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Review Article

Response of Sweet Potato (*Ipomoea batatas*) to Drought Stress: Review

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Abstract: Sweet potato has an excellent nutritional content and beneficial to farmers operating in drought-stressed areas. However, drought induces a number of morphological, physiological, and biochemical alterations in sweet potatoes, which can have a detrimental effect on their agronomic and economic output. For example, drought reduces root output, branching, leaf area index, stem height and length, stomatal closure, leaf size, and photosynthesis. Furthermore, it causes oxidative stress, which results in the creation of reactive oxygen species (ROS) that are harmful to plants. Plants employ many signaling pathways to respond to water stress by modifying their growth patterns, activating antioxidants, accumulating suitable solutes and chaperones, and making stress proteins. These physiological, metabolic, and genetic modifications can be served as the best indicators for choosing drought-tolerant genotypes. Assessing of the physiological and biochemical features of certain varieties is important for the implementation of drought resistance measures. Adapted genotypes can be selected and improved for particular growing conditions by using suitable tools and drought tolerance-related selection criteria. By regulating genetics in this way, the improvement of drought-resistant varieties may become cost-effective for smallholder farmers.

Keywords: Abiotic stress, Biosynthesis, Drought tolerant, Genetic modification, Metabolism, Photosynthesis.

1. INTRODUCTION

Sweet potato (*Ipomoea batatas*) is a nutritionally important crop belonging to the Convolvulaceae family. Its origin is in Mexico and Venezuela in the Central or South Americans continent. Sweet potato has become the 3rd largest cultivated root crop after potato and cassava globally based on its nutritional and agronomic resilience and food security properties (Neela and Fanta, 2019). Today, sweet potato is cultivated in over 120 countries worldwide (Sugri *et al.*, 2017) with over 133 million tons of annual production. Continentally, Africa and Asia are the leading producers of sweet potato with 95% of production coming from developing countries, bringing sweet potato to the 5th and 6th important food crop respectively in developing countries and in the world. Sweet potato is nutritionally an important source of beta-carotene, a precursor of vitamin A, vitaminsB6, and C (Robertson *et al.*, 2018). The storage roots are rich starch reservoirs with carbohydrates, dietary fibre, minerals, and vitamins for human consumption and animal feeding (Baba *et al.*, 2018). Sweet potato helps in the economic uplifting of humans and serving as a food security crop. It maintains healthy blood pressure, prevents constipation due to its high fibre content, has anti-cancer agents, reduces the risk of obesity, diabetes, heart disease, and overall mortality in humans (Anderson *et al*., 2009) and serve as a liver purification crop. The high fibre, phytochemicals, and iron content in sweet potato promote fertility in women (Slavin and Lloyd, 2012). Sweet potato contains a low glycaemic index scale, regulates blood sugar level and insulin resistance in diabetic patients, and thus serves a homeostatic property in human health. The glycaemic index of sweet potato reduces the risks of stroke by 24% (Zuo *et al*., 2019).

However, globally, drought is a major abiotic stress factor affecting sweet potato production areas. In agricultural production, drought, or water deficiency is a major limiting factor that prevents crops from achieving their genetically determined potential maximum yield. About two-thirds of the world including Southern Africa, West- and North-Africa, central America, west and mid-west of North America, southern and eastern parts of South America, the Near East, and Central Asia; and three-quarters of Western Europe, India, Western Australia, and Northern China are prone to drought and desertification due to drought affecting 52 million humans annually (Low *et al*., 2017; Low *et al*., 2020). Drought negatively affects plant growth through various biochemical, morphological, and physiological processes. It inhibits photosynthetic activities and disturb the metabolic processes of the crops, resulting in imbalance in photosynthesis, respiration, translocation, stomatal movement, light absorption, and ion uptake (Fang and Xiong, 2015; Razi and Muneer, 2021). It also causes reduction in mineral nutrient uptake and disorder in many various metabolic processes.

