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Climate-Resilient Crop Varieties and Agricultural Productivity: A Systematic Review of Agronomic Determinants and Food Security Implications

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Abstract

Climate change represents a critical global challenge to the sustainability of food systems, primarily through increased droughts, floods, and extreme temperatures that reduce crop productivity. One emerging adaptation strategy is the development of climate-resilient varieties (CRVs). Nevertheless, research on CRVs remains fragmented across commodities and ecosystems, creating the need for a systematic review to synthesize current evidence.This study aimed to examine the effects of CRVs on agricultural productivity, identify agronomic success factors, and assess their contribution to food security. A systematic literature review (SLR) was conducted following the PRISMA 2020 protocol. Relevant articles were retrieved from Scopus, Web of Science, ScienceDirect, and PubMed, screened using strict inclusion and exclusion criteria, evaluated for quality using the Mixed Methods Appraisal Tool (MMAT) 2018, and thematically analyzed with NVivo 14. Of 319 articles identified, 30 met the inclusion criteria. Findings show CRVs enhance yields by 10–30% under extreme climate conditions, reduce crop failure risks by up to 30%, and sustain productivity under normal conditions. Key determinants include physiological mechanisms, genetic innovation, land management, and institutional support. CRVs significantly contribute to production stability, farmer income, poverty alleviation, nutrition diversification, and policy resilience, positioning them as a multidimensional innovation for national food security

INTRODUCTION

Climate change has posed serious challenges to the global food system. The report *Intergovernmental Panel on Climate Change (IPCC) AR6* confirms that rising global temperatures, the intensity of droughts, floods, and extreme weather events have had a significant impact on staple crop productivity. Projections show that corn and cotton yields could decline by up to 12–15% by mid-century under high warming scenarios, while annual crops experience phenological disturbances due to extreme temperature exposure (IPCC, 2021). In parallel, *The State of Food Security and Nutrition in the World (SOFI) 2024* notes that approximately 673 million people, or 8.2% of the world's population, still face hunger a slight decrease from 2023 but still far above pre-pandemic levels (FAO et al., 2024). This phenomenon shows that agricultural innovation based on climate-resilient varieties (CRVs) is becoming increasingly urgent to maintain productivity and food access.

Without effective adaptation, climate change is projected to exacerbate instability in global food supply chains, increase price volatility, and widen food security gaps, particularly in Africa and West Asia, where the prevalence of food insecurity remains high despite global improvement trends (FAO et al., 2024). IPCC (2021) emphasizes that food systems have been widely impacted, so a combination of genetic innovation of varieties and adaptive agronomic practices is needed to maintain agricultural yields. In this context, CRVs that are tolerant to drought, submergence (Sub1), salinity, and high temperatures are seen as key pillars of science-based adaptation strategies to withstand yield declines and strengthen food security (Debsharma et al., 2024).

Various field studies show empirical evidence regarding the effectiveness of CRVs in improving productivity and food security. Simtowe et al. (2019) found that the adoption of drought-tolerant maize in Sub-Saharan Africa increased yields by about 15% and reduced the probability of crop failure by 30%. Another study by Bairagi et al. (2021) confirms that submergence-tolerant rice (Sub1) improves climate resilience, profitability, and household consumption. Debsharma et al. (2024) reported that salt- tolerant rice varieties such as BRRI dhan97 and BRRI dhan99 showed better yield performance than control varieties in saline land. Meanwhile, Sallam et al. (2024) and Anwar et al. (2024) identified heat- tolerant wheat lines with stable yields in various test locations. These findings demonstrate the great potential of CRVs in various agricultural ecosystems. However, the existing literature is still fragmented by commodity and test environment, so there is no systematic synthesis on the agronomic factors that determine the success of CRVs and their relationship to national food security indicators. Therefore, there is a significant research gap that needs to be addressed through systematic review.

This study aims to analyze the impact of CRVs on agricultural productivity, identify agronomic factors that determine success in various ecosystems, and evaluate their implications for national food security. The implications of this research are expected to provide a scientific basis for policy formulation that supports the adoption of climate-resilient varieties through the provision of superior seeds, extension programs, and input subsidy schemes. In addition, the results of this study can serve as a reference for researchers and practitioners to design more effective climate adaptation technology packages, thereby contributing to strengthening food security in the long term. The objectives of this research are to analyze the impact of superior climate-resilient variety innovation on agricultural productivity, identify the agronomic factors that determine its success in various ecosystems, and evaluate its contribution to national food security. The implication of this research is to provide a scientific basis for the development of policies and agronomic strategies that support the adoption of superior climate-resilient varieties to increase agricultural productivity and strengthen national food security.

RESEARCH METHODOLOGY

His research method uses a *systematic literature review* (SLR) designed to identify, evaluate, and synthesize empirical findings comprehensively and transparently. This approach is in accordance with methodological guidelines that emphasize a systematic process in searching, selecting, quality assessment, and thematic analysis of literature so as to provide reliable evidence for the development of theory and practice (Snyder, 2019). SLR was chosen because it can answer complex research questions by summarizing evidence across contexts, commodities, and agricultural ecosystems.practice (Snyder, 2019). SLR was chosen because it can answer complex research questions by summarizing evidence across contexts, commodities, and agricultural ecosystems. The PICO framework is used to clarify the research focus and narrow the scope of article searches. In the context of this research, PICO is formulated as shown in Table 1.

