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Sorghum Production in Northern Namibia: Farmers' Perceived Constraints and Trait Preferences

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Abstract: Sorghum (*Sorghum bicolor* [L.] Moench) is a valuable crop in the dry regions of the world, including Namibia. Due to the intensity and recurrence of drought and heat stress in the traditional sorghum growing areas, there is a need to breed and deploy new generation farmer-preferred and climate-smart cultivars to serve the diverse value chains. Therefore, the objectives of this study were to assess the present state of sorghum production in northern Namibia and document farmers' perceived production constraints and trait preferences in new varieties to guide drought-tolerance breeding. A survey was conducted using a participatory rural appraisal in the following six selected sorghum-growing constituencies in Namibia: Kapako and Mpungu (Kavango West Region), Eenhana and Endola (Ohangwena Region), and Katima Mulilo Rural and Kongola (Zambezi Region). Data were collected using a structured questionnaire involving 198 farmers in 14 sampled villages across the regions. Results revealed variable trends in sorghum production among respondent farmers when disaggregated by gender, age, number of households, education level, cropping systems, types of varieties grown, and perceived production constraints. An equal proportion of male and female respondent farmers cultivate sorghum, suggesting the value of the crop to both genders in Namibia. Most respondent farmers (63.6%) were in productive age groups of <40 years old. In the study areas, low-yielding landrace varieties, namely Ekoko, Okambete, Makonga, Kamburo, Nkutji, Katoma, Fuba, Dommy, Kawumbe, and Okatombo, were widely cultivated, and most of the farmers did not use chemical fertilizers to cultivate sorghum. Farmers' perceived sorghum production constraints in the study areas included recurrent drought, declining soil fertility, insect pest damage, high cost of production inputs, unavailability of improved seed, lack of alternative improved varieties with farmers' preferred traits, lack of organic manure, limited access to market and limited extension service. The key farmers' preferred traits in a new sorghum variety included high grain yield, early maturity, and tolerance to drought, in the field and storage insect pests. The study recommends genetic improvement and new variety deployment of sorghum with the described farmers-preferred traits to increase the sustainable production of the crop in Namibia.

Keywords: farmer-preferred traits; Namibia; participatory rural appraisal; sorghum breeding; production challenges

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1. Introduction

Sorghum (*Sorghum bicolor* [L.] Moench) is a valuable crop in the arid and semi-arid regions of the world. Sorghum is the 5th most-produced cereal crop, following maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), and barley (*Hordeum vulgare* L.) globally [1]. It is a staple food crop in Africa and Asia and a vital source of industrial raw material to manufacture feed, bio-ethanol, and syrup [2,3]. Sorghum grain is rich in macro and micro-nutrients and antioxidants [4–7]. Sorghum grain is processed to prepare various food products (e.g., porridge, bread, snacks, biscuit, and grain flakes) [8–10]. The grain is consumed as boiled, steamed, popped, or roasted [11]. Furthermore, malting sorghum grain is used for brewing traditional household drinks and in the African beer industry [12–14]. Globally, sorghum is produced on estimated agricultural land of 44.6 million ha producing 68.3 million tons of grain per year [1]. The lead sorghum producer countries in Sub-Sahara Africa are Nigeria, Ethiopia, Sudan, Niger, and Burkina Faso, producing 6.4, 5.1, 2.1, 1.8, and 1.8 million tons/year, respectively [1].

In Namibia, sorghum is the second most cultivated cereal crop after pearl millet (*Pennisetum glaucum* [L.]), and both are produced under rainfed agricultural system [1]. It is widely cultivated in the northern regions of the country, such as in Zambezi, Kavango East, Kavango West, Otjozondjupa, Oshikoto, Oshana, Ohangwena, Omusati, and Kunene regions [15–17]. In the country, sorghum is mainly cultivated by smallholder farmers for food and cash income [16,18]. An estimated agricultural land of 17,800 ha is devoted to sorghum production providing grain outputs of 3300 tons/year in 2020 [1]. The mean national yield of sorghum in Namibia is below 0.3 ton/ha, which is lower than the mean yield of 1 ton/ha for Africa, 4 tons/ha for South Africa [1], and the mean yield potential of the crop of 9.3 tons/ha [19].

The economic value of sorghum is not realized in Namibia [2]. The main reasons for low sorghum productivity in the country are yet to be systematically studied and documented to guide research and development of the crop. Elsewhere, the major biotic stresses for sorghum production are bird damage, parasitic weeds and pre-harvest insect pests (e.g., fall armyworm, aphid, and armoured cricket), and diseases (e.g., anthracnose, downy mildew, and head smut) [20–22]. The major abiotic stresses of the crop are drought, extreme temperatures, and poor soil fertility [23,24]. In Namibia, the low sorghum productivity is partly attributable to the continued use of traditional cultivars that are low yielding and susceptible to drought and heat stress conditions. Only two sorghum varieties (Macia and Red Sorghum) introduced in 1999 are widely grown in Namibia.

Namibia is a water scarce and arid to semi-arid country. The intensity and recurrence of drought and heat stress are the major constraints to potential sorghum production in the drier and traditional growing regions of the world, including Namibia [15,17]. Therefore, there is a need for a new variety design and deployment with farmer-preferred traits and tolerance to pre and post-flowering drought stresses to offset the yield gap resulting from abiotic and biotic stresses [25–27]. Sorghum research and development should be guided by the needs and preferences of the farmers and value chains which is to be ascertained through market research.

The participatory rural appraisal (PRA) is an effective multidisciplinary tool and one form of market research. It helps to assess and document sorghum production constraints and farmers' perceived trait preferences in new varieties for demand-led breeding and product development. Incorporation of farmers' desirable traits is essential for the wide adoption of climate-smart and drought-tolerant cultivars to serve the diverse value chains of sorghum. PRA tools have been applied by various workers and made several recommendations to define breeding goals [21,24,28,29]. Sorghum research and development is in its infancy in Namibia. No recent PRA studies have documented the major production constraints and farmer-trait preferences as a guide for demand-led sorghum breeding programs. Therefore, the objectives of this study were to assess the present state of sorghum production in northern Namibia and document farmers' perceived production constraints and trait preferences in new varieties for drought-tolerance breeding.

