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Review Article

SORGHUM IS CLIMATE SMART CROP – A REVIEW

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Global food securities build-up due to climate change emphasizing the need to concentrate on crop enhancement. Climate change immensely disturbs the agricultural system by reducing crop production. Changes in weather conditions such as high-temperature occurrences and extreme rain events, famines and submerging negatively affect the production of staple food crop, posing trouble to ecosystem adaptability. In view of this, it's essential to concentrate and acclimatize climate–resilient food crops which need lower inputs and produce sustainable yields through colourful biotic and abiotic stress-tolerant traits. Sorghum "the camel of cereals" is one similar food crop that's less sensitive to climate change vulnerabilities. It's a rainfed crop and provides numerous essential nutrients. Understanding sorghum sensitivity to climate change provides a compass for the enhancement of the crop both in terms of volume and quality and alleviates food and feed security in unborn climate change scripts.

Agriculture worldwide faces the enormous challenge to meet increasing demands for food, feed and fuel, resulting from a growing and increasingly affluent human population (Grafton *et al*., 2015). This challenge is complicated by climate change, which is expected to negatively affect agriculture in manyplaces through increasing temperature, changing rainfall patterns, increased climate variability, and frequency of extreme events (Lipper *et al*., 2014, Rosenzweig *et al*., 2014). Close to 1 billion people went hungry in 2010 according to the Food and Agriculture Organization (FAO) of the United Nations. In 2011, hunger plagued the Horn of Africa, hit by the worst drought in 60 years. The future is daunting too: food needs are projected to increase by 70% by 2050 when the global population reaches 9 billion, while climate change is projected to reduce global average yields. Climate change will affect agriculture through higher temperatures, greater crop water demand, more variable rainfall and extreme climate events such as heat waves, floods and droughts (USDA, 2016). Marginal areas, where low yields and poverty go hand in hand, may become even less suited for agriculture as a result of land degradation through deforestation, wind and water erosion, repetitive tillage and overgrazing. Many impact studies point to severe crop yield reductions in the next decades without strong adaptation measures particularly in Sub-Saharan Africa and South Asia, where rural households are highly dependent on agriculture and farming systems are highly sensitive to temperature increases and volatile climate. One assessment based on a pessimistic assumption about global warming, estimates that by the 2080s world agricultural productivity will decline by 3-16 % (Gornall *et al*., 2010).

Diverse end uses of a crop commodity, in addition, to use as food and feed, make profitable agriculture with more returns unit^{-1} land investment. This is more distinct in a crop like sorghum, which is a widely adaptable species and is cultivated in tropical, subtropical, and temperate regions (Downing *et al*., 2017).The major effects of climate change are the increased frequency and magnitude of extreme climate events such as extreme rainfall events, increased dry spells, droughts, water shortages, land degradations, and a rise in sea levels. All these effects could negatively impact the global agricultural system which in turn leads to food insecurity in all its dimensions availability, stability, access, and utilization (Peng *et al*., 2019). Growing crops, that are drought and heat resistant, is one form of adapting to the impacts of climate change.

Sorghum is one of the crops which have inherited its trait to adapt and grow in harsh climates from its origin. It grows in dry conditions, and tolerates heat, salt, and waterlogging, making it an ideal crop for semi-arid areas where many of the world's poor life. It is now realized that sorghum is of prime importance for the sustainable livelihood of rural poor farmers who cannot afford purchased inputs (Gomez and Rodriguez,2022).Sorghum [*Sorghum bicolour* (L.) Moench] ranked fifth among the world's most important crops. More than 70% of the world's total production of sorghum comes from developing countries in Asia and Africa, where the crop is grown with limited input of water and nutrients (Mundia *et al*., 2019). In India, sorghum is cultivated during both *kharif* (rainy) and *rabi* (post-rainy) seasons mainly as a rainfed crop (92% of the area) with about 85% of the production concentrated in Maharashtra, Karnataka and Andhra Pradesh, all falling under warm semi-arid region (Ananda *et al*., 2020). Hence, sorghum is one of the major food crops in drought-prone environments but has great potential for crop improvement for food, feed, fodder and biofuel production ("FFFF").