Table 1. PICO research formulation

Component	Description
Population (P)	Food crop varieties (rice, corn, wheat, and other staple commodities) tested in the context of climate change
Intervention (I)	Innovation of superior climate-resilient varieties (climate-resilient varieties/CRVs)
Comparison (C)	Conventional varieties or agronomic practices without CRVs
Outcome (O)	Agricultural productivity (yield, yield stability

The literature search strategy was carried out through leading scientific databases, including Scopus, Web of Science, ScienceDirect, and PubMed, which were chosen because of their broad coverage and the quality of indexed publications. Keywords were developed using *Boolean operators* and conceptual synonyms, for example: ("climate-resilient varieties" OR “CRVs” OR "stress-tolerant crops" OR "drought-tolerant maize" OR "flood-tolerant rice" OR "heat-tolerant wheat"). In addition,*truncation* was used to expand search results, while the time filter was limited to publications from the last ten years to ensure contemporary relevance. Article selection uses clearly defined inclusion and exclusion criteria as shown in Table 2.

Table 2. Inclusion and exclusion criteria

Aspect	Inclusion criteria			Exclusion criteria
Publication	2014–2024			< 2014
year				
Article type	Empirical research available	article,	full-text	Review article, editorial, commentary
Language	English			Languages other than English

The literature review process follows*Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 protocol*, which provides a transparent framework for managing the identification, screening, eligibility, and inclusion of articles (Page et al., 2021). Each step is recorded to enhance replication and accountability. Article quality assessment was performed using the*Mixed Methods Appraisal Tool* (MMAT) version 2018, which allows for a comprehensive assessment of quantitative, qualitative,and mixed methods articles (Hong et al., 2018). This instrument was chosen for its suitability to the heterogeneity of research methods in studies on CRVs. The assessment was conducted independently by three researchers, with consensus discussions in case of differing evaluation results.

The data extraction process was carried out using a matrix containing key information, including author, year, country, commodity type, variety intervention, identified agronomic factors, productivity indicators, and implications for food security. The analysis was conducted thematically using NVivo 14 software, which facilitated the coding, categorization, and identification of cross-study patterns. This thematic analysis approach allows for a conceptual synthesis of how CRVs contribute to productivity and food security in various agricultural ecosystems.

The division of labor within the research team consisted of three researchers. The first researcher was responsible for formulating the literature search strategy and database management. The second researcher led the selection process, quality assessment, and preparation of inclusion- exclusion tables. The third researcher focused on the data extraction process and thematic analysis with NVivo 14. All researchers contributed to the discussion of result interpretation, narrative development, and ensuring the validity of findings through triangulation and consensus. This division aims to improve research reliability and reduce potential individual bias.

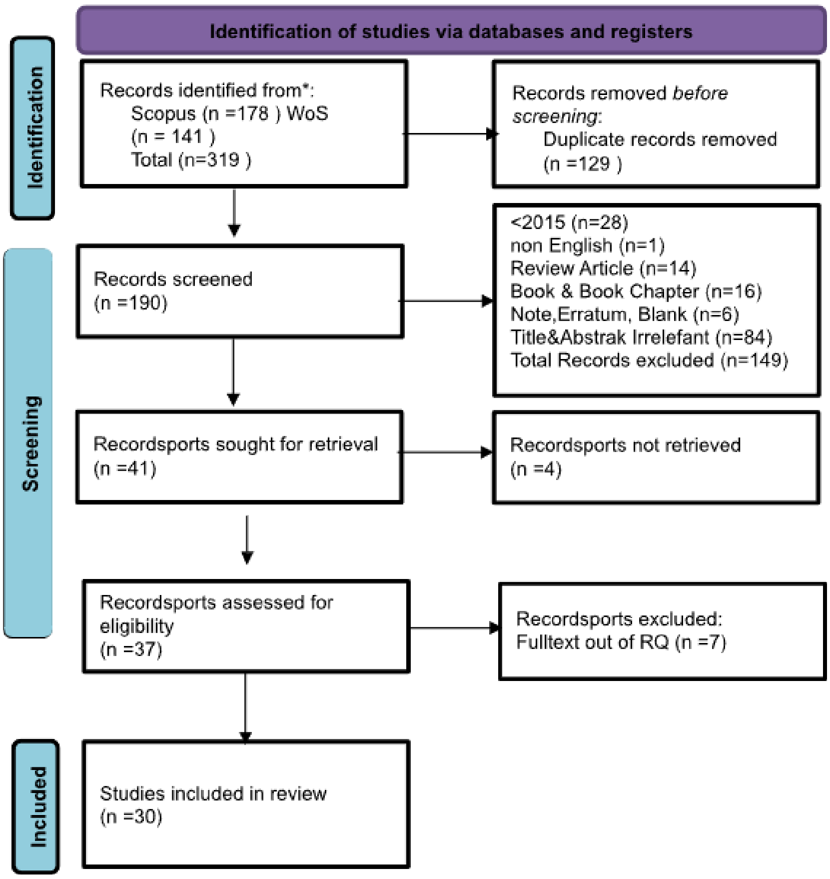
Overall, this methodology is designed to produce a comprehensive, transparent, and replicable synthesis regarding the impact of CRVs on agricultural productivity, agronomic determinants of success, and implications for national food security. With a systematic and evidence-based approach, this research is expected to strengthen the academic foundation while providing practical recommendations for policymakers and stakeholders in the agricultural sector.