2. Materials and Methods

2.1. Description of the Study Areas

This study was conducted in six selected constituencies sampled from three regions in northern Namibia, namely Kapako and Mpungu (Kavango West Region), Eenhana and Endola (Ohangwena Region), and Katima Mulilo Rural and Kongola (Zambezi Region) (Figure 1). In the study areas, sorghum is popularly intercropped with pearl millet, groundnut (*Arachis hypogaea* L.), Bambara groundnut (*Vigna subterranea* [L.] Verdc), roselle (*Hibiscus sabdariffa* L.), watermelon (*Citrullus lanatus* L.), and various cucurbit species [15,30]. The study areas have one cropping season from October to April following the main rain. The total annual rainfall ranges from 300 mm to 700 mm, with minimum and maximum temperatures of 17 °C and 35 °C, respectively [31]. Mixed-farming systems of crop production and livestock husbandry are the dominant form of agriculture. Agriculture is the primary economic sector and source of income and livelihood in the study areas [16].

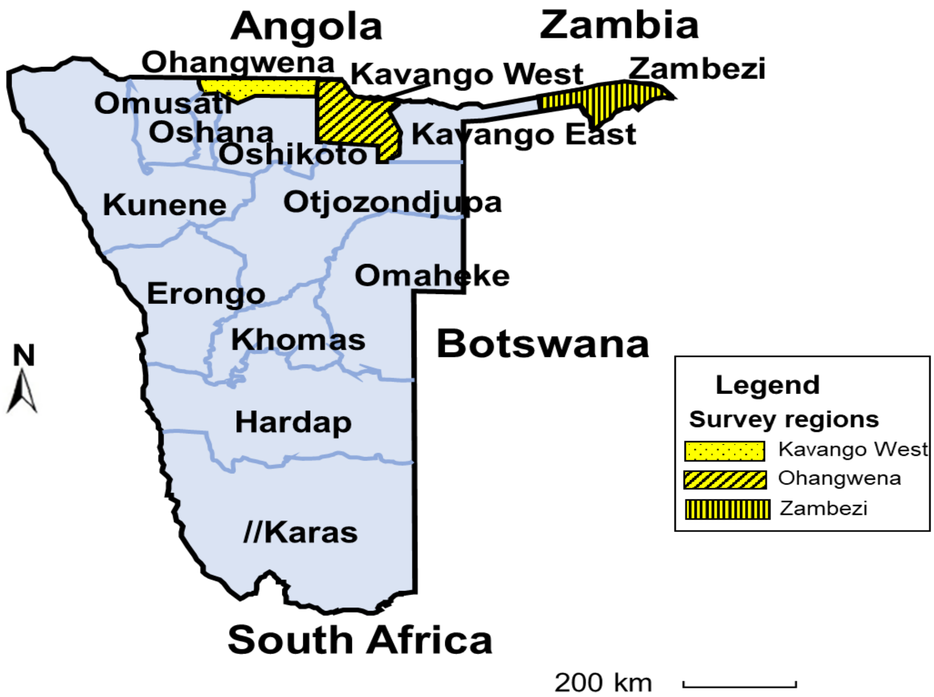

Figure 1. Map of Namibia showing the study regions highlighted in yellow.

2.2. Sampling Procedures

Multistage purposive sampling was used to collect data in the selected constituencies during the 2020/21 cropping season (Table 1). In Namibia, a constituency is the smallest administrative unit consisting of 3600 to 60,000 people. Rural constituencies consist of villages with 600 to 2000 inhabitants with six to ten people per household [32]. A total of 198 sorghum farming households were randomly sampled in the 14 villages across six constituencies in three regions. The extension officials in the sampled constituencies assisted with the selection of villages. The officials are employees of the Ministry of Agriculture, Water and Land Reform (MAWLR) stationed at the Agricultural Development Centres (ADC) of the Directorate of Agricultural Production, Extension and Engineering Services (DAPEES). The main criterion for village selection was based on sorghum area coverage and production. The extension officials from DAPEES and the Directorate of Agricultural Research and Development (DARD) facilitated group discussions with farmers and seed growers to collect the data on the households' general socio-economic status, sorghum production constraints, and varietal preferences. Household heads or close relatives were respondent farmers in the interview.

Table 1. Description of the three regions and six constituencies in northern Namibia selected for the study.

Region	Constituency	Village	Number of Farmers Sampled	Gender		Ecological Region	Latitude	Longitude	Altitude (masl)
				Male	Female				
Kavango West	Kapako	Sinzogoro	10	2	8	Zambezian Baikiaea woodlands and Kalahari acacia–baikiaea woodlands	17°53′09.8″ S	19°29′42.5″ E	1120
		Mukundu	10	4	6		17°56′57.7″ S	19°32′59.7″ E	
	Mpungu	Mpungu	10	1	9		17°40′26.9″ S	18°14′38.1″ E	
		Silikunga	10	4	6		17°41′00.6″ S	18°18′54.8″ E	
Ohangwena	Eenhana	Eenhana	20	13	7	Angolan Mopane woodlands and Zambezian Baikiaea woodlands	17°29′58.9″ S	16°19′11.0″ E	1100
		Elundu	15	10	5		17°28′58.2″ S	16°25′05.3″ E	
		Ohaihana	15	7	8		17°27′20.6″ S	16°22′44.5″ E	
	Endola	Onepandaulo	15	8	7		17°39′16.7″ S	15°40′40.4″ E	
		Endola	20	9	11		17°35′30.2″ S	15°42′48.1″ E	
		Oshapwa	15	6	9		17°38′28.0″ S	15°39′38.6″ E	
Zambezi	Katima	Mubiza	18	10	8	Zambezian and mopane woodlands, and Zambezian Baikiaea woodlands	17°30′40.9″ S	24°19′20.9″ E	950
		Kwena	10	7	3		17°48′25.0″ S	24°23′04.8″ E	
	Kongola	Kongola	15	9	6		17°45′00.9″ S	23°25′52.6″ E	
		Sachona	15	9	6		17°46′45.3″ S	23°25′02.6″ E	
	Total		198	99	99				

masl = metres above sea level.