What is climate-smart agriculture?

Climate Smart Agriculture (CSA) is an approach in which technological, strategic and investment conditions are developed to reach sustainable agricultural development for food security under climate change. The extent to which climate change is affecting agricultural systems necessitates ensuring comprehensive consolidation of these effects into

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national agricultural planning, investments and programs. CSA is transforming and reorienting sustainable agricultural systems to support food security under the new realities of climate change (Rashid *et al.*, 2021).

Objectives of CSA

CSA is striving to increase agricultural productivity in terms of climate smart crops, food security, and farmers' adaptive capacity and lowering greenhouse gas emissions as well. The main objectives of CSA are given below:

- Sustainable increase of food security by agricultural productivity
- Building resilience and adapting to climate change
- Developing opportunities for reducing greenhouse gas emissions

What is climate smart crop?

The climate smart crop is a part of climate smart agriculture programme where different crop Varieties with the characteristics of climate-resilient, crucial defence against extreme temperatures, water scarcity, the emergence of new pests and diseases, and nutritional insecurity. Over last few decades several varieties have been tested and released and adopted by farmers, several millets, pulses have been taken under this climate smart crop. The new varieties combat a range of challenges typical in dry regions. They can flourish in areas where rainfall is low and erratic, offer greater and more stable yields, and have a higher tolerance to stress factors such as diseases, pests, drought, and extreme temperatures. Many varieties also offer improvements in nutritional value and quality (Kumar *et al.*, 2019).

Sorghum- The climate smart crop

The ability of sorghum to produce the grain and fodder in harsh environments has made it a climate-smart crop. In better soils and better rainfall, cash crops have replaced sorghum. But owing to its C_4 metabolism with high biomass production and its relatively high tolerance to several stress factors it is difficult to replace sorghum in least endowed areas, especially in the climate change scenario despite the stiff competition from other cereals (Malabadi *et al.*, 2022). Global warming is turning warm climates hot, while cold climates are becoming warm, and sorghum can adapt to both the situations. Sorghum's water uses efficiency and its adaptability to raise biomass in water stress conditions makes it an apt crop for climate change that is resulting in frequent dry spells even during the crop season (Hatfield and Christian, 2019). Furthermore, it is expected that sorghum can produce substantial yield increases because of the warming in Germany and also can cope with drier summer months because of its adapted physiology (Degener, 2015). One of the needs to cope with the changing climate scenario of rising temperature (hence increasing evaporation) is to improve the heat and drought tolerance of major food crops like wheat, rice and maize. The progress in these areas is generally low due the complex nature of traits associated with these stresses. Sorghum and/or millets is a group of crops which have already inherited higher tolerance to heat, drought, salinity etc. Therefore, these crops have a better chance to get adapted to these supra-optimal conditions. Sorghum is able to tolerate drought better than most other grain crops and can be attributed to an exceptionally well developed and finely branched root system, which is very efficient in the absorption of water, it has small leaf area plant^{-1}, which limits transpiration, the leaves fold up more efficiently during warm, dry conditions than that of maize; it has an effective transpiration ratio of 1:310, as the plant uses only 310 parts of water to produce one part of dry matter. The epidermis of the leaf is corky and covered with a waxy layer, which protects the plant from desiccation; the stomata close rapidly to limit water loss; during dry periods, sorghum has the ability to remain in a virtually dormant stage and resume growth as soon as conditions become favourable. Even though the main stem an die, side shoots can develop and form seed when the water supply improves (Palak *et al.*,2022).

