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Environmental and climate changes and their impact on seed production: A review

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ABSTRACT
This study looked at how the rapid changes in the temperature and environment over the past few decades have affected agricultural seed production in terms of quantity, quality, and genetic diversity, both directly and indirectly. Since seeds are the basis of agriculture, any disturbance to the conditions in which they are produced has an adverse effect on both sustainable agricultural productivity and food security. In addition to environmental pollution and soil degradation, the most notable effects of climate change were emphasized, including drought, rising temperatures, altered rainfall patterns, and a rise in the intensity of extreme weather events. It has been demonstrated that these variables impact mother plant growth phases, seed maturity, germination rates, and storability. They may even contribute to a reduction in crop genetic diversity. Additionally, the study examined the role. The study also looked at how agricultural adaptation can lessen the detrimental effects of these changes on seed production. Examples of this include creating varieties that are resistant to heat and salinity, enhancing irrigation systems, and implementing smart farming practices.

Keywords: Climate change, Environmental change, Seed production, Sustainable agriculture, Temperature, Drought, Genetic diversity.

Introduction

Among the most urgent issues facing agribusiness worldwide now are environmental and climate change. The production of crops and, more especially, the quality and availability of seeds are being significantly impacted by these changes, which are characterized by rising temperatures, shifting precipitation patterns, an increase in the frequency of extreme weather events, and changes in the composition of the atmosphere. Food security and agricultural productivity are based on seeds, and any interruption in their production can have an impact on the entire food chain (Yuan et al., 2024). The timing of flowering, pollination, and seed maturity are all affected by climate change, which may diminish overall yield, germination rates, and seed viability. The health and growth of seeds are also threatened by environmental stressors such as drought, salt, heat waves, and insect outbreaks. Adaptive strategies, such as developing resilient crop varieties, improving farming practices, and setting up more dependable seed distribution and storage systems, are necessary for seed production systems to overcome these challenges (Maity et al., 2023). In light of continuous worldwide changes, it is essential to comprehend how environmental and climatic dynamics relate to seed production in order to ensure sustainable agriculture. The purpose of this study is to investigate the critical elements that connect seed physiology, production efficiency, and long-term agricultural resilience to climatic variability (Mba et al. 2025). One of the most important issues facing the globe today is climate change, which dominates conversations and debates about environmental change worldwide (O'Neill et al., 2017). Specialty crop growers in rural and emerging regions struggle to adjust to these shifting climatic conditions, and the impact of this shift on the agricultural industry is evident. Due to the disruption of the precise balance necessary for the growing of specialized crops, these conditions can have a substantial impact on their production costs and revenues, by altering the water cycle, temperature, and soil fertility, shifting climatic patterns can have a big effect on agricultural output (Malhi et al., 2021). Because of high consumption rates, seasonal variations, changing consumer preferences, and changing global demands, specialty crops are susceptible to market changes. Customers are becoming more inclined to adopt a vegan diet. By increasing access to nutrient-dense options and ensuring the availability and stability of the food supply, specialty crop production resilience can help achieve the Sustainable Development Goals (SDGs) established by the UN, particularly SDG 2: Zero Hunger and SDG 3: Good Health and Well-Being (Pandey and Pandey, 2023). The concept of environmental sustainability includes a number of elements that are pertinent to specialty crops. For instance, the availability of cover crops like switch grass, fescue, and clover can support environmental sustainability by improving soil health, water management, and biodiversity conservation (Quintarelli et al., 2022). Innovation and Research: The most crucial component of enhancing resilience in the production of specialty crops is research. First, by establishing sustainable farming practices and climate adaption tactics, they make it possible to use breeding programs and genetic engineering techniques to produce specialty crop varieties that are resistant to environmental challenges, pests, and diseases (Rivero et al. 2022). And efficient methods for managing pests and diseases, which also make it easier to introduce new methods and technology to producers of specialty crops and keep them up to date on the most recent research. Additionally, research aids in determining the ideal soil composition (Gałazka et al., 2020). To evaluate nutrient levels, moisture content, and general soil health, farmers can also install intelligent devices for soil quality analysis. This makes it possible for them to administer pesticides and fertilizers more accurately, which lowers the possibility of overuse and minimizes greenhouse gas (GHG) emissions and hazardous discharge into water bodies. These systems incorporate predictive models that evaluate both historical and current data to forecast the best use of inputs, increasing resource efficiency and encouraging greener habits. By lowering labor costs and encouraging sustainable farming, robotics and automation further improve the precision of input applications. By employing machine learning algorithms to forecast probable hazards, including insect infestations or disease outbreaks, these intelligent systems also increase crop yield and resilience by enabling farmers to take preventative action and shield crops from potential harm (Ghazal et al., 2024).

