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RESEARCH ARTICLE

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# Sorghum production in Nigeria: opportunities, constraints, and recommendations

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**ABSTRACT**

Sorghum (*Sorghum bicolo* [L.] Moench) production has considerable socio-economic values in sub-Saharan Africa for food security and to serve the increased industrial demands due to high population pressure and climate change. However, the production and productivity of the crop are yet to be expounded in Nigeria for economic gains. Therefore, the objective of this study was to present the current opportunities and constraints to sorghum production in Nigeria. A participatory rural appraisal (PRA) study was conducted in three selected sorghum growing zones in northern Nigeria involving 250 farmers. Socio-economic data were collected through surveys and focus group discussions. Sorghum was cultivated mainly by males (80%) who had grade 6-12 level of education (31.3%), with the productive age of 21-45 years (75.7%) and a household family size of below five members (52.3%). Low yielding landrace varieties such as Kaura (37.4%) and Fara-fara (29.3%) were the most widely cultivated types across the study zones due to their good grain quality. The major farmers' preferred traits from a sorghum variety were high yield, drought tolerance and *Striga* resistance. The study recommends integrated sorghum technology development incorporating the described preferences of the farmers for sustainable production and economic gains of the cropble production.

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## Introduction

Sorghum (*Sorghum bicolor* [L.] Moench) is the 5th most important world cereal crop after maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), and barley (*Hordeum vulgare* L.) (FAO 2019). It is a staple food crop in the drier parts of Africa, China, and India (Ajeigbe et al. 2018; Mrema et al. 2020). The largest world's sorghum producers are the USA with total annual grain production of 8.7 million tons from 2.0 million hectares, Nigeria (6.9 million tons and 5.4 million hectares), Ethiopia (5.3 million tons and 1.9 million hectares), and Sudan (3.7 million tons in 6.8 million hectares) (FAO 2019). Nigeria is the leading sorghum producer, followed by Ethiopia in Africa in terms of total production. Sorghum is the largest staple cereal crop accounting for 50% of the total output and occupying about 45% of the total land area devoted to cereal crops production in Nigeria (FAO 2019). The sorghum productivity in the country is 1.23 t $ha^{-1}$, which is relatively low compared with the world average of 1.45 t $ha^{-1}$ and the USA with 4.58 t $ha^{-1}$ (FAO 2019). Sorghum is relatively tolerant to drought and waterlogging (Curtis 1967; Mrema et al. 2017) and has a wide adaptation to varied soil conditions (Ajeigbe et al. 2018). These characteristics make sorghum the staple crop of choice in Africa's most drier regions to pursue food and income security. However, sorghum productivity in the region is low (≤1.0 t $ha^{-1}$) due to several production constraints.

Nigeria's bulk of sorghum production is derived from the Northern Guinea and Sudan/Sahel ecologies of Northern Nigeria. Sorghum is regarded as a traditional food crop in this agro-ecologies. In Northern Nigeria, sorghum is consumed in various forms, including as a *Tuwo* (a thick porridge made from dry-milled, nonfermented grain flour

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eaten with soup), *Kumu* or *Ogi* (flour paste made by wet milling after fermentation and cooked like a thin porridge), fermented pancakes and snack as roasted grain (Ega et al. 1992; NRC 1996). Occasionally, sorghum grain is fermented for malting and used in preparing local brewing products. Industrially, sorghum is predominantly used by companies producing beverages, breakfast cereals, and confectionery and a small percentage of the grain is also used as animal feed. The stalks are used to build shelters or fences and as livestock feed. Other future sorghum values are recognised in the country, including as raw materials for the biofuel industries (GAIN 2020).

The crop's economic potential has not been fully realised in Nigeria and sub-Saharan African (SSA) countries due to a number of production and productivity constraints. Lack of high yielding sorghum varieties, declining soil fertility, drought stress, *Striga* infestation, limited access to production inputs and credit facility and finance are among the factors accounting for the low sorghum production and product development (Sani et al. 2013). Sorghum research programmes in Nigeria have pioneered the development and release of varieties suited to some specific agro-ecological zones for industrial purposes (Ajeigbe et al. 2018). However, small-scale farmers, who account for over 90% of sorghum production, prefer to use their farm-saved seed of local unimproved varieties due to their intrinsic quality attributes such as good eating quality, adaptation, low insect pest attack and minimum production input requirements. However, the local landraces have low yield potential, long maturity, tall plant height, and are non-responsive to improved agronomic management practices (Ajeigbe et al. 2018). Climate change models show a high probability (>90%) of an increased in water scarcity and temperature, which will be detrimental to food production in many tropical areas, especially in West Africa (Battisti and Naylor 2009). Breeding drought-tolerant and climate-resilient sorghum varieties have the potential to offset the yield gap presented by climate change (Fedoroff et al. 2010). Ndjeunga et al. (2015) reported that only about 20% of the total sorghum production area is planted with improved cultivars in Nigeria. Mundia et al. (2019) opined that small-scale farmers in the region use landraces because of poor access to seed of improved cultivars and production technologies (Mundia et al. 2019) and a lack of financial support (Ajeigbe et al. 2018).

The participatory rural appraisal (PRA) is a multidisciplinary research tool and a form of market research to guide future crop production and breeding. The PRA method engages farmers and stakeholders to seek their insights and production challenges, which could help develop new technologies that will meet their needs and requirements. The ultimate aim of a plant breeder and agronomist is to develop a cultivar adopted by farmers and needed by the value chains. According to Morris (2002), farm-level decision to adopt a modern variety is influenced by a complex and highly variable set of factors such as the household's demographic characteristics, expected profitability, consumption preferences, availability and cost of the seed of the improved variety, among others. Langyintuo *et al.,* (2008) argued that farmers might not adopt an appropriate technology because of inadequate information and limited access. Farmer positive perception of a new technology is vital if it is to be adopted. Understanding farmer perceptions of the appropriateness of production technology characteristics can strengthen the focus of plant breeding and guide appropriate technology development and deployment strategies. PRA studies have been conducted in sorghum production areas in the eastern and central part of the northern region of Nigeria to assess farmer's perceptions of modern technologies and production constraints (Baiyegunhi and Fraser 2009; Okoro and Ujah 2009; Gourichon 2013; Sani et al. 2013; Ajeigbe et al. 2018). However, the production and productivity of the crop is yet to be expounded in Nigeria for economic gains. Therefore, the objective of this study was to present the current opportunities and constraints to sorghum production in Nigeria and make recommendations as a guide to new variety design and sustainable production.

