Journal of Ethnic Foods

ORIGINAL ARTICLE

Open Access

Distribution, traditional utilization, processing, and health benefits associated with the consumption of morama bean [*Tylosema escululetum* (Burch.)]: a survey from selected districts of Botswana

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Abstract

Morama bean [*Tylosema escululetum* (Burch.)] is a nutrient-dense underutilized legume that can address protein-energy and micronutrient malnutrition in developing countries. An ethnographic study using a snowball sampling method was conducted in Kweneng, Ghanzi, Southern, and Central districts of Botswana. The survey sought to gather and document information about demographic characteristics, traditional use, cultural norms, harvesting, processing, preservation, and health benefits of morama beans. A 5-point Likert-type scale was used to assess and rate the respondent(s) perceptions on traditional utilization and potential of the bean. The data was analyzed using Statistical Package for the Social Sciences (SPSS) and thematic grouping. It was found that morama bean is distributed in Botswana's sandy desert regions and is consumed by people who are native or migrated into these areas. Roasting in heated sand (mean = 4.93) and boiling fresh beans with water or milk (mean = 4.49) were the most popular methods of cooking morama beans. Across the four districts, morama bean was found to be an important component in traditional food and medicinal mixtures for undernourished infants, and expectant and lactating mothers, mostly prepared with soft porridge. Respondents cited a significant lack of scientific knowledge about the bean's medicinal properties (mean = 1.27–1.38), indicating the need for additional research. The nutritious density of morama beans (mean = 4.87) and their potential for processing into value-added products (mean = 4.10) were known to the respondents. As a result, the bean has a high potential to improve food and nutrition security in these communities.

Keywords Botswana, Morama bean, Indigenous knowledge, Indigenous foods, Traditional processing, Food and Nutrition security

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Introduction

Worldwide population expansion is driving up food demand [1]. The demand for nutrient-dense plant-based foods is growing throughout sub-Saharan Africa presenting a significant opportunity to support rural populations' income, health, food, and nutrition security [2]. Indigenous edible plants in Botswana are consumed in diverse amounts, forms, and dietary combinations, which helps to supplement staple diets [3]. Legumes have many functional properties in food applications, such as gelling, oil absorption, water retention, pasting, and foaming. In addition, they are also widely used as animal protein substitutes [4]. Plant-based foods have historically played a significant role in the lives of the tribes who live in Botswana, serving as a source of food, cultural heritage, medicine, and income [5].

Morama bean [*Tylosema escululetum* (Burch.)] is a nutrient-dense wild legume, naturally abundant in some South African countries such as Botswana, South Africa, and Namibia with huge potential for domestication [2, 6]. This leguminous plant grows freely in the veld, yielding pods that usually contain two, but occasionally up to six brownish spherical seeds containing a ripe white bean [7, 8]. Despite limited research resources, plans are being put forward to develop wild-growing legumes known as 'orphan legumes' [6, 9]. This includes morama beans through crop breeding to produce domesticated high-yielding and early maturing alternatives [6]. Morama bean is a hardy plant because it flourishes in unfertile soils and high temperatures and has huge potential in food-to-food fortification applications [2, 10]. However, its incorporation in food formulations remains limited [2]. Morama plant is native to the Kalahari Desert, and it is known for its beans that are rich in fat or lipid (24–48%) and protein (29–39%) [2, 11]. This makes morama beans a great source of lipids and plant-based protein. Soybean contains about 35–45% protein and 15–25% fat [12]. Lokuruka [13] reported 45 g/100 g protein and 25 g/100 g fat in soybeans, in addition, 25 g/100 g protein and 50 g/100 g fat in groundnuts. This implies that morama bean has higher fat content and similar protein content as soybeans.

Groundnuts and morama beans have similarities in terms of their lipid or fat content, however, morama bean has a higher total protein level. The fatty acids profile of morama bean is rich in healthy mono- and di-unsaturated fatty acids; oleic acid (42.16% of total fatty acids), linoleic acid (31.11% of total fatty acids), and palmitic (13.80% of total fatty acids) [14, 15]. These fatty acids are crucial for various bodily functions, including maintaining cell membrane integrity, supporting cardiovascular health, and providing anti-inflammatory benefits [16]. The bean is a good source of minerals such as iron (3.95 mg/100 g), zinc (6.2 mg/100 g), magnesium (274.5 mg/100 g), and diverse phytochemical compounds comparable to common legumes such as soya and groundnuts [2, 11]. Previous research points morama bean being a good source of B vitamins, such as folate and vitamin ADEK [14, 17]. Vitamin E has substantial antioxidant properties and is found in significant amounts in morama beans [14, 18]. Tocopherols, important vitamin E isomers, have been investigated in morama beans [18, 19]. Mitei et al. [19] reported 199.10 μg/g total tocopherols in morama bean. Previously, the concentrations of alpha and gamma-tocopherol in morama beans have been reported to be 113 μg/g db and 339 μg/g db, respectively [18]. Anti-nutrients are naturally occurring components found in plant-based diets [20]. Oxalate, cyanogenic glycosides, saponins, tannins, phytate, gossypol, lectins, protease inhibitors, amylase inhibitors, and goitrogens are all found in varying amounts in plants [21, 22]. The composition of several of these components in the case of the morama bean is not well understood or researched [23]. However, because these substances decrease the gut's ability to absorb and digest nutrients, their presence in the diet continues to be a serious concern [20].

Similarly to soybeans, morama bean is a great source of protein since it contains all the essential amino acids in different amounts [11]. Its amino acid profile is dominated by non-essential amino acids glutamic acid, aspartic acid, and tyrosine [11, 14, 24]. However, of major concern, the sulfur-containing amino acids methionine (0.05 g/100 g) and cystine (0.55 g/100 g) are markedly low in the bean [14]. Methionine is one of the essential amino acids that the body cannot produce and can only be obtained from the diet [14]. Similarly to morama bean, soy protein is devoid of sulfur-containing methionine despite being known to be well-balanced in amino acid profile [25]. The utilization of plant-based proteins in meals is gaining popularity throughout the world [26]. This is due to their numerous uses for both edible and non-edible functions, including their biodegradable nature [26, 27]. Since plant-based proteins are more environmentally friendly than those derived from animals, they may help address the current climate change challenges worldwide [26]. In this regard, the potential of proteins derived from sustainable sources, such as morama beans, might be investigated in the joint battle against climate change and protein malnutrition [26, 27].

According to FAO, more than 3.1 billion people (42%) could not afford nutritious diets in 2021 [28]. Worryingly, there is a risk that new, advanced plant-based products will only be available to a select few affluent people [17]. Consequently, this may make it difficult for underprivileged, marginalized individuals to obtain enough nutrient-dense food. In the case of Botswana, marginalized

groups remain in a precarious state in terms of their nutritional and poverty status [29]. Botswana is currently faced with several socioeconomic issues. They include unemployment (above 20%) and a high prevalence of poverty in rural areas in some settlements estimated at 46% [30]. This is despite efforts by the government of Botswana to improve rural dwellers' livelihoods. Social inclusion policies, rural employment opportunities, and agricultural-oriented poverty eradication programs have been developed [29, 30]. However, the livelihoods of many people in rural Botswana are still hugely dependent on natural resources. Thus, indigenous plants such as morama beans make up a large proportion of the diets of marginalized groups [7, 31]. Achieving zero hunger by 2030 and eliminating poverty are two Sustainable Development Goals [28] that could enhanced by the use, value addition, and promotion of morama bean and its byproducts.

