



Major Production Constraints and Spider Plant [*Gynandropsis gynandra* (L.) Briq.] Traits Preferences Amongst Smallholder Farmers of Northern Namibia and Central Malawi

Barthlomew Yonas Chataika^{1,2*}, Levi Shadeya-Mudogo Akundabweni¹, Julia Sibiya³, Enoch G. Achigan-Dako⁴, Dêêdi E. O. Sogbohossou⁴, Kingdom Kwapata⁵ and Simon Awala¹

¹ Department of Crop Production and Agricultural Technologies, School of Agriculture and Natural Resource and Fisheries, University of Namibia, Oshakati, Namibia, ² Center for Coordination of Agricultural Research and Development in Southern Africa (CCARDESA), Gaborone, Botswana, ³ School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa, ⁴ Laboratory of Genetics, Horticulture, and Seed Science, Faculty of Agronomic Sciences, University of Abomey-Calavi, Godomey, Benin, ⁵ Department of Horticulture, Lilongwe University of Agriculture and Natural Resources, Lilongwe, Malawi

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*Correspondence:

Barthlomew Yonas Chataika
barthchataika@gmail.com

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Spider plant (*Gynandropsis gynandra* (L.) Briq.) is among the most important African Leafy Vegetables (ALVs) as a source of essential nutrients with the potential of contributing significantly to household food and nutritional security and mitigation of hidden hunger. Nevertheless, the vegetable is considered an orphan crop and its production is challenged by inadequate research to identify and improve traits preferred by smallholder farmers. The research was conducted to identify the main challenges impacting the production of spider plants and identify traits preferred by smallholder farmers in northern Namibia and central Malawi for use in demand-led crop improvement. Semi-structured interviews involving a random selection of 197 farming households from five regions of northern Namibia and three districts of central Malawi were conducted. In addition, six key informant interviews and four focus group discussions were conducted to triangulate the findings. Data were analyzed using IBM SPSS version 20. Fischer's exact test was used to test for independence in the ranking of production constraints and agronomic traits, while Kendall's Coefficient of Concordance (W) was used to measure agreement levels in the ranking across the countries. Farmers indicated lack of seed, poor soil fertility, poor seed germination and drought as the main production challenges across the two countries. Production constraints were ranked differently ($p < 0.001$) across the study sites suggesting the influence of biophysical and socio-economic factors associated with production. High yield and drought tolerance were considered the most important agronomic traits among the smallholder farmers in both countries. The findings of this study are useful for designing demand-driven pre-breeding trials that prioritize the needs of the end-users. Demand-led breeding has the potential to stimulate the production and utilization of spider plant, hence contributing to household food and nutritional security.

Keywords: production constraints, trait preferences, nutritional security, demand-led plant breeding, variety adoption, hidden hunger

INTRODUCTION

Indigenous vegetable species possess qualities such as nutritional, nutraceutical, industrial, ethnomedicinal and biocultural significance that are key to the socio-economic wellbeing of humanity, however, their real potential is yet to be exploited (Singh et al., 2020). Improving traits preferred by stakeholders is particularly important in these indigenous vegetables, which have been under-utilized, neglected by research and are less preferred than exotic vegetables despite their potential roles in contributing to household food and nutritional security (van der et al., 2009; Mbugua et al., 2011; Keatinge et al., 2015). Nevertheless, studies have shown that variety improvement does not guarantee acceptance and adoption by farmers unless the improved genotypes possess desirable traits (Vom Brocke et al., 2010; Nakyewa et al., 2021). Inventive measures that align research priorities with the traits preferred by the different stakeholders along the value chain, while addressing main production constraints, constitute a critical component in market-led plant breeding.

Spider plant (*Gynandropsis gynandra*) is one such indigenous vegetable that has been reported to be nutritionally superior to exotic vegetables such as cabbages (Mbugua et al., 2011). It supplies adequate amounts of vitamins A, C, and E, minerals such as iron, zinc, calcium and magnesium, and beta-carotene (Chweya et al., 1997; Agbo et al., 2009; van der et al., 2009; Mbugua et al., 2011; Jinazali et al., 2017; Somers et al., 2020). When processed, the spider plant is reported to retain more vitamin C compared to other vegetables such as amaranths (Silue, 2009). Furthermore, Stangeland et al. (2008) in Uganda, showed spider plant as a major contributor to the total dietary antioxidants when compared to several other indigenous vegetables. It has also been suggested through research that dietary polyphenolic phytochemicals such as flavonoids, polyphenols, glucosinates, terpenoids, and essential ions accumulate in the leaves of spider plants, thus promoting health through retardation or inhibition of chronic diseases development (Sivanesan and Begum, 2007; Anbazhagi et al., 2009; Moyo and Aremu, 2021).

