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Heat and Drought Stress Response and Related Management Strategies in Oilseed Rape

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ABSTRACT

Oilseed rape (*Brassica napus* L.) is one of the most important oil crops severely affected by heat or drought stress. Although the acreage and production of oilseed rape have been increasing steadily in the world, there are still serious concerns about edible oil demands supply for 9.1 billion by 2050. In addition, ongoing climate change and the susceptibility of oilseed rape to abiotic stresses threaten oilseed rape production in many parts of the world. Oilseed rape crops are particularly concerned with more frequent heat and drought stress. By facing oilseed rape crop with heat or drought stress, reduction in yield and yield component, oil concentration and change in fatty acids composition and phenological traits would be expected. On the other hand, there are several ways to mitigate the severe response of the plant to heat or drought stress such as detecting tolerant genotypes and modifying the planting method, sowing date, and tillage system. Additionally, optimization of plant growth regulators, fertilizers, bacterial growth regulators, and superabsorbent polymers is recommended to decrease the negative effects of drought or heat stress. Therefore, although heat or drought tolerance causes yield reduction but utilizing appropriate methods could reduce their disastrous effects.

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1. Introduction

Brassicaceae is considered one of the top 10 economically essential crop plant families (Warwick *et al.*, 2006). Among this family, oilseed rape (*Brassica napus* L) has been used for thousands of years for oil production (Wu *et al.*, 2018). According to the FAO report, oilseed rape is ranked as the second main oilseed crop after soybean, which is harvested in the area of 44130191 ha all over the world (FAO, 2018).

Abiotic stress like heat and drought stress causes yield reduction. This could be due to assimilating supply limitation which is the main reason for seed absorption (Mendham and Salisbury, 1995). Based on the previous definition of heat and drought stress for oilseed rape, 20/18 ºC, 28/18ºC, and 35/18ºC are defined as normal-, moderate- and high-temperatures, respectively. Likewise, 90% and 50% of water availability are defined as low and high water shortage stress (Gan *et al.*, 2004). Oilseed rape yield is significantly affected by drought conditions (Resketo and Szabo, 1992; Richards, 1978). Ongoing climate change leads to increased abiotic stress, including heat and drought stress that threatened oilseed rape production (Lobell and Gourdji, 2012). It has been also reported that oilseed rape and other Brassica species are most affected by drought because they are mainly grown in the arid and semi-arid regions. Therefore, different strategies have been hired to cope with drought stress, including; developing irrigation systems, improving crop management, and applying plant breeding methods (Majidi *et al.*, 2015). In the current review, we discussed the response of oilseed rape to heat or drought stress in terms of yield and yield components, phenology, oil and protein concentration, fatty acid composition and physiology. Additionally, different management strategies like detection of

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drought tolerant cultivars and optimization of plant growth regulators, fertilizers, bacterial growth regulators, and superabsorbent polymers are reviewed in this study.

2. Oilseed rape response to heat and drought stress

2.1. Yield and yield components response

Based on the published results, a decrease in yield component in response to heat and drought stress leads to a grain yield reduction in oilseed rape. It was shown that complete irrigation during flowering and primary stages of pod development, increases pod number and seed number in pods; but the average of 1000 seed weights was less affected than seed number in a pod (Jensen *et al*., 1996). It has been reported that drought stress caused decreases in the number of branches per plant, the number of seeds per pods, the number of pods per plant, 1000-seed weight, seed yield, plant height, and oil content (Bagheri and Jamaati-e-Somarin, 2011; Jan *et al*., 2017; Mirzaei *et al*., 2013) Ten days of water shortage and high temperature affected flowering, bud formation, and pod development (Gan *et al*., 2004).

It has been found that high temperature reduced 75%, 25%, and 22% of main stem pods, seed pod, and seed weight, respectively. Additionally, pod formation, flowering, and pod development were reduced by 15%, 58%, and 77% under high-temperature, respectively which lead to yield reduction (Gan *et al*., 2004). The flower number and Seed size and weight are the major yield components which reduced under heat or drought stress conditions in oilseed rape (Jan *et al*., 2017). The reduction of seed weight has been also reported for wheat and lupins under heat stress (Reader *et al*., 1997; Stone and Nicolas, 1994). It has been shown that heat stress reduces the seed filling duration of oilseed rape (Aksouh-Harradj *et al*., 2006). Aksouh-Harradj et al. reported considerable seed weight reduction under episodes of heat stress. They reported seed weight reduction as the main factor responsible for yield reduction under heat shock at the flowering stage (Aksouh-Harradj *et al*., 2006).

