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REVIEW ARTICLE

Effect of drought and saline stress on seed quality

■ **M. PRAKASH**

SUMMARY

Seed germination and seedling establishment are the critical stages for all the plants. Insufficient seed germination and seedling emergence under abiotic stress conditions are the main constraints in the production of crops. These abiotic stresses particularly during seedling, vegetative and reproductive stages will certainly affect the crops and drastically reduce not only the seed yield but also the quality of seeds. In this review, an attempt has been made to present the available literature on effect of drought and saline stress in important crops.

Key Words : Drought, Salinity, Seed yield, Quality

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Quality seed production is very important in maintaining crop yield in all the crops. Plant growth is seriously affected by abiotic stresses such as drought, salinity or temperature. Drought and salinity are one of the most important limiting factors for agricultural crop production all around the world. Drought and salinity stresses during vegetative or early reproductive growth usually reduces yield by reducing the number of seeds, seed size and seed quality. These stresses not only affect the yield but also the quality of seeds harvested which in turn affect the next crop also.

Stress :

'Stress' or 'pressure' was introduced into the theory of elasticity as an amount of force for a given unit area (Cauchy, 1821). Plant stress has been defined as 'any unfavourable condition or substance that affects or blocks a plant's metabolism, growth or development' (Lichtenthaler, 1996).

Stress factors (or stresses) coming from outside need to be distinguished from stresses (or strains) within an organism. Factors that induce stress can be 'biotic', resulting from living organisms, such as fungi and insects, or 'abiotic', resulting from nonliving factors, such as drought, extreme temperatures, salinity and pollutants, for example heavy metals.

Abiotic stress :

Stress in plants includes any factors that could lead to the death of the plant. Alternately, exposure of plants to abiotic stresses like temperature (heat, cold chilling/ frost), water (drought, flooding), salinity, radiation (UV, ionizing radiation), chemicals (mineral deficiency/excess, pollutants heavy metals/pesticides, gaseous toxins), mechanical (wind, soil movement, submergence) cause reduction of more than 50 per cent of agricultural

AUTHOR FOR CORRESPONDENCE

M. PRAKASH, Department of Genetics and Plant Breeding, Faculty of Agriculture, Annamalai University, Annamalai Nagar, CHIDAMBRAM (T.N.) INDIA
Email: geeth_prakash@yahoo.co.in

production. Abiotic stresses adversely affect growth and productivity and trigger a series of morphological, physiological, biochemical and molecular changes in plants (Bhatnagar *et al*., 2008). Adaptation or tolerance to these stresses is absolutely necessary to maintain growth and life cycle of plants.

Despite the long-standing interest of plant scientists in stress concepts, surprisingly little attention has been given to seeds. Hence, a review on influence of abiotic stress on seed maturation and seed quality is attempted in this paper.

Drought stress :

Effect of drought stress on pollen grain viability :

Drought stress is a main abiotic stress that limits crop pollination by reducing pollen grain availability, increasing pollen grain sterility, decreasing pollen grain germination and pollen tube growth. The viability of maize pollen is related to its water content and to the drying conditions of the atmosphere. Drought stress has induced adverse effects on male gametophyte development resulting in fewer numbers of viable pollen.

In wheat, barley, and rice, abscisic acid (ABA) was implicated as a cause of pollen sterility. In maize, the decrease in the sugar stream due to losses in photosynthetic rate under drought stress appeared to be critical for the development of the female inflorescence.

Starch is considered a major energy source for pollen development and germination, hence the absence of this energy source could lead to pollen sterility. The level of starch has been reduced in anthers from plants exposed to water stress. Drought stress affects pollen grain viability by blocking the process of pollen grain germination and development. This process is also affected by the increase in level of ABA and limiting sources of energy such as sugar, starch and carbohydrate under drought stress .

Effect of drought stress on ovary development :

Development of ovary is one of the most vulnerable phases in response to drought stress (Boyer and Westgate, 2004) and it's very sensitive to insufficient energy sources.

Ovary abortion can account for substantial kernel losses when maize experiences low water potential near the time of pollination. The failure of silks to elongate can lead to the completion of pollen shed before silks emerge, which consequently decreases kernel numbers.

In soybean, ovary abortion was caused by only 2 or 3 days of low water potential, which was enough to inhibit leaf photosynthetic rates. Several studies have reported that ovary abortion under drought stress was related to breakdown of ovary starch (Andersen *et al*., 2002) or the delivery mechanisms of sugars more than the release mechanisms of sugars from the carbohydrate reserves in the parent plants.

