

Review

Optimizing Water Conservation in South Africa's Arid and Semi-Arid Regions Through the Cultivation of Indigenous Climate-Resilient Food Crops

Nomzamo Sharon Msweli *¹, Isaac Azikiwe Agholor¹, Mishal Trevor Morepje¹, Moses Zakhele Sithole¹, Tapelo Blessing Nkambule¹, Variety Nkateko Thabane¹, Lethu Inneth Mgwanya¹ and Nombuso Precious Nkosi¹

School of Agricultural Sciences, University of Mpumalanga, Mbombela 1200, South Africa; isaac.agholor@ump.ac.za (I.A.A.); 201503045@ump.ac.za (M.T.M.); mooses.sithole@ump.ac.za (M.Z.S.); 201739895@ump.ac.za (T.B.N.); 201988429@ump.ac.za (V.N.T.); 201971976@ump.ac.za (L.I.M.); 201627434@ump.ac.za (N.P.N.)

* Correspondence: 201836335@ump.ac.za

Abstract: The semi-arid and dry regions of South Africa experience shortages of water resources, which poses major challenges to livelihoods exacerbated by climate change. Despite the importance of indigenous food crops in optimizing water conservation, limited research has been conducted on effective strategies for promoting indigenous crops. This paper explores the potential of indigenous crops in optimizing water conservation in South Africa. This review paper adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist to ensure transparency, rigor, and reproducibility. A comprehensive literature search was conducted across several databases, including Scopus, Web of Science, and Google Scholar. This review found that indigenous crops, such as sorghum and cowpeas, have innate traits that enable them to flourish in environments where water resources are limited. According to the findings of this study, these indigenous crops are resilient to drought and optimize water use efficiency. This review recommends the creation of a national database for indigenous climate-resilient food crops, which can act as an information hub for research and development. In maximizing the water use efficiency of indigenous crops, sustainable water management techniques remain critical. The results of this study have important implications for sustainable agriculture and water conservation in South Africa.

Keywords: water conservation; semi-arid; cultivation; indigenous crops; climate resilient; water resources



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1. Introduction

The southern region of South Africa is home to most indigenous crops. The area is semi-arid, with average temperatures of between 10 °C and 30 °C [1]. The area receives 400 mm of rain on average per annum with varying patterns of precipitation. The summer season is from November to March, and the average humidity is 40% [2]. The Middle East and North Africa were the first regions in the globe to face a severe water deficit, followed by Southern Africa [1]. In the arid and semi-arid grasslands of South Africa, droughts are common and can have detrimental effects on livelihoods and income [2]. A rising problem that is affecting many regions of the world is water scarcity, and South Africa is not an exception. Over 40% of the world's population is already facing water shortages,

and this number is predicted to rise in the coming years [3]. Furthermore, one disturbing observation is that freshwater that is fit for human consumption makes up less than 3% of the world's water supply. South Africa is prominent in the region for being one of the most water-scarce regions with sufficient data on water resource availability.

Within South Africa, agricultural activities account for about 60–65% of total water demand, making it the major water user in the continent. Practicing rainfed agricultural activities remains a challenge in the region as precipitation dwindles over time. This reduces the amount of fertile arable land in the nation and raises the unpredictable nature of agriculture. Water resources have been a challenge for farmers, resulting in decreases in agricultural production with escalating food prices in South Africa. The degradation of land, soil, animals, plants, and water balance, through human activities in arid areas, are incredibly diverse. Aridity is also a common occurrence in these regions, with arid zones making up 18.8% of the total area. In arid regions, water is a scarce resource, and evapotranspiration also accounts for a large portion of water loss. However, the regular use of groundwater at a rate higher than that at which it is replaced through the water cycle is a common occurrence in the arid regions of South Africa [4].

Water conservation can be defined in many ways, such as the following: (i) an indigenous approach in water use that is climate-resilient and environmentally friendly [5]; (ii) any advantageous reduction in water loss, use, or waste; (iii) a decrease in water consumption achieved by putting efficiency measures in place; or (iv) better water management techniques that increase the advantageous applications of water conservation measures including any behavior modification, gadget, technology, or enhanced design or procedure used to cut down on water loss, waste, or consumption [6,7]. Most water conservation initiatives are aimed at ensuring the sustainable use of water resources, energy conservation, and the conservation of habitats [8].

This study is highly significant due to its timely and critical contribution to addressing some of the most pressing challenges in South Africa's agricultural sector, namely, water scarcity, climate change, and food security [9]. By focusing on the potential of indigenous crops like sorghum, millet, cowpeas, and Bambara groundnuts, this research offers a scientifically grounded solution to enhance agricultural resilience in arid and semi-arid regions. Thus, the relevance of this study is more pronounced given South Africa's vulnerability to climate change, which is projected to exacerbate water scarcity and reduce the agricultural productivity of conventional crops [10,11]. By showcasing the water use efficiency (WUE), drought tolerance, and economic and health benefits of indigenous crops, this study offers practical insights that can be immediately applied to improve agricultural practices and ensure long-term sustainability. This study seeks to raise awareness on the economic potential of indigenous crops. This study provides evidence that these crops can be more economically viable for smallholder farmers, reducing input costs and increasing yields, thus addressing both food security and the livelihoods of rural communities. Furthermore, the growing market demand for these crops, particularly due to their nutritional and environmental benefits, positions them as an attractive alternative to water-intensive crops [12]. These benefits make this research highly relevant for policymakers, agricultural practitioners, and development organizations focused on sustainable agriculture and rural development.