Yield is the final quantitative trait affected by heat or drought stress conditions. Heat or drought stress lead to the reduction of yield of oilseed rape (Gan *et al*., 2004). It has been reported the yield reduction is up to 52%, especially on the main stem in the sensitive oilseed rape cultivars by the heat shock for the short time. On the other hand, low or no yield reduction was observed under mild temperature stress (Aksouh-Harradj *et al*., 2006).

2.2. Phenological responses

It should be considered that heat or drought stress has its effects at each phenological stage. The seedling establishment phenological stage is defined as a critical stage that could be damaged to the crop under abiotic stress (Raza *et al*., 2017). Drought stress during seed sowing leads to poor seed germination and seedling emergence (Mwale *et al*., 2003). It has been reported the recovery exhibition when the oilseed rape faced abiotic stress at the earlier growth stage. On the other hand, the severe reduction in yield and yield component was already reported when oilseed rape faced heat or drought stress at the reproductive growing stage (Gan *et al*., 2004). Under late-season drought stress, the oil yield of oilseed rape is decreased particularly during the flowering and seed-filling stages.

Studies have shown that seed filling, pollination, and flowering are sensitive stages to drought stress in many plants (Robertson *et al*., 2004). The maximum yield reduction of oilseed rape was obtained when water stress occurred at the pod forming stage (Masoud, 2007). The flowering stage and pod setting are critical stages to drought stress in oilseed rape (Rao and Mendham, 1991). Effects of different irrigation regimes at the flowering stage on oilseed rape showed that water stress decreased significantly grain yield and biological yield (Mathur and Wattal, 1995).

Several studies also reported that the flowering and seed forming stages are the most sensitive stage in oilseed rape under drought stress which cause the reduction of seed weight, grain yield, and oil content (Din *et al*., 2011; Haq *et al*., 2014; Mirzaei *et al*., 2013). However, varieties like Con-III showed appropriate performance at different growth stages under drought stress conditions (Haq *et al*., 2014). Additionally, it has been shown that heat stress induces flowering and also flowering primordia (Angadi *et al*., 2000; Tayo and Morgan, 1975). Under the high temperature, fertile pods could be developed from the early formed flowers; while they might not be able to do so for the later-formed flowers (Angadi *et al*., 2000; Tayo and Morgan, 1975).

2.3. Oil and protein concentration

Oil and protein contents are the main quantitative characteristics of oilseed rape affected strongly by heat and drought stress. It has been reported that oil concentration is reduced under heat (Aksouh-Harradj *et al*., 2006) and drought stress (Tesfamariam *et al*., 2010). A cool environment, as well as adequate water supply, leads to an increase in the oil content; while heat or drought stress causes the reduction of oil content (Aslam *et al*., 2009; Mailer and Pratley, 1990; Mailer and Cornish, 1987; Mendham *et al*., 1990; Pritchard *et al*., 2000; Walton *et al*., 1999). These conditions are critical especially during flowering and crop maturity (Aslam *et al*., 2009; Walton *et al*., 1999).

The oil and protein content of oilseed rape seeds is influenced by heat or drought stress greatly (Aslam *et al*., 2009; Canvin, 1965). It has been shown by decreasing in growing season rainfall, oil percentage of oilseed rape decreased while protein percentage is increased (Pritchard *et al*., 2000; Si *et al*., 2003; Si and Walton, 2004). Mild temperature caused the induction of the oil/protein ratio of oilseed rape cultivars; while heat shock increases the protein concentration and reduced the oil concentration of oilseed rape seeds (Canvin, 1965). It has been shown that long-time mild temperature could not disturb oilseed rape production like short-time heat shock (Aksouh-Harradj *et al*., 2006).

