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Sorghum as a household food and livelihood security crop under climate change in South Africa: A review

Extreme events, declining rainfall and increasing temperatures under climate change threaten smallholder households' food and livelihoods security. The potential of sorghum (*Sorghum bicolor* [L.] Moench) to contribute to food security and livelihoods of smallholders in South Africa has not been realised, despite its resilience to heat and drought, due to its marginalisation in research, breeding, the scale of production, and policy support. Consequently, to reduce vulnerability and boost sorghum's position as a key climate change adaptation crop, in this review we examined some biophysical, socio-economic, socio-cultural and institutional barriers that constrain its production and performance on smallholder farms in South Africa. We further suggest pertinent issues to be addressed to improve production and productivity on smallholder farms. Increasing awareness, policy development and support, and capacitation of extension services, as well as improving market access, agronomic and cultural practices, and availability of more locally adapted sorghum varieties are requisite factors in addressing the prevailing constraints limiting sorghum production. Furthermore, tailored and site-specific studies at farm and landscape level are imperative for informed management and decision support. Thus, an integrated and multidisciplinary approach is key in fostering significant improvement in sorghum production and performance in smallholder systems in South Africa to reduce climate change vulnerability.

Significance:

- Sorghum has the potential to bolster food and livelihoods of smallholder farmers in South Africa.
- Socio-economic, socio-cultural and biophysical challenges limit sorghum production and performance in South Africa.
- An integrated and multidisciplinary approach is required to optimise the opportunities to improve sorghum production and performance in South Africa.

Introduction

Climate change negatively impacts the four pillars of food security – namely, availability, access, utilisation and stability – and their interactions.¹ The Intergovernmental Panel on Climate Change's most recent report² highlighted increasing temperature, changing precipitation patterns, increased frequency of extreme events such as heatwaves, tropical cyclones and incidence of agricultural and ecological droughts as the main drivers that jeopardise food security under escalating climate change. Consequently, yields of staple crops such as maize have decreased across Africa, widening food insecurity gaps.³

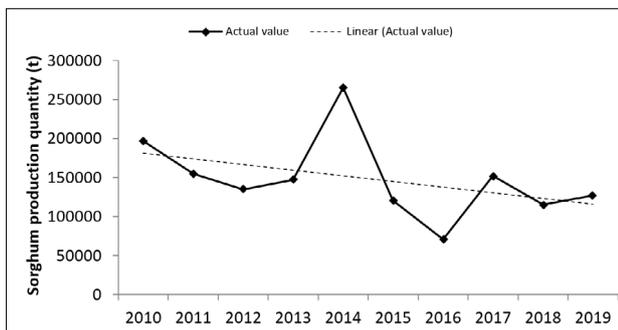
A significant proportion of the most food insecure populace is found in Africa⁴; thus, a shift from current food production strategies, practices and crop choices that have repeatedly failed to meet the food needs of the people is required. Rainfed agriculture accounts for about 90% of staple food production in sub-Saharan Africa⁵; such systems are especially susceptible to climate change due to its direct effect on water availability. Crop production strategies, such as crop intensification and diversification^{6,7}, can present opportunities to secure household food and livelihood needs under climate change risks. Diversified crop production that exploits climate resilient and/or smart crops such as sorghum – known for their ability to withstand various abiotic stresses such as heat and drought⁸ – presents one alternative to secure food and livelihoods of smallholder farmers.

In South Africa, declining production output of maize is a major cause for concern given the significant role it plays in the daily diets of South Africans.⁹ While efforts to improve productivity and ensure the sustainability of maize production are at the centre of various efforts aimed at improving food security¹⁰, neglecting alternative crops narrows the prospects of developing robust and resilient food systems. Therefore, it is imperative to understand and develop the value chains of alternative crops so as to increase the range of options available to smallholder farmers to adapt to climate change. Although sorghum is South Africa's third cereal of importance, it is characterised by an inadequately developed and poorly understood value chain, and is marginalised in terms of research, breeding, production and policy support; therefore, it is characteristically a neglected and underutilised crop.¹¹ Industrially, sorghum is used in the manufacture of value-added products such as malted porridge meal, instant energy drink, gluten free flour as well as industrial beer brewing, while in smallholder households, it is mainly used in the preparation of various meals such as thin and thick porridge, fermented porridge as well as malting in artisanal beer brewing.¹² Because of its various uses, sorghum can potentially contribute to improved access to food, and if marketed it can improve household income, thus improving livelihoods. Importantly, sorghum's ability to withstand various abiotic stresses such as heat and drought, as well as extensive periods of water logging, reinforce it as a key climate change adaptation choice crop.⁸

