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# SUSTAINABLE MAIZE (*Zea mays* L.) PRODUCTION UNDER DROUGHT STRESS BY UNDERSTANDING ITS ADVERSE EFFECT, SURVIVAL MECHANISM AND DROUGHT TOLERANCE INDICES

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**ABSTRACT**

Maize is an essential dietary component in human food and in animal feed formulation. With the rising trend of global climate change, grain yield and quality losses of maize are expected to increase, because of various biotic and abiotic stress in all over the world. Among these, drought is most considerable one; it remarkably influences growth and yield traits of maize. Hence, the improvement of drought tolerant maize genotypes has potential to stabilize and even though increases the grain yield of maize. Therefore, developing cultivars tolerant to drought stress is a challenge for breeders. There are two ways to mitigate drought stress in maize production, either by developing and practicing improved drought

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management practices, or by developing and using drought-tolerant cultivars. Even though researchers in all over the world are trying to develop maize genotypes those are tolerant to drought stress; however, a effective breeding program is required to develop and detect the drought-tolerant traits. Therefore, the present review aim to address the adverse effect of drought stress on growth, yield traits, physiological and biochemical process of maize. It also attempts to identify the survival mechanism under drought stress for genetic improvement of maize. The present review also noticed that plant growth regulators, on enzymatic antioxidants especially osmoprotectants as exogenous applications and soil amendments of fertilizer (organic and inorganic) can also modify the morphological, physiological as well as chemical process of plants for better adaptation under harsh environments.

## 1 Introduction

Maize is an important cereal crop with a wider range of uses than other cereals (Olaniyan, 2015). Its demand is increasing day by day because of diverse uses, include human consumption, livestock feed formulation, pharmaceutical, textile industries and biofuel (Ali et al., 2010). However, the production capacity of maize is not adequate to meet the utilization demand. Therefore, to meet the increasing demands greater efforts should be taken under different environmental conditions (Karasu et al., 2015). Maize is a necessary crop which is using as food, fodder, fuel, as well as in the manufacture of industrial products. Furthermore, oil of maize is also appropriate for human consumption due to the presence of unsaturated fatty acids.

Among the abiotic factors, drought is one of the major environmental constrains, that limits the productivity of crop (Hossain et al., 2013; Hassan et al., 2016), through changing the growth, physiology and metabolism of plants (Lunde et al., 2007; Islam et al., 2011). Drought stress is a major constraint to agricultural production in many developing countries of the arid and semi-arid regions of the world (Turhan & Baser, 2004; Golbashy et al., 2010). Grain yield is the most commonly studied parameters; therefore primary aim of any research is to increase the grain yield (Ignjatovic-Micic et al., 2014). While, grain quality parameters have less attention but various studies have suggested that water stress reduced the various quantitative or qualitative traits such as grain protein, oil and starch content (Boyer & Hannah, 2001; Rehman et al., 2011; Rashwan et al., 2016; Barutçular et al. 2016 b; Barutçular et al. 2016d ; EL Sabagh et al.,2017b; EL Sabagh et al., 2018; Abdelaal et al., 2017). According to Zhao et al. (2009) maize protein components are sensitive to drought stress when it occurs during grain filling stage.

Drought affects the plant from seedling to maturity and yield reduction at the reproductive phase is greater than the vegetative and grain filling periods (Khalili et al., 2010). According to Khodarahmpour & Hamidi (2012) drought stress at the vegetative, pollination and grain filling periods can cause losses in maize yield by 15, 40, and 60%, respectively. Drought causes higher yield reduction in maize than those caused by other potential climatic factors (Shaw, 1977). When it occurred during silking-tasseling phase (flowering and pollination) it reduces grain yield by as much as 7% per day of stress. Prolonged period of drought shortened the grain filling period and finally reduced grain yield of maize (Gooding et al., 2003). While, developing cultivars tolerant to drought is challenging for breeders (Timsina & Connor, 2001).