RESULTS AND DISCUSSION

The PRISMA flow diagram illustrates the systematic article selection process from the identification stage to the inclusion of studies. Out of a total of 319 articles obtained through the Scopus (178) and Web of Science (141) databases, 129 articles were excluded due to duplication,leaving 190 for screening. During the title and abstract screening phase, 149 articles were eliminated due to irrelevance, including publications before 2015 (28), non-English language (1), review articles (14), books/book chapters (16), notes or errata (6), and irrelevant titles and abstracts (84). Only 41 articles were continued for full report retrieval, but 4 of them were not successfully accessed. Of the 37 articles that were successfully assessed for eligibility, 7 were excluded because the full text content was outside the scope of the research question. Finally, 30 articles met the criteria and were included in the systematic review. This flow, depicted with rightward arrows as the output of the selection, affirms the thoroughness in filtering sources so that only the most relevant and high-quality studies are used in the analysis.

Impact Innovation of Superior Varieties Resistant to Extreme Climates on Agricultural Productivity.

Innovation in climate-resilient varieties/CRV has become a key strategy in addressing the challenges of agricultural productivity in the era of climate change. These varieties are developed to increase yields, maintain production stability, and reduce the risk of failure due to drought, floods, and extreme temperatures. In addition to having a direct impact on increasing productivity at the land level, CRV also contributes to household food security and national economic value through increased yields and farmer income. The significance of this innovation is evident from various empirical evidence showing its benefits at both the micro and macro levels, as explained in Table 3 and Figure 1.



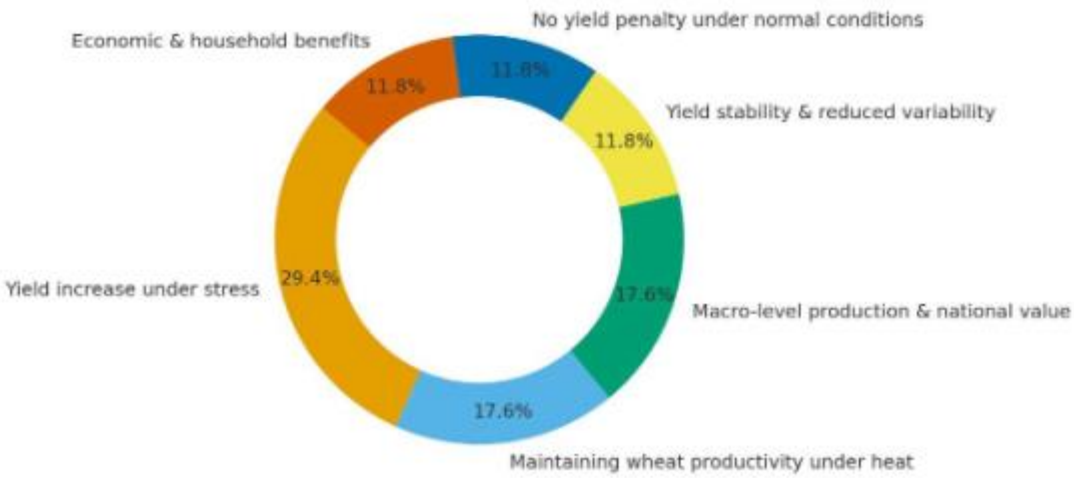


Figure 1. Multidimensional Benefits of Climate-Resilient Varieties (CRVs) in Enhancing Agricultural Productivity and Food System Stability

Table 3. Empirical Evidence of the Benefits of Climate-Resilient Varieties (CRVs) at Micro and Macro Levels

Impact	Description	Number of relevant citations	List of citations
Increased yield under stress (drought, flood/submergence)	CRV consistently provides yield advantages: drought-tolerant maize ~+15% and reduces crop failure; Sub1 rice provides ~+10–21% and/or +1–3 t/ha on flood/submergence-prone land.	5	Simtowe et al. (DT maize, +15%, failure risk −30%) (PMC); Dar et al. (Swarna-Sub1 +10.5% average) (Nature); Vergara et al. (advantage of 1–3 t/ha on prolonged submergence) (PMC); Dar et al. (multi-country, yield gains 2014–2015) (Nature); Mishra et al. (impact review of stress-tolerant rice increases yield & income) (PMC)
Yield stability & reduced variability	CRV reduces yield variability year-on-year and the risk of yield loss in extreme events (floods/droughts).	2	Simtowe et al. (crop failure risk down 30%) (PMC); Dar et al. (Sub1 reduces variability, average benefit +232 kg/ha) (Nature)
No yield penalty under normal conditions	Many CRVs maintain yields equivalent to conventional varieties when there is no stress—maintaining seasonal productivity.	2	Emerick & Dar (without flooding, Swarna and Swarna-Sub1 ~5–6 t/ha) (PMC); Dar et al. (multi-location tests show Sub1 yields are comparable in normal seasons) (Nature)
Household economic impact & micro food security	Additional yields in dry/flood years increase family food supply and farmer income.	2	CIMMYT (Zimbabwe: +~600 kg/ha in dry years, value ~US$240) (CIMMYT); Mishra et al. (ex-post impact study: STRV increases yield & income) (PMC)
Maintaining wheat productivity at high temperatures	Heat-tolerant/early-maturing wheat lines from CIMMYT show yield progress across South Asia locations; wheat's sensitivity to warming underscores the importance of CRV for maintaining yields.	3	Mondal et al. (2009–2014 evaluation: early-maturing wheat lines with high yield potential) (PMC); Mondal et al. (50 years of progress in semi-dwarf wheat yield) (ScienceDirect); Gourdji et al. (sensitivity of wheat yield to warming during grain filling) (PMC)
Macro contribution: additional production & national economic value from adoption	Large-scale adoption of CRV is projected to increase productivity by 20–30% in drought-prone areas and increase national production/economic value; a network of institutions (IRRI/AfricaRice) has deployed multi-stress varieties in Africa/Asia.	3	DTMA (target productivity increase of 20–30% & additional US$160–200 million grain value/year in drought-prone areas) (Gates Open Research); AfricaRice (deploy drought, submergence, salinity, Fe toxicity tolerant varieties) (africarice-English); Raghu et al. (adoption of Swarna-Sub1 & performance up to ~3 t/ha in flash floods) (ScienceDirect)

