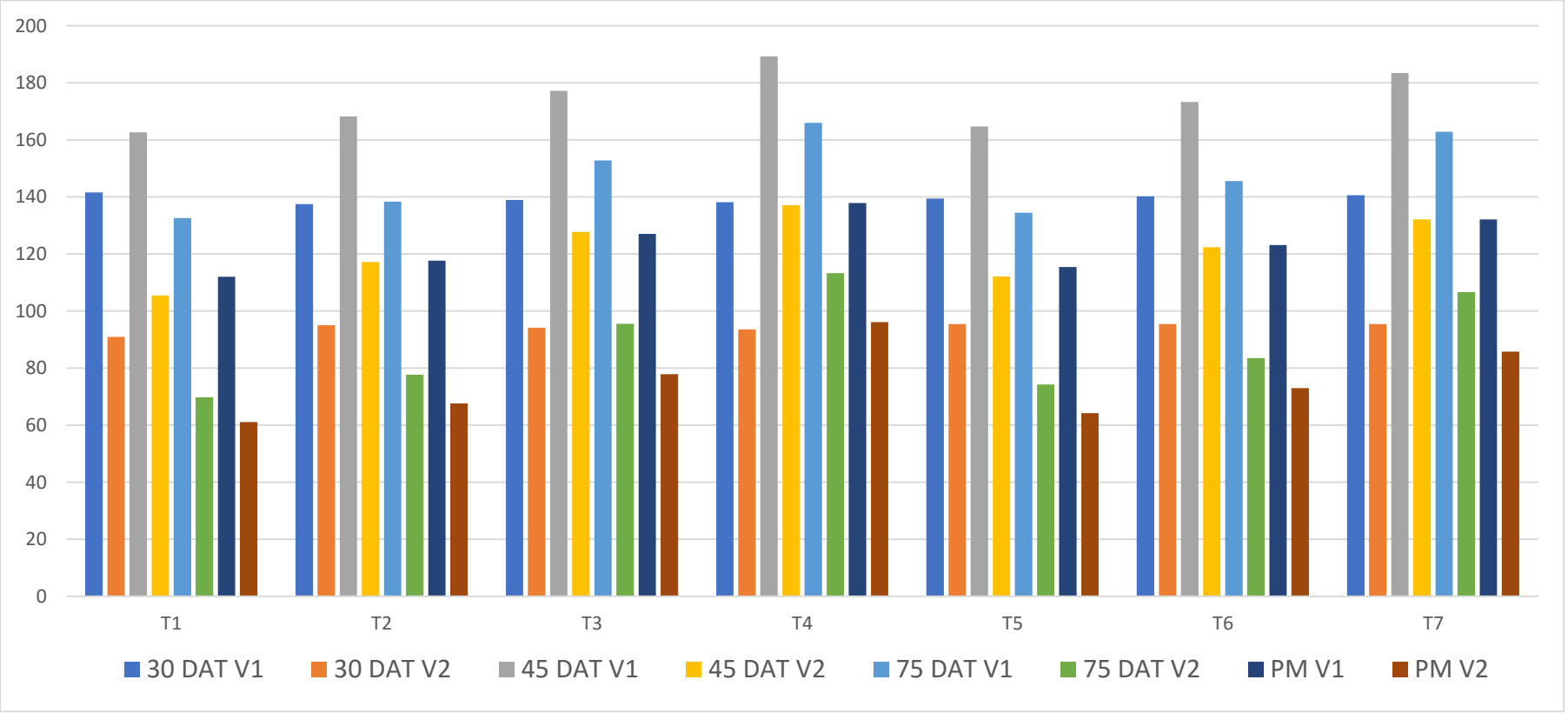
Table 4.3.5: Effect of sorbitol and mannitol on Superoxide Dismutase-SOD (unit g^{-1} fresh weight) activity at various growth stages of rice under salinity stress

Treatments	SOD activity at 30 DAT			SOD activity at 45 DAT			SOD activity at 75 DAT			At Physiological maturity		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	141.55	90.92	**116.24**	162.71	105.44	**134.08**	132.61	69.82	**101.22**	112.05	61.09	**86.57**
T2	137.49	95.06	**116.28**	168.22	117.22	**142.72**	138.33	77.71	**108.02**	117.72	67.6	**92.66**
T3	138.94	94.21	**116.58**	177.18	127.77	**152.48**	152.82	95.50	**124.16**	127.09	77.85	**102.47**
T4	138.19	93.63	**115.91**	189.29	137.15	**163.22**	165.95	113.25	**139.60**	137.92	96.16	**117.04**
T5	139.41	95.45	**117.43**	164.71	112.12	**138.42**	134.51	74.22	**104.37**	115.42	64.21	**89.82**
T6	140.26	95.43	**117.85**	173.28	122.39	**147.84**	145.6	83.53	**114.57**	123.14	72.99	**98.07**
T7	140.61	95.40	**118.01**	183.48	132.15	**157.82**	162.85	106.63	**134.74**	132.15	85.76	**108.96**
MEAN	**139.49**	**94.30**		**174.12**	**122.03**		**147.52**	**88.67**		**123.64**	**75.09**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.6**	**NS**		**0.19**	**0.55**		**0.23**	**0.68**		**0.15**	**0.44**	
Treatments	**1.13**			**0.35**	**1.03**		**0.44**	**1.27**		**0.28**	**0.83**	
VxT	**1.59**			**0.5**	**1.45**		**0.62**	**1.79**		**0.4**	**1.17**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Table 4.3.5: Effect of sorbitol and mannitol on Superoxide Dismutase-SOD (unit g^{-1} fresh weight) activity at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR 23

V2: Sarju 52

4.4 PHYSIOLOGICAL CHARACTERS

4.4.1 Relative Water Content (RWC) %

The data pertaining to the Relative Water Content (RWC) of leaves were recorded at 30, 45, and 75 days after transplanting (DAT), and at physiological maturity under salinity stress. The influence of foliar application of sorbitol and mannitol at various concentrations are presented in Table 4.4.1 and illustrated in Figure 4.4.1. Salinity stress led to a marked reduction in RWC across all treatments, indicating a substantial impairment in the plant's ability to maintain water balance under high salinity concentrations (Trotti J *et al*., 2024).

Among the treatments, the highest RWC values were recorded in T4-sorbitol@80ppm (79.11%, 74.23% and 68.02 %), followed by T7-mannitol@80ppm, across all growth stages. These treatments resulted in substantial improvements in leaf hydration relative to the untreated control (T1), affirming the role of sugar alcohols in enhancing osmotic adjustment.

Varietal analysis showed that V1-CSR23 consistently maintained significantly higher RWC values (81.58%, 76.13%, and 70.72%) compared to V2-Sarju 52 (76.64%, 72.32%, and 65.32%) at 45, 75 DAT, and physiological maturity, respectively. This indicates that V1-CSR 23 possesses more efficient water conservation and osmotic regulation mechanisms, likely contributing to its superior stress tolerance.

Analysis of variance indicated a significant beneficial effect (6-7%) with foliar application of osmoprotectants. At 75 DAT and physiological maturity, V2- Sarju 52 showed a 6.57% and 6.99% increase respectively. Whereas, V1-CSR-23 recorded a 6.38% increase at physiological maturity following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V2 (Sarju 52) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7).

The improvement in RWC observed under osmoprotectants treatments is supported by previous studies by Reddy I.N.B.L. *et al.,* (2017) and Choudhary S *et al.,* (2023). They reported that foliar applied sorbitol and mannitol enhanced water retention in salinity stressed plants by decreasing osmotic potential and promoting solute accumulation. These compounds facilitate the preservation of cell turgor and hydration, thereby bolstering plant resilience under stress.