Despite its importance, the vegetable remains underutilized in many parts of sub-Saharan Africa. It grows as a weedy volunteer crop in farmers' fields and in the wild during the rainy season (Kolberg, 2001); as such, its availability is also seasonal. *G. gynandra* remains semi-domesticated due to a myriad of challenges associated with production, research, processing, and marketing. Production challenges range from poor germination and lack of quality seed (Abukutsa-Onyango, 2007; Onyango et al., 2013), erratic rainfall (Pachpute, 2009), declining soil fertility, insect pests, competing preferences amongst producers, and inadequate skills in agronomic practices (Chauvin et al., 2012). The latter underscores the neglect spider plant has been subjected to by research and extension services, leading to low yields. For example, Chweya (Chweya, 1997), reported an estimated yield of between 1.0 to 3.0 tons/ha using locally available resources, compared to the potential yield of 20.5 to 30 tons/ha which was obtained in Kenya under ideal management practices. Amongst the factors that are believed

to contribute to the low yield are drought stress, use of low-yielding unimproved seeds of spider plant, low soil fertility, poor farming techniques, and limited research by the National Agricultural Research Institutes (Vorster and Rensburg, 2005). In an attempt to address the challenges of low yield in traditional vegetables, Mbugua et al. (2011) identified crop production practices, introduction of new species, demonstrations, and seed production techniques as top research priorities. Plant characters that are believed to contribute to the high yield (Kiebre et al., 2015) include stem height, number and size of leaves, level of flower production, leaf biomass, and number of primary branches. Furthermore, researchers (Kiebre et al., 2015) showed that the degree of selection, adoption and utilization amongst farmers varied with location and cultural background (Kimiye et al., 2007; Uusiku et al., 2010), suggesting the need for site-specific studies, particularly in Malawi and Namibia where information of production constraints affecting smallholder farmers is lacking. Over the last 20 years, several collaborative research and development efforts were initiated on indigenous vegetables including spider plants (Govindasamy et al., 2020). However, these initiatives have overlooked the engagement of farmers, thus falling short in tackling the root challenges and priorities of the farmers.

Participatory identification of production constraints faced by smallholder farmers and spider plants' trait preferences is expected to provide insights in designing strategies for addressing these challenges across the value chain, hence promoting the species' production, processing, and utilization. More often, farmers' preferred attributes are ignored and hence might lead to rejection or non-adoption of varieties (Basavaraj et al., 2015). The objective of this study was to identify spider plant production constraints and traits preferred by smallholder farmers of northern Namibia and central Malawi for use in demand-led plant improvement.

MATERIALS AND METHODS

Study Sites

The survey was conducted in three districts of central Malawi and five regions of northern Namibia. Malawi is located in southeastern Africa, in between 9° and 18° S and 32° and 36° E while Namibia is in the southwestern part of Africa, between 17° and 29° South and 11° and 26° East. Malawi has eight Agricultural Development Divisions (ADD) and 28 District Agricultural Development Offices, which are made up of 154 Extension Planning Areas (EPAs) (Chinsinga, 2008). Namibia uses regions as its first-level sub-national administrative divisions, which are further sub-divided into constituencies. There are 14 regions and 121 constituencies that host agricultural offices in Namibia (Marius et al., 2017).

In Malawi, the study was conducted at Dedza, Ntcheu and Lilongwe District Agricultural Offices in 2019, while in Namibia, the study was conducted in Okavango West, Ohangwena, Omusati, Oshana and Oshikoto regions in the year 2018 (Table 1). In this study, the districts and Extension planning areas in Malawi were stratified at the same level as the

TABLE 1 | Geographic location of the three districts of central Malawi and the five regions of northern Namibia where the study was conducted.

Country	District/Region	Site	Coordinates		Elevation (masl)
			Latitude	Longitude	
Malawi	Dedza	Mayani	14.09°S	34.25°E	1,345
	Ntcheu	Sharpvalley	14.61°S	34.73°E	625
	Lilongwe	Bunda	14.18°S	33.80°E	1,132
Namibia	Okavango West	Kapako	18.27°S	18.43°E	1,008
	Ohangwena	Engela	18.43°S	15.69°E	1,104
	Omusati	Anamulenge	17.60°S	16.82°E	1,114
	Oshana	Okatana	18.41°S	14.85°E	1,099
	Oshikoto	Omuntele	18.42°S	16.91°E	1,089

regions and constituencies in Namibia, respectively, for the sake of comparisons.

The study regions in Namibia are characterized by hot and dry semi-arid climatic conditions. Day temperatures are mostly hot (18–34°C), while night temperatures can be as cool as 0–10°C. Rainfall ranges from 350 to 700 mm, the highest being in the Okavango region, and is influenced by Benguela current from the Atlantic Ocean (Whiting, 2008). The soils range from barren sand and rock to low-quality sand-dominated to relatively fertile soils (Green, 2021). The soils are dominated by calcisols, fluvisols, and arenosols.

