

Drought and salinity stress management for higher and sustainable canola (*Brassica napus* L.) production: a critical review

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Abstract

The oil of canola (*Brassica napus* L.), a globally important major oilseed crop, is used for salads, frying, the development of margarines, shortenings, and other food products. However, the growth and yield of canola are mainly restricted by drought and salinity, which can become acute in climate change. The exogenous application of some antioxidants has been shown to enhance tolerance to drought and salinity in select plants. Therefore, a thorough understanding of the effect of drought and salinity stress is crucial for understanding their adverse effect on canola cultivation and to establish useful strategies to maximize oil productivity. Given the economic importance of this crop, we reviewed studies within the extensive canola literature to assess the adverse effects of abiotic stresses, with a special emphasis on drought, water deficit and salinity, and how these stresses impact its growth and productivity in a bid to determine the role that antioxidants might play in alleviating the adverse effects of environmental stresses. This review notes how the productivity of canola tends to decrease under different abiotic stresses due to their adverse effect on morphological, physiological and biochemical processes, including lowered or reduced leaf area, leaf relative water content, stability of cell membranes, photosynthetic capacity, stomatal conductance, damage to chlorophyll and the production of reactive oxygen species. In addition, this review also discusses management strategies that would allow researchers or farmers to mitigate salinity and drought stress by using compatible solutes, nutrient management or other means to maximize canola yield. The application of antioxidants to soil, in combination with essential nutrients, alongside other management strategies, may assist in alleviating the harmful effects of environmental stresses in canola production.

Keywords: Antioxidants; Adverse effects; Canola; Drought; Salinity stress; Yield.

Abbreviations: AsA_ascorbic acid; chl *a*_chlorophyll *a*; chl *b*_chlorophyll *b*; GB_glycine betaine; MDA_malondialdehyde; RLWC_relative leaf water content; ROS_reactive oxygen species; RWC_relative water content; SA_salicylic acid.

Nutritional importance and other uses of canola

Canola, a sub-group of *Brassica napus* L., also known as oilseed rape, is a major oilseed crop and was globally ranked third in terms of production among oilseed crops (Johnston et al., 2002; Ashraf and McNeilly, 2004). Canola seeds contain 25% protein and 40-42% oil, 60% oleic acid and 8.8% linoleic acid (Hu et al., 2006), and 20-30% stearate in transgenic canola seeds (Hawkins and Kridl, 1998). Canola oil is used for salads and frying, as well as to develop margarines,

shortenings, and other food products (de Oliveira et al., 2015). High contents of erucic acid (Food Standards Australia New Zealand, 2003) and glucosinolates (Cartea and Velasco, 2008) can be toxic to humans and animals. Canola seeds have a low erucic acid (26%) and glucosinolate (49%) content (Knutsen et al., 2016). In canola, protein and oil content is affected by the level of erucic acid and glucosinolate (Shi et al., 2011). The European Food Safety Authority established in

2016 a tolerable daily intake of 7 mg kg⁻¹ body weight (bw) day⁻¹ for erucic acid based on the lack of any observed adverse effect of 0.7 g kg⁻¹ bw day⁻¹ on lipidosis in young rats and newborn piglets (Knutsen et al., 2016). The safety limit of consumption of erucic acid in oil used to be < 2% and < 30 μmol g⁻¹ of glucosinolate in oil-free meals (Nelson and Grombacher, 1992). In humans, almost all erucic acid is absorbed from the digestive tract (Bézar et al., 1994).

The World Health Organization (WHO) estimates that globally, cardiovascular diseases account for the deaths of 17.7 million people annually, or 31% of all deaths (WHO, 2017). Canola oil helps to lower cholesterol in humans since it is rich in two healthy essential fatty acids, linoleic acid (ω-6 fatty acid) and α-linolenic acid (ω-3 fatty acid) in a 2:1 ratio, which is nutritionally ideal, and low levels of unhealthy fatty acids (CCC, 2017a). Thus, canola may play an important role in nutritional security in the developing world, explaining its increasing demand from and consumption by diet-conscious consumers (Namvar and Khandan, 2015). Additionally, the residue left after oil extraction is rich in protein and can be used for animal feed (Din et al., 2011; Dawood and Sadak, 2014). Canola can also serve as a catch crop as it is able to absorb high levels of nitrate from the soil, thus reducing nitrogen leaching in autumn and winter (Malagoli et al., 2005).