## Materials and method

### *Description of the study area*

The study was conducted in the northern region of Nigeria in three agro-ecological zones, namely, the Sub-humid Southern Guinea Savannah, the Northern Guinea Savannah and the Sahel Savannah. The zones are known for their sorghum production and are characterised by semi-arid to arid agro-ecologies. The geographical positions of the study zones are shown in Figure 1, and their typical agro-ecological characteristics are summarised in Table 1. Northern Nigeria has two distinct meteorological seasons: the rainy season from May to September and the dry season from October to early May. The mean annual rainfall varies from 500 to 1,500 mm and temperatures between 17°C to 40°C. The maximum humidity may increase drastically during the middle of the rainy season to about 96% in August and drop sharply to about 10% during harmattan around December. Agriculture is the primary sector of the economy in the region. Crop production and

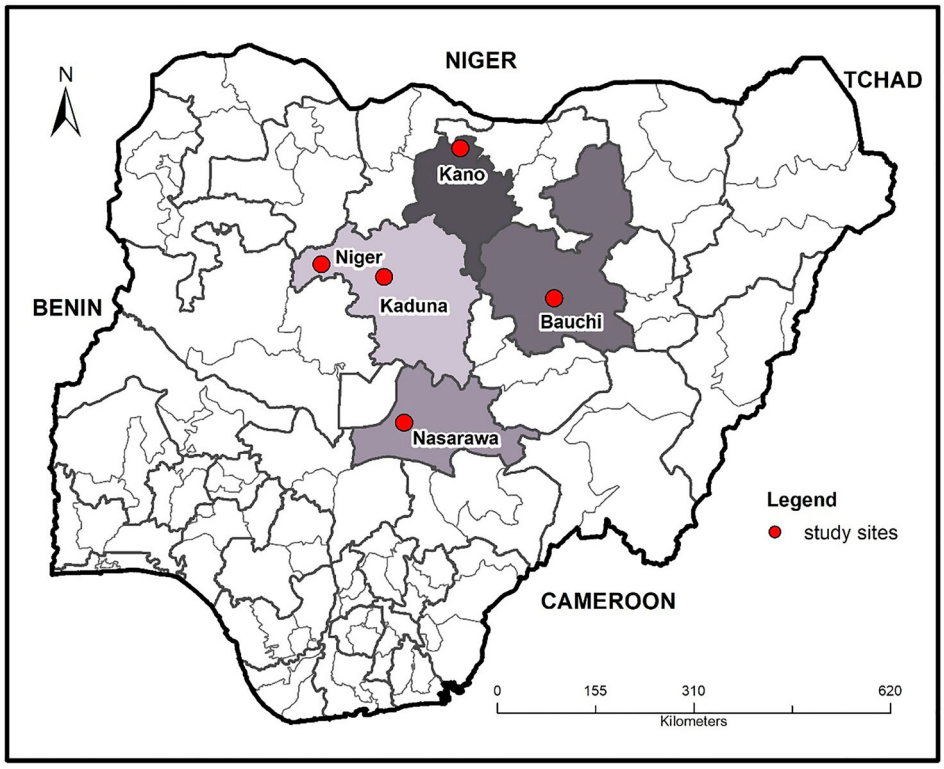


**Figure 1.** Map of Nigeria showing the study zones

livestock rearing are the key activities for about 80% of the total population (NBS 2019).

### *Sampling procedure*

A multi-stage purposive sampling was used for the study based on the dominance of sorghum production and the occurrence of drought. The study was conducted in three agro-ecological zones in northern Nigeria (North-West, North-Central and North-East) selected based on the importance of sorghum production. Two states in each zone were sampled. In each state, two local government areas (LGAs) were sub-sampled. From each LGA five wards were selected. A ward is the smallest administrative unit in Nigeria. From each ward, one village known for experiencing recurrent droughts was purposely selected, and 25 farmers with the experience of sorghum production were selected in each village. The target wards and villages were chosen based on sorghum area coverage, production, consumption and prior information on the occurrences and severity of drought and *Striga* infestation with the assistance of the agriculture development project (ADP) officers. Overall, the survey was conducted in 10 LGAs selected from five states. A total of 250 farmers that cultivated sorghum during the 2018/19 cropping season participated in the study with ADP officers and two researchers (Socio-Economist and Plant Breeder) drawn from the Institute for Agricultural Research (IAR) Samaru, Nigeria. A further five focus groups were established with 145 farmers for focus group discussions (FGDs). Each focus group had between 20 and 30 farmers selected by local leaders and ADP officers. Participants for FGDs were sampled based on their experience in sorghum production and gender balance.

**Table 1.** Description of the study locations for the participatory rural appraisal conducted in Northern Nigeria in 2018/2019

| Zone | State | Agro-ecology | Latitude | Longitude | Altitude (masl) |
|---|---|---|---|---|---|
| *North-West* | Kano | Sahel Savannah | $12^0$ 26′ N | $8^0$ 30′ E | 488 |
| | Kaduna | Sub-humid Southern Guinea Savannah | $10^0$ 36′ N | $07^0$ 25′ E | 250 |
| *North-Central* | Nasarawa | Southern Guinea Savannah | $8^0$ 32′ N | $07^0$ 42′ E | 600 |
| | Niger | Southern Guinea Savannah | $10^0$ 47′ N | $06^0$ 32′ E | 243 |
| *North-East* | Bauchi | Sahel Savannah | $10^0$ 18′ N | $09^0$ 50′ E | 616 |

masl = meters above sea level

### Data collection

Primary data were collected through a semi-structured questionnaire interview and FGDs. Demography, socio-economic characteristics, sorghum production constraints, sorghum production inputs, types of crops grown, attributes of farmers' most preferred sorghum variety and trait preferences were recorded.