By the end of the century, drought, dry spells, and water scarcity are expected to worsen, especially in arid areas [13]. South Africa's arid and semi-arid regions are constrained by climate change and droughts, which increase water scarcity [14]. Under these circumstances, conventional crops frequently fail because of water stress, resulting in lower yields and food insecurity. Indigenous crops are found in the local environment and inherently resistant to drought but are underutilized despite their potential for suste-

nance [14]. According to several studies [15,16], some species of indigenous crops are also limited by harsh weather conditions, despite their reputation for being resistant to climate change [15,16]. The importance of indigenous crops cannot be overemphasized; however, little is known about their properties of resilience in terms of mitigating the impact of climate change. There is a myriad of advantages in the cultivation of indigenous crops both in terms of livelihoods and their resilient traits [17,18]. Therefore, the purpose of this study is to investigate the potential of indigenous climate-resilient crops in optimizing water conservation in South Africa's arid and semi-arid regions.

2. Methodology

This paper employed a systematic review to address water conservation in arid and semi-arid regions, leveraging on indigenous climate-resilient food crops common in South Africa. This review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency, rigor, and reproducibility [19–21]. This review was guided by key research questions: (i) What are the indigenous food crops cultivated in the arid and semi-arid regions of South Africa? (ii) In what ways are these indigenous crops and other agronomic practices associated with climate resilience traits? (iii) What are the challenges and opportunities in promoting these crops for water conservation?

To address these questions, a comprehensive literature search was conducted across several databases, including Scopus, Web of Science, and Google Scholar. The search strategy employed a combination of keywords and Boolean operators (AND, NOT, and OR) to retrieve relevant studies focusing on “indigenous crops”, “water conservation”, “South Africa”, “climate-resilient agriculture”, “semi-arid regions”, “traditional farming practices”, and “drought-tolerant crops” [22,23]. The search was restricted to journals and articles published in the English language spanning the early 2000s to late 2024 to ensure the coverage of recent and relevant studies. Studies were selected based on predefined inclusion and exclusion criteria, encapsulating studies that focused on indigenous food crops in the arid and semi-arid regions of South Africa. The articles and papers excluded were those that did not meet the search criteria (Figure 1).

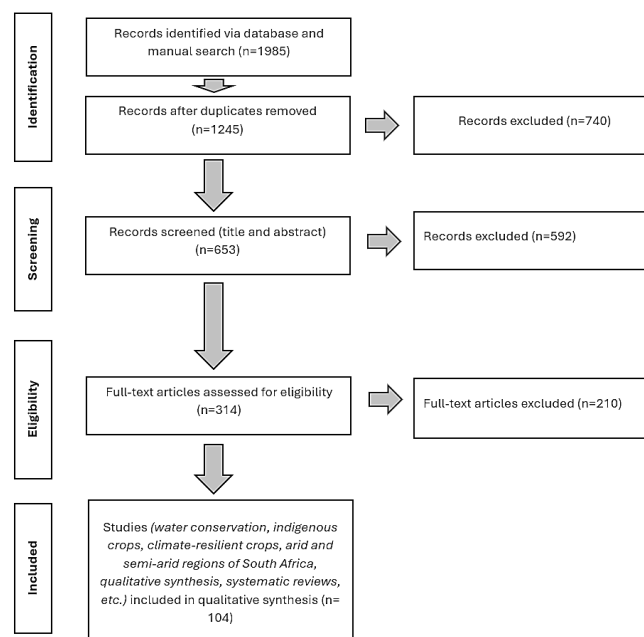


Figure 1. Literature search and screening flowchart used for this study.

The data were explained using a narrative approach. Descriptive statistics were employed to present quantifiable data, such as the frequency of crops studied and geographical coverage. Thematic analysis was used to identify common agricultural practices and challenges, while comparative analysis was applied to evaluate water conservation strategies across different crops and regions of South Africa [24].

This review paper acknowledged certain limitations, including the exclusion of non-English publications, which may have led to the omission of some results, and the reliance on the available literature, potentially overlooking unpublished findings. Additionally, there is the possibility of bias in such a study that relies only on already-reported data. Thus, ethical approval was not required for this review, as it involved a secondary data analysis of the publicly available literature.