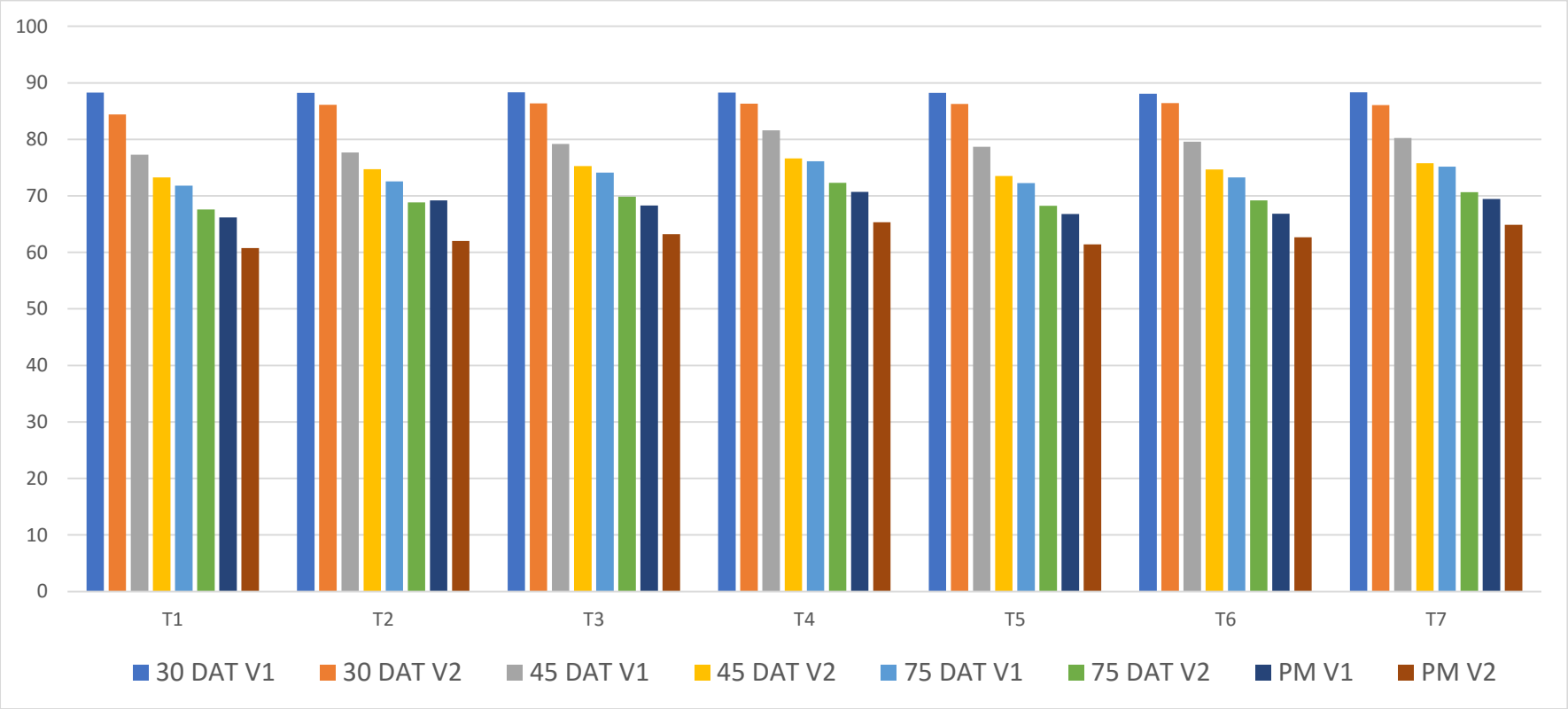
Table 4.4.1: Effect of sorbitol and mannitol on Relative Water Content (RWC) (%) at various growth stages of rice under salinity stress

Treatments	RWC at 30 DAT			RWC at 45 DAT			RWC at 75 DAT			At Physiological maturity		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	88.28	84.40	**86.34**	77.26	73.29	**75.28**	71.79	67.57	**69.68**	66.21	60.75	**63.48**
T2	88.25	86.10	**87.18**	77.67	74.70	**76.19**	72.57	68.84	**70.71**	69.22	62.02	**65.62**
T3	88.32	86.36	**87.34**	79.19	75.27	**77.23**	74.11	69.84	**71.98**	68.31	63.23	**65.77**
T4	88.27	86.31	**87.29**	81.58	76.64	**79.11**	76.13	72.32	**74.23**	70.72	65.32	**68.02**
T5	88.24	86.28	**87.26**	78.71	73.51	**76.11**	72.27	68.26	**70.27**	66.77	61.41	**64.09**
T6	88.07	86.43	**87.25**	79.61	74.65	**77.13**	73.29	69.19	**71.24**	66.85	62.69	**64.77**
T7	88.32	86.05	**87.19**	80.25	75.79	**78.02**	75.19	70.64	**72.92**	69.44	64.87	**67.16**
MEAN	**88.25**	**85.99**		**79.18**	**74.84**		**73.62**	**69.52**		**68.22**	**62.90**	
Factors	**SEm±**	**CD at 5%**		**SEm ±**	**CD at 5%**		**SEm ±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.21**	**NS**		**0.05**	**0.15**		**0.04**	**0.12**		**0.19**	**0.57**	
Treatments	**0.39**			**0.1**	**0.28**		**0.08**	**0.23**		**0.36**	**1.06**	
VxT	**0.55**			**0.14**	**0.40**		**0.11**	**0.32**		**0.51**	**1.5**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Figure 4.4.1: Effect of sorbitol and mannitol on Relative Water Content (RWC) (%) at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR 23

V2: Sarju 52

4.5 YIELD AND YIELD ATTRIBUTING TRAITS

4.5.1. Panicle length (cm)

The data on panicle length and the influence of foliar application of sorbitol and mannitol at various concentrations under salinity stress are presented in Table 4.5.1 and illustrated in Figure 4.5.1. Salinity stress significantly reduced panicle length in both rice varieties, reflecting the detrimental impact of ionic and osmotic imbalances on reproductive development (Rehman, A.U *et al*., 2024). However, foliar application of osmoprotectants significantly mitigated this effect, leading to notable improvements in panicle length under saline conditions.

The longest panicle length was recorded under treatment T4-sorbitol@80ppm (25.31 cm), followed by T7-mannitol@80ppm (24.79 cm). These treatments significantly outperformed the untreated control-T1 (21.82 cm), which exhibited the shortest panicle length due to impaired cell expansion, disrupted assimilate transport, and inhibited reproductive growth.

Analysis of variance indicated a highly significant beneficial effect (13-15%) with foliar application of osmoprotectants. The salt tolerant variety, V1- CSR 23 showed a 14.52% increase, whereas, V2-Sarju 52 recorded a 13.01% increase following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V1 (CSR 23) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7).

These observations align with the findings of Biswas S *et al.,* (2023), who reported enhanced shoot and reproductive growth in maize under osmotic stress following sorbitol application. Similarly, Devika O.S *et al.,* (2021) highlighted the role of osmoprotectants in sustaining reproductive development by preserving membrane stability and metabolic function during critical stages such as flowering and grain setting.

4.5.2 Panicle bearing tillers plant^{-1}

The data on panicle bearing tillers plant^{-1} and influence of foliar application of sorbitol and mannitol at various concentrations under salinity stress are presented in Table 4.5.1 and illustrated in Figure 4.5.1. The analysis revealed that salinity stress significantly reduced the number of productive tillers, indicating a strong inhibitory effect on tiller development and survival (Wei H.H *et al*.,2020). However, foliar application of osmoprotectants significantly alleviated these adverse effects and improved tiller productivity under saline conditions.

The maximum number of panicle bearing tillers were recorded under treatment T4-sorbitol@80ppm (14.76), followed closely by T7-mannitol@80ppm (13.15). These treatments significantly outperformed the untreated control-T1 (6.78), which exhibited the lowest tiller count, likely due to compromised cellular division, disrupted hormonal signalling, and impaired assimilate distribution under salinity stress.

Varietal differences were statistically significant, with V1-CSR 23 producing a greater number of panicle bearing tillers (15.7) compared to the salt susceptible variety, V2-Sarju 52 (13.82), underscoring its superior genetic adaptability and stronger response to exogenous osmoprotectants.

Analysis of variance indicated a highly significant beneficial effect (52-56%) with foliar application of osmoprotectants. The salt susceptible variety, V2- Sarju 52 showed a 55.79% increase, whereas, V1-CSR 23 recorded a 52.61% increase following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V2 (Sarju 52) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7).

The improvement in panicle bearing tillers plant^{-1} production can be attributed to the dual role of sorbitol and mannitol in mitigating oxidative stress, stabilizing hormonal balance and preserving membrane integrity. These findings are supported by Dhakal P *et al.,* (2020), who reported enhanced antioxidant defences following mannitol treatment under salinity stress. Similarly, Devika O.S *et al.,* (2021), and Hassanein A. *et al.,* (2021) demonstrated that sorbitol application promoted productive tillering and overall reproductive vigour by maintaining physiological stability in stressed plants.