### Data analysis

The data collected were subjected to statistical analysis using the cross-tabulation procedure to determine the relationships among study zones and assessed variables. Descriptive statistics, percentages, χ2 values and Kruskal–Wallis test (H-test) were carried out to ascertain the existence of significant differences in the socio-economic characteristics of sampled sorghum farmers. Farmers perceived production constraints to sorghum production were subjected to rank analysis using Kendall's coefficient of concordance ($W$). Kendall's coefficient of concordance ($W$) was adopted to measure agreement among several (m) quantitative or semiquantitative variables after assessing a set of $n$ objects of interest. In this study, the variables are farmers, assessing the perceived sorghum production constraints. The individual respondent was also entitled to give their constraint ranking, from less important to the most important constraint. The Kendall's concordance coefficient (W) is given as:

$$W = 12\left|\frac{\sum T^2 - (\sum T)^2}{m^2(n^2 - 1)}\right| \quad (1)$$

Where: $T$ is the sum of ranks for each variable,

$m$ is the number of ranks and,

$N$ is the number of constraints (variables) being ranked

The value of the W ranges between 0 and 1, 1 representing perfect concordance between the farmers and 0 illustrating strong disagreement among the farmers in ranking the perceived production constraints. Data were subjected to analyses using IBM Statistical Package for Social Sciences (SPSS)−20 (SPSS 2020).

## Result

### Socio-economic description of sampled households

The Kruskal–Wallis test for socio-economic characteristics of sampled sorghum farmers in the study areas is shown in Table 2. The results revealed a significant difference ($p < 0.05$) among zones for all variables assessed except for the level of education. Results from the interviewed respondents showed that 80.0% of the interviewed farmers ($p < 0.0001$, $\chi2 = 17.294$) were males and 20.0% were females in the three surveyed zones, which implied that men still play dominant roles in sorghum production and related enterprises in the study area. Few female farmers participated in this survey except in the North-West, which had 35.0% female respondent farmers. In comparison, the North-East Zone had the lowest percentage (6.0%) of interviewed female farmers (Table 2). Among the respondent farmers, 75.7% were between 21 and 45 years of age ($p < 0.0001$, $\chi2 = 54.982$), indicating that middle-aged adults dominated sorghum production. Sorghum producing farmers' mean age was 34, 37, and 38 years for North-Central, North-West, and North-East zones, in that order. About 17.0% of respondents aged over 45 years accessed their long-term knowledge of sorghum diversity and sorghum cultivation trends in Northern Nigeria. About 7.3% of the respondents aged between 12–20 years old were categorised as young adults. In the surveyed areas, it is customary for young adults and children to help on sorghum farming. The focus group discussion revealed that children aged 12–15 years engage in farm work such as land preparation for sorghum planting (May), sowing of sorghum seeds (early June), and helping to deliver cooked food to the farm for the family members and or labourers engaged in farming activities. A high proportion (73.3%) of the respondents had formal education among the surveyed zones, and secondary (Grade 6–12) level of education had the highest proportion of literate farmers with 31.3%. Most of the respondent farmers (26.3%) attended primary school (Grade 1–6 education), and 31.3% attended secondary education (Grade 6–12). In comparison, the least proportion was recorded or tertiary level of education (above Grade 12) at 15.5%. Only about 26.3% of respondents had no formal education (Table 2). Most respondent farmers in North Central and North-West zones had education levels ranging from Grade 1–12. North-West recorded the highest proportion of individuals completing primary (30.0%) and secondary (40.0%) level of education while North-East recorded the highest proportion of farmers who had no formal education (34.0%). Education is vital to the improvement of agricultural management and productivity and the creation of rural prosperity. Farmers with formal education can easily make decisions about their farms and adopt innovative agricultural production methods.

The focus group discussion revealed that farmers with formal education have a better understanding and knowledge, while non-formal education gives the farmer hands-on training and better farming methods. In all the surveyed zones, most of the interviewed

**Table 2.** Kruskal-Wallis test for socioeconomic characteristics of sampled sorghum farmers in the study zones of Northern Nigeria

| | North-Central | | North- East | | North-West | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variables | Freq. | % | Freq. | % | Freq. | % | DF | χ2 value | *P*-value | %Mean |
| **Sex of the respondent** | | | | | | | | | | |
| Male | 81.0 | 81.0 | 47.0 | 94.0 | 65.0 | 65.0 | 2 | 17.294 | 0.0001 | 80.0 |
| Female | 19.0 | 19.0 | 3.0 | 6.0 | 35.0 | 35.0 | | | | 20.0 |
| **Age of farmer (years)** | | | | | | | | | | |
| 12–20 | 0.0 | 0.0 | 0.0 | 0.0 | 22.0 | 22.0 | 4 | 54.982 | 0.0001 | 7.3 |
| 21–45 | 67.0 | 67.0 | 45.0 | 90.0 | 70.0 | 70.0 | | | | 75.7 |
| >45 | 33.0 | 33.0 | 5.0 | 10.0 | 8.0 | 8.0 | | | | 17.0 |
| **Level of Education** | | | | | | | | | | |
| Non-formal | 30.0 | 30.0 | 17.0 | 34.0 | 16.0 | 16.0 | 6 | 11.893 | 0.0640 | 26.7 |
| Primary (Grade 1–6) | 23.0 | 23.0 | 13.0 | 26.0 | 30.0 | 30.0 | | | | 26.3 |
| Secondary (Grade 6-12) | 34.0 | 34.0 | 10.0 | 20.0 | 40.0 | 40.0 | | | | 31.3 |
| Tertiary (> Grade 12) | 13.0 | 13.0 | 10.0 | 20.0 | 14.0 | 14.0 | | | | 15.7 |
| **Household size (persons)** | | | | | | | | | | |
| 1–5 | 28.0 | 28.0 | 23.0 | 46.0 | 83.0 | 83.0 | 4 | 68.509 | 0.0001 | 52.3 |
| 6–10 | 49.0 | 49.0 | 22.0 | 44.0 | 17.0 | 17.0 | | | | 36.7 |
| >10 | 23.0 | 23.0 | 5.0 | 10.0 | 0.0 | 0.0 | | | | 11.0 |
| **Land size (hectares)** | | | | | | | | | | |
| 01.–5 | 68.0 | 68.0 | 45.0 | 90.0 | 93.0 | 93.0 | 4 | 47.418 | 0.0001 | 83.7 |
| 5.1-10 | 32.0 | 32.0 | 1.0 | 2.0 | 7.0 | 7.0 | | | | 13.7 |
| >10 | 0.0 | 0.0 | 4.0 | 8.0 | 0.0 | 0.0 | | | | 2.7 |
| **Farmer means of livelihood** | | | | | | | | | | |
| Crop and livestock farming | 63.0 | 63.0 | 31.0 | 62.0 | 81.0 | 81.0 | 6 | 13.636 | 0.0340 | 68.7 |
| Self-employed (artisans) | 27.0 | 27.0 | 11.0 | 22.0 | 12.0 | 12.0 | | | | 20.3 |
| Employee (labourers) | 10.- | 10.0 | 8.0 | 16.0 | 6.0 | 6.0 | | | | 10.7 |
| Unemployed | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 1.0 | | | | 0.3 |