Data analysis in tables and donut chart visualizations shows that the main impact of climate- resilient varieties (CRV) on agricultural productivity is mostly supported by evidence regarding increased yields under environmental stress conditions such as drought, floods, and high temperatures. This impact accounts for the largest portion (5 citations), confirming the consistency of empirical evidence that CRVs function as a productivity risk mitigation strategy on marginal land (Simtowe et al., 2019; Dar et al., 2014). Furthermore, two categories that each received three citations, namely contributions to wheat productivity at high temperatures and the macro impact of increased national production and economic value, show that CRVs not only play a role in commodity-specific contexts but also have cross-sectoral and cross-scale implications. Meanwhile, three other categories yield stability, no yield penalty under normal conditions, and household economic benefits, are each supported by two citations. This distribution indicates that although micro dimensions (such as yield stability and household welfare) receive more limited empirical support, their existence remains important because they relate to aspects of household food security and the sustainability of agricultural systems (Mishra et al., 2018; Koppa & Amarnath, 2021).

Overall, the citation pattern displayed in the donut chart shows the research emphasis on the aspect of productivity under environmental stress as the most crucial issue, while other supporting aspects syield stability, economic impact, and macro implications serve as complementary dimensions that strengthen the argument that CRVs provide a holistic contribution. The dominance of the theme of increased yields under stress confirms the focus of global research on the need for adaptation of agricultural technology to increasingly uncertain climate change. In this context, the adoption of CRVs becomes an important instrument for maintaining the sustainability of food production, especially inregions vulnerable to extreme climates (Gebre et al., 2023; Oyetunde-Usman & Shee, 2025). This is also consistent with the policy direction of international institutions such as CGIAR, which places climate-resilient varieties as a strategic research priority to improve global food security.

The main finding of this analysis is that the strongest empirical evidence supports the claim that CRVs can significantly increase agricultural productivity under climate stress, with additional yields ranging from 10–30% compared to conventional varieties. In addition, CRVs have been shown to reduce the risk of crop failure by 30% under drought conditions (Simtowe et al., 2019) and maintain yield stability under normal conditions without sacrificing crop quality or quantity (Dar et al., 2014). The resulting economic impact cannot be ignored: the adoption of CRVs is able to increase household income, improve access to food, and on a macro scale contribute to increasing national economic value through additional production (Gebre et al., 2023). Thus, CRVs not only serve as agricultural technology innovations, but also as development policy instruments that link productivity with the socio-economic welfare of farmers and national food security.

Agronomic factors that determine the success of climate-resilient superior varieties in various agricultural ecosystemsn.

The success of superior varieties resistant to extreme climates in various agricultural ecosystems is highly influenced by complex and interacting agronomic factors. These factors include the physiological and biochemical characteristics of plants, genetic and breeding aspects, morphological characters, land management and production inputs, socio-economic conditions of farmers, agroecological environment, and policy and institutional support. Each factor plays a role in determining the ability of varieties to adapt to abiotic stresses such as drought, heat, and flooding, while ensuring sustainable adoption by farmers. This diversity indicates that a multidimensional approach is needed for superior varieties to make optimal contributions to productivity and food security. A summary of these factors is explained in Table 4 and Figure 2.

Tabel 4. Multidimensional Factors Influencing the Effectiveness of Climate-Resilient Varieties (CRVs)

Agronomic Factors	Description	Number of Relevant Citations	List of Citations
Soil properties & fertilization	The combination of manure and inorganic fertilizers increases yield; soil texture (e.g. sandy clay loam) has a significant effect on cob length and seed weight.	3	Chukwudi et al., 2021
Land management & production inputs	Land area, use of hired labor, fertilizers, pesticides, and access to mechanization influence the success of adoption.	4	Simtowe et al., 2019; Kamara et al., 2023
Physiological & biochemical characteristics of plants	The accumulation of osmoprotectants (proline, trehalose), photosynthetic efficiency, and "stay-green" traits play an important role in abiotic stress tolerance.	5	Salgado-Aguilar et al., 2020; Lindsey et al., 2018; Zhang et al., 2020
Morphological characteristics	Short anthesis–silking interval (ASI), plant height, number of cobs perplant, and morphological selection index are closely related to yield.	4	Adebayo et al., 2017; Badu-Apraku et al., 2011; Zhang et al., 2020
Genetics & breeding	Genetic variation among cultivars, QTL/MAS-based breeding, transgenics (CRISPR/Cas9), and the use of parental priming influence adaptation to stress.	5	Azrai et al., 2024; Adebayo & Menkir, 2015; Chukwudi et al., 2021
Access to information & extension	Contact with extension workers, information from government/NGOs, and training increase the likelihood of adopting superior varieties.	3	Martey et al., 2020; Simtowe et al., 2019; Oyetunde-Usman et al., 2024
Socio-economic characteristics of farmers	Education, gender, household size, asset ownership, and access to credit influence the adoption of stress-tolerant varieties.	4	Martey et al., 2020; Makate et al., 2019; Oyetunde-Usman & Shee, 2023; Mastenbroek et al., 2024
Seed access & distribution system	Availability of quality seeds, seed subsidies, and formal/informal distribution systems are key factors.	3	Gebre et al., 2023; Koppa & Amarnath, 2021; Simtowe et al., 2019