2.3. Data Collection and Analysis

Data were collected using a semi-structured questionnaire, transect walk in sorghum fields, and group discussion. Data collection through structured interviews included socio-demographic description (age, gender, number of households, and education level), sorghum production, cropping systems, and constraints. Transect walk in sorghum fields and group discussion were used to identify field insect pests and diseases, current varieties grown, and key suggested traits preferred by farmers in a new sorghum variety. Farmers' grown varieties were recognized by indigenous names, traits, and different uses such as food, local beverages, animal feed, and construction. Quantitative and qualitative data collected through questionnaires were coded and analysed through cross-tabulations to determine significant differences and compute chi-square values to make inferences. Major crops grown and sorghum production constraints were subjected to pairwise rankings based on respondent farmers' importance weights. Data were analysed using Statistical Package for Social Sciences (SPSS) for Windows, Version 27.0 (IBM Corp: Armonk, NY, USA) [33].

3. Results

3.1. Socio-Demographic Description of Sorghum Growing Farmers

Basic socio-demographics disaggregated by gender, age, number of households, and education level status among respondent farmers across constituencies are summarized in Table 2. Gender of the respondent farmers was significantly different (χ^2 = 13.225; p = 0.021) across constituencies. There was an equal gender representation of the respondent farmers across constituencies. The proportion of female respondent farmers were at 75% for Mpungu and 70% for Kapako, which were higher values than male respondent farmers for Katima Mulilo Rural (60.7%), Eenhana (60%) and Kongola (60%). Age group was significantly different (χ^2 = 43.806; p = 0.000) with majority of respondent farmers being 30 to 39 years (39.4%) compared to 25.3% for 40 to 49 years, 24.2% for 18 to 29 years, and 11.1% for ≥50 years. The highest proportion (46%) of younger respondent farmers (18 to 29 years) were in Eenhana compared to Kapako (5%), Mpungu (10%), Katima Mulilo Rural (10%), and Endola (38%). Katima Mulilo Rural had the highest percentage (16.7%) of elderly respondent farmers (>50 years); Eenhana had (8%), Endola (8%), Kapako (10%), Kongola (14.3%), and Mpungu (15%). Education level was significantly different (χ^2 = 72.954; p = 0.000) across constituencies. The majority of respondent farmers (37.4%) attained secondary education compared to 23.7% for no formal education, 19.7% for primary, 11.6% for a university degree, and 7.6% for a diploma from colleges or vocational training institutions. The highest respondent farmers with no formal education were in Kapako (65%) followed by Mpungu (50%), Eenhana (22%), Endola (20%), and Katima

Mulilo Rural (10%). The highest percentage level of respondent farmers who attained degree level were in Katima Mulilo Rural (26.7%), Endola (16%), and Eenhana (10%). The number of family members per household was significantly different (χ^2 = 59.263; p = 0.000) across constituencies. The majority of farming households (38.4%) consisted of 4 to 6 people per household followed by 7 to 9 (30.8%), 1 to 3 (21.7%), and ≥10 (9.1%). The highest proportion of farming households with the least number of people per household (1 to 3) was scored in Eenhana (34%), followed by 26% for Endola, 23.3% for Katima Mulilo Rural, and 14.3% for Kongola. The highest percentage of farming households with ≥10 persons per household was scored in Mpungu (30%) and Kapako (25%) compared to 3.6% for Kongola, 4% for Endola, and 13.3% for Katima Mulilo Rural.

Table 2. The proportion of age, gender, number of households, and education level among respondent farmers in six selected constituencies of northern Namibia.

Variable	Kapako	Mpungu	Eenhana	Endola	Katima	Kongola	Mean
Gender							
Male	30.0	25.0	60.0	46.0	60.7	60.0	50.0
Female	70.0	75.0	40.0	54.0	39.3	40.0	50.0
Chi-Square test	DF = 5		χ^2 = 13.22		p-value = 0.02		
Age of farmers							
18–29	5.0	10.0	46.0	38.0	10.0	0.0	24.2
30–39	35.0	55.0	30.0	38.0	43.3	46.4	39.4
40–49	50.0	20.0	16.0	16.0	30.0	39.3	25.3
>50	10.0	15.0	8.0	8.0	16.7	14.3	11.1
Chi-Square test	DF = 15		χ^2 = 43.80		p-value = 0.00		
Level of Education							
None	65.0	50.0	22.0	20.0	10.0	0.0	23.7
Primary	15.0	35.0	18.0	20.0	13.3	21.4	19.7
Secondary	20.0	5.0	46.0	38.0	26.7	67.9	37.4
Diploma	0.0	5.0	4.0	6.0	23.3	7.1	7.6
Degree	0.0	5.0	10.0	16.0	26.7	3.6	11.6
Chi-Square test	DF = 20		χ^2 = 73.00		p-value = 0.00		
Household size							
1–3	5.0	5.0	34.0	26.0	23.3	14.3	21.7
4–6	20.0	10.0	52.0	48.0	20.0	50.0	38.4
7–9	50.0	55.0	14.0	22.0	43.3	32.1	30.8
≥10	25.0	30.0	0.0	4.0	13.3	3.6	9.1
Chi-Square test	DF = 15		χ^2 = 59.30		p-value = 0.00		

DF = degrees of freedom, χ^2 = Chi-square value.

3.2. Sorghum Cropping Systems

Sorghum production and the cropping systems across constituencies are summarized in Table 3. Sorghum farm size varied significantly (χ^2 = 49.77; p = 0.000) across constituencies. The majority of the respondent farmers (29.3%) had a farm size of 4 to 5 ha, while 25.8% had 6 to 7 ha, 22.5% had 2 to 3 ha, 18.2% with ≥8 ha, and ≤1 ha (4.5%). The highest proportion of smaller farm size (≤1 ha) were scored in Kapako (15%), Mpungu (10%), Katima Mulilo Rural (10%), and Kongola (3.6%), whereas the highest percentages of larger farm size (≥8 ha) were recorded in Kapako (35%), Katima Mulilo Rural (23.3%), Mpungu (20%), and Eenhana (16%).

Table 3. Sorghum production and cropping systems in six selected constituencies of northern Namibia.