A strong negative correlation between oil and protein has been observed especially in response to abiotic stress (Aksouh *et al*., 2001; Aslam *et al*., 2009; Bouchereau *et al*., 1996; Canvin, 1965; Cowling and Tarr, 2004; Dornbos and Mullen, 1992; Gibson and Mullen, 1996; Gunasekera *et al*., 2006; Pritchard *et al*., 2000; Triboi-Blondel and Renard, 1999). A similar model of starch/protein synthesis in cereals is hypothesized for oil/protein synthesis in oilseeds (Aksouh-Harradj *et al*., 2006).

2.4. Fatty acid composition

Fatty acid compositions are strongly affected by heat or drought stress conditions. The oil markets are demanding oilseeds with high oleic acid and linolenic acid profiles (Aslam *et al*., 2009); but this composition might be prevented by heat or drought stress by decreasing oleic acid and inducing linolenic acid.

It was shown that under drought stress the oil and linoleic acid contents decreased, but the glucosinolate, stearic acid, and erucic acid contents increased (Moghadam *et al*., 2011; Ullah *et al*., 2012). It has been reported that heat stress increased oleic acids but led to decreasing in linoleic and linolenic acids during seed maturation of oilseed rape (Canvin, 1965; Downey, 1983; Gibson and Mullen, 1996; Green, 1986). Additionally, saturated fatty acids including palmitic and stearic acids are increased during heat stress (Aksouh-Harradj *et al*., 2006). On the other hand, it has been observed that oleic acid saturated fatty acid decreased under drought stress while linoleic acid and linolenic acid increased (Aslam *et al*., 2009). It should be noted that any change in the fatty acid composition depends on the genotype (Aslam *et al*., 2009).

Glucosinolates are also accumulated in oilseed rape seeds when the plant is faced with heat or drought stress after a flowering stage which leads to a reduction of oil quality (Bouchereau *et al*., 1996). It has been reported that heat shock for the short time showed less effect on the composition of fatty acids (Aksouh-Harradj *et al*., 2006).

2.5. Physiological response

It has been already reported a reduced level of relative water contents, osmoticthe potential, fresh and dry weight of shoot and root, shoot and root length, crop growth rate, relative growth rate, and leaf area index (LAI) under drought stress in oilseed rape (Khan *et al*., 2010; Moaveni *et al*., 2010).

It was also found the meaningful reduction of mineral composition including K^+, Ca^{2+}, N, and P in oilseed rape under drought stress (Ashraf *et al*., 2013). Based on previous results, genotypes with a higher concentration of K+ and N in their shoot are more tolerant to drought stress notably at the flowering stage (Ashraf *et al*., 2013).

On the other hand, the accumulation of some metabolites like proline has been observed frequently (Khan *et al*., 2010). Rainbow cultivar, which was identified as a drought-tolerant cultivar, produced more proline under drought stress (Din *et al*., 2011). Accumulation of proline and increase in ascorbate peroxidase activity and K^+ uptake have been reported as drought tolerance induction mechanisms in oilseed rape (Moradshahi *et al*., 2004). Proline maintains the osmotic pressure, stabilizes the cell membrane, and protects the proper protein structure from denaturing (Claussen, 2005).

3. Management strategies

There are several strategies to mitigate heat or drought stress for oilseed rape crops. The main aims of the applied methodologies are to conserve water as well as increase water use efficiency (Raza *et al*., 2017).

3.1. Planting methods

Optimization of the planting methods is defined as the essential way to mitigate heat or drought stress. Broadcasting in oilseed rape leads to yield reduction due to imbalanced water availability, poor seedling establishment, and uneven seed distribution (Mwale *et al*., 2003). Several methods have been used in oilseed rape cultivation to conserve the water stress; including furrow planting (Zhang *et al*., 2007) raised bed planting (Kukal *et al*., 2010), and drill sowing (Aiken *et al*., 2015). It has been shown the better emergence and crop stands in drill sown rather than the broadcast method in oilseed rape (Aiken *et al*., 2015). Young et al reported a better seed yield and oil percentage in drill sowing than broadcasting (Young *et al*., 2008). Additionally, furrow sowing showed better growth of the plant and also a higher yield than ridge sowing in oilseed rape (Shabani *et al*., 2013). Furrow sowing has been introduced as one of the main strategies in water saving. The seed yield and water use efficiency increased 13.7% and 13.2%, respectively than ridge sowing (Buttar *et al*., 2006). Additionally, the water evaporation decreased by utilizing furrow sowing (Buttar *et al*., 2006).