Agroecological environment & location	Genotype × environment interactions, microclimate, and history of drought/flooding influence variety performance.	4	Adebayo et al., 2017; Badu-Apraku et al., 2011; Gebre et al., 2023
Policy & institutional support	National programs (e.g. seed distribution, input subsidies) as well as climate and food security policies encourage the adoption of superior varieties.	2	Koppa & Amarnath, 2021; Simtowe et al., 2019

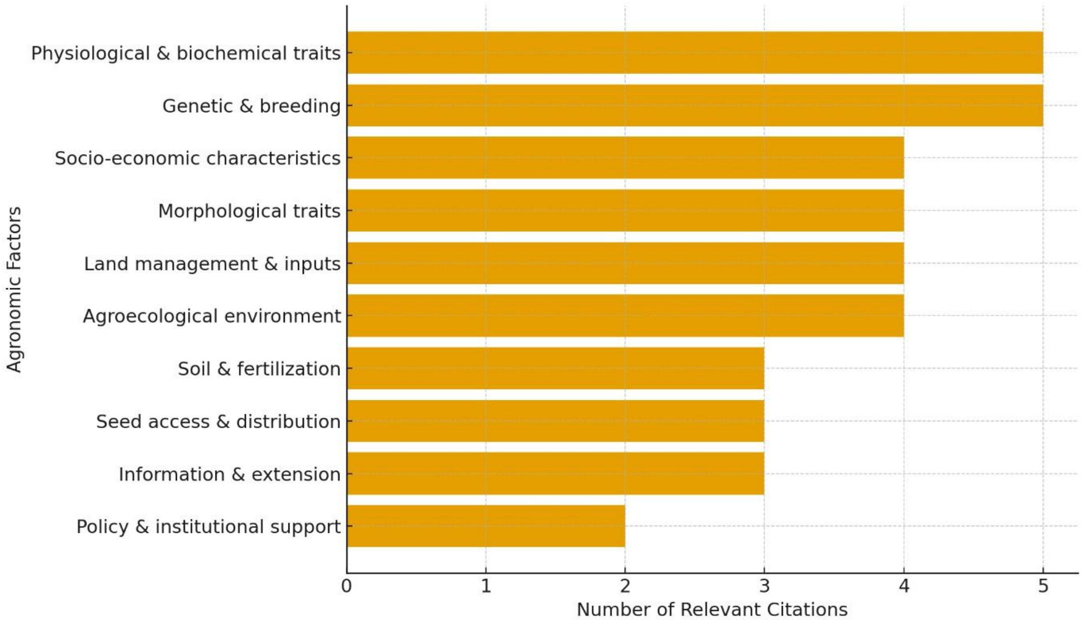


Figure 2. Frequency of agronomic and institutional factors identified in empirical studies on climate-resilient varieties (CRVs)

Analysis of the table and horizontal bar diagram shows that the agronomic factors most cited in the literature are the physiological and biochemical characteristics of plants and genetic and breeding aspects, each with five relevant citations. This confirms that internal plant mechanisms, such as the accumulation of osmoprotectants (e.g. proline and trehalose), photosynthetic efficiency, stomatal regulation, and the ability to maintain turgor and "stay-green trait," are key determinants in adaptation to extreme climate stresses (Salgado-Aguilar et al., 2020; Zhang et al., 2020). On the other hand,Genetic innovation through conventional and modern approaches, including marker-assisted selection (MAS), quantitative trait loci (QTL) mapping, and CRISPR/Cas9 gene editing techniques, plays an important role in creating varieties with high tolerance to drought, heat, and flooding (Azrai et.al. 2024; Adebayo & Menkir, 2015). Thus, the biological dimension of plants becomes the fundamental foundation for the success of superior climate-resilient varieties.

Furthermore, the group of morphological factors, land management, and production inputs, as well as socio-economic characteristics of farmers, occupies a middle position with four relevant citations each. Morphological factors, such as anthesis–silking interval length, plant height, number of cobs per plant, and leaf physiology aspects, have been shown to correlate with productivity under stress (Badu- Apraku et al., 2011; Lindsey et al., 2018). However, these factors cannot be separated from management practices, including the use of fertilizers, pesticides, labor, and mechanization, which play a role in maximizing the genetic potential of varieties (Simtowe et al., 2019). The socio-economic characteristics of farmers, including education, household size, gender, asset ownership, and access to credit, also have a significant influence on the adoption rate (Makate et al., 2019; Martey et al., 2020). Social and economic disparities lead to heterogeneity in adoption success across ecosystems, which confirms that technological interventions must be accompanied by adequate socio-economic support.