There are two ways to mitigate stresses, either by developing and practicing improved stress management practices, or by developing and using drought-tolerant cultivars (Farooq et al., 2011). Therefore, it is very essential to improve existing as well as new breeding methods by using multi-disciplinary approaches for developing good genotypes that are tolerant to abiotic stresses specially drought for Arid and Semi-Arid environments of the globe (Cairns et al., 2012a).

Stress tolerance indices are useful tools to determine high productivity and stress tolerance potential of genotypes of crop. It has been commonly accepted that identifying high productivity genotypes under stress and non-stress conditions are more beneficial than the developing new verities (Lan, 1988; Mitra, 2001; Jafari et al., 2009; Naghavi et al., 2013; Barutçular et al., 2016a). For screening drought-tolerant genotypes, the most commonly used stress tolerance indices are stress susceptibility index (SSI) (Fischer & Maurer, 1978), stress tolerance index (STI), tolerance index (TOL) (Rosielle & Hamblin, 1981), yield index (YI) (Gavuzzi et al., 1997), yield stability index (YSI) (Bouslama & Schapaugh, 1984), mean productivity (MP) and geometric mean productivity (GMP) (Fernandez, 1992).

Present review aimed to understand the adverse effect of drought stress on growth, yield traits, physiological and biochemical process of maize and also attempt to identify the survival mechanism under drought stress. In this review, author also tried to identify the important drought tolerance indices that help in

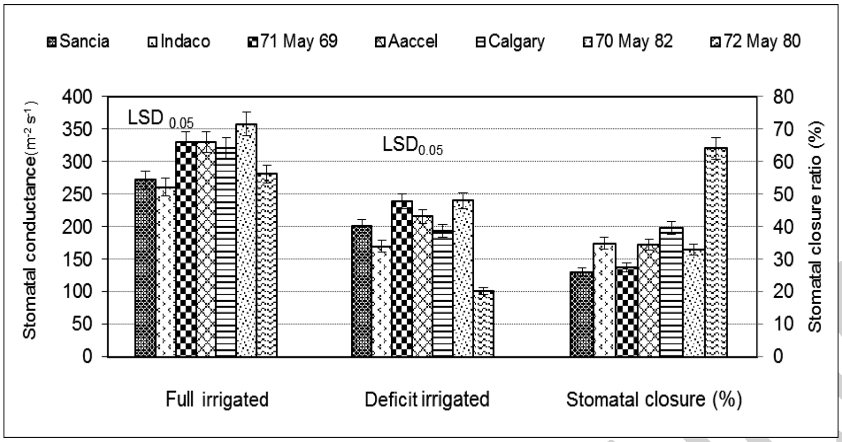


Figure 1 Stomatal conductance (mmol $m^{-2}$ $s^{-1}$) of maize genotypes recorded at 7 days after anthesis under full irrigation and deficit irrigation regimes (EL Sabagh et al., 2017a).

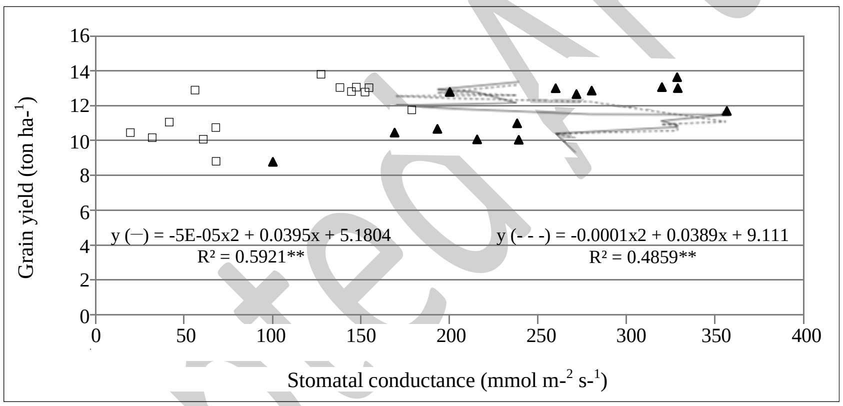


**Figure 2** Relationships between grain yield and stomatal conductance of maize at 7 (Δ,▲, - - - ) and 21 (□, ■, —) days after anthesis under full irrigation (▲,■) and deficit irrigation (Δ, □) regimes (EL Sabagh et al., 2017a).

selection of stress tolerant genotypes and can use as selection criteria.