4.5.3 Total grains panicle^{-1}

The data on the total number of grains panicle^{-1} and the influence of foliar application of osmoprotectants at various concentrations under salinity stress are presented in Table 4.5.1 and illustrated in Figure 4.5.1. The results indicated a significant reduction in grain number under salinity stress, underscoring the high sensitivity of reproductive development to salinity stress (Li, R *et al*., 2024). However, foliar application of osmoprotectants effectively mitigated this adverse effect, significantly enhancing grain production under stress conditions.

The maximum number of grains panicle^{-1} were recorded in treatment T4-sorbitol@80ppm, (197) followed by T7-mannitol@80ppm (193.61). These treatments performed significantly better than the untreated control-T1 (173.61), which exhibited the lowest grain count due to disrupted processes such as pollen viability, fertilization, and grain setting under salinity. The notable improvement under osmoprotectants treatments suggests that sorbitol and mannitol helped preserve reproductive function during critical developmental stages by alleviating cellular and metabolic damage.

Varietal comparisons revealed that the salt tolerant variety, V1-CSR 23 consistently produced a higher number of total grains panicle^{-1} (207.89) as compared to the salt susceptible variety, V2-Sarju 52 (186.11). Thus, indicating its superior reproductive resilience and greater tolerance to salinity-induced stress.

Analysis of variance indicated a highly significant beneficial effect (11-13%) with foliar application of osmoprotectants. The salt tolerant variety, V1-CSR 23 showed a 12.35% increase, whereas, V2-Sarju 52 recorded a 11.34% increase following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V1-CSR 23 exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7). The positive impact of polyols on the total grain's panicle^{-1} is likely linked to their roles in enhancing osmotic adjustment, minimizing oxidative damage, stabilizing membrane and enzymatic activity during reproductive development. These findings are supported by Pamuru R.R. *et al.,* (2021), who reported improved spikelet fertility and grain filling under sorbitol treatment. Whereas, Geng P *et al*., (2008) also emphasized on the mannitol's effectiveness in preserving physiological integrity under saline conditions.

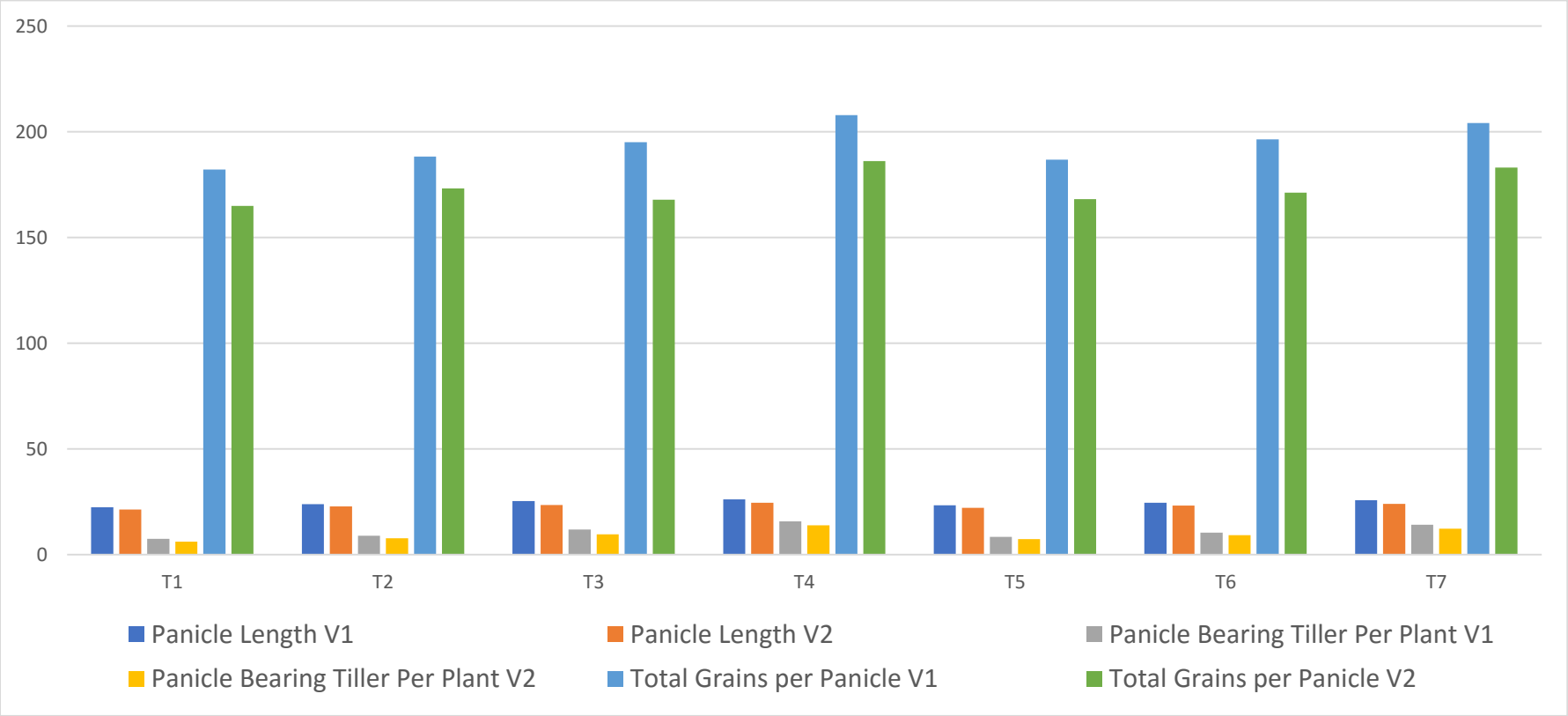
Table 4.5.1: Effect of sorbitol and mannitol on panicle length (cm), panicle bearing tillers plant^{-1} (count) and total grains panicle^{-1} (count) at various growth stages of rice under salinity stress

Treatments	Panicle length			Panicle bearing tillers plant^{-1}			Total grains panicle^{-1}		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	22.31	21.33	**21.82**	7.44	6.11	**6.78**	182.22	165.00	**173.61**
T2	23.81	22.74	**23.28**	8.89	7.67	**8.28**	188.34	173.22	**180.78**
T3	25.31	23.46	**24.39**	11.8	9.56	**10.68**	195.11	167.89	**181.50**
T4	26.10	24.52	**25.31**	15.7	13.82	**14.76**	207.89	186.11	**197.00**
T5	23.24	22.14	**22.69**	8.34	7.22	**7.78**	186.89	168.11	**177.50**
T6	24.42	23.20	**23.81**	10.4	9.11	**9.76**	196.44	171.22	**183.83**
T7	25.68	23.90	**24.79**	14.1	12.2	**13.15**	204.11	183.11	**193.61**
MEAN	**24.41**	**23.04**		**10.95**	**9.38**		**194.43**	**173.52**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.03**	**0.09**		**0.05**	**0.16**		**1.11**	**3.22**	
Treatments	**0.06**	**0.16**		**0.1**	**0.29**		**2.07**	**6.03**	
VxT	**0.08**	**0.23**		**0.14**	**0.41**		**2.93**	**8.52**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Figure 4.5.1: Effect of sorbitol and mannitol on panicle length (cm), panicle bearing tillers plant^{-1} (count) and total grains panicle^{-1} (count) at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR 23

V2: Sarju 52

4.5.4 Number of sterile grains & Sterility %

The data pertaining to the number of sterile grains and associated sterility % and the effect of foliar application of sorbitol and mannitol at various concentrations under salinity stress are presented in Table 4.5.4 and illustrated in Figure 4.5.4. The highest values for sterility were observed in the untreated control (T1). Thus, underscoring the detrimental impact of salinity on critical reproductive processes such as pollen viability, fertilization, and grain development (Li Z *et al*.,2023).

Conversely, treatments T4-sorbitol@80ppm (61.12 and 31.24%) followed by T7-mannitol@80ppm (62.17 and 32.34%) significantly reduced both number of sterile grains and sterility % respectively. These findings highlight the efficacy of osmoprotectants in mitigating salinity induced reproductive impairment. Whereas, the highest values for number of sterile grains and sterility% were observed in the untreated control-T1 (65.78, 38.11%) respectively. The reduction in sterility under osmoprotectants treatments is likely due to their role as compatible solutes, which helps them in supporting reproductive functions such as pollen germination and pollen tube elongation under osmotic stress.

Varietal comparisons revealed that the salt tolerant variety, V1-CSR 23 exhibited significantly lower sterility (56.56 sterile grains and 27.20% sterility%) than the salt susceptible variety, V2-Sarju 52 (65.67 sterile grains and 35.28% sterility%), indicating a stronger inherent resilience to salinity stress.