Effect of drought stress on flower characteristics :

Flowering is one of the most important growth stage affected by drought stress. Drought stress interferes with flower period, flower opening, nectar production, and turgor maintenance of floral organs. Water stress detrimentally affects flower induction, pollen production and subsequently leads to failure of fertilization and hence grain set. Water stress during flower induction and inflorescence development leads to a delay in flowering (anthesis), or even complete inhibition of flowers. The effect of drought stress on pollination traits is briefly discussed (Table 1).

Table 1 : Effects of drought stress on pollination traits

Yield traits	Effects related to drought	References
Grains per spike	Decreased number of grains per spike	Samarah (2004) and Samarah *et al.* (2009a).
Fertile florets	Decreased number of fertile florets	Otegui and Slafer (2004).
Fertile spikes per plant	Decreased number of fertile spikes per plant	Samarah (2004) and Samarah *et al.* (2009a).
Sterile spikes per plant	Increased number of sterile spikes	Sanchez *et al.* (2002) and Samarah (2004).
Spikes per plant	Decreased number of spikes per plant	Sanchez *et al.* (2002); Samarah (2004) and Samarah *et al.* (2009a).
Individual grain weight	Decreased weight of individual grain	Sanchez *et al.* (2002); Samarah (2004) and Samarah *et al.* (2009a).
Grain yield	Decreased grain yield	Samarah (2004) and Samarah *et al.* (2009a).
Spike number per square meter	Decreased spike number per square meter	Sanchez *et al.* (2002); Garcia (2003) and Samarah *et al.* (2009a).
Straw yield	Decreased straw yield	Sanchez *et al.* (2002); Garcia (2003); Samarah (2004) and Samarah *et al.* (2009a)
Harvest index	Decrease harvest index	Samarah *et al.* (2009a).

Effect of drought stress on seed set :

Seed set is affected by all the development and growth processes in reproductive stage such as pollen grain and ovary development under drought stress. It's strongly correlated with yield, e.g. final number of seeds per kernel is one of the indicator for seed set percentage. Also, it's sensitive to biochemical contents such as ABA and energy sources. Inadequate energy source such as sugar and increased level of ABA leads to reduced seed set percentage by increased number of seed abortion and abnormality (Liu *et al*., 2004).

Low seed set percentages are related to several factors such as reduced pollen grain availability, increased ovary abortion (Boyer and Westgate, 2004), increased pollen grain sterility (Al-Ghzawi *et al*., 2009), slow stigma and style elongation, reduced time of pollination, lower pollen grain germination activity, pollen tube growth, and less development of fertilized seeds.

Water deficit in the meiotic stage also reduced grain set in self pollinated wheat and rice. In cereals, several lines of evidence have suggested that drought-induced large concentrations of abscisic acid in the reproductive structures exert a negative effect on fruit/seed set. Water deficits imposed during the reproductive development of dry beans can decrease number of flowers and pods per plant and number of seeds per pod.

An increase in abscisic acid content in the generative organs is one of the factors suggested to play a role in seed abortion and yield reduction in response to drought stress (Liu *et al.*, 2005). In soybean, pod set was positively correlated with photosynthetic rate and negatively correlated with the abscisic acid in pods (Liu *et al*., 2004).

Effect of drought stress on seed quality :

Drought stress during reproductive growth lowered seed germination and vigor. Seed quality, estimated by standard germination, was lower for seeds harvested from plants grown under drought than seeds harvested from irrigated plants.

Drought stress imposed on soybean during seed fill stage decreased standard germination by 5 per cent, seed vigor, as estimated by the decrease in seedling dry weight by 12 per cent, and an increase in electrical conductivity of seed leachate by 19 per cent. Drought stress during soybean pod fill reduced seed vigor, as measured by the accelerated aging test, but had no effect on lab and field emergence.

A reduction in seed vigor, estimated by electrical conductivity and cold tests, was observed in pea seeds obtained from plants exposed to drought stress during the entire reproductive period, but seed germination was not affected. It has been reported that decrease in seed quality was higher when drought stress occurred during the seed filling stage. Late-terminal drought stress imposed on barley plant after beginning of seed filling period had no effect on standard germination, but significantly reduced seed vigor by estimated the germination after accelerated aging test.

In peanut, water deficit during seed development slightly lowered seed germination, but had no effect on seedling vigor. Recently, Samarah *et al*. (2009b) found that the germination and vigor of soybean as estimated by the germination after accelerated aging test affected soybean seed quality by increasing the proportion of small-sized category seed (consisted of shriveled, wrinkled, undeveloped, and misshaped seeds), which had lower germination than large seeds due to exposed to drought stress.