Morama bean is a major part of the diet of the native Khoi San tribe of the Kalahari region [17]. Some other tribes also consume it to some extent; for instance, the Herero and Tswana populations reside in areas where morama beans are abundant [7]. However, despite its nutritional advantages, morama bean remains neglected and underutilized [2]. This is partly due to limited knowledge about the bean because it mainly grows only in certain secluded desert areas. In addition, knowledge about the bean is still considered sacred, safeguarded, and only understood by a few among the tribes where it grows. Traditional healers are among the few people in this population group who are knowledgeable and appear to safeguard the information [32]. In a previous study, Chigwaru [32] sought to learn more about the health advantages of morama beans in two regions of Botswana: Jwaneng and Gantsi. However, no study has thoroughly investigated the traditional uses, cultural norms, harvesting, processing, and health advantages of the morama bean in the areas where it is consumed. Overall, it remains imperative that morama bean utilization is promoted as an important component of improved food formulations for marginalized populations and wider food applications. This survey study aimed to gather and document information on the traditional use, cultural norms, harvesting, processing, and health benefits of morama beans to form the basis for subsequent scientific studies on the commodity.

Methodology

Study design and area

An ethnographic survey design was used since the study targeted a particular community [33] that is involved in morama bean utilization. The study was conducted in four districts of Botswana as shown in Fig. 1 and several villages in each selected district. The districts and villages were purposively selected because the morama bean only grows in these districts which are commonly dominated by sandy desert soils [7]; hence the dwellers were considered credible sources of the study [34]. The districts and villages selected were Kweneng (Malwelwe, Maboane, and Tsetseng), Ghanzi (D'Kar, Gantsi, East and West Hanahai, Chobokwane and Charleshill), Southern (Maokane, Mokhomma and Gasita) and Central (Kuugae, Malatswai and Khwee). A snowball sampling method was used in this study since the targeted size of the population was not known. Not everyone in the study area is into morama bean utilization. Therefore, the sample size was based on chain referral since the population is considered hidden and snowball was the only alternative for random sampling [35, 36]. Global Positioning System (GPS) coordinates for the study areas were recorded.

Survey and interviews

A pre-tested structured questionnaire and KoboCollect application downloaded on laptops and mobile phones were used for primary data collection. Data collection was done between September and October 2023. In each village, the village chief was consulted to request consent for the survey to be carried out. Face-to-face interviews were conducted. Interviews were conducted with 221 respondents reached through chain referral, of whom 54 were from Kweneng, 62 were from Ghanzi, 50 were from the Southern district, and 55 were from the Central district. The sample size was considered satisfactory because it is more than 100, and the analysis was based on descriptive statistics and ANOVA, thus limiting the chance of standard errors of parameter estimates being affected [37]. In some villages, locals pinpointed valuable key informants mainly adults, traditional healers, and birth attendants with an intensive knowledge of morama bean to approach and interview. The interviews began with a brief awareness of the purpose of the survey and how it would be conducted. The survey questions covered demographic characteristics, traditional use, cultural norms, harvesting, processing, preservation, and health benefits of morama beans. Respondents' opinions regarding the potential, health benefits, traditional use, and obstacles to morama bean consumption were evaluated using a 5-point Likert-type scale. The Likert scale is a well-established tool designed to assess human attitudes, offering strong psychometric qualities and flexibility. Using a 5-point Likert-type scale, respondents rated Likert-type items according to how much they agreed or disagreed: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree [38, 39]. Participants demonstrated the traditional roasting method of morama bean

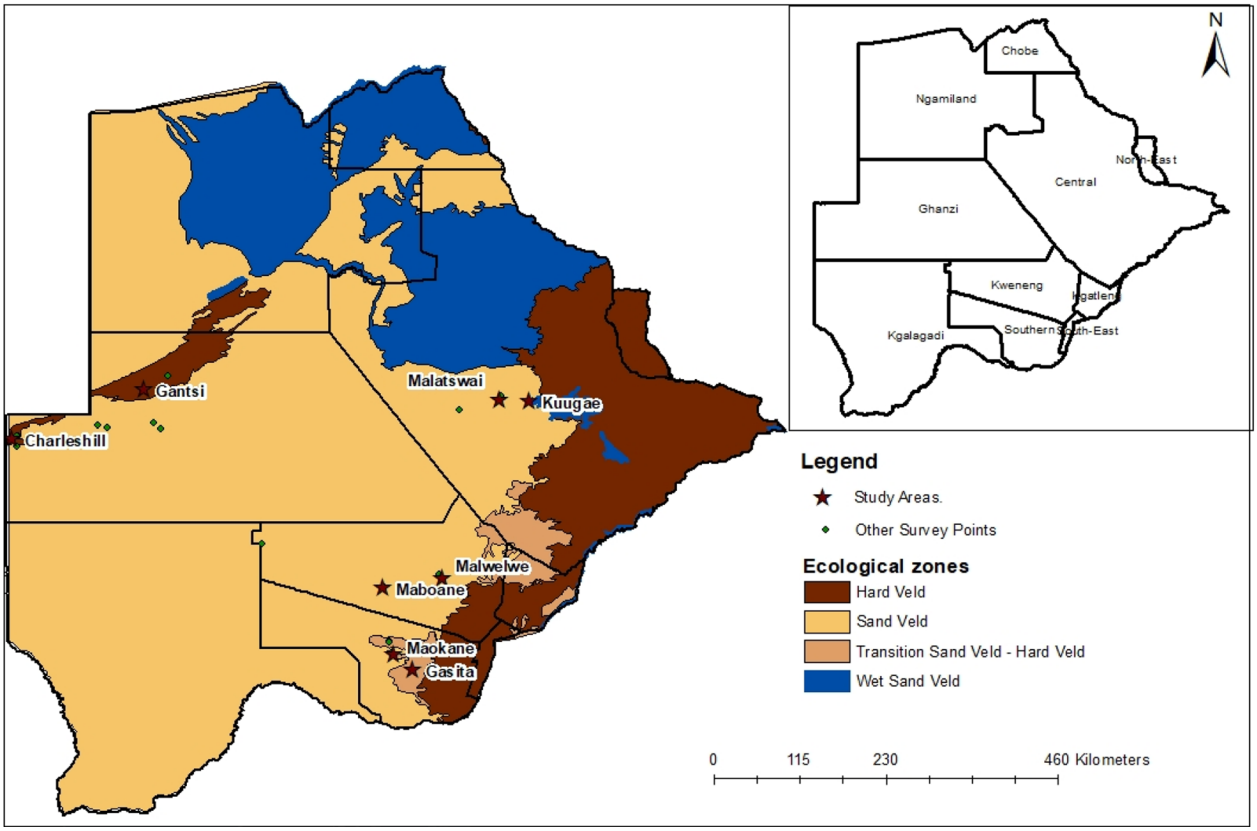

Fig. 1 An ecological zone-based map of Botswana that displays survey areas and sample collecting locations

in Malwelwe village (23.98° S and 25.24° E). During the activity, images and observations were recorded.