## 2 Influence of drought on establishment of maize seedling

Drought is one of the main abiotic stresses which limiting crop growth rate and have negative consequences on various cellular activities. Wenkert et al. (1978) reported reduction in cellular elongation and carbohydrate wall synthesis in germinating seed when they exposed to water stress. Detrimental effect of drought stress on the initial phase of growth and seedling establishment of maize plants cannot be ignored (Shao et al., 2008). Drought stress reduced the rate of seed germination in maize crops; however, maize varieties respond positively in response to drought stress (Anjorin et al., 2017). The drought tolerant maize genotypes germinated earlier than the non-drought tolerant maize varieties under critical level of soil moisture when maize varieties were subjected to varying water regimes. Naturally, plant employs several adaptive measures to cope with harsh weather conditions, such adaptive measures bring about changes or adjustment in the physiological and biochemical processes of plant. Closing of stomata, number of leaves formed per plant, total leaf area produces, and plant height are reduced to minimize water loss under water shortage (Boyer & Kramer, 1995; Anjum et al., 2011). Similarly, Saliendra & Meinzer (1991) also reported that reduction in water potential induces stomatal closures resulting in a decline in the rate of photosynthesis, leaf growth and ultimately yields.

Two types of organic solutes (i.e., nitrogen-containing compounds and the hydroxyl compounds) produce by plants under stress condition for metabolic adjustment these compatible organic solutes contains sugars, polyols, betaines and proline (Yancey et al., 1982). In young maize water stress metabolites such as soluble sugar and proline increased with increased water stress while starch content and relative water content reduced with increased drought (Izanloo et al., 2008; Nayer & Reza, 2008; Anjorin et al., 2016). Selection for drought tolerant plant using the biochemical component have been described as a fast indirect and reliable method of drought tolerant selection even for plants at the seedling stage (Schiop et al., 2015). However, drought tolerant maize varieties that produced highest antioxidant metabolites are not usually the highest yielding varieties (Anjorin et al., 2016; Anjorin et al., 2017). Similarly, Nazarli & Faraji (2011) suggested that several factors should be put into consideration when selecting for drought tolerance in maize. They also noticed that drought tolerance is a complex process that depends on action and interaction of different physiological, biochemical parameter as well as different morphological traits, such as leaf rolling, efficient rooting system, etc.

**3 Physiological responses of maize verities under drought**

The performance of crop under drought condition is a complex phenomenon, when drought occurs during the reproductive growth stage, plant reduce the demand for carbon by decreasing the size of sink which eventually diminished the grain yield of crop (Reynold et al., 2006). Acclimation of different organic solutes make changes in the various physico-biochemical processes changes such as plant structure, growth, osmotic potential of plant tissue and antioxidant defenses in plants lead to adapt/survive plant under drought condition (Duan et al., 2007; Chen et al., 2010; Köksal, 2011). While, in most cases grain yield and drought adaptation are complex phenomenon (Bruce et al., 2002). Also, in drought breeding programmes, identification of phenotypic, ideotype traits and donors are important (Cairns et al., 2012b). The changes in leaf morphology induced by drought caused higher reflectance in the visible spectra between stressed and unstressed maize leaves (Genc et al., 2013).