Although sweet potato is generally said to be a drought tolerant crop, selection of appropriate genotypes for drought conditions is still essential. Almost all plants have drought tolerance however the degree of the tolerance varies from one species to another and even within the same species due to various reasons like different severity of drought, duration of drought, the organizational level of the plant, and the developmental stage of the plant species (Fahad *et al*., 2017; Raza *et al*., 2019; Yadav *et al*., 2020). Hence, understanding the morphological and physiological responses of sweet potato to drought can help to determine the traits to be used as selection criteria in breeding programs for yield improvement under drought conditions (Sallam *et al*., 2019). In the context of climate change, the frequency and the severity of drought is expected to rise most especially in Africa in the coming decades (Low *et al*., 2020). Different drought response mechanisms in sweet potatoes such as drought escape (earliness), drought avoidance (root depth), and drought tolerance (maintaining assimilation under drought conditions) need to be identified and new sweet potato varieties should be improved using this information to combat the negative effect of drought to the sweet potato cultivation (Low *et al*., 2020). Therefore, the objective of this review is to assess the effect of drought on the sweet potato and its mitigation practices.

2. Effect of Drought on Sweet potato

Drought is a meteorological term commonly defined as a period without significant rainfall (Whilhite, 2000). The crop physiologists' understanding of drought stress is that it occurs when available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration and evaporation (Jaleel et al., 2009). Drought stress is considered to be a moderate loss of water, which leads to stomatal closure and limitation of gas exchange. Desiccation is a much more extensive loss of water which can potentially lead to gross disruption of metabolism and cell structure and eventually to the cessation of enzyme catalyzed reactions (Blum, 2009). It is characterized by a reduction in soil water content, diminished leaf water potential and turgor loss, closure of stomata and a decrease in cell enlargement and growth. According to Sairam and Saxena (2000) drought is not only the lack of rainfall; it can also be defined by its impacts such as crop shortages and indirect impact, for example, food price increases. Sairam and Saxena (2000) further explained drought as 'an exogenous supply side-shock that causes marked declines in agricultural output, export earnings, employment and income levels.

2.1. Effect of Drought on Physiological Activities of Sweet potato

Drought affects several biochemical and physiological processes of plants, such as translocation, respiration, the uptake of ions, photosynthesis, nutrient and sugar metabolism, and phytohormones. Cell membranes can be destroyed, and leaf water potential can be diminished by drought. Furthermore, heavy drought causes the cessation of photosynthesis and metabolic disorders, and it can lead to the death of plants (Kapoor *et al*., 2020). However, the drought sensitivity of plants depends on the degree and duration of the stress, the plant variety, and the development stage in which the drought occurs (Liu *et al*., 2023). There are two known mechanisms that reduce the negative effects of drought stress in plants, namely stress avoidance and tolerance mechanisms. Stress avoidance refers to a plant's ability to sustain the high-water potential of its tissues under drought stress. Kapoor *et al*. (2020) reported that plants reach such levels by increasing their water uptake through deep root systems or by reducing their transpiration losses through thin or meaty leaves.

Drought is associated with changes in leaf anatomy and ultrastructure for most plant species (Rollins *et al*., 2013). Typical changes include leaf drying, reductions in stomata quantity, stomatal conductance, changes to cell walls, leaf hardening, leaf rolling, and the early induction of senescence. A study found that drought had a detrimental effect on sweet potato growth to the extent that no significant differences were observed among genotypes under severe drought conditions (Laurie, 2014). Mgcibelo (2014) observed that different environmental conditions influence the growth, yield, and nutritional quality of sweet potato. It has been emphasized that sweet potato is drought resistant and increases its level of secondary metabolites (for example, amino acids and β-carotene) under drought stress as a form of water stress protection (Yadav *et al*., 2021). These metabolites are useful to humans, as phytochemicals are conducive to a healthy lifestyle. Although sweet potato is a drought-tolerant crop, it is drought-sensitive, especially at its early growth stages (Mgcibelo, 2014). Delazari *et al*., (2018) also showed that sweet potato growth is severely stunted under drought conditions, which affects its yield.

