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Enhancing climate resilience in Sorghum production

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Abstract

Climate change poses significant challenges to global agriculture, impacting crop yields, water availability, and food security. Sorghum, a staple crop for millions in semi-arid regions, is highly valued for its resilience to drought and heat. However, escalating climate variability necessitates enhanced strategies to fortify its resilience further. This review paper aims to explore and synthesize current strategies and innovations in enhancing climate resilience in sorghum production. We examine genetic improvement, agronomic practices, and technological interventions designed to improve sorghum's adaptability to climate stressors. The ultimate objective is to outline a comprehensive approach that integrates these strategies, ensuring sustainable sorghum production under changing climatic conditions.

Keywords: Sorghum, climate change, global agriculture, water availability, food security

Introduction

Sorghum (*Sorghum bicolor*) is a critical cereal crop for food security in many parts of Africa, Asia, and the Americas. Its natural tolerance to drought and heat makes it a key crop in the face of climate change. However, as climate variability increases, there is an urgent need to adopt strategies that further enhance this resilience, ensuring stable yields and food security. This review focuses on the multifaceted approach required to address this challenge, including genetic, agronomic, and technological interventions (Chadalavada K, 2021) [1].

Main Objective

The main objective of enhancing climate resilience in sorghum production is to develop and implement integrated strategies that improve sorghum's tolerance to environmental stresses caused by climate change, such as drought, heat, and pest pressures (Reddy BV, *et al.* 2011) [2].

Traditional Breeding

Traditional breeding, also known as conventional breeding, is the age-old practice of selecting plants with desirable traits and breeding them to produce offspring that inherit those traits. This method relies on the natural genetic variability within a plant species and has been utilized by humans for thousands of years to enhance crop yields, improve disease resistance, and increase drought tolerance, among other desirable characteristics. In the context of sorghum production, traditional breeding is a fundamental tool for enhancing climate resilience, addressing challenges such as extreme weather conditions, pests, and diseases that are exacerbated by climate change (Kothari K, *et al.* 2020) [3]. The traditional breeding process begins with the identification of plants that exhibit favorable traits. These traits might include enhanced yield, improved nutritional content, resistance to pests and diseases, tolerance to drought and heat, or any combination thereof. Breeders meticulously select parent plants that possess these desired characteristics, ensuring that the traits can be passed on to the next generation. Once suitable parent plants are identified, they are cross-pollinated (Mwangi B, *et al.* 2021) [4]. This can be a labor-intensive process, especially in plants like sorghum that can self-pollinate. To ensure cross-pollination, breeders may have to manually transfer pollen from one plant to another or employ techniques to prevent self-pollination, such as removing the male parts of flowers on a plant to ensure it can only be fertilized with pollen from another plant with the desired traits.

The offspring produced from this cross, known as the F1 generation, are then grown and assessed for the presence and expression of the targeted traits (Srivastava A, *et al*. 2010) [5]. This evaluation process is critical and can take several growing seasons. Breeders select the best-performing individuals and may cross them again with other selected plants or backcross them with one of the parent plants to stabilize the desired traits over several generations. As promising lines are developed, they undergo field testing in various environments to assess their performance under different climatic and soil conditions. This step ensures that the new varieties will perform well across a wide range of environmental conditions, making them more adaptable and resilient to the impacts of climate change. Traditional breeding is a time-consuming process that requires patience, as it may take many years to develop a new variety. However, its advantages lie in its simplicity and the fact that it does not require sophisticated technology or equipment. It utilizes the natural genetic diversity within a species, promoting biodiversity. Furthermore, because it does not involve the insertion of foreign DNA, the varieties developed through traditional breeding are widely accepted and can be used by farmers everywhere, including those in regions with restrictions on genetically modified organisms (GMOs) (Elramlawi HR, *et al*. 2019) [6].