Abiotic stresses reduce crop productivity

Crop productivity can decrease due to the adverse effects of different abiotic stresses, including salinity (Paulsen, 1994) and drought (Zirgoli and Kahrizi, 2015). However, since abiotic stresses are unpredictable, the best way to cope with them is to develop tolerant varieties that perform well under stress as well as under optimum environmental conditions, a strategy that has worked well in wheat (Nouri et al., 2011; Hossain and Teixeira da Silva, 2012, 2013). However, the development of cultivars that are tolerant to abiotic stresses is a time-consuming process. Enhancing a plant's tolerance to drought and salinity is thus a viable approach to resolving the challenge of abiotic stress tolerance in arid and semi-arid environments, at least in wheat (Talebi, 2009).

Hossain et al. (2012) found that high temperature during drought is a key constraint for the growth and productivity of spring rain-fed wheat and barley, ultimately caused by a deficit in soil moisture and low relative humidity. Drought stress affects plant growth by reducing nutrient uptake and impairs the active transport of photosynthates (Hu and Schmidhalter, 2005; Jaleel et al., 2009). Nutrient deficiency is even observed in fertilized fields due to a reduced rate of diffusion of nutrients from the soil matrix to the root surface and translocation to sites of photosynthesis in maize leaves (Hu et al., 2007). Hu and Schmidhalter (2005) and Silva et al. (2011) indicated that reduced plant growth under drought stress might be due to reduced nutrient uptake and transport from roots to the shoot due to restricted transpiration rates, impaired active transport, and membrane permeability. Umar (2006) noticed that the nutrient film around soil particles became thin under drought stress, thereby increasing the distance by which ions had to move, resulting in poor diffusion of ions into plant roots in sorghum, mustard and groundnut. In common bean and flax, the relative level of photosynthates depends on soil moisture supply to plants (Chikov et al., 2001).

Salt and osmotic stresses inhibit or delay cowpea and wheat seed germination and seedling establishment (Almansouri et al., 2001; El-Shaieny, 2015). Salt stress negatively affects plant growth via oxidative stress, especially ion toxicity, nutritional and hormonal imbalance, and osmotic stress (Parida and Das, 2005; Ashraf, 2009). In addition, salt stress degrades pigments such as chlorophyll (chl), but the level depends on the level of tolerance of the cultivar to the salt, the enzymes involved in photosynthesis such as Rubisco show lower activity, while reduced photosynthetic ability is caused by damage to photosystem II (Ashraf and Harris, 2013). The salt-induced degradation of chl starts with the elimination of phytol, which is caused by enhanced chlorophyllase activity (Fang et al., 1998).

Mitigating abiotic stress in plants

The accumulation of some compatible solutes (proline and sugars) is proportional to the change of external osmotic pressure, and this helps to obtain an ionic balance in vacuoles and cytoplasm inside the cell (Hasegawa et al., 2000), thereby protecting cell structure and supporting continued water influx (Parida and Das, 2005). The exogenous application of osmoprotectants is a shotgun approach to mitigate the negative effects of abiotic stresses, including drought stress (Ashraf and Foolad, 2007). Several organic compatible solutes such as proline take part in plant stress tolerance (Ali and Ashraf, 2011). Proline is found widely in plants and accumulates in large quantities in response to environmental stresses such as drought, salinity, and extreme temperatures (Mattioli, 2009). Proline is correlated with the relief of cellular osmotic stress, detoxification of excess ammonia, stabilization of proteins and/or membranes and enhancing the stability of some cytoplasmic and mitochondrial enzymes (Ozdemir et al., 2004). The exogenous application or excessive production, for example through transgenic plants, of proline may prevent the harmful effects of salt stress by stimulating cell growth, enhancing metabolism, or reducing the oxidation of membrane lipids (Parida and Das, 2005; Szabados and Savouré, 2010).