Physiological trait such as stomatal conductance is an important feature which influenced yield significantly under drought stress and it is an important indirect drought tolerant crop selection criterion (Dodd, 2003; Koc et al., 2008). Stomatal conductance is a key trait of photosynthetic leaf that significantly influenced by water stress (Jiang et al., 2006). But, soil drying/drought leads to a decrease in stomatal aperture and stomatal conductance (Songsri et al., 2013; EL Sabagh et al., 2017a; Barutçular et al., 2017), therefore, plants under drought condition exhibited reduced rate of photosynthesis. Higher stomatal conductance could be a major determinant for high grain yield in maize under stress condition at grain filling stage (Munjal & Rana 2003). Drought could lead to increased stomatal density and reduced stomatal size, for adaptation of plants under drought stress (Martinez et al. 2007). In maize, some drought tolerant genotypes reduced leaf stomatal conductance more on the onset of drought (Ray & Sinclair, 1997). A significant genotyic variation in relation with stomatal conductance of maize genotypes recorded at 7 and 21 days after anthesis under full irrigation and deficit irrigation regimes (EL Sabagh et al., 2017a; Figure 1 & 2). Similarly, Bahar et al. (2009) found a positively correlation effect between stomatal conductance and yield. Similarly, Kolb & Robberecht (1996) reported a significant association between stomatal conductance and transpiration. However, a non-significant correlation between stomatal conductance and grain yield was also reported by Anjum et al. (2008).The remarkable genotypic variation in the stomatal conductance was observed by Bahar et al. (2009).

Generally, reduced canopy senescence and higher leaf chlorophyll are correlated with the increased grain yield of hybrids under well-watered conditions (Lee & Tollenaar, 2007; Barutçular et al., 2016c). A significant relationship was recorded between SPAD value and grain yield of wheat after anthesis, while no significant association was observed during middle and late grain-filling stages (Monneveux et al., 2008; Akhter et al., 2016). Further, SPAD values could be used as a criterion of grain yield in wheat (Barutçular et al., 2016e). Athar & Ashraf (2005) found that water deficit in root zone caused a reduction in leaf area, chlorophyll and photosynthetic rate of maize. The reduction in relative water contents under drought resulted in wilting, stomatal closure and growth reduction (Lawlor & Cornic, 2002; Unyayar et al., 2004). Abiotic stresses led to changes in the membrane permeability (electrolyte leakage) of plants (Abdelaal et al., 2018).

**4 Effect of drought on grain yield and yield components of maize**

According to Abd El-wahed et al. (2015); EL Sabagh et al. (2017a); Abdelaal et al. (2017), the grain weight and other yield traits' values under well-irrigated condition (without moisture stress) were increased significantly as compared with drought condition. Yield attributes such as stem length, ear height, number kernels row$^{-1}$, grain weight, grain yield, biomass yield and harvest index of maize were adversely affected by drought stress (EL Sabagh et al., 2017a). The similar type impacts of water deficit and well-water regimes on the yield traits and grain yield of maize had been reported in several studies (Cakir, 2004; Moser et al., 2006; Rivera-Hernandez et al., 2010). Shoa Hoseini et al. (2007) and Golbashy et al. (2010) reported that under drought stress, reduction in the total grain yield of maize are attributed to the reductions in number of kernels per row and total number of kernels per ear. Under water stress, kernels plant$^{-1}$ of maize was decreased significantly that ultimately lead to decrease the grain yield of maize (Yazar et al., 1999).

Water stress during the critical stage of silking to early grain filling, caused inhibition in photosynthesis rate and consequently lowers the carbohydrate reserves that are insufficient to support optimum reproductive development; causes reduction in the photosynthates mobilization to seeds and there by reduction of grain weight (Eck, 1986). While, Kamara et al. (2003) found that disruption of irrigation at grain filling period decreasing grain weight, due to decrease in the remobilization of photosynthates into the grains. Other researchers noticed that the reduction in grain yield was primarily associated with reduction in number of kernel and secondarily kernel weight when drought stress was imposed during the vegetative and reproductive growth phases in maize (Pandey et al., 2000; Shoa Hoseini et al., 2007; Golbashy et al., 2010). Likewise, drought stress between initial flowering and grain filling stage reduced total grain yield primarily by reducing vegetative growth, which consequently resulted in reduced number of grain and grain yield (Frederick et al., 2001; Leta et al., 2001; Karimian et al., 2005; EL Sabagh et al., 2017a). While, drought stress at pollination stage affects grain formation of maize because of reduced photosynthesis, leading to assimilate deficiency, increase production of sterile pollen ultimately reduced number of grain per ear (Setter et al., 2001; Araus et al., 2010). Farooq et al. (2009) noticed that the deficiency of water vegetative to reproductive stage of maize leads to severe reduction in yield of crop. Earlier findings also reported that anthesis period is the most sensitive stage to drought in maize growth and development that ultimately reduced that grain yield (Cakir, 2004, Zharfa et al., 2011; EL Sabagh et al., 2015a; Barutçular et al., 2016a). Stone et al. (2001), Bänziger et al. (2002) and Zharfa et al. (2011) established a strong relationship between biomass accumulations (especially after silking) with grain yield. Furthermore, they also observed that the higher growth rate ability of cultivars reduced when they are exposed to water stress condition.