3.2. Sowing date

Sowing date is one of the essential parameters in oilseed rape to cope with drought stress. On-time sowing led to on-time maturity of the plant before facing late seasonal heat and drought stress. It has been already reported that the delayed sowing of oilseed rape considerably decreased seed and oil yield (Sharghi *et al*., 2011; Shirani Rad *et al*., 2017).

3.3. Minimum tillage

Stubble retention and reduced tillage lead to saving soil water by decreasing evaporation losses, surface runoff, and increasing soil water infiltration (Ji and Unger, 2001; Van Eerd *et al*., 2014). The enhanced oilseed rape grain yield and oil content were already shown by the minimum tillage with 4 t ha^{-1} residue through providing favorable rainfall interception and favorable soil surface characteristics. Therefore, it is possible to maintain heat and drought stress conditions by effective residue management and practicing minimum tillage (Abdullah, 2014).

3.4. Application of plant growth regulators

The application of plant growth regulators is anotherstrategy to mitigate heat or drought stress through modification of the physiological process. These regulators adjust roots, leaves, and stem formation, elongation, germination, and flowering. Exogenous application of these regulators could mitigate the negative effects of heat and drought stress (Raza *et al*., 2012; Raza *et al*., 2017). It has been also observed that the oil content is increased utilizing plant growth regulators (Ullah *et al*., 2012).

Several plant growth regulators have been used previously like ascorbic acid, abscisic acid, salicylic acid, gibberellic acid, and cytokinin to enhance heat or drought tolerance (Farooq *et al*., 2009; Shafiq *et al*., 2014; Ullah *et al*., 2012). The Foliar application of salicylic acid and methanol showed more influence to maintain relative water content compared to ascorbic acid under drought stress at the flowering stage (Kalantar Ahmadi *et al*., 2015). Salicylic acid plays an important role to improve seed proteins under water deficiency and counteract the disastrous effects of drought stress on oil quality indices (Farooq *et al*., 2009; Shafiq *et al*., 2014; Ullah *et al*., 2012).

Erucic acid also reduced the oil quality by increasing the pungent smell of oil as well as glucosinolate especially under heat or drought stress that could also be inhibited by using salicylic acid (Ullah *et al*., 2012). It has been shown that the foliar application of plant growth regulators including salicylic acid and putrescine declined the negative effects of drought stress through induction of relative water contents, chlorophyll content, carotenoid content, and proline content (Ullah *et al*., 2012).

Glucosinolates accumulation is one of the major problems in oilseed rape production under heat or drought stress (Bouchereau *et al*., 1996). It has been already reported that by putrescine application the accumulation of glucosinolates is reduced significantly (Ullah *et al*., 2012). Penconazole is another reported growth regulator which could decrease the negative effects of drought stress in oilseed rape through the induction of 1,1-diphenyl-2-picrylhydrazyl, succinate dehydrogenase, chlorophyll, carotenoid, and K+ content in oilseed rape under drought stress (Rezayian *et al*., 2018).

3.5. Application of fertilizers

The efficiency of fertilizers is affected by abiotic stress like water deficiency. The water use efficiency of plants is improved by soil fertility (Buttar *et al*., 2006; Caviglia and Sadras, 2001). Fertilized soil leads to deep and large root systems (Caviglia and Sadras, 2001). Therefore, the consumption of fertilizers should be considered to reduce the negative effects of high temperatures and drought stress.

One of the essential fertilizers for oilseed rape growth is nitrogen, but it is necessary to balance the use of this fertilizer under drought stress (Danesh-Shahraki *et al*., 2008). It has been reported that vermicompost plays a positive role in oilseed rape under drought stress conditions. Vermicompost application leads to gain higher growth, biomass, and yield of oilseed rape under drought stress (Rashtbari *et al*., 2012).