Analysis of variance indicated a significant beneficial effect (7-9% for number of sterile grains and 20-24% for sterility%) with foliar application of osmoprotectants. The salt tolerant variety, V1- CSR 23 showed a decrease of 8.24% in number of sterile grains and 23.53% in sterility%. Whereas, V2-Sarju 52 recorded a 7.09% decrease in number of sterile grains and 20.80% in sterility% following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V1-CSR 23 exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7). These results are consistent with earlier studies by Saddhe A. A *et al.,* (2021) who demonstrated that osmoprotectants improve panicle fertility and reduce sterility in salinity-affected plants. While, Khanna K. *et al.,* (2023) highlighted the role of mannitol in safeguarding reproductive development through oxidative stress mitigation.

4.5.5 Number of fertile grains & Fertility %

The data on the number of fertile grains and fertility % and the effect of foliar application of sorbitol and mannitol at various concentrations under salinity stress are presented in Table 4.5.4 and illustrated in Figure 4.5.4. The findings revealed that salinity stress significantly reduced both number of fertile grains and fertility % (Li Z *et al*.,2023). However, foliar application of osmoprotectants significantly alleviated these negative effects, leading to substantial improvements.

The lowest values for number of fertile grains and fertility % were recorded in the untreated control-T1 (107.84 and 61.89% respectively) underscoring the detrimental impact of salinity on pollen viability, fertilization efficiency, and grain filling. In contrast, the highest values for number of fertile grains and fertility % were observed under T4-sorbitol@80ppm (135.90 and 68.76%), followed closely by T7-mannitol@80ppm (131.44 and 67.67%) respectively. This highlights the effectiveness of these osmoprotectants in enhancing reproductive performance under stress.

The salt tolerant variety, V1-CSR 23 consistently exhibited higher numbers of fertile grains and fertility % (151.34 grains and 72.80%) compared to the salt susceptible variety, V2-Sarju 52 (120.45 grains and 64.72%) respectively. Analysis of variance indicated a highly significant beneficial effect (20-22% for number of fertile grains and 8-12% for fertility%) to foliar application of osmoprotectants. The salt susceptible variety, V2- Sarju 52 showed an increase of 21.40% in number of fertile grains and 11.34% in fertility%. Whereas, V1-CSR 23 recorded a 20.04% increase in number of fertile grains and 8.79% in fertility% following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V2 (Sarju 52) exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7). These results are in agreement with the findings of Geng P *et al.,* (2008), and Devika O.S *et al.,* (2021), who reported that exogenous application of osmoprotectants enhances reproductive resilience by mitigating oxidative and osmotic stress.

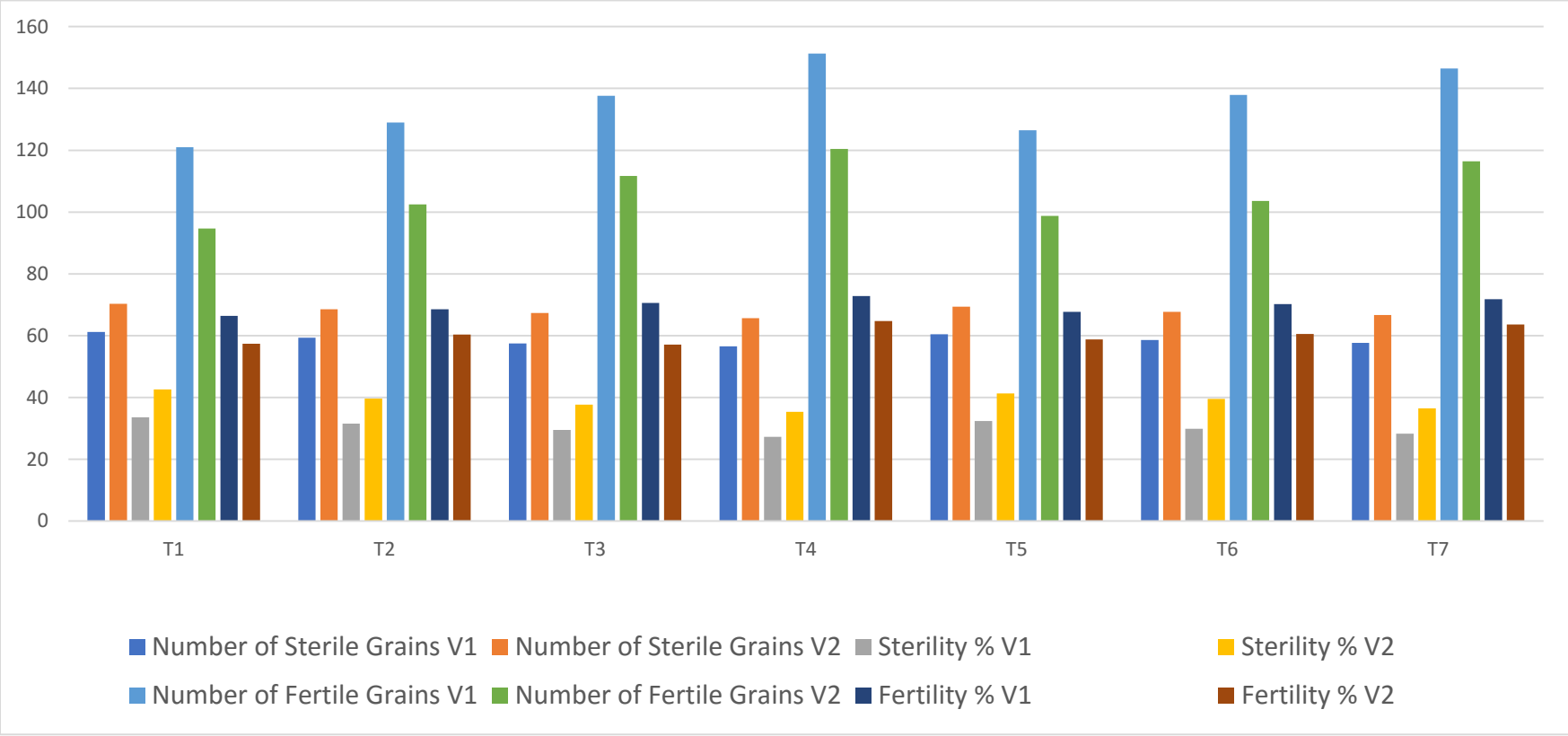
Table 4.5.4: Effect of sorbitol and mannitol on number of sterile grains (count), sterility %, number of fertile grains (count) and fertility % at various growth stages of rice under salinity stress

Treatments	Number of sterile grains			Sterility %			Number of fertile grains			Fertility%		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	61.22	70.33	**65.78**	33.60	42.62	**38.11**	121.00	94.67	**107.84**	66.40	57.38	**61.89**
T2	59.33	68.56	**63.95**	31.51	39.63	**35.57**	129.00	102.44	**115.72**	68.49	60.37	**64.43**
T3	57.44	67.33	**62.39**	29.44	37.66	**33.55**	137.67	111.67	**124.67**	70.56	57.12	**63.84**
T4	56.56	65.67	**61.12**	27.20	35.28	**31.24**	151.34	120.45	**135.90**	72.80	64.72	**68.76**
T5	60.44	69.33	**64.89**	32.35	41.24	**36.80**	126.44	98.78	**112.61**	67.65	58.76	**63.21**
T6	58.56	67.67	**63.12**	29.81	39.52	**34.67**	137.89	103.56	**120.73**	70.19	60.48	**65.34**
T7	57.67	66.67	**62.17**	28.26	36.41	**32.34**	146.44	116.44	**131.44**	71.74	63.59	**67.67**
MEAN	**58.75**	**67.94**		**30.31**	**38.91**		**135.68**	**106.86**		**69.69**	**60.35**	
Factors	**SEm ±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.03**	**0.08**		**0.04**	**0.13**		**0.17**	**0.49**		**0.53**	**1.53**	
Treatments	**0.05**	**0.14**		**0.08**	**0.24**		**0.31**	**0.91**		**0.98**	**2.86**	
VxT	**0.07**	**0.2**		**0.12**	**0.34**		**0.44**	**1.29**		**1.39**	**4.05**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR-23, V2: Sarju 52

Figure 4.5.4: Effect of sorbitol and mannitol on number of sterile grains (count), sterility %, number of fertile grains (count) and fertility% at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR-23

V2: Sarju 52

4.5.6 Grain yield plant^{-1} & Grain yield m^{-2} (g)

The data regarding grain yield plant^{-1} and grain yield m^{-2} and effect of foliar application of sorbitol and mannitol at various concentrations under salinity stress are presented in Table 4.5.6 and illustrated in Figure 4.5.6. The results clearly demonstrated that salinity stress significantly reduced both yield parameters, reflecting the adverse impact of salinity stress on plant growth, assimilate partitioning, and reproductive efficiency (Li Z *et al*., 2023). However, foliar application of osmoprotectants notably improved yield performance, even under salinity stress conditions.