3. An Overview of Indigenous Climate-Resilient Food Crops of South Africa

Food and nutritional insecurity, poverty, and increases in disease prevalence are all problems that South Africa faces. These challenges are not peculiar to South Africa as the country has embarked on agricultural intensification. South Africa has embraced the cultivation of traditional and commercial crops as a panacea to abate inadequate food production [25,26]. However, most indigenous crops in South Africa are neglected, with a preference for conventional exotic crops. Given the genetic diversity and nutritional importance of indigenous crops and their ability to withstand adverse local conditions, it is time to properly prioritize their production. Strengthening the production of indigenous crops remains a viable alternative to increasing local livelihoods and food security [27,28]. Examples of indigenous crops include *Amaranthus spp.*, wild mustard (*Brassica spp.*), sweet potatoes (*Ipomoea batata*), wild melon (*Curcubita spp.*), taro (*Colocasia esculenta*), Bambara groundnut (*Vigna subterranean*), cowpea (*Vigna unguiculata*), millets (*Eleusine coracana*, *Panicum miliaceum*, *Pennisetum glaucum*, *Setaria italic*), and sorghum (*Sorghum bicolor*) [25]. Mathews [28] described the following indigenous crops as the top five that are underutilized, yet they have so much to offer to humans in terms of nutrition.

- Pearl millet (*Pennisetum glaucum*) is of the Poaceae family. Pearl millets are rich in fiber, phytochemicals, and fatty acids. This crop is drought-tolerant.
- *Sorghum bicolor* L. (sorghum) is a crop that is part of the *Graminea* family and has a high carbohydrate content. It is a drought-tolerant and climate-resistant crop. This crop plays a huge role in the fight against food insecurity and hunger in Northeast Africa.
- Cowpea (*vigna unguiculate*) is a member of the *Fabaceae* family. The cowpea is cultivated for its grain which can be consumed dry or fresh and their leaves as Morogo. Cowpeas are nutrient-rich, containing nutrients that are good for human health including plant-based proteins, fiber, Vitamins (A, C, thiamine, folate, and B6), Iron, Selenium, Zinc, Magnesium, Phosphorus, and Copper.
- Bambara groundnut (*vigna subterranean*) groundnut is an underutilized indigenous legume species that is widely grown in the drier regions of sub-Saharan Africa, including South Africa. It is an annual plant that takes three to six months to mature, depending on the weather and variety.
- *Amaranthus* is in the *Amaranthaceae* family, and there are around 70 distinct genera of *Amaranthus* in Africa, and different types are consumed, while others are considered as weeds that have spread naturally from other places around the world.

These indigenous crops are part of the crops cultivated in South Africa with peculiar characteristics for adaptation to climatic stress [29].

In the past, the bulk of rural residents relied heavily on these crops for their food security. However native crop farming has decreased because of the promotion of exotic

major crops. These crops provide sustainable food production because they are well suited to the tough and marginal local growth conditions [26].

4. The Superiority of Indigenous Crops for Water Conservation and Agricultural Sustainability

Indigenous crops, such as sorghum, millet, cowpeas, and Bambara groundnuts, demonstrate superiority over non-indigenous crops in addressing the challenges faced by the agricultural sector in South Africa's arid and semi-arid regions. These regions receive an average annual rainfall of only 450 millimeters, which is far below the global average of 860 millimeters [30]. Unlike non-native crops, indigenous crops are highly drought-tolerant and require significantly less water to produce viable yields. For instance, sorghum uses 350–500 liters of water to produce one kilogram of grain, compared to the much higher water requirements of many non-native crops [31,32]. Millet exhibits similar efficiency, requiring only 300–500 liters per kilogram of grain [31]. These crops are uniquely suited to thrive under water-scarce conditions, maintaining over 70% of their yield potential even in prolonged droughts.

The ability of indigenous crops to conserve water is further amplified by their compatibility with water management practices such as rainwater harvesting. In semi-arid regions like Limpopo, rainwater harvesting has increased crop yields by 30–50%, even during years of below-average rainfall [33]. This technique can be used to capture up to 80% of available rainfall and channel it directly to the crop root zones, significantly reducing water loss and enhancing productivity [34]. Sorghum and millet particularly benefit from these methods, as their deep root systems can access moisture stored in deeper soil layers. This synergy between indigenous crops and sustainable water conservation practices makes them ideal for mitigating the impacts of South Africa's erratic and limited rainfall.

Economically, indigenous crops also outperform their non-native counterparts, offering significant cost-saving benefits to farmers. Crops like cowpeas and Bambara groundnuts require up to 40% less investment in inputs such as fertilizers and pesticides due to their natural adaptation to local soil and pest conditions [35,36]. Moreover, these crops are gaining popularity in niche markets for their nutritional value and sustainability. For instance, Bambara groundnuts are increasingly sought after in most local sub-Saharan Africa (SSA) markets, often fetching more than a 10% premium compared to conventional crops [37]. This makes indigenous crops a more financially viable option, particularly for smallholder farmers with limited resources.

The relevance of indigenous crops is further underscored by the projections of climate change impacts on South Africa's agricultural landscape. By 2050, semi-arid regions are expected to experience a 10–20% decrease in rainfall and a temperature increase of 2–3 °C [38,39]. These changes will exacerbate water scarcity and reduce the viability of water-intensive crops. Indigenous crops, with their superior drought resilience and lower water requirements, are uniquely positioned to adapt to these climatic shifts, ensuring continued food production and security. Their ability to thrive under such conditions highlights their role as an indispensable resource for sustainable agriculture in the region.

In closing, indigenous crops provide an unmatched combination of water efficiency, resilience, economic viability, and climate adaptability, making them statistically superior to non-native crops in South Africa's arid and semi-arid regions. By leveraging their natural advantages and integrating them with sustainable agricultural practices, these crops offer a robust solution to the pressing challenges of water scarcity, food insecurity, and climate change. Their adoption is not only a scientific imperative but also a practical pathway to ensuring long-term agricultural sustainability in South Africa.