DF = degrees of freedom, $\chi^2$ = Chi-square value, Freq. = Frequency, % = Percent

sorghum growers had family sizes of less than 10. In North-West, 83.0% of the interviewed farmers had a family size of ≤5 individuals, whereas, in the North Central, 49.0% of the respondents had a family size of 5–10 individuals. Only a few interviewees had a family size greater than 10, with the most (23.0%) being in the North Central zone. Focus group discussions revealed that family size has a vital role in farm labour in the three surveyed zones' rural farming systems. The household heads are primarily senior citizens and weak. Therefore, they may not have the energy to meet the labour-intensive requirements of sorghum production, and in most cases, they do not have the finance to hire workers. The young males in the household often help with field activities. The female members are majorly responsible for housework, including nurturing the children.

The focus group discussion further revealed that women actively participate in sorghum planting and harvesting activities. There was a significant difference ($p < 0.0001$, $\chi2 = 47.418$) in the farm sizes of sorghum farmers among the three zones (Table 2). About 52.3% of respondents owned a farm of <5 hectares, whereas 36.7% owned a farm ranging from 5 to 10 hectares, and 11.0% owned a farm of >10 hectares. The respondents' farm size was skewed mainly to the small-scale landholding (0.1–5.0 hectares) in the study area, which implies that sorghum production in the study area falls within a small-scale (1.0–5.9 ha) farm holding enterprise. The PRA further revealed a statistically significant difference ($p < 0.0001$, $\chi2 = 13.636$) for means of livelihood for respondents. From the results, most of the respondents are engaged in farming as a means of livelihood across the study regions, with an average of 68.0%. Apart from agriculture, about 20.3% of the respondents reported were self-employed, owning a business in their community, such as buying and selling farm inputs and foodstuffs. A smaller proportion of the respondents (10.7%) work on bigger farms in their community and the neighbouring areas.

## *Sorghum production inputs*

Production inputs such as seed, inorganic fertilisers and crop protection chemicals are imperative for increasing agricultural productivity. Results revealed a non-significant difference ($p > 0.05$, $\chi2 = 4.442$) difference among zones for the type of sorghum seed use by respondents (Table 3). The majority of the farmers (74.4%) reported using low yielding local landraces that have been developed through mass selection and saved from the previous harvest. The farmers have been using farm-saved seeds for several generations, often inheriting from their parents or sourced from neighbours or family members. Only 28.0%, 34.0%, 19.0% of the respondents in North-Central, North-East, and North-West, respectively, used seeds of improved varieties bought from seed companies or received from research institutes. Results on the type of fertilisers used by respondents revealed a significant difference ($P = 0.001$; $\chi2 =$

**Table 3.** Sorghum production inputs used by respondent farmers in three selected zones in Northern Nigeria (percentage)

| Variables | North-Central | North- East | North-West | DF | χ2 value | *P*-value | %Mean |
|---|---|---|---|---|---|---|---|
| **Seed use** | | | | | | | |
| Modern cultivar | 28.0 | 34.0 | 19.0 | 2 | 4.442 | 0.109 | 27.0 |
| Farm saved | 72.0 | 66.0 | 81.0 | | | | 73.0 |
| **Type of fertiliser** | | | | | | | |
| None | 18.0 | 4.0 | 12.0 | 6 | 38.716 | 0.0001 | 11.3 |
| Organic (farmyard manure) | 3.0 | 16.0 | 8.0 | | | | 9.0 |
| Inorganic (NPK, Urea) | 51.0 | 22.0 | 60.0 | | | | 44.3 |
| Combination | 28.0 | 58.0 | 20.0 | | | | 35.3 |
| **Use of crop protection chemical** | | | | | | | |
| No | 37.0 | 22.0 | 29.0 | 2 | 3.772 | 0.152 | 29.3 |
| Yes | 63.0 | 78.0 | 71.0 | | | | 70.7 |

DF = degree of freedom, *** represents 0.1% significance level, $\chi^2$ = Chi-square value

38.716). Use of inorganic fertiliser (e.g. compound fertiliser such as NPK 20:10:10) was the highest (44.3%) among the farmers, followed by the combination of inorganic and organic fertiliser (e.g. NPK 20:10:10 and farmyard manure) (35.3%) among respondents. Farmers apply farmyard manure during land preparation, while a combination of NPK and Urea fertilisers are applied before or at flowering. Only about 11.3% of the respondents reported not applying fertilisers for sorghum production. Factors such as the high cost of inorganic fertilisers, lack of low yield response of landraces to fertiliser application and lack of knowledge on the recommended fertiliser rate have limited the use of inorganic fertilisers in the study areas. The use of crop protection chemicals for the control of weeds (e.g. glyphosate, a non-selective systemic herbicide), insect pests (Karate 5EC; a broad-spectrum insecticide), and diseases (Mancozeb, a broad-spectrum fungicide) was higher among the respondents (70.7%) across the study areas during the sorghum production season (Table 3).

## *Types of crops cultivated in the study areas*

Table 4 summarises other crops grown in the surveyed zones. The crops listed by the respondents included maize, soybean, rice, cowpea, and millet in decreasing order of importance. The *Chi-square* test revealed a significant difference ($\chi^2$ 8.716; $P = 0.0001$) in the proportions of crops grown among the respondents in the three study areas. More respondent farmers across the study regions cultivate maize (20.7%) and millet (16.3%). The cultivation of cereals (such as maize) and legumes (cowpea) affords the farmers opportunity to diversify the family's dietary intake and sell excess produce in the local markets to earn cash. Focus group discussions revealed that extra produce is sold at the end of the farming season, usually around December–February, to buy clothes, settle debts, conduct house maintenance, and purchase farming implements such as hoes and cutlass. Other crops reportedly grown by the respondents included groundnut, yam, and sesame. The cultivation of sorghum and other cereals and pulses have been known since time immemorial in the study area.

The results from Table 4 further elucidated the degree of crop diversification among the respondents. The livelihood strategies in the study area tend to combine various ways of earning a living in addition to the primary production of crops. Such diversification serves a dual purpose of alternative income and job opportunities for the smallholder farmers in rural areas.