The exogenous application of glycine betaine (GB), a quaternary ammonium compound, i.e., an amino acid derivative that is an effective solute, improves the growth and tolerance of a wide range of plants under various stress conditions and enhances their survival by regulating a number of physiological and biochemical processes (Ashraf and Foolad, 2007; Aghaei and Komatsu, 2013). GB and proline are organic osmolytes that accumulate in several plant species in response to different stress conditions (Ashraf and Foolad, 2007; Ali and Ashraf, 2011). GB maintains osmotic balance and can also scavenge free radicals generated under abiotic stress, so exogenous foliar application of GB is a recommended approach to induce stress tolerance in crops (Ashraf and Foolad, 2007). Like GB and proline, some organic acids such as citric acid are osmolytes that can accumulate in halophytic plants in response to saline and alkaline stress (Sun and Hong, 2011). To counter the deleterious effects caused by the excessive production of reactive oxygen species (ROS), plants scavenge ROS in a mechanism that involves coordination between signaling and metabolic pathways in which enzymatic and non-enzymatic antioxidants act as a defense mechanism to

regulate the levels of ROS (Mittler, 2002; Suzuki et al., 2012). In a process that uses multiple redox reactions, the active oxygen in ROS is deactivated (Tuteja, 2007; Sharma et al., 2012). Cell membrane damage, which is caused by salinity, can be determined by the rate of formation of a lipid peroxidation product, malondialdehyde (MDA) (Gill and Tuteja, 2010). When the activity of antioxidant enzymes increases, the level of MDA decreases (Sharma et al., 2012). Salt-tolerant plants have lower levels of MDA, which indicates reduced salt-induced injury to membranes (Sairam et al., 2002).

Salicylic acid (SA) is actively involved in various biochemical and physiological mechanisms of plants, and helps them mitigate the adverse effects of water deficit stress (Hayat et al., 2010). SA acts as an antioxidant by increasing the levels of glutathione, which is involved in scavenging ROS, thus SA serves as an important messenger molecule in a plant's response to biotic and abiotic stresses (Herrera-Vásquez et al., 2015). SA impacts stomatal function, chl content, transpiration rate, and respiratory pathways, for example by alleviating the decrease in photosynthetic capacity of grapevine leaves (Wang et al., 2010), so it might possess a physiological role, and would most likely be involved in the regulation of some photosynthetic reactions (Horváth et al., 2007).

The roles of ascorbic acid (AsA), a small, water-soluble antioxidant, in plant growth and other developmental processes are well documented (Pignocchi and Foyer, 2003). AsA acts as a primary substrate in the cyclical pathway to detoxify and neutralize the damaging effect of superoxide radicals and singlet oxygen, which are produced by the Mehler reaction and photorespiration, by adjusting glutathione and different enzymatic antioxidants (Noctor and Foyer, 1998). The removal of free radicals helps AsA to increase stress tolerance and reduce oxidative stress (Shalata and Neumann, 2001). The foliar application of AsA in sunflower increased the rate of photosynthesis by increasing chl content and improved soluble sugar content (Ebrahimi and Bybordi, 2012).

Considering these broad issues underlying abiotic stresses in plants, and their mitigation, this review attempts to assess some of the adverse effects of abiotic stresses on canola, with special reference to drought, water deficit and salinity, and to determine the possible role that antioxidants or other additives, as well as agronomic practices, may have in alleviating these stresses.

Drought, water and salinity stress adversely affect canola

Effect of drought stress on canola growth and productivity

Drought is one of the most important abiotic constraints that restricts the growth and yield of crop plants by influencing physiological and biochemical processes. Drought, as a result of low soil water content, results in increased salinity, which limits nutrient supply, so drought and salinity stress often cause stress in plants concomitantly (Hu and Schmidhalter, 2005). The major common undesirable impact of drought and salinity on canola is a decrease in yield-related attributes as well as a decline in the quality of seed and oil (Zamani et al., 2010). For example, Jensen et al. (1996) found that the application of early or late drought reduced seed yield by 8% and 17%, respectively. This is because salinity lowers oil and

linoleic acid contents, but increases glucosinolate and stearic acid contents (Moghadam et al., 2011). However, during stress, canola plants produce different organic solutes that allow them to survive under adverse conditions by improving their physiology (Zahedi and Moghadam, 2011). Yield decreased in drought-stressed canola plants that accumulated glucosinolate at the flowering stage (Bouchereau et al., 1996).