Malawi's climate is sub-tropical with distinct wet and dry seasons. The country gets a unimodal pattern of rainfall ranging between 725 to 2,500 mm per annum. Rainfall patterns change following the movement of the Inter-Tropical Convergence Zone (ITCZ) (McSwweney et al., 2010). Average temperatures range from 25 to 37°C in the hot, dry season, and 17 to 27°C in the cool, dry winter season, but can also fall to between 4 and 10°C (www.metmalawi.com). The soils are generally fertile and dominated by luvisols in the Lilongwe plain and Cambisols along the Rift Valley (Vargas and Omuto, 2016). Bunda in Lilongwe district lies on the middle altitude (1,132 masl) of the Lilongwe plain and experiences a medium amount of rainfall of around 900 mm/annum. Mayani in Dedza district is in medium to high altitude (1,345 masl) agroecological zone, receiving medium to high rainfall (1,000–1,600 mm/annum) and is characterized by relatively clay loam red soils (Government of Malawi., 1999; Munthali et al., 2019). Finally, Sharpvalley in Ntcheu district lies in the low altitude Rift Valley (625 masl), is characterized by high temperatures of above 39°C and receives low rainfall (600 mm/annum). The area has fertile alluvial soils belonging to a class of cambisols (Malawi Government, 2012; Vargas and Omuto, 2016).

Sampling Design, Research Tools

Three study tools namely (1) semi-structured interviews, (2) focus group discussions (FGD) and Key Informant Interviews (KII) were used to collect the relevant data. FGDs involved farmer groups while KIIs targeted agricultural extension staff in the Ministry of Agriculture and Food Security (MAFS) in Malawi and the Ministry of Agriculture Water and Forestry (MAWF) in Namibia.

Sampling of the farmers was done at different levels in each of the two countries. Firstly, the selection of the study districts in central Malawi and regions in northern Namibia was based on the outcome of the preliminary field survey and literature review. The outcome of the preliminary survey indicated some exposure to the production of indigenous vegetables in central Malawi and the natural growth of spider plants in crop fields in the five regions of northern Namibia. In addition, the selection of the districts in Malawi was based on their potential in vegetable production. For example, Dedza, and Ntcheu districts were the major vegetable-producing districts in the central region of Malawi, while the site selected in Lilongwe benefited from the research outreach activities in indigenous vegetable production conducted by Lilongwe University of Agriculture and Natural Resource (LUANAR). In Namibia, the selection of constituencies in each of the regions was random. Finally, samples of 97 and 100 farming households were randomly drawn from the three districts of central Malawi and five regions of northern Namibia, respectively.

The interviews targeted the head of the household or the spouse. In addition, four FGDs were conducted, each in Sharpvalley Extension Planning Area (EPA) in Ntcheu district, Mayani EPA in Dedza district, and Bunda EPA in Lilongwe district. In northern Namibia, the FGDs were conducted at Engela constituency in Ohangwena region. Finally, two and four agricultural extension staff from Malawi and Namibia, respectively, were interviewed as key informants to triangulate information obtained from household interviews and FGDs.

The farming households were mobilized and sampled with assistance from the Agricultural extension staff based at the Extension Planning Areas (EPAs) in Malawi and regional and constituency offices in Namibia. The interviews for the sampled households were conducted at their homesteads after explaining the objectives of the study and getting their consent. Demographic characteristics and ethnicity of the sampled households were documented. In order to identify the production constraints, a preliminary survey and literature review was conducted, and this led to the prioritization of eight (8) key challenges for farmers to rank using an adapted Hedonic scale of 1 to 8 (Mutoro, 2019) where one stood for the most critical challenge while eight stood for the least critical challenge. The scale of 1 to 8 was used because there were eight challenges

that were ranked. Preferred traits were identified by asking the farmers to list the three key traits they would prefer in a spider plant and thereafter rank the chosen traits on a scale of 1 to 3, where 1 represented the most important and three the third most important trait. The responses were triangulated through the FGDs and KIIs.

Data Analysis

Descriptive and chi-square statistics were performed to identify production challenges and trait preferences. Normality, equality of variance, and homoscedasticity assumptions were tested using Shapiro-Wilk ($p > 0.05$) (Shapiro and Wilk, 1965) and Wilcoxon tests (Ngome and Foeken, 2012) while nonparametric Levene tests ($p > 0.05$) (Nordstokke and Zumbo, 2010) was used to test the equality of variances for production constraints and trait preferences across countries and regions/districts. Pearson Chi-square test for independence was performed for variables with $<20\%$ of the cells having the frequency of five (5). For cells that had more than 20% of cells with a frequency of less than five, Fischer's exact test was used (Millot, 2011; Crawley, 2013). Nevertheless, a comparison between Pearson chi-square and Fisher's exact test produced similar output. The levels of agreement in the rankings amongst the farming households across the research sites and Countries was measured using Kendall's Coefficient of Concordance (W) (Kendall, 1939; Slotboom, 1987; Van den Brink and Koele, 2002). In order to identify the most critical production constraints, the Friedman test was used because the rankings were ordinal variables. For the groups in which the Friedman test showed that there were statistical differences, further *post hoc* tests using Wilcoxon signed-rank tests were done. All analyses were performed using Statistical Package for Socio Scientists (SPSS) for Windows, Version 20, NY: IBM Corp. Further ranking of the production constraints was done using a modified rapid informant rank, a model proposed by Lawrence et al. (2005) and cited in Hoffman and Gallaher (2007).