The effects of drought stress on soybean [*Glycine max* (L.) Merr.] seed quality may be influenced by morphological plant characteristics and the timing of drought stress. Determinate soybean plants were grown near to ascertain the influences of the timing and frequency of drought stress and pod position on seed quality (as measured by germination, seedling dry weight, and seed leachate current). Plants were well-watered (high reproductive load) or drought-stressed at flowering (E)to decrease potential seed number (low reproductive load). Subsequent drought stresses were implemented at the full pod (R4), seed formation (R5), and full seed (R6) stages, in addition to a non stressed treatment. (Smiciklas *et al*., 1992).

The R2 + R4 drought-stress treatment significantly decreased seed number and did not increase weight per seed compared with the single R4 drought stress treatment. The imposition of an R2 drought-stress decreased plant dry weight compared with the nonstressed control. The duration of seed-fill period was reduced by an R5 or R6 single drought-stress treatment compared with the non stressed control. But, multiple drought-stress treatments had a similar duration of seed-fill compared with corresponding single drought-stress treatments (Smiciklas *et al*., 1992).

Reductions in seed quality by R5 or R6 drought stress were not prevented by the imposition of an R2 drought-stress. For example, germination percentages were not increased and seed leachate current was not decreased by multiple periods of drought stress, compared with the corresponding single drought-stress treatments. The visual rating of seed quality characteristics did not differ among the drought-stress treatments between the reproductive loads (data not shown). In contrast, R2 + R4 drought-stressed seed had increased seedling dry weight compared with the R4 drought-stress treatment (Smiciklas *et al*., 1992).

The effect of water stress on seed quality has been investigated in soybean (Simiciklas *et al*., 1992) and in peas (Fougereux *et al*., 1997). They observed that water stress during the seed filling period induced a reduction in seed quality assessed by germination and conductivity results. This reduction was not seen with earlier water stress.

Pervez *et al*. (2009) conducted experiments to assess the effect of drought stress on seed yield, seed quality and growth of tomato, in green house in plastic pots with tomato cv. 'MONEYMAKER' with four treatments *i.e.* early stress (when first truss has set the fruits), middle stress (when fruits in first truss were fully matured and started changing their colour), late stress (when fruits on first truss were ripened fully), with a control of no stress. Analysis of data showed that drought stress had non-significant effect on vigour, quality and yield of tomato seed. Whereas plant height, number of leaves and number of fruits per plant showed significant results toward drought stress. Withholding irrigation at flowering and seed setting stages significantly decreased grain yield, protein yield and length of the grain filling period (Hasanpour *et al.,* 2012).

Jean-Nicolas Enjalbert *et al*. (2013) studied brassicaceae germplasm diversity for agronomic and seed quality traits under drought stress cinditions. They found a significant decrease in linolenic acid content was observed under dryland conditions in brassicaceae germplasm. *B. carinata* had the highest levels of erucic acid with 42 per cent on average. *B. juncea* accessions showed a large range of oil profiles, related to their geographical origin. Oil profile characteristics such as high linolenic acid were correlated with fitness traits such as height and biomass.

El Balla *et al*. (2013) conducted an experiment to investigate the effect of water stress on seed yield and seed quality of onion (*Allium cepa* L.). Water stress was imposed at four stages of reproductive growth, namely, bolting, flowering, seed formation and seed maturation stage, respectively. Watering was withheld for an interval of 2 weeks only once for every treatment "growth stage" during the first season, while during the second season, the interval of watering was extended to 3 weeks. Water stress at any stage of reproductive growth significantly reduced seed yield and its effect was variable depending on plant growth stage. Water stress at the time of anthesis significantly decreased the diameter of seed head in first season and the average number of seeds per floret was significantly decreased with stress at bolting stage. In the second season, the number of florets per umbel and umbel diameter were reduced by water stress. In the first season, 1000 seed weight was not affected, but in the second season, it was significantly reduced with water stress at seed formation stage. Seed germination and field emergence were not affected. However, water stress at bolting in the second season resulted in lower seed quality.

Seed viability was higher in seeds produced under irrigated than rainfed conditions. Seed quality of bambara groundnut may be reduced underwater-limited production conditions. Following seed enhancement practices such as priming may assist farmers to achieve better emergence. They also suggested that in the long term, seed production should be done under optimum conditions in order to achieve high-seed quality (Chibarabada *et al*., 2015).

Effect of salinity stress :

Effect of salinity stress on seedling growth :

Salinity is one of the major abiotic stresses in arid and semi-arid regions that substantially reduces the yield of major crops by more than 50 per cent (Bray, 2000). Salinity affects 7 per cent of the world's land area for around 930 million ha (Munns, 2002). Salinity is one of the most serious factors limiting crops production, especially the sensitive ones (Zadeh and Naeini, 2007). Currently, high soil salinity affects the agricultural production in a large proportion worldwide (Bybordi *et al*., 2010).