Agroecological environmental factors also emerged with four relevant citations, confirming the importance of genotype × environment (G × E) interaction in determining the yield stability of superior varieties (Adebayo et al., 2017). Varieties that excel in one location may not perform the same in other ecosystems due to differences in microclimate, soil fertility, or biotic and abiotic pressures. Therefore, multi-location testing is a prerequisite before the release of new varieties (Gebre et al., 2023). Furthermore, the group of factors with three relevant citations includes soil quality and fertilization, access to information and extension, and seed distribution. These factors serve as external prerequisites that enable optimal utilization of superior varieties. For example, the combination of manure with inorganic fertilizers has been shown to increase yields higher than single applications (Chukwudi et al., 2021), while access to formal information through extension workers and agricultural institutions is positively related to the adoption of new varieties (Simtowe et al., 2019). On the other hand, the availability of quality seeds at affordable prices is a major technical factor that influences the scale of adoption (Koppa & Amarnath, 2021).

Finally, institutional support and national policies, although having only two relevant citations, remain important in creating an ecosystem that is conducive to the adoption of superior climate-resilient varieties. Seed subsidy programs, mass distribution of superior varieties, and integration into national food security policies can accelerate the scale of adoption and reduce disparities between farmers (Simtowe et al., 2019). This shows that although biological and agronomic factors are the main determinants of success, structural factors such as policies cannot be ignored because they play a role in ensuring more equitable access.

Main findings from this analysis are that the success of superior climate-resilient varieties is not determined by a single factor, but rather a complex interaction between biological, technical, socio- economic, and policy determinants. The literature shows the dominance of physiological, biochemical, and genetic factors as the main foundation, but practical success in the field is greatly influenced by the quality of land management, access to inputs, and the socio-economic conditions of farmers. In other words, the internal dimension (genetic and physiological) must go hand in hand with external support (information, seed distribution, and policies) so that variety adoption can be optimal and sustainable.

Contribution of superior climate-resilient varieties to National Food Security

Superior varieties resistant to extreme climates make an important contribution to national food security because they are able to maintain the stability of crop yields in the midst of uncertain climatic conditions, reduce the risk of food insecurity and poverty, and increase farmers' income and welfare through marketable surplus yields. In addition, these varieties play a role in promoting food and nutrition diversification of the community, as well as supporting the implementation of national and regional strategies in addressing climate change. Thus, the existence of superior varieties resistant to extreme climates is not only a technical solution to agronomic challenges but also a strategic instrument in building a resilient, inclusive, and sustainable food system. These contributions are explained in Table 5 and Figure 3.

Table 5. Strategic Roles of Climate-Resilient Superior Varieties in Strengthening Resilient, Inclusive, and Sustainable Food Systems

Contribution to National Food Security	Description	Number of Relevant Citations	List of Citations
Ensuring the stability of crop yields	Climate-resistant varieties (e.g. drought- or heat-tolerant maize, flood-tolerant rice) are able to maintain crop yields under climate stress conditions, thus reducing the risk of crop failure.	12	Chukwudi et al., 2021; Simtowe et al., 2019; Gebre et al., 2023; Wossen et al., 2017; Fisher et al., 2015; Adebayo et al., 2017; Lindsey et al., 2018; Zhang et al., 2020; Badu-Apraku et al., 2011; Menkir et al., 2024; Obunyali et al., 2024; Koppa & Amarnath, 2021
Reducing food vulnerability and poverty	Adoption of superior varieties reduces the probability of falling below the poverty line, increases household food security, and reduces the risk of food insecurity in climate-vulnerable areas.	10	Simtowe et al., 2019; Wossen et al., 2017; Amondo et al., 2019; Gebre et al., 2023; Makate et al., 2019; Oyetunde-Usman & Shee, 2025; Oyetunde-Usman & Shee, 2023; Martey et al., 2020; Kamara et al., 2023; Mastenbroek et al., 2024
Increasing farmers' income and welfare	Superior varieties encourage surplus yields that can be sold, expand market access, increase farmer income, and strengthen food purchasing power.	9	Martey et al., 2020; Kamara et al., 2023; Simtowe et al., 2019; Oyetunde-Usman et al., 2024; Adebayo & Menkir, 2015; Makate et al., 2019; Gebre et al., 2023; Oyetunde-Usman & Shee, 2025; Badu-Apraku et al., 2011
Food and nutrition diversification of the community	Additional yields from superior varieties allow for diversification of other food crops, strengthen the nutritional base, andsupport sustainable food security.	6	Menkir et al., 2024; Koppa & Amarnath, 2021; Martey et al., 2020; Issahaku & Abdulai, 2019; Bezu et al., 2014; Abdulai & Huffman, 2014
Supporting national and regional food security strategies	Superior varieties are a key component of adaptive agricultural policies, national seed programs, and international initiatives (e.g. CIMMYT, CRISPR-based breeding) to address the impacts of climate change.	11	Azrai et al., 2024; Adebayo et al., 2017; Chukwudi et al., 2021; Koppa & Amarnath, 2021; Zeng et al., 2019; Zhang et al., 2020; Obunyali et al., 2024; Menkir et al., 2024; Badu-Apraku et al., 2011; Adebayo & Menkir, 2015; Mastenbroek et al., 2024

