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Impacts of Climate-Induced Shocks on High-Value Legume Production in SADC Region: A Systematic Review

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Impacts of Climate-Induced Shocks on High-Value Legume Production in SADC Region: A Systematic Review

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Climate change poses serious threats to South African agriculture, where economies heavily rely on rain-fed farming, and adaptive capacity is limited. The Southern African Development Community (SADC) faces severe climate-related shocks, including extreme weather events like droughts, unpredictable rainfall, water shortages, and rising temperatures, all of which harm legume productivity and soil health. Grain legumes, crucial for food security, nutrition, and income, are especially vulnerable despite their resilience and nutritional value. These crops are vital to the region's economy and diets but remain under-researched in terms of market competitiveness under climate stress. This review of studies from the past 20 years examines how climate shocks impact legume yields, supply chains, and market competitiveness in SADC. Results show that droughts, heatwaves, and erratic rainfall can lower yields by 15–78%, weaken soil fertility, and impair nitrogen fixation. Water scarcity remains a major challenge, with low irrigation adoption due to infrastructure and cost barriers. Elevated CO_2 levels provide limited yield increases, often offset by heat stress, while pest outbreaks driven by climate variability further threaten productivity. Market access and trade are also affected, causing price spikes and supply disruptions that harm competitiveness. Despite growing interest, a lack of integrated research and weak institutional support hinder effective policy responses. The review emphasizes the need for climate-resilient legume varieties, better irrigation systems, pest control, and strategic policy reforms.

Keywords: Climate Change, High Value, Legumes, Climate Shocks, SADC

Introduction

Climate change is posing serious problems for the agriculture and food production industries in developing countries with mostly agro-based economies (Mutengwa et al., 2023). Their reliance on rain-fed agriculture puts them at risk due to this global problem (Abbasi et al., 2014). Due to its lack of adaptation and reliance on agriculture, Southern Africa is the region most at risk from the consequences of climate change (FAO, 2019). The region is vulnerable to a range of climatic shocks because of its poor capacity for adaptation and its strong reliance on rain-fed agriculture, especially in rural areas (Mucova et al., 2021). The majority of the Southern African Development Community's (SADC) economy is open, modest, and reliant on commodities. They are therefore susceptible to outside shocks, the consequences of which are closely linked to the status of the global economy (Wambogo et al., 2016). Almost 70% of people in the majority of SADC countries rely on the agricultural industry for their jobs, money, and food (Global Network Against Food Crises, 2019). Additionally, the GDP of the majority of SADC countries comes from agriculture (FAO, 2015). The estimated agricultural contribution to the GDPs of SADC countries increases to 16% when South Africa is taken out of the equation, and it can potentially reach 21% for low-income countries (World Bank, 2016). Due to inadequate institutional, financial, and technological capabilities, southern Africa and much of Africa are more likely to experience negative climate change effects (Food Security Information Network, 2020).

Grain legumes, also known as pulses, have long been staple foods with a significant role in the global food and nutrition economy (Kumar et al., 2022). Protein, complex carbs, and vital mineral nutrients are abundant in these crops (Conti et al., 2021). Because of their capacity to fix nitrogen biologically and adapt to marginal soil conditions, legumes are a reliable cash crop for smallholder farmers in many parts of the world (Dutta et al., 2022). Often referred to as "poor man's meat," grain legumes are nature's priceless gift to humanity because they are high in essential elements, vitamins, dietary fiber (10–23%), and protein (16–50%) (Kumar et al., 2022). Grain legumes contain a variety of nutrients in addition to protein, including vitamins, sugars, carbohydrates, mono and polyunsaturated fatty acids, and over 15 essential mineral elements (Raju & Menon, 2020). These are also a great source of folic acids, dietary fiber, and non-nutritional bioactive substances like lectins, polyphenolics, phytate, and trypsin inhibitors (Karuwal et al., 2021). Consuming pulses regularly helps prevent a number of illnesses, including heart disease, type 2 diabetes, and some types of cancer (Gantenbein & Kanaka-Gantenbein, 2021). Additionally, grain legumes lower the risk of obesity (Borresen et al., 2017).

Over 92 million tons of grain legumes are produced worldwide on an area of about 81 million hectares (Ma’ruf et al., 2022). India is the largest consumer of grain legumes and produces almost one-fourth of the world's annual production (Sharma, 2021). The main producers of grain and legumes are China, Myanmar, Canada, Australia, Brazil, Argentina, the United States, and Russia. From cold to warm seasons, legumes can tolerate a range of weather conditions (Fouad Abobatta et al., 2021). In various parts of the world, legumes are used as a vegetable or side dish, as well as a cover crop in arid areas and as animal feed (Kebede, 2021). Common beans, often known as dry beans, are the most traded and consumed grain legume crop in Southern African homes (Uebersax et al., 2023). Beans rank third in terms of calories and income in SADC, where they constitute the primary staple and the second-most significant source of dietary protein (Chamkhi et al., 2022). Because they provide vital proteins and nutrients, legumes are an important part of the world's food systems (Beebe et al., 2013). However, agricultural production is seriously threatened by climate change, especially for crops like legumes that are sensitive to it (Vink & Kirsten, 2002).

Agri-food market shifts (supply adjustments and increased demand), climate accountability regulations, and changes in productivity and yield are the main path-ways that climate change affects the agricultural sector (Asafu-Adjaye, 2014). The Intergovernmental Panel on Climate Change (IPCC) estimates that between 2030 and 2052, temperatures would increase by 1 to 5 degrees Celsius if current global warming trends continue (IPCC, 2023a). Plant growth is negatively impacted by rising temperatures alone, which also affects loss during handling and transportation and lowers yields, productivity, and product quality (IPCC, 2023b). Acute water stress is also experienced by agricultural lands due to issues with water distribution and availability as well as growing water scarcity (IPCC, 2023b). Furthermore, the complexity of food production is made worse by the rising frequency of natural disasters like floods and droughts (Quandt et al., 2023). Given the agricultural sector’s sensitivity to climate change and the fact that climate change is the world’s most pressing threat, measuring market competitiveness of legumes cannot be disregarded (Dawson et al., 2020). In order to develop suitable policy responses on assistance or support schemes, if any, that can be given to farmers, such as export assistance, technological assistance, input subsidies, and import regulations, it is imperative to measure competitiveness, including determining the cause of a lack of competitiveness (Nolasary et al., 2023).