Some elements are beneficial for plants, such as aluminum, calcium, cobalt, sodium, selenium, silicon and, zink. These elements are documented as positive regulators for plant growth and abiotic stress tolerance (Epstein, 2009; Rezayian *et al*., 2018). Silicon is an important fertilizer element that acts in plant water status and ion balance which enhanced the volume and weight of roots and drought tolerance (Ahmed and Khurshid, 2011; Sonobe *et al*., 2010). It was also shown that silicon application induced active osmotic adjustment roots and enhanced water uptake in oilseed rape under drought stress. Additionally, silicon application induces CAT and SOD activities and inhibits lipid peroxidation which leads to the induction of the antioxidant system and drought tolerance (Habibi, 2014).

Heat or drought stress increases the rate of reactive oxygen species (ROS). It was shown that selenium foliar applications cause an increase in antioxidant enzyme activities which lead to reduced ROS activities in oilseed rape (Zahedi and Moghadam, 2011). It was already shown the positive effect of selenium foliar application on plant height, pod numbers, number of seeds in pod, biological yield, grain yield, oil yield and harvest index (Zahedi *et al*., 2009). Likewise, zink foliar application enhanced the performance of oilseed rape under water deficiency conditions and its foliar application is recommended for regions subjected to water stress (Shahsavari *et al*., 2014).

3.6. Application of bacterial plant growth promoter

Several studies reported various bacteria (i.e., *Azotobacter* sp., *Azospirillum* sp., *Acetobacter* sp., *Bacillus*, *Pseudomonas* sp.) as plant growth promoters that enhance abiotic stress (Turan *et al*., 2006). Plant growth-promoting *Rhizobacteria* could regulate growth and yield under abiotic stress (Thakore, 2006). *Azospirillum* spp inoculation can improve drought tolerance and the growth of plants in arid and semiarid regions (Ilyas and Bano, 2010). The inoculation of seeds by *Azospirillum* mitigates deleterious effects of drought stress in oilseed rape by improving germination percentage, root area, chlorophyll contents, water potential which affected seeds per pod and seed weight per plant (Maimona *et al*., 2016).

3.7. Application of superabsorbent polymers

One of the ways to increase the available water in the soil is by applying superabsorbent polymers that supply water to crop roots (Pawlowski *et al*., 2009). The irrigation frequency could be decreased by superabsorbent polymers by increasing the irrigations gaps, thereby saving on water cost and energy (Sivapalan, 2001). It has been already reported that the linoleic acid content increased by using superabsorbent polymer, but the other components decreased (Moghadam *et al*., 2011).

Recently, the application of zeolite as a superabsorbent polymer has increased in agricultural production under abiotic stress because of its cation exchanging capacity and high absorption capacity (Shirani Rad, 2011). The application of zeolite reduces the nutrients leaching, particularly nitrates which plays an essential role in agricultural production (Zahedi *et al*., 2009). One of the important roles of zeolite is its selective uptake which regulates the diffusion of nutrients leads to plants overcoming deficiencies (Masoud, 2007). Other characteristics of zeolite that make it an excellent material for soil reinforcement are its inexpensiveness, supply abundance, and structural stability that enhance drought stress tolerance and optimize fertilizer use (Ok, 2003).

Lipid peroxidation and oxidative stress which is mediated by the production of oxygen radicals are defined as an issue during heat and drought stress of oilseed rape production, especially for sensitive ones. Superabsorbent polymers like zeolite could mitigate this limitation to some extent. It has been already reported by addition zeolite to the soil the drought tolerance of oilseed rape increased through the increasing of soil ability of water-saving, root length, dry weight, germination percent and root/shoot ratio (Armandpisheh *et al*., 2009; Tohidi Moghadam *et al*., 2009; Zahedi and Moghadam, 2011).

3.8. Application of tolerant cultivars

The responses of cultivars are different under heat and drought stress conditions. As an example, no response to heat stress during mid-pod development has been observed for cultivar Insignia while cultivar Surpass400 was mostly affected by heat stress and was not able to complete its seed filling (Aksouh-Harradj *et al*., 2006).