When drought affects the reproductive stages (flowering to pod development stage) of canola, final yield is significantly reduced since pod formation and seed size are hindered, resulting in fewer siliques per plant and seeds per silique, ultimately resulting in lower economic yield, as assessed by lower grain yield and oil yield per unit production area (Ghobadi et al., 2006). Gan et al. (2004), in canola and mustard, and Sinaki et al. (2007) in canola, showed that drought stress induced flower and fruit drop, finally reducing overall production. Canola seed yield can be reduced, even by a short period of soil moisture stress, during reproductive stages (Ahmadi and Bahrani, 2009). For example, drought stress applied at the anthesis stage in four canola cultivars reduced leaf relative water content (RWC_{leaf}) and stomatal conductance, eventually reducing yield, as assessed by number of pods per plant and number of grains per pod (Jamshidi Zinab et al., 2015). Moaveni et al. (2010) found that drought stress significantly reduced oil yield, grain yield, 1000-grain weight, number of siliques per plant and number of grains per silique. Similarly, Shirani Rad and Zandi (2012) found that plant height, number of branches or siliques per plant, number of seeds per silique, 1000-seed weight, seed, biological, and oil yields, oil content, but not harvest index, were significantly reduced by drought stress. Plant reproductive organs or seeds acquire or store resources from the vegetative parts of the plant in canola, thus reduced water uptake finally results in poor silique and seed formation (Ghobadi et al., 2006).

Effect of water stress and soil water deficit on canola growth and productivity

Morrison and Stewart (2002), Hassanzadeh et al. (2005), Rahnama and Bakhshandeh (2006), Nasri et al. (2008), Tesfamariam et al. (2010), Zakerin et al. (2014), EL Sabagh et al. (2017) and Kandil et al. (2017) found that under water deficit stress, yield and yield components of canola were significantly negatively affected, as indicated by a reduced number of siliques per plant, plant height, plant weight, as well as a number of other physiological parameters in the vegetative stage that had a direct negative impact on the vegetative stage (fewer flowers, smaller seed), a common phenomenon among crop plants and forage species (Martiniello and Teixeira da Silva, 2011), ultimately reducing seed and oil yield. A reduction in water use efficiency can reduce grain yield by as much as *circa* 30-60% in canola, depending on the genotype (Mousavi et al., 2010).

RWC_{leaf} is an essential physiological parameter to measure drought stress tolerance in plants (Sánchez-Blanco et al., 2002). RWC_{leaf} , osmotic potential, and leaf temperature in canola and mustard were also adversely influenced by drought stress (Fanaei et al., 2009). As much as 48% of RWC_{leaf} in canola was lost under water stress (Sharma et al., 1992). Under water stress, an increase in the concentration of cell electrolytes disturbs the normal metabolic function of

cell organelles (Mahajan and Tuteja, 2005). Similarly, cell turgidity, as well as the growth of cells and tissues, are adversely affected by water stress, as a result of cell collapse, as was observed in cyclamen (Oertli, 1986) and sunflower (Benlloch-González et al., 2015).

In canola, Gibon et al. (2000) noticed that drought stress significantly reduced chl content, but only between -0.1 MPa and -3.0 MPa, when proline content peaked. Din et al. (2011) also found, in canola, that drought stress significantly reduced chl content by an average of 24%, and ranging between 13% and 45%, depending on the cultivar, while proline accumulated as much as 81% and 59% at the flower initiation and pod-filling stages, respectively. In canola, water stress significantly decreased chl ($a+b$) content in the vegetative, flowering and 50% pod-formation stages (Sharma et al., 1992). Water deficit significantly reduced chl content and RWC_{leaf} by about 25-30% (EL Sabagh et al., 2017). Reduced leaf chl content in response to water stress is caused by ROS production, which damages the chloroplasts (Gill and Tuteja, 2010).

The ultimate effect of water deficit on canola is a reduction in plant height, number of branches, pod length, grain size (1000-grain weight) and yield and thus a deterioration of product quality, i.e., reduced oil yield by about 40% (Istanbulluoglu et al., 2010). Canola is most sensitive to water stress during the flowering stage and least sensitive during the vegetative and seed-filling stages, with the former resulting in crop maturation 127 days early, reduced water use efficiency, seed and oil yield, and oil content (Tesfamariam et al., 2010).

