ISSN (E): 2583 – 0821

Sun. Agri.:e- Newsletter, (2025) 5(12), 79-82

Article ID: 498

Osmoprotectants: The Natural Mechanism Helping Plants Thrive in High Heat and Drought

Anshuman Singh[1], Ashutosh Sharma[2], Chander Mohan[3*], Vikram Singh Gaur[4], Chandu Singh[5], Rakesh Kumar[2]

[1]ICAR–IASRI, New Delhi
[2]RLB Central Agricultural University, Jhansi, U.P., India
[3]ICAR-IIMR, Regional Maize Research and SPC, Begusarai, Bihar, India
[4]College of Agriculture, Balaghat, JNKVV, Jabalpur, M.P., India
[5]ICAR–IASRI, New Delhi

Open Access

*Corresponding Author
Chander Mohan*

Available online at
www.sunshineagriculture.vitalbiotech.org

Article History
Received: 1. 12.2025
Revised: 5. 12.2025
Accepted: 10. 12.2025

INTRODUCTION

1. The Silent Crisis in the Plant Cell

Imagine a summer day when the sun is relentless and the soil is cracked and dry. For a plant, such conditions represent a life-or-death challenge. Elevated temperatures cause proteins to lose their structural integrity through denaturation, while water scarcity leads to severe cellular dehydration, ultimately resulting in wilting and growth inhibition. Globally, these combined stresses collectively referred to as abiotic stresses are the primary limiting factors for crop productivity. To survive under such hostile conditions, many plant species have evolved a sophisticated internal defense strategy: the synthesis and accumulation of osmoprotectants. Osmoprotectants are compound naturally synthesized in the plants are no directly involved in the growth and development but provide strength to the plants for survival under acute environmental condition. These compounds function as a biochemical emergency system, enabling plants to sustain vital cellular processes even when water availability is severely limited. Impact of drought and high temperature stress on plant cells leading to osmoprotectant (proline, glycine betaine, sugars and polyols) accumulation. Some plant chaperons like heat-sock proteins may also helpful in the survival under long-term water deficit condition and high temperature stress. These compounds contribute to osmotic adjustment, stabilization of proteins and membranes and enhanced plant stress tolerance.

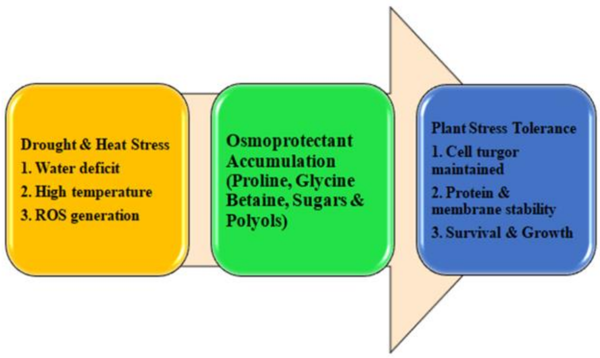

Figure-1: Role of osmoprotectants in plant tolerance to drought and heat stress

ISSN (E): 2583 – 0821

2. The Mechanics of Osmoprotection

Osmoprotectants are small, highly soluble organic molecules that play a crucial role in cellular stress tolerance. They remain electrically neutral at the physiological pH of the cell, which allows them to accumulate in large amounts without interfering with enzyme activity or metabolic pathways. Because of their non-toxic and metabolically compatible nature, osmoprotectants do not disrupt protein structure, membrane function, or cellular signaling, even at high intracellular concentrations. For this reason, they are referred to as "compatible solutes." By contributing to osmotic balance and stabilizing macromolecules, osmoprotectants help cells maintain normal physiological functions during environmental stresses such as drought, salinity, and high temperature. The protective role of osmoprotectants is primarily achieved through two interrelated mechanisms.

Class	Example compound	Primary role
Amino Acids	Proline	Most common, highly effective at stabilizing proteins and scavenging ROS.
Betaines	Glycine Betaine	Excellent membrane and enzyme stabilizer, widely used in research.
Sugars/Polyols	Trehalose, Mannitol	Acts as an energy source stabilizes cell membranes during desiccation.