## 5 Genotypic and phenotypic variation of maize genotypes under drought stress

The significant variations among different maize genotypes with respect to grain yield and yield traits indicate the existence of genetic variation and possibility of selection for drought tolerance genotypes (EL Sabagh et al., 2017a). Reality of high differences among maize hybrids for drought tolerance had been reported by several investigators (Golbashy et al., 2010). The adverse influence of drought stress on the physiological traits of maize genotypes by reducing the production of dry matter disrupts the partitioning of carbohydrates to grains and decreasing the harvest index (Mostafavi et al., 2011). Anjum et al. (2011) observed a positively reduction of kernels row$^{-1}$, kernel weight, kernels cob$^{-1}$, grain yield, biological yield and harvest index of maize, when a maize plant was exposed to drought at the tasseling stage. Pandey et al. (2000) noticed that yield loss in maize genotypes between 22.6 to 26.4% caused by deficit water which ultimately reduced the number of kernels as well as grain weight.

## 6 Correlation analysis between growth traits and yield attributes

A suitable index should have a positive relationship with grain yield under stress conditions as reported by Golbashy et al. (2010) and Shoa Hoseini et al. (2007). Positive relationship coefficient was reported between grain yield and grain weight while kernels row$^{-1}$ was negatively associated with yield. Also, a significant relationship was reported between grain yield and drought resistance index (DRISC) ($r=0.784$, $P<0.037$) (in the young leaves) under water stress environment (EL Sabagh et al., 2017a and Figure 2). Higher value of DRISC indicated highly resistance of maize genotypes under drought stress and might be used as drought tolerant genotypes for future breeding program. Stress tolerance index (STI) is also an important index that could be used to identify stress-tolerant high yielding genotypes (Sanjari, 2000; Kharrazi & Rad, 2011). The correlation between stomatal conductance and grain yield were significant (but non-significant) at early milky stage ($r = 0.165$) but non-significant at late milky stage ($r = -0.234$) under normal watering, while no positive correlation between stomatal conductance and grain yield was observed at early maturity stage under water stress condition (Bahar et al., 2009). Maize grain yield was negatively correlated with root and leaf growth rates under water stress condition. However, Zharfa et al. (2011) reported strong correlations between root growth and maize grain yield under normal condition.

## 7 Selection of drought tolerant genotypes based on tolerance indices

Drought tolerance is often a tedious process because of complex genotypes and environment interactions (Fernandez, 1992; Naghavi et al., 2013). Several drought tolerance indices are used to identify drought-tolerant genotypes, based on yield loss as compared with normal conditions (Mitra, 2001; Jafari et al., 2009; Naghavi et al., 2013). Barutçular et al. (2016a) observed a high relationship between the grain yield and drought tolerance indices and also noticed that these are most suitable in selection indices to identify the best maize genotypes for drought condition (Figure 3 & 4). Drought sensitivity and tolerance indices of the maize genotypes were determined on the basis of grain yield obtained under stress condition.

The relationship between grain yield and drought tolerance indices might be used to screen a good genotypes which are

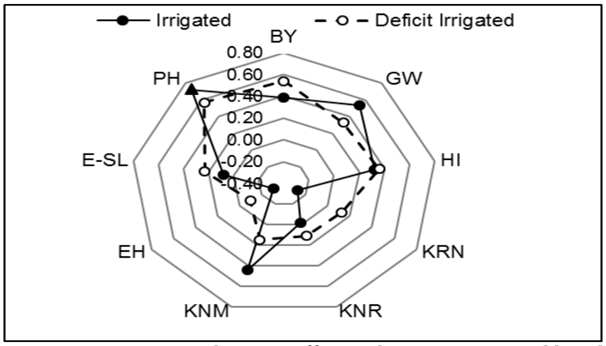


Figure 3 Pearson correlation coefficient between grain yield and agronomic traits of maize hybrids under irrigation regimes (Two years average) (Barutçular et al., 2016a), here † indicates significant at P=0.057 level; PH, plant height; E-SL, ear-up stem length; EH, ear height; KRN, kernel row number per-ear; KNR, kernel number per row; KNA, kernel number per area; GW, grain weight; HI, harvest index; GY, grain yield; BY, biomass yield.

