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OSMOTIC ADJUSTMENT AND DROUGHT RESISTANCE OF WHEAT (*TRITICUM AES*TIVUM L.) - A SHORT REVIEW

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Abstract

Drought is the most limiting environmental factor affecting wheat growth and productivity and thus, breeding for drought tolerance is a main objective for cereal breeders. Progress in drought tolerance breeding of wheat depends upon genetic diversity existing among genotypes about of their responses to different stressors. One of the physiological parameter is the osmotic adjustment can be enhanced through selection and breeding. Osmotic adjustment is the only cellular process that is activated under water stress conditions and that makes it possible to maintain cellular turgor.
This study presents some physiological patterns in wheat plants under drought condition, with focus on osmotic adjustment. The used methods included searching of databases, such as Web of Science or Google Scholar, in order to identify relevant results.
Crop plants synthesize several osmolytes to provide osmotic balance at the cellular level, and those osmolytes, under drought stress, provide the plants' osmotic adjustment. Osmotic adjustment is critical for regulating cell turgor for the maintenance of plant metabolic activity, growth, and productivity. Generally, drought tolerant wheat genotypes show a clear response towards osmotic adjustment. This indicates the key role that osmotic adjustment plays in drought tolerance and yield sustainability under drought stress.

***Key words**: wheat, drought, osmotic adjustment, yield*

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most significant cereal crops grown in the semi-arid and temperate regions of the world. Globally, wheat is contributing to 20% of the caloric and protein intake of human population (Cosgrove, 2021). Wheat is very important as a food product, providing a large part of the carbohydrates and proteins needed by humans and representing more than half of the calories consumed by mankind. The forms in which wheat is used in human nutrition are very diverse, the most widespread being bread (Ișlicaru et al., 2021).

Since ancient times, wheat has been used, more than any other plant, in human nutrition throughout its entire history. Wheat bran is particularly valuable forage for dairy cows due to its richness in crude protein and carbohydrates (Cola and Cola, 2020, 2019 a, 2019 b).

Alongside climate impact, a range of regional and global political and economic factors intensify food insecurity and long term vulnerability in certain regions (Bonciu et al, 2021a). All over the world, multi-annual studies have been carried out on the adaptability and stability of cereals (Roșculete et al., 2021).

Nowadays, one of the negative effects of climate change on natural vegetation and cereal crops are changes in landscape features and exacerbating the attack of pathogens and pests with impact on environment and yields (Paraschivu et al., 2015; Cotuna et al., 2021; Sărățeanu et al., 2023). Also, climate change may affect the multi-disease resistance (MDR) in wheat and grains quality due to some pathogens able to produce toxic metabolites (Cotuna et al., 2022 a, b; Păunescu et al., 2022).

Drought affects 60% of the wheat production in high-income countries and 30% in least developed countries (Ahmad et al., 2018). To keep up with the demand, modern strategies need to be developed to increase wheat yield under this changing environment (Bonciu et al., 2021 b; Hunter et al., 2017; Verbeke et al., 2022).

Droughts create a shortage of water that can affect all parts of life, but has the greatest impact on agricultural production. Modern biotechnology has a significant potential to contribute to food security and sustainable development (De Souza and Bonciu, 2022 a, b).

Wheat is remarkably adaptable, but drought conditions mean bad news for this harvest - and the next. Thus, drought affects wheat differently depending on the growth stage (Paunescu et al., 2021; Tatar et al., 2016).

The plasma membrane is the protective cell membrane found on the cell's exterior. Their function is to protect the cells' inner material from the outside environment. The plasma membrane is made up of a semi-permeable lipid bilayer (Alberts et. al., 2002).

Plants accumulate sufficient solutes to match, in osmolarity, the increased ion concentrations in the soil solution. This osmotic adjustment maintains cell turgor and the volume of organelles within the cells of the growing plant (Munns et al., 2019).

Osmotic adjustment, in particular, plays a key role in plant resistance to high salt and drought stress conditions, especially when causing severe osmotic stress, through the accumulation of low molecular weight solutes and inorganic ions that reduce the osmotic potential of the tissues (Munns et al., 2020).

Osmotic adjustment is the only cellular process that is activated under water stress conditions and that makes it possible to maintain cellular turgor. Turgor is what makes living plant tissue rigid. Loss of turgor, resulting from the loss of water from plant cells, causes flowers and leaves to wilt. Turgor plays a key role in the opening and closing of stomata in leaves.

Some results show a positive correlation among plant yield and osmotic adjustment in wheat, this being a key indicator to screen the wheat genotypes against drought stress (Mahmood et al., 2020).

MATERIALS AND METHODS

The main objective of this short review was the present some physiological patterns in wheat plants under drought condition, with focus on osmotic adjustment. The used methods included searching of databases like Web of Science or Google Scholar, in order to identify relevant results.