The lowest grain yield plant^{-1} and meter^{-2} was recorded in the control treatment-T1 (18.28 g and 676.44 g respectively), where salinity stress was imposed without any mitigating treatment. Conversely, the highest grain yield plant^{-1} and m^{-2} was observed under T4 (sorbitol@80ppm) (51.81g and 1880.00 g), followed closely by T7 (mannitol@80ppm) (46.87 g and 1734.14 g) respectively. These findings suggest that exogenous application of osmoprotectants effectively alleviated yield loss by enhancing physiological resilience under stress.

The salt tolerant variety, V1-CSR23 consistently outperformed the salt susceptible variety, V2-Sarju 52 in grain yield plant^{-1} and meter^{-2}, recording 56.22 g plant^{-1} and 2080.03 g m^{-2}, compared to 47.40 g plant^{-1} and 1679.98 g m^{-2}, respectively.

Analysis of variance indicated a highly significant beneficial effect (63-65%) to foliar application of osmoprotectants. The salt tolerant variety, V1- CSR 23 showed an increase of 64.53% in grain yield plant^{-1} and meter$^{-2.}$ Whereas, V2-Sarju 52 exhibited a 63.39% increase in grain yield plant^{-1} and meter^{-2} following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V1-CSR 23 exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7).

The positive effects of polyols on grain yield plant^{-1} and meter^{-2} may be attributed to their roles as compatible solutes, facilitating osmotic adjustment, scavenging ROS, and stabilizing cellular membranes and enzymes. These observations align with findings by Dhakal P *et al.,* (2020) and Pamuru R.R. *et al.,* (2021), who reported improved yield components in salinity-stressed crops treated with osmoprotectants.

4.5.7 Straw yield plant^{-1} & Straw yield m^{-2} (g)

The data concerning to straw yield plant^{-1} and m^{-2} and the effect of foliar application of sorbitol and mannitol at various concentrations under salinity stress are presented in Table 4.5.6 and illustrated in Figure 4.5.6. The results revealed a significant increase in straw yield due to salinity stress (Roy, S.K *et al*., 2014), while the application of osmoprotectants notably improved biomass production across all treatments.

The highest straw yield plant^{-1} and m^{-2} was recorded under the control treatment-T1 (25.4g and 937.95g respectively). This suggests that salinity stress impacted straw yield likely due to impaired water uptake, ion toxicity, and reduced grain filling efficiency. In contrast, the lowest straw yield plant^{-1} and m^{-2} was observed in T4-sorbitol@80ppm (12.3g and 456.95g), followed by T7-mannitol@80ppm (14.4g and 534.65 g) respectively. These findings indicate that foliar application of osmoprotectants improved the plant's ability to maintain overall biomass under saline conditions.

The salt tolerant variety, V1-CSR 23 (12.9 g and 477.3 g) outperformed the salt susceptible variety, V2-Sarju-52 (11.8g and 436.6g) in terms of straw yield plant^{-1} and m^{-2} respectively. However, analysis of variance indicated a highly significant beneficial effect (100-111%) to foliar application of osmoprotectants. The salt susceptible variety, V2- Sarju 52 showed a decrease of 111%, whereas, V1-CSR-23 exhibited a 100% decrease in straw yield plant^{-1} and m^{-2} following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V2-Sarju 52 exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7).

The beneficial effects of polyols on straw yield plant^{-1} and m^{-2} are in line with previous studies by Ejaz S. *et al.,* (2020) and Pleyerová I. *et al.,* (2022), who reported improved biomass and resource allocation in salinity-stressed plants treated with osmoprotectants. These compounds help mitigate oxidative damage and enhance nutrient assimilation, thereby contributing to better yield.

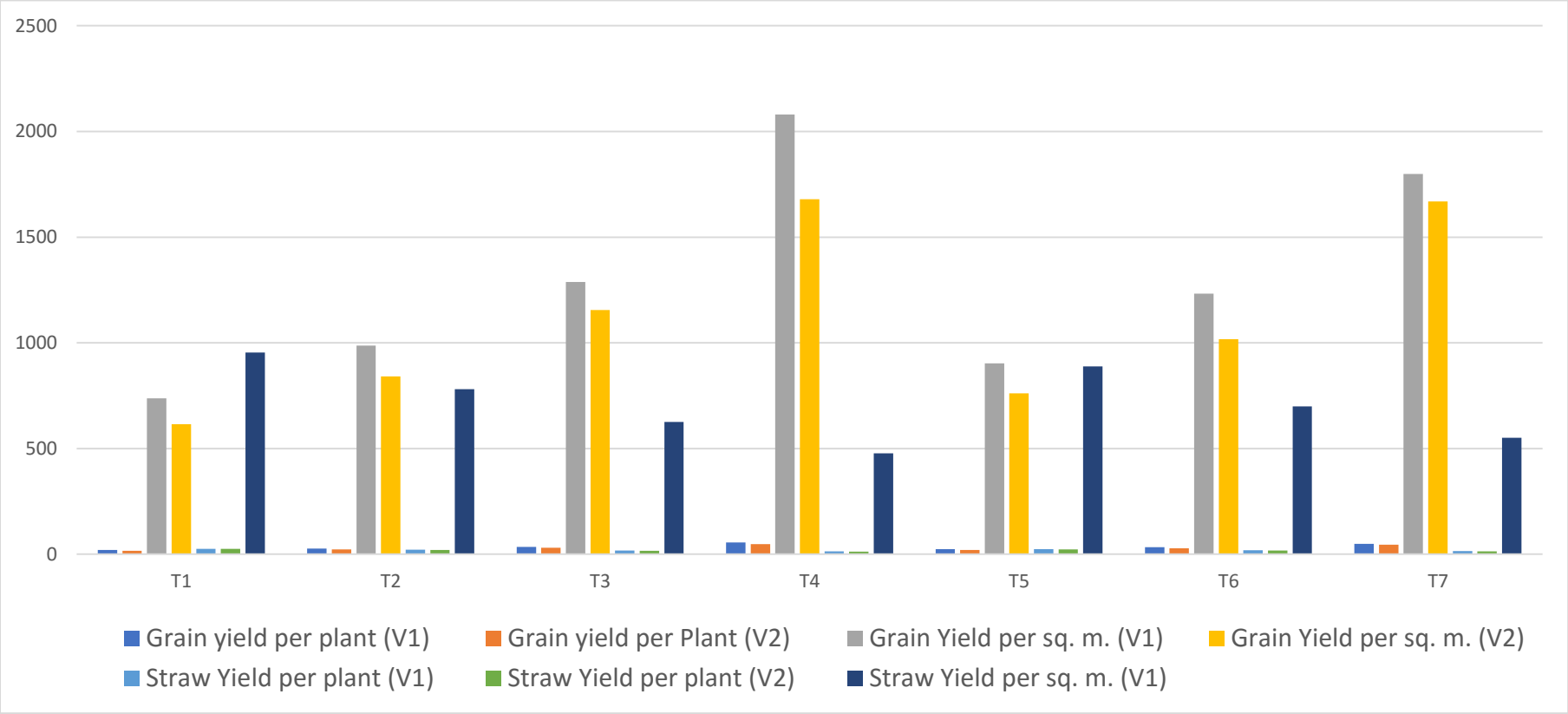
Table 4.5.6: Effect of sorbitol and mannitol on grain yield plant^{-1} (g), grain yield m^{-2} (g), straw yield plant^{-1} (g) and straw yield m^{-2} (g) at various growth stages of rice under salinity stress