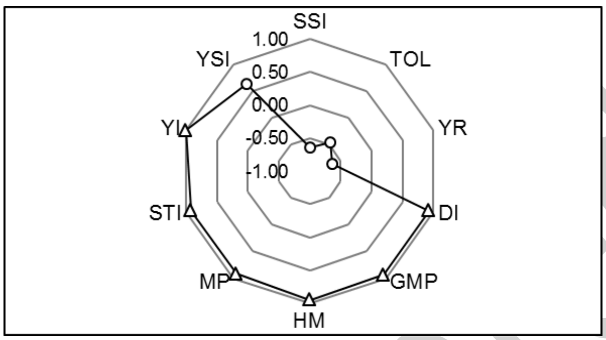


Figure 4 Pearson correlation coefficients between grain yield and drought indices (Two years average) (Barutçular et al., 2016a), here ** indicate significant P<0.01 level; SSI, stres susceptibility index; TOL, tolerance index; YR, yield reduction ratio; DI, drought resistance index; GMP, geometric mean productivity; HM, harmonic mean; MP, mean productivity; STI, stres tolerance index; YI, yield index; YSI, yield stability index.

suitable to grow under drought condition (Barutçular et al., 2016a; Figure 3 & 4). Genotypes with high values of STI, GMP and MP can be selected as drought tolerant genotypes (Hossain et al., 2013; Barutçular et al., 2016a; Figure 3 & 4). Furthermore, Hossain et al. (2013) and EL Sabagh et al. (2017a) noticed that TOL and SSI appeared to be most suitable indices for selection of high yielding genotypes under drought stress. The genotypes with high values of yield stability index (YSI), drought resistance index (DI) and harmonic mean (HM) might be selected as tolerant genotypes to water stress ( Barutçular et al., 2016a and Figure 3 & 4). In the view of Abdipour et al. (2008), MP, GMP and STI were suggested as the best indices for separating drought tolerant genotypes. Khalili et al. (2012) and Jafari et al. (2009) observed that GMP, MP, and STI indices were significantly associated with yield under well-irrigated and drought stress conditions and could be used in maize breeding programs as a reliable selection methods to produce drought tolerant maize hybrids.

## 8 Approaches for enhancing the productivity of maize

Plants can survive under different stress conditions by mobilizing various defense mechanisms as well as altering their physiological metabolism and growth pattern (Mittler, 2002). Various previous investigations revealed that severe drought condition critically affects the biochemical, physiological and morphological procedure of maize crop (Basu et al., 2010; EL Sabagh et al., 2016a). Zhang et al. (2009) reported that during osmotic stress (drought), an increase in external osmolarity that ultimate result in an efflux of water from the interior, leading to a reduction in the turgor pressure in the cell as well reduction in the cytoplasmic volume.

Plant growth regulators also play significant role in drought tolerance, these growth regulator always work in coordination with several growth processes ( Anjum et al., 2011; Abo-Youssef et al. 2017; Abdelaal et al., 2017, Figure 5). Various organic