Data analysis

Data analyses were performed using Statistical Package for the Social Sciences (SPSS) IBM version 20 (Armonk, New York). Descriptive analysis was performed to obtain frequencies, means, and standard deviations of quantitative data. The Likert-type data was analyzed using frequency (percent frequency), means calculated on a scale of 1 to 5, and standard deviation. Where the following class intervals were used to range the means, (≤ 1.45) = strongly low perception, (1.46–2.45) = low perception, (2.46–3.45) = moderate perception, (3.46–4.45) = high perception, (≥ 4.46) = strongly high perception [38, 40]. Qualitative data was summarized and analyzed by thematic grouping. It is hypothesized that morama bean's geographical location will not significantly impact the use and processing techniques. One-way analysis of variance (ANOVA) was conducted to assess if there is a difference [39] in the traditional processing of morama beans across the four districts. Tukey HSD test was conducted as a post-hoc analysis to identify differences in morama bean traditional processing within the four districts.

Results and discussion

Demographic household characteristics of participants and distribution of morama bean in Botswana

Gender, age, tribe, marital status, family dynamics, academic qualification, employment status, source of income, and government assistance provided to households were among the socioeconomic characteristics gathered in the study. Most responders were females in the four study regions (Table 1). Across the districts, 104 (47.1%) of the respondents were men, and 117 (52.9%) were women. In this study, the proportion of women was marginally higher than men. However, according to Kgosikoma et al. [41], currently morama bean sales primarily benefit women and children. Since women and children are viewed as the most vulnerable members of Botswana's rural communities, improving their standard of living is crucial [29, 41]. Most respondents ranged between 25 and 64 years (66.1%). This is a category of prime able working group. The youth, 18–24 years of age made up 15.4% of the respondents while 18.6% were the elderly (65 years and above). The elders were valuable

Table 1 Demographic household characteristics of participants from four districts of Botswana

	Kweneng ($n=54$)		Ghanzi ($n=62$)		Southern ($n=50$)		Central ($n=55$)		Total ($n=221$)
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency	
Gender									
Female	32	59.3	33	53.2	26	52	26	47.3	117 (52.9%)
Male	22	40.7	29	46.8	24	48	29	52.7	104 (47.1%)
Age group									
18–24 years	8	14.8	9	14.5	10	20	7	12.7	34 (15.4%)
25–64 years	34	63	46	74.2	28	56	38	69.1	146 (66.1%)
65 + years	12	22.2	7	11.3	12	24	10	18.2	41 (18.6%)
Marital status									
Single	41	75.9	35	56.5	22	44	14	25.5	112 (50.7%)
Married	8	14.8	12	19.4	13	26	14	25.5	47 (21.3%)
Cohabiting	1	1.9	15	24.1	7	14	17	30.9	40 (18.1%)
Widow	3	5.6	0		7	14	10	18.1	20 (9.0%)
Divorced	1	1.9	0		1	2	0		2 (0.9%)
Head of the family									
Husband	15	27.8	18	29.0	18	36	15	27.3	66 (29.9%)
Wife	10	18.5	3	4.8	0		1	1.8	14 (6.3%)
Single mother	17	31.5	13	21.0	12	24	15	27.3	57 (25.8%)
Bread winner	12	22.2	28	45.2	20	40	24	43.6	84 (38.0%)
Gender of breadwinner									
Female	4	33.3	8	28.6	8	40	3	12.5	23 (27.4%)
Male	8	66.7	20	71.4	12	60	21	87.5	61 (76.2%)
Size of household									
Less than 5	17		23		32	64	31	56.4	103 (46.6%)
6–10	28		31		17	34	23	41.8	99 (44.8%)
10 +	9	16.7	8	12.9	1	2	1	1.8	19 (8.6%)
Highest level of academic qualification									
None	16	29.6	16	25.8	8	16	25	45.5	65 (29.4%)
Primary	10	18.5	14	22.6	10	20	9	16.4	43 (19.5%)
Junior SS	20	37.0	18	29.0	18	36	13	23.6	69 (31.2%)
Senior SS	7	13.0	4	6.5	9	18	5	9.1	25 (11.3%)
University	1	1.9	10	16.1	5	10	3	5.5	19 (8.6%)
Employment status									
Not working	34	63	22	35.5	24	48	31	56.4	111 (50.2%)
Part time	15	27.8	9	14.5	9	18	5	9.1	38 (17.2%)
Casual employment	3	5.6	9	14.5	7	14	16	29.1	46 (20.8%)
Full time	2	3.7	5	8.1	10	20	3	5.5	26 (11.8%)
Source of income									
Livestock keeping	2	3.7	10	16.1	5	10	4	7.3	21 (9.5%)
Crop farming	11	20.4	7	11.3	1	2	0		19 (8.6%)
Mixed farming	18	33.3	15	24.2	28	56	0		61 (27.6%)
Agricultural business	3	5.6	5	8.1	0		0		8 (3.6%)
Non-agricultural business	10	18.5	13	21.0	7	14	32	58.2	62 (28.1%)
None	10	18.5	12	19.4	9	18	19	34.5	50 (22.6%)
Government assistance									
Yes	14	25.9	8	12.9	13	26	9	16.4	44 (19.9%)

Table 1 (continued)

	Kweneng (*n* = 54)		Ghanzi (*n* = 62)		Southern (*n* = 50)		Central (*n* = 55)		Total (*n* = 221)
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency	
No	40	74.1	54	87.1	37	74	46	83.6	177 (80.1%)
Tribe									
Bakgalagadi	53	98.1	19	30.6	6	12	0		78 (35.3%)
Basarwa	0		29	46.8	0		51	92.7	80 (36.2%)
Bangwaketse	0		3	4.8	39	78	1	1.8	43 (19.5%)
Baherero	0		10	16.1	0		0		10 (4.5%)
Batswapong	0		0		1	2	0		1 (0.5%)
Bakalaka	1	1.9	0		0		1	1.8	2 (0.9%)
Barolong	0		0		4	8	0		4 (1.8%)
Bapedi	0		0		0		1	1.8	1 (0.5%)
Bakgatla	0		1	1.6	0		0		1 (0.5%)
Bakwena	0		0		0		1	1.8	1 (0.5%)

key informants for the study due to their knowledge and experience in morama bean use. According to Mogopodi et al. [42], natives in the study communities continue to be extremely important because of their extensive knowledge and expertise in the sustainable use and protection of indigenous knowledge and indigenous plants like the morama bean.