## *Farmer preferred sorghum varieties in Northern Nigeria*

The study also investigated farmers' preferred variety in Northern Nigeria using the local names, and the results are shown in Table 5. The Kruskal–Wallis test revealed a significant difference ($\chi^2 = 77.774$; $P = 0.001$) for farmer preferred sorghum variety among the study zones in Northern Nigeria. Farmers grow several sorghum varieties in any cropping season that match the growing conditions and their food preferences. Other factors that made the local landraces preferable to the respondents include low input requirement, drought resistance, *Striga* tolerance, low bird damage, and seed availability.

The majority of the farmers across the region preferred Kaura (37.4%) and Fara-fara (29.3%) varieties compared to all other varieties owing to compact panicles, bulging grains and adapted to the dry Sudan Savanna zone. The next farmer preferred variety is Guinea Corn (7.0%) due to its wide food and feed grain utilisation. The respondents reportedly cultivate different sorghum varieties such as Bagaje, Buhu Arha and others in both mono- and inter-cropping farming systems (Table 5). The most preferred sorghum varieties in Northern Nigeria have been Kaura and Fara-fara, which are well adapted to the region and cultivated for food.

**Table 4.** Other crops grown by sorghum farmers in a cropping season in Northern Nigeria

| | North-Central | | North-East | | North-West | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Crop* | Frequency | Percent | Frequency | Percent | Frequency | Percent | *DF* | $\chi^2$ *value* | *P-value* | *%Mean* |
| Cowpea | 18.0 | 14.8 | 14.0 | 16.1 | 30.0 | 12.7 | 12 | 22.945 | 0.028 | 14.5 |
| Maize | 25.0 | 20.5 | 14.0 | 16.1 | 60.0 | 25.4 | | | | 20.7 |
| Rice | 17.0 | 13.9 | 14.0 | 16.1 | 38.0 | 16.1 | | | | 15.4 |
| Soybean | 16.0 | 13.1 | 13.0 | 14.9 | 49.0 | 20.8 | | | | 16.3 |
| Millet | 23.0 | 18.9 | 16.0 | 18.4 | 19.0 | 8.1 | | | | 15.1 |
| Pepper | 15.0 | 12.3 | 7.0 | 8.0 | 13.0 | 5.5 | | | | 8.6 |
| Others | 8.0 | 6.6 | 9.0 | 10.3 | 27.0 | 11.4 | | | | 9.4 |

DF = degree of freedom, $\chi^2$ = Chi -square value

## Farmers preferred traits in a sorghum variety

Table 6 presents farmers' preferred traits in a sorghum variety in Northern Nigeria. The results showed significant differences ($\chi^2$ = 34.116; $P$ = 0.0001) among farmers' traits preferences across the three study zones. High yield was the most preferred trait (34.3%), followed by drought resistance (28.3%), *Striga* resistance (13.5%) and grain quality/taste (11.8%). In the North-West, about 54 respondents preferred high-yield variety followed by tolerance to drought (53 respondents) and good taste (24 respondents). *Striga* resistance was the second most preferred sorghum trait among respondents in North-Central after high yield. *Striga hermonthica* (also referred to as witchweed), a parasitic weed that attacks and significantly reduces sorghum yields, is the most predominant species in northern Nigeria. The results show that different regions have different trait preferences, suggesting the need to develop a specific variety to meet the farmers' needs across the zones.

## Farmer perceived constraints to sorghum production

Farmer perceived sorghum production constraints in Northern Nigeria are presented in Table 7. About 34.6% of the North-Central farmers indicated that lack of access to production inputs was the overriding constraint for sorghum production in the area, followed by *Striga* infestation (20.7%). Drought stress was the primary production constraint in the North-East (22.4%), followed by a lack of access to production inputs (21.1%). The main constraint to sorghum production in the North-West includes lack of access to production inputs (33.6%), drought stress (23.5%) and limited agricultural lands (13.4%). The least important constraint from the pooled sample was land availability (6.9%), suggesting that the farmers are yet contending with the land allocated for the sorghum production.

Respondent farmers were asked to rank the constraints listed in Tables 7 and 8 in order of importance.

**Table 5.** List of and proportion (%) of farmer preferred varieties of sorghum across the study zones in Northern Nigeria

| | North-Central | | North-East | | North-West | | *DF* | $\chi^2$ *value* | *P-value* | ***%Mean*** |
|---|---|---|---|---|---|---|---|---|---|---|
| Variety | Frequency | Percent | Frequency | Percent | Frequency | Percent | | | | |
| Kaura | 75.0 | 43.9 | 23.0 | 19.7 | 77.0 | 48.7 | 18 | 77.774 | 0.0001*** | 37.4 |
| Fara-fara | 46.0 | 26.9 | 39.0 | 33.3 | 44.0 | 27.8 | | | | 29.3 |
| Guinea Corn | 9.0 | 5.3.0 | 8.0 | 6.8 | 14.0 | 8.9 | | | | 7.0 |
| Bagaje | 1.0 | 0.6 | 10.0 | 8.5 | 4.0 | 2.5 | | | | 3.9 |
| Buhu arha | 0.0 | 0.0 | 10.0 | 8.5 | 8.0 | 5.1 | | | | 4.5 |
| Gajera | 7.0 | 4.1 | 4.0 | 3.4 | 0.0 | 0.0 | | | | 2.5 |
| Doguwa | 8.0 | 4.7 | 7.0 | 6 | 0.0 | 0.0 | | | | 3.6 |
| Yalel | 11.0 | 6.4 | 3.0 | 2.6 | 0.0 | 0.0 | | | | 3.0 |
| Mori | 5.0 | 2.9 | 1.0 | 0.9 | 5.0 | 3.2 | | | | 2.3 |
| Others | 9.0 | 5.3 | 12.0 | 10.3 | 6.0 | 3.8 | | | | 6.5 |

DF = degree of freedom, *** represents 0.1% significance level, $\chi^2$ = Chi value

**Table 6.** Farmers preferred traits in a sorghum variety across the study zones in Northern Nigeria

| | *North-Central* | | *North- East* | | *North-West* | | *DF* | $\chi^2$ value | *P-value* | ***%Mean*** |
|---|---|---|---|---|---|---|---|---|---|---|
| *Traits* | Frequency | Per cent | Frequency | Per cent | Frequency | Per cent | | | | |
| High yield | 46 | 31.7 | 27 | 35.1 | 54 | 36.2 | 10 | 34.116[a] | 0.0001*** | 34.3 |
| Grain quality/taste | 15 | 10.3 | 7 | 9.1 | 24 | 16.1 | | | | 11.8 |
| Early maturity | 4 | 2.8 | 4 | 5.2 | 4 | 2.7 | | | | 3.5 |
| Drought tolerance | 34 | 23.4 | 20 | 26.0 | 53 | 35.6 | | | | 28.3 |
| *Striga* resistance | 35 | 24.1 | 10 | 13.0 | 5 | 3.4 | | | | 13.5 |
| Insect pest and disease resistance | 11 | 7.6 | 9 | 11.7 | 9 | 6.0 | | | | 8.4 |