RESULTS

Demographic Characteristics

The majority of the participants were female-headed households (76.6%), constituting 61.9% in Malawi and 91.0% in Namibia. Married participants comprised 84.5% in Malawi and 44.0% in Namibia. The average household size was lower in Malawi (5) than in Namibia (11). The ages of the study participants ranged from 19 to 86 years in Malawi and 17 to 96 years in Namibia, with an overall mean of 48 years. The reproductive age category of 23 to 54 years comprised the majority of the participants in both countries. The respondents from Malawi were relatively younger (46.3 years) than those from Namibia (50.0 years). The average number of years spent in formal education ranged from 0 to 12 years. Using the number of years spent in formal education as a measure of literacy levels suggested that respondents from Namibia were more literate (6.56 years) than their counterparts in Malawi (2.31 years).

Production Constraints of Spider Plant Amongst Smallholder Farmers in Malawi and Namibia

Chi-square test and Pearson correlation showed that the ranking on each of the production constraints was independent of the farming households (S1), countries (Figure 1), and study sites in each of the two countries (Table 2).

The ranking of production constraints amongst households across the two countries and the study sites was statistically different ($p < 0.001$) (Table 2). In addition, Kendall's coefficient of concordance (W_a), which is a measure of the strength of agreement in rating different parameters, showed different levels of agreement on the ranking of the constraints affecting spider plants production amongst smallholder farmers across the study sites in the two countries. The strongest agreement in the scoring was observed amongst farmers of the Okavango region ($w = 0.864$), seconded by the Omusati region ($w = 0.651$), both in Namibia. There was generally a weak agreement, as shown by the low value of Kendall's coefficient, in the ranking of the production challenges amongst farmers in Malawi when compared to Namibia. The overall ranking ($w = 0.151$) was closer to zero than one, implying weak agreement on the scoring of the production constraints amongst the respondents.

The study identified lack of seed, low soil fertility, and poor seed germination as the most critical challenges, while diseases were perceived as the least amongst the eight factors studied. There were some consistencies in the ranking of the constraints amongst some study sites. For example, farmers in Dedza and Lilongwe scored lack of seed as the most critical challenge, seconded by poor seed germination and then low soil fertility, while farmers in Ntcheu considered lack of seed, drought, and lack of markets as the main challenges. There was consistency in the ranking of production challenges across the three tools used (household interviews, FGDs and KII) in the study areas of Malawi. In Namibia, low soil fertility was ranked as the most critical challenge in Omusati, Oshikoto, and Ohangwena regions, while lack of seed and drought were ranked number one problems in Oshana and Okavango regions. All the study regions in Namibia ranked diseases as the least problem except in the Okavango region, where lack of markets was considered the least challenge of the eight challenges under study (Table 2). The focus group discussion in Ohangwena highlighted low soil fertility and poor seed germination as the main challenges while the key informants suggested dry spells as amongst key challenges.

Comparative analysis using RIR identified spider plant production constraints in the same order as Friedman's test. Lack of seed was identified as the most important challenge with the RIR of 5.9, low soil fertility, and poor seed germination were identified as the second and third most important constraints with RIR = 5.3 and 4.9 respectively (Figure 2 and S2). Diseases were considered the least important. Separating the means using the Kruskal Wallis test showed statistical differences of the RIR between Malawi and Namibia

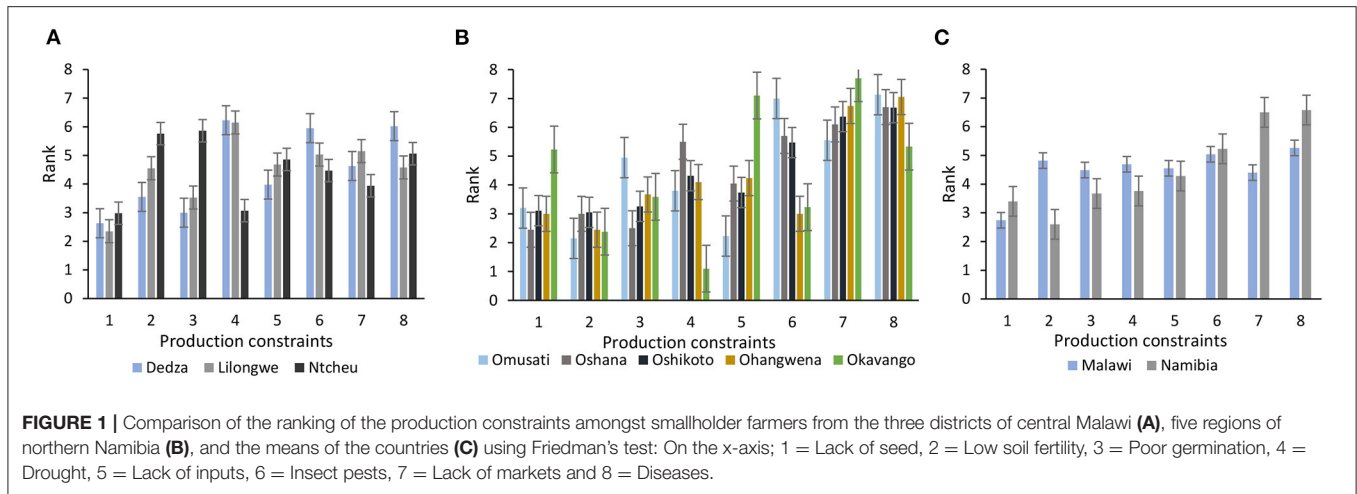


TABLE 2 | Mean ranking of the eight production constraints of spider plants amongst 197 smallholder farmers of central Malawi and northern Namibia using a scale of 1 to 8, where 1 represents the most critical constraint and 8 the least critical constraint.