Consequently, we reviewed the literature to outline the barriers to sorghum production on smallholder farms in South Africa, explore how climate change will affect sorghum performance, and examine some key factors that ought to be addressed to promote adoption and improved performance of sorghum under smallholder systems to allow for more diversified crop production as a strategy to adapt to climate change in South Africa.

Overview of sorghum production in South Africa

Sorghum in South Africa is produced on both commercial and smallholder farms, across six provinces, namely, the Free State, Limpopo, Mpumalanga, North West, Gauteng and KwaZulu-Natal.¹³ It is predominantly grown in the western region, possibly due to its increased tolerance for drier growing conditions.¹⁰ Sorghum production mainly occurs under dryland cultivation in South Africa, which accounts for up to 99% of the sorghum cultivated area.¹⁴ In the commercial sector sorghum production trends have been variable, with some notable decreases in the past decade and an average annual production output of 148 370 tonnes between 2010 and 2019 (Figure 1).⁹ Availability of production data on smallholder systems is limited^{13,15}, which could possibly be due to lack of documentation and/or non-significant yield output from the sector. As such, efforts to characterise and quantify the contribution of smallholder production to national sorghum grain stocks are essential.



Data source: FAOSTAT cropping database.⁹

Figure 1: Sorghum production output in South Africa, 2009–2019.

According to the Bureau for Food and Agricultural Policy, South Africa is a net importer of grain sorghum and is expected to maintain this status until 2027.¹⁴ This assertion suggests a fundamental need to boost production, both in the commercial and smallholder sectors, to meet domestic needs and curb imports. As such, there is an opportunity to generate income and secure livelihoods for the vast number of South Africa's smallholder farmers – a strategy that is commonly considered key to advancing Africa's agricultural productivity and creating employment.^{16,17}

Barriers to smallholder sorghum production in South Africa

Land and soil related constraints

The geographical location of smallholder farms is a direct result of historical patterns of dispossession and impoverishment imposed through the apartheid legislation.¹⁸ The system fostered settlement of black people in marginal areas (former 'homelands'), with limited agricultural potential in terms of soil fertility and climate.¹⁹ The majority of farms are smaller than 2 ha, and hence the farmers face the challenge of the inadequacy of farmland, as well as the insecurity of tenure.^{20,21} Moreover, continuous cultivation, which is often accompanied by inadequate fertiliser applications, leads to nutrient mining²², thus further degrading the soil. In a study by Mofokeng et al.²³, soil fertility was identified as one of the constraints to sorghum productivity. Interestingly, in the same study, weed infestation, specifically *Striga*, was rated as a second major constraint. Consequently, this was indicative of the far-reaching problem of poor soil fertility, which the farmers might not have been aware of, as *Striga* infestation is a symptom of depleted soil fertility, as documented in several studies.^{24–26} Thus, inadequate soil fertility significantly impacts sorghum productivity on smallholder farms.

Climatic factors

Dryland agricultural production disproportionately increases the susceptibility of crops to rainfall variability and uncertainty, dry spells and droughts. Based on statistical methods, i.e. regression techniques, Wenzel¹⁵ showed that moisture stress is a key factor that limits sorghum yields in South Africa. In addition to moisture stress, heat stress is also

critical, with heat and moisture stress often occurring concurrently, resulting in more severe effects than either singularly.²⁷ Also, drought was rated by farmers as one of the top three limiting factors of sorghum productivity in Limpopo Province.²³

Limited access to improved seeds

Another barrier to sorghum productivity on smallholder farms is the tendency to use grain from previous harvests as seed for the subsequent growing season, as observed by Mofokeng et al.²³ in Limpopo Province. This was despite its ranking as the priority crop in the study area; and thus reflects lack of sufficient investment in improved inputs for sorghum production. The use of the previous crops' grain as seed for the next season was also observed in sorghum and finger millet production in Zimbabwe by Rurinda et al.²⁸, with loss of quality during storage emerging as a challenge. Therefore, the use of recycled seeds is another major barrier to sorghum productivity on smallholder farms.

