Agricultural Water Management 201 (2018) 152–166

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Review

Drought stress in sunflower: Physiological effects and its management through breeding and agronomic alternatives

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ARTICLE INFO

Keywords:
Achene and oil yield
Physiology
Biochemistry
Genetics
Agronomy
Sustainable water management

ABSTRACT

Drought is the most important crop production limiting factor in the changing climate scenario and its intensity is predicted to increase in future. Sunflower is an important oilseed crop having 8% share in the world oilseed production. Although, it is a moderately drought tolerant crop, severe drought causes reduction in the seed and oil production. Therefore, to ensure sustainable sunflower achene and oil production, it is very important to understand the relationship among the physiological, biochemical, genetic and agronomic basis of drought for its sustainable management. Impact of drought stress on various aspects of sunflower has been reported earlier but there is not a single study describing the physiological, biochemical and genetic basis of drought in sunflower at molecular and crop level. In this review manuscript, influence of drought on sunflower achene yield and oil quality has been analyzed critically at both cell, plant and crop level, and the possible management options to mitigate the severity of the drought stress are proposed. Available literature describing the impact of drought stress on physiological and biochemical aspects (like, photosynthesis, water relations, nutrient uptake and oxidative damage), morphological and growth parameters and achene yield and oil quality has been discussed critically. Based on the discussion on the impact of drought stress, various management strategies, such as breeding for drought tolerance (conventional or biotechnological), exogenous application of hormones and osmoprotectants, seed treatment and soil nutrient management has been reviewed and discussed. It is concluded from discussion that sunflower responds to water stress by osmotic adjustments, turgor maintenance, carbon assimilation maintenance and hormonal regulations. A comprehensive research on integration of different management options, including agronomic management, conventional breeding and modern biotechnological advances, is needed for the sustainable improvement of sunflower achene yield and oil quality under drought stress. This may also contribute significantly under a climate change scenario.

1. Introduction

Sunflower (*Helianthus annuus* L.) is an annual oilseed crop globally cultivated on 24.77 million hectares with a production of 44.31 million metric tons and it has 8% share in world oilseed market (USDA, 2016). Sunflower contains 40–50% oil and 17–20% protein, thus have a fair potential to narrow the gap between production and consumption of edible oil and animal feed in the world. Actually, it is a crop of tropical and subtropical regions with semi-arid to arid climate, and frequently grown in dry lands or on supplementary irrigation. Therefore, the crop is affected by ambient environmental conditions like heat and drought (Pekcan et al., 2015; Robert et al., 2016).

However, in a climate change scenario or/and with the onset of early droughts, the crop may be affected by drought stress (Debaeke et al., 2017). In addition to the hiking problem of water stress, the area devoted to irrigated food production systems is expected to decrease resulting in lesser food production (Alexandratos and Bruinsma, 2012; Farooq et al., 2012). Nonetheless, expansion of irrigated land is not

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https://doi.org/10.1016/j.agwat.2018.01.028
Received 5 September 2017; Received in revised form 24 January 2018; Accepted 29 January 2018
0378-3774/

possible because of water competition among domestic, industrial and agricultural users (Alexandratos and Bruinsma, 2012). Severe water competition among different users will predominately change the irrigated lands to rain-fed systems and ultimately crops have to suffer from periodic events of drought stress (Elliott et al., 2014). Hence, all of agricultural crops and even the moderately drought tolerant crops such as sunflower will be badly affected by drought stress. Severe drought events have been recorded in Asia and beyond, including the countries with arid and semiarid climates during the last decades (Miyan, 2015; Farooq et al., 2012, 2014), which made management of drought stress more challenging.

Although, sunflower is moderately drought tolerant crop (due to drought escape behavior), it is highly sensitive to drought and heat stresses from early flowering to achene filling due to inefficiency in regulating the leaf expansion and transpiration rates under inadequate availability of soil moisture (García-López et al., 2014). The decline in soil moisture leads to leaf wilting, which results in substantial yield reduction in semi-arid areas receiving the low rainfall (Aboudrare et al., 2006). Several reports indicate that drought stress significantly reduces sunflower achene yield, oil yield and oil quality globally (Soleimanzadeh et al., 2010; Babaeian et al., 2011; Oraki and Aghaalikhana, 2012; Ibrahim et al., 2016). However, the effects of drought stress on sunflower productivity are not same for all the growth stages. Exposure to drought at some specific phenophases like germination, anthesis, and achene filling etc., is the most critical factor causing up to 50% yield reduction in sunflower (Kalarani et al., 2004; Hussain et al., 2008). Early season drought stress suppresses germination, stem elongation and leaf area (Fulda et al., 2011; Fatemi, 2014), while drought stress at anthesis results in the formation of empty achene production due to pollen infertility (Lyakh and Totsky, 2014; Totsky and Lyakh, 2015). More available water at initial growth stages results in good vegetative growth, but the subsequent low moisture availability at flowering and grain filling stages significantly reduces the yield due to high transpiration demands (Aboudrare et al., 2006).