Production constraint	Malawi (N = 97)				Namibia (N = 100)					Overall (N = 197)	
	Dedza	Lilongwe	Ntcheu	Mean	Omusati	Oshana	Oshikoto	Ohangwena	Okavango	Mean	
Lack of seed	2.63	2.35	2.98	2.74	3.20	2.45	3.11	3.00	5.23	3.40	3.07
Low soil fertility	3.55	4.55	5.76	4.82	2.15	3.00	3.05	2.45	2.38	2.60	3.70
Poor germination	3.00	3.53	5.86	4.49	4.95	2.50	3.26	3.67	3.59	3.67	4.08
Drought	6.23	6.15	3.07	4.69	3.80	5.50	4.32	4.10	1.10	3.76	4.22
Lack of inputs	3.98	4.68	4.86	4.55	2.23	4.05	3.74	4.24	7.10	4.28	4.41
Insect pests	5.95	5.03	4.47	5.04	7.00	5.70	5.47	3.00	3.23	5.23	5.13
Lack of markets	4.63	5.15	3.94	4.40	5.55	6.10	6.37	6.74	7.70	6.50	5.46
Diseases	6.02	4.58	5.06	5.26	7.13	6.70	6.68	7.05	5.33	6.58	5.93
Kendall's W	0.342	0.215	0.204	0.098	0.651	0.488	0.367	0.452	0.864	0.356	0.151
Chi-Square	71.758	30.144	67.031	66.525	91.133	68.317	48.745	66.395	120.916	249.38	207.908
P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

($p < 0.001$) except for lack of inputs and insect pests (Figure 2).

Spider Plant Agronomic Trait Preferences Amongst Smallholder Farmers of Central Malawi and Northern Namibia

Table 3 shows that high yield (27.5%) and drought-tolerant (28.3%) traits were the most preferred agronomic traits across the study districts of central Malawi. The majority of farmers in Dedza and Lilongwe districts perceived high yield as the most important trait, followed by drought tolerance, while farmers from Ntcheu district selected drought tolerance as the most preferred trait. Disease resistance had the least percentage in Malawi amongst the five major agronomic traits that were considered in this study.

In northern Namibia, 31.1% of farmers preferred the incorporation of drought-tolerant traits seconded by pest resistance (24.6%) in spider plants (Table 3). There was

consistency in selecting drought tolerance as the most important trait, seconded by pest resistance, across the regions of northern Namibia, except the Omusati region, which considered good germination (27.0%) as the second most important trait. Disease resistance was the least preferred trait in Namibia (10.0%).

There was consistency in the selection of the most important traits based on the percentages (Table 3) and the ranks (Table 4) across the two countries. Malawi ranked drought tolerance (1.57 ± 0.081) as the most preferred trait seconded by high yield (1.88 ± 0.093). In northern Namibia, drought was considered as the most important trait (1.14 ± 0.055) as well, and it was seconded by pest resistance (1.87 ± 0.050). The mean scores for the trait preferences were statistically different in both Malawi and Namibia ($p < 0.001$).

Normality tests using Kolmogorov-Smirnov and Shapiro-Wilk tests showed that the scores were not normally distributed ($p > 0.05$) (S3 and S4). In addition, the Lavene test for homogeneity also showed that the variances for the trait scores were not homogeneous.