Molecular Breeding and Genomics

Molecular breeding and genomics are advanced techniques that have revolutionized the field of plant breeding by leveraging the knowledge of genetics and molecular biology to develop new plant varieties with desired traits more efficiently and accurately than traditional breeding methods. These approaches use information about the genetic makeup of plants, identifying specific DNA sequences associated with desirable traits, such as drought tolerance, disease resistance, or improved nutritional content. This allows plant breeders to select individuals for breeding based not just on observable characteristics but on their genetic potential, significantly speeding up the development of new crop varieties with enhanced traits. Molecular breeding involves several techniques, including marker-assisted selection (MAS), where genetic markers associated with desirable traits are used to screen and select plants even before the traits can be observed. This is particularly useful for traits that are difficult to measure, appear late in plant development, or are influenced by environmental conditions, as it allows for the selection of plants with the desired genetic makeup early in the breeding process. By doing so, breeders can more rapidly accumulate desired genes in new crop varieties, improving their efficiency and effectiveness. Genomics, the study of an organism's entire genome, provides a comprehensive understanding of the genetic architecture underlying complex traits. High-throughput sequencing technologies have made it possible to sequence whole genomes of numerous plant species, including sorghum, enabling researchers to identify genes and genetic variations responsible for specific traits. With this knowledge, plant breeders can employ genomic selection, a method that predicts the breeding value of a plant based on the sum of its genetic markers, to select individuals that are likely to produce the best offspring. Another aspect of molecular breeding and genomics is the use of genetic engineering and gene editing techniques, such as CRISPR/Cas9, to directly modify or edit the DNA of plants to introduce or enhance specific traits. While these techniques offer precise control over the introduction of desired traits, they are distinct from conventional molecular breeding methods and are subject to different regulatory and public acceptance issues.

Molecular breeding and genomics have several advantages over traditional breeding methods. They can significantly reduce the time and resources required to develop new plant varieties, allow for the precise introduction of traits, and enable the stacking of multiple traits in a single variety. Furthermore, these techniques can be used to enhance the genetic diversity of crops by introducing beneficial traits from wild relatives or different species that would be difficult or impossible to achieve through traditional crossbreeding methods (Webber H, *et al*. 2014) [7].

Soil and Water Management

In the context of sorghum production, soil and water management are crucial aspects of cultivation that significantly impact crop yield, quality, and resilience to environmental stresses. Sorghum, known for its drought tolerance, is a staple crop in many semi-arid and arid regions of the world. However, optimizing soil health and efficiently managing water resources can further enhance its productivity and sustainability, especially under the challenges posed by climate change.

Soil management in sorghum production involves practices that maintain or improve soil health and fertility. Given that sorghum is often grown in marginal soils with low fertility, enhancing soil organic matter is a key strategy. This can be achieved through the incorporation of organic amendments such as compost, manure, and crop residues, which improve soil structure, increase water retention, and stimulate beneficial microbial activity. The use of cover crops and green manures in rotation with sorghum can also contribute to soil health by preventing erosion, suppressing weeds, and fixing atmospheric nitrogen in the case of leguminous cover crops.

Crop rotation is another vital component of soil management, helping to break cycles of pests and diseases and reduce the build-up of soil pathogens that can affect sorghum. Rotating sorghum with other crops can also help in balancing nutrient uptake and depletion, ensuring more sustainable soil fertility management.

Water management is particularly critical in sorghum production due to the crop's common cultivation in water-limited environments. Efficient water use practices, such as drip irrigation or sprinkler systems, can significantly reduce water wastage by delivering water directly to the plant root zone, where it's needed most. These systems can be more water-efficient compared to traditional flood or furrow irrigation methods and can be critical in regions facing water scarcity.

Conservation tillage practices, including no-till and reduced till, play a significant role in water conservation. By minimizing soil disturbance, these practices help to preserve soil moisture, reduce runoff, and maintain a more stable soil structure. This approach not only conserves water but also reduces soil erosion and improves carbon sequestration in the soil.

Mulching is another effective technique for conserving soil moisture and managing water in sorghum fields. Applying organic or inorganic mulches on the soil surface can significantly reduce evaporation, suppress weed growth, moderate soil temperature, and improve water infiltration.

In regions where water availability is unpredictable, rainwater harvesting and the construction of water catchment systems can provide supplemental water for irrigation during dry periods. These practices capture rainwater that would otherwise be lost as runoff and store it for use when water is scarce, ensuring that sorghum crops receive adequate water throughout their growth cycle.

Soil and water management in sorghum production are interlinked practices that require a holistic approach to agriculture. By focusing on improving soil health and optimizing water use, farmers can enhance sorghum's natural resilience to drought and other environmental stresses, improve yields, and contribute to the sustainability of sorghum as a key crop for food security in many parts of the world (Dhankher OP, *et al*. 2018) [10].