Effect of salinity stress on canola growth and productivity

Similar to drought stress, soil salinity is also a major abiotic stress that decreases the productivity of crops worldwide (Yamaguchi and Blumwald, 2005). When exposed to salt stress, the growth and development of many plant species, including *Brassica* species, is negatively affected by limiting physiological, biochemical and metabolic processes as a result of osmotic stress, ion toxicity, and reduced water and mineral availability (Hasegawa et al., 2000).

In *Brassica* spp., salinity reduced the levels of nutrients (Fe, Mn, Zn) in leaves, stems and roots at flowering and pod stages (Chakraborty et al., 2016). Reduced plant height caused by saline stress is caused by reduced osmotic and leaf water potential, and increased electrolyte leakage (Dolatabadi and Toorchi, 2017). Salt stress negatively impacted canola seed germination (Mahmoodzadeh, 2008), radicle and plumule length and seedling fresh weight (Bybordi and Tabatabaei, 2009; Bybordi, 2010a), reduced biomass (Bybordi, 2010b), inhibited the seed-filling phase, reduced the number of seeds per pod, number of pods per plant, pod length and plant height (Zamani et al., 2010; Mohammadi et al., 2012), formed fewer leaves, branches, flowers, siliques, shorter siliques, and fewer seed per silique and 1000-seed weight (Mahmoodzadeh, 2008), reduced leaf size and nutrient absorption levels of leaves (Shainberg and Shalhevet, 2012), reduced root, hypocotyl and leaf growth in seedlings with a concomitant rise in IAA oxidase and peroxidase activity (Bybordi et al., 2010a), reduced chl a , chl b and total chl content (Nazarbeygi et al., 2011; Bahrani, 2013), reduced total fatty acids by 25% (Bybordi et al., 2010b), reduced dry matter, plant height, seed yield and

1000-seed weight (Shabani et al., 2013), and reduced root length, seedling fresh weight, seedling dry weight, RWC, ion leakage and chl content in seedlings of five cowpea cultivars (El-Shaieny, 2015). The decrease in chl content as salinity increased resulted in lower dry weight and reduced leaf area, but this reduction in leaf area and plant height did not occur in salt-resistant canola cultivars (Kamrani et al., 2013). Proline accumulated in the roots of seedlings a salinity-tolerant canola cultivar but in the shoots of a salinity-sensitive cultivar (Saadia et al., 2012).

Rameeh (2012) found in eight canola genotypes that as salinity increased, potassium (K^+) ion concentration decreased while the concentration of calcium (Ca^{2+}) and sodium (Na^{2+}) ions increased, reducing photosynthetic rate. This despite the fact that an increase in Na^{2+} and the Na^+/K^+ ratio in shoots and roots tends to occur under salt stress in a mangrove species (Parida and Das, 2005). The accumulation of Na^{2+} and chlorine (Cl^-) ions increases osmotic potential and decreases water availability and nutrient uptake by plant roots (Acosta-Motos et al., 2017). Toxic metabolic Na^{2+} ions compete with K^+ in several major physiological processes in cells (Tester and Davenport, 2003). Therefore, electrolyte leakage, which increases in response to salinity (Mohammadreza et al., 2012), is due to increase in metabolites and concentration of ions, which is associated with an increment of Cl^- and Na^+ entry and exclusion of K^+ . These resulted in a significant reduction of shoot and root dry weight, number of leaves and shoot height under salt stress (Bandeh-hagh et al., 2008). Islam et al. (2001) observed that high salt concentration in the root zone affected growth and yield in canola and mustard by upsetting water and nutritional balance. The decrease in seed yield in *Brassica* spp. as a result of salinity stress is due to lower stomatal conductance, nutrient uptake and photosynthesis, greater ion toxicity and an imbalance of nutrient availability (Ashraf and McNeilly, 2004).