The genetic potential of oilseed rape genotypes at various growth stages is different (Ashraf *et al*., 2013). The different responses of varieties have already been reported in plant biomass production for oilseed rape under drought stress (Abedi and Pakniyat, 2010). This variation in plant responses has also been demonstrated in nutrients (K+, Ca+, N, P) uptake of oilseed rape varieties under drought stress. So that, more reduction in nutrient uptake was observed in sensitive varieties that might be due to less solubility and altered physiological process of sensitive varieties (Fageria *et al*., 2002; Garg, 2003). This reduction in nutrient uptake in sensitive varieties is also might be due to a reduction in transpiration rate, active transport, membrane permeability, and tissue nutrient concentration (Baligar *et al*., 2001; Gunes *et al*., 2006; McWilliams, 2019).

The superior cultivars under drought stress are different in their morphological and physiological aspects. For example, Rainbow, which was chosen as a drought-tolerant cultivar, produced more proline under drought stress (Din *et al*., 2011). It has been reported that root/shoot length is not the same among different cultivars and whole plants, root length, root/shoot ratio are significantly affected by drought stress (Khalaj *et al*., 2007).

Additionally, different varieties showed various reactions in their germination rates, and most of the varieties showed a reduction in their germination (Shahverdikandi *et al*., 2011). Among the evaluated cultivars in the west of Iran, Hayola401 has been reported as the most tolerant with higher grain yield and yield component (Mirzaei *et al*., 2013). Another study reported Elite as the most drought tolerant (Sepehri and Golparvar, 2011). Sarigol cultivar also showed the least water consumption efficiency rate (Nazemi and Alhani, 2014). However, another study of the effect of drought stress on oilseed rape cultivars, Sarigol and Zarfam yielded more than Okapi under drought conditions (Zarei *et al*., 2010).

4. Tolerant varieties determination

High temperatures and drought stress are common abiotic stresses which oilseed rape varieties faced particularly in the tropical regions. Therefore, it is necessary to check new promising oilseed rape genotypes in the various tropical regions before releasing the new cultivar which confirms their relative tolerance to heat and drought stress (Bakhshi *et al*., 2021). However, some methods have already been introduced to ensure the high tolerance of oilseed rape genotypes to abiotic stress and reviewed in the continues.

Relative water content (RWC) is identified as one of the essential characteristics to determine leaf water status of genotypes to detect heat or drought tolerance ones. The following formula represents how to calculate the RWC. In the formula, FW is the recorded fresh weight, DW is the recorded dry weight (dried leaves at high degree for several hours) and TW is the recorded turgid weight (floated in distilled water until turgescence) (Majidi *et al*., 2015).

$$\mathrm{RWC} = \frac{\mathrm{FW-DW}}{\mathrm{TW-DW}} \times 100 \qquad (1)$$

Water use efficiency (WUE) is also introduced as an indirect drought-tolerant cultivar selection method for grain yield under drought stress conditions in oilseed rape (Faraji *et al*., 2009). Water use efficiency is usually calculated based on the grain yield or total biomass produced per unit of water consumed by crops.

Identifying tolerant genotypes among the available resources of oilseed rape would be a valuable method to cope with stress. Several types of research have been performed to identify tolerant and susceptible cultivars using stress-tolerant and susceptibility indices. Analyzing stress tolerance indices is reported as one of the standard methods in terms of drought tolerance evaluation (Clarke *et al*., 1992). Mean Productivity (Rosielle and Hamblin, 1981), Tolerance Index (Rosielle and Hamblin, 1981), Geometric Mean Productivity (Fernandez, 1993), Stress Tolerance Index (Fernandez, 1993), Stress Index (Fischer and Maurer, 1978b), Stress Susceptibility Index (Fischer and Maurer, 1978b), Yield

Stability Index (Bouslama and Schapaugh, 1984) and Harmonic Mean Productivity (Schneider *et al.*, 1997) are some essential indices for identifying drought-tolerant and susceptible varieties. Evaluation of cultivars under normal and stress conditions simultaneously has been also reported as a beneficial way to identify drought-tolerant cultivars (Simane *et al.*, 1993). According to the stress tolerance index and geometric mean productivity, Licord and Talaye cultivars were the most appropriate ones; Zarfam and Modena were found as resistant and sensitive to drought stress, respectively (Yarnia *et al.*, 2011). Likewise, by stress susceptibility index, Sarigol cultivar is categorized as drought-sensitive, while, Hyola308 and SW5001 were drought tolerant among spring cultivars (Khalili *et al.*, 2012). The formulas of stress tolerance indices are presented in table 1.