Drought affects sweet potato structure not only at the tissue and cellular levels but also at the subcellular level. A study by Gouveia et al. (2019) assessed the physiological responses of sweet potato samples to conditions of water shortage. Sweet potato samples that had an improved WUE were found to be the most drought resistant (Gouveia *et al*., 2019). In other similar studies, sweet potato samples showed the best physiological and biochemical responses to water stress treatment, showing in particular a higher ratio of above-ground to below-ground plant parts (root/shoot), lower total biomass loss, and lower stress index values (Liu *et al*., 2023). In addition, the studied sweet potato samples showed a good phenotypic response, including water efficiency and nitrogen efficiency for growth and vital functions, as well as higher root mineral content, chlorophyll content index (CCI) values, and shoot nitrogen content (Gouveia *et al*., 2019). Furthermore, all the samples reduced their biomass by 55.4%, thereby showing drought avoidance behavior under stress conditions. However, all the samples showed differences depending on their water distribution, chlorophyll level, and nutrient utilization. The sweet potato genotypes increased their WUE by +68.1% on average, and the highest water uptake occurred through transpiration. Furthermore, the samples' chlorophyll content index values decreased by −5.3% as a result of a decrease in their photosynthetic rate. Their nitrogen efficiency ratios increased by +38.1%. Additionally, their nitrogen use efficiency increased by +54.4%. Their nitrogen harvest index values also increased, on average, by +2.9%. Overall, drought was shown to reduce the size of sweet potatoes (root/shoot ratio) as a result of investment in shoot development (Gouveia *et al*., 2019).

Another study found that plant signal transduction, phenylpropanoids, an isoquinoline alkaloids, and flavonoid biosynthesis play important roles in the regulation of the tolerance of plants to drought stress. According to the results of a transcriptomic analysis, the tolerance mechanisms of sweet potato varieties are very different, and occasionally some varieties respond oppositely. One drought-sensitive variety resisted drought stress by up-regulating signal production, whereas another drought-sensitive variety avoided drought stress by down-regulating isoquinoline alkaloid biosynthesis and nitrogen/carbohydrate metabolism. Moreover, on the one hand, some drought-tolerant varieties regulated flavonoid and carbohydrate metabolism or isoquinoline alkaloid biosynthesis and nitrogen/carbohydrate metabolism in response to stress; on the other hand, another drought-tolerant variety increased photosynthesis activity and carbon fixation processes. The high drought-tolerant variety was not affected by stress and responded to water deficiency by regulating the cell wall. These pathways are important indicators for selecting the breeding lines of sweet potato (Liu *et al*., 2023).

2.2. Effect of Drought Stress on Growth of Sweet potato

Plant roots interconnect the physiological and biochemical reactions in stems and general plant growth to changes in plant nutrition, photosynthesis, water relations, respiration, nutrient metabolism and growth promoters (Blum, 2009; Jaleel et al., 2009). Water stress inhibits cell enlargement more than cell division. A prolific root system has the advantage of supporting accelerated plant growth during early crop growth stages and extracts water from shallow soil layers that is otherwise easily lost to evaporation (Jaleel et al., 2009).

The prolific root system of sweet potato makes it a drought tolerant crop, although supplementary irrigation is required at the time of planting for proper sprouting and establishment (Mukhopadhyay *et al*., 2011). Water stress reduces stem extension and internode diameter of sweet potato cultivars. The severity of this reduction is reported to differ with different cultivars (Saraswati *et al*., 2004). Inhibition of cell expansion and cell growth is mainly the result of low turgor pressure under water stress conditions. Osmotic regulation can enable the maintenance of cell turgor for survival or can assist plant growth under severe drought conditions (Farooq *et al*., 2009). Water stress reduces leaf growth which in turn reduces the leaf area of plants (Blum, 2009; Jaleel et al., 2009).

2.3. Effect of Drought Stress on Yield of Sweet potato

Drought is a worldwide obstacle to high sweet potato yields because most sweet potato plants grow in semi-arid regions. Because of the complexity of the genetic and physiological mechanisms of water deficiency resistance, a greater emphasis on increasing our genomic understanding of sweet potato's reaction to stress will help us develop strategies for maintaining its productivity under stressful conditions. Laurie *et al*., (2022) found that some genotypes of sweet potato had a high resistance to drought and a good yield index (%) under drought treatment. The same genotypes had higher geometric mean productivity (GMP), stress tolerance index (STI), and mean productivity (MP) values, indicating that they had high tolerance under both conditions. The study's correlation analysis showed that YP and yield stress (YS) had highly positive correlations with the STI, MP, and GMP, and that they can be used as indicators for selecting drought-tolerant genotypes. Further, the stress tolerance index has been suggested as a useful indicator for areas under severe stress (Cryril *et al*., 2015).