Variables	Kapako	Mpungu	Eenhana	Endola	Katima	Kongola	Mean
Land size (ha)							
≤1	15.0	10.0	0.0	0.0	10.0	3.6	4.5
2–3	20.0	35.0	8.0	16.0	43.3	28.6	22.2
4–5	25.0	15.0	44.0	34.0	13.3	25.0	29.3
6–7	5.0	20.0	32.0	38.0	10.0	28.6	25.8
≥8	35.0	20.0	16.0	12.0	23.3	14.3	18.2
Chi-Square test	DF = 20		χ^2 = 49.77		*p*-value = 0.00		
Cropping system							
Mono-cropping	0.00	0.0	16.0	0.0	20.0	17.9	9.6
Intercropping with pearl millet, maize, cowpea and groundnut	100.0	85.0	68.0	72.0	73.3	57.1	73.2
Crop rotation with cowpea	0.00	15.0	16.0	28.0	6.7	25.0	17.2
Chi-Square test	DF = 10		χ^2 = 29.54		*p*-value = 0.00		
Perception of respondent farmers on soil status of their crop lands							
Poor	20.0	10.0	2.0	4.0	6.7	0.0	5.6
Medium	55.0	60.0	80.0	80.0	63.3	57.1	69.7
Fertile	25.0	30.0	18.0	16.0	30.0	42.9	24.7
Chi-Square test	DF = 10		χ^2 = 21.16		*p*-value = 0.02		
Fertilizer use							
Yes	5.0	0.0	52.0	42.0	23.3	14.3	29.8
No	95.0	100.0	48.0	58.0	76.7	85.7	70.2
Chi-Square test	DF = 5		χ^2 = 33.53		*p*-value = 0.00		
Land preparation method							
Hand hoeing	15.0	15.0	0.0	0.00	20.0	3.6	6.6
Plough	85.0	80.0	100.0	100.0	66.7	67.9	86.9
Conservation agriculture	0.0	5.0	0.0	0.0	13.3	28.6	6.6
Chi-Square test	DF = 10		χ^2 = 54.90		*p*-value = 0.00		

DF = degrees of freedom, χ^2 = Chi-square value. Note: conservation agriculture involves ridge tillage and planting between raised beds.

Cropping systems among respondent farmers were significantly different (χ^2 = 29.541; p = 0.001) across sorghum production regions. The majority of farmers (73.2%) intercropped sorghum with pearl millet, maize, cowpea, and groundnut to optimize output from small landholdings. A relatively low proportion of the respondent farmers practice crop rotation with cowpea (17.2%) as a strategy to utilise legumes for biological nitrogen fixation to maintain soil fertility levels. The small proportion of respondent farmers practicing sorghum mono-cropping (9.6%) across constituencies was attributable to its flood tolerance to grow in portions of fields prone to waterlogging after heavy rainfall. Kapako scored the highest proportion (100%) of intercropping with pearl millet, maize, and cowpea, followed by Mpungu (85%), Katima Mulilo Rural (73.3%), and Endola (72%) (Figure 2). Katima Mulilo Rural had the highest (20%) proportion of mono-cropping compared to 17.9% for Kongola and 16% for Eenhana. Endola had the highest rate (28%) of farmers practising crop rotation of sorghum with cowpea compared to Kongola (25%), Eenhana (16%), and Mpungu (15%).

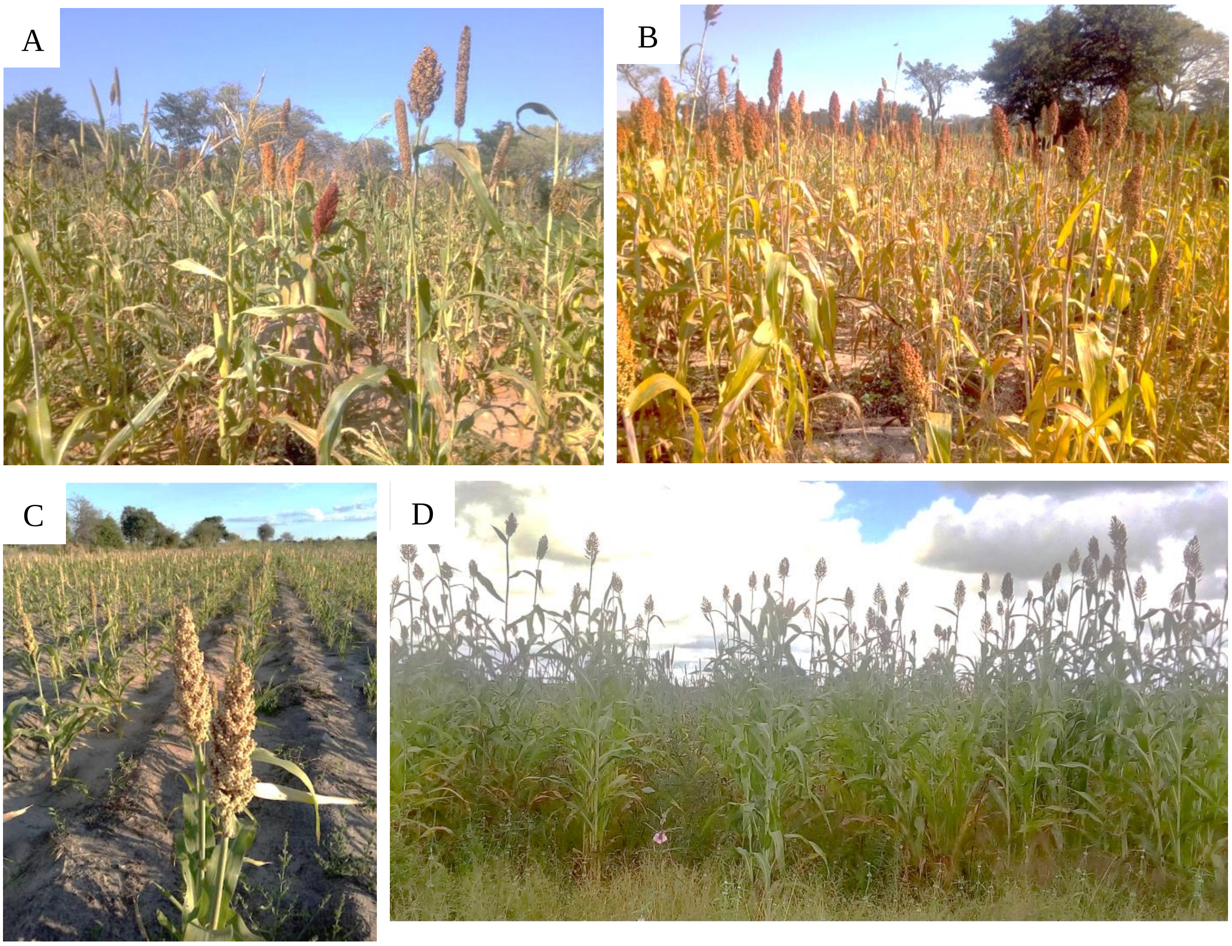

Figure 2. Sorghum cultivation in northern Namibia; note intercropping with pearl millet and maize (**A**), mono-cropping with hand broadcasting method (**B**), the introduced variety Macia planted in between ridges prepared using a ripper (**C**), and the tall traditional variety (Nakare) planted in rows in flat beds (**D**). (Photos: Maliata Athon Wanga. Pictures were taken from respondent farmers' fields during the transect walk in Kavango West Region).