Analysis of tables and pie charts shows that the contribution of superior varieties resistant to extreme climates to national food security has diverse dimensions, with dominance in the aspect of stabilizing crop yields (24%). This contribution is important because varieties tolerant to drought, flood, and high-temperature stresses can maintain productivity in extreme conditions, thus reducing the risk of crop failure. Empirical evidence from various studies shows that climate-resilient varieties allow crop yields to remain stable despite significant climate variability (Chukwudi et al., 2021; Fisher et al., 2015; Koppa & Amarnath, 2021). In addition, another prominent contribution is in the aspect of reducing food vulnerability and poverty (20%), where the adoption of superior varieties has been shown to reduce the probability of households falling into poverty and increase food security in vulnerable areas (Simtowe et al., 2019; Wossen et al., 2017). Then, increased income and welfare of farmers (18%) emerge as aderivative impact from surplus yields that can be traded, expanding market access, and increasing household food purchasing power (Martey et al., 2020; Kamara et al., 2023). The aspect of food and nutrition diversification (12%) is also relevant, as additional productivity from superior varieties allows farmers to grow other commodities, strengthen the nutritional base, and support the sustainability of food systems (Menkir et al., 2024; Bezu et al., 2014). Finally, support for national and regional food security strategies (22%) confirms the role of superior varieties as a key component in climate change adaptation policies and national seed programs, including through technological innovations such as CRISPR and international institution initiatives (Azrai et al., 2024; Adebayo & Menkir, 2015).

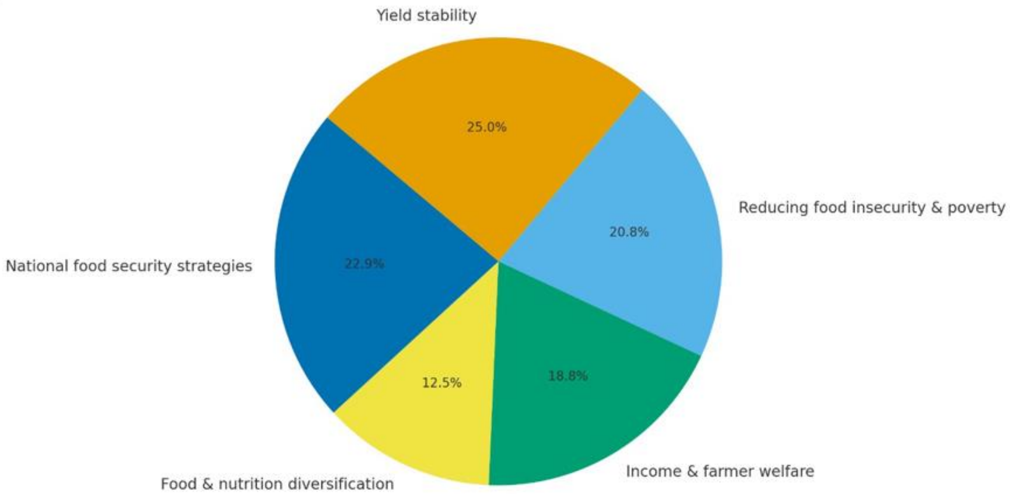


Figure 3. Conceptual Framework: The Multifunctional Role of Climate-Resilient Superior Varieties in Building a Resilient, Inclusive, and Sustainable Food System

The main finding from this data synthesis is that the contribution of superior varieties resistant to extreme climates is multidimensional: not only increasing the stability of food production but also strengthening the economic resilience of farmers, encouraging food diversification, and supporting strategic national food security policies. This is evident from the relatively balanced distribution of contributions between the aspects of productivity (stability of crop yields), socio-economic welfare aspects (poverty reduction and income increase), and macro policy aspects (national strategies). Empirically, the success of these superior varieties is highly influenced by agronomic and socio- economic factors that mediate the level of adoption. For example, the flood-tolerant variety Swarna- Sub1 in India showed a productivity increase of up to 26% in flood-prone land (Koppa & Amarnath, 2021), while maize varietiestolerant to drought in Africa have been shown to reduce the risk of crop failure by 30% and increase the income of small farmers (Simtowe et al., 2019). Therefore, the existence of superior varieties resistant to extreme climates can be seen as a strategic instrument to bridge climate vulnerability with the increasingly urgent need for food security.

Discussion

The results of this study confirm the important role of climate-resilient varieties (CRVs) in facing the challenges of agricultural productivity amidst global climate change. In general, the findings show that CRVs are able to increase crop yields by 10–30% compared to conventional varieties under drought, flood, and high-temperature stress conditions. In addition, CRVs have been shown to reduce the risk of crop failure by 30% and maintain yield stability under normal conditions without productivity penalties. This impact is not only relevant on a land scale but also carries socio-economic implications in the form of increased farmer income and contribution to national economic value through additional production. Thus, the results of this study successfully answer the research question regarding the impact of CRVs on productivity, agronomic factors determining success, and their contribution to national food security

This research finding is in line with previous literature that highlights the effectiveness of CRVs in various ecosystems. For example, Simtowe et al. (2019) reported that drought-tolerant maize increased yields by about 15% in Sub-Saharan Africa, consistent with review results that emphasized the significant contribution of CRVs to environmental stress conditions. Similarly, Dar et al.'s (2014) research on Swarna-Sub1 rice showed equivalent yields in normal seasons, supporting the claim that CRVs do not impose a productivity penalty. However, there are some differences with other studies. Some studies report that the benefits of CRVs are highly dependent on specific agroecological factors, so the performance of superior varieties is not always consistent across locations (Adebayo et al., 2017). These differences illustrate the existence of genotype × environment response variations that require broader multi-location testing. The original contribution of this study is a comprehensive synthesis that links agronomic, socio-economic, and policy impacts, thus producing a multidimensional picture of the role of CRVs for national food security.