Agili *et al*., (2012) identified several sweet potato genotypes with high productivity and good tuber quality, as well as tolerance to drought. The identified genotypes recorded high STI values and exceptionally low susceptibility index values. The study's correlation analysis showed that YP and YS had very significant positive correlations with the STI, MP, and GMP. These parameters can be useful as indicators for selecting genotypes for tolerance. In addition to its direct impact on yields, drought can also reduce the potential benefits of crop management practices, such as fertilizer application and pest and disease management. Drought requires additional periods of irrigation, which increases overhead production costs (Rimsaite *et al*., 2021). A lack of sufficient water for sweet potatoes, especially in their early stages of development, can lead to low tuber yields and a poor tuber quality. A prolonged period of drought can also significantly reduce sweet potato yield as well as the quality of its root tubers, causing great economic losses to farmers (Gouveia *et al*., 2019). Therefore, it is necessary to improve the water use efficiency of agricultural crops, especially in areas with water shortages and where supplementary irrigation is required. In warmer crop cultivation areas, the effects of water stress are also increased by high temperatures (Ekanayake and Collins, 2004).

Sweet potato yield is also significantly affected by stunted growth as a result of drought conditions. A study that exposed sweet potato to a medium level of water stress found that this had a negative effect on all of its characteristics, but that it still allowed for different genotypes to be distinguished; exposure to high stress had the opposite effect. Laurie *et al*., (2015) reported that a good yield is very much dependent on the plant maintaining a proper crown cover, stomatal conductivity, and stem length. Stem length and leaf area index measurements were strongly correlated with yield and can therefore be used as screening tools in future investigations. The main objective of sweet potato breeding in many regions of the world, especially those affected by drought, is to obtain varieties that combine drought tolerance with a high yield. In this regard, the study of the physiological and biochemical features of certain varieties is important for the implementation of drought tolerance measures. In addition, it is necessary to carry out yield modeling to reduce the time and costs associated with repeating trials in larger areas.

3. CONCLUSIONS

Drought is the main environmental stress that reduce the productivity of sweet potato worldwide. Drought induces a number of morphological, physiological, and biochemical alterations in sweet potatoes, which can have a detrimental effect on their agronomic and economic output. It causes reduction in root yield, branching, canopy cover, leaf area index, stem height and length, stomatal closure, leaf sizes, and photosynthesis in sweet potato. Moreover, drought triggers oxidative stress that generates reactive oxygen species (ROS) being harmful to the plants. To survive the effect of these ROS and other negative pressures of drought, sweet potatoes synthesize and accumulate some molecules such as carbohydrates, proline, sugar alcohols, polyamine, and glycine betaine to adjust their osmotic pressure and serve as osmoprotectants. These physiological, metabolic, and genetic modifications can be employed as the best indicators for choosing drought-tolerant genotypes.

The optimal solution for developing a methodology to assess the drought tolerance of sweet potato is to grow the plant under field conditions where irrigation is applied without the interference of normal precipitation. Apart from field experiments, the adoption of strategies such as efficient water use, the proper selection of drought-tolerant genotypes, mass screening, conventional and molecular assisted selection (MAS), the exogenous application of hormones, the use of osmoprotectants on seeds or plants, and the development of genetic engineering methods for drought tolerance are recommended. Adapted genotypes can be selected and improved for particular growing conditions by using suitable tools and drought tolerance-related selection criteria. By regulating genetics in this way, the creation of drought-resistant varieties may become cost-effective for smallholder farmers.