The perception of respondent farmers on soil fertility status of their fields varied significantly (χ^2 = 21.155; p = 0.020) across constituencies. The majority of respondent farmers perceived that the fertility status of their soils was medium fertile (69.7%) followed by fertile (24.7%) and infertile (5.6%) across the study areas. Kapako recorded the highest number of respondent farmers who reported poor soil fertility (20%) followed by 10% for Mpungu and 6.7% for Katima Mulilo Rural. Respondent farmers in Kongola (42.9%), Katima Mulilo Rural (30%) and Mpungu (30%) had the highest proportion of reported fertile soils.

Fertilizer use among constituencies was significantly different (χ^2 = 33.529; p = 0.000). The majority of respondent farmers (70.2%) do not use fertilizers, compared to 29.8% who use them. Kraal manure was the most used organic fertilizer by respondent farmers, whereas NPK and urea acquired through the Government Dry Land Crop Production Program (DCPP) were widely used inorganic fertilizers (data not shown). Mpungu had the most (100%) respondent farmers without fertilizer use followed by Kapako (95%), Kongola (85.7%), and Katima Mulilo Rural (76.7%). Respondent farmers used different land preparation methods. The majority of them (86.9%) prepared land using mouldboard or disc plough pulled by a tractor or draft animal power. Land preparation using hand hoeing (6.6%) and conservation agriculture (CA) using a ripper (6.6%) were the least practised across constituencies. Conservation agriculture which involves ridge tillage and planting between raised beds to provide better drainage, soil health, and reduce erosion and runoff, is a newly introduced land preparation method in sorghum production constituencies (Figure 2C). Katima Mulilo Rural scored the highest proportion of land preparation by hand hoeing (20%) compared to Kapako (15%) and Mpungu (15%). Kongola had the highest proportion of land preparation with a ripper (28.6%) followed by Katima Mulilo Rural (13.3%) and Mpungu (5%).

3.3. Major Crops Grown in Northern Communal Areas of Namibia

Pairwise ranking of the major crops grown in studied constituencies is presented in Table 4. In terms of total production area sorghum was ranked 4th after pearl millet, maize, and cowpea across the study area. Pearl millet was considered most important in Mpungu, Eenhana, and Endola, whereas maize was the most crucial crop in Kapako, Katima Mulilo Rural, and Kongola. Sorghum was ranked as less important in Kapako, Mpungu, and Endola than pearl miller, maize, cowpea, and groundnut. In addition, farmers listed other important food or horticultural crops such as Bambara groundnut, roselle, and cucurbits (e.g., watermelon, pumpkins and squashes) (data not shown).

Table 4. Pairwise ranking of major crops grown in six selected constituencies of northern communal areas of Namibia.

Crop	Kapako (N = 20)		Mpungu (N = 20)		Eenhana (N = 50)		Endola (N = 50)		Katima (N = 30)		Kongola (N = 28)		Total (N = 198)	
	Mean	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**
Millet	1.6	2	1.3	1	1.0	1	1.0	1	2.4	2	2.1	2	1.5	1
Maize	1.4	1	1.9	2	3.2	3	2.6	2	1.1	1	1.0	1	2.1	2
Cowpea	3.3	3	3.7	3	2.7	2	3.2	3	3.9	4	4.0	4	3.4	3
Sorghum	4.5	5	4.2	5	3.9	4	4.2	5	2.8	3	2.9	3	3.7	4
Groundnut	4.3	4	4.0	4	4.2	5	3.9	4	4.8	5	5.0	5	4.3	5

3.4. Sorghum Varieties Grown in the Study Areas and Uses

Sorghum production and use among respondent farmers in the studied constituencies is presented in Table 5. The type of varieties grown across the study areas were significantly different (χ^2 = 21.425; p = 0.000). The majority of the respondent farmers (89.9%) grew landraces such as Ekoko, Okambete, Makonga, Kamburo, Nkutji, Katoma, Fuba, Dommy, Kawumbe, and Okatombo compared to introduced varieties (10.1%) such as Macia and Red sorghum. Kongola had the highest proportion of respondent farmers growing introduced varieties (28.6%) compared to Katima Mulilo Rural (20%), Kapako (10%), and Mpungu (10%). Endola had the highest proportion of farmers growing landraces (100%) followed by Eenhana (96%), Kapako (90%), and Mpungu (90%).

Sorghum uses across constituencies varied significantly (χ^2 = 86.169; p = 0.000). The crop was popularly produced for multi-purposes as food for households and markets (39.9%) followed by solely for food for households (38.4%), and household food and feed (7.1%) across the constituencies. Kapako had the highest proportion of respondent farmers (85%) for growing sorghum for food compared to 70% for Mpungu, 60% for Katima Mulilo Rural, and 46.4% for Kongola. Sorghum production for food and market was higher in Endola (62%), followed by Eenhana (42%), Kongola (35.7%), and Katima Mulilo Rural (30%). Across constituencies, sorghum was least used for animal feed (2%); feed and market (2.5%); market (4%); and for food, feed, and market (6.1%). Eenhana was the only constituency that recorded the production of sorghum solely for feed (8%). Respondent farmers in Endola (62%) had the highest score for producing sorghum for feed and market, followed by Eenhana (42%), Kongola (35.7%), and Katima Mulilo Rural (30%). Eenhana had the highest number of respondent sorghum farmers growing the crop solely for the marketplace (6%) compared to 5% for Mpungu, 4% for Endola, and 3.6% for Kongola. The use of sorghum for food, feed, and market was the highest in Endola (14%), then 10.7% for Kongola and 4%

for Eenhana. Household requirements of sorghum grain varied significantly (χ^2 = 48.666; p = 0.000) across constituencies. Majority of households (40.9%) across constituencies required 200 to 299 kg/year of sorghum grain followed by 100 to 199 kg/year (39.4%), 300 to 399 kg/year (8.6%), ≥400 kg/year (7.6%), and <99 kg/year (3.5%). Kongola had the highest proportion of households with the lowest (7.1%) sorghum grain requirement of <99 kg/year compared to Mpungu (5%), Eenhana (4%), and Katima Mulilo Rural (3.3%). The highest household sorghum grain requirement (≥400 kg) was 23.3% for Katima Mulilo Rural, 17.9% for Kongola, 5% for Kapako, and 4% for Eenhana.