Pests and diseases

Although climate change poses an imminent threat to crop productivity due to the heat and moisture stress effects, these factors also influence pathogen–host interactions and the emergence of novel pests and diseases has also become increasingly common.^{29,30} Mofokeng et al.²³ found that farmers considered bird damage and weevils as the most prevalent and serious challenges under sorghum producing systems. According to unpublished reports by the Directorate of Climate Change and Disaster Risk Reduction at the Department of Agriculture, Land Reform and Rural Development (DALRRD) in South Africa, an estimated 1 million migratory pests such as *Quelea* birds can destroy up to 4 tonnes of small grain crops per day, which can result in a complete loss of harvest. As such, this can have a major impact on the shunning of small grains as choice crops.

Lack of institutional support such as extension

Several studies have reported that institutional support such as extension services in smallholder systems is frequently limited.^{16,21} Myeni et al.²¹ reported that an astounding 99% of smallholder farmers lack access to extension services in the eastern parts of the Free State Province. This is worsened by the long-standing challenge of institutionalised inefficiencies in extension services provision, as argued by Aliber and Hall¹⁶ who found that the government departments responsible for supporting farmers make poor use of the resources at their disposal and do not have an adequate appreciation of their clientele. Pereira¹² pointed out that some extension officers are not knowledgeable and familiar with sorghum, which further compounds the problem of inadequate institutional support systems.

Attitudes and social perceptions

Hadebe et al.⁸ indicated that existing social perceptions and historical stereotyping of sorghum as a 'poor man's crop' contribute to the shunning of the crop, in preference to crops such as maize, despite the comparatively lower water requirement of sorghum relative to maize. Similar observations were made by Mabhaudhi et al.¹¹ whose review of neglected and underutilised crop species indicated that cultivation of these crop species in sub-humid and semi-arid agroecological zones of South Africa is impacted by negative societal perceptions, thus limiting their acceptance and cultivation. Mostly, the negative attitudes are underpinned by lack of knowledge, as many people are not aware of the numerous value-added products derived from sorghum, the health benefits, or the availability of an existing local market.^{12,14}

Climate change projections and potential impacts on sorghum production

Although reputed as a drought and heat tolerant crop, under dryland production, sorghum is susceptible to rainfall variability and uncertainty, seasonal dry spells and droughts.^{11,31,32} As such, in order to harness the benefits of sorghum as a choice crop to ensure food and livelihood security in the face of climate change risks, it is imperative to understand climate change impacts on sorghum. Modelling studies have been helpful in this regard.

In South Africa, droughts have been confirmed for 8 of 30 seasons between 1983/1984 and 2014/2015 in the Luvuvhu catchment in Limpopo.³³ Moeletsi et al.³⁴ projected likely occurrences of severe to extreme droughts between 2039/2040 and 2078/2079. In another study, Calzadilla et al.³⁵ predicted that, by 2050 < mean national temperatures will increase by 5–8 °C, with much reduced rainfall in the west and south of the country, and an increased risk of heavy rainfall events in the eastern parts of the country. Weepener et al.³⁶ projected a southern expansion of the hot desert zone into the southern parts of the Northern Cape and northern parts of the southwestern Cape. They further predicted that the production area for some summer crops such as maize and sorghum could shrink due to changes in rainfall and temperature regimes, which could mean more land use competition – thus the need to address pertinent issues such as creating a balance between competing land uses, crop choices and policy measures to ensure optimal resource use efficiency amongst numerous arising issues.