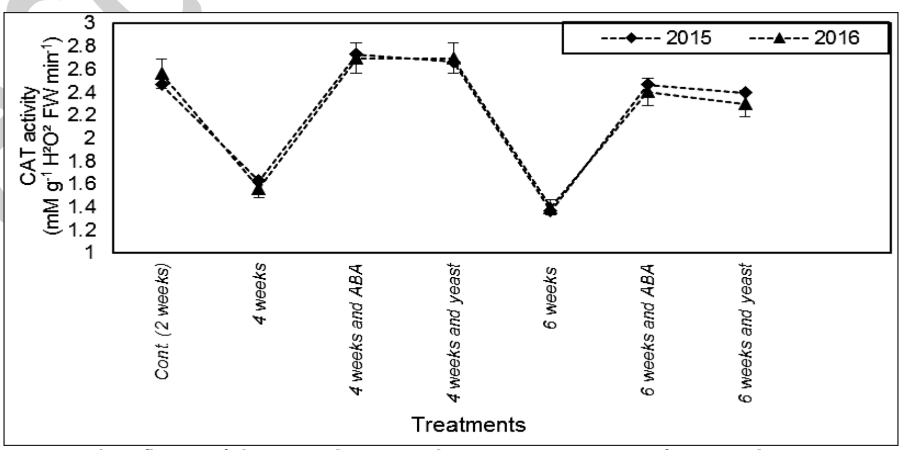


Figure 5 The influence of abscisic acid (ABA) and yeast on CAT activates of maize under water stress conditions during 2015 and 2016 seasons (Abdelaal et al., 2017).

compatible solutes include proline (PRO), glycine betaine (GB), trehalose (Tre), salicylic acid (SA), ascorbic acid (AsA) and several others before or during environmental stress can protect plants against stress damage through increasing inside plant solutes (Monyo et al., 1992; Mattioli, 2009; Ali & Ashraf, 2011; Kaya et al., 2013; Reddy et al., 2013).

Several studies reported that exogenous application of proline (PRO) help to survive plant under different abiotic stresses including drought (Ali et al., 2007; Ali et al., 2008). Although little attention has been given to the role of PRO in uptake and accumulation of inorganic nutrients in plants, however, many studies have given much attention on stress tolerance in plants as a compatible osmolyte for osmotic adjustment during drought stress (Ali et al., 2007; Ali et al., 2008). Role of glycine betaine (GB) as an effective compatible solute against various environmental stresses including drought is well established (Ashraf & Foolad, 2007; Zhang et al., 2009). Further, Salicylic acid (SA) acts as an endogenous signal molecule responsible for inducing tolerance of plants under environmental stress (Gunes et al., 2005). It is also involved in biochemical pathways, stress and disease resistance and many other plant responses (Kovacik et al., 2009). According to Elwana & El-Hamahmy (2009), SA enhanced photosynthetic rates, leaf area and plant dry matter production (Khan et al., 2003). Salicylic acid also acts as a potential non enzymatic antioxidant and help in adjust of plant physiological activity like photosynthesis rate (Arfan et al., 2007). Gharib et al. (2016) reported effect of SA on the growth and yield components of wheat crop under drought stress conditions.

Further, exogenously applied ascorbic acid (AA) ameliorates adverse effects of drought (Dolatabadian et al., 2010; Khalil et al., 2010). It has been reported that maintenance of water status is regulated by stomatal conductance and rate of transpiration and AA played significant role in these two physiological processes (Ashraf, 2009). Ascorbic acid has been also used to prevent the unfavorable impacts of salt stress in several crops (Khan et al., 2010). Some other researchers (Dolatabadian et al., 2010; Dolatabadian et al., 2010; Khalil et al., 2010; Yazdanpanah et al. 2011) also reported that under stress environments, the ascorbic acid plays a positive role in adjustment of mechanisms of photosynthesis and the defense roles against oxidative stress.

Abscisic acid (ABA) could be enhancing plants resistance to environmental stresses (Giraudat et al., 1994). Pre-soaking seed treatment with ABA was positively improving the antioxidant enzymes activity seedlings of maize under water stress conditions (Jiang & Zhang 2002). Application of ABA stimulated the morphological and anatomical modify which could provide the roots to breakthrough compacted soil (Hartung et al.,1994). Abdelaal et al. (2017) found that grains ear$^{-1}$, 100 grain weight and grain yield of maize was highly influenced by abscisic acid (ABA) and yeast under water stress conditions (Figure 6). The active yeast extract significantly improved growth and agronomical attributes of plants (Rania Nassar et al., 2011; Hammad, 2008). Further, the agronomical traits positively enhanced in stressed treated plants in maize and improved the growth characters and antioxidant enzymes activity by abscisic acid (ABA) and yeast application, Figure 5 and 6 (Abdelaal et al., 2017). Application of ABA significantly improved the antioxidant enzymes activity under drought stress in corn plant (Lee & Luan , 2012; Abdelaal et al., 2017).