The morama bean is abundantly distributed in wild Botswana's sandy desert regions. As depicted in Fig. 1, the bean tends to grow well in the sand veld ecological zone or between the peripheral areas between the sand and hard veld zones. These areas are usually characterized by infertile soils, long dry periods, and high temperatures of about 28–37 °C [2]. There is a great diversity of tribes in Botswana, and each one is territorial in its area [43]. As expected in study areas, most respondents were Basarwa (36.3%), followed by Bakgalagadi (35.2%). The Basarwa tribe also known as the Khoi San are the original inhabitants of the Kalahari Desert and are the major consumers of morama bean [17]. In the Sesarwa/Khoi San language, the bean is called *qhwii* (Table 2). As observed in this study, Bakgalagadi which means people of the Kalahari, are also the major consumers of morama bean. In Sekgalagadi, the morama bean is known as *riqhama/dithama.* Morama bean is also found in large quantities in the Southern district (Fig. 1). The Bangwaketse tribe resides in the Southern district in considerable numbers [44]. In the Southern District, 78% of the respondents were Bangwaketse, and 12% were Basarwa. The Ovaherero tribe, who also resides in the Ghanzi district, consumes morama beans to some extent. In the Ovaherero language, the bean is known as *ombanui* (singular) or *ozombanui* (plural) (Table 2). The bean is also known by several colloquial names, including *braaiboonjie, moramaboontjie, elandboontjie* (Afrikans); gemsbok bean (English); morama, *marama,* (Tswana); *marumana* (Thonga); *tsi, tsin* (San) and *gami* (Khoi) [11, 45]. A small number of other tribes have moved to locations where morama beans are present and as a result, they use the beans to some extent. Family dynamics naturally portrayed men as the heads of their households, either as breadwinners or husbands (Table 1).

Based on the study, morama bean grows in areas with a high prevalence of illiteracy and unemployment. A large proportion of the respondents did not have any formal education (29.4%) or at least completed lower levels of education, junior secondary (19.5%) or senior secondary education (31.2%). As expected, the study population had university representation (8.6%). Many of the study population were not working or not formally employed. Overall, slightly more than half (50.2%) of the respondents were not working at all or at least depended on part-time (17.2%) or casual employment (20.8%). Only a mere number, 11.8% had formal full-time jobs with fewer of them in Kweneng (3.7%) and Central district (5.5%). This demonstrates that the Basarwa (*San*), who made the most of this study population, are not reliant on formal employment and have long been well-known hunters and gatherers [47].

Despite the Botswana government's effort to extend resources to these population groups [30], they are still reluctant to formal education and job opportunities. Based on study observations and interviews, Basarwa found in Ghanzi and Central district remain dependent on selling traditional medicinal herbs and mixtures to sustain their livelihoods. Based on observation, they sell a wide range of native seasonal wild fruits and edible plants such as morama bean. Unlike other tribes in Botswana,

Table 2 Traditional knowledge, utilization, harvesting, processing, and preservation of morama bean in four districts of Botswana

	Kweneng	Ghanzi	Southern	Central
Native name (s)	Morama (Setswana) Riqhama/dithama (Sekgalagadi)	Morama (Setswana) Riqhama/dithama (Sekgalagadi) Qhwii (Sesarwa) Ombanui (singular)/Ozombanui (plural) [Otjiherero]	Morama (Setswana)	Morama (Setswana) Qhwii (Sesarwa)
Edible parts	Ripe bean and immature root (mature roots are not consumed)	Ripe bean and immature root (*sesuane*)	Ripe bean and immature root (*sesuane*)	Ripe bean and immature root (*sesuane*)
Bean maturity period	3 to 4 months. October/November (flowering) to January/February (ripens)	3 to 4 months	3 to 4 months	3 to 4 months
Harvesting season	February (fresh green beans) to winter season (dry beans)	February (fresh green beans) to winter season (dry beans)	February (fresh green beans) to winter season (dry beans)	February (fresh green beans) to winter season (dry beans)
Consumption patterns in society and cultural norms	All population groups consume the bean (infants, children, pregnant mothers, ailing patients, lactating mothers, adults, and elderly) No cultural norms reported	All population groups consume morama beans No cultural norms associated with morama bean were reported	All population groups consume morama beans No cultural norms were reported	All population groups consume morama beans No cultural norms were reported
Description of sensory parameters (taste and texture)	Tastes like peanuts/groundnuts Not bitter when roasted unless overly roasted	Tastes like peanut butter and peanuts It has too much oil hence the soft texture	It tastes like peanuts when roasted with a pleasant nutty smell. It is not consumed raw as it is bitter	Slightly bitter when raw. Not consumed raw Tastes like peanut butter when roasted May taste bitter to non-regular or first-time consumers
Effects of morama bean consumption	Negative effect: It causes constipation and bloating [46] Positive effect: Cleanse digestive system or important for a healthy gut	Negative effect: Constipation [46] Negative effect: It has a high fat content. Hence it can be bad for the heart Positive effect: Increased thirstiness	Negative effect: Too oily therefore it can be bad for the heart and can also result in weight gain Positive effects: Induces thirstiness resulting in drinking lots of water (good for a healthy body function)	Negative effect: Weight gain and constipation Positive effect: the desire to drink lots of water
Storage and preservation	Storage duration: 12–60 months. The unshelled bean can be stored for prolonged years without losing quality [2] Woven jute Polypropylene bags	Storage duration: 2–60 months Polypropylene bags Closed buckets Away from wet areas	Storage duration: 4–60 months Sacks Closed containers	Storage duration: 12–36 months Polypropylene bags, sacks, and closed containers Away from wet areas It can be stored for many years without affecting or changing the quality because of the hard shell Unshelled morama is not infested by weevils

Table 2 (continued)

	Kweneng	Ghanzi	Southern	Central
Traditional use of morama beans	Fresh green morama beans (*nyebu*) are boiled in water and consumed Dry beans are commonly roasted and consumed [7, 8] Appetizer: Beans are mixed with traditional plants such as mogose (*bauhinia petersiana*) by Bakgalagadi and given to kids either on soft porridge (*motogo*) or can be licked as powder [32] Beans are regularly cooked with lerotse or samp and consumed	Fresh green morama beans (*nyebu*) are boiled in water and consumed Dry beans are commonly roasted and consumed [7, 8] Basarwa tribe mix powdered morama bean with other traditional plants particularly a plant known as *ghyee* and given to kids as an appetizer. It helps individuals gain weight and improve growth [32] Commonly cooked with *lerotse or lengangale* Boiled in water to make cooking oil or roasted and pounded to make butter	Fresh green morama beans (*nyebu*) are boiled in water and consumed Dry beans are commonly roasted and consumed [7, 8]	Fresh green morama beans (*nyebu*) are boiled in water or milk and consumed Dry beans can be pounded and cooked as porridge with water Both fresh or dry beans can be pounded sieved and cooked with milk as porridge (*ntiane*) Dry beans are roasted and consumed [7, 8] Basarwa tribe mix powdered morama been with other traditional plants and give the powdered mixture to undernourished kids or adults on soft porridge [32]
Description of traditional processing methods	Boiling: Fresh beans are boiled in water for 10–30 min. Salt can be added to improve taste Roasting in hot sand: Clean sandy soil is heated in a traditional pot in an open wood fire. Then morama beans are added when the sand is hot. The beans are then roasted with constant stirring until the beans start to pop producing a pleasant nutty smell. The nut turns golden brown when roasted accordingly Roasting in hot sand beneath a fireplace: Morama beans are also roasted in sand beneath a traditional fireplace until cooked. The processing can be done overnight	Boiling: Fresh beans are boiled in water and consumed Roasting in hot sand: Morama beans are roasted in the hot sand in a traditional pot with constant stirring until the beans start to pop producing a pleasant nutty smell Roasting in hot sand beneath a fireplace until cooked or sometimes overnight Boiling to make cooking oil: Morama beans are pounded, mixed with water, and boiled. A lather forms which is removed, and oil is collected	Boiling: Fresh beans are boiled in water Roasting in hot sand: Morama beans are roasted in the hot sand in a traditional pot with constant stirring until the beans start to pop producing a pleasant nutty smell Roasting in hot sand beneath a fireplace until cooked or sometimes overnight	Boiling: Fresh beans are boiled in water. Salt can be added for taste Roasting in hot sand: clean sand is heated in a traditional pot. Then morama beans are added when the sand is hot. The beans are then roasted with constant stirring until the beans starts to pop producing a pleasant nutty smell. The nut turns golden brown when roasted fully Roasting in hot sand beneath a fireplace until cooked or sometimes overnight