5. SWOT Analysis of Water Conservation Strategies in Arid and Semi-Arid Regions of South Africa

In South Africa's arid and semi-arid regions, conserving water is essential to maintain sustainable and environmental farming practices. Preservation against loss or waste may be synonymous with the conservation process. In a nutshell, this means using all the technology at our disposal to maximize the nation's water resources. In essence, water conservation seeks to balance supply and demand. Demand and supply and management-oriented approaches can be used to conserve water. Depending on the type of water used, domestic, agricultural, or industrial, the solutions may differ [7,40].

Every practice has its own SWOT analysis, which is a framework that is used to identify and evaluate strengths, weaknesses, opportunities, and threats relating to a particular concept and helps in strategic planning, decision making and problem solving. Using the SWOT analysis methodology, the table below provides an overview of the main water conservation strategies, highlighting their potential difficulties and real-world applications (Table 1).

Table 1. SWOT analysis of water conservation strategies.

Water Conservation Strategy	Strengths	Weaknesses	Opportunities	Threats	Citation
Rainwater harvesting	<ul style="list-style-type: none"> - Prevention of soil erosion - Improvement in ecological environment - Makes water supply self-sufficient - Makes full and effective use of local stormwater runoff 	<ul style="list-style-type: none"> - Lack of integration of key techniques - Low rainwater utilization efficiency 	<ul style="list-style-type: none"> - Less costly and simple to run, install, and maintain - Dilution during refilling; improves quality of groundwater 	<ul style="list-style-type: none"> - Environmental pollution from use of low-quality materials 	[41–44]
Drip irrigation	<ul style="list-style-type: none"> - Minimal water losses - Improves crop yields by distributing required water 	<ul style="list-style-type: none"> - Very expensive to install and maintain - Smallholder farmers have limited access to technology 	<ul style="list-style-type: none"> - Increase utilization in regions that are water-scarce 	<ul style="list-style-type: none"> - Depends on water source that is reliable for constant operations 	[7,41]
Mulching	<ul style="list-style-type: none"> - Improves irrigation uniformity by minimizing water runoff - Preserves soil heat and entropy, benefitting crop growth in cooler conditions - Conserves soil moisture by reducing evaporation and deep-water leakage 	<ul style="list-style-type: none"> - Decreases soil organic matter, affecting soil fertility - Broken plastic films hinder soil nutrient absorption 	<ul style="list-style-type: none"> - Promotes mulching as affordable water-saving method for small-scale farmers 	<ul style="list-style-type: none"> - Increased greenhouse gas emissions due to use of synthetic mulches - Long-term soil degradation from reduced soil organic matter under synthetic mulches 	[45–48]
Cultivation of indigenous crops	<ul style="list-style-type: none"> - Require less water than exotic crops and are drought-tolerant - Strengthens ecosystems and enhances biodiversity - Contributes to food security in water-scarce regions 	<ul style="list-style-type: none"> - Availability of seeds is very limited for some indigenous crops - Lack of awareness about nutritional, economic, and ecological benefits of these crops among farmers 	<ul style="list-style-type: none"> - Improves resilience against climate change in arid and semi-arid regions - Increases market demand for organic and healthy traditional food 	<ul style="list-style-type: none"> - Competition from fast-growing exotic crops - Lack of indigenous knowledge and farming practices related to these crops 	[49–52]

6. Evidence of Water Conservation Potential Through Indigenous Food Crops

6.1. Indigenous Grains and Legumes

Another project commissioned by the Water Research Commission of South Africa [53] analyzed the water use of certain indigenous legume and grain crops for sustainable production in rainfed farming. This study involved conducting systemic reviews of the literature on indigenous grain crops and legumes, as well as conventional field trials and experiments. The literature review results indicated that there were different indigenous

grain crops and legumes that are nutritious and suitable for rainfed farming. Thus, the project focused on a range of crops including sorghum, Bambara groundnut, cowpea, dry beans, and groundnuts. From the review, it was noted that sorghum had great potential under rainfed conditions through its comparatively high WUE and water constraint stress tolerance. The results of the study also showed that legumes were adaptable to different conditions; however, the available research only focused on a few major legume crops, neglecting minor grain legumes which are also indigenous to Africa, with more adaptability to water-constrained conditions.

In the referenced study, sorghum displayed great adaptability to water constraints in rainfed farming conditions through physiological and phenological plasticity. In terms of grain legumes, the study found that minor indigenous grain legumes showed good performance and adaptability to water constraints. However, major grain legumes had comparatively better performance in the same conditions. This is mainly because major grain legumes have been involved in crop improvement efforts, which is not the case for minor grain legumes. The study identified Bambara groundnut as an indigenous legume with great potential for further crop improvement. Intercropping systems that involved indigenous cereal, legume, and grain crops were also assessed. The results showed that intercropping generally enhanced soil water availability due to the legumes serving as live mulch, reducing water loss through evaporation [54]. In rainfed conditions, intercropping resulted in the improved productivity of sorghum, suggesting that there was improved WUE.