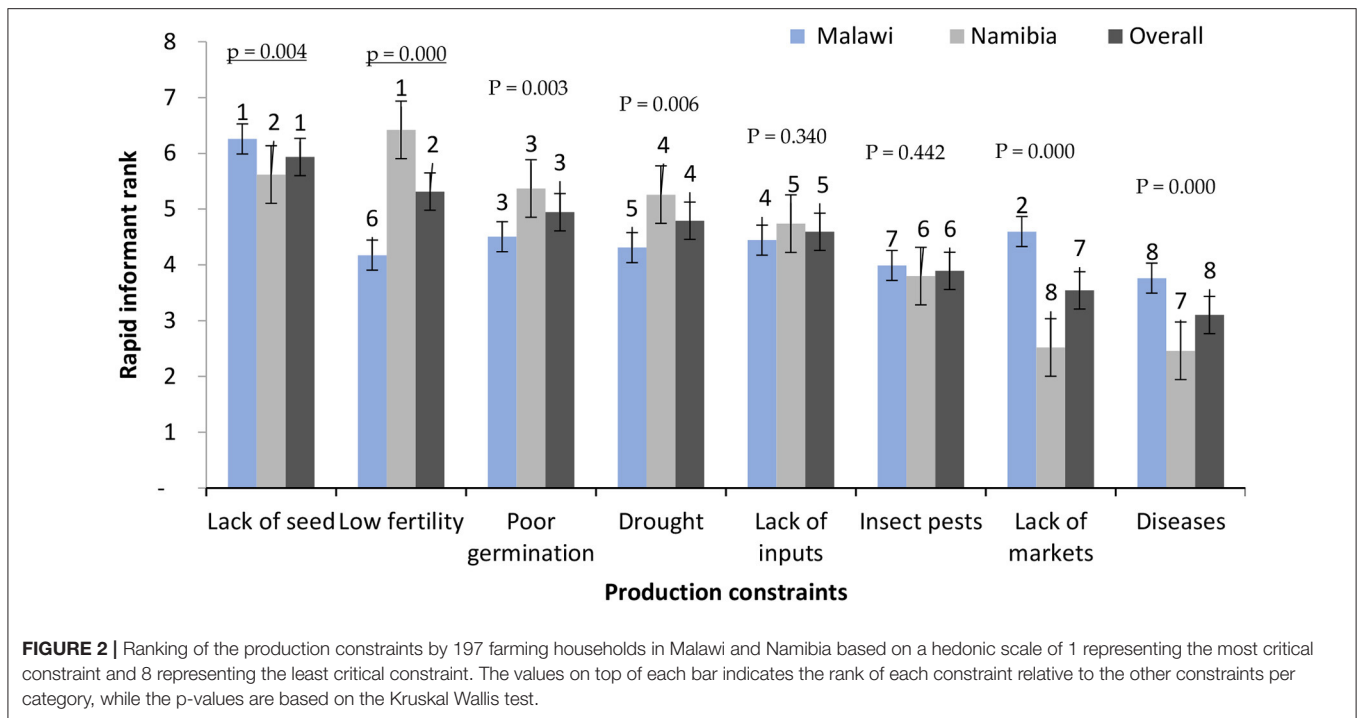


FIGURE 2 | Ranking of the production constraints by 197 farming households in Malawi and Namibia based on a hedonic scale of 1 representing the most critical constraint and 8 representing the least critical constraint. The values on top of each bar indicates the rank of each constraint relative to the other constraints per category, while the p-values are based on the Kruskal Wallis test.

TABLE 3 | Proportion of farming households from the three districts of central Malawi and the five regions of northern Namibia showing a preference for specific agronomic traits of spider plant traits.

		Preferred agronomic traits				
		Drought tolerance	Pest resistance	Disease resistance	High yield	Good germination
Central Malawi	Dedza (n = 78)	23.1	20.5	11.5	28.2	16.7
	Lilongwe (n = 60)	25.0	16.7	8.3	31.7	18.3
	Ntcheu (n = 127)	33.1	18.9	11.8	25.2	11.0
	Mean (n = 265)	28.3	18.9	10.9	27.5	14.3
Northern Namibia	Omusati (n = 63)	30.2	19.0	12.7	11.1	27.0
	Oshana (n = 59)	28.8	23.7	11.9	15.3	20.3
	Oshikoto (n = 53)	32.1	26.4	7.5	15.1	18.9
	Ohangwena (n = 59)	32.2	27.1	5.1	11.9	23.7
	Okavango (n = 46)	32.6	28.3	13	23.9	2.2
	Mean (n = 280)	31.1	24.6	10.0	15.0	19.3

DISCUSSION

Production Constraints of Spider Plant Amongst Smallholder Farmers

The main production challenges, which included lack of quality seed, poor soil fertility, poor germination and drought, relay bottlenecks associated with the popularization of not only spider plants but also other orphan indigenous vegetables in general and are consistent with findings from other studies (Chweya and Eyzaguirre, 1999; Abukutsa-Onyango, 2007; Onyango et al., 2013). The observed statistical differences in the ranking of production constraints across the study districts of central Malawi and study regions of northern Namibia suggest differences in biophysical and socio-economic contexts

in the two countries that might have influenced the farmers’ ranking. Although this study did not explore the effects of specific biophysical and socioeconomic factors on the ranking of production constraints, literature suggests that climatic uncertainty, pests and diseases prevalence, labor availability, lack of seed, soil fertility, availability of land, access to inputs and availability of water could be some of the factors that influence farmer’s perceptions (Riar et al., 2017).

The main challenges were unavailability of seed and low soil fertility in Malawi and Namibia, respectively. The statistical differences ($p < 0.001$) in the ranking of the production traits between the countries might be due to the differences in the factors affecting seed availability and the soil requirements of spider plants. According to the findings from the FGD and KII,

TABLE 4 | Preference of the spider plant traits across the study sites in Malawi based on three choices as the most important trait (1), second most important trait (2), and third most important trait (3).