In the leaves of five salt-stressed canola cultivars, ROS-scavenging enzymes (Superoxide dismutase, SOD; catalase, CAT; Glutathione reductase; Monodehydroascorbate reductase), as well as reduced glutathione concentration were higher than in unstressed leaves (Bybordi et al., 2010c). Even though salt increased levels of MDA, hydrogen peroxide (H_2O_2) and phenolics were observed in a salt-sensitive canola cultivar, low levels of MDA in salt-tolerant canola plants accumulate high cellular levels of H_2O_2 (Rasheed et al., 2014). *In vitro* plantlets grown in the presence of NaCl and SA showed increased levels of chl, carotenoids and flavonoids, proline and soluble protein (Razavizadeh, 2015).

Despite these negative effects, oilseed brassicas have wide tolerance to salt stress allowing them to adapt to a wide range of cultural, climatic and biological environments (Ashraf and McNeilly, 2004).

Management strategies for canola under drought and salt stress

Management of canola under drought stress

Hydroponics combined with the addition of AsA can improve the physiology of salt-stressed canola (Bybordi, 2012). The foliar application of antioxidants (AsA or SA, at 200 mg l^{-1} each) under various irrigation intervals impacted canola productivity by reversing the negative impact of water deficit,

and highest seed yield was observed in a two-year study when both antioxidants were applied (EL Sabagh et al., 2017). In that study, as the distance between irrigation intervals widened, from 25, to 35, and then to 45 days, RWC_{leaf} , chl content, number of siliques per plant, seed yield, oil content and oil and protein yield decreased significantly, but the application of AsA or SA restored values, or even improved them, relative to the control. AsA at 25 mM reduced the harmful results of NaCl-induced oxidative stress, as observed by an increase in SOD, CAT and POX activity, and improved protein and chl content (Dolatabadian et al., 2008, 2009). SA plays a role as a non-enzymatic antioxidant in canola (Salarizdah et al., 2012) and was found to enhance the antioxidant ability of canola leaf cells and initiate new protein synthesis in the photosynthetic apparatus under drought stress, thereby improving photosynthesis (Tirani et al., 2013). SA stabilized RWC more than AsA in different deficit irrigation (soil moisture) treatments in canola (Ahmadi et al., 2015). Ullah et al. (2012) also found that application of SA and putrescine mitigated the adverse effects of drought on canola by enhancing the accumulation of soluble proteins and proline, thereby improving RWC_{leaf} . They also noted that the applied SA and putrescine maintained the water availability of canola plants, improved the accumulation of the osmolyte proline and protected photosynthetic pigments from the adverse effects of drought stress. Moisture-stressed canola seeds that were coated with a polymer did not improve seed germination relative to control and film-coated seeds (Willenborg et al., 2004).

Physical means to alleviate salinity stress have also been used to a limited extent in canola. Mohammadi et al. (2012) exposed canola seeds to laser irradiation showed an improvement of yield and yield-related components.

Management of canola under salinity stress

Several researchers have attempted to assess the response of canola to salt stress by trying to overcome salt-induced damage via the use of proline or GB (Bandehagh et al., 2013; Dawood and Sadak, 2014), which generally positively impacts the physiology and growth of plants (Ashraf and Foolad, 2007). Bandeh-hagh et al. (2008) conducted a study with 12 canola cultivars exposed to different levels of salinity stress (125 or 250 mM NaCl) and found that proline improved the osmotic adjustment of all cultivars as salinity level increased. At 250 mM, the contribution of Na^+ and proline to osmotic adjustment was 1.4- and 1.7-fold higher than at 125 mM, while GB contributed less to osmotic adjustment than proline.

Similarly, Sakr et al. (2012) conducted a field experiment to assess whether 200 mg L⁻¹ proline and 400 mg L⁻¹ GB could mitigate the harmful effect of soil salinity stress on canola. They found that all growth parameters, photosynthetic pigments, K and P contents decreased as salinity stress increased, but proline and GB alleviated these negative effects. The application of triacontanol, a plant growth regulator, to salt-stressed canola plants improved proline and GB levels, as well as a host of other physiological parameters (Shahbaz et al., 2013). The accumulation of compatible solutes such as proline and GB allow canola plants to maintain water balance and develop salt tolerance (Athar et al., 2009, 2015). Athar et al. (2009) found that exogenous application of GB and proline at the seed