It is noteworthy that, although several studies have predicted likely changes in climate change variables such as temperature, rainfall, CO₂ emissions and droughts in South Africa, there is a scarcity of modelling of sorghum crop responses, compared to other sub-Saharan African countries.^{31,32} In South Africa, only a handful of such studies were found. For example, Chimonyo and Mabhaudhi³⁷ used a process-based crop model, APSIM (Agricultural Production Systems Simulator) to develop and make recommendations for improving the productivity of sorghum-cowpea intercrop systems under water-scarce conditions. In another study, Zinyengere et al.³⁸ showed that DSSAT could be used for modelling maize and sorghum yields under data limited conditions. Clearly, there are limitations with regard to putting forward recommendations for agronomic practices, management and decision support for sorghum production so as to optimise its productivity and benefits. Consequently, we used a few examples from other parts of Africa to highlight some projected effects of climate change on sorghum (Table 1).

Table 1: Projected climate change effects on sorghum response in Africa

Modelled climate change variable	Sorghum response	Reference
Increasing temperature	Declining grain yield	39
Rainfall decline and increased minimum and maximum temperatures	Grain yield decline of early maturing varieties	40
Early growing season droughts	Declining grain yield	32
Increased occurrence of El Niño Southern Oscillation (ENSO)-induced climate extremes	Declining grain yield	41
Temperature increases and rainfall reductions	Yield reduction	42
Mean temperature increases of 1.4–2.8 °C	Increasing yield	43
Dry spell of 10 days or longer during the period from flag leaf appearance to start of grain filling	Grain yield decline	43

The variable responses of sorghum to climate change effects in simulation studies (Table 1) attest to a significant degree of spatio-temporal and local-scale vulnerability to climate variability³², thus calling for in-depth studies on the microclimate/farm and landscape level under local conditions.

Sorghum as a climate smart crop

Various morphological, physiological and phenological mechanisms enable sorghum to escape, avoid and tolerate drought and heat stress.^{8,44} Further, under extreme drought conditions, some sorghum genotypes are able to adopt a dormant adaptive mechanism called drought recovery where plants are able to resume growth and gain yield after exposure to severe drought.⁴⁵

The ability to sustain metabolic reactions and physiological activities under stress make up sorghum’s physiological drought tolerance mechanism.⁴⁴ The physiological responses hinge on its ‘stay green’ genetics, which allow for delayed leaf senescence, thus conferring tolerance to post-flowering drought stress.^{44,46,47} Further, a high chlorophyll content, chlorophyll fluorescence as well as low canopy temperature and high transpiration enable sorghum to withstand heat and moisture stress.^{8,48} Additionally, sorghum’s tolerance to heat is mostly due to its superior ability in osmotic adjustment and stomatal regulation.⁴⁴

A reduction of phenological phase duration, grain set, grain number and size, and grain-filling duration, comprise some of the phenological adaptation mechanisms of sorghum.⁴⁹ Early flowering and increased early vigour are the most salient phenological drought escape mechanisms which allow shortened growing seasons, thereby enabling the crop to reach yield formation and grain filling stages well before episodes of limited soil water and excessive atmospheric temperatures, thus reducing risk of significant yield reductions.⁸ Additionally, sorghum exhibits a unique flowering behaviour termed early morning flowering which allows for completion of flowering before dawn, thereby promoting maintenance of pollen viability, especially under heat-stress conditions.⁵⁰

Morphologically, a prolific root system is central to sorghum’s drought adaptation.⁴⁴ Sorghum has long roots with a high root density at deeper depths that allows access to water in the deeper layers of the profile during water-scarce periods.⁵¹ Additionally, other root characteristics credited for successful avoidance of dehydration in sorghum include increased number of secondary roots, length, volume, dry weight and root length density.⁴⁴

Prospects for smallholder sorghum production in South Africa

Awareness creation

Sorghum is produced at a significantly lower scale compared to maize in South Africa.⁹ Although production in smallholder systems is hindered by several barriers that also impact maize and other crops, factors such as attitudes and socio-cultural perceptions additionally constrain the scale of production and productivity of crops such as sorghum.^{8,23} As such, there is a need to break such cycles through information dissemination that raises awareness on the importance of sorghum as a climate smart crop to manage the risk of food insecurity in the wake of climate variability and uncertainty. In addition, public awareness campaigns to educate people and disseminate more information on the practices and market value of sorghum in communities are necessary interventions to dispel the negative perceptions of and attitudes towards this crop.¹² The study by Mofokeng et al.²³ in parts of Limpopo is telling of the possibility of acceptance of sorghum as a priority crop and cultivation in significant plots; thus, with the right institutional, technological and policy support, sorghum production can be expanded.