DF = degree of freedom, $\chi^2$ = Chi value

**Table 7.** Farmer perceived constraints to sorghum production across the study zones in Northern Nigeria (%)

| | North-Central | | North-East | | North-West | | DF | $\chi^2$ value | *P*-value | %Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| Constraints | Frequency | Percent | Frequency | Percent | Frequency | Percent | | | | |
| Lack of access to production inputs | 72 | 34.6 | 32 | 21.1 | 80 | 33.6 | 12 | 61.294[a] | 0.0001*** | 29.8 |
| Drought stress | 29 | 13.9 | 34 | 22.4 | 56 | 23.5 | | | | 19.9 |
| *Striga* infestation | 43 | 20.7 | 30 | 19.7 | 15 | 6.3 | | | | 15.6 |
| Bird damage | 25 | 12.0 | 26 | 17.1 | 17 | 7.1 | | | | 12.1 |
| Lack of access to credit | 19 | 9.1 | 10 | 6.6 | 19 | 8.0 | | | | 7.9 |
| Stem borer pest | 16 | 7.7 | 12 | 7.9 | 19 | 8.0 | | | | 7.9 |
| Limited agricultural lands | 4 | 1.9 | 8 | 5.3 | 32 | 13.4 | | | | 6.9 |

DF = degree of freedom, *** represents 0.1% significance level, $\chi^2$ = Chi value

The ranked data were subjected to Kendall's coefficient of concordance analysis to draw an overall rank on the farmer constraints to sorghum production, and the results are presented in Table 8. This was necessary to ascertain the level of agreement in the ranking of the perceived constraints.

The Kendall's coefficient of concordance (W) computed from the analysis were 0.203, 0.226, 0.163 and 0.309 for the pooled sample, North-Central, North-East North-West, respectively. The estimated value of W indicates about 22, 16, and 31% level of agreements among respondents from North-Central, North-East, and North-West, respectively, on the ranking of productions constraints. Thus, there was a relatively low level of agreement among the respondents. When pooled samples were considered, the agreement level was about 20%, reflecting a low level of agreement. This is depicted in the ranked constraints, which differs slightly from the percentage distribution of farmer perceived constraints. The most ranked constraint across all surveyed zones was confirmed to be a lack of production inputs. In addition, the pooled sample suggested drought stress was the second pressing constraint. The zone-specific concordance values showed that *Striga* infestation was the second most pressing constraint perceived by sorghum farmers across the study regions. Kendall's coefficient of concordance revealed limited agricultural lands was the least perceived constraint to sorghum production in the study zones.

## Discussion

### *Socioeconomic description of sampled households*

Sorghum cultivation is predominant in Northern Nigeria, where it is a traditional crop supporting the dietary needs of rural farmers for time immemorial. Sorghum provides food, fodder, raw material, and a source of cash income to rural farmers. However, farmers in the region realise low sorghum yields due to numerous biotic, abiotic, and socio-economic constraints that limit productivity. Hence, a participatory rural appraisal (PRA) was conducted to decipher the critical sorghum production constraints and farmer preferred traits in Northern Nigeria.

The Kruskal Wallis test revealed a significant difference among the North-Central, North-East and the North-West zones in most assessed socio-economic characteristics (Table 2). The search and adoption of modern farming technologies are relatively easy for educated farmers. The study revealed that most of the respondents had attained some level of formal education (Table 2), with 31.3% of the respondents having a grade 6–12 level of education. This is contrary to Fidelugwuowo (2021) findings, who reported that only 13.0% of respondents farmers had grade 6–12 levels of education. Other respondents with no formal education obtain extension service or farm information through the Hausa language, the predominant language in the

**Table 8.** Farmers perceived constraints to sorghum production and summary Kendall's coefficient of concordance across the study zones in Northern Nigeria

| | Pooled Sample | | North Central | | North East | | North West | |
|---|---|---|---|---|---|---|---|---|
| Constraints | Mean Rank | Position | Mean Rank | Position | Mean Rank | Position | Mean Rank | Position |
| Lack of access to production Inputs | 7.51 | 1st | 5.14 | 1st | 6.07 | 1st | 6.10 | 1st |
| Drought stress | 4.21 | 2nd | 3.74 | 4th | 4.38 | 3rd | 4.38 | 3rd |
| *Striga* infestation | 4.09 | 3rd | 4.71 | 2nd | 4.52 | 2nd | 4.52 | 2nd |
| Bird damage | 3.67 | 4th | 3.74 | 3rd | 3.70 | 4th | 3.71 | 4th |
| Lack of access to credit facilities | 3.55 | 5th | 3.53 | 5th | 3.42 | 5th | 3.42 | 7th |
| Stem borer pest | 3.44 | 6th | 3.40 | 6th | 3.41 | 6th | 3.42 | 5th |
| Limited agricultural lands | 3.41 | 7th | 3.36 | 7th | 3.40 | 7th | 3.42 | 6th |
| *Kendall's W*[a] | *0.203* | | *0.226* | | *0.163* | | *0.309* | |
| *DF* | *6* | | *6* | | *6* | | *6* | |
| *P-Value* | *0.0001* | | *0.0001* | | *0.0001* | | *0.0001* | |

DF = degree of freedom, *Kendall's W*[a] = Kendall's coefficient of concordance.

Northern region of Nigeria. Education helps farmers reduce transaction costs for accessing and interpreting data regarding alternative income-generating activities (Mrema et al. 2017) and agricultural subsidies (Okoro and Ujah 2009). Adewuyi and Okunmadewa (2001) pinpointed that education significantly impacts farmers' managerial and technical skills. The respondents' significant literacy level showed that farmers in the Northern region could adopt modern and innovative technologies for productive farming to ensure food security.