Treatments	Grain yield plant^{-1}			Grain yield m^{-2}			Straw yield plant^{-1}			Straw yield m^{-2}		
	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN	V1	V2	MEAN
T1	19.94	16.62	**18.28**	737.79	615.09	**676.44**	25.8	24.9	**25.4**	954.6	921.3	**937.95**
T2	26.66	22.75	**24.70**	986.54	841.62	**914.08**	21.1	19.8	**20.5**	780.7	732.6	**756.65**
T3	34.80	31.23	**33.01**	1287.66	1155.37	**1221.52**	16.9	15.9	**16.4**	625.3	588.3	**606.8**
T4	56.22	47.40	**51.81**	2080.03	1679.98	**1880.00**	12.9	11.8	**12.3**	477.3	436.6	**456.95**
T5	24.41	20.58	**22.49**	903.24	761.30	**832.27**	24	22.8	**23.4**	888	843.6	**865.8**
T6	33.32	27.50	**30.41**	1233.00	1017.54	**1125.27**	18.9	17.9	**18.4**	699.3	662.3	**680.8**
T7	48.63	45.11	**46.87**	1799.17	1669.11	**1734.14**	14.9	13	**14.4**	551.3	518	**534.65**
MEAN	**34.85**	**30.17**		**1289.63**	**1105.72**		**19.21**	**18.01**		**616.34**	**675.40**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.68**	**1.98**		**6.55**	**19.03**		**0.01**	**0.04**		**0.47**	**1.35**	
Treatments	**1.27**	**3.7**		**12.25**	**35.61**		**0.02**	**0.07**		**0.87**	**2.53**	
VxT	**1.8**	**5.24**		**17.32**	**50.35**		**0.03**	**0.1**		**1.23**	**3.58**	

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR-23, V2: Sarju 52

Figure 4.5.6: Effect of sorbitol and mannitol on grain yield plant^{-1} (g), grain yield m^{-2} (g), straw yield plant^{-1} (g) and straw yield m^{-2} (g) at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR 23

V2: Sarju 52

4.5.8 Test weight (g)

The data on test weight and effect of foliar application of sorbitol and mannitol at various concentrations under salinity stress are presented in Table 4.5.8 and illustrated in Figure 4.5.8. It indicates that salinity stress had a detrimental impact on grain quality, as reflected by a significant reduction in test weight. This decline is likely due to impaired grain filling and disrupted assimilate translocation under stress, resulting in lighter and poorly developed grains (Zheng C *et al*., 2021).

The lowest test weight was observed in the control treatment-T1 (25.45 g), where plants were subjected to salinity without any osmoprotectants application. In contrast, the highest test weight (26.56 g) was recorded under T4-sorbitol@80ppm, followed closely by T7-mannitol@80ppm (26.45 g), demonstrating the effectiveness of these osmoprotectants in enhancing grain development under saline conditions. These treatments significantly outperformed the control and other treatments, underscoring their role in mitigating the adverse effects of salinity on grain weight.

Among the two cultivars, the salt susceptible variety, V2-Sarju 52 recorded a higher test weight (29.45 g) compared to the salt susceptible variety V1-CSR23 (23.66 g), indicating better grain filling capacity in this variety. However, analysis of variance indicated a significant beneficial effect (2-7%) with foliar application of osmoprotectants. The salt tolerant variety, V1- CSR 23 showed an increase of 6.38% in the test weight. Whereas, V2-Sarju 52 exhibited a 2.41% increase in test weight following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V1-CSR 23 exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7). These results align with the findings of Biswas *et al*., (2023) and Dhakal P *et al.,* (2020), who reported that salinity stress adversely affects grain weight due to poor assimilate partitioning and grain development, but the application of compatible solutes like sorbitol and mannitol can alleviate these effects.

4.5.9 Harvest index (%)

The data on harvest index and effect of foliar application of sorbitol and mannitol at various concentrations under salinity stress are presented in Table 4.5.8 and illustrated in Figure 4.5.8. It indicates that the foliar application of sorbitol@80ppm-T4 (80.70%) followed by mannitol@80ppm-T7 (77.09%) resulted in the highest harvest index. These values were significantly higher than those observed under other treatments, indicating the effectiveness

of these concentrations in improving assimilate partitioning towards economic yield under salinity stress. Whereas, the lowest value for harvest index was observed in the control treatment-T1 (41.81%), where plants were subjected to salinity without any osmoprotectants application.

Among the two cultivars evaluated, the salt tolerant variety, V1-CSR 23 (81.34%) consistently exhibited a higher harvest index compared to the salt susceptible variety, V2-Sarju 52 (80.07%). This reflects V1-CSR 23's superior capacity for maintaining reproductive efficiency under saline conditions.

Analysis of variance indicated a highly significant beneficial effect (46-50%) to foliar application of osmoprotectants. The salt tolerant variety, V2-Sarju 52 showed an increase of 50% in the harvest index. Whereas, V1-CSR 23 exhibited a 46.41% increase in harvest index following (T4) sorbitol@80ppm application as compared to the control. Notably, significant genotypic interactions were observed, with V2-Sarju 52 exhibiting a more pronounced response to sorbitol@80ppm (T4) followed by mannitol@80ppm (T7).

The improvement in harvest index under sugar alcohols treatments can be attributed to enhanced net photosynthetic efficiency, improved antioxidant enzyme activity, and accelerated scavenging of ROS. Thus, collectively supporting better carbon assimilation and translocation to reproductive sinks. These findings are in line with the reports of Devika O.S. *et al*., (2021) and Hassanein A. *et al.,* (2021), who demonstrated that the application of compatible solutes such as osmoprotectants mitigates the adverse effects of salinity on grain filling and ultimately enhances the harvest index.

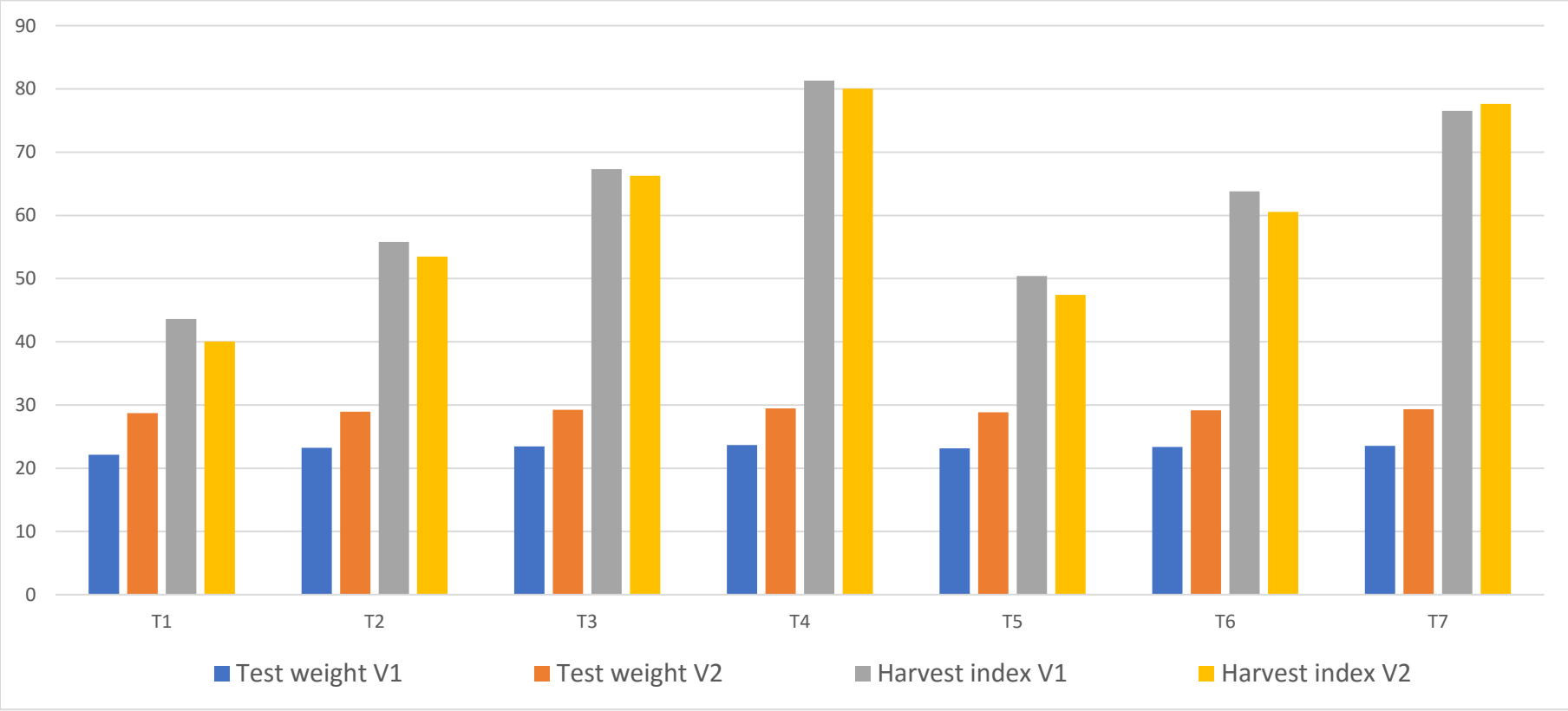
Table 4.5.8: Effect of sorbitol and mannitol on test weight (g) and harvest index (%) at various growth stages of rice under salinity stress