6.2. Water Use Efficiency

The arid and semi-arid regions of South Africa favor the cultivation of indigenous climate-resilient crops because of their low water demand and drought tolerance [55]. For instance, sorghum has the trait of being deep-rooted, which assists in permeating soil for available water without necessarily depending on the surface runoff. Additionally, these crops use stomatal control, which minimizes water loss through transpiration and permits gas exchange and transpiration. A high degree of stomatal control, for instance, enables cowpea to preserve water and continue photosynthetic activities even under drought [56].

Water utilization is also significantly influenced by the morphology and structure of leaves. For example, the thick, waxy leaves of Bambara groundnuts minimize water loss by transpiration, whereas the dense trichomes of sorghum shield the plant from high temperatures [57]. To save water and lessen the effects of drought, many crops also employ drought avoidance strategies such as drought-induced leaf dormancy during drought. In general, these crops are a desirable choice for farmers and people in the semi-arid and arid regions of South Africa, supporting sustainable agriculture and food security [58].

Sorghum, cowpea, and Bambara groundnut are examples of indigenous climate-resilient crops that exhibit notable variations in production, drought tolerance, and water usage efficiency when compared to other crops [59]. Owing to their reduced water requirements and higher water use efficiency, indigenous crops are better suited to the dry and semi-arid regions of South Africa, which have limited water resources. In drought situations, their yields are comparable or even higher, giving communities a more reliable supply of food [60].

Indigenous crops, including drought-tolerant cowpea varieties and sorghum, have deep-rooted structures that enable them to withstand drought conditions [61–63].

6.3. Drought Tolerance of Indigenous Crops

A report published by the Water Research Commission of South Africa explored the water use and drought tolerance of selected traditional crops [29]. The report includes

different studies that were based on field trials and experiments conducted in the KwaZulu Natal province, along with other collaborators. The data obtained were analyzed to reflect the water use and drought tolerance of the selected traditional crops as highlighted below:

- Cowpeas.

The study explored two different cowpea varieties, with notable differences in seed coat color. Cowpeas are known for their ability to adapt to semi-arid conditions through their deep-rooting system, which allows them to access subsoil moisture. Both varieties were found to perform well under rainfed field conditions [41]. However, the findings further indicate that the white birch variety performed better in rainfed conditions as compared to irrigated conditions. This further demonstrates the drought tolerance of cowpeas, making them suitable for semi-arid and arid conditions.

- Bambara Groundnut.

The study explored drought tolerance for different Bambara groundnut varieties. The results show that drought tolerance varied among the different varieties. Seed coat color was identified as one of the characteristics that may be used to select drought-tolerant Bambara groundnut varieties. Generally, Bambara groundnut demonstrated good drought tolerance and avoidance mechanisms under rainfed conditions as compared to irrigated cultivation [42]. As a response to water stress under rainfed conditions, the plants minimized water loss by closing the stomata and reducing plant height and leaf number. Therefore, Bambara groundnut demonstrated good drought tolerance through its phenological plasticity.

- Wild Mustard.

Different wild mustard landraces were investigated for their drought tolerance. The results indicated that drought tolerance varied among different landraces. Generally, the study found that wild mustard plants were able to cope well under water stress conditions by reducing plant height, leaf number, and leaf area under rainfed conditions as compared to irrigated conditions. The results further demonstrated the influence of planting dates on the overall performance of wild mustard plants, with the plants performing better when planted in spring as compared to being planted in winter [43]. Thus, wild mustard plants have great potential for production in water-constrained conditions.

The studies quoted in this sub-section highlight how different indigenous crops contribute to optimal water conservation through different mechanisms mainly associated with water use efficiency [44]. This means that indigenous crops have good potential for production in semi-arid and arid regions in South Africa. However, there is still a need for further studies that look at a wider variety of crops and the influence of other factors such as planting dates and farming practices on the water use of indigenous crops in water-constrained conditions. The highlighted studies were also mainly based on field trials and experiments that were conducted over a specific period. There is, therefore, a need for more studies focusing on the long-term water use of indigenous crops in water-limited conditions. This will allow for the consistent and periodical measurement of important variables to identify crop varieties that are the most suitable for semi-arid and arid regions [45].

6.4. Adaptation to High Temperatures

In dry and semi-arid areas, indigenous crops have developed several adaptive traits, assisting them in withstanding high temperatures [61]. These adaptive traits include stomatal management to control plant temperature and stop water loss, the synthesis of heat shock proteins, and antioxidant systems like catalase and superoxide dismutase. Another important factor in lowering heat stress and encouraging cooling is the shape of leaves. Some native crops have leaves that are positioned to reduce exposure to direct sunlight,

while others have tiny hairy leaves that reflect sunlight [64]. These modifications all contribute to assisting indigenous crops in adjusting to high temperatures and maintaining their cellular functions [65].

Lastly, indigenous climate-resilient crops have been the subject of numerous field tests in the arid and semi-arid regions of South Africa [61,66]. The findings from the literature demonstrate that, in comparison to other crops, cowpeas depict good traits of water use efficiency [67].