Sophisticated approaches are needed to sustain the productivity of existing crops and meet the challenge of food security in the area of global climate change, increasing population pressure and decreasing resources. Being a rich source of edible oil and protein, sunflower can play a vital role in evading the production gap of edible oil and protein in the world. However, effective use of available germplasm and technology needs to be well explored for sustaining the sunflower productivity under increasing risk of water scarcity. Although many individual efforts have been made to assess the effects of drought stress on sunflower yield and oil quality (Gholamhoseini et al., 2013; Manivannan et al., 2015), determine the role of different management options to mitigate the adverse effects of drought stress, and explore the physiological (Baloğlu et al., 2012; Ghobadi et al., 2013), biochemical and molecular responses (Bowsher et al., 2016) of the crop to drought stress, however, no comprehensive review interlinking all aspects is available.

In this article, effects of drought stress on growth, phenology, light harvesting, assimilate partitioning, nutrient and water relations, achene/oil yield, and oil quality of sunflower have been discussed. Management and crop improvement options for drought tolerance in sunflower are also described.

2. Physiological and biochemical responses to drought stress

The crop plants respond to drought stress through changes in biochemical and physiological cascades that range from photosynthesis to metabolic processes. Plants exhibit various responses at the onset of drought stress, which vary from whole plant to cellular and molecular level. Some major physiological and biochemical responses of sunflower to drought stress are described in the following sections.

2.1. Photosynthesis

Photosynthesis is one of the key metabolic pathways, responsible for growth and development with the help of carbon fixation and light harvesting by plant leaves. Photosynthetic efficiency of plant species depends not only on their genetic potential to absorb light energy and utilize it for the production of carbohydrates, but is also influenced by the environmental stresses (Andrianasolo et al., 2016). It has long been known that instead of being a C_3 plant, sunflower has a high photosynthetic potential (similar to C_4 plant maize) i.e., 25–32 μmol CO_2 fixed $m^{-2} s^{-1}$ of leaf (Fock et al., 1979; Potter and Breen, 1980). The high photosynthetic potential of sunflower is due to the presence of stomata on both sides of the leaf, which results in more tissue permeability for CO_2 diffusion and high RuBisCO activity (Ghobadi et al., 2013; Killi et al., 2017).

The process of photosynthesis in sunflower under drought stress is affected by two distinct mechanisms: (i) through decreased CO_2 diffusion within the leaf due to closure of stomata and (ii) through the inhibition of metabolism of CO_2 (Tezara et al., 1999). Growth and productivity of sunflower is strongly affected under moisture deficit conditions due to low photosynthesis rate resulting due to stomatal closure, thus restricting CO_2 diffusion into the leaves (Flexas et al., 2004). RuBP has a significant role in photosynthesis and is key to dark reaction. The capacity of carboxylation and RuBP regeneration decreases in severely stressed intact leaves (Galmés et al., 2013), but in drought tolerant genotypes its content increases in response to prolonged drought (Pankovic et al., 1999), which indicate more RuBP generation as a sign of drought tolerance.

The stomatal conductance and the assimilation of CO_2 in sunflower leaves reduces with an enhancement in the drought intensity (Correia et al., 2005; Iqbal et al., 2009; Ghobadi et al., 2013); nonetheless a genotypic variability exists for reduction in stomatal conductance and CO_2 assimilation in response to drought stress (Andrianasolo et al., 2016; Iqbal et al., 2009). In a study, Tezara et al. (2002) found an increase in net CO_2 assimilation rate in sunflower seedlings due to elevated CO_2 level with a simultaneous reduction in RuBisCO contents. However, the activity of RuBisCO was enhanced. Thus, we can conclude that the elevated CO_2 increases the efficiency of RuBisCO even under water stress. In a study, Ghobadi et al. (2013) found that drought stress negatively affected the photosynthesis, stay green, photosystem-II photochemical efficiency, and stomatal conductance, and observed variation in genotypic response for aforementioned traits. In another study, Kulundžić et al. (2016) found that the photosynthetic efficiency was decreased in different sunflower genotypes under drought stress. Cechin et al. (2015) also found that drought reduced the stomatal conductance which ultimately reduced the concentration of intercellular CO_2 and photosynthesis.

Drought stress reduces photosynthesis in sunflower through stomatal closure and reduced CO_2 fixation. Stomatal closure mediated restricted CO_2 diffusion in the leaves is more dominating in sunflower compared to CO_2 assimilation. Elevated CO_2 level can compensate the drought induced photosynthetic damage under drought stress.

2.2. Water relations

Sunflower possesses stronger ability to use the available soil water due to strong tap root system. Drought stress affects the sunflower growth and productivity mainly by decreasing the water potential, cell division/expansion, owing to loss of turgor, leaf relative water contents as well as the water potential and its components viz., turgor potential (Ψ_t) and osmotic potential (Ψ_o) (Correia et al., 2006; Kiani et al., 2007a).

Drought stress decreases the water potential in sunflower (Ghobadi et al., 2013). For example, various studies have reported a leaf water potential of −0.48 to −1.74 MPa in sunflower under diverse environmental conditions (Prasad et al., 1985; Rachidi et al., 1993), however, it