Breeding based on the wild relative’s gene pool and landraces

The utilisation of crop wild relatives is an invaluable source of diversity and crop advancement. Success with the use of the gene pool of crop wild relatives to improve traits such as disease and pest resistance, nutritional value, yield, and tolerance to abiotic stresses has been experienced with other crops like maize, rice and wheat.^{52,53} Ananda et al.⁵⁴ posits that there is a huge untapped potential for sorghum improvement from the wild gene pool, which could harbour useful genes for abiotic and biotic stress tolerance. Further, landraces have been found to be an invaluable source of various traits, which could be introgressed into modern varieties, enhancing adaptation and productivity in stress-prone environments to cope with current climate changes.^{55,56} Virk and Witcombe⁵⁷ ascribed locals’ preference of landraces over improved varieties to good adaptability to the environment, local farming system, and familiarity with the food quality produced by local varieties, thus breeding efforts ought to harness and build on these so as to produce more locally adaptable and acceptable varieties.

Increased participatory research for trait selection in breeding

The use of participatory approaches in the selection of breeding traits for sorghum will likely result in more socially and economically acceptable varieties, thus improving the uptake of sorghum in smallholder farms. In the wake of climate change, although the obvious focus of many breeding programmes may be resilience and tolerance to heat and water stresses, farmers' perceptions of the most yield-limiting constraints which should be integrated into the breeding process may differ from those perceived by researchers. For example, in Mofokeng et al.'s²³ study, drought was rated as the third most important constraint, after bird damage and *Striga*, while heat stress was rated fourth²³ – underscoring the need to integrate farmers' perceptions and preferences in trait selection. Furthermore, farmers indicated preference for sweet sorghum varieties with good porridge making quality.²³ In another study, in Burkina Faso, vom Brocke et al.⁵⁸ used participatory techniques as an inclusive tool for trait selection in sorghum breeding and revealed that farmers' methods for defining traits were more multifaceted, and inextricably linked to climatic patterns than the breeders' formal understanding of the same traits, thus emphasising the need for breeders to adjust their selection criteria to suit the basic needs of small-scale farmers in semi-arid regions of sub-Saharan Africa.

Availability and access to improved seeds

Studies have shown that it is common for small grain farmers to recycle seeds.^{23,28} In the study by Mofokeng et al.²³, although sorghum was the priority crop, recycling of seed was observed, implying that it was not entirely an issue of the importance of the crop, but may be related to factors such as affordability, beliefs and habits, or availability of varieties of choice. Interdisciplinary research is therefore required to unpack the multidimensional and multilayered complexities associated with the socio-cultural and socio-economic issues around small grain production in smallholder farming systems.

Integrated soil fertility management

Stewart et al.⁵⁹ point out that access to inorganic fertiliser, its use and related implementation issues are critical to enhancing soil fertility and crop yields in sub-Saharan Africa. This is particularly important in sorghum production whose nutrition is commonly relegated to reliance on residual fertility¹²; thus, this issue should be at the core of interventions aimed at improving sorghum productivity in smallholder systems in sub-Saharan Africa. Sorghum requires about 85 kg/ha N to achieve a grain yield of 2–3.5 t/ha⁶⁰; as such, concerted efforts from the government and private sector are required to ensure that fertiliser inputs are affordable and accessible to smallholder farmers. Rurinda et al.²⁸ reported that seed emergence of sorghum was severely inhibited when no fertiliser was applied at planting, whereas application of nitrogen and phosphorus fertilisers resulted in 3–4 times more grain. Further, in a meta-analysis of sorghum response to soil fertility options in Africa, there was a 47–98% yield increase with nitrogen and phosphorus fertiliser application.⁶¹

Additionally, organic nutrient management resulted in sorghum yield increases of 43–87% over controls in numerous studies across Africa.⁶¹ Malobane et al.⁶² also indicated that organic material management is beneficial in the management of marginal soils utilised for biofuel sorghum production in South Africa.