Despite growing awareness, there are not many thorough studies that concentrate on how climate-induced production shocks especially impact legumes' ability to compete in the market (Haile et al., 2017a). Although the majority of research has been on the competitiveness of agricultural commodities generally, little is known about how climate-induced production shocks affect the market competitiveness of legumes, which are also produced in significant amounts in Southern Africa. There is a dearth of quantitative research on the direct impacts of climate variability (temperature fluctuations, precipitation patterns, and extreme weather events) on legume yields. The existing research often overlooks legumes in favor of cereals or other main crops. Additionally, a lot of analyses of the effects of climate change are region-specific, focusing mostly on important cereal-producing regions while ignoring important legume-producing regions, particularly in developing nations where legumes are a staple crop. Research on how production shocks impact market prices, supply chains, and legumes' competitiveness in relation to other crops is also lacking. A comprehensive understanding of the problem is hampered by the dearth of interdisciplinary research that integrates economics, climate science, and agricultural sciences. This multidisciplinary method may shed light on the wider effects of climate change on the competitiveness of legumes.

Information on whether SADC's agricultural policies and strategies have resulted in the creation of competitive markets for legumes is also lacking, despite the organization using agricultural policy to direct efforts toward improving agricultural marketing systems, agricultural development, and economic growth (England et al., 2018; Haile et al., 2017b; Muimba-Kankolongo, 2018; Sikuka, 2019). As a result, this study thoroughly examines data regarding the competitiveness of the SADC legume market in the context of climate change. Through the following pathways, the study specifically aims to support agricultural marketing policy-decision-making: promoting sustainable practices that improve soil health; educating consumers about the nutritional and environmental benefits of legumes to increase demand and market share; fostering collaborations among farmers, government agencies, non-governmental organizations, and businesses to create a supportive ecosystem for legume production and marketing; and encouraging research for climate resilient legume varieties that can withstand changing conditions.

Methodology

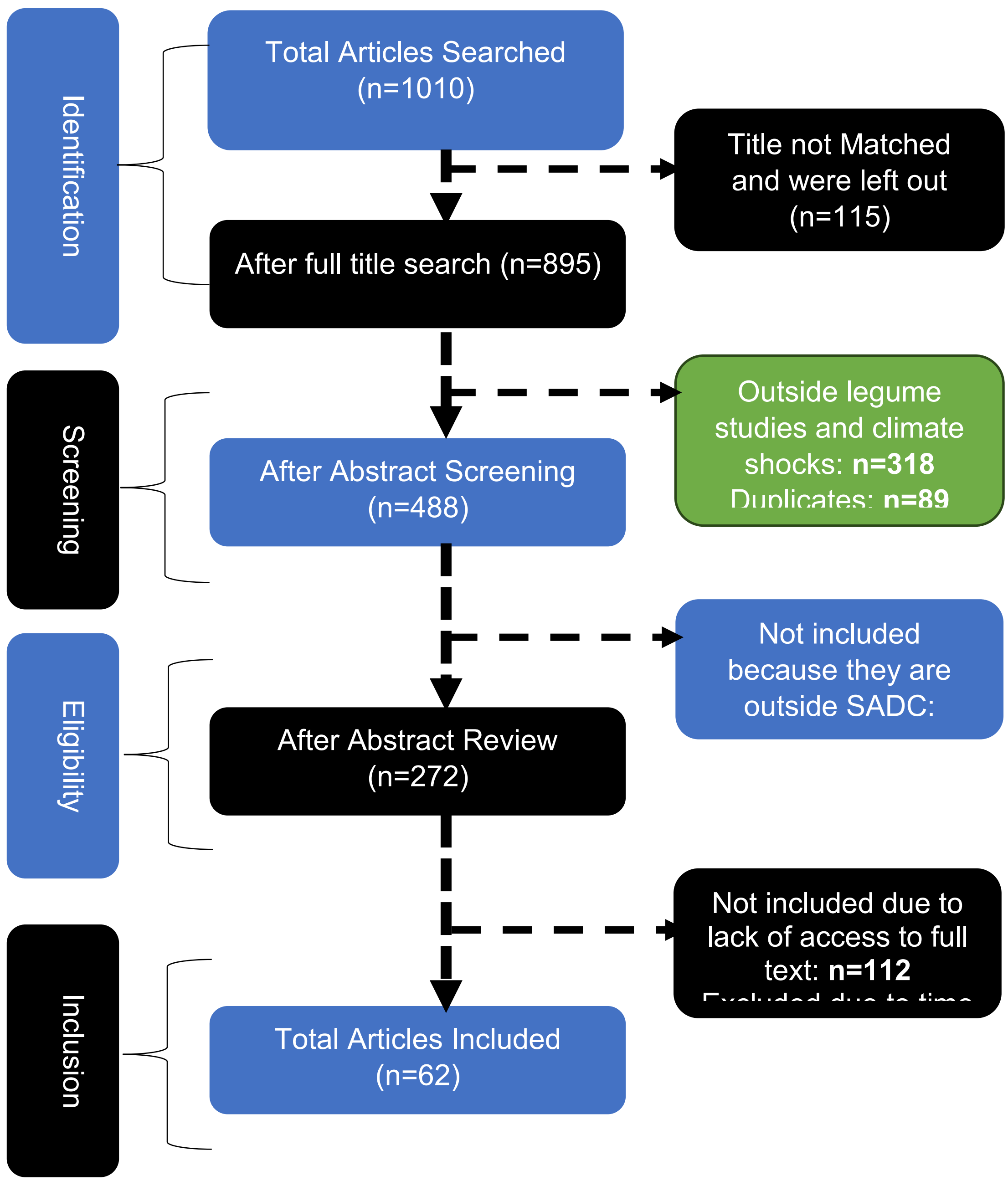
We conducted an extensive literature search using Scopus and Google Scholar, focusing on studies published from 2005 onwards and exclusively covering the effects of climate-induced shocks on the production and productivity of high-value legumes within the Southern African Development Community (SADC) region (Fig. 1). The search terms included “climate variability,” “climate change,” “legume,” “legume production,” “legume performance,” “Southern Africa,” “SADC,” “common beans,” “soybeans,” “groundnuts,” “pigeon peas,” and “cowpeas.”