Preference level	Central Malawi		Northern Namibia		Overall	
	Score	Rank	Score	Rank	Score	Rank
Drought tolerance	1.57 ± 0.081	1	1.14 ± 0.055	1	1.34 ± 0.05	1
Pest resistance	2.10 ± 0.104	3	1.87 ± 0.050	2	1.97 ± 0.053	2
High yield	1.88 ± 0.093	2	2.67 ± 0.074	4	2.17 ± 0.074	3
Disease resistance	2.17 ± 0.132	5	2.18 ± 0.104	3	2.18 ± 0.083	4
Good germination	2.16 ± 0.144	4	2.91 ± 0.040	5	2.60 ± 0.074	5
Mean			1.99 ± 0.049		1.95 ± 0.035	
<i>P</i> -value	> 0.000		> 0.001		> 0.000	
Lavene test	0.063		<i>P</i> = 0.000		<i>P</i> = 0.000	

the farmers from the three sites of Malawi were exposed to spider plant production through a project that was implemented by the Lilongwe University of Agriculture and Natural Resources (LUANAR), which had been phased out before the farmers could establish a means of sustainable seed production. The project might have raised the demand for seed without necessarily putting mechanisms for sustainable seed production at either the household level or at a commercial level. This claim, however, needs further investigation to establish the effective demand for seed and identify any prevailing seed multiplication initiatives which might have been noticed during this study. For decades, spider plant has been considered as semi-wild and a vegetable for the poor in the society (Shilla et al., 2019) leading to lack of motivation to start own production. The bias toward exotic vegetable species could be one of the reasons why spider plants remained semi-wild and without any commercial seed production initiatives in both countries. Govindasamy et al. (2020) reported widespread use of recycled poor quality seed of indigenous vegetables in Zambia, which could be a reflection of the high cost of certified seed, amongst other factors, thus leading to low production of the species. Due to the constrained land holding capacity of 0.7 ha per household in Malawi (<https://www.ccardesa.org/malawi>), there were not many fields lying fallow where spider plants could grow naturally. The plants growing in the crop fields were more often pulled out as weeds before reaching maturity, as per the observations from FGDs, thus leading to declining trends in spider plant diversity (Chataika et al., 2010). The declining trends in soil seed banks point to the need to embark on seed production. On the contrary, landholding size in northern Namibia is large (Gonye et al., 2017), and farmers could afford to leave some fields fallow, thus allowing spider plant to grow naturally in the rainy season (Chataika et al., 2010). Farmers used to harvest the spider plants during the rainy season and process it for use in the dry season. This could have been one of the reasons why lack of seed was the second major challenge after low soil fertility in northern Namibia.

The study regions of northern Namibia comprised generally of poor sandy soils when compared to the soils of Dedza, Ntcheu, and Lilongwe. Cambisols and Luvisols, which were the characteristic of the study sites in Malawi, are naturally endowed

with good chemical properties (Vargas and Omuto, 2016) that make them more fertile than the calcisols found in the study sites of Namibia. Literature suggests that spider plants grow in abundance in fertile soils (Chataika et al., 2010; Gonye et al., 2017). This might explain why farmers in northern Namibia considered poor soil fertility one of the most critical challenges. Transect walk in the fields of farmers in Malawi and Namibia showed that spider plants growing in fertile soils were generally taller and more vigor than those growing in poor sandy soils, confirming the importance of soil fertility in promoting the production of spider plants.

Poor germination was another challenge that was more pronounced in northern Namibia than in Malawi. The findings are consistent with several studies which identified poor germination and seed dormancy as important production constraints of spider plants (Abukutsa-Onyango, 2007; Oluoch et al., 2009; Tibugari et al., 2012; Ndinya et al., 2020). Ngoze and Okoko (2003) demonstrated that the use of good seed has the potential to contribute about 30 percent to the total crop production. Researchers have worked on improving the germinability of spider plants (Mashingaidze, 2000; Ekpong, 2008; Tibugari et al., 2012; Shilla et al., 2016; Blalogue et al., 2020) but have not been successful in attaining the recommended rate of 85% (Abukutsa-Onyango, 2007). Different researchers (Shilla et al., 2016) recommended further studies on a more diverse and large number of accessions taken from different storage periods to address the contrasting observations on the low germination rate of *G. gynandra*.

Drought was amongst the four key challenges that affected the production of spider plants across the two countries. This is consistent with several authors who singled out frequent droughts in many parts of sub-Saharan Africa (SSA) as causing devastating impacts on agriculture and food security (Benson and Clay, 1998; Chabvungma et al., 2015; Katengeza et al., 2018). Drought was particularly mentioned as the main challenge in Sharpevely, Ntcheu district, possibly because this area experiences frequent droughts, being on a lee-ward side of the Kirk range mountains. In contrast, the sites in Dedza and Lilongwe were associated with lower temperatures and higher rainfall; as such, farmers did not consider drought as a main challenge. In a related study, Abukutsa-Onyango (Chauvin et al.,

2012) observed that spider plants are susceptible to water stress implying that they could not survive in drought conditions. Furthermore, water stress was found to be one of the major constraints in vegetable production in peri-urban areas of Botswana (Madisa et al., 2010).

The identified key production challenges provide a platform for targeted agronomic and plant improvement research that would respond to the needs of the farmers and other players in the value chain, hence promising high acceptance and adoption of the generated technologies. Research aimed at availing better quality seeds, introducing drought-tolerant traits in adaptable accessions, breaking seed dormancy coupled with identification of optimum nutrient levels would likely lead to higher yields and influence farmers to adopt the cultivation of spider plants. The increased production and productivity of spider plants would in turn contribute to attaining the recommended vegetable intake of 73 kg per capita per annum (Yang and Keding, 2009).