Table 5. Sorghum varieties and uses in six selected constituencies of northern communal areas of Namibia.

Variable	Kapako	Mpungu	Eenhana	Endola	Katima	Kongola	Mean
Varieties grown							
Introduced	10.0	10.0	4.0	0.0	20.0	28.6	10.1
Landraces	90.0	90.0	96.0	100.0	80.0	71.4	89.9
Chi-Square test	DF = 5		χ^2 = 21.43		p-value = 0.00		
Use type							
Food	85.0	70.0	18.0	10.0	60.0	46.4	38.4
Feed	0.0	0.0	8.0	0.0	0.0	0.0	2.0
Market	0.0	5.0	6.0	4.0	3.3	3.6	4.0
Food and feed	0.0	0.0	16.0	6.0	6.7	3.6	7.1
Food and Market	15.0	25.0	42.0	62.0	30.0	35.7	39.9
Feed and market	0.0	0.0	6.0	4.0	0.0	0.0	2.5
Food, feed and market	0.0	0.0	4.0	14.0	0.0	10.7	6.1
Chi-Square test	DF = 30		χ^2 = 86.17		p-value = 0.00		
Household requirements of sorghum grain (kg)							
<99	0.0	5.0	4.0	2.0	3.3	7.1	3.5
100–199	55.0	60.0	30.0	36.0	30.0	46.4	39.4
200–299	40.0	35.0	50.0	58.0	23.3	17.9	40.9
300–399	0.0	0.0	12.0	4.0	20.0	10.7	8.6
≥400	5.0	0.0	4.0	0.0	23.3	17.9	7.6
Chi-Square test	DF = 20		χ^2 = 48.67		p-value = 0.00		

DF = degrees of freedom, χ^2 = Chi-square value.

3.5. Constraints to Sorghum Production

The major constraints to sorghum production in the study constituencies is presented in Table 6. Respondent farmers across the study areas ranked drought and heat stress as major constraints followed by declining soil fertility, insect pest damage, high cost of production inputs, unavailability of improved seed, lack of alternative improved varieties with farmers' preferred traits, lack of organic manure, limited access to market, and limited extension service. Declining soil fertility resulted from farmers' continued cultivation without replenishment of nutrients in the soil, including through the application of organic or inorganic fertilizers. Major crop pests observed during the transect walk included birds (quelea and dove birds), fall armyworms, midges, aphids, head caterpillars, stink bugs, and armoured bush crickets. Diseases observed included grain mold, anthracnose, loose smut, rust and ergot, and the parasitic red flowered *Striga* (*Striga asiatica* L.). High costs of production inputs were reported in the areas attributed to ploughing services and crop management such as weed, pest and disease control, harvesting, and post-harvest handling of the grain. Farmer-saved seed of low-yielding landraces were widely used due to the unavailability of improved seed and lack of alternative improved varieties with farmers' preferred traits. Farmers sold sorghum grain mainly in the informal markets such as open markets and trading with neighbours, and there were no formal markets and incentives to promote the production of the crop. Due to limited extension service, farmers lacked information on improved agronomic management for sorghum production and its value chain.

Table 6. The major constraints to sorghum production ranked by respondent farmers in six selected constituencies of northern communal areas of Namibia.

Constraints	Kapako (N = 20)		Mpungu (N = 20)		Eenhana (N = 50)		Endola (N = 50)		Katima (N = 30)		Kongola (N = 28)		Total (N = 198)	
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Drought and heat stress	1.9	2	2.2	2	1.9	3	1.5	1	1.6	2	2.0	4	1.8	1
Poor soil fertility	2.4	6	1.8	1	1.7	2	2.0	6	2.1	4	1.7	3	1.9	2
Pests (aphid, fall armyworms, birds)	3.1	8	3.0	9	2.3	7	1.5	2	1.5	1	1.5	2	2.0	3
High cost of production inputs	2.7	7	2.9	8	1.5	1	1.6	4	2.8	7	2.1	6	2.1	4
Unavailability of improved seed	1.8	1	2.6	5	1.9	4	1.5	3	3.0	8	2.4	8	2.1	5
Lack of varieties with farmers' preferred traits	2.3	4	2.2	3	2.6	9	2.4	8	2.0	3	1.4	1	2.2	6
Lack of organic manure	3.2	9	2.7	7	2.1	5	1.8	5	2.3	5	2.2	7	2.2	7
Limited access to market	2.3	5	2.7	6	2.2	6	2.0	7	3.2	9	3.3	9	2.5	8
Limited extension service	2.2	3	2.4	4	2.3	8	3.0	9	2.4	6	2.0	5	2.5	9

3.6. Varieties Grown by Farmers and Preferred Traits

A summary of the results of the group discussions on sorghum varieties and preferred traits across the study areas is presented in Table 7. The variety Macia was widely cultivated for white grain colour, short plant height, and early maturity, and the variety Red sorghum was preferred for high grain yield, medium plant height, and medium to late maturity. The seed for these varieties was mainly sourced from the ADCs of the MAWLR. Farmer-saved seed was the major source of planting material derived from landraces and the informal markets. Distinguished sorghum landraces grown for the white grain colour included Ekoko, Okambete, Saye-saye, Makonga, Mombe, Kamburo, Nkutji, and Katoma. The white grains were mainly used to prepare porridge locally referred to as pap, isima, inkoko, and oshifima; traditional pancake (oshikwiila and mungome); and to brew non-alcoholic beverages (sikundu, chilubu, oshikundu, and maheu). Traditional non-alcoholic beverages are used for feeding the sick and lactating women. Red grain colour sorghum is widely grown to prepare local beverages such as non-alcoholic and alcoholic (marovhu) drinks. Prominent landraces with red grain colour were Fuba, Dommy, Murwa, Nehutu, Kawumbe, and Mutjuma gongombe. Other landraces widely grown for high stem sugar content for chewing are Nyova, Okalya, Nswe, Nakafo, and Kamburo. Farmers identify sorghum varieties for high stem sugar by the dull green leaf midrib colour. Landrace varieties with gooseneck type panicle are generally called Kotovava, Kakumbama, Kankota, and Omusamane iteka ondaku and were grown for grain production. Landrace Esha/Eha was preferred for fresh grain roasting quality as a snack. Varieties identified for tall plant height were Oshilyalyaka, Tjwatama, Tou, Nakare, and Makonga. Tall varieties were important for animal feed and the construction of a fence around the homestead. Landrace Shorty, Tumbi, Kawumbe, and Okatombo are important for short plant height and early maturity for late planting and drought escape. Landraces such as Nakafo are known for drought tolerance, Fuba for flooding tolerance, and Siboni zuba, which have longer glumes, are important for bird damage resistance.