Amis of the study:

1. To investigate how the quantity and quality of seeds produced are impacted by drought and other climate change-related issues, such as rising temperatures.
2. To investigate the effects of environmental changes on parent plant development and seed production, such as pollution and soil degradation.
3. To raise awareness of the challenges the seed production sector faces in agriculture due to changing weather patterns.
4. To analyze the main agricultural technologies of today and adaptation techniques for climate and environmental change.
5. To provide practical recommendations and concepts for improving seed production and ensuring its sustainability in view of current and future environmental conditions.

Climate-Induced Stress Effects on Seed Yield and Quality: Since the introduction of high-quality seed of high-yielding varieties in the 1960s, Indian agriculture has seen a paradigm change in agricultural production that has aided in accomplishing the objectives and effects of the green revolution. However, the smooth pursuit of increased production has been slowed down by a number of new issues that have emerged in addition to the inherent constraints in agriculture. For this reason, it has been stressed that Indian agriculture needs a second green revolution. The efficient use of resources is what makes the second green revolution possible. Everyone agrees that using other resources and improved technologies is useless without high-quality seed (Maity et al., 2023).

The most important prerequisite for achieving the desired production level of the second/evergreen revolution is seed, both in terms of quality and availability. Among these, the pressing subject of climate change and its likely effects on seed quality and seed production itself have not received much attention until recently, despite the fact that the issue is extremely real. Seed quality is determined by a number of factors, including the seed's physical and genetic purity, germination, viability, vigor, health, and appearance, including size, shape, weight, and color. The climate conditions that persist throughout the crop's growth phase, harvest, following seed processing, and storage affect each of these factors (Thapa, 2024). Weather anomalies, especially during seed planting, cause significant variations in total seed production and, in turn, in seed quality. If the climate is unfavorable, the number and quality of seeds will be lost, which will reduce their market value and availability. This will then lead to a reduction in crop area and a bad agricultural harvest. The nation's food and nutritional security as well as farmers' livelihoods are thus negatively impacted. However, the Intergovernmental Panel on Climate Change assessment states that, after India's coastline ecology, the Himalayan ecosystem is one of the most sensitive regions to climate change. The primary driver of Hill's socioeconomic status is agriculture. Due to its significance and urgency, we examined in this chapter the possible effects of climate change on seed setting and quality parameters, which in turn affect seed performance and production, as well as the workable solutions that combine traditional and contemporary knowledge bases to address those problems holistically (Kumar et al., 2022).

Effects of Pollution and Soil Degradation on Seed Productivity: These days, a number of environmental risk compounds found in soil around the world have shown significant restriction of crop seed germination, endangering the food supply and security. The inhibitory effects of environmental risk compounds on seed germination are thoroughly summarized and discussed in this article. These substances include heavy metals, micro plastics, petroleum hydrocarbons, salt, phenols, essential oils, agricultural waste, antibiotics, and more. Critical research is done on the effects of different environmental risk compounds' species, concentrations, and particle sizes. Additionally, the three main ways that environmental danger compounds are inhibited are explained: preventing water absorption, causing oxidative damage, and harming seed cells, organelles, and cell membranes. Numerous practical coping strategies, including coating, seed priming, biological remediation, genetic modification, bio char/compost addition, and seed priming, are suggested to mitigate these adverse effects (Luo et al., 2024). Also, the plant world is full of germination inhibitors, such as phenols, cyanides, alkaloids, essential oils, amino acids, and others, which prevent seeds, spores, and other plant reproductive material from germinating. Depending on whether they impair the seed's morphology, structure, or physiology, these inhibitors can be categorized as either germination retarders or germination destructors. Seed dormancy and germination retarders are closely related. By using the right dosage, exogenous retarders can prolong the "dormancy" phase of perishable or non-dormant seeds. They offer a wide range of potential uses as preservatives for long-term germplasm resources or for seed preservation after harvest. As a class of relatively high-efficiency, low-specificity "toxic chemicals," germination destructors are quite helpful for applying herbicides that are both ecologically safe and effective. The primary issues with germination inhibitor research methods at the moment include the challenge of identifying the precise endogenous compounds and the lowest inhibitory concentration required to induce dormancy, as well as the possibility that applying exogenous inhibitors will harm seeds physiologically. In the future, we should improve the monitoring of germination inhibitors, investigate the deeper molecular mechanisms and the mechanisms of action of particular substances, and lastly investigate novel advancements and novel uses of various inhibitors (Chenyin et al., 2023).