Market development and access

Hadebe et al.⁸ highlighted the need for a drive towards marketing and distribution of existing sorghum high-end products, and the development of a wide range of processed products from sorghum, as a strategy to increase sorghum production in sub-Saharan Africa. This holds true as observed for maize across the globe, for which the demand as livestock and poultry feed has seen its demand surge tremendously.⁶³ In this regard, gathering of information regarding consumers' preferences is of utmost importance so as to develop market products that meet consumers' preferences.¹²

Moreover, in South Africa, local production continues to fail to satisfy local industry needs for sorghum¹⁴, thus, there exists a market that local producers can supply. It has, however, been noted that market access remains one of the key limiting factors for the development of emerging commercial and smallholder farmers. This is characterised by institutional and technical constraints, with control by a few corporate companies that impose excessive regulatory and compliance requirements, beyond the means of emerging farmers.⁶⁴ Consequently, unlocking market access will be critical for the entry of smallholders into mainstream commercialisation.⁶⁵ A shift from entirely subsistence-oriented crop production to industry-oriented crop production has a high potential to secure both food and livelihood security for smallholders.⁶⁶

Improved extension support

Access to extension services is acknowledged as key to the development of resilient smallholder farming systems. Extension services provide critical support in improving agricultural productivity through awareness raising, capacity building and the provision of up-to-date information on sustainable agricultural practices, input supply, access to markets and credit as well as early warnings on droughts, weather forecasts and climate change adaptation strategies.²¹ The key issues to be addressed with regard to extension support include increasing extension personnel so as to reduce the farmer:extension ratios, and increasing efficiency in the operation of extension services through training and capacity building.

Use of models as decision support tools

The use of global circulation models and process-based crop simulation models has been applied across the world to enact climate change scenarios and possible crop responses, so as to come up with strategies to avoid crop failure and improve crop productivity.^{31,40,41,67} Chimonyo and Mabhaudhi³⁷ successfully showed that crop modelling could be used as a decision tool for planting date and plant population selection to enhance yield and water use efficiency in a sorghum-cowpea intercrop under water-scarce conditions. Overall, we found that there was lack of adequate research and simulation studies for sorghum production systems in South Africa, hence limited decision support exists. Addressing this issue could harness the opportunities that sorghum presents as a climate smart crop. Research should be backed up by inclusive information dissemination and tailored packaging so that it reaches the targeted groups including farmers, policymakers and extension services to be beneficially used to inform decision-making and proper planning.

Conclusion

There is mounting research on climate change effects on various crops, as it is becoming increasingly pertinent to proffer strategies to reduce human vulnerability to climate change through improved and robust food systems. Sorghum is acknowledged as one of the neglected and underutilised crops that can be harnessed to counteract the risks to food and livelihood security of smallholder farmers imposed by the changing climate. Sorghum can contribute to household food security as it can be utilised in the preparation of household meals, but also holds potential to secure livelihoods, due to the existence of a local unfulfilled market that smallholders can tap into in South Africa. However, similar to other crops, sorghum is vulnerable to climate change impacts, although responses show spatio-temporal and site-specific variability, thus necessitating more research to improve understanding and inform decision-making. Despite the numerous socio-economic, socio-cultural, biophysical and institutional barriers that constrain sorghum production in smallholder farms, there is scope to overcome these and increase production and performance through multidisciplinary and integrated approaches and efforts.

Competing interests

We have no competing interests to declare.

Authors' contributions

N.D.: Conceptualisation; literature review, analysis and synthesis; writing – initial draft; writing – revisions. A.N. and E.D.: Conceptualisation; review and revision. P.C., M.M., S.M. and I.K.: Review and revision.

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