their way of life is not dependent on farming. The Basarwa people have never farmed crops or kept livestock [47]. In Botswana, farming is an intangible cultural legacy. There were limited agricultural practices by the respondents, particularly in the Central district (7.3%). A small proportion of the respondents (19.9%) relied on government assistance initiatives such as food rations, the Livestock Management and Infrastructure Development (LIMID) program, and old age pension for those over 65. The Botswana government began the LIMID initiative in 2007 to enhance citizen empowerment and reduce poverty, especially among women and youth, by providing packages including small livestock (goats and sheep), Tswana chickens, and guinea fowls [29]. However, among the four study districts, the uptake of this program is still relatively low. Therefore, other means to address poverty among these vulnerable groups remain paramount.

Traditional utilization of morama bean in Botswana

Traditional main uses of morama bean

Traditionally, the major use of morama beans in Botswana is for home consumption. Across the four districts, 83.7% of respondents consumed morama beans in their homesteads while 16.3% reserved morama beans for business (Table 3). Shelled and unshelled beans cost around Botswana Pula 10–15 (USD 0.73–1.09) for a 500 ml cup. Across all four districts, a majority (78.3%) consume the bean occasionally while 21.3% consume the bean regularly. Occasional consumption was based on the availability due to the seasonality of the bean. Regular consumers of morama beans tend to stockpile the bean during harvesting season and consume it often throughout the year. In Botswana, where the bean is abundant, it remains neglected and is only found and collected from the wild when needed [7]. This may explain the markedly low consumption of the bean across all districts. In addition, morama bean is seasonal, it is available for harvesting between February and July (Table 2). Therefore, its consumption may be limited or restricted by availability due to seasonality. The ripe bean which may be fresh or dry is the major edible part, while a young immature root is also often consumed. Mature roots are not consumed because they may cause vomiting (Table 2). On the contrary, in Namibia, the starch-rich tuber is edible and has economic value because of its high water-holding capacity [6]. Mature morama tuber may have other beneficial health uses such as curing diarrhea, headaches, stomach cramps, and controlling hypertension [32]. Different parts of morama in combination with other plants such as Devil's claw (sengaparile), *Acacia nigrescens* (mokala) bean, and *Acokanthera oppositifolia* (serokolo) are reported to provide a wide variety of health benefits [32, 48]. Pounded morama roots and leaves are thought to help woman's health during their postmenstrual cycle [32].

Consumption patterns and potential side effects

Popularly consumed as a snack, the bean is used in rural communities to feed vulnerable groups such as infants, pregnant, breastfeeding mothers, and the elderly owing to its high nutritional status [7, 11]. Table 3 presents the consumption patterns of morama beans. The respondents reported that morama bean is consumed by any individual in any population age group. A majority (91.0%) of respondents indicated that morama bean does not seem to cause major side effects, while a mere 9.0% reported side effects. The possible side effects reported were heart problems and weight gain possibly due to the high oil or fat content nature of morama beans. It is

Table 3 Traditional uses, consumption patterns, and side effects of morama bean across four districts of Botswana

District	Kweneng ($n=54$)		Ghanzi ($n=62$)		Southern ($n=50$)		Central ($n=55$)		Total ($n=221$)
	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency	Frequency	% Frequency	
Use of morama bean									
Home consumption	52	96.2	48	77.4	43	86	42	76.4	185 (83.7%)
Business	2	3.7	14	22.6	7	14	13	23.6	36 (16.3%)
Consumption of morama bean									
Occasionally	50	92.6	43	69.4	40	80	40	72.7	173 (78.3%)
Regularly	4	7.4	18	29.0	10	20	15	27.3	47 (21.3%)
Never	0		1	1.6	0		0		1 (0.5%)
Morama bean causes side effects									
Yes	5	9.3	8	12.9	5	10	2	3.6	20 (9.0%)
No	49	90.7	54	87.1	45	90	53	96.4	201 (91.0%)

reported that the fat content of morama bean is relatively high (24–48%) [2, 11]. Nonetheless, the fat composition of morama bean is mostly comprised of healthy mono- and di-unsaturated fatty acids [14]. The possible side effects of consuming morama beans pointed out by the respondents (9%) were individual perceptions. This may be probably their knowledge that oily and fatty foods cause heart problems and weight gain. Plant-based foods are important for medicinal purposes where they are native [5]. In Kweneng, Ghanzi, and Central districts, the Bakgalagadi and Basarwa tribes commonly mix morama beans with other traditional plants and give them to kids or adults as a powder to lick or add to soft porridge (*motogo*). According to the respondents, this serves as an appetizer and improves growth in kids or helps adults with appetite problems.

In all four districts, respondents did not report morama beans had any allergies. Previous studies have shown that morama beans do not contain commonly reported food allergens, cyanogenic glycosides, or enzymes that catalyze cyanogenic glycosides to hydrogen cyanide. The observation differs from other well-known legumes that can produce cyanogenic and allergic reactions [7, 11]. As a result, morama beans appear to be a good alternative to legumes like peanuts, soybean, and lupine which are known to cause harmful allergic reactions [7]. However, as a common occurrence with nuts and legumes [49], in three districts, Kweneng, Southern, and Central, the respondents reported cases of bloating and constipation after consumption of morama beans particularly when consumed in large amounts. Nuts and legumes constituents particularly high fat and fiber are suspected to affect gut physiology and microbiota and subsequently cause abdominal gas, bloating, and distention [46]. As aforementioned, morama bean has high fat content [2] which may alter gastrointestinal physiology.