With increasing concerns on the adverse changes in environmental quality, the consequent effects on food and nutritional security, and the need for increasing food production unit^{-1} resource land investment for an ever-increasing population, crops like sorghum have good prospects of penetrating the food baskets of a wider range of consumers, both rural and urban, poor and rich in the developed and developing nations. Sorghum acts as a principal source of energy, protein, vitamins, and minerals for millions of the poorest people living in droughty regions, who cultivate sorghum for consumption at home and in certain cases for feeding their cattle. It is consumed as whole grain or processed into flour, from which traditional meals are prepared (Grazon *et al.*,2019). Another type, the sweet sorghum, is a renewable and carbon-neutral biofuel alternate energy resource. Sugarcane, sugar beet, corn, and wheat are other alternate energy sources, but at the cost of source as food. Such conflict of food and fuel are alleviated by sweet sorghum because it can be processed into both biofuel and valuable coproducts, thus meeting the various requirements of food, fuel, and fodder (Ananda *et al.*,2020). Despite the outstanding issues related to ethanol production and yield, bioethanol derived from sweet sorghum could progressively substitute a significant proportion of the fossil fuels required to meet the growing energy demand (Ahmad *et al.*, 2018). In comparison to corn, sweet sorghum is considered a more efficient and cost-effective source of energy because of the lower nitrogen input and water requirement for its production (Pfeiffer *et al.*, 2013). All these factors make sorghum a climate-smart crop.

Modern tools for climate smart sorghum production

Climate change, which includes high temperatures and drought, is projected to have a detrimental effect on plant agronomic conditions as well as soil nutrients, diseases, and pests. As a result, climate-resilient varieties with broad spectrum and long-term tolerance to both biotic and abiotic stresses are required. The new genetic engineering method for crop enhancement is precise genome editing (Raza *et al*., 2019). Climate change has put a pressure on researcher, farmers and scientists working in the field of agriculture to adopt new technologies to cope with the prevailing issues. No doubt there is still need to improve genetic potential of sorghum for higher tolerance to these abiotic stresses.Sorghum crop improvement programs along with strategic crop adaptation approaches are designed to cope with the negative impacts of climate change and further maintaining the production and income of small holders. Different adaptation approaches like crop management practices, breeding, and biotechnological approaches could enhance the sorghum grain productivity and quality under extreme climatic scenarios to a great extent (Pozo *et al*.,2019). The following adaptation strategies could benefit the sorghum crop from climate change impacts.

Palanivel *et al.* (2022) identified tissue culture, molecular marker development, genetic manipulation, and genomics resources as key tools in the improvement of sorghum. Xin *et al*. (2008) advocated the use of 0.1–0.5% (v/v) EMS solution to induce mutagenesis in sorghum. Chemical mutation breeding programs are favoured over genetic modification (GM) approaches, as it is not subjected to the same regulatory process. Development of hybrid sorghum varieties has contributed to a global increase in productivity (Thawari *et al*., 2000). A few genomic resources are available for wild sorghum species. The sorghum genome sequence (Paterson *et al*., 2009) is a resource that will allow analysis of wild germplasm and generation of genomic resources in these species. In an extensive paper on sorghum expressed sequence tags (EST), Pratt *et al*. (2005) reported key genes for drought and pathogenesis from a large set of 16,801 transcripts. These ESTs and other cereal genomics data can be used as a platform to ascertain the sequence of their homologs in the wild species (Shapter *et al*., 2009).