The selected articles were analyzed to extract relevant information on how climate variability and extreme weather events influence legume production outcomes such as yield, resilience, and market competitiveness (e.g., prices, market shares, and trade flows). The findings from these studies were synthesized to provide a comparative understanding of the responses of different legume species to climate shocks across the SADC region. The guiding research question was: “How do climate-induced production shocks impact the production and productivity of legumes in SADC?”

To ensure relevance and quality, inclusion and exclusion criteria were applied. Studies were included if they focused on legumes within SADC countries, addressed climate-induced production shocks, analyzed legume performance, and were published in English within the last 20 years. Studies unrelated to legumes, SADC, climate-induced shocks, and grey literature lacking rigorous methodology were excluded.

A structured data extraction sheet was used to capture key information from the selected studies, including author(s), publication year and findings related to production shocks and legume performance. The data were analyzed using thematic synthesis, identifying key patterns and relationships between climate-induced production shocks, legume production, and market competitiveness. Following the **Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)**, the initial search returned 1010 papers (Figure 1). After removing studies published after 2005, the search returned 895 papers. Studies that did not discuss climate and legume performance were excluded from the analysis. Duplicates were also excluded from the analysis. The review, therefore, included 62 papers.

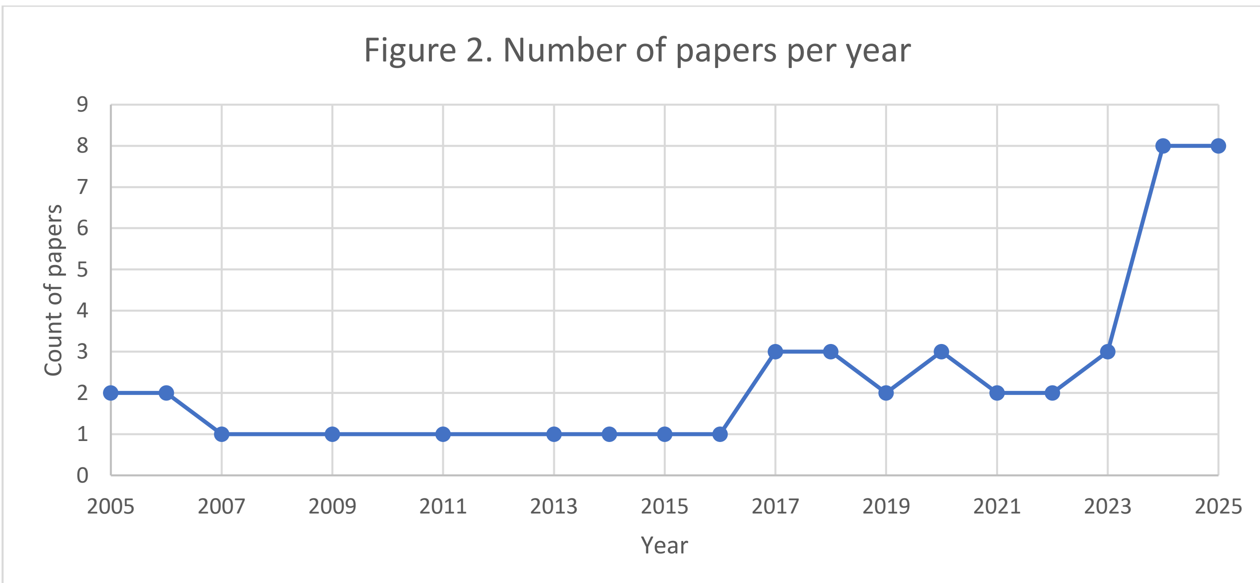
Figure 1. PRISMA flow diagram



Results and Discussion

Articles published per year

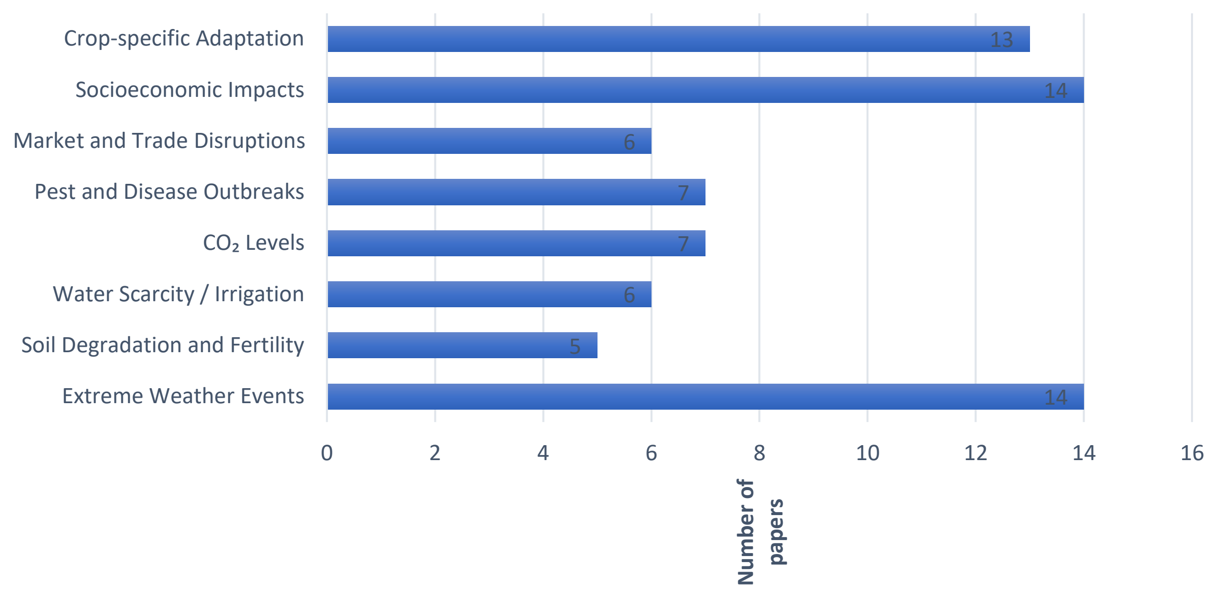
The trend in the number of articles published between 2005 and 2025 clearly indicates an increase in research on the impact of climate change on legumes in the SADC area (Figure 2). From 2005 to roughly 2015, relatively few studies were carried out, with most years generating only one publication, showing that this was still a developing study field. Between 2016 and 2020, there was a minor increase to roughly two or three publications each year, indicating a steady growth in interest, likely connected to the rising global focus on climate change, food security, and extreme climatic events. From 2021 to 2023, research activity was consistent but moderate, with two to three publications published each year. However, beginning in 2024, there is a dramatic increase to eight publications every year, indicating that the topic of climate change and legume production has gained great traction.