Uses of morama bean for medicinal and health purposes

It was observed that consuming morama beans makes people feel thirsty (Table 2) hence respondents from the Kweneng and Southern districts believe this could be necessary for maintaining the body's health by clearing the digestive tract. In the Kweneng area, Bakgalagadi often combines it with *mogose* (*Bauhinia petersiana*). In Ghanzi district, Basarwa combines morama bean with *ghyee,* a wild herb, and feeds it to infants or expectant mothers. A study by Chingwaru [32] also reported the usage of morama bean in combination with other traditional plants, for example mixing with *ntcono* (a wild cucumber) to make a concoction that improves milk production in lactating mothers and improves undernourished children's appetite. During the study, it was noted that the respondents were reluctant and privy to releasing knowledge, particularly on the medicinal use of morama beans. As reported by Chingwaru [32], traditional doctors and birth attendants are the most knowledgeable in morama bean use as a medicinal component.

Traditional processing methods and preservation of morama bean in Botswana

Traditional processing methods of morama bean

Traditionally, the commonly known morama bean processing method is roasting which is also used to reduce the bitter taste of the bean [7]. Morama beans are cooked before they can be consumed since they have an unpleasant, slimy texture and are not edible when raw [7]. Table 4 shows that most of the respondents (96.8%) in this study mainly process the dry beans by roasting and consuming them as a snack (mean = 4.93, $\sigma = 0.48$). This observation agrees with Holse [7] and Mmonatau [8] who also reported that the bean is roasted in hot sand across all districts of Botswana. Figure 2 illustrates the traditional morama bean roasting process. After adding clean sand and heating it over a wood fire, morama beans are added to the pot. The beans are then roasted on hot sand with constant stirring (for about 2–3 min) until the shell turns dark brown/black and the beans start to pop/break producing a pleasant nutty smell. The edible bean part turns golden brown when roasted accordingly. The alternative traditional roasting method, which appears to be practiced sporadically, involves roasting morama beans in hot sand beneath a traditional fireplace sometimes overnight.

According to this study, the other popular traditional processing method of morama bean is boiling freshly harvested green beans (mean = 4.49, $\sigma = 1.25$). A significant proportion of respondents (83.7%) strongly agreed and indicated that consuming freshly boiled morama beans is a major processing method immediately after harvesting (Table 4). Across all four districts surveyed, fresh green beans commonly referred to as *nyebu* in the Setswana language, are peeled off to remove the outer layer then boiled in water and consumed (Fig. 3b). Some people add salt to aid taste. A one-way ANOVA (Table 5) revealed no significant difference (df = 3, $F = 1.93$, $p = 0.13$) in roasting of morama beans across the four districts. However, there was a significant difference (df = 3, $F = 3.92$, $p = 0.01$) in the boiling of green beans and subsequent consumption as vegetables among the four districts. This may be explained by the entirely different cooking methodologies employed by Basarwa located in the Central district. The beans are peeled and boiled with milk. In addition, Basarwa also tends to pound fresh and dry beans, sieve, and cook with milk as porridge. The milk porridge is known as *ntiane*. In some Botswana tribes, using raw or fermented milk to prepare either sorghum or maize meal porridge is common [50,

Table 4 Respondents perceptions on the utilization and potential benefits of morama bean across four districts of Botswana

Likert items	SA (5)	A (4)	N (3)	D (2)	SD (1)	Mean	σ
Traditional use of morama bean		Frequency	(%)				
It is consumed raw	7 (3.2)	4 (1.8)	5 (2.3)	1 (0.5)	204 (92.3)	1.23	0.85
It is roasted and consumed as a snack	214 (96.8)	4 (1.8)	0 (0)	0 (0)	3 (1.4)	4.93	0.48
It is roasted and mixed with maize to make porridge	30 (13.6)	6 (2.7)	3 (1.4)	3 (1.4)	179 (81.0)	1.67	1.40
The bean is boiled with maize to make porridge	17 (7.7)	4 (1.8)	2 (0.9)	6 (2.7)	192 (86.9)	1.41	1.14
Source of oil for cooking	19 (8.6)	3 (1.4)	12 (5.4)	5 (2.3)	182 (82.4)	1.52	1.22
Green beans are boiled and consumed as vegetables	185 (83.7)	8 (3.6)	1 (0.5)	6 (2.7)	21 (9.5)	4.49	1.25
Green beans are mixed with soup	9 (4.1)	1 (0.5)	6 (2.7)	9 (4.1)	196 (88.7)	1.27	0.88
Used to make alcohol	3 (1.4)	0 (0)	1 (0.5)	3 (1.4)	214 (96.8)	1.08	0.49
Processed into cosmetics	18 (8.1)	0 (0)	3 (1.4)	2 (0.9)	198 (89.6)	1.36	1.11
Composite mean						2.11	0.98
Knowledge of the value, health benefits, and potential of the bean							
The morama bean is nutritious	204 (92.3)	10 (4.5)	4 (1.8)	1 (0.5)	2 (0.9)	4.87	0.54
Morama bean has antioxidant capacity and reduces the risk of asthma, diabetes, cardiovascular diseases	4 (1.8)	4 (1.8)	25 (11.3)	5 (2.3)	183 (82.8)	1.38	0.89
Used for treatment of diarrhoea	3 (1.4)	1 (0.5)	18 (8.1)	8 (3.6)	191 (86.4)	1.27	0.74
Used for treatment of eye infection	3 (1.4)	3 (1.4)	17 (7.7)	5 (2.3)	193 (87.3)	1.27	0.77
Morama beans can help improve household food security as a source of income through sale	154 (69.7)	61 (27.6)	0 (0)	1 (0.5)	5 (2.3)	4.62	0.73
Morama beans can be processed into value-added products	110 (49.8)	60 (27.1)	31 (14.0)	3 (1.4)	17 (7.7)	4.10	1.17
Composite mean						2.91	0.81
Barriers to morama bean consumption or utilisation							
Traditional customs, taboos, and beliefs	2 (0.9)	1 (0.5)	5 (2.3)	2 (0.9)	211 (95.5)	1.10	0.53
Lack of knowledge on the nutritional quality of morama bean	19 (8.6)	12 (5.4)	82 (37.1)	5 (2.3)	103 (46.6)	2.27	1.33
Cooked/roasted morama bean tastes bitter and is unpalatable	4 (1.8)	7 (3.2)	6 (2.7)	6 (2.7)	198 (89.9)	1.25	0.81
It is scarce and the harvest amount is usually limited	60 (27.1)	10 (4.5)	3 (1.4)	8 (3.6)	140 (63.3)	2.29	1.79
Controlled harvesting regulations	11 (5.0)	2 (0.9)	15 (6.8)	6 (2.7)	187 (84.6)	1.39	1.02
Removing the shell is a challenge	48 (21.7)	83 (37.6)	5 (2.3)	7 (3.2)	78 (35.3)	3.07	1.64
Modern alternative food choices	11 (5.0)	11 (5.0)	68 (30.8)	10 (4.5)	121 (54.8)	2.01	1.23
Composite mean						1.91	1.19

Likert scale: SA = Strongly Agree (5), A = Agree (4), N = Neutral (3), D = Disagree (2), SD = Strongly Disagree (1)

Frequency (% Frequency). $N = 221$

Means were calculated on a scale of 1–5 from the Likert scale. σ = standard deviation

Where means, (≤ 1.45) = strongly low perception, (1.46–2.45) = low perception, (2.46–3.45) = moderate perception, (3.46–4.45) = high perception, (≥ 4.46) = strongly high perception [38, 40]

51]. The Tukey HSD test revealed a significant difference ($p = 0.004$) in the boiling of green beans between Ghanzi and Central districts. The difference may be attributed to the use of either water or milk. While people in the Central district typically use water and milk as an alternative, those in Ghanzi district cook morama beans with water. It is interesting to note that only in the Central district, was it discovered that morama beans were cooked with milk. The Basarwa tribe constituted most of the Central district's study population. Nevertheless, the Ghanzi district is also home to Basarwa. This observation of differences in cooking may be influenced by several factors among the tribes. For example, things like variations in regional customs and ethnic or local preferences. As a result, Basarwa in Botswana might have unique customs and preferences.