Climate Variability and Its Impact on Seed Sector Resilience: Particularly in Ethiopia, where farming is the main source of income, climate change and variability characterized by rising temperatures, changed precipitation, and a rise in extreme weather have a substantial impact on agriculture. According to current climate trends, staple crop yields in Sub-Saharan Africa are expected to decrease by 10% to 20% by 2050, endangering rural economies and food security. By 2050, Ethiopia's maize yields might drop by 15% as a result of rising temperatures and unpredictable rainfall. Ethiopia is not alone in these difficulties; other climate-vulnerable regions, such as South Asia and Latin America, are also at risk. For example, heat stress and shifting monsoon patterns may cause South Asia's rice and wheat production to drop by 10% to 15% by the middle of the century, impacting millions of smallholder farmers (Abebaw, 2025). Developing a successful agricultural adaptation plan is essential to ensuring food security in a world where climate change is posing challenges. To deal with the unpredictable effects of climate change, governments and private citizens around the world have been implementing both short-term and long-term reaction methods. The most common short-term adaptation strategies among farmers worldwide, regardless of their agro-ecological zone, were found to be crop and livestock diversification, changing or optimizing planting dates, land, pest and nutrient management decisions, insurance, and temporary migration. Although on a small scale, farmers used capital-intensive long-term adaptation measures such as changing crop types and locations, modernizing farms and using new technologies, improving water management techniques, and permanent labor migration. Implementing sustainable agriculture policy in tandem with coordinated climate change adaptation methods is a logical, practical, and economical way to address the potential consequences of abrupt or gradual climatic scenarios (Prasad et al. 2023). Both researchers Dawid and Boka (2025) confirmed that Floods, droughts, and crop pests are some of the ways that climate change affects agricultural output. The study's goals were to investigate farmers' perspectives on climate change, adaptation tactics, and barriers to adaptation, as well as to pinpoint the variables influencing the selection of climate change adaptation tactics that impact agricultural output (Parra-López et al. 2024). Climate change has significant and varied effects on agriculture, endangering livelihoods and food security worldwide. Established agricultural techniques are disrupted by rising temperatures, changing precipitation patterns, and an increase in the frequency of extreme weather events. Heat stress, water scarcity from protracted droughts, and heightened susceptibility to pests and illnesses in warmer climates all contribute to declining crop production. Reduced productivity and health issues affect livestock. Farmers' ability to anticipate and adjust is strained by altered growing seasons, which throw off planting and harvesting schedules. Vulnerable farming communities are disproportionately impacted by these issues, which exacerbate social and economic inequality.