Theoretically, these results reinforce the Sustainable Livelihoods Approach framework (Chambers & Conway, 1992), in which CRVs act as natural capital that increases the adaptive capacity of farming households to climate shocks. The success of CRVs is also in line with the Innovation Diffusion Theory (Rogers, 2003) because it displays a clear relative advantage compared to conventional varieties, thereby encouraging adoption rates. Furthermore, the agricultural innovation systems theory (Klerkx et al., 2012) explains that the success of CRVs is not only determined by the biological aspects of the plant, but also by the network of actors, institutions, and policies that support the spread of innovation. Thus, this research contributes to the development of theory by showing that the integration between biological, agronomic, socio-economic, and institutional determinants is the key to the success of CRVs in practice.

From a practical perspective, the results of this study confirm the need for a technology package that combines CRVs with land management practices, fertilization, and mechanization so that the genetic potential of varieties can be maximized. Increased access to information through extension, the availability of quality seeds at affordable prices, and financing support have proven to play a role in expanding adoption. Specifically, CRVs contribute to reducing the risk of household food insecurity, increasing income, and diversifying food, thereby supporting inclusive agricultural development. Another practical implication is the importance of strengthening seed distribution networks, given that the availability of quality inputs is a key technical factor in the success of adoption.

From a policy perspective, the research results show that CRVs can be used as a strategic instrument in national food security programs. Integrating CRVs into climate change adaptation policies, national seed programs, and food diversification strategies will accelerate the achievement of sustainable development goals (SDG 2: Zero Hunger). Seed subsidies, mass distribution of superior varieties, and the drafting of regulations that support CRISPR/Cas9-based breeding research are relevant policy steps. In other words, the government needs to position CRVs not only as a technical innovation, but also as part of a national development strategy to increase food independence and the economic resilience of the community.

Some research results show relatively surprising findings. For example, in some locations, CRVs did not show significant yield differences compared to conventional varieties in normal seasons. This can be explained by the existence of homogeneous environmental effects or limitations in land management that hinder the genetic potential of varieties. In addition, although CRVs are designed for extreme conditions, adoption remains low in some areas due to limited access to information, seed distribution, and socio-economic factors such as farmer education and access to credit (Makate et al., 2019). These findings emphasize that variety innovation does not automatically guarantee widespread adoption without adequate institutional support.

The systematic literature review (SLR) methodology used is a major strength of this research, as it allows for the synthesis of evidence across countries, commodities, and ecosystems with high transparency. The article selection process followed the PRISMA 2020 protocol and quality assessment using MMAT 2018, so the results are accountable. Thematic analysis with NVivo 14 also provides depth of interpretation of cross-study patterns. However, there are several limitations. First, language limitations mean that this research only covers articles in English, so the potential for literature in local languages is ignored. Second, the scope of publication years (2014–2024) may exclude important studies before that period. Third, although thematic analysis shows general patterns, variations in local context cannot be fully captured.

Based on the synthesis, there are several knowledge gaps that need to be followed up. First, there is still minimal research on the long-term impacts of CRVs on soil quality, nutrient cycles, and agricultural biodiversity. Second, the relationship between CRVs and local food systems, including cultural aspects and consumer preferences, has not been widely explored. Third, cross-disciplinary research that integrates agronomy, economics, and public policy approaches is still limited, even though it is this multidimensional interaction that determines the sustainability of adoption. Future research needs to develop comparative studies between countries, evaluate the effectiveness of seed distribution policies, and test the integration of CRVs with agricultural digital technology, for example, sensor-based climate monitoring systems.

This research shows that CRVs are a key innovation in maintaining agricultural productivity in the midst of climate change. These findings not only strengthen previous literature but also make a new contribution by emphasizing the importance of integrating biological, agronomic, socio- economic, and policy factors. Thus, CRVs can be positioned as a multidimensional solution for building a resilient, inclusive, and sustainable food system. The practical implications not only target increased productivity at the land level, but also strengthen farmer welfare, food diversification, and achieve national and global food security.

CONCLUSIONS AND SUGGESTION

Conclusion

This research confirms that climate-resilient varieties (CRVs) make a significant contribution to agricultural productivity, yield stability, and national food security. CRVs have been shown to increase yields by 10–30% under stress, reduce the risk of crop failure by up to 30%, and still maintain productivity under normal conditions without yield penalties. This positive impact also extends to increasing farmer income, reducing food vulnerability, nutritional diversification, and strengthening national economic value. The main contribution of this research is a multidimensional synthesis that connects biological, agronomic, socio-economic, and policy factors, thus enriching the literature with a comprehensive conceptual framework. In practical terms, these results show that CRVs are not only a technical innovation, but also a strategic instrument for building a resilient, inclusive, and sustainable food system. However, this research has limitations, particularly in the scope of language, publication period, and limited local context, so generalization of findings needs to be done carefully

Suggestion

Future research needs to be directed at long-term evaluation of the impact of CRVs on soil quality, nutrient cycles, and agricultural biodiversity, as well as their relationship with consumer preferences and local food systems. Cross-disciplinary studies that integrate agronomy, economics, public policy, and agricultural digital technology are also important to reveal the complex interactions that determine the success of adoption. In addition, comparative research between countries and analysis of the effectiveness of seed distribution policies need to be expanded so that empirical insights are deeper. With these steps, CRVs can continue to be positioned as a key innovation in facing the challenges of climate change while strengthening global food security.

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