RESULTS AND DISCUSSIONS

Drought is effectively one of the most destructive natural disasters in terms of loss of life resulting from its consequences such as widespread crop failure, wildfires and water stress. Exacerbated by land degradation and climate change, droughts are increasing in frequency and severity by 29% since 2000, affecting 55 million people each year. Experts warn that by 2050, droughts may harm approximately three quarters of the world's population (Figure 1) (Vogt et al., 2018).

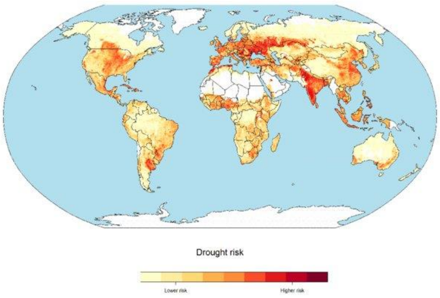

Figure 1. Drought Risk based on the risk components (Vogt et al., 2018)

There is a necessity to understand the physiology more in depth and how this physiology is impacted by drought stress (Verbeke et al., 2022).

According to the current concept, cell membranes are formed by a phospholipid bilayer and proteins. The essential characteristic of membranes is the maintenance of membrane fluidity, the loss of which is at the expense of functionality. Thus, the loss of water leads to structural changes of the phospholipid bilayer, but also of the membrane protein fraction. Serious dehydration of the cells leads to the appearance of lipid droplets in the cytoplasm, which can disappear once they are rehydrated. Remarkable metabolic engineering efforts have demonstrated the plasticity of vegetative tissues such as leaves to synthesize and package large amounts of storage lipids, which enable future applications in bioenergy and the engineering of high-value lipophilic compounds (Guzha et al., 2023).

The declining availability of land and water has a negative effect on cereal value chains. The water potential is the resultant of component potentials, the most important of which are two opposing ones, namely the turgor and the osmotic potential. In soil, the water retention curve describes the relation between soil water content and soil water potential.

Differences in the capacity of osmotic adjustment between genotypes have been observed by Zivcak et al. (2009). Climate changes entail increased temperatures, and not only drought events. The combined effects of these abiotic stresses have been studied in wheat (Asseng et al., 2015; Kadam et al., 2014).

The water relations parameters involved in assimilated flow in wheat (*Triticum aestivum* L.) grains were measured by Fisher and Cash-Clark (2000) at several points from the flag leaf to the endosperm cavity in normally and water-stressed plants. Their results show the importance of the sieve tube unloading step in the control of assimilates import.

In a recent study, Verbeke et al. (2022) assess the physiology, and more particular the osmotic adjustment, of a drought sensitive wheat cultivar experiencing both pre- and post-anthesis drought. The relative water content clearly influenced the osmotic potential (Figure 2).

The authors suggest that, under drought, sugars are being concentrated to preserve leaf functioning (Verbeke et al., 2022).

Before anthesis, rewatering restored the xylem and osmotic potential quickly. After anthesis, the osmotic potential was not completely recovered in the stem and flag leaf and remained low for longer. Also, the water flow is prioritized to the flag leaf at the expense of the stem water reserves (Verbeke et al., 2022).

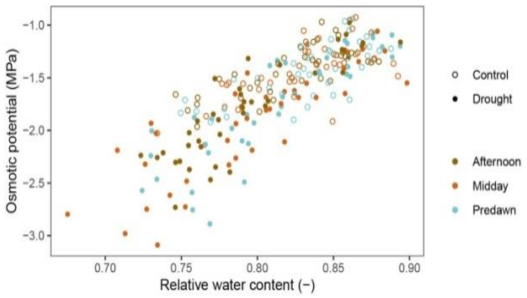

Figure 2. Relation between the osmotic potential and relative water content in the stems of wheat (Verbeke et al., 2022)

After anthesis, the wheat plants thus maintain a high sugar content in the stem. This allows the plants to maintain turgor. Bramley et al. (2015) also showed that wheat is able to preserve stem turgor under drought, even better than in the flag leaf. The authors attributed this to osmoregulation with the ultimate goal of directing water predominantly to the flag leaf.

Energy-efficient osmotic adjustment requires use of Na^+ and Cl^- in vacuoles, and of K^+ and compatible organic solutes in the cytoplasm (Munns et al., 2020).

Potential of drought tolerance in some wheat genotypes were explored by Mahmood et al. (2020) under drought and well-watered conditions. The results reported by authors show a considerable variation for an osmotic adjustment and yield components, coupled with genotype and environment interaction. Also, reduction in yield per plant, thousand kernel weight, and induction of osmotic adjustment was detected (Mahmood et al., 2020).

Wheat, along with corn, rice and soybeans, are key elements in the food safety and sustainability debate. The competition of human consumption versus animal feed fuels long debates over the environmental footprints of land and water exploitation, and the greenhouse gas emissions of growing crops, and the synergies between sustainable and healthy diets.