Integrated Pest and Disease Management

Integrated Pest and Disease Management (IPDM) in sorghum production involves a holistic approach to managing pests and diseases that threaten this vital crop. Given sorghum's importance as a staple food and feed crop in many parts of the world, particularly in semi-arid regions where challenging conditions prevail, the implementation of IPDM is crucial for sustainable production. This approach combines various strategies to manage pests and diseases effectively, minimizing reliance on chemical pesticides, and promoting ecological balance and crop health (Badigannavar A, *et al*. 2018) [12].

In the context of sorghum production, IPDM starts with a thorough understanding of the ecosystem, including the types of pests and diseases that commonly affect sorghum, their life cycles, and how they interact with their environment. This knowledge is foundational for developing effective management strategies that are tailored to local conditions and challenges.

One of the primary strategies in IPDM for sorghum is the use of resistant varieties. Plant breeders have developed sorghum cultivars that are resistant or tolerant to key pests and diseases, such as anthracnose, sorghum midge, and striga. Growing these varieties can significantly reduce the need for chemical interventions and provide a foundational layer of protection against crop losses.

Cultural practices play a significant role in IPDM for sorghum. Crop rotation and intercropping with non-host plants can interrupt the life cycles of pests and diseases, reducing their prevalence and impact. Proper planting dates and densities can also minimize the risks of pest and disease outbreaks by avoiding peak periods of pest activity and reducing conditions conducive to disease development. Maintaining field hygiene by removing crop residues and weeds that can harbor pests or pathogens is another critical aspect of cultural control. Biological control is an environmentally friendly component of IPDM, utilizing natural enemies of sorghum pests, such as predators, parasitoids, and beneficial microorganisms, to keep pest populations under control. For instance, releasing beneficial insects that prey on sorghum pests or applying microbial agents that suppress disease-causing pathogens can help manage pest and disease pressures without harming non-target organisms or the environment.

When chemical controls are necessary, IPDM promotes the targeted and judicious use of pesticides. This involves selecting products that are effective against the pest or disease in question but have minimal impact on beneficial organisms and the environment. Application timing and methods are carefully considered to maximize efficacy and minimize waste and runoff. Monitoring and scouting are essential to identify when pest or disease pressures reach economic thresholds that justify the use of chemical controls, ensuring that interventions are timely and effective. IPDM in sorghum production is not a one-size-fits-all approach but requires continuous adaptation and integration of practices based on ongoing monitoring, research, and local conditions. By employing a combination of genetic, cultural, biological, and chemical strategies, farmers can manage pests and diseases in a way that is sustainable, environmentally friendly, and economically viable. This comprehensive approach supports the resilience of sorghum production systems, contributing to food security and the well-being of communities dependent on this crucial crop.

Analysis and Discussion

Enhancing climate resilience in sorghum production integrates genetic improvements, agronomic practices, and technological innovations to address the multifaceted challenges posed by climate change. Genetic advancements have enabled the development of sorghum varieties that are more tolerant to drought and heat, laying a critical foundation for resilience. These efforts are complemented by agronomic practices such as soil and water management and integrated pest and disease management, which optimize the growing environment and bolster the plant's defenses against stressors. Technological innovations, including precision agriculture and climate forecasting, offer tools for precise management and prediction of climatic impacts, enabling more informed decision-making. The synergy between these strategies is key to enhancing sorghum's resilience, ensuring sustainable production, and securing food supplies in vulnerable regions. The challenge remains in effectively integrating and scaling these approaches to meet the diverse conditions and resources of sorghum producers worldwide.

Conclusion

The enhancement of climate resilience in sorghum production is a critical endeavor that necessitates a multidimensional approach combining genetic improvements, agronomic best practices, and cutting-edge technological innovations. By developing sorghum varieties with improved tolerance to extreme weather conditions and implementing sustainable management practices, we can safeguard this vital crop against the adverse effects of climate change. The integration of precise agricultural technologies further supports these efforts by enabling more efficient resource use and better decision-making. As we move forward, the key to success will lie in the collaborative efforts of researchers, farmers, policymakers, and stakeholders across the agricultural sector. Together, they can drive the adoption of these strategies at scale, ensuring the sustainability and security of sorghum production for future generations. This holistic approach not only contributes to the resilience of sorghum but also exemplifies a sustainable path forward for global agricultural practices in the face of an increasingly unpredictable climate.

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