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RESEARCH ARTICLE

EFFECTS OF DROUGHT STRESS ON THE PHYSIOLOGY AND YIELD OF THE MAIZE: A REVIEW

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ABSTRACT

Maize is a cereal crop mainly cultivated in arid and semi-arid regions, where drought stress due to changing environment is affecting crop growth, development and yield. The aim of this literature review is to offer discourse on different physiological changes, germination and yield performance of maize under stressful environment of drought. The stressful environment due to water deficit causes a great alteration in a wide range of the physiological, biochemical and molecular process in maize which ultimately causes negative effect in yield. Drought stress influence in growth, development, yield and quality of the crop with impairment in the plant height, leaf area and biomass. A great variation in the photosynthetic process due to reduction in the photosynthetic pigments (chlorophyll a, chlorophyll b), stomatal conductance, photosystem activity, enzymes occur under water deficit condition in maize. Drought induce reduction in the soil moisture which results an unbalanced concentration of macro and micro nutrients leading to nutrient deficiency in plant. Maize is susceptible to drought during germination. Drought stress limits the germination process and early seedling growth. The severe and prolonged drought duration hampers more in reproductive stage during anthesis period than vegetative stage affecting final grain yield in maize crop.

KEYWORDS

Drought, Photosynthesis, Yield, Maize, Physiology

1. INTRODUCTION

Maize (*Zea mays L.*) a cereal crop belonging to the Poaceae family is now considered as one of the major crop contributing to food security and the most important forage crop globally. Maize is mainly cultivated in the arid and the semiarid areas (Zhang, 2004). China is the second largest maize producer in the world because the planting area of maize in china is large (Meng et al., 2013). About 60 % of the maize growing areas are subjected to heat and drought stress, which may result in 30 % yield loss per year in China. Maize serves as food and corn oil for human consumption, feed for livestock and poultry and raw material for agro based industries. Maize nutrient composition constitutes of about 10 % protein ,72 % starch, 4 % of fat, supplying an energy density of 365 Kcal/ 100g and also provides B vitamins , essential minerals along with fiber but lacks vitamin B_{12} and vitamin C and is a poor source of calcium , folate and iron (Nuss and Tanumihardjo, 2010).

Climate change is causing various environmental stress affecting plant growth and development which ultimately affects crop productivity. Plant in nature are exposed to various abiotic and biotic stress. Drought stress is one of the adverse factor of plant growth and productivity and is considered a serve threat for sustainable crop production in the condition of changing climate and to the date of today 25- 30 % yield reduction observed in some vulnerable areas. The frequent occurrence of drought has brought a great challenge to maize production (Wang et al., 2011). The changing climate pattern of world project the drought and heat stress as a major threat to maize cultivation resulting a decrease in world maize production by 15- 20 % each year (Chen et al., 2012; Fischer, 2014).

Maize is a cereal crop demanding high water requirement to complete its different stages of life cycle. Inadequate water supply at any stage induces drought stress which brings greater alteration in the morphological, physiological and biochemical activities in maize plant. Water stress affects different aspects of maize physiological metabolism, photosynthesis, vegetative growth with decrease in plant height, leaf area, ear per plant, nutrient availability and composition with slow nutrient mineralization remobilization which ultimately reduces grain yield (Earl and Davis, 2003; Zaidi et al., 2004). Maize has been reported to be very sensitive to drought throughout its growing season (Cakir, 2004). The grain yield response of maize is greatly determined by the severity and duration of the drought on the developmental stage (Ge et al., 2012). Drought effects on vegetative stage restricting on the function and structure of the leaf, stem and root while in the reproductive stage inhibits on the silk and tassel development. Although, vegetative and reproductive stage requires water, anthesis period is most critical period leading to greatest decrease in grain yield in maize. Drought stress during vegetative stage of maize production reduces yield by 25 % but during silking stage reduces grain yield by 50 % (Denmead and Shaw, 1960).

The objective of the present study aims to determine the effects of drought stress on the physiological process such as photosynthesis, germination performance, nutrient uptake and the yield of the maize crop.