Gender (male and female household head) had significant impact on access to technical information, extension services, training, and farm inputs. The majority of the respondents in the study have a male household head (Table 2). This can be attributed to the land tenure system in Nigeria, which favours male ownership of land. The reason could also be attributed to the dominant role of patriarchy in West Africa which prompts the male to assume a leadership role in both men and women. However, in some parts of the North-West and North-Central region, female farmers play a significant role in sorghum farming activities on a par with male farmers. In almost all cases and zones, the female farmers are not the owners of the farm plot. They are allowed to run the farm because either their husbands are engaged in nonfarm labour, or the women are allocated the poorest part of the land where valuable crops like maize cannot thrive (Curran and Cook 2009; Jirgi et al. 2019). The result of restricted access to better land and other farm inputs is lower productivity on land farmed by women. The gender difference (20.0%) between male and female farmers present in the study agrees with the reported average gender difference (20–30%) across sub-Saharan African countries (Kilic et al. 2015; Mukasa and Salami 2015; Gebre et al. 2019). Age significantly influences farmers' decision-making process to adopt improved farming technologies and other production-related decisions. The significant difference (Table 2) among zones for household members' age among the respondents revealed that different age groups practice sorghum cultivation. The study further revealed that more than two-thirds (75.7%) of the sorghum farmers in Northern Nigeria were still within their productive age of 21 - 45 years (Table 2). This agrees with Jirgi et al. (2019) findings that the majority of sorghum farmers are within an active age group (20-45 years). The participation of young farmers in sorghum cultivation suggested a better future for crop production enterprise in Nigeria. The younger farmers will be more flexible to new ideas and risks; hence, they are expected to adopt innovations more readily than older farmers. This finding agrees to that of Adenegan et al. (2013), who reported that age significantly impacts farm and farmer productivity. However, Eboh et al. (2004) and Oyediran et al. (2017) reported an aged population among sorghum farmers due to the youth reluctance in crop farming. The gradual inflow of the younger entrepreneurial labour force into sorghum production may be attributed to the increased price and demand of sorghum and the government's renewed vigour to promote local production in recent times (FEWS NET 2020).

The study revealed that small farm holdings (0.1–5.0 hectares) dominate sorghum production in Northern Nigeria (83.7% respondents). The present finding agrees with Shaib et al. (1997) and Sabo et al. (2017), who reported that small farm holdings dominate Nigeria's agriculture accounting for about 81% of the total farm area and 95% of the agricultural output. The significant differences in farm sizes and the preponderance of small farm sizes in the study area implied that smallholder farmlands are highly fragmented. In the rural areas of Northern Nigeria, the majority of the farmers obtain their farmland through inheritance. The larger the household size, the more fragmented the land at the household head's demise. Small farms hinder large scale agricultural activity such as farm mechanisation and access to credit necessary to expand cultivation and invest in facilities such as irrigation. Therefore, it is imperative to implement land protection and consolidation policies that decrease the current fragmentation trend. Previous studies by Baiyegunhi and Fraser (2009) in Kaduna state, Sani et al. (2013) in Bauchi state and Oyediran et al. (2017) in Katsina state showed a similar preponderance of small-scale producers of sorghum in the respective states. Adama et al. (2016) reported that small-scale farmers are the backbone of Nigerian agriculture, implying that Nigeria's agricultural policy thrust should be centred around the smallholder farmers.

The household size enhances labour availability which can be used for different agricultural activities (Oyewole 2012). The average household size across the study region was about five persons (52.3%) implying a reasonable number of family labour to accomplish various farm operations. Sorghum in Nigeria is often produced by extended family members who are vertically (unmarried sons, married sons and their families) or horizontally (brothers and multiple wives) related to the family's patriarch. The older patriarch ensures the cultivation of large plots of land with the sole aim of meeting the staple food needs of the overall extended family (Thériault et al., 2017). The significance of household size in agriculture hinges on the availability of labour for farm production, the total area cultivated to

different crop enterprises, the amount of farm produce retained for domestic consumption, and the surplus for the marketplace (Olusayo et al. 2019). The primary occupation of the majority (68.7%) of the respondents is farming. This suggests that farming is the mainstay of the economy in the region. However, some respondents engage in non-farming activities such as retail marketing, artisanship, and transportation.

### Sorghum production inputs

Although sorghum requires little improved technologies to be a profitable crop, the effects of climate change and declining soil fertility in Northern Nigeria are changing that perception. The study revealed a significant difference among respondents on fertiliser use for sorghum production (Table 3). The majority of the respondents reportedly use organic (9.0%) and inorganic (44.3%) fertilisers and their combinations (35.3%) for sorghum production. These results agree with Omonona et al. (2019), who reported that over 50% of sorghum farmers in Nigeria use fertilisers during the cropping season. Inorganic fertilisers are officially subsidised in Nigeria for crop production. However, unlike maize and rice farmers, the subsidised fertilisers are not readily accessible by sorghum farmers, resulting in farmers across the regions augmenting the application of inorganic fertiliser with an organic type of fertiliser such as farmyard manure or compost. In addition, the farmers reported applying fertiliser below the recommended rate. Although sorghum seeds of imported variety are available in Nigeria, the respondents reportedly cultivate local landraces due to their intrinsic quality attributes such as eating quality, local adaptation, low pest attack and reduced production input demand. However, the currently introduced varieties lack the attributes needed by farmers. Also, poor extension services limit their availability in rural communities. This limited access to quality seeds of improved varieties, hindering the adoption of the available varieties. In addition, there is a lack of interest by seed companies in marketing the seeds of sorghum. Also, sorghum is excluded in the government's low-interest Anchor Borrowers Program (ABP), limiting farmers access to inputs. These combined negatively affected sorghum production and productivity in Nigeria (Gourichon 2013; Mundia et al. 2019; GAIN 2020).

### Crops cultivated by the respondents

Farming is the economic mainstay of the Sudan savanna, Northern Guinea savanna, Southern Guinea savanna, and the Jos Plateau of Northern Nigeria. In 2019, sorghum was grown on an estimated 6 million hectares of land (Shahbandeh 2020). Sorghum is produced as a mixed crop with maize, millet, and other leguminous crops such as cowpea, groundnut, and soybean (Shahbandeh 2020). The low input requirement allows sorghum to fit in new and emerging farming systems as farmers grow more profitable crops like maize and soybean. Farmers in the North-West intercrop sorghum late in the season with vegetables such as tomatoes and onions, while North-Central farmers intercrop with tuber crops such as yam. Intercropping is rewarding to the farmers to maximise output from their small landholdings and utilise legumes' biological nitrogen fixation attributes to improve soil fertility or the high yield of cereals such as maize for the market.