Modern Agricultural Technologies and Climate Adaptation Strategies: Climate change presents a wide range of problems to agricultural activities because agricultural productivity is weather and climate related and essentially depends on climate stability. Reduced food yields and crop area, effects on biotic and abiotic factors, financial losses, and higher labor and equipment expenses are some of the negative effects of climate change. Crop varieties and management, including land use change and innovative breeding techniques; water and soil management, including agronomic practices; farmer training and knowledge transfer; financial schemes, insurance, migration, and culture; agricultural and meteorological services; and research and development, including the creation of early warning systems, are some strategies and actions for agricultural adaptation that can be prioritized at the local and regional levels (Grigorieva et al., 2023). In the face of mounting environmental challenges, particularly the growing effects of climate change, agriculture faces a significant problem in providing the world's expanding food demand in a sustainable manner. Climate change is also largely caused by agriculture. Agriculture using digital technologies can help mitigate and adapt to climate change. Remote sensing for crop monitoring, big data for forecasting water shortages and pest outbreaks, artificial intelligence for tracking and identifying pests, the Internet of things for precise fertilizer management, nanotechnology for soil improvement, robots for targeted spraying, block chain for better soil management and supply chain transparency, and more are some of the recognized uses of digital technologies in agriculture (Annappa et al., 2023). In recent decades, the amount of land under cultivation has increased in part to meet the demand for growing agricultural products. In addition to the inherent limitations of land supply, there is fierce competition for the current agricultural lands, which further restricts the expansion of agricultural land. In order to prevent additional environmental harm, agricultural productivity must increase more quickly than population growth. Sustainable intensive farming, or the more efficient use of agricultural land and water resources, is the main driver of development. Based on socioeconomic costs, environmental effects, or public health, the current worldwide trends in food consumption are unsustainable. Sustainable food consumption should be a goal for the expanding population because it has significant effects on the environment, society, and health. In light of this, the advantages of eating foods that are less damaging to the environment during production should also be highlighted in the context of nutrition education and consumption policy, in contrast to other food kinds whose manufacturing results in a significant need for raw materials (Fróna et al., 2019). Air pollution and climate change have a significant impact on food systems, which also play a major role in these environmental issues. In order to mitigate climate change, improve air quality, and support the sustainable development of food systems, it is essential to comprehend the intricate relationships that exist between food systems, climate change, and air pollution. The effects of air pollution and climate change on food systems, as well as the greenhouse gas and air pollutant emissions from agri-food systems and their role in both global air pollution and climate change, must be addressed in order to close this gap. As well as how agri-food systems contribute to air pollution and global climate change through their emissions of greenhouse gases and other air pollutants. This report also provides an overview of different mitigation and adaptation techniques, including as modifications to food supply networks and agricultural practices. It is imperative that food systems undergo significant modifications in order to improve adaptation and lower emissions. In order to facilitate the shift to sustainable food systems, this review identifies future research areas and provides a critical assessment of recent studies on the relationships between food systems, climate change, and air pollution (Hong et al., 2025).

Sustainable Seed Production Strategies under Changing Environmental Conditions: The detrimental effects of climate change on food security can be mitigated by adaptation measures. Since seed security dictates the crop planting area and subsequently impacts food supply, it should receive more attention as a crucial component of food security, particularly in key seed production locations like China's Hexi Corridor. Although this area is a major producer of grain (including wheat and field maize) and maize seed, the sustainable growth of agriculture is severely hampered by the lack of water resources and the inefficient use of nitrogen (N) and water (Chen et al., 2023). The development of seed systems is a key component of agricultural development since seeds have the potential to significantly improve farming systems' resilience, mitigate and adapt to climate change, offer wholesome foods, and lower poverty. However, pursuing these many objectives frequently necessitates making trade-offs, which results in various methods for developing seed systems (Kilwinger et al., 2025). Agricultural productivity is being challenged by climate change, particularly in Africa. One viable tactic to boost food security, lower poverty, and raise yields in East Africa amid climate change is the adoption of improved or varied seed types. There haven't been many thorough impact analyses, nevertheless, that connect the benefits of better seeds to household welfare. This study assesses how diverse seed systems affect Kenyan and Ugandan agricultural households' output, sales, revenue, consumption, and seed storage (Otieno et al., 2022). Tourism and research endeavors are intertwined with the preservation of the Antarctic environment. In order to encourage scientific research and reduce human impact on natural ecosystems, the physiological deterioration of latent seeds and other characteristics, some of which may contribute to the establishment of vegetation in Antarctica, can be studied using this species as a potentially useful biological model. Despite research on *C. quitensis* reproduction and germination, no current compilation of data on its reproductive biology and seed characteristics has been produced that could help with its conservation. In order to determine the causes of the drop in seed quality, this study synthesizes and critically evaluates the current understanding of *C. quitensis* reproduction in both wild and managed settings. We suggest that germination and seedling establishment are influenced by growing circumstances, seed shape, and interactions with entophytic fungi. We also point out important knowledge gaps that need to be filled in order to comprehend the phenology of the species, how biotic and abiotic factors affect its development, seed conservation tactics, and biotechnological applications (Ontivero et al., 2024). Researchers are investigating new and effective ways to guarantee stable and secure food supply as a result of the dangers that climate change poses to agriculture globally. In addition to being effective at lowering yield loss, these new tactics also need to adhere to consumer safety and environmental regulations, which specifically address limitations on the use of pesticides and the introduction of genetically modified organisms, such as CRISPR/Cas edited lines. Priming, among other methods, increases plants' endogenous potential and is a simpler and comparatively less expensive way to deal with the effects of biotic and abiotic challenges. Specifically, pre-sowing seed priming has demonstrated obvious benefits in enhancing germination and seedling establishment as well as tolerance to biotic and environmental variables during the course of the plant's life cycle. Pre-sowing seed priming, in particular, has demonstrated definite long-lasting impacts by enhancing germination and seedling establishment as well as tolerance to biotic and environmental variables throughout the plant's life cycle. At the seed level and later in the established plant, this tolerance response to a variety of unfavorable stimuli is linked to physiological, metabolic, and genetic systems and responses. We'll go over the genetic and epigenetic processes that allow plants to develop this tolerance response and the trans-generational impact it has on their offspring. Lastly, the potential contributions of various seed priming techniques to a more economically and environmentally sustainable agriculture will be examined (Cañizares et al. 2025). In order to satisfy changing consumer and social needs while adhering to the Sustainable Development Goals (SDGs), it is crucial to integrate cutting-edge technologies, promote interdisciplinary collaboration, and put forward-thinking policies into place. Precision breeding, digital agriculture, high-throughput technologies, and genetic editing are revolutionizing plant breeding by providing previously unheard-of opportunities to understand gene-environment interactions, produce desired traits, and increase crop productivity. But in this situation, responsible innovation that takes ethical considerations and legal frameworks into account is still crucial. To effectively navigate the benefits and problems brought about by this period of exponential change, stakeholders including breeders, farmers, legislators, and consumers—must collaborate and interact. Diverse viewpoints and experiences can be leveraged through inclusive and multidisciplinary discussions, fostering a resilient and sustainable future for seed production and plant breeding. Access to a variety of high-quality seeds is essential, particularly in underdeveloped countries. Investments in farmer-centric strategies, capacity building, and seed infrastructure empower farmers and increase seed security. Important it is to rethink plant breeding and seed systems by embracing technology, encouraging teamwork, and coordinating tactics with the SDGs. The envisioned future entails plant breeding and seed production that successfully answer changing societal and consumer needs by utilizing the potential of exponential changes. This will support agricultural resilience, global food security, and sustainability (Atapattu et al., 2024).