Number of articles per theme

The figure depicts how your systematic literature review's publications are distributed across different themes (Figure 3). The results show that Extreme Weather Events and Socioeconomic Impacts are the most researched themes, with 14 publications apiece. This demonstrates a great emphasis on both the immediate effects of climatic shocks and the larger social and economic ramifications of climate change on legume production in the SADC area. Crop-specific Adaptation receives a lot of attention, with 13 publications demonstrating that research is increasingly focused on how individual crops such as beans, cowpeas, groundnuts, and pigeon peas adapt to changing climatic circumstances. On the other hand, themes such as Pest and Disease Outbreaks and CO_2 Levels (7 papers each) and Market and Trade Disruptions and Water Scarcity/Irrigation (6 papers each) are moderately covered, indicating that while these issues are recognized, they have received less attention compared to broader climate and socioeconomic themes. Soil Degradation and Fertility is the least explored theme, with only 5 papers.

Figure 3. Number of papers per theme



Extreme Weather Events

The reviewed literature demonstrates that extreme weather events fundamentally alter agricultural systems across Southern Africa through multiple pathways. Wang et al. (2025) established that heat stress during October-December planting seasons significantly influences crop diversification patterns in Zambia, with district-level data showing a 0.0029 Simpson Diversification Index (SDI) increase from October heat stress. However, household-level analyses revealed that November heat stress promoted diversification but December heat stress reduced it by 15-20% due to planting delays. Temporal patterns also emerged, with Ainembabazi (2018) documenting how the 2015-16 El Niño caused unprecedented yield declines of between 56-78% that permanently altered farming systems in Botswana and Zimbabwe. Looking forward, Thomas et al. (2022) project worsening conditions, with average crop yields expected to decline 9.2% by the 2060s and extreme low-yield events becoming six times more frequent. Regional variations are significant, as Mugiyo et al. (2023) found Zimbabwe particularly susceptible to El Niño impacts, showing strong correlations (R^2=43%) between oceanic indices and rainfall variability. Beyond direct yield reductions, extreme weather events disrupt farming practices by limiting access to water resources and increasing production costs. Farmers must invest in irrigation systems, drought-resistant seed varieties, and soil conservation techniques to mitigate losses. However, these adaptation strategies require financial resources that many smallholder farmers in SADC lack, further constraining productivity.

Soil Degradation and Reduced Fertility

The studies reveal climate, soil and crop interactions that are degrading agricultural productivity across the region. This alters legume production and productivity by disrupting nitrogen fixation, reducing soil moisture retention, and exacerbating yield variability. Rising temperatures and erratic rainfall patterns accelerate soil degradation, forcing farmers to adopt adaptive strategies such as intercropping and improved soil management. However, smallholder farmers face significant barriers due to limited access to soil amendments and irrigation infrastructure, making climate-smart agricultural policies essential for ensuring long-term legume productivity and food security in the region. McCarthy et al. (2024) provided compelling evidence from Malawi that legume intercropping systems reduced drought-related yield losses by 60-65% compared to conventional monocultures, highlighting the importance of biological nitrogen fixation in maintaining soil fertility under stress. Their research also found that some traditional conservation methods, like stone bunds, increased losses during droughts by 8-12%. However, Otwe’s (2024) review demonstrated how rising temperatures disrupt critical rhizobial symbioses in legumes, thus reducing nitrogen fixation efficiency by 30-40% under heat stress conditions. At the landscape level, Olabanji et al. (2021) found significant variations in soil water retention capacities across South Africa, with sandy clay loams maintaining 58% more plant-available water than loamy sands during dry periods. These soil-specific responses help explain the 42-58% yield variations observed under similar climatic conditions. Overall, climate change is accelerating soil degradation through moisture loss, nutrient depletion, and microbial disruption pathways, where severe impacts are faced by smallholder farms that lack access to soil amendments.

Water Scarcity and Irrigation Challenges

Water availability remains a fundamental constraint to agricultural adaptation in SADC, with precipitation declines directly impacting production, particularly in rainfed systems. Additionally, reliance on increasingly variable rainfall, accounting for 70% of agricultural water use, exposes farmers to heightened risks of drought-induced losses. Water availability emerges as a critical limiting factor for agricultural adaptation across the studies. The econometric analysis conducted by Belloumi (2014) among 11 countries established that a 10% precipitation decline could reduce agricultural production by 0.965%, with effects magnified in rainfed systems common to smallholder farms. Despite these risks, Wang et al. (2025) found irrigation adoption remained strikingly low among Zambian smallholders, whereby infrastructure access explains less than 5% of diversification patterns. This contrasts with findings from Olifants Catchment in South Africa, where Olabanji et al. (2021) reported yield improvements of 39-270% when combining supplemental irrigation with adjusted planting dates. The disparity likely reflects unequal infrastructure development, as the Potsdam Institute's 2023 risk profile notes that 70% of agricultural water use in SADC countries depends on increasingly variable rainfall. While irrigation has proven effective in boosting yields, adoption remains low among smallholders due to infrastructure limitations and financial constraints. The disparity in irrigation success between Zambia and South Africa underscores the uneven development of water management systems, with regions like Olifants Catchment benefiting from supplemental irrigation and adjusted planting dates. Farmers have tried to develop alternative strategies, such as in Malawi, where 51% adoption of water conservation techniques among households facing consecutive droughts and rainwater harvesting, which increased yields by 14-21% in controlled trials (McCarthy et al., 2024). However, scaling these solutions remains challenging, as Kori et al. (2024) found only 9.5% of South African smallholders had adopted more efficient irrigation technologies due to cost barriers.