germination and seedling stages ameliorated the damage effects of salt stress on canola and increased germination and seedling growth properties. They also noted that GB and proline protected membranes and proteins against the destabilizing effects of dehydration during abiotic stress. When Sakr and Arafa (2009) applied spermine or AsA to salinity-stressed canola plants, the content of photosynthetic pigments, K and P decreased while the content of proline, soluble sugars, AsA, Na and Cl increased. Dawood and Sadak (2014) conducted a pot experiment in Egypt to study the effect of 10, 15 and 20 mM GB on growth, photosynthetic pigments, osmoprotectants, antioxidant enzymes, seed yield quality and yield of canola under moderate and severe drought stress. They found that GB at all concentrations significantly increased the contents of IAA, proline, and total soluble sugars, but significantly decreased the content of MDA, H₂O₂, and antioxidant enzymes (POX, PPO, SOD, CAT, APX and NR) in canola under drought stress. Similarly, all levels of GB also significantly increased seed yield, oil, carbohydrate, protein, total phenolic content, tannins, and antioxidant activity of drought-stressed seeds relative to the control.

Managing abiotic stresses in canola via improved agronomic practices

Abiotic stresses can be mitigated by developing resistant/tolerance genotypes, or by developing suitable agronomic practices that can allow crops to adapt to a changing climate, such as the use of bio-regulators in cluster bean (Meena and Meena, 2017). Agronomic aspects such as adjustments to sowing time, depth, and plant density, soil manipulation through tillage practices, irrigation scheduling, soil salinity or sodicity reclamation, and plant nutrient supply with precise application of required fertilizers, can all improve crop growth and thus productivity (Hu et al., 2017). The majority of canola research that aimed to improve these aspects were to attain higher resource use efficiency, maximize farm output of economic products, improving farmers' income, and to improve and/or maintain soil health and sustainability (Shekhawat et al., 2012; Ravella et al., 2018).

Conclusion

Drought and salinity are two major abiotic stresses that can negatively affect canola growth and productivity. Sensitivity to salt in *Brassica* spp. is strongly dependent on the cultivar or genotype used (e.g., Su et al., 2013), each with a different salinity tolerance or threshold level, with *B. napus* and *B. campestris* classified as semi-saline-tolerant species (Miyamoto et al., 2012). A total of 34 canola accessions showed a range of sensitivities to salt stress under hydroponic conditions (Ulfat et al., 2007). Given the high heritability of yield-related traits in canola (Ali et al., 2003), selection for salt-resistant varieties using traditional breeding may be a viable strategy. In canola, the salinity tolerance level of early stages of the crop is higher than later growth stages (Ashraf and McNeilly, 2004). Salinity above a threshold level reduces crop yield (Purty et al., 2008). The ideal development of suitable salt-tolerant varieties should thus be based on the salt tolerance at different developmental stages (Athar et al., 2009). Physiological and biochemical alterations in plants

caused by both these stresses occur mainly due to lowered stomatal conductance, a decrease in chl content, limited enzyme activity, higher ROS-induced oxidative damage, and poor membrane stability, ultimately leading to a decrease in seed yield and yield-related attributes. Even so, simply by selecting cultivars that yield higher 1000-seed weight may allow for the selection of saline-tolerant canola (Rameeh et al., 2012). Some negative consequences of abiotic stresses are inevitable, but select management or breeding (Mansoori et al., 2017) strategies, such as the use of drought-resistant genotypes, adjustment of crop sowing date (Gul and Ahmad, 2007), use of mulch materials, adjusted irrigation (Gul and Ahmad, 2004), adjusted fertilization (Ahmad et al., 2007; Ebrahimian et al., 2017), and other agronomic methods (CCC, 2017b), may ensure higher productivity in canola. For example, deficit irrigation that omits watering at the flowering and seed-ripening stages will cause the greatest reductions in grain and oil yield, so if water via irrigation is to be limited, then this should not occur at these stages (Istanbulluoglu et al., 2010). The exogenous application to soil of some osmoprotectants or compatible solutes with organic amendments and essential nutrients may provide an economically viable and environmentally sound management strategy for sustainable canola production under abiotic stress in arid and semi-arid environments. When all of these agronomic options are exhausted, a range of molecular strategies to improved abiotic stress resistance in *Brassica* spp. exist (Zhang et al., 2014).

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