The Fertilizer application management, balanced nutrients in plants are a major element to enhance the growth and productivity of crop under semiarid conditions (Amanullah et al.,2016). Intensive using of mineral fertilizers a main problem to environmental and production cost (EL Sabagh et al., 2015c; EL Sabagh et al., 2016b; EL Sabagh et al., 2016c). The implementation of organic and inorganic fertilizers combined

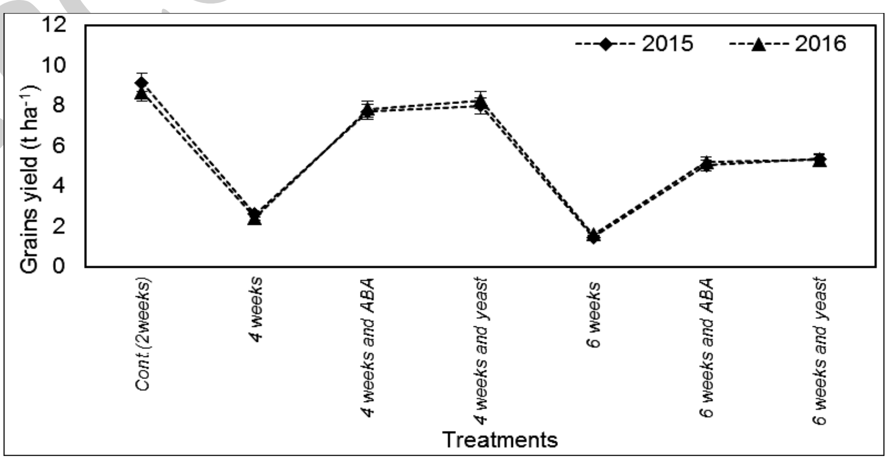


Figure 6 Grain yield as influenced by abscisic acid (ABA) and yeast of maize plants under water stress conditions during 2015 and 2016 seasons (Abdelaal et al., 2017).

might improve the activities of soil and nutrient availability (He & Li, 2004; Nasim et al., 2012). Application of organic fertilizers is very effective for reducing negative effect of stress environment and to increase the yield and quality of crops (Ahmad & Jabeen, 2009; EL Sabagh et al., 2015b). While a positive relationship between amount of irrigation water and grain yield at different Farmyard manure (FYM) treatments under drought stress condition, indicating that FYM in combination with amount of irrigation help to survive plants under deficit water stress condition (Abd El-Wahed et al., 2015). Organic fertilizers might play an important role to solve environmental pollution problems that caused by agroindustrial wastes (Preap et al.,2002 ; Gharieb et al. , 2016).The combined chemical and poultry manure fertilization (50:50) produced the maximum yield and its traits of maize (Nasim et al. (2012). According to Azab (2016) application of half rate of the chemical NPK combined with bio-fertilizers was effective and logic to achieve the maximum productivity under the condition of investigation in maize.

**Conclusion**

From the present review, it can be concluded that, with the rising trend of global climate change, especially due to drought stress, growth and yield of maize reduce significantly all over the world especially in Arid and Semi-Arid region of the world. Hence, the use of drought tolerant maize genotypes has potential to stabilize the grain yield of maize. Therefore, developing cultivars tolerant to drought stress is challenging for breeders to face the future climate changing condition. Suitable stress tolerance index should be have a positive or negative relationship with grain yield of maize under drought stress. Plant growth regulators, non-enzymatic antioxidants especially osmoprotectants as exogenous applications and soil application of fertilizer (organic and inorganic) can also modify the morphological, physiological as well as biochemical process of plants for better adaptation under harsh environments.

**Conflict of interest**

All the authors declare that there is no conflict of interest.

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