Drought susceptibility index can help to screen more stable genotypes for drought tolerance. It has been applied to measure the stress tolerance in wheat as a useful tool for heat and drought stress (Yu et al., 2018). According to Mahmood et al. (2020), drought tolerant wheat genotypes showed responses towards osmotic adjustment in the biplot analysis (Figure 3). This indicates the key role that osmotic adjustment plays in drought tolerance and yield sustainability under drought stress.

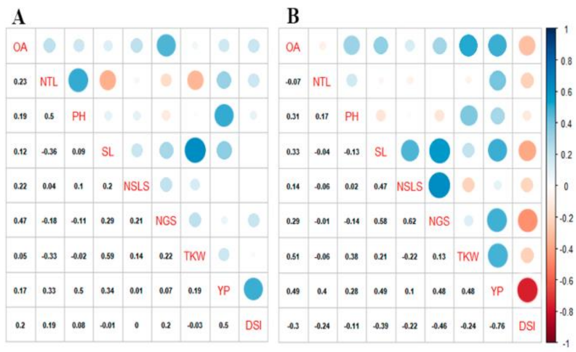

Figure 3. Correlation matrix between osmotic adjustment (OA) and yield traits. (A) = well-watered conditions; (B) = drought stress environment (Mahmood et al., 2020)

Studies undertaken by Paunescu in 2017 and published in 2023 showed that there were significant differences in terms of initial water content, water loss after 4 hours and water loss after 20 hours, between years and between varieties. The variety x year interaction is significant and indicates that the responses of the varieties were influenced by the year in which the experiment was conducted. There was no correlation between the initial water content and the water loss during the first 4 hours, the correlation coefficient being very small (r = -0.091), so it cannot be said that a variety whose initial water content is high will have a loss of water in the first 4 hours (Paunescu, 2017, 2023).

Under drought conditions, oxidative degradation products occur at the cellular level, leading to oxidative stress. Numerous experiments on the study of wheat drought resistance showed cell-based induction of enzyme oxidative stress protection systems (Păunescu et al., 2021).

Recent results (Figure 4) showed that the antioxidant enzyme activity in wheat was actively and strongly regulated by root traits; also, proline and soluble sugars were the main osmoregulatory agents in wheat under PEG and NaCl stress conditions (Fu et al., 2023).

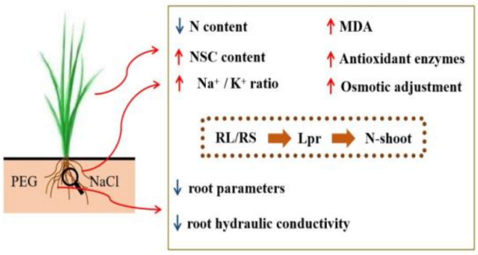

Figure 4. Response and the relation of root hydraulic conductivity and the physiological characteristics of wheat under PEG and NaCl stress (Fu et al., 2023)

Maintaining of the redox state of the cell, improving the antioxidant defence system and osmotic potential in wheat can be helped by some nutrients like phosphorus, potassium, sulphur, and sodium. Drought causes osmotic and oxidative stress in plants (Iqbal et al., 2020). Also, heat causes water scarcity, osmotic and oxidative stress to crops that enhances ROS production, protein misfolding and denaturation. On the other hand, chilling leads to osmotic and oxidative stress, nutritional imbalance. Salinity is responsible for water scarcity and ionic imbalance, osmotic and oxidative stress, restricted uptake and translocation of water and mineral nutrients, decreased stomata opening and reduced photosynthesis (Kumari et al., 2022).

The plant cuticle is found at the surface of aerial plant organs and thus represents the plants' outermost point of interaction with their environment (Würschum et al., 2020).

Osmotic adjustment is critical for regulating cell turgor for the maintenance of plant metabolic activity, growth, and finally productivity (Sharp et al., 1990). Crop plants synthesize compatible osmolytes (proline, polyamines, proteins, glycine, etc.) to provide osmotic balance at the cellular level (Taji et al., 2014). Under salinity and drought stress, those osmolytes provide the plants osmotic adjustment.

Polyethylene Glycol (PEG), a polyether compound with high molecular weight, induces osmotic stress and is helpful to investigate the effect of water limitations on plant growth. PEG can be used to adjust the osmotic potential of aqueous solutions (Jallouli et al., 2019).

CONCLUSIONS

Osmotic adjustment plays a key role in plant resistance to high salt and drought stress conditions, especially when causing severe osmotic stress, through the accumulation of low molecular weight solutes and inorganic ions that reduce the osmotic potential of the tissues.

Osmotic adjustment is critical for regulating cell turgor for the maintenance of plant metabolic activity, growth, and finally productivity.

There is a considerable variation for an osmotic adjustment and yield components in wheat, coupled with genotype and environment interaction.

Maintaining of the redox state of the cell, improving the antioxidant defence system and osmotic potential in wheat can be helped by some nutrients like phosphorus, potassium, sulphur, and sodium.

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