Changes in Carbon Dioxide (CO_2) Levels

The changes in climatic conditions show varying interactions between CO_2 levels and crop physiology across Southern Africa. Chilambwe et al. (2022) demonstrated differential crop responses, with soybean yields in the Eastern Province of Zambia increasing by 12-18% under increased CO_2 levels, while cereal yields in Central Province declined by 3-6% under similar conditions. These findings align with Dave et al. (2024) physiological studies showing CO_2-mediated photosynthesis gains in legumes are partially offset by heat-induced reproductive failures during critical flowering stages. Accordingly, Potsdam Institute (2023) analysis projected that CO_2 fertilization effects could theoretically increase crop yields in some regions, but these benefits are not sustained to the plant's maturity as they would likely be negated by concurrent temperature increases and rainfall variability. Regional variability in CO_2 responses was also evidenced in Serdeczny et al. (2017) multi-model analysis, which found that some C_3 crops might benefit from higher CO_2 concentrations, but other associated climatic changes would reduce suitability for 35% of current cropland across SADC countries by 2050. Of concern, Zinyengere et al. (2013) noted that even for responsive crops, the 15% potential yield gains from CO_2 enrichment were typically negated by the 20-30% losses from accompanying heat stress.

Pest and Disease Outbreaks

The intensification of pest and disease pressures due to climate change is reshaping legume production in SADC, with rising temperatures and erratic rainfall patterns expanding the range and severity of infestations. Fall Armyworm outbreaks, locust invasions, and fungal pathogens are becoming more frequent, leading to significant yield losses and compounding the effects of other climate-induced shocks. Climate-mediated changes in pest and disease dynamics are emerging as a major threat to regional agricultural value chains, especially legumes. Kori et al. (2024) found that 72% of surveyed South African farmers reported increased pest pressures, particularly Fall Armyworm (Spodoptera frugiperda) infestations that reduced crop yields by 30-50% during outbreak years. The meta-analysis conducted by Malhi et al. (2021) projected that pest-related losses could increase 10-25% per 1°C of warming, with expanding ranges for key threats like locusts and fungal pathogens. Siamabele (2021) found that soybeans are relatively resilient with 40% lower pest susceptibility compared to maize, though this advantage is diminished under extreme heat conditions (>35°C). The 2023 ACAPS report highlighted how post-cyclone recovery in Malawi was hampered by concurrent pest outbreaks, creating compound stresses that reduced overall productivity by 15-20 percentage points beyond individual shock impacts. Otwe (2024) warned that the natural pest resistance of cowpea may weaken as climate change alters traditional predator-prey dynamics, with laboratory studies showing 28% reduced parasitism of major pests under increased temperatures. Also, farmer adaptation strategies remain limited as noted by Wang et al. (2025) who found only 18% of Zambian smallholders had access to climate-resilient pest control methods thus forcing most to rely on crop diversification as their primary defense.

Market and Trade Disruptions

Climate shocks are increasingly disrupting agricultural markets through both supply and price mechanisms. Nguyen et al. (2024) shows how drought-induced staple food crop shortages triggered price spikes exceeding 150% in Mozambique and Nigeria, with effects persisting for a range of 3-5 growing seasons. Wang et al. (2025) spatial analysis revealed market access disparities, showing farms within 5km of paved roads diversified 21% more than isolated households, though the poorest quintiles remained unable to capitalize on market opportunities due to liquidity constraints. Trade policy reactions often exacerbate volatility. Yeboah (2024) found that export restrictions during climate shocks amplified price fluctuations by 30-40% regionally. The 2023 El Niño impacts illustrate these dynamics, with ACAPS projecting 50% production declines in Zambia, potentially destabilizing cross-border trade networks that supply 30% of regional maize.

Socioeconomic Impacts

Climate impacts are increasing existing inequalities across multiple dimensions. Wang et al. (2025) quantified significant gender disparities, with female-headed households showing 0.025 SDI lower diversification capacity and 28% reduced access to climate information. Ngoma et al. (2024) identified 76% of Zambian smallholders as highly climate-vulnerable, particularly female-managed farms, which comprised 63% of the most at-risk cohort. However, (Vesco et al., 2021) conflicts, the results were that climate-induced crop failures increased communal violence risks by 14% in agriculturally dependent areas, mediated through livelihood desperation and resource competition. Nevertheless, the human toll is staggering, as noted by Adom (2024) who projects that 200 million Africans may face extreme hunger by 2100 under current trajectories. Farm incomes are projected to decline by 36-61%, potentially. Surveys also reveal that 82% of Southern Africa smallholders report food shortages after climate shocks, where recovery periods extend to 3-7 years for the most vulnerable households (Kori et al., 2024).

Climate Resilience and Adaptation in SADC Legume Farming Systems

African legume farming is facing mounting climate shocks, from rising temperatures and erratic rainfall to soil erosion and changing farming landscapes. The analysis of climate change impacts on legume production systems in Southern Africa reveals several critical insights that need careful consideration. The evidence demonstrates that legumes possess inherent advantages for climate-resilient agriculture, but their performance under changing climatic conditions presents both opportunities and challenges that require understanding and management. The analysis of climate change impacts on legume production systems in Southern Africa reveals several critical insights that need careful consideration. The evidence demonstrates that legumes possess inherent advantages for climate-resilient agriculture, but their performance under changing climatic conditions presents both opportunities and challenges that require understanding and management.

A central finding emerging from the reviewed studies is the physiological response of legumes to increased temperatures and CO_2 levels. Unlike cereal crops that show more linear responses to climate variables, legumes exhibit threshold-based sensitivities that create distinct management challenges (Dave et al., 2024; Harvey et al., 2014). The nonlinear relationship between temperature and legume productivity is noteworthy, where yields remain stable until critical thermal limits are exceeded, which typically affects sensitive reproductive stages (Chilambwe et al., 2022). This pattern was consistently observed across multiple legume species, though with varying threshold temperatures. The implication is that relatively modest increases in average temperatures may have disproportionately large impacts on legume productivity.

The temporal dimension of climate impacts on legumes reveals important patterns. Legumes generally demonstrate better resilience to single-season drought events compared to cereals, at the same time, their recovery capacity from consecutive climate shocks appears more limited (Ainembabazi, 2018). This has implications for crop sequencing and rotation strategies in climate-variable environments. Also, legumes show promising potential for climate risk diversification at the grass root level. Their incorporation into cropping systems provides temporal and spatial risk-spreading benefits that are particularly valuable under increasing climate variability (Mccarthy et al., 2020; McCarthy et al., 2024). However, these are limited by significant barriers in seed systems, knowledge transfer and market development that currently constrain legume adoption in many areas (Nordhagen & Pascual, 2013).