Table 7. Names of landraces and varieties grown by farmers and preferred traits in northern Namibia.

Variety	Preferred Traits	Drawbacks
Macia	Early- to medium-maturity, short plant height, white grain colour	Sensitive to moisture stress at germination, susceptible to bird
Red sorghum	Medium- to late-maturity, medium plant height, red grain colour	Susceptible to stalk borer and weevil
Ekoko, Okambete, Saye-saye, Makonga, Tumbi, Tou, Mombe, Nakare, Kamburo, Nkutji and Katoma	White grain colour for flour to prepare porridge and non-alcoholic beverages	Late-maturity, susceptible to aphid and ergot
Okatombo, Dommy, Murwa, Nehutu, Kawumbe and Mutjuma gongombe	Red grain colour to prepare local beverages non-alcoholic and alcoholic	Late-maturity, susceptible to weevil
Nyova, Okalya, Nswe and Kamburo	High stem sugar	Poor grain yield
Esha/Eha	Fresh grain roasted and eaten as a snack	Poor grain yield
Oshilyalyaka, Tjwatama, Tou, and Makonga.	Tall plant height for animal feed and construction of a fence around the homestead	Poor grain yield, lodges and late maturity
Tumbi, Kawumbe, and Okatombo	Short plant height and early maturity	Susceptible to bird
Nakafo	Drought tolerance and stem sugar	Poor grain yield
Fuba	Flooding tolerance	Late-maturity and poor grain yield
Siboni zuba	Non preferred by birds	Poor grain yield and difficult to thresh

4. Discussion

Incorporating farmer-preferred traits is key to the adoption of new generation varieties in the traditional sorghum growing areas. This study focused on an assessment of the present state of sorghum production to understand farmers' perceived production constraints and trait preferences in new varieties as a guide for current and future breeding. This is the first study for documenting farmer' perception on sorghum production and trait preferences in northern communal areas of Namibia using a PRA.

Results revealed clear trends in sorghum production amongst the sampled respondent farmers disaggregated by gender, age, number of households, education level, cropping systems, types of varieties grown, and perceived production constraints. This suggested that the adoption of improved sorghum varieties in the study area depends on new varieties that possess farmers' trait preferences. The data assembled in this study are useful to select market-preferred traits to incorporate in breeding drought-tolerant varieties for the dry conditions and serve the diverse value chains in Namibia.

4.1. Socio-Economic Status

The socio-economic status of smallholder farmers strongly influences the adoption of new varieties [34–36]. In the present study, the sampled respondent farmers were male (50%) and female (50%) across constituencies, indicating equal economic value of sorghum production to men and women in northern communal areas of Namibia (Table 2). The higher proportion of female respondent farmers (75%) in Mpungu constituency suggested the important role women had in sorghum production. Hence, a high percentage of men were involved in none crop production activities in urban areas, mining, and fishing industries. This proportion was higher than 53.5% of females reported in the Agriculture Communal Sector Census in the Kavango West region [32]. A higher proportion of male respondent farmers (>60%) in Katima Mulilo Rural, Kongola and Eenhana areas could be attributed to the land tenure system and tradition in Namibia where men are the majority of the landowner and household leaders. The male proportion in the present study corroborates with the Namibia Census of Agriculture 2013/2014 for Ohangwena (54.8%) and Zambezi (51.9%) [32]. Therefore, gender variations in the present study indicates the necessity of awareness of traits preference by both genders to integrate into new sorghum varieties.

Younger farmers can be targeted for being flexible and ready in risk-taking to introduce improved varieties for adoption [37]. In the present study, the proportion of respondent farmers in productive age groups of <40 years old (63.6%) is higher than 50.9% reported in the previous study [32], indicating it is relatively easy to introduce improved sorghum varieties in the northern communal area of Namibia (Table 2). Formal education is essential for farmers to search for information on new varieties compared to non-formal or uneducated farmers [21,28,38]. In the present study, the majority of the respondent farmers (56.6%) had attained secondary education. This indicates that farmers in the study area can understand the need to cultivate improved varieties. The proportion of farmers who attained secondary education in the present study is higher than 33% reported in northern Namibia [32]. The household size is essential for labour and farm activity distribution in smallholder agriculture [39–41]. In the present study, a higher proportion of respondent farmers scored for 4–6 (38.4%) and 7–9 (30.8%) persons per household, indicating limited availability of labour for crop production and other agricultural activities. In the study areas, smallholder farmers practiced mixed farming involving animal husbandry and crop production, which requires labour distribution [16]. Therefore, sorghum varieties that can be easily handled using mechanization can be recommended to reduce labour requirements in sorghum production.