Although salt stress affects all growth stages of a plant, seed germination and seedling growth stages are known to be more sensitive for most plant species (Cuartero *et al*., 2006). Furthermore, germination and seedling stage are predictive of plant growth responses to salinity (Cuartero *et al*., 2006). Therefore, seeds with more rapid germination under salt stress and/or normal conditions may be expected to achieve a rapid seedling establishment and more salt tolerance and hence higher yields (Munns, 2002).

An experiment was conducted in 2011 to evaluate the effects of salt stress (control, 4, 8, and 12 dS/m NaCl, respectively) on seed quality of lentil. Seeds were harvested at ten day intervals in three stages (55, 65 and 75 days after flowering, respectively).Changes in seed weight and electrical conductivity of seed leachates were recorded for seeds harvested at these stages. Germination percentage, germination rate and seedling dry weight were also determined for seeds of final harvest (75 days after flowering) (Kazem Ghassemi-Golezami *et al*., 2012).

Mean seed weight of lentil linearly increased during grain filling from 55 to 75 days after flowering. However, seed weight decreased as salinity increased. The extent of this reduction under 8 and 12 dS/m was more evident than that under 4 dS/m NaCl salinity. Decreasing seed weight of lentil under salinity may be attributed to the reduction of carbon metabolism and photosynthesis (Kazem Ghassemi-Golezami *et al*., 2012).

Electrical conductivity of seed leachates linearly decreased, with progressing seed development and enhancing seed weight under different salinity treatments. Increasing NaCl salinity continuously increased electrical conductivity of lentil seed leachates. High electrical conductivity of lentil at earlier stages of seed development may be due to immaturity (Kazem Ghassemi-Golezami *et al*., 2012).

Mean seed weight, germination percentage, germination rate and seedling dry weight significantly decreased, but electrical conductivity of seed leachates increased with increasing NaCl salinity. Reduction in seed quality under moderate and severe salinities was comparatively high. Reductions in germination percentage, germination rate and seedling dry weight for seeds produced under saline conditions may be related with ion imbalances (Na+ and Cl^-) and membrane disruption (Kazem Ghassemi-Golezami *et al*., 2012).

Seed weight of chickpea cultivars (ILC, Jam and Pirooz) linearly increased during grain filling from 38 to 69 days after flowering. However, 100-seed weight decreased with increasing salinity (Ghassemi-Golezani and Roozbeh, 2011).

Seed viability of chickpea cultivars increased with progressing seed development and enhancing seed weight under different treatments. Nevertheless, Increasing NaCl salinity continuously reduced seed viability of chickpea cultivars (Ghassemi-Golezani and Roozbeh, 2011).

Seed germination rate of the cultivars was also increased with increasing seed weight and viability under control and salinity treatments. Germination rate of seeds at different stages of development decreased, as salinity stress severed (Ghassemi-Golezani and Roozbeh, 2011).

Effect of salinity stress on crop growth :

Salt stress reduced carbon metabolism (Soussi *et al*., 1999 and Balibrea *et al*., 2000) and photosynthesis (Soussi *et al*., 1998), leading to the production of small seeds in chickpea. These results are compatible with those reported by Zeng and Shanon (2000) for rice and Ghassemi-Golezani and Hossinzadeh-Mahootchy (2009) for soybean. Decreasing seed weight of soybean under salinity was attributed to the reduction of seed filling duration (Ghassemi-Golezani and Hossinzadeh-Mahootchy, 2009).

Low seed viability of chickpea cultivars at earlier stages of seed development was due to immaturity. Nevertheless, percentage of seed viability increased with progressing seed development and enhancing seed weight, similar to that reported for common bean and faba bean. Reductions in seed viability under saline conditions may be related with ion imbalances and membrane disruption or with osmotic effect of salt stress. Water stress caused by salinity during pod formation had negative effects on seed viability of groundnut (Reddy *et al*., 2003). Changes in seed vigour of chickpea cultivars as measured by seed germination rate were closely related with variations in seed weight and viability. Seed vigour decreased before viability loss. Therefore, reductions in germination rate under salinity stress occurred before losing seed viability (Ghassemi-Golezani and Roozbeh, 2011).

Ayman El-Sabagh *et al.* (2015) evaluated effects of salinity stress on seed yield and quality of three soybean cultivars and found that all the three soybean culivars had a negative response to salinity stress and for most of the measured plant yield traits, oil and protein content. Among the cultivars, the highest value of seed yield, seed oil and protein per cent were observed in Giza -111when compared to other cultivars under salinity conditions and concluded that Giza -111 cultivar showed more capability to survive under salinity condition compared with another cultivars.

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