

Biological and Agricultural Potential of Sorghum (Sorghum Bicolor L.) in Climate-Smart and Sustainable Agricultural Systems

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ABSTRACT: Sorghum (Sorghum bicolor L.) represents one of the most promising cereal crops for future agriculture due to its exceptional tolerance to drought, salinity, and high temperature stress. This extended scientific article analyzes the biological, ecological, agronomic, and economic potential of sorghum cultivation within climate-smart agricultural frameworks. The synthesis integrates plant physiology, crop management, sustainability science, and digital agriculture concepts. Results highlight sorghum as a strategic crop for food security, resource conservation, and agroecosystem resilience.

KEYWORDS: Sorghum; sustainable agriculture; climate change; drought tolerance; crop resilience; digital farming

1. INTRODUCTION

Global agriculture faces unprecedented challenges caused by climate variability, water scarcity, and soil degradation. Traditional cereals such as maize and wheat are increasingly vulnerable to environmental stress. Sorghum has gained renewed attention as a resilient crop capable of sustaining production under marginal conditions. Its adaptability makes it essential for ensuring long-term agricultural sustainability and food system stability[1].

2. BIOLOGICAL AND PHYSIOLOGICAL CHARACTERISTICS

Sorghum is a C4 photosynthetic species characterized by high radiation use efficiency and superior water-use efficiency. Morphological adaptations include a deep root system, leaf wax deposition, osmotic adjustment, and efficient stomatal regulation. These features enable the plant to maintain metabolic activity during prolonged drought periods. Genetic diversity among sorghum genotypes allows adaptation to a wide range of agro-ecological zones[4].

Biological Characteristics

Sorghum is a C4 monocotyledonous species belonging to the Poaceae family. It exhibits significant genetic diversity and includes several types such as grain sorghum, forage sorghum, and sweet sorghum. The plant has a deep fibrous root system, a solid stem, and a panicle-type inflorescence.

Table 1. Key Morphological Traits of Sorghum

Trait	Description
Root system	Deep, fibrous, drought-resistant
Stem	Solid culm, 0.5–4 m height
Leaves	Narrow, waxy cuticle
Inflorescence	Panicle (compact or loose)
Grain	Small caryopsis, various colors

Physiological Characteristics

Sorghum demonstrates high photosynthetic efficiency due to its C4 metabolism. It is highly tolerant to drought, heat, and moderate salinity. Mechanisms such as stomatal regulation, osmotic adjustment, and dormancy contribute to its resilience.

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Table 2. Physiological Adaptations

Factor	Adaptation
Drought	Leaf rolling, stomatal closure
Heat	Optimal growth at 25–35°C
Water efficiency	High water-use efficiency
Salinity	Moderate tolerance
Nutrients	Efficient N and P uptake

3. AGRONOMIC PERFORMANCE AND CROP MANAGEMENT

Sorghum adapts well to diverse soils and requires fewer inputs than other cereals. It is suitable for crop rotation and sustainable farming systems. It is sown when soil temperature exceeds 12°C and has a growth cycle of 90–140 days. Sorghum demonstrates stable yield performance even under reduced rainfall conditions. Optimal agronomic practices include conservation tillage, precision sowing, balanced fertilization, and integrated pest management. Crop rotation involving sorghum improves soil organic matter and reduces pest pressure, contributing to sustainable production systems.

Table 3. Agronomic Practices

Parameter	Recommended Value	Remarks
Soil type	Sandy to clay	Well-drained preferred
pH	6.0–7.5	Tolerates variation
Sowing temp.	12–14°C	Minimum threshold
Growing season	90–140 days	Depends on hybrid
Fertilization	Moderate NPK	Improves yield

4. ENVIRONMENTAL AND ECOLOGICAL BENEFITS

Compared with conventional cereals, sorghum requires significantly less irrigation and nitrogen fertilization, resulting in reduced greenhouse gas emissions. Its cultivation on marginal lands prevents soil erosion and enhances biodiversity. Sorghum residues contribute to carbon sequestration and soil regeneration processes.

5. INTEGRATION INTO DIGITAL AND PRECISION AGRICULTURE

Modern digital agriculture technologies enhance sorghum productivity through remote sensing, artificial intelligence, and data-driven decision systems. Satellite monitoring enables early detection of stress factors, while predictive analytics optimize irrigation scheduling and fertilizer application. These innovations support climate-smart farming strategies.

6. NUTRITIONAL AND ECONOMIC IMPORTANCE

Sorghum grain contains proteins, dietary fiber, antioxidants, and essential micronutrients. Its gluten-free nature supports functional food industries and specialized nutrition markets. Economically, sorghum contributes to livestock feeding systems, bioethanol production, and renewable bioenergy development.

Sorghum (*Sorghum bicolor* L. Moench) is a nutritionally valuable cereal crop that plays a crucial role in food security, particularly in arid and semi-arid regions. It is rich in carbohydrates (70–75%) and provides moderate protein content (8–12%), although lysine is a limiting amino acid. Sorghum is also a significant source of dietary fiber and is naturally gluten-free, making it suitable for individuals with celiac disease.

It contains essential minerals such as iron, zinc, phosphorus, and magnesium, along with B-complex vitamins. Additionally, sorghum is rich in bioactive compounds (phenolics, flavonoids, tannins) with antioxidant properties. However, anti-nutritional factors like phytates and tannins may reduce nutrient bioavailability, which can be improved through processing methods such as fermentation and thermal treatment[3,5].

Sorghum is the fifth most important cereal crop globally and has high economic value due to its adaptability and low production costs. It thrives in marginal environments and requires fewer inputs, making it ideal for sustainable agriculture. It has multiple uses: human food, animal feed, biofuel production (especially sweet sorghum), and industrial applications. Sorghum contributes significantly to rural economies and is increasingly recognized as a climate-resilient crop, essential for adapting agriculture to climate change[3].

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7. MATERIALS AND METHODS

The research employed systematic literature review methodology using scientific databases such as Web of Science, Scopus, and ScienceDirect. Comparative agronomic indicators analyzed included yield stability, drought tolerance, biomass productivity, and environmental impact. An interdisciplinary analytical framework integrated agronomy, plant physiology, and sustainability science.

8. RESULTS AND DISCUSSION

The synthesis of scientific evidence confirms sorghum's capacity to maintain productivity under abiotic stress conditions. Yield stability, efficient water consumption, and wide adaptability position sorghum as a key component of resilient agricultural systems. Challenges include limited farmer awareness and insufficient processing infrastructure in some regions.

9. FUTURE RESEARCH PERSPECTIVES

Future research directions include genomic breeding programs, climate-adaptive cultivar development, integration of artificial intelligence into crop monitoring, and expansion of sustainable sorghum value chains in Europe and globally.

10. CONCLUSIONS

Sorghum represents a highly valuable crop from both nutritional and economic perspectives. Its nutrient profile and adaptability make it essential for sustainable agriculture and global food security[2].

Sorghum represents a biologically efficient and environmentally sustainable crop suitable for climate-resilient agriculture. Expanding sorghum cultivation contributes to food security, resource conservation, and diversification of farming systems. Continued technological innovation and policy support will enhance its agricultural importance.

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