Table-1: Major classes of plant osmoprotectants and their primary functions under abiotic stress

3. Osmotic Adjustment

Plant cells maintain their rigidity and functional integrity through turgor pressure, which is generated by the inward pressure of water against the cell wall. Under drought conditions, depletion of soil moisture lowers external water potential, causing water to move out of plant cells. This loss of water results in reduced turgor pressure and eventual wilting. Osmoprotectants, like the amino acid Proline and the quaternary ammonium compound Glycine Betaine (GB), work by increasing the concentration of solutes inside the cell. This makes the cell's internal environment "saltier" than its surroundings, causing water to be drawn *into* or *retained* within the cell. This osmotic adjustment is crucial for:

3.1. Maintaining Turgor: Keeping the cell plump, this is necessary for growth processes like cell expansion and for keeping the leaves open to capture sunlight.

3.2. Nutrient Flow: Ensuring the internal water-based transport systems remain functional.

4. The Bodyguard: Protection of Cellular Machinery

High temperature and water deficit promote the formation of reactive oxygen species, which can damage proteins, membranes and other cellular components. Stress conditions also cause enzymes and structural proteins to lose their functional conformation. Osmoprotectants act as molecular chaperones by accumulating around proteins and membrane surfaces, forming a stabilizing hydration layer. This protective environment helps preserve protein structure, maintain enzyme activity and stabilize cellular membranes. In particular, osmoprotectants protect the membranes of chloroplasts and mitochondria, thereby supporting photosynthesis and energy metabolism under stress conditions.

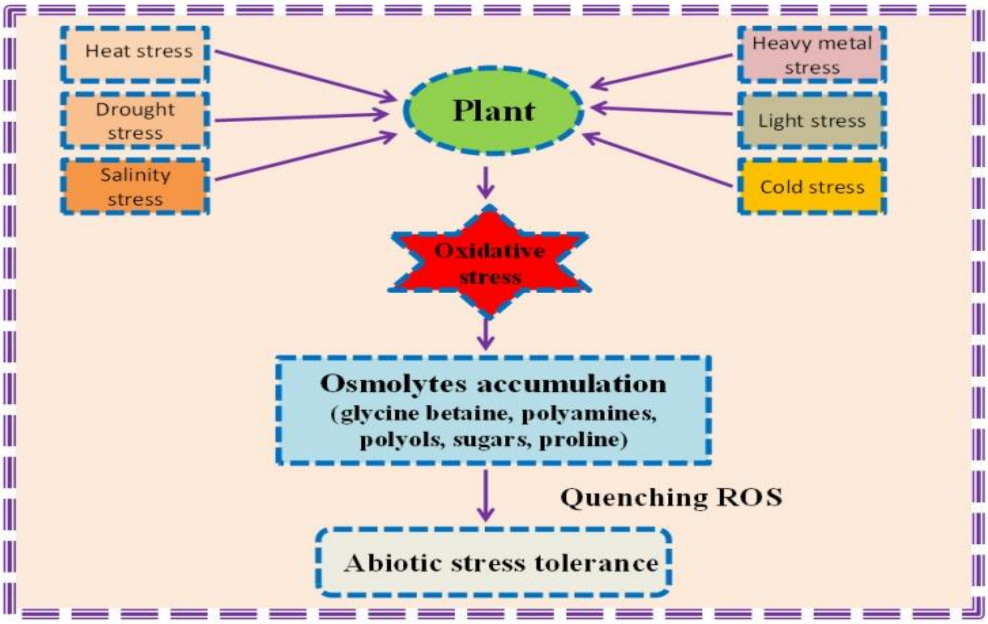

Figure-2: Schematic representation of plant response to abiotic stress and the role of compatible osmolytes (osmoprotectants)

5. The Future of Farming: Bioengineering Resilience

Advances in the understanding of osmoprotectant-mediated stress tolerance have significantly expanded the toolkit available for developing resilient agricultural systems under changing climatic conditions. Osmoprotectants such as proline and glycine betaine play central roles in protecting plants from drought, heat, and salinity stress by stabilizing proteins, membranes, and cellular structures, as well as by maintaining osmotic balance and redox homeostasis. The identification and characterization of key genes involved in their biosynthesis, including P5CS for proline and BADH and CMO for glycine betaine, have enabled targeted genetic interventions in major cereal crops such as wheat, rice, and maize.