2. METHODOLOGY

This paper mostly uses secondary sources of information. All the information's included in this review paper were surfed and collected different articles published in different journals, FAO reports.

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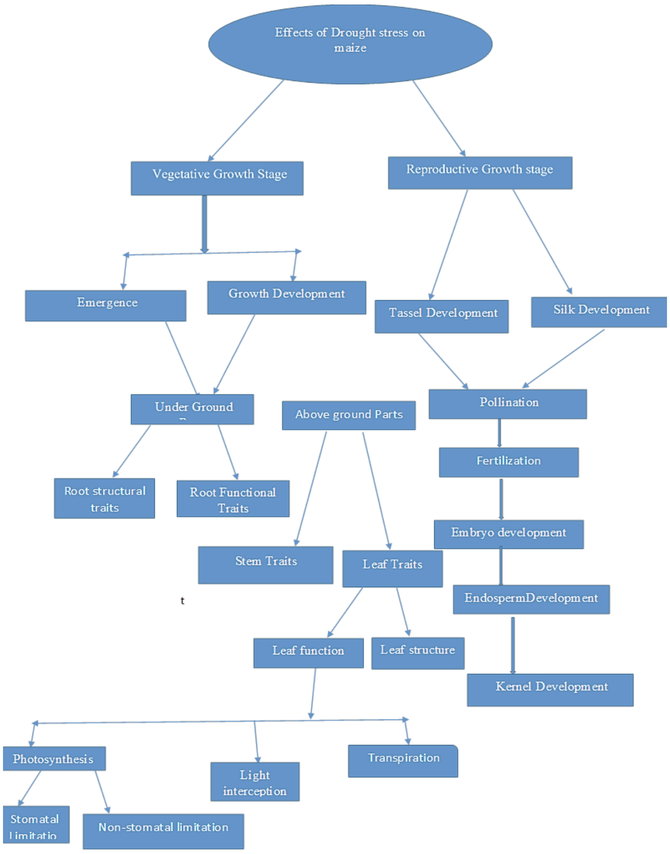

Figure 1: Effect of Drought stress on vegetative and reproductive growth stages of maize (Jain et al., 2015)

3. Result and Discussion

3.1 Physiological effects

Drought stress impairs many physiological processes. The stressful environment induced by drought brings a great alteration in physiological, biochemical and metabolic process that ultimately affect yield of maize (Zaidi et al., 2004). Photosynthesis is much more affect under drought stress. Drought causes retardation in growth, impairs relative water content and a great reduction in the chlorophyll content in the leaves (Yang et al., 2006). Alteration in nutrient uptake, root signaling, germination and seedling growth, respiration and different defense mechanism occurs as a result of prolonged drought stress in maize crop.

3.1.1 Root signaling under drought stress

Root growth response is the important parameter to check the drought stress effects as it helps to uptake nutrient and water from the shallow soil layers and support plant growth. The root length of the maize plant gets elongated under mild drought stress to uptake more water from the soil but under serve drought stress root length get reduced. The reduction in the crown root number indicates more water acquisition under water deficit stress in maize genotypes from drying soil (Gao and Lynch, 2016). Although drought stress reduces the rate of cell division in root, root growth was not largely inhibited (Sacks et al., 1997). Drought stress causes low water availability which causes increase in root: shoot ratio due to the less sensitiveness of root to shoot growth by lower water potentials (Wu and Cosgrove, 2000). Root signals different factors under drought stress. Abscisic Acid (ABA), cytokinin, ethylene, malate and other factors are used for the indication of root signaling (Ahmad et al., 2011). Obstruction in root produced cytokinin transformation from root to shoot is a signal to response in nutrient deficiency (Schachtman and Shin, 2007).