REFERENCES

- Agili, S., Nyende, B., Ngamau, K., & Masinde, P. (2012). Selection, yield evaluation, drought tolerance indices of orange-flesh sweet potato (Ipomoea batatas Lam) hybrid clone.
- Anderson, J. W., Baird, P., Davis Jr, R. H., Ferreri, S., Knudtson, M., Koraym, A., Waters, V., & Williams, C. L. (2009). Health benefits of dietary fiber. *Nutrition reviews*, *67*(4), 188-205.
- Baba, M., Nasiru, A., Karkarna, I. S., Muhammad, I. R., & Rano, N. B. (2018). Nutritional evaluation of sweet potato vines from twelve cultivars as feed for ruminant animals. *Asian Journal of Animal and Veterinary Advances*, *13*(1), 25-29.
- Blum, A. (2009). Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. *Field crops research*, *112*(2-3), 119-123.
- Cyril, A., Guaf, E., & Komolong, B. (2015). Screening sweetpotato (Ipomoea batatas) genotypes under soil moisture deficit condition using stress tolerance indices. *Archives of Applied Science Research*, *7*(11), 23-29.
- Delazari, F. T., Assis, I. R., Cabrera, D.F., Ferreira, M. G., Dias, L. E., Rueda, A., Zanuncio, J. C., & Silva, D. J. (2018). Morpho-physiological characteristics by sweet potato cultivars as function of irrigation depth. *Anais da Academia Brasileira de Ciências*, *90*, pp.3541-3549.
- Ekanayake, I. J., & Collins, W. (2004). Effect of irrigation on sweet potato root carbohydrates and nitrogenous compounds. *Journal of Food Agriculture and Environment*, *2*, pp.243-248.
- Fahad, S., Bajwa, A. A., Nazir, U., Anjum, S. A., Farooq, A., Zohaib, A., Sadia, S., Nasim, W., Adkins, S., Saud, S., & Ihsan, M. Z. (2017). Crop production under drought and heat stress: plant responses and management options. *Frontiers in plant science*, p.1147.
- Fang, Y., & Xiong, L. (2015). General mechanisms of drought response and their application in drought resistance improvement in plants. *Cellular and molecular life sciences*, *72*, pp.673-689.
- Farooq, M., Wahid, A., Kobayashi, N. S. M. A., Fujita, D. B. S. M. A., & Basra, S. M. A. (2009). Plant drought stress: effects, mechanisms and management. *Sustainable agriculture*, pp.153-188.
- Gouveia, C. S., Ganança, J. F., Nóbrega, H. G., Freitas, J. G., Lebot, V., & Carvalho, M. Â. (2019). Drought avoidance and phenotypic flexibility of sweet potato (Ipomoea batatas (L.) Lam.) under water scarcity conditions. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *47*(4), 1037-1046.
- Jaleel, C. A., Manivannan, P. A. R. A. M. A. S. I. V. A. M., Wahid, A., Farooq, M., Al-Juburi, H. J., Somasundaram, R. A. M. A. M. U. R. T. H. Y., & Panneerselvam, R. (2009). Drought stress in plants: a review on morphological characteristics and pigments composition. *Int. J. Agric. Biol*, *11*(1), 100-105.
- Kapoor, D., Bhardwaj, S., Landi, M., Sharma, A., Ramakrishnan, M., & Sharma, A. (2020). The impact of drought in plant metabolism: How to exploit tolerance mechanisms to increase crop production. *Applied Sciences*, *10*(16), p.5692.
- Laurie, R. N. (2014). *Biochemical, physiological and agronomic response of various sweet potato cultivars/varieties to drought stress in rainout shelters and field conditions* (Doctoral dissertation).
- Laurie, S. M., Bairu, M. W., & Laurie, R. N. (2022). Analysis of the nutritional composition and drought tolerance traits of sweet potato: selection criteria for breeding lines. *Plants*, *11*(14), p.1804.
- Liu, E., Xu, L., Luo, Z., Li, Z., Zhou, G., Gao, H., Fang, F., Tang, J., Zhao, Y., Zhou, Z., & Jin, P. (2023). Transcriptomic analysis reveals mechanisms for the different drought tolerance of sweet potatoes. *Frontiers in Plant Science*, *14*, p.1136709.
- Low, J., Ball, A., Magezi, S., Njoku, J., Mwanga, R., Andrade, M., Tomlins, K., Dove, R., & Van Mourik, T. (2017). Sweet potato development and delivery in sub-Saharan Africa. *African Journal of Food, Agriculture, Nutrition and Development*, *17*(2), pp.11955-11972.
- Low, J. W., Ortiz, R., Vandamme, E., Andrade, M., Biazin, B., & Grüneberg, W. J. (2020). Nutrient-dense orange-fleshed sweetpotato: advances in drought-tolerance breeding and understanding of management practices for sustainable next-generation cropping systems in sub-Saharan Africa. *Frontiers in Sustainable Food Systems*, *4*, p.50.
- Mukhopadhyay, S. K., Chattopadhyay, A., Chakraborty, I., & Bhattacharya, I. (2011). Crops that feed the world 5. Sweetpotato. Sweetpotatoes for income and food security. *Food security*, *3*, pp.283-305.
- Neela, S., & Fanta, S. W. (2019). Review on nutritional composition of orange-fleshed sweet potato and its role in management of vitamin A deficiency. *Food science & nutrition*, *7*(6), 1920-1945.
- Raza, A., Razzaq, A., Mehmood, S. S., Zou, X., Zhang, X., Lv, Y., & Xu, J. (2019). Impact of climate change on crops adaptation and strategies to tackle its outcome: A review. *Plants*, *8*(2), p.34.
- Razi, K., & Muneer, S. (2021). Drought stress-induced physiological mechanisms, signaling pathways and molecular response of chloroplasts in common vegetable crops. *Critical Reviews in Biotechnology*, *41*(5), pp.669-691.
- Rimsaite, R., Gibson, J., & Brozović, N. (2021). Informing drought mitigation policy by estimating the value of water for crop