The interaction between CO_2 and legume physiology presents another challenge. The interaction between rising CO_2 levels and crop physiology in Southern Africa presents a complex dynamic where potential yield gains are often counterbalanced by adverse climatic conditions. While increased CO_2 concentrations can enhance photosynthesis in legumes, studies indicate that these benefits are frequently undermined by heat-induced reproductive failures during critical flowering stages, limiting overall productivity. The regional variability in CO_2 responses further complicates adaptation strategies, as some crops, particularly C_3 species, may experience temporary yield improvements, while others face declining suitability due to intensified temperature stress and erratic rainfall patterns. Additionally, projections suggest that while CO_2 fertilization could theoretically boost crop yields, these gains are unlikely to be sustained through plant maturity due to concurrent environmental stressors. The challenge is particularly pronounced for smallholder farmers, who lack access to advanced climate adaptation technologies and soil amendments necessary to mitigate these effects. The C_3 legumes like soybeans theoretically benefit from CO_2 fertilization effects, however, field studies demonstrate these gains are frequently offset by associated increases in temperature and changes in water availability (Serdeczny et al., 2017). This suggests that climate models focusing solely on CO_2 effects may substantially overestimate potential productivity gains for legume crops.

Perhaps the most significant finding regarding legume adaptation potential relates to their symbiotic nitrogen fixation capacity. Multiple studies confirm that legumes maintain their ability to fix atmospheric nitrogen under moderate climate stress, but the efficiency of this process declines markedly under increased heat and drought conditions (Dave et al., 2024; Otwe, 2024). This has important implications for both crop productivity and soil fertility management, as the nitrogen contribution from legumes may become less reliable in precisely those conditions where soil fertility maintenance is most critical. The physiological mechanisms behind this decline appear related to impaired rhizobial activity and reduced nodule formation under stress conditions.

Comparative studies consistently show legumes outperform cereals like maize under water-limited conditions, though with substantial variation among legume species (Dave et al., 2024; Wang et al., 2025). Cowpea and pigeon pea demonstrate strong drought tolerance, making them valuable components of climate adaptation strategies. However, this advantage is context-dependent, as some legumes show sensitivity to waterlogging during irregular rainfall events that are becoming more common in certain regions (Olabanji et al., 2021). Nonetheless, all legumes would perform better under optimal rainfall conditions, meaning that currently, Southern Africa is losing potential yield to climate-related factors. Although alternative strategies such as water conservation techniques and rainwater harvesting have shown promise in Malawi, scaling these solutions remains difficult due to cost barriers and limited access to efficient irrigation technologies. Addressing these challenges requires targeted investments in irrigation infrastructure, improved water governance, and climate-resilient agricultural policies to ensure sustainable legume production in the region.

Legumes are highly sensitive to pests and disease. While some legume species show natural resistance to key pests, evidence suggests these defenses weaken as climate change alters traditional pest life cycles and geographic ranges (Kori et al., 2024). The expansion of pest activity periods and the emergence of new pest species combinations are concerning trends among farmers across the region. While some legumes, such as soybeans, exhibit relative resilience, extreme heat conditions weaken their natural defenses, making them increasingly susceptible to pest damage. The disruption of predator-prey dynamics further exacerbates the problem, reducing the effectiveness of biological pest control mechanisms. Smallholder farmers, who lack access to climate-resilient pest management strategies, are disproportionately affected, relying on crop diversification as their primary defense. However, this approach is insufficient to counteract the growing threats posed by climate-mediated pest outbreaks. To safeguard legume production, policymakers must prioritize the development and dissemination of climate-smart pest management solutions, including improved monitoring systems, resistant crop varieties, and sustainable biocontrol methods.

The socioeconomic dimensions of legume production under climate change reveal important considerations. Legumes offer climate adaptation potential for smallholder farmers, although gender disparities in access to legume production resources and information persist (Doss et al., 2015). Female farmers often face challenges in adopting improved legume varieties or accessing legume markets, which limits the equitable distribution of climate adaptation benefits. Additionally, market systems for legumes exhibit both resilience and vulnerability to climate shocks. The dual food and cash crop nature of many legumes provides some risk-spreading advantages compared to staple cereals (Nguyen et al., 2024). However, underdeveloped processing infrastructure and inconsistent market demand in many areas limit the ability of farmers to capitalize on these advantages during climate stress periods.

The reviewed evidence collectively suggests that while legumes represent a valuable component of climate-resilient agricultural systems, their performance cannot be taken for granted under changing climatic conditions. Their advantages relating to cereals are real but require careful varietal selection, management adaptation, and supportive policies to fully realize their potential. Underlying physiological responses, ecological interactions, and socioeconomic factors mean that legume-based climate adaptation strategies must be carefully tailored to specific agroecological and social contexts.

These findings reaffirm the adaptation imperative, farmers will require climate-resilient varieties, precision irrigation, improved soil conservation, and sustainable agronomic management to sustain production. Government incentives, investment in climate-smart agriculture, and researcher–farmer partnerships will be central to securing Africa's food future. If the legume farmers do not adapt, the projected losses would worsen food insecurity and threaten livelihoods across the continent. Through preparatory policies, research, and innovation, the climate challenges can be recast as opportunities for resilience and agricultural transformation.

Climate Shocks and Key Legumes in SADC

Common beans (Phaseolus vulgaris)

Adaptation strategies against climate change are proving to be a game changer for bean production. In a research paper by Onzima et al. (2019), the authors studied the impact of adaptation strategies on bean yields in the central and northern regions of Uganda, finding that these practices positively affected productivity. Meanwhile, in Tanzania, researchers assessed climate change impacts on common bean production and estimated yield gains of 10–48% under varying climate scenarios. However, the Bean Atlas 2.0 shows even more staggering impacts. It identifies enhanced temperatures as a major threat to bean farming in Africa and anticipates that former bean-producing regions will no longer be suitable for cultivation in the future. As early as 2030 and 2050, the bean-producing zones of targeted areas are likely to decrease significantly due to current climate variability, particularly temperature rise and drought. As a result, bean cultivation may need to shift to higher elevation areas, such as the Ethiopian highlands, the South Kivu region of the Democratic Republic of Congo, and the southern highlands of Tanzania's south highlands(Mourice et al., 2016).