Spider Plant Trait Preferences Amongst Smallholder Farmers of Central Malawi and Northern Namibia

Crop production decisions are a reflection of the farmer's preferences and are based on the incentives and restraints associated with agricultural systems. This implies that knowledge of farmer-preferred crop attributes can provide useful guidance for helping researchers to design plant breeding programs that would likely enhance adoption (Baidu-Forson J. et al., 1997) and hence contribute to improving productivity and incomes (Baidu-Forson J. J. et al., 1997). Drought tolerance was the most preferred trait both in Namibia and Malawi. In the recent past, droughts have become more frequent and intense, leading to devastating effects on a growers' harvest. This has led farmers to consider drought tolerance as one of the most important traits. Drought-tolerant varieties can enable farmers to adapt to the changing conditions to deliver greater yield to sustain the increasing population, which is estimated at 9 billion people by 2050 (Loboguerrero et al., 2019). In sub-Saharan Africa, where climate variability already limits agricultural production, 95% of food comes from rain-fed farms. There is, therefore, a need to prioritize the development of drought-tolerant varieties of *G. gynandra*. Since information on the genetic control of drought is not available in *G. gynandra*, Sogbohossou et al. (2018) suggested the use of information from well-studied sister species, such as *A. thaliana* (Bouchabke et al., 2008; Liang et al., 2011) and *Brassica* spp. (Wu et al., 2012; Zhang et al., 2014) to facilitate the genetic characterization for drought. Nhamo et al. (2019) reported the highest occurrences of drought in Africa, in 2015/16 season, affecting over 410 million people and causing economic damage of over USD 6.4 billion. The Southern African Development Community (SADC), to which Malawi and Namibia belong, was the most affected. This is because most of the region is characterized by a semi-arid climate, and the economies are heavily dependent on climate-sensitive rain-fed agriculture.

In addition to drought tolerance, farmers also preferred genotypes resistant to pests, particularly because of their

implications on the cost of production and quality of leaves. It was observed that farmers across the two countries were aware of the additional costs associated with managing pests in susceptible varieties and also the low market value of the leaves damaged by pests. The finding agrees with Nakyewa et al. (2021), who identified pest resistance to be amongst the farmer preferred traits in *Solanum aethiopicum* L., Shum., after high seed and leaf yield. Ndinya et al. (2020) observed that farmers considered pest and disease resistance as the second most important criteria for accepting a variety after considering good germination (Ndinya et al., 2020), thus underpinning the importance of pest resistance. Furthermore, farmers were cognizant that pest infestation would lead to reduced leaf yield and that the damaged green leaves fetched less money at the markets. During FGDs, researchers came across a rare situation where some participants indicated that some consumers preferred damaged leaves as a manifestation that the vegetables had not been treated with chemicals, which could potentially be a health hazard. The observation suggests an emerging class of consumers who are health conscious, as observed by other researchers. The development of pest-resistant varieties would, therefore, not only increase leaf yield and quality but also reduce environmental damage associated with the use of pesticides, reduced cost of production, increased market prices and increased trust from consumers who pay particular attention to healthy foods (Bruschi et al., 2015).

High leaf yield was another trait that was rated high amongst the smallholder farmers, particularly in Malawi. In Namibia, the preferences on drought tolerance and pest resistance were aimed at improving leaf yield and quality as an ultimate goal, as confirmed through FGDs and KII. The finding implies that any other agronomic and physiological factors associated with improved yield would likely be preferred by farmers. For example, genotypes with numerous broader leaves would likely be preferred by farmers as observed in Kenya (Mutoro, 2019), where farmers ranked spider plant genotypes based on the number of leaves per stem. In other studies, seed viability and germination, color, number of branches, maturity time, taste, and trichomes density were considered as some of the characters farmers used for selecting or rejecting a variety (Ssozi and Akundabweni, 2012; Mutoro, 2019; Ndinya et al., 2020).

The findings suggest that cultivar development needs to take into account preferences amongst stakeholders in the value chain, including adapting to various environmental and ecological considerations. The involvement of relevant stakeholders in the development of new cultivars would assist breeders in including desired traits which would lead to reducing adoption bottlenecks and enhancing the acceptability of the new varieties (Adeniji and Aloyce, 2013).

CONCLUSIONS

The study identified lack of seeds, poor soil fertility, poor germination, and drought as the main production

challenges in central Malawi and Northern Namibia. Drought tolerance, high yield, and pest resistance were considered the most preferred agronomic traits of spider plants. The findings of the study will help researchers, specifically breeders, develop varieties by prioritizing traits that are likely to address priority challenges and, at the same time, incorporating the desired attributes in order to gain acceptance by the farming communities. The ultimate goal of the spider plant breeding program, therefore, should aim at increasing leaf yield as a quantitative character while addressing the identified production challenges and preferred agronomic traits.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

BC: conceptualization, methodology, software, formal analysis, investigation, writing—original draft preparation, visualization, and data curation. BC, LA, EA-D, and JS: validation. EA-D: resources and funding acquisition. BC, LA, JS, EA-D, DS, KK, and SA: writing—review and editing. LA, EA-D, JS, and KK: supervision. EA-D and LA: project administration. All authors have read and agreed to the published version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fsufs.2022.831821/full#supplementary-material>

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