4.2. Sorghum Production and Cropping Systems

The majority of sorghum producers in northern communal areas of Namibia are smallholder farmers with a farm size of <6 ha [15,17,30]. In the present study, farm sizes of ≤5 ha (56%) agree with the ideal land size that smallholder farmers can manage to produce food and cash income for the households. Newsham and Thomas [17], and Iijima et al. [42] reported that sorghum was relatively tolerant to waterlogging stress, which farmers planted near seasonal wetland (ndombe) prone to water-logging after heavy rainfall. In the present study, the majority of respondent farmers (73.2%) intercropped sorghum with other crops such as pearl millet, maize, cowpea, and groundnut, agreeing with Hillyer et al. [15] and Horn et al. [30]. Thus, new varieties for intercropping compatibility require novel traits to compete with the companion crops. Intercropping is vital for the optimization of output from small landholdings, maintaining soil fertility through legume crops' biological nitrogen fixation and providing food diversity and nutrition security at the household level. Further, legume crops such as cowpea, groundnut, and Bambara groundnut are essential companion crops for biological nitrogen fixation [43,44]. In the present study, a small proportion of respondent farmers with the perception that their soil fertility was medium fertile (69.7%) and fertile (24.7%) could be the reason for the majority of farmers (70.2%) not applying fertilizers. The present study agrees with spatial fertilizer use advocated for developing countries [45] due to availability, high cost, lack of awareness, and incentives on production input for smallholder farmers in sub-Saharan Africa [46,47]. The current status of respondent farmers applying fertilizer reveals the need for varieties that can grow in low fertile soils to improve productivity. Further, the land preparation method is vital for sustainable land use and management of the crop. The most used conventional land preparation methods were mouldboard plough and disc harrow, and mono-cropping revealed the need to develop varieties with high root biomass for soil carbon sequestration, higher yield, and drought tolerant [48].

Sorghum is a relatively drought tolerant and low water requirement crop (450–650 mm) [49] compared to 500–800 mm for maize [50,51]. In the present study, sorghum was ranked the fourth most important crop in production area after pearl millet, maize and cowpea. Hence, the crop's economic potential was not realized in drought-prone areas of Namibia. Thus, farmers risked crop failure by growing maize in drought-prone areas due to its well-established market system in the country. Therefore, policies and regulations to establish the market are required to increase sorghum production. In the present study, 89.9% of farmers cultivated low-yielding landrace varieties, indicating the need to develop farmers' preferred varieties combining high grain yield with abiotic and biotic tolerant traits [52,53]. The use of landraces was aggravated by limited seed availability due to the country's lack of seed and variety regulation system. Therefore, the need for the implementation of the Seeds and Seeds Varieties, and Plant Breeders' Rights Acts to promote seed dealers and new variety registration in Namibia. Sorghum grain was mainly produced for household consumption and the surplus (78.3%) was sold for cash income. Moreover, the need of sorghum grain per household <300 kg/year (83.8%) suggested that the crop is consumed in a small quantity. This revealed the need to promote sorghum beyond household consumption such as exploiting value addition for various food products such as bread, biscuit, and grain flakes [9,10]; popped sorghum as snacks [8,11]; and animal feed and the brewing industry.

4.3. Constraints to Sorghum Production

There is a high yield gap of sorghum in Namibia and elsewhere in Africa. This is mainly attributed to abiotic and biotic stresses in the country. Farmers' perceived sorghum production constraints identified elsewhere in Africa included drought, lack of seed for improved varieties, storage pests and field pests, poor soil fertility, lack of market, heavy rainfall, *Striga* infestation, bird damage, high cost of production inputs (e.g., fertilizers, insecticides, fungicides and herbicides), anthracnose and smut diseases, and poor agronomic knowledge [21,24,28,29]. In agreement with these reports, respondent farmers' perceived sorghum production constraints in the present study included recurrent drought, declining soil fertility, insect pest damage, high cost of production inputs, unavailability of improved seed, lack of alternative improved varieties with farmers' preferred traits, lack of organic manure, limited access to market, and limited extension service. Drought is rampant in Namibia, attributed to the country's arid to semi-arid climate conditions and low and erratic rainfall [16,31]. Declining soil fertility was mainly due to a low input farming system practised in small-scale and inaccessibility to organic manure and chemical fertilizers due to the high cost [15,17,30]. The unavailability of improved seed, lack of alternative improved varieties with farmers' preferred traits limited access to market, and limited extension service were attributed to lack of established value chains for the crop in the country. Thus, there is a need for further studies to guide the production and breeding of sorghum for the market in the country. Therefore, a demand-led breeding and product development approach is recommended to assist with establishing sorghum value chains in Namibia.

4.4. Varieties Grown by Farmers and Suggested Traits

Landraces are well-adapted to low-input farming systems and possess essential quality traits for food and beverages [2,18]. In the present study, most of the landraces were described as late maturity and low grain yielders. Grain yield was the main trait of interest, and grain colour was of secondary importance depending on the household consumption and market. The majority of farmers cultivated both red and white grain colour sorghum in the same field. The landrace varieties were not evaluated for cultivation and further breeding. Therefore, there is a need to evaluate and characterize landraces to select useful breeding populations for different trait-based breeding programs, including grain yield, fodder, and dual-purpose cultivars. Due to the intensity and recurrence of drought and heat stress, drought tolerance was identified as the main trait to incorporate in new sorghum varieties for the northern agro-ecologies of Namibia. The respondent farmers expressed willingness to adopt new drought tolerant sorghum variety with high grain yield and early maturity, whereas field and storage insect pests are of secondary importance. Sorghum variety with early-maturity and short plant height are important for drought escape and lodging resistance [54–56]. Therefore, this study reveals the need for breeding and deploying new sorghum varieties with a high grain yield, early maturity, and tolerance to drought, field, and storage insect pests to increase the production and productivity of the crop in Namibia.

5. Conclusions

Developing and deploying sorghum varieties to serve the diverse needs of farmers and value chains is vital for adopting new climate-smart cultivars. Participatory Rural Appraisal (PRA) was carried out in six constituencies to assess the present state of sorghum production in northern Namibia, and document farmers' perceived production constraints and trait preferences in new varieties to guide drought-tolerance breeding in Namibia. Results revealed variable trends in sorghum production changes among respondent farmers. An equal proportion of male and female respondent farmers cultivate sorghum, suggesting the crop's value to both genders in northern Namibia. Sorghum was mainly intercropped with pearl millet, maize, cowpea, and groundnut to optimize output from small landholdings and maintaining soil fertility. The majority of the respondent farmer grew landrace varieties, namely Ekoko, Okambete, Makonga, Kamburo, Nkutji, Katoma, Fuba, Dommy, Kawumbe, and Okatombo without fertilizers. Recurrent drought was identified as a major production constraint, followed by declining soil fertility, insect pest damage, high cost of production inputs, unavailability of improved seed, lack of alternative improved varieties with farmers' preferred traits, lack of organic manure, limited access to market, and limited extension service. The study recommends breeding and deployment of improved seed of sorghum varieties with farmers' preferred traits, including the high grain yield; early maturity; and tolerance to drought, field, and storage insect pests to increase the production and productivity of the crop in Namibia.

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