3.1.2 Nutrient Uptake

Mineral nutrients are essential for the crop growth and development. Plants generally absorb nutrients in the form of inorganic ions. Drought causes reduction in the soil moisture due to which uptake of inorganic ions on the root surface is impaired resulting in nutrient deficiency in plants (Amtmann and Blatt, 2009). This nutrient deficiency induced by drought is due the reduction in ion mobility and absorption in the soil solution. Drought stress reduces the transpiration rate and root absorption capacity which ultimately leads to reduction in nutrient uptake by the maize (Tanguilig et al., 1987). Drought reduces mineralization rate which depends on the micro-organism and enzyme activity. Decrease in the transpiration rate due to drought stress restricts the transport of nutrients from base to the shoots but the ion concentration for the macro and micro nutrients was not affected. The growing tissues are the strong sink for nutrients so nutritional changes are clearly observed in growing tissues than the non - growing tissues. A relative higher concentration of minerals is observed in growing leaves despite of reduction in relative water content under drought stress condition (Hu et al., 2007).

All the micro and macro nutrients are essential for the growth and productivity of maize. The concentration of nutrients is high in growing leaves than the matured ones but drought causes alteration in this. The ion concentration reach high at leaf base, minimum at leaf elongation zone and unchanged at the tip of leaf (A et al., 2005). N concentration is high in the growing tissue than in mature ones. So, drought induced deficiency symptoms first observed in younger leaves. An unbalanced concentration of macro nutrient N, P, K is observed in different plant parts under drought stress where N concentration was found in the order N roots >N leaves >N stem and P and K concentration is found lower in the roots than in stem and leaves for Xida 889 and Xida 319 cultivars (Hussain et al., 2019). The nutrients needed for the plants are adhered in the soil solution and uptake by plants through the roots. The nutrient availability in the soil and transport of the nutrients in the plants gets lowered under the drought stress (Hu et al., 2007).

3.1.3 Photosynthesis

The yield of the crop depends upon all the photosynthetic product produced by the crop during photosynthesis. Photosynthesis helps to fulfill the chemical energy expended in many metabolic processes by converting light energy into chemical energy but drought has damaging effect on the photosynthetic process of plant. Drought stress has a direct impact on the photosynthetic apparatus, by hampering major components of photosynthesis like the thylakoid electron transport , the carbon reduction cycle and the stomatal control of the CO_2 supply and also causes peroxidative destruction of lipids , the disturbance of water balance and increase in accumulation of carbohydrates (Allen and Ort, 2001).

The reduction in the photosynthetic activity was observed due to drought induced stomatal and non- stomatal limitations (Saibo et al., 2009; Yordanov et al., 2003). Stomata are the chief sites for transpiration and gaseous exchange. Drought stress induces stomatal closure which has a inhibitory effect on the transpiration of water and low CO_2 concentration due to reduced CO_2 diffusion through the mesophyll (Chaves et al., 2009; Flexas et al., 2007). Non-stomatal limitations such as tissue dehydration, decrease in the metabolic rate, decline in the regeneration of ribulose 1,5 – biphosphate carboxylase/oxygenase (Rubisco) and ribulose biphosphate (RuBP), decrease in rubisco activity and photophosphorylation all causes decline in photosynthesis (Tezara et al., 1999; Bota et al., 2004). A strong reduction in uptake of CO_2 due to drought stress decreases the demands for the products of the phytochemistry: ATP and NADPH (Efeoglu et al., 2009).

The photochemical activity of Photosystem II (PSII) reduces from Q_A to PQH_2 under mild drought stress while the whole electron transport chain from the donar side of PSII to PSI end electron acceptor is inhibited under severe drought stress (Liu et al., 2018). This causes poor transport of electrons through the photo systems. Photosystem II is more affected than PSI under drought stress. Water deficit stress results damage to the PS II oxygen evolving complex and inactivation of the PSII reaction centers (Lu and Zhang, 1999). The over reduction of photosynthetic electron chain or inactivation of the oxygen evolving complex results in the formation of the Relative Oxygen Species (ROS) which can lead to photo inhibition and oxidative damage (Hakala et al., 2005; Nishiyama et al., 2006). The environmental stress like drought increases the level of ROS in plants which causes protein degradation, lipid peroxidation, DNA fragmentation and ultimately cell death (Apel and Hirt, 2004).