Table 1. Stress tolerant indices to identify tolerant varieties

Indices	Formula	References
Tolerance Index	$\mathrm{TOL} = \mathrm{YP} - \mathrm{YS}$	(Rosielle and Hamblin, 1981)
Mean Productivity	$\mathrm{MP} = \frac{(\mathrm{Yp} + \mathrm{Ys})}{2}$	(Rosielle and Hamblin, 1981)
Stress Tolerance Index	$\mathrm{STI} = \frac{\mathrm{Yp} \times \mathrm{Ys}}{(\bar{\mathrm{Y}}\mathrm{p})^2}$	(Fernandez, 1993)
Geometric Mean Productivity	$\mathrm{GMP} = \sqrt{\mathrm{Yp} \times \mathrm{Ys}}$	(Fernandez, 1993)
Yield Reduction	$\mathrm{YR} = \frac{\mathrm{YP} - \mathrm{Ys}}{\mathrm{YP}} \times 100$	(Choukan *et al.*, 2006)
Yield Index	$\mathrm{YI} = \frac{\mathrm{Ys}}{\bar{\mathrm{Y}}\mathrm{s}}$	(Gavuzzi *et al.*, 1997)
Harmonic Mean Productivity	$\mathrm{HM} = \frac{2(\mathrm{Yp} \times \mathrm{Ys})}{(\mathrm{Yp} + \mathrm{Ys})}$	(Schneider *et al.*, 1997)
Relative Drought Index	$\mathrm{RDI} = \frac{\left(\frac{\mathrm{Ys}}{\mathrm{Yp}}\right)}{\left(\frac{\bar{\mathrm{Y}}\mathrm{s}}{\bar{\mathrm{Y}}\mathrm{p}}\right)}$	(Fischer and Maurer, 1978a)
Modified stress tolerance index for non-stressed	$\mathrm{K1STI} = \frac{\mathrm{Yp}^2}{\bar{\mathrm{Y}}\mathrm{p}^2} \times \mathrm{STI}$	(Farshadfar and Sutka, 2002)
Modified stress tolerance index for stressed	$\mathrm{K2STI} = \frac{\mathrm{Ys}^2}{\bar{\mathrm{Y}}\mathrm{s}^2} \times \mathrm{STI}$	(Farshadfar and Sutka, 2002)
Yield Stability Index	$\mathrm{YSI} = \frac{\mathrm{Ys}}{\mathrm{Yp}}$	(Bouslama and Schapaugh Jr, 1984)
Stress Susceptibility Index	$\mathrm{SSI} = \frac{(1 - \frac{\mathrm{Ys}}{\mathrm{Yp}})}{(1 - (\frac{\bar{\mathrm{Y}}\mathrm{s}}{\bar{\mathrm{Y}}\mathrm{p}}))}$	(Fischer and Maurer, 1978a)

Abbreviation

GMP: Geometric Mean Productivity; HM: Harmonic Mean Productivity; K1ST1: Modified stress tolerance index for non-stressed; K2ST1: Modified stress tolerance index for stressed; LAI: leaf Area Index; MP: Mean Productivity; RWC: Relative Water Content; RDI: Relative Drought Index; SSI: Stress Susceptibility Index; STI: Stress Tolerance Index; TOL: Tolerance Index; WUE: Water Use Efficiency; YR: Yield Reduction; YI: Yield Index; YSI: Yield Stability Index;

Conflict of interest

The author declared that they have no conflict of interest.

Consent for publications

The author read and approved the final manuscript for publication.

Availability of data and material

The author declared that they embedded all data in the manuscript.

Authors' contributions

The idea, doing and writing the article was conducted by Behnam Bakhshi.

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