7. Strategies for Promoting Indigenous Food Crops to Optimize Water Conservation

Indigenous crops are very tolerant to harsh weather, which makes them ideal for areas that are prone to drought, like South Africa's dry and semi-arid regions. Over the years, these crops have adapted to survive in nutrient-poor soils, high temperatures, and conditions of minimal rainfall. Pearl millet (*Pennisetum glaucum*), for example, grows in environments that are inappropriate for wheat (*Triticum*). Furthermore, indigenous food crops frequently use less water and fewer inputs, including pesticides and fertilizers, which lowers production costs and adverse environmental effects like river and natural water contamination. Thus, South Africa can strike a balance between preserving water resources and increasing agricultural output in dry and semi-arid regions while raising food security by substituting indigenous crops for water-intensive commercial crops in these areas.

Therefore, the strategies that can be used to promote water conservation through the utilization of indigenous crops include research and development (R&D), improving the agricultural value chain (AVC) and market, improving post-harvest management practices and the shelf life of indigenous crops, promoting water use efficiency through sustainable water management practices, and advocating for policy change and incentives for those farming indigenous crops. These strategies are explained in detail in Sections 7.1–7.5.

7.1. Research and Development (R&D)

To maximize the potential of indigenous crops to conserve water in arid and semi-arid areas, research and development (R&D) expenditure is crucial. Genetic enhancement is one area of emphasis as the yield, pest resistance, and drought tolerance of indigenous crops may all be improved via selective breeding and biotechnological developments [68,69]. For example, millet can become more competitive with commercial crops like maize by creating cultivars with greater yields and shorter growth cycles [70]. These advancements not only boost output but also persuade farmers to use these crops as sustainable substitutes [71].

Researching the interplay between soil and water to identify the best-growing conditions for indigenous crops is another essential component of R&D. Sustainable farming methods may be guided by knowledge of the particular soil types, nutritional requirements, and water requirements of various crops. For instance, studies on cowpea variations have revealed a great deal of variation in water use efficiency, which enables researchers to suggest certain cultivars for areas with scarce water supplies [72–74]. Through extension services, farmers may be informed of these discoveries, guaranteeing that the best crops are planted in certain locations [75].

R&D is equally important in knowledge transfer and capacity building. By clearing up misunderstandings and offering helpful gardening advice, farmer training programs grounded in scientific research can increase the uptake of indigenous crops [76]. Solutions need to be adapted to local needs and circumstances through cooperative research including farmers, scientists, and politicians. South Africa can fully realize the potential of its indigenous crops and establish them as a pillar of water-efficient agriculture by giving research and development top priority.

7.2. Improving the Agricultural Value Chain (AVC) and Market

For indigenous crops to be widely adopted and economically viable, the agricultural value chain (AVC) must be developed. Raising consumer knowledge of these crops' ecological and nutritional advantages is one approach to this [77,78]. Public awareness initiatives backed by collaborations between the public and business sectors can emphasize the health advantages of regional cuisine like amaranth greens or sorghum porridge [79]. To establish a steady demand base, schools, hospitals, and community groups may also help include these crops in regular diets [80].

Creating supply networks and marketplaces specifically for indigenous crops is another issue causing poor consumer demand for indigenous crops, leading to underutilization [81,82]. These crops may be made more accessible and profitable by creating markets, transportation systems, and processing facilities, especially in local communities. Initiatives in branding and packaging, such as designating local foods as "climate-smart", "water-efficient", or "sustainably sourced", might increase consumer confidence and the acceptance of finished products from indigenous crops [83].

In addition, involving the private sector is also crucial for market integration and increased production scale as collaborations between companies and farmers can result in the creation of value-added goods that may target specific markets, including ready-to-eat snacks or gluten-free flours [84,85]. Additionally, the prospect for export must be investigated particularly for internationally recognized indigenous commodities like marula (*Sclerocarya birrea*) and rooibos (*Aspalathus linearis*) [86]. By guaranteeing that farmers receive just compensation for their labor, raising the AVC for indigenous crops can promote more involvement in water-efficient crops.

7.3. Improving Post-Harvest Processes and Fruit Preservation Technology

A major obstacle to the cultivation of indigenous crops, especially in arid and semi-arid areas, is post-harvest losses [87]. The creation of economical processing methods is necessary to address these losses. For instance, grains may be kept from spoiling while being stored by using solar-powered dryers to lower their moisture content [88]. In addition to lowering transportation costs and increasing market readiness, innovations like mobile milling equipment may assist farmers in processing their crops on-site into commercial forms like flour or oil [89].

Another crucial component of post-harvest management is storage options as indigenous crops are frequently cultivated in areas where conventional storage techniques are insufficient to guard against environmental influences and pests [90]. Post-harvest losses can be considerably decreased by implementing metal silos or hermetically sealed storage bags [91]. Smallholder farmers who depend on indigenous crops as their main source of income and food security would especially benefit from these innovations. To increase the marketability and shelf life of indigenous crops, value addition is also essential [92]. For example, turning cowpeas into canned beans or millet into packaged morning cereals might appeal to urban customers and raise the crops' economic worth [93,94]. In South Africa's dry and semi-arid regions, investing in post-harvest procedures guarantees that indigenous crops will continue to be viable over time, promoting food security and water conservation.