A study reported that a reduction in net photosynthesis (33.2 %), transpiration rate (37.84 %), stomatal conductance (25.54 %), water use efficiency (50.87 %), intrisinic water use efficiency (11.58 %) and intercellular CO_2 (5.86%) under drought stress as compared to well water control in maize (Anjum et al., 2011). Drought stress not only causes damage to the phosynthetic pigments but it also leads to deterioration of thylakoid membranes due to which there is reduction in photosynthetic capacity in plants (Ahmad et al., 2011; Huseynova et al., 2009). A study observed that the chlorophyll content (a, b, a+b) in all maize cultivars

Doge, Vero and Luce reduces under stress condition (Efeoglu et al., 2009). The strong drought induced stress reduces Chl a content thus reducing chl a/b ratio which indicates a loss of photosynthetic eaction centres (PS I and PS II) but the resistance genotypes have higher chlorophyll content than the susceptible ones. Carotenoid also decreases in parallel with the chlorophyll content but a significant increase anthocyanin and proline content in maize cultivars is observed (Efeoglu et al., 2009).

3.1.4 Respiration

The studies on drought stress effect on respiration are rarely found. The oxygen consumption percentage decreases fastly in cultivar 704 than cultivar 301 in both root and shoots due to the effect of PEG (Mohammadkhani and Heidari, 2008). The rate of decrease in photosynthesis is faster than respiration which results decrease of the ratio of photosynthesis to respiration causing an photorespiration. Photorespiration can cause death of the plants if increases rapidly.

3.1.5 Relative Water Content (RWC)

Relative Water Content is a measure of the plant water status. It is related with the water uptake by root and the water loss by the transpiration. RWC reduces under drought stress condition but can be maintained by rewatering. The relative water content of maize cultivars 'Doge', 'Vero' and 'Luce' decreases when exposed to drought but can be recovered after watering. Maize cultivars show wilt symptoms and rolling of the leaf throughout the period of drought (Efeoglu et al., 2009).

3.1.6 Defense Mechanism

Plants develop different protection mechanisms such as relating osmotic adjustment , water circulation , reaction to oxidative stress , detoxification , protection or degradation of proteins, Absciscic acid (ABA) synthesis, carbon and nitrogen metabolism and may others in order to be prevented from the damaging effect of the relative oxygen species (Hien et al., 2003; Mahajan and Tuteja, 2005; Pinheiro et al., 2004; Sherwin and Farrant, 1998). Under drought stress, maize increases resistance to transpiration, osmotic adjustment and other adaptive mechanism to compensate water deficit condition. A significant increase anthocyanin and proline content in some maize cultivars is observed (Efeoglu et al., 2009).

3.2 Germination and seedling growth

The water availability and movement in the seeds is essential for promotion of the seed germination, initial root growing, shoot elongation and also for the uniform crop stand establishment. Seed ambition is the first step for seed germination which occurs due to the distinct levels of osmotic potential between the dry seed and the water in the substrate of germination (Liu et al., 2015). The water content for the maize seed must be at least 35% to 45 % of seed dry mass to occur for the germination process but the highly negative osmotic potential makes the germination not possible, affecting the water uptake (Meneses et al., 2011). Germination was significantly affected by drought stress. The exposure of the seed to highly negative osmotic potential reduces the germination capacity drastically.

The germination percentage of maize reduces from 93% to a minimum of 25% when the seeds of maize are exposed to lower osmotic potential of -0.8 MPa (Oliveria Carlos Eduardo da Silva et al., 2019). The seed germination and seedling growth are the critical stages for water stress (Ahmad et al., 2009). The Germination potential which is used to evaluate germination rate and germination uniformity, is found declined in both Zhengdan 958 and Liansheng 15 varieties under the drought stress induced by different mannitol concentration (Liu et al., 2015). A group researchers observed a decline in the germination rate, germination index, vigour index, the root and the root fresh weight, root – shoot ratio, length of the root and shoot, drought resistance coefficient under the stimulated drought stress with different concentration of mannitol on two maize varieties Zhengdan958 and Liansheng15 (Liu et al., 2015).