Through conventional breeding, marker-assisted selection, and modern biotechnological approaches such as transgenic expression and genome editing, it is now possible to enhance the endogenous accumulation of osmoprotectants in crops. These strategies aim to produce climate-smart varieties capable of rapidly activating osmoprotectant biosynthesis in response to environmental stress signals. Such crops show improved photosynthetic efficiency, enhanced antioxidant capacity, and greater yield stability under water-limited and high-temperature conditions. Importantly, inducible or stress-responsive promoters are being employed to ensure that osmoprotectant production is tightly regulated, minimizing metabolic costs under non-stress conditions. Beyond genetic strategies, exogenous application of osmoprotectants represents a complementary and practical approach for improving stress tolerance, particularly in regions where access to improved cultivars may be limited. Foliar sprays containing proline, glycine betaine, or compatible solutes such as trehalose have been shown to enhance water-use efficiency, protect photosynthetic machinery, and reduce oxidative damage during episodes of drought or heat stress. This approach is especially valuable in stress-prone agro-ecosystems, where extreme weather events can be predicted but not avoided. Together, genetic enhancement and exogenous application of osmoprotectants offer integrated solutions for sustainable crop production. By combining molecular advances with field-level management

ISSN (E): 2583 – 0821

practices, agriculture can better adapt to climate variability, ensuring food security while reducing vulnerability to environmental stressors.

CONCLUSION

Osmoprotectants represent far more than passive stress-related metabolites; they reflect the evolutionary ingenuity of plants in adapting to hostile environments. By contributing to osmotic adjustment and acting as molecular stabilizers, osmoprotectants protect proteins, membranes, and organelles from damage caused by drought and high temperature stress. Their ability to maintain cellular hydration, enzyme functionality, and membrane integrity allows essential metabolic processes to continue under adverse conditions. As climate change intensifies the frequency of heat waves and water scarcity, understanding and utilizing osmoprotectant-based mechanisms becomes increasingly important. Harnessing these natural protective strategies through breeding, biotechnology, and agronomic practices offers a sustainable approach to enhancing crop resilience, stabilizing yields, and safeguarding global food security in an uncertain environmental future.

REFERENCES

Ashraf, M. and Foolad, M.R. (2007). Roles of glycine betaine and proline in improving plant abiotic stress resistance. *Environmental and Experimental Botany*, 59(2), pp.206–216.

Bartels, D. and Sunkar, R. (2005). Drought and salt tolerance in plants. *Critical Reviews in Plant Sciences*, 24(1), pp.23–58.

Farooq, M., Wahid, A., Kobayashi, N., Fujita, D. and Basra, S.M.A. (2009). Plant drought stress: effects, mechanisms and management. *Agronomy for Sustainable Development*, 29, pp.185–212.

Hasegawa, P.M., Bressan, R.A., Zhu, J.K. and Bohnert, H.J. (2000).Plant cellular and molecular responses to high salinity. *Annual Review of Plant Physiology and Plant Molecular Biology*, 51, pp.463–499.

Hayat, S., Hayat, Q., Alyemeni, M.N., Wani, A.S., Pichtel, J. and Ahmad, A. (2012). Role of proline under changing environments. *Plant Signalling & Behavior*, 7(11), pp.1456–1466.

Krasensky, J. and Jonak, C. (2012). Drought, salt and temperature stress-induced metabolic rearrangements and regulatory networks. Journal of Experimental Botany, 63(4), pp.1593–1608.

Serraj, R. and Sinclair, T.R. (2002).Osmolyte accumulation: can it really help increase crop yield under drought conditions? *Plant, Cell & Environment*, 25(2), pp.333–341.

Sharma, A, Shahzad, B, Kumar, V, Kohli, S.K., Sidhu, G.P.S., Bali, A.S., Handa, N, Kapoor, D, Bhardwaj, R and Zheng B. (2019). Phytohormones Regulate Accumulation of Osmolytes Under Abiotic Stress. *Biomolecules*, 9(7), p.285.

Slama, I. and Abdelly, C., Bouchereau, A., Flowers, T.J. and Savoure, A. (2015). Diversity, distribution and roles of osmoprotective compounds accumulated in halophytes under abiotic stress. *Annals of Botany*, 115(3), pp.433–447.

Szabados, L. andSavouré, A. (2010). Proline: a multifunctional amino acid. *Trends in Plant Science*, 15(2), pp.89–97.

Verslues, P.E., Agarwal, M., Katiyar-Agarwal, S., Zhu, J. and Zhu, J.K. (2006). Methods and concepts in quantifying resistance to drought, salt and freezing. *Plant Journal*, 45(4), pp.523–539.

Yancey, P.H. (2005). Organic osmolytes as compatible, metabolic and counteracting cytoprotectants in high osmolarity and other stresses. *Journal of Experimental Biology*, 208, pp.2819–2830.