7.4. Policy and Incentives

Promoting the production of indigenous crops can be greatly aided by financial incentives and policy changes. The initial expenses of seeds, equipment, and water-efficient technologies can be covered by subsidies to produce indigenous crops, which would facilitate farmers' transition from conventional commercial to indigenous crops. To promote

the adoption of drought-tolerant crops in areas with limited water resources, governments may, for instance, provide seed grants for sorghum and millet [95,96].

Credits for water conservation are yet another powerful motivator with tax credits or subsidies awarded to farmers that use water-saving techniques and grow indigenous crops [97,98]. In addition to promoting sustainable farming, these programs support national objectives to lower agricultural water use. Municipalities may redirect freshwater for other vital purposes, like urban usage and environmental protection, by conserving water resources. Establishing an environment that supports the development of indigenous crops requires strategic policy. This involves incorporating indigenous crops into agricultural extension initiatives and national food security plans. To promote indigenous crops as a sustainable substitute for commercial crops that require a lot of water, policymakers can also fund research projects, market expansion, and public awareness campaigns. These initiatives guarantee that water conservation is given top priority in agriculture policy at all levels.

7.5. Promoting Water Use Efficiency Through Sustainable Water Management Practices

To maximize the water use efficiency of indigenous crops, sustainable water management techniques are crucial. For example, drip irrigation, which delivers water straight to the roots of plants, is a very efficient way to reduce water waste [99,100]. Even in regions with limited water resources, this method may be modified for smallholder farmers utilizing reasonably priced gravity-fed systems. Another technique that lowers evaporation and preserves soil moisture is mulching. Farmers may improve soil health and maintain ideal moisture levels by covering soil with organic materials like straw or crop waste [101].

For indigenous crops, which frequently thrive in soils with little organic matter, this method is very advantageous as mulching also reduces weed competition for nutrients and water [99,102]. In areas where rainfall is erratic or seasonal, rainwater harvesting systems can offer an extra supply of irrigation water. During dry spells, indigenous crop cultivation can be supported by methods like building ponds or contour bunds to collect and store rainfall [103]. When combined with technology for monitoring soil moisture, these methods guarantee the sustainable and effective use of water resources [104], strengthening the resilience of agricultural systems in arid and semi-arid areas.

8. Barriers to the Adoption of Indigenous Food Crops in South Africa

8.1. Cultural and Social Constraints

The degradation of conventional systems and the cultural perception of farmers are barriers to the adoption of indigenous crops. In the past, farmers relied on meat and fresh blood combined with milk to survive, while green plants were solely considered animal feed and not fit for human use. Consuming traditional veggies is also linked by some to poverty [105–108]. Younger and urban consumers are more likely than elderly and rural consumers to report negative perceptions of associating indigenous crops with irrelevant crops and deeming them outdated.

According to a study by Afari-sefa et al. [105], the proportion of traditional vegetables to the total area under production is adversely and strongly correlated with the education level of farmers. This could be explained by the fact that farmers typically increase their investment in non-traditional vegetable crop cultivation as their level of education rises. There is a need for a more active approach to encourage farmers to incorporate more variations into vegetable farming since there is a degradation of conventional knowledge.

8.2. Lack of Awareness and Knowledge

The lack of knowledge about the benefits of indigenous crops amongst farmers and their consumers is a vital adoption barrier for these crops. A study by Kansime et al. [49] indicated that some farmers are not aware that some weeds are nutrient-dense vegetables. Farmers lack knowledge about the ecological and nutritional benefits of indigenous crops, leading to the inclination to grow known staple foods such as wheat and sorghum [35]. Among modern consumers, the consumption and cultivation of indigenous crops are very low because they characterize them as low-status or subsistence food [51].

8.3. Economic and Market Challenges

Poor market integration and undeveloped value chains threaten the commercial sustainability of native food crops. In many nations, smallholder farmers primarily operate informal food markets where they prepare, distribute, and sell indigenous and traditional food crops [5]. In addition to being impacted by price, culture, accessibility, seasonality, and availability, their consumption may also be impeding their larger-scale production. Their availability in both official and informal markets may be restricted as a result [52].

The demand for traditional African vegetables has grown recently, but farmers' ability to provide consumers with better produce has been hampered by the lack of access to the high-quality seeds of preferred varieties. Due to market demand trends, input costs, timely availability, seed quality, and crop sale revenue, farmers are facing barriers to accessing traditional vegetable seeds [105]. Despite the abundance of agronomic, financial, and nutritional advantages that traditional vegetables offer, Tanzanian and other sub-Saharan African countries' production and marketing of these crops are limited by issues like low-quality and scarce seeds, as well as other production-related risks, a lack of suitable market information and support systems (like cold storage), and high post-harvest losses, all of which hinder farmers from taking full advantage of the opportunities that traditional vegetable crops present [105].

Certified indigenous seeds and other agricultural inputs are not easily accessible for farmers. When farmers believe that traditional vegetable seeds will not be available in time for the upcoming cropping season, they tend to decrease the percentage of their traditional vegetable-farmed area within the total cropping mix, leading to an inconsistent supply for consumers [109].