### Farmer preferred sorghum varieties and traits

The majority of sorghum-growing areas in Nigeria are occupied by traditional landrace varieties such as Kaura, Fara-fara and Guinea corn. The landraces are indigenous to the localities and are grown extensively as rainfed crops in Northern Nigeria (Mundia et al. 2019). Farmers grow more than one variety of sorghum in a field; for instance, in Zaria, Nigeria, more than 100 local landraces have been identified to be cultivated by local farmers (NRC 1996). Selected varieties were mainly derived from local landraces through mass selection (such as Fara-fara and Kaura). Sometimes, the landraces are improved by introgressions from exotic lines obtained from international organisations such as ICRISAT. Sorghum genetic improvement is conducted by National Agricultural Research Systems (NARS) in Nigeria, such as the Institute for Agricultural Research (IAR) Samaru. The Kruskal Wallis test revealed a significant difference for most preferred sorghum varieties among the respondents (Table 5). Kaura (37.4%) and Fara-Fara (29.3%) were the dominant varieties preferred across all zones, followed by the Guinea race (7.0%). The Kaura varieties have large grains with yellow endosperm that are derived from durra-caudatum races. The Fara-fara variety is an early-maturing, large-seeded, white-grained sorghum derived from guinea-caudatum races (Curtis 1967). In addition, the Kaura and Fara-fara sorghums varieties possess higher grain quality, produce acceptable *kamu* and *kunu* traditional foods in Nigeria, and high market demand in Nigeria. These characteristics have made the local landraces the most preferred varieties over the modern and introduced types.

The traits of interest to farmers are an important attribute that forms breeding and socio-economics research premises. The results from the study revealed high yield as the most essential farmer preferred trait across all

regions (Table 6). The findings revealed farmers' openness to accepting high yielding and improved cultivars with other traits of interest. Tolerance to drought and *Striga* are traits of interest to sorghum farmers in Northern Nigeria (Table 6). Sorghum is cultivated under rainfed conditions in Northern Nigeria, where drought and *Striga* infestation cause severe economic damage to sorghum production (Reddy et al. 2009). High yielding cultivars that mature early and with drought and *Striga* tolerance attributes can be developed through breeding to release novel varieties for production in low/erratic rainfall environments like Northern Nigeria.

### *Farmer perceived constraints to sorghum production*

The results revealed that limited access to production inputs such as improved seed, fertilisers, and crop protection chemicals are the most important sorghum production problems perceived by the farmers in the study area (Table 7). This is followed by drought stress, *Striga* infestation and bird damage. Kendall's coefficient of concordance revealed a low agreement between respondents who ranked the perceived production constraints in sorghum production. The farmers ranked production inputs as key perceived constraints to sorghum production. Limited access to production inputs ranked the highest among the perceived constraints because smallholder farmers seldom have access to quality seeds of improved varieties, fertilisers, and crop protection chemicals. Limited access to production inputs contributed significantly to sorghum's low production and productivity in Nigeria (Philip et al. 2009; Mundia et al. 2019). These findings agree with reports from Reddy et al. (2009) on sorghum production constraints in Africa.

Contrary to our results, a study conducted by Mengistu et al. (2019) in Ethiopia ranked anthracnose disease and birds attack as the most important sorghum production constraints. Nigeria launched the Agricultural Transformation Agenda (ATA) program in 2009, which had played an important role in improving farmers' access to sorghum production input in selected farming communities in Northern Nigeria (Ajeigbe et al. 2017). An appraisal of the ATA program revealed that improved production technologies in farmers' fields increased yield on average by 46% across the study areas. However, the program's success is yet to be upscaled to reach all sorghum farmers in Nigeria. Therefore, the present findings underscore the need for a systematic approach to improving farmers' adoption of new production technologies.

Sorghum production is an essential component of food security and economic empowerment for smallholder farmers in Nigeria. The study assessed farmer preferences and identified key production constraints that farmers encounter in sorghum farming in three agro-ecological zones of Nigeria. The results indicated that sorghum farmers in the study zones are primarily male, educated, young and possess small landholdings. Farmers in the study area grow a wide array of local landraces to meet different purposes, and the most important landrace varieties are Kaura and Fara-fara. The different varieties grown serve many purposes, such as food, feed, and raw material for malting and brewing. The most farmer-preferred traits of sorghum across the three study zones are high yield, tolerance to drought and *Striga*. Farmers will likely adopt improved cultivars with attributes such as early maturity, tolerance to drought, and *Striga* and good taste to ensure reliable and stable yield under erratic rainfall prevalent in the region. Sorghum production in the study area is constrained by several factors whose importance varies across the regions. The most critical constraints are limited production inputs, drought stress, *Striga* infestation, and bird damage. Therefore, to sustain sorghum production, there is a need to breed and release high yielding, early maturing, drought and *Striga*-tolerant cultivars with good food quality traits for production in semi-arid regions of Northern Nigeria.

The study highlighted the challenges smallholder farmers encounter in sorghum production in Nigeria. Therefore, based on the survey findings, it is recommended that the sorghum seed business be supported by incentives and subsidies to rural farmers in remote areas. Nigerian policymakers can address the identified production constraints of limited access to production inputs by making sorghum a focus crop in the anchor borrowers' program (ABP), which provides farmers with a low-interest loan for purchasing production inputs.

Sorghum outreach programs that disseminate information on improved varieties and new technologies need to be supported at the grassroots levels to ensure the adoption of high yielding and improved cultivars. Production constraints such as lack of high yielding cultivars, drought stress and *Striga* infestation can be addressed by breeding programs. Therefore, it is recommended that the sorghum breeding program consider integrating the farmer-preferred traits and the highlighted constraints during the development of improved sorghum varieties suitable for production in the semi-arid regions.

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No potential conflict of interest was reported by the author(s).

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## Author contributions

***Shimelis, Baloua Nebie, and Chris O. Ojiewo*** conceptualised the research, sourced funding and provided supervision. Questionnaire design, development and administration was performed by Hussein Shimelis and Muhammad Ahmad Yahaya. Statistical analyses were performed by Muhammad Ahmad Yahaya and Gideon Danso-Abbeam. Muhammad Ahmad Yahaya drafted the original manuscript. Hussein Shimelis, Baloua Nebie, and Chris O. Ojiewo critically revised the manuscript. All authors read and approved the final manuscript.

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