Some people in the community cook morama bean with samp or melon (lekatane/lerotse in Setswana) (*Citrullus lanatus* var. *citroides*) or dried melon (lengangale) (Table 2). The respondents claimed that when the bean is cooked with samp, it improves the texture and softness. Using morama bean as a source of oil for cooking was lowly perceived (mean = 1.52, $\sigma = 1.22$) as a traditional processing method practiced by the respondents (Table 4). However, an elderly respondent from the Ghanzi district who seemed to have skills in extracting

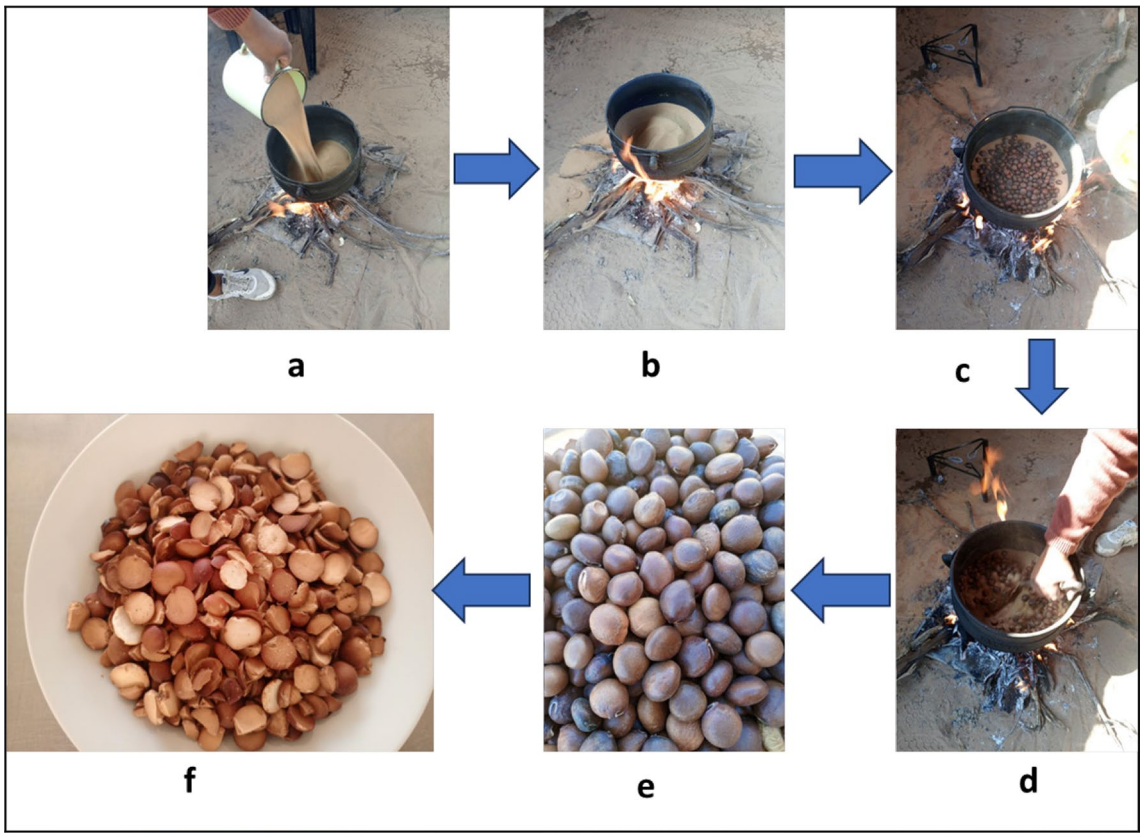

Fig. 2 Traditional roasting morama beans using hot sand on a three-legged pot over a wood fire. **a** Clean sand is put in a pot, **b** sand is heated over a traditional wood fire, **c** morama beans are added into the pot, **d** the beans are roasted in hot sand with constant stirring, then transferred to cool sand. The sand is then sieved **e** the bean shell turns dark brown/black during roasting, **f** golden-brown edible portion of the bean is released from the shell

cooking oil from morama beans described the process. The morama bean is ground, combined with water, and then boiled to obtain a homemade cooking oil. Boiling causes a foam or lather to form on top. The lather is removed, then floating oil that can be used for cooking is collected. For the other investigated potential traditional processing methods of morama bean, an overall low perception was observed from the respondents. For example, roasting and mixing with maize to make porridge (mean = 1.67, σ = 1.40), boiling the bean with maize to make porridge (mean = 1.41, σ = 1.14), cooking fresh beans with soup (mean = 1.27, σ = 0.88), processing beans to make alcohol (mean = 1.08, σ = 0.49) and cosmetics (mean = 1.36, σ = 1.11) (Table 4). Nonetheless, it was evident that despite being generally lowly perceived as traditional morama bean processing methods, they were practiced sporadically in specific areas. For example, pounding morama beans and then cooking with either water or milk to make porridge or adding the powder to prepared maize or sorghum soft porridge was practiced in the Central district (Table 2).

Preservation and storage of morama bean

Morama bean is susceptible to chemical reactions due to high lipid and protein content which can subsequently influence the functional and sensory parameters of byproducts [52]. However, one respondent narrated that when morama bean is stored appropriately away from wet areas either in polypropylene bags, woven jute, or closed containers shelf-life is extended (Table 2). It rarely loses quality or gets infested by storage pests such as weevils; a phenomenon attributed to its hard protective shell [2]. Morama beans retain quality and palatability for many years [45] suggesting that the bean has good preservation and storage stability. Respondents did not specify how long it should be kept, but they did indicate that it could be kept for up to five years (60 months) if the right conditions are met (Table 2). When asked to describe the taste, smell, and texture of the roasted morama bean, the respondents compared the taste to that of roasted peanuts and described the texture as soft. This was possibly related to the high oil or fat content of morama bean. Generally, the respondents liked the

Fig. 3 Morama bean plant (**a**). Freshly harvested and peeled morama beans (*nyebu*) ready to be boiled (**b**)

Table 5 Difference in traditional processing methods of morama bean among the four districts of Botswana

Dependent variable	Sum of squares	*df*	Mean square	*F*	Significance
It is roasted and consumed as a snack					
Between groups	1.32	3	0.44	1.93	0.13
Within groups	49.52	217	0.23		
Total	50.84	220			
Grean beans are boiled and consumed as vegetables					
Between groups	17.75	3	5.92	3.92	**0.01**
Within groups	327.49	217	1.51		
Total	345.24	220			

*The mean difference is significant at 0.05 level

pleasant nutty aroma of roasted beans which previous investigations reported to have been possibly caused by Maillard reactions [53].