Treatments	Test weight			Harvest index		
	V1	V2	MEAN	V1	V2	MEAN
T1	22.15	28.74	**25.45**	43.59	40.03	**41.81**
T2	23.25	28.95	**26.10**	55.82	53.47	**54.64**
T3	23.45	29.25	**26.35**	67.31	66.26	**66.79**
T4	23.66	29.45	**26.56**	81.34	80.07	**80.70**
T5	23.15	28.85	**26.00**	50.42	47.44	**48.93**
T6	23.35	29.15	**26.25**	63.81	60.57	**62.19**
T7	23.55	29.35	**26.45**	76.55	77.63	**77.09**
MEAN	**23.22**	**29.11**		**62.69**	**60.78**	
Factors	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
Variety	**0.01**	**0.04**		**0.11**	**NS**	
Treatments	**0.01**	**0.02**		**0.2**		
VxT	**0.01**	**0.03**		**0.28**		

T1: Control, T2: Sorbitol@40ppm, T3: Sorbitol@60ppm, T4: Sorbitol@80ppm, T5: Mannitol@40ppm, T6: Mannitol@60ppm

T7: Mannitol@80ppm. V1: CSR 23, V2: Sarju 52

Figure 4.3.4: Effect of sorbitol and mannitol on test weight (gm) and harvest index (%) at various growth stages of rice under salinity stress



T1: Control T2: Sorbitol @40ppm T3: Sorbitol@60ppm T4: Sorbitol@80ppm T5: Mannitol@40ppm T6: Mannitol@60ppm

T7: Mannitol@80ppm

V1: CSR 23

V2: Sarju 52

Chapter V

SUMMARY AND CONCLUSIONS

This chapter covers the complete sum-up of experimental findings of the research work entitled "**Mitigating the adverse effect of salinity stress on rice (*Oryza sativa* L.) through osmoprotectants**". The experiment was conducted during Kharif season of 2023-24 at Plant Physiology Farm, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.). The objectives of this research work are given below:

1.To study the effect of sorbitol and mannitol on growth parameters and biochemical changes of rice under salinity stress.

2.To find out the effect of sorbitol and mannitol on yield and yield attributes of rice under salinity stress.

The treatments consisted of foliar sprays of sorbitol (40, 60 and 80 ppm) and mannitol (40, 60 and 80 ppm). An untreated control set was also maintained. The results obtained are being summarized as under: -

1. In general, the salinity stress suppressed the growth of morphological parameters such as plant height, dry weight, tiller number plant^{-1} and root length in both varieties. Accordingly, the visible effects were seen in the control treatment and the extent of suppression were varied. Eventually, the maximum plant height, tiller number, root length, and total dry biomass were observed in plants treated with foliar application of sorbitol@80 ppm (T4), followed by mannitol@80 ppm (T7). The salt-tolerant genotype, V1-CSR 23, demonstrated significantly superior performance in terms of morphological parameters. However, the salt-sensitive cultivar, V2-Sarju 52, also exhibited measurable improvements in morphological traits mainly in plant height and root length with an increase of 5.94% and 15.23 % at 45 DAT respectively, over control following osmoprotectants application.

2.Salinity stress significantly delayed phenological progression mainly days taken 50% flowering and days taken physiological maturity in both rice cultivars. Accordingly, the visible effects were seen in the control treatment and the extent of suppression were varied. However, foliar application of sorbitol@80ppm (T4) followed by mannitol@80ppm (T7)

effectively alleviated the adverse effects of salinity, as reflected in improved phenological development in both V1-CSR 23 and V2-Sarju 52. Moreover, a pronounced effect was observed in the salt-tolerant variety, V1- CSR 23 with a decrease of 5.05% and 3.43% over control in days taken 50% flowering and days taken physiological maturity.

3. The salinity stress significantly suppressed key biochemical activities in both the varieties as visible in the control treatment. But, the application of osmoprotectants significantly enhanced the biochemical activity in both rice genotypes. These included elevated levels of photosynthetic pigments (chl. a, b, and total chlorophyll), Total Soluble Carbohydrates (TSC), Nitrate Reductase (NR) activity, Superoxide Dismutase (SOD) activity, and optimized Na□ and K□ ion balance in leaf tissues. An enhanced effect was observed in V1-CSR 23 than V2-Sarju 52 over control in the treatment (T4)sorbitol@80ppm. However, the magnitude of improvement was consistently greater in V2-Sarju 52, reaffirming its superior biochemical adaptability in chl. a (25% at physiological maturity), chl. b (50% at physiological maturity), K^+ ion content (6.59% at 75 DAT and 7.91% at physiological maturity), NR activity (45.71% at physiological maturity), TSC (51.51% at physiological maturity) and SOD activity (38.35% at 75 DAT) over control under salt stress conditions.

4. A detrimental effect of salinity stress was observed in Relative Water Content (RWC), a critical physiological marker of plant water status as visible through the control treatment. But eventually, it was significantly enhanced under foliar application of sorbitol@80ppm (T4) followed by mannitol@80ppm (T7) in both genotypes. Overall, V1-CSR 23 maintained a consistently higher RWC compared to V2-Sarju 52, indicating greater osmotic adjustment and water retention capacity under salinity stress. Nevertheless, Sarju 52 expressed highly significant results at 75 DAT and physiological maturity with an increase of 6.57% and 6.99% respectively over control.

5. Lastly, yield and yield contributing parameters including panicle length, number of panicle-bearing tillers, number of fertile grains $panicle^{-1}$, fertility %, total grains $panicle^{-1}$, grain yield $plant^{-1}$ and m^{-2}, straw yield $plant^{-1}$ and m^{-2}, test weight, and harvest index were all negatively supressed by the harmful effect of salinity stress. However, the osmoprotectants positively influenced them with foliar application of sorbitol@80ppm(T4) followed by mannitol@80ppm (T7). Importantly, a reduction in the number of sterile grains and sterility percentage was also observed, indicating improved reproductive efficiency.

6. Ultimately, V1-CSR 23 exhibited superior agronomic performance compared to V2- Sarju 52. Key metrics in which V1-CSR 23 indicated a positive response included panicle length (26.10 cm), panicle-bearing tillers (15.7), total grains panicle^{-1} (207.89), number of fertile grains (151.34), fertility % (72.80%), grain yield plant^{-1}(56.22 g), and m^{-2} (2080.03 g), straw yield plant^{-1} (12.9 g) and m^{-2} (477.3 g). In contrast, V2-Sarju 52 recorded 24.52 cm, 13.82, 186.11, 120.45, 64.72%, 47.40 g, 1679.98 g, 12.9 gm and 436.6 g respectively. However, V2-Sarju 52 produced more sterile grains (65.67) and exhibited a higher sterility % (35.28%) relative to V1-CSR 23 (56.56 and 27.20% respectively). Regardless, V2-Sarju 52 exhibited statistically highly significant results in panicle bearing tillers plant^{-1}(55.79%) number of fertile grains (21.40%), fertility% (11.34%), straw yield plant^{-1} and m^{-2} (111%) as compared over control.

7. The salt-sensitive variety, V2-Sarju 52 recorded a higher test weight (29.45 g) than V1-CSR 23 (23.66 g). However, V1-CSR 23 displayed a superior harvest index (81.34%) compared to V2-Sarju 52 (80.07%), highlighting more efficient assimilate partitioning towards grain production in the tolerant genotype. But eventually, V2-Sarju 52 exhibited highly significant results statistically in terms of harvest index (50%) as compared over control.

CONCLUSIONS

The current study highlights that foliar application of sugar alcohols can substantially alleviate the detrimental effects of salinity stress. Thereby, contributing to improved crop performance and yield stability under saline conditions. The foliar application of sorbitol@80ppm (T4) followed by mannitol@80ppm (T7) under salinity stress conditions demonstrated a significant positive impact on the physiological, morphological, biochemical, and phenological traits of rice. Ultimately, leading to improved yield and varietal performance.