production. *Environmental Research Communications*, *3*(4), p.041004.

- Robertson, T. M., Alzaabi, A. Z., Robertson, M. D., & Fielding, B. A. (2018). Starchy carbohydrates in a healthy diet: the role of the humble potato. *Nutrients*, *10*(11), p.1764.
- Rollins, J. A., Habte, E., Templer, S. E., Colby, T., Schmidt, J., & Von Korff, M. (2013). Leaf proteome alterations in the context of physiological and morphological responses to drought and heat stress in barley (Hordeum vulgare L.). *Journal of experimental botany*, *64*(11), pp.3201-3212.
- Sairam, R. K., & Saxena, D. C. (2000). Oxidative stress and antioxidants in wheat genotypes: possible mechanism of water stress tolerance. *Journal of Agronomy and Crop Science*, *184*(1), pp.55-61.
- Sallam, A., Alqudah, A. M., Dawood, M. F., Baenziger, P. S., & Börner, A. (2019). Drought stress tolerance in wheat and barley: advances in physiology, breeding and genetics research. *International journal of molecular sciences*, *20*(13), p.3137.
- Sapakhova, Z., Raissova, N., Daurov, D., Zhapar, K., Daurova, A., Zhigailov, A., Zhambakin, K., & Shamekova, M. (2023). Sweet Potato as a Key Crop for Food Security under the Conditions of Global Climate Change: A Review. *Plants*, *12*(13), p.2516.
- Saraswati, P., Johnston, M., Coventry, R., & Holtum, J. (2004, September). Identification of drought tolerant sweet potato (Ipomoea batatas (L.) Lam) cultivars. In *Proceedings of the 4th International Crop Science Congress, Brisbane, Australia* (pp. 1-6).
- Slavin, J. L., & Lloyd, B. (2012). Health benefits of fruits and vegetables. *Advances in nutrition*, *3*(4), 506-516.
- Sugri, I., Maalekuu, B. K., Gaveh, E., & Kusi, F. (2017). Sweet potato value chain analysis reveals opportunities for increased income and food security in Northern Ghana. *Advances in Agriculture*, *2017*.
- Wilhite, D. A. (2000). Drought as a natural hazard: concepts and definitions.
- Yadav, B., Jogawat, A., Rahman, M. S., & Narayan, O. P. (2021). Secondary metabolites in the drought stress tolerance of crop plants: A review. *Gene Reports*, *23*, p.101040.
- Yadav, S., Modi, P., Dave, A., Vijapura, A., Patel, D. and Patel, M., 2020. Effect of abiotic stress on crops. *Sustainable crop production*, *3*.
- Zuo, L., Prather, E.R., Stetskiv, M., Garrison, D.E., Meade, J.R., Peace, T.I. and Zhou, T., 2019. Inflammaging and oxidative stress in human diseases: from molecular mechanisms to novel treatments. *International journal of molecular sciences*, *20*(18), p.4472.