Groundnuts (Arachis hypogaea)

Groundnut production in Africa is both challenged and presented with opportunities by climate change. Tabe-Ojong et al. (2023) conducted a study that identified that the promotion of climate-resilient groundnut varieties in West Africa greatly enhances production, consumption, and commercialization, enabling farmers to remain resilient to unpredictable weather conditions. However, a review by ICRISAT (2017) showed that increased CO_2 levels can enhance photosynthesis, although climate change is not good for groundnut productivity, with increased temperatures and erratically fluctuating rainfall threatening the yields. Kabambe et al. (2018) in southern Malawi showed that poor rainfall and soil barrenness have led to groundnut yields of merely 754 kg/ha on average, and soil fertility management, drought-tolerant varieties, and climate-resilient agriculture are needed urgently. Other similar studies in Africa concur with the above, and a study in Nigeria concludes that climate variability results in yield loss of as much as 30%, whilst drought-resistant varieties are 20–40% more productive than regular varieties (Azeez & Oyekanmi, 2021). In East Africa, adoption of genetically modified groundnut varieties has been slow despite their demonstrated resistance to drought and pests, and modeling showing that by 2040–2069 groundnut yields in Southern Africa could be cut by roughly half due to rising temperature and reduced soil moisture (Urban et al., 2017).

Soybeans (Glycine max)

Soybean production is increasingly being subjected to the vagaries of climate change, including temperature fluctuation, unpredictable rainfall, and climate extremes. The threats have been put into perspective by a review by Zhu & Troy (2018), which approximated that human-caused climate change directly caused one-third of the global soybean production deficit in 2012 and that projected warming will reinforce losses. In South America, research has shown that low precipitation is a major contributor to reduced soybean yield, and climate shocks are projected to rise (Westbrook et al., 2021). In West Africa, research indicates that productivity for soybeans could decline by 3% to 13.5% due to climate variability, but rising CO_2 levels can partly offset losses by raising yield by 14.8% to 31.3% (He et al., 2022). In South Africa, climate models estimate that a 3°C temperature rise would cut soybean yields by 16% in Brazil, 12% in Arkansas, and 7% in France, with even larger losses at elevated temperature levels. Studies in Nigeria further confirm the importance of nitrogen fixation in soybean yields, showing that improved management of soil fertility can mitigate climate-induced yield loss (Arimi et al., 2020; Ayanwuyi & Akintonde, 2012; Basu, 2010; Tabe-Ojong et al., 2023).

Cowpeas (Vigna unguiculata)

Cowpea cultivation is increasingly threatened by climate variability, and rainfall, temperature, and humidity were found to explain 61% of yield variation, as reported by Arimi et al. (2020) in a study on Cowpea farmers' vulnerability and adaptation to climate change in Ido Local Government Area of Oyo State, Nigeria. Research in Mississippi also revealed that drought and rising nighttime temperature can decrease cowpea yield by 63% and seed protein content by 25%, reflecting the nutritional risk of climate change (Nelson et al., 2014). Similarly, Mohammed et al. (2020) confirmed climate change to be negatively impacting Nigerian cowpea production and recommended early planting and resistant varieties as key adaptation choices. Across West Africa, the literature suggests that high soil humidity, caused by high rainfall frequency, can also reduce cowpea production, particularly under semi-arid conditions (Ayanwuyi & Akintonde, 2012). In Sub-Saharan Africa, the literature emphasizes the imperative to breed climate-resilient cowpea varieties to counter biotic and abiotic stresses and enhance food security (Yahaya & Timothy, 2015). A simulation study in Ghana and Burkina Faso singled out some genotypes of cowpea which are more tolerant to water- and heat-stress and therefore are suitable candidates for future climate adaptation (Andy, 2018).

Pigeon peas (Cajanus cajan)

Pigeon pea production in SADC countries, including Malawi, Mozambique, Zambia, and South Africa, is increasingly vulnerable to climate change. In Malawi, yields remain low, averaging only 442 kg/ha due to erratic rainfall and low soil fertility (Khoza et al., 2019). In South Africa, however, research indicates that intercropping pigeon peas with maize improves grain yield and soil moisture retention, providing a promising strategy for drought resilience among smallholders (Taba-Morales et al., 2020). Across the region, climate models project rising temperatures and increased rainfall variability by 2050, underscoring the need for heat- and waterlogging-tolerant varieties (Zhu & Troy, 2018). Studies in Kenya, which share comparable agroecological conditions, show that improved pigeon pea varieties significantly enhance yields and bolster climate adaptation (Tabe-Ojong et al., 2023). Nonetheless, intercropping models predict a 10–20% decline in pigeon pea yields by 2100 due to climate stress (Kwena, 2021), highlighting the urgency for climate-smart breeding and agronomic innovations throughout SADC.

Conclusion and Policy Implications

This systematic literature review demonstrates that while significant knowledge exists on crop-specific responses, socioeconomic implications, and adaptation practices, the evidence base remains fragmented and sometimes inconsistent across regions and methodological approaches. It has been demonstrated that extreme weather events, such as heat waves, unpredictable rainfall, and El Niño cycles, lower agricultural yields, interfere with planting plans, and affect farming systems. Adaptive responses such as intercropping, conservation agriculture, and irrigation offer clear potential for mitigating some of these impacts, yet adoption remains uneven.

However, there are certain critical information gaps in the literature. First, there is limited geographical coverage and uneven data dissemination throughout Sub-Saharan Africa. While many studies have focused on West and East Africa, Southern and Central African nations like Malawi, Mozambique, and Zambia have received less attention, particularly regarding commodities like cowpeas and soybeans. Second, most studies do not disaggregate the effects of climate change by agro-ecological zones, agricultural techniques, and individual legume species. Third, socioeconomic aspects of adaptation are often understudied. Fourth, there is a lack of long-term modeling and scenario-based predictions that consider compound risks, including insect outbreaks, disease prevalence, and market fluctuations. Fifth, insufficient attention has been paid to the resilience of the entire legume value chain. Most current research concentrates on production-related issues, with only a few studies examining post-harvest handling, storage, processing, and market dynamics under climatic stress. Therefore, more cross-country comparative research is needed to capture spatial variations in legume responses to climate stressors. Studies should increasingly integrate biophysical modelling with socioeconomic analysis to ensure that adaptation strategies are both technically viable and socially inclusive. The limitation of this study lies in its reliance on published studies, which may exclude valuable insights from grey literature and farmer-led innovations.