The effect of nutrients and hormones on sorghum to overcome drought

Sorghum grain, the fifth-most significant cereal in the world, thrives in dry circumstances and can withstand heat, salt, and water logging.Among the extreme habitats, drought is most harsh abiotic stress affecting growth, development and productivity of crops. But the nutrients which are present in the soil or added by humans and also different types of hormones helps the plant to prevent drought condition and improves the different physio-parameters *viz*., plant growth and yield. Mineral elements have numerous functions in plants including maintaining charge balance, electron carriers, structural components, enzyme activation, and providing osmoticum for turgor and growth,through many of those processes they help the plant to combat with the stress condition (Titare *et al*.,2005). It has been demonstrated that using standard micronutrients can reduce the effects of drought stress on agricultural crop plants (Karim and Rahman, 2015; Dimkpa and Bindraban, 2016; Lamaoui *et al*., 2018). By improving water usage efficiency, maintaining cell membrane stability, which prevents tissue flaccidity from drought-induced wilting, and detoxifying harmful free radicals that build up in plant cells during water scarcity (Cakmak, 2000; Karim and Rahman, 2015), micronutrients reduce the impacts of drought on plants. These behaviours are connected to the various ways that micronutrients influence the activation of several enzymes and physiological plant processes associated with abiotic stress, water balance, or nutrient uptake. When there is a shortage of water, plants produce more abscisic acid (ABA) to maximise stomatal closure and conserve water (Karim and Rahman, 2015; Lamaoui *et al*., 2018). Zn has been demonstrated to increase ABA production in plants, enhancing ABA's ability to regulate stomata under water stress. Works have been published where ZnO nanoparticles has been studied at 1, 3, and 5 mg Zn kg^{-1} concentration on sorghum and it has exelantly accelerated plant development, promoted yield, fortify edible grains with critically essential nutrients such as Zn, and improved N acquisition under drought stress (Dimkpa *et al*., 2019). The production of phytohormones including indole acetic acid (IAA)can combat during stress conditions such as droughtby changing the root architecture. IAA affects cell division, extension and differentiation, controls various processes of vegetative growth, and increases the rate of xylem and root development, and resistance to various stressful conditions (Miransari and Smith, 2014). IAA production has been reported in drought tolerant bacteria including *Bacillus altitudinis* (Kumaravel *et al*., 2018), *Pseudomonas simiae*, *Pseudomonas koreensis*, *Carnobacterium sp*. (Kumari *et al*., 2016). Sharma *et al*. (2004) monitored the changes occur with ABA, GA_3, NaCl and drought treatments on sorghum in germination rate, growth, and phosphatase enzymes. Germination decreased markedly under ABA, NaCl and drought treatments. Significant decrease in endosperm fresh weight was observed in draught stress condition. A significant increase in acid phosphatase activity was observed under ABA and NaCl treatments. Ahmed *et al*. (2014) studied the distribution of silicon in plant organs in water stress condition with the treatments (Si200:200 ml l^{-1} of potassium silicate and Si_0: control orabsence of silicon) were replicated thrice with two sorghum cultivars and it has shown a better growth and development with respect to leaf area index, SPAD chlorophyll contents and transpiration rate due to Si nutrition.Asgharipour and Haidari (2011) suggested from the obtained data that there is a close relationship between K application status and the resistance of growth to drought stress in sorghum plant. The effect of K supply on growth was significant under droughtstress conditions since vegetative growth parameters, yield and yield attributes of plants irrigated at 30% FC were greater at plots fertilized with the K_2SO_4 in a rate of 200 and 250 kg ha^{-1} than control (without K fertilizer). The researcher came to a conclusion that the application of K fertilizer within the sufficiency range (150 to 250 kg K_2SO_4 ha^{-1}) was beneficial in alleviating the effect of drought on the growth and nutrients uptake of sorghum.

From the above it is inferred that an integrated approach is required to face the challenges of food security under climate change from global to local level as well as from research to policies and investment level. The whole agricultural sector can be shifted onto climate smart agriculture pathways with right policies, practices and investments. It will increase the food security by decreasing the impacts of climate change to global food security on long term. Climate-smart agriculture actually moves the agriculture from an unstable system towards a more efficient, resilient and sustainable system with the help of naturally auto-control mechanisms. Practices and approaches of climate smart crop production can be utilized by farmers, but the implementation of climate change adaptation and mitigation options not only rely on purely technical basis, but they also depend on social support from the population involved. It is very important to facilitate the farmers by giving the opportunities that are sustained by research institutions and policy. The ultimate challenge today is to provide technologies that will enable transformation of subsistence sorghum farming into a commercial and profitable production system that can compete at global level. Future research should focus on producing sorghum-based functional foods in which raw sorghum grains, malted grains, or malt extracts are used as an ingredient. Under a changing climate regime, sorghum would assume renewed importance as a food and industrial crop, and therefore, concerted efforts to breed sorghum for diverse end uses are necessary. Furthermore, considering the future demand for sorghum, immediate attention is required to reassess the crop research, overcoming specific production problems for further improvement of productivity, fine-tuning of processing technologies, creation of demand, marketing facilities, and policy changes that would enhance the farm income and employment generation without diverting from the major goal of sustaining food and nutritional security.

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