Importance this study: Because it tackles a significant issue that impacts the fundamentals of food security in both rich and developing nations, this study is notable. Understanding how climate change impacts seed production, the main source of agricultural inputs, is crucial given its deteriorating implications. In order to guarantee the continuous production of high-quality and efficient seeds, which will improve agricultural productivity and environmental sustainability, the report also emphasizes the significance of creating both scientific and practical solutions.

Expected Findings:

1. The amount and quality of seed production are clearly correlated negatively with climate change, which encompasses factors like increasing temperatures and shifting rainfall.
2. Environmental issues including pollution and inadequate soil have a direct effect on the growth phases of parent plants, resulting in weak or incomplete seed.
3. Seeds grown under erratic environmental conditions have a limited storage capacity, which limits their usage in later seasons.
4. A decrease in genetic variety brought on by an over dependence on a few numbers of hardy cultivars, which could compromise the resilience of the agricultural system.
5. The potential to boost seed production efficiency by implementing climate-smart farming practices, like employing greenhouses, drip irrigation, and choosing cultivars that can withstand harsh weather.

Conclusion

Understanding how various aspects of the agriculture industry, especially seed production, are impacted by the current global climatic and environmental changes is crucial. According to the study's findings, unpredictable weather patterns and environmental degradation drastically reduce the quantity and quality of seeds produced, putting food security and agricultural sustainability at risk. Developing cultivars that can tolerate extreme weather and implementing smart, sustainable agricultural techniques are essential to overcoming these challenges. A stable and secure agricultural future also depends on supportive policies and awareness-raising to enhance seed production and protect it from the consequences of climate change.

Recommendations

1. New seed varieties that can withstand harsh environmental conditions like drought, salt, and high temperatures should be developed.
2. When growing seeds, use sustainable and smart agricultural methods to lessen negative environmental effects.
3. Invest in agricultural science to develop new methods for pollination, germination, and climate change seed protection.
4. Raise farmers' awareness of the importance of selecting appropriate cultivars and modern farming techniques to fight climate change and protect the environment.
5. Clearly state national policies that support local seed production and the conservation of plant genetic resources.

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