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Appendix

Table 1: Summary of articles included in the review

Theme	Author(s)	Key Findings / Results
Extreme Weather Events	Wang et al. (2025), Alawode et al (2025), Mpandeli et al. (2018) Maposa (2023), Chesterman et al (2020)	Heat stress during planting affects crop diversification; the Temporal effects of heat stress on diversification are complex. Climate change in southern Africa is increasingly causing cross-sectoral impacts such as reduced rainfall and declining agricultural production.
	Ainembabazi (2018)	2015–16 El Niño caused yield declines of 56–78% in Botswana and Zimbabwe; Extreme events cause long-term structural changes in farming systems
	Thomas et al. (2022)	Crop yields projected to decline 9.2% by the 2060s; extreme low-yield events more frequent; Climate change to increase the frequency of drought and crop failures
	Mugiyo et al. (2023) Gizaw et al. (2017)	Crop yields strongly correlated with oceanic indices and rainfall (El Niño); Regional vulnerability varies; Zimbabwe is highly susceptible
	Gbetibouo and Hassan (2005) Hewitson and Crane (2006) Challinor et al. (2006)	Production of field crops was sensitive to marginal changes in temperature as compared to changes in precipitation.
Soil Degradation and Fertility	McCarthy et al. (2024), Kiwia et al. (2019)	Legume intercropping reduces drought yield loss; Intercropping is effective for soil fertility.
	Otwe (2024), Shahid (2025).	Heat stress reduces rhizobial symbiosis and nitrogen fixation; Rising temperatures impair legume nitrogen fixation crucial for fertility
	Olabanji et al. (2021)	Soil water retention varies by type; Soil type drives yield variability under drought conditions
Water Scarcity / Irrigation	Belloumi (2014), Mangena, (2018).	Decline in precipitation leads to production decline; Rainfall variability is critical for agricultural production, especially in rain-fed systems
	Wang et al. (2025)	Low irrigation adoption among smallholders; Infrastructure and financial barriers limit adaptation.
	Olabanji et al. (2021)	Supplemental irrigation plus adjusted planting boosts yields; Irrigation provides significant yield gains where infrastructure exists
	McCarthy et al. (2024)	Adoption of water conservation in Malawi increased yields. Water conservation is effective, but scaling remains a challenge
	Kori et al. (2024)	Smallholders use efficient irrigation technology due to costs; Financial barriers limit irrigation tech adoption
CO_2 Levels	Chilambwe et al. (2022), Zinyengere et al. (2013); Zhu & Troy (2018); He et al. (2022), Gachene et al. (2014).	Soybean yields increased with higher CO_2; CO_2 effects are crop-specific and influenced by temperature effects; Soybean production is vulnerable, but potential gains from CO_2
	Dave et al. (2024); Serdeczny et al. (2017)	CO_2-driven photosynthesis gains offset by heat-related reproductive failures. Potential CO_2 benefits often negated by heat stress
	Serdeczny et al. (2017)	Some C_3 crops benefit from CO_2; CO_2 fertilization benefits vary regionally, often insufficient to offset climate risks
Pest and Disease Outbreaks	Kori et al. (2024)	South African farmers report increased pests; Fall Armyworm reduces yields, Pest pressure rising with climate; severe impacts on yields
	Malhi et al. (2021)	Pest-related losses increase 10–25% per 1 °C warming; Climate change likely to exacerbate pest-related yield losses
	Siamabele (2021)	Soybeans relatively resilient; lower pest susceptibility relative to maize; Pest resistance varies by crop; heat stress diminishes resilience
	Otwe (2024)	Climate changes disrupt natural pest control

	Wang et al. (2025)	Small proportion of smallholders use climate-resilient pest control; they mostly rely on diversification; Limited adaptation options increase vulnerability
	Kori et al. (2024); Wang et al. (2025)	Pest management and irrigation adoption remain limited; Climate-smart pest and water management essential for resilience
Mark et and Trade Disruptions	Nguyen et al. (2024), Gbetibouo and Hassan (2005)	Climate shocks destabilize food markets: climate change affected the revenues of field crops, including groundnuts and soy beans
	Wang et al. (2025)	Farms near roads diversify more; poorest farmers have limited market access; Infrastructure drives market opportunities; liquidity constraints limit benefit.
	ACAPS (2023) Semosa (2025), Paremoer (2018).	50% production decline during El Niño in Zambia threatens regional maize trade; Large-scale climate shocks disrupt supply chains of legumes, hence affecting trade.
Socioeconomic Impacts	Wang et al. (2025)	Female-headed households have 0.025 lower diversification; 28% less access to climate information; Gender disparities limit adaptive capacity
	Ngoma et al. (2024)	Smallholders are climate-vulnerable; Climate vulnerability is concentrated among female smallholders
	Vesco et al. (2021)	Crop failures increase communal violence risk by 14%; Livelihood stress linked to social conflict
	Kori et al. (2024)	82% of SADC smallholders report food shortage aftershocks, with recovery taking 3–7 years for the most vulnerable households
	McCarthy et al. (2024); Dave et al. (2024); Otwe (2024) Makonya, (2020). Chiipanthenga, (2020).	Legumes' nitrogen fixation declines under heat and drought; physiological thresholds critical for yield
	Fischer et al. (2005) Challinor et al. (2009)	The results from the study suggest that critical impact asymmetries due to both climate and socio-economic structures may deepen current production and consumption gaps between the developed and developing world
	Nordhagen & Pascual (2013)	Seed systems and market constraints limit legume adoption; Socioeconomic barriers inhibit scaling of climate-resilient legume systems
	Doss et al. (2015); Nguyen et al. (2024)	Gender disparities and market limitations reduce equitable benefit distribution
Crop-specific Adaptation Insights	Onzima et al. (2019); Mourice et al. (2016); Beebe et al. (2011)	Beans threatened by temperature rise; cultivation zones shifting to higher elevations
	Tabe-Ojong et al. (2023); Kabambe et al. (2018)	Groundnut production is challenged by soil fertility and drought.
	Arimi et al. (2020); Mohammed et al. (2020); Gerrano et al. (2022) Mujaju et al. (2017) Chakauya et al. (2023)	Cowpea yields are vulnerable to drought and temperature; breeding for resilience is essential
	Khoza et al. (2019); Taba-Morales et al. (2020), Musokwa and Mafongoya (2020), Hoeschle-Zeledon (2019), Recha, et al (2025), Chirwa et al. (2007) Hassen et al. 2017	Pigeon pea yields low; intercropping improves drought resilience