Overall, CSR 23 (V1) recorded higher panicle length, grain number, test weight, and harvest index, supported by its stronger vegetative growth and stress-buffering mechanisms. Whereas, Sarju 52 (V2) showed significant improvements in panicle-bearing tillers, fertile grains, fertility percentage, straw yield, and assimilate production efficiency under osmoprotectants support. Importantly, in V1-CSR 23, a clear reduction in the number of sterile grains and overall sterility percentage was observed. This directly contributed to its

enhanced grain yield and harvest index. These reductions reflect better reproductive success and stress resilience during flowering and grain filling stages.

While both genotypes benefitted from osmoprotectants application, the salt-sensitive variety, V2-Sarju 52 exhibited greater physiological strength in response to treatments. This suggests a greater scope for osmoprotectants mediated amelioration in genotypes inherently more susceptible to salinity stress. The coordinated improvements across morphological, biochemical, and reproductive traits underscore the effectiveness of sugar alcohols in enhancing yield stability under salinity. Thus, highlighting their potential integration into varietal management strategies for rice production. However, these findings suggest further validation under varied agro-climatic conditions and across multiple genotypic backgrounds to confirm their broader applicability.

Chapter VI

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DEPARTMENT OF PLANT PHYSIOLOGY

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Thesis title: "Mitigating the adverse effect of salinity stress on rice (*Oryza sativa* L.) through osmoprotectants"

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ABSTRACT

A field study titled "**Mitigating the adverse effect of salinity stress on rice (*Oryza sativa* L.) through osmoprotectants**" was conducted during Kharif 2023-24 at the Plant Physiology Farm, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, 224229 (U.P.), using a Factorial Randomized Block Design with three replications. Seven treatments involving foliar sprays of sorbitol and mannitol at varying concentrations (40, 60, and 80 ppm) and a control were evaluated on two rice genotypes *viz.*, V1-CSR 23 (salt-tolerant) and V2-Sarju 52 (salt-susceptible). Observations on morphology physiology, phenological, biochemical, and yield and yield attributing traits were recorded at 30, 45, 75 DAT and at physiological maturity. Overall, sorbitol@80 ppm (T4), followed by mannitol@80 ppm (T7), significantly enhanced morphological parameters including plant height, number of tillers plant^{-1}, root length, dry matter accumulation. An improvement in the phenological advancement mainly days taken 50% flowering and physiological maturity was also observed under salinity stress. The osmoprotectants treatments improved biochemical characters viz., photosynthetic pigments (chlorophyll a, b and total chlorophyll content), Total Soluble Carbohydrates (TSC), Nitrate Reductase (NR) activity, Superoxide Dismutase (SOD) activity, and Na /K content. An improvement in physiological character i.e., Relative Water Content (RWC) was also observed. Yield components including panicle length, number of panicle-bearing tillers, number of fertile grains panicle^{-1}, fertility percentage, number of sterile grains panicle^{-1}, sterility percentage, total grains

panicle^{-1}, grain yield & straw yield (plant^{-1} and m^{-2}), test weight, and harvest index were all positively influenced by foliar application of sorbitol@80ppm (T4) followed by mannitol@80ppm (T7). Overall, V2-Sarju 52 exhibited significant improvement as compared to V1-CSR 23, indicating greater ameliorative potential in sensitive genotypes. These results affirm the role of polyols in conferring salinity tolerance and require a broader validation across genotypes and agro-climatic zones.

Keywords: DAT, ppm, sorbitol, mannitol, salinity stress

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पादप कार्यिकी विभाग

आचार्य नरेंद्र देव कृषि एवं प्रौद्योगिकी विश्वविद्यालय,

कुमारगंज, अयोध्या- 224249 (उत्तर प्रदेश)

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सेमेस्टर: चतुर्थ

डिग्री: परास्नातक कृषि

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प्रमुख विषय: पादप कार्यिकी

लघु विषय: मृदा विज्ञान और कृषि रसायन विज्ञान

थीसिस का शीर्षक: "ऑस्मोरप्रोटेक्टेंट्स के माध्यम से चावल (*Oryza Sativa* L.) पर लवणता तनाव के प्रतिकूल प्रभाव को कम करना।

प्रमुख सलाहकार और अध्यक्ष: डॉ. ए.के. सिंह (प्राध्यापक)

सारांश

अभ्यास का शीर्षक **"ऑस्मोरप्रोटेक्टेंट्स के माध्यम से चावल (*Oryza Sativa* L.) पर लवणता तनाव के प्रतिकूल प्रभाव को कम करना।"** विषय पर एक क्षेत्रीय अध्ययन खरीफ २०२३-२४ के दौरान आचार्य नरेंद्र देव कृषि एवं प्रौद्योगिक विश्वविद्यालय, अयोध्या (उ.प्र.) के फसल कार्यिकी खेत पर किया गया। यह प्रयोग कारकात्मक यादृच्छिक पूर्ण खंड विधि (Factorial Randomized Block Design) के अंतर्गत तीन पुनरावृत्तियों के साथ संपन्न किया गया। अध्ययन में सोर्बिटोल एवं मैनिटोल के विभिन्न सांद्रणों (40, 60 एवं 80 पीपीएम) के पत्तियों पर छिड़काव तथा एक नियंत्रण उपचार सहित कुल सात उपचारों का मूल्यांकन किया गया। इनका परीक्षण दो धान की किस्मों- CSR 23 (लवण सहिष्णु) और सरजू 52 (लवण-संवेदनशील) पर किया गया। पौधों की आकृति विज्ञान, शरीर क्रिया विज्ञान, जैव रासायनिक एवं उपज से संबंधित गुणों का अवलोकन 30, 45, 75 दिनों की आयु पर तथा शारीरिक परिपक्वता की अवस्था पर किया गया। सोर्बिटोल@80 पीपीएम, इसके पश्चात मैनिटोल@80 पीपीएम के प्रयोग से पौध की ऊंचाई, प्रशाखा संख्या, जड़ विकास, शुष्क द्रव्यमान संचय एवं जैविक घटनाओं की प्रगति में उल्लेखनीय सुधार देखा गया। ओस्मोप्रोटेक्टेंट उपचारों ने जैव रासायनिक विशेषताओं जैसे हरितलवक की मात्रा, कुल घुलनशील शर्करा (TSC), नाइट्रेट रिडक्टेज (NR) क्रियाशीलता, सुपरऑक्साइड डिसम्यूटेज (SOD) क्रियाशीलता एवं

Na□/K□ अनुपात में भी सुधार किया। इसके अतिरिक्त, शरीर क्रियात्मक गुण जैसे सापेक्ष जल की मात्रा (Relative Water Content-RWC) में भी सुधार दर्ज किया गया। उपज घटकों जैसे कि बाली की लंबाई, बाली-धारण करने वाले प्रशाखा की संख्या, प्रति बाली उर्वर दानों की संख्या, उर्वरता प्रतिशत, बाँझ दानों की संख्या, बाँझता प्रतिशत, कुल दानों की संख्या, प्रति पौधा एवं प्रति वर्ग मीटर दाने एवं पुआल की उपज, परीक्षण भार तथा कटाई सूचकांक (Harvest Index) पर भी सोर्बिटोल @80 पीपीएम तथा इसके पश्चात मैनिटोल @80 पीपीएम के फोलियर प्रयोग का सकारात्मक प्रभाव पड़ा। यद्यपि CSR 23 ने समग्र रूप से बेहतर प्रदर्शन किया, परंतु सरजू 52 में तुलनात्मक रूप से अधिक सुधार देखा गया, जिससे यह संकेत मिलता है कि संवेदनशील किस्मों में ओस्मोप्रोटेक्टेंट्स के प्रयोग से पौध वृद्धि एवं उपज प्राप्त किया जा सकती है। इस अध्ययन से यह प्रमाणित होता है कि पॉलीओल्स लवणीय तनाव सहिष्णुता को बढ़ाने में महत्वपूर्ण भूमिका निभाते हैं, जिसकी पुष्टि विभिन्न किस्मों एवं कृषि-जलवायु क्षेत्रों में विस्तृत परीक्षणों द्वारा की जानी चाहिए

मुख्य शब्द: DAT, ppm, सोर्बिटोल, मैनिटोल, लवणता तनाव

(डॉ. ए.के. सिंह)

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