8.4. Policy and Institutional Barriers

Local institutional arrangements can, at times, hinder the scaling and adoption of innovations. Factors such as restrictive property rights, the cultural perception of innovations, and gender-based norms can act as significant barriers, particularly in rural areas. As noted by Lasning and Markiewicz [110], cultural beliefs, practices, and existing local institutional frameworks may discourage the adoption of new initiatives and reduce farmers' willingness to experiment with other practices.

Historically, South African policymakers have given priority to staple foods, marginalizing indigenous crops in the process. Indigenous crops are excluded from agricultural development because government subsidies and extension assistance are primarily directed towards commercial farmers [111]. Furthermore, farmers who want to embrace indigenous crops face major obstacles due to the absence of organized seed systems and propagation materials. Farmers sometimes produce fewer traditional vegetables when they believe that seeds are not accessible in time for production, so it is also critical that the government enact enabling policies to improve the timely availability of traditional vegetable seeds and prevent geographical gaps [111].

8.5. Climate and Environmental Concerns

Climate variability poses significant challenges to the adoption and production of indigenous crops in South Africa. Farmers report rainfall scarcity and excessive temperature increases as primary hazards, which directly contribute to the declining yields of indigenous crops. These climate stressors not only reduce production but also threaten food security at the household level, as the yields often fail to meet basic requirements [112]. It is commonly acknowledged that agricultural production systems are significantly impacted by climate change, which also poses a danger to crop sustainability and production [113].

9. Policy Implications, Recommendations, and Future Directions

9.1. Policy Implications

There are considerable policy implications for growing native climate-resilient food crops in South Africa's semi-arid and arid regions. Firstly, the necessity of a paradigm change in the nation's agricultural policies is emphasized, moving away from an emphasis on large-scale farming and towards a more egalitarian and sustainable strategy that gives small-scale regional food systems priority [114]. It is also emphasized how crucial it is to acknowledge and defend indigenous populations' rights to their ancestral lands, resources, and knowledge. Furthermore, a coordinated policy strategy including several government departments and stakeholders is necessary to promote indigenous climate-resilient food crops [115]. This includes, among other departments, the Department of Science and Technology, the Department of Agriculture, the Department of Environmental Affairs, and the Department of Land Reform and Rural Development. It also calls for cooperation with civil society organizations, research institutions, and the private sector to leverage resources, expertise, and funding [116].

9.2. Conclusions and Recommendations

This paper concludes that it is very crucial to maximize water conservation in the arid and semi-arid regions of South Africa. The cultivation of indigenous climate-resilient food crops is a system for improving food production, increasing water security, and alleviating poverty. According to the data, certain crops, such as cowpeas, sorghum, etc., have native characteristics that allow them to withstand the weather conditions and water scarcity in certain regions, which lessens the pressure on water supply sources. However, a multifaceted strategy that challenges the difficult interactions between the physical, economic, environmental, and institutional issues is necessary for the effective adoption of these crops.

The following policy measures are suggested to maximize water conservation through the production of local climate-resilient food crops. To initiate this process, the South African government should establish a national policy framework that acknowledges the significance of climate-resilient food crops and indigenous knowledge systems in attaining sustainable agriculture and water conservation. In addition to offering incentives for farmers and communities to adopt these crops, this framework should also include standards for the preservation, marketing, and sustainable use of native food crops.

Moreover, the government should provide financial and technical assistance to indigenous communities and small-scale farmers to enable them to grow and sell indigenous climate-resilient food crops. This could involve funding for irrigation systems, seeds, equipment, and training, as well as support for market access and development. Furthermore, to enhance the sustainability and productivity of domestic climate-resilient food crops, the government should invest in research and development. This could involve providing funding to universities, research institutions, and civil society organizations to conduct studies on the potential of these crops and develop new farming practices and technologies.

Ultimately, the government should establish a nationwide database and information system to document and disseminate information about indigenous climate-resilient food crops, including their characteristics, uses, and cultivation practices. This would facilitate the sharing of knowledge and best practices among farmers, researchers, and policymakers and support the scaling up of these crops [117].

9.3. Future Directions

Regarding potential future paths, the following should be considered: To fully realize the potential of native climate-resilient food crops, further research is needed to investigate their role in supporting water conservation and sustainable agriculture in South Africa. Future studies should concentrate on the animal and agricultural species that are the most suitable for the arid and semi-arid areas of the nation, as well as the farming methods and technologies that can be used to maximize their sustainability and production.

Moreover, training programs and capacity building are required to help indigenous communities and small-scale farmers grow and sell native climate-resilient food crops. The goal of these initiatives should be to provide farmers with the knowledge and skills they need to adopt these products and to access markets and negotiate fair prices [118]. Furthermore, policy and regulatory frameworks are needed to support the conservation, promotion, and sustainable use of native climate-resilient food crops. This includes frameworks for regulating the trade in these crops and protecting indigenous knowledge and intellectual property.

Ultimately, raising awareness among consumers about the benefits of native climate-resilient food crops is crucial. This includes highlighting their nutritional value, cultural significance, and role in water conservation and sustainable agriculture. Campaigns to promote these crops in marketplaces, communities, and schools, as well as supporting their inclusion in national food security and nutrition programs, are necessary.

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