ABA helps to promote the growth of the plants by developing stress resistance mechanism in plants. Abscisic acid is an important phytoharmone, not only because of its regulatory functions in physiological and developmental processes but also because it is the main regulator in adaptive response to drought stress (Lou et al., 2017). The treatment of the maize seedlings at different concentration of S-ABA (abscissic acid) causes an increase in the root length, bud length, root fresh weight, root dry weight, bud dry weight under drought stress (Yao et al., 2019). This shows that S- ABA mitigate the effect of the drought stress on maize seedlings at the varying degrees. The soaking of the maize seedlings promotes the germination of the maize seed but has an inhibitory effect under high concentrations. Out of many treatments carried, treatment of 4 mg/ kg S –ABA found the best to overcome the drought stress (Yao et al., 2019).

3.3 Yield

Drought stress severely affect the growth and the yield attributes of maize plants. Not only on a single factor, the yield of maize due to water stress is dependent on various factors, including plant developmental stage, severity and duration of water limitations (Farooq et al., 2009). The deficit of water retard the growth in terms of plant height, leaf area, number of leaves per plant, cob length, shoot fresh and dry weight per plant (Anjum et al., 2011). A group researchers reported a high reduction in the yield and the yield components such as kernel rows / cob, kernels /cob, 100 kernel weight, grain yield /plant, biological yield / plant and harvest index in maize exposed to drought stress (Anjum et al., 2011).

A great variation in the biomass accumulation is found under drought stress. A significant difference in total biomass accumulation and partitioning to stem, leaves and grains at mid-silking, grain–filling and at maturity under both well- watered and well deficit condition was found in drought stress situation. The result showed that water deficit condition reduced the total biomass accumulation at mid – silking by 37%, at grain filling period by 34% and at maturity by 21 % as compared with the well-watered condition (Kamara et al., 2003). A wider drought period during tasseling and ear formation stages leads to decrease in the maize yield by 66- 93 % (Cakir, 2004).

In maize crop drought causes tasseling and silking desynchronization followed by decrease in grain setting and kernel abortion (Celebi et al., 2010). A delay of 4-5 days in tasseling and the silking under water stress of 35 % FC as compared to plants grown under 75% FC condition causes delay on the onset of the grain filling and maturation period (Ge et al., 2012). Water deficit at pre-anthesis delayed tasseling by 2-3 days and silking by 1-2 days (Shirazi et al., 2011). This delay in silking induces barrenness because the pollen supply exhausted before the silk appears (Lu et al., 2011). Thus, pollen is also responsible for a reduction in the grain yield due to drought stress, which is associated with delay in the tasseling and the silking.

The early loss of the lower leaves caused due to prolonged and increased soil water stress leads to reduction in the interception of the incoming solar radiation which ultimately decreases biomass accumulation and grain yield in maize (Cakir, 2004). The photosynthetic active radiation is use to produce dry matter in plants. The higher efficiency in absorption of PAR leads to higher dry matter accumulation. Severe drought stress for a longer duration causes leaf rolling reducing the area of leaf for canopy absorption. Drought stress reduces canopy absorption of photosynthetically active radiation, radiation use efficiency and harvest index that finally leads to decrease in maize yield (Earl and Davis, 2003). Drought reduces yield finally, but some genotypes of hybrid and open pollinated varieties performed a bit better than the landraces under drought condition (Kamara et al., 2003). Improved genotypes possess the highest leaf, stem, ear and total biomass than landraces. Cultivars exposed to drought stres.

4. Conclusion

Drought is the major limiting factor for maize production in the arid and the semi-arid regions. Drought causes physiological, morphological and the biochemical damages to the plants which leads to the weaker crop yield and in serve cases food shortage. The prolonged drought and higher intensity of drought at different growth and developmental stages has detrimental effect on different physiological processes. The photosynthetic responses to drought stress is quite intricate. The duration and the intensity of the drought stress affect photosynthetic capacity. The genes involved in the photosynthesis under drought stress can up and down the mechanism. Thus, by understanding the expression pattern of such genes, transgenic lines of maize with enhanced photosynthetic capacity should be developed under drought stress. Nutrient uptake through the root decreases as the root surface area and soil moisture reduction causes low availability of ions. As, reproductive stage is most critical to determine the final grain yield of maize, irrigation at the pre-anthesis period will also help to cope the detrimental effect of drought on yield..

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