Knowledge of the value, health benefits, and potential of morama bean in Botswana

Participant's knowledge of the value of morama bean

When asked to rate their understanding of morama bean's value, health benefits, and potential, respondents indicated a high perception concerning morama bean being nutrient-dense and useful for developing food products with added value (Table 4). The respondents strongly agreed (69.7%) that morama beans can help improve household food security as a source of income through sales (mean = 4.62, $\sigma = 0.73$). The respondent (s) were aware of the high nutritional value of morama bean (mean = 4.87, $\sigma = 0.54$). A study by Kgosikoma et al. [41] revealed the knowledge and positive market potential of morama products such as morama oil, morama butter, and morama snack bar in the Kweneng and Southern districts of Botswana where morama bean is abundant. Worryingly, the Kweneng district is known to be one of the poverty-stricken districts of Botswana. However, morama products which can help with income and improve the livelihoods of people in these areas remain unavailable in the market [41]. This suggests that the potential use of morama beans in producing a range of products is still unrealized or untapped.

Morama bean potential health benefits

Several health claims associated with the consumption of morama beans were reported by respondents. For example, some respondents referred to the bean as a "vitamin' that can address any nutritional limitation. Other respondents appreciated its ability to cleanse the digestive tract and its importance as a major component in medicinal concoctions used by traditional birth attendants and doctors (Table 2). Previous scientific studies revealed the therapeutic potential of morama bean [48]. The knowledge of morama bean consumers was investigated to determine whether they were aware of these health advantages. Awareness of the bean's high nutritional content (mean = 4.87) and therapeutic qualities (mean = 1.27–1.38) were inversely correlated. The study population's lack of knowledge of the bean's scientific medicinal properties may cause this. For example, they had a limited understanding of the bean's antioxidant capacity and ability to reduce the risk of asthma, diabetes, and cardiovascular diseases (mean = 1.38, $\sigma = 0.89$). As revealed earlier, knowledge about medicinal properties is considered sacred, safeguarded and only known by a few in the community such as traditional healers and birth attendants [32]. Therefore, many participants were less knowledgeable about the bean's medicinal properties. In addition, most were unaware of its traditional use for treating diarrhoea (mean = 1.27, $\sigma = 0.74$) or eye infections (mean = 1.27, $\sigma = 0.77$). This is despite previous studies that morama bean extracts can help cure diarrhoea and digestive disorders [48]. Morama beans are believed to enhance the immune system while powdered beans are reported to be used to treat eye infections [11]. The bean's high concentration of phytochemicals like polyphenols in the cotyledons and testae makes it effective medicinally and prophylactically against infectious microorganisms [48]. This may explain its traditional use in treating digestive and contagious diseases, particularly by some *San* people.

Prior research has demonstrated that the cotyledon and testae of morama beans are abundant in phenolic and flavonoid compounds [48]. Depending on the extraction method, their contents vary in the bean. Lekalake et al. [54] reported 1.72 mg GAE/g total phenols and 0.00023 mg CE/gm total flavonoids in morama bean. Previously, Chingwaru et al. [54] detected phenolic acids, primarily gallic acid (23.4 mg/100 g), caffeic acid (38.9 mg/100 g), protocatechuic acid (PCA, 152.5 mg/100 g), syringic acid (12.7 mg/100 g), and sinapic acid (59.2 mg/100 g). In addition, flavonoids, primarily catechin (11.5 mg/100 g), fisetin (39.2 mg/100 g), quercetin (23.5 mg/100 g), rutin (25.7 mg/100 g), and kaempferol (20.0 mg/100 g), were detected. Numerous investigations have shown that extracts of various plants high in polyphenols have inhibitory effects on infectious microbes, including drug-resistant bacteria, fungi, and viruses [55]. For example, polyphenols prevent norovirus by preventing the virus's early stages of reproduction [56]. The growth cycle of viruses like influenza, herpes, hepatitis, rotavirus, and coronavirus is inhibited [55] by bioactive or phytochemicals like quercetin, gallic acid, and epigallocatechin that have been discovered in morama bean [48]. As shown, morama bean is rich in gallic acid, caffeic acid and quercetin [57]. Previous studies have highlighted the bioactive anticancer properties, for example, gallic acid [58], caffeic acid [59], and quercetin [60]. Therefore, it can be concluded that morama bean has the potential to provide anticancer agents based on their phenolic and flavonoid makeup.

Chingwaru et al. [57] investigated the effect of morama cotyledon and seed coat ethanolic and water extract's anti-rotaviral activity against rotavirus (RV) infection. The findings showed that *T. esculentum* extracts, particularly seed coat ethanolic extracts (0.01–0.001 mg/mL), significantly inhibited RV in vitro [57]. These results imply that morama beans may be a significant source of RV-fighting microbicides. These findings explain the intensive traditional use of morama bean as an important ingredient in children's diets as the current study found. Globally, rotavirus is a leading cause of acute gastroenteritis in newborns and young children under five [61]. The bean cotyledon's high phenolic acid content (particularly gallic acid) is responsible for the observed anti-rotaviral properties [58]. According to WHO estimates, about 611,000 people die from rotavirus (RV) infections yearly, primarily in underdeveloped nations [61]. Therefore, this concludes that incorporating morama beans in children's food is essential.

As aforementioned, morama beans contain important therapeutic agents that are useful in suppressing infectious microorganisms and diseases according to Chingwaru [48]. The author however noted that further studies are needed to be carried out to ascertain the potential positive effect of morama bean on health promotion. Omotayo [2] reported that the medicinal, nutritional, and economic advantages of morama beans are supported by a paucity of scientific data. Generally, most morama bean consumers in this study gave positive feedback about the health benefits of consuming the bean. Since the respondents appeared to be aware that morama beans may be processed into value-added products (mean = 4.10, $\sigma = 1.17$), there are consequently numerous applications for the bean that can be created and be advantageous to these communities.

Challenges in morama bean consumption or utilization in Botswana

Barriers to morama bean consumption or utilization resulted in low composite score (mean = 1.91, σ = 1.19) (Table 4). This shows a generally low perceived level in the Likert items concerning potential obstacles that may prevent the maximum use or consumption of morama beans. Subjective social standards and beliefs frequently impact how indigenous products are used [41]. This study reported no traditional customs, taboos, or cultural beliefs associated with morama bean use and consumption (Tables 2 and 4). A high proportion of respondents (95.5%) strongly disagreed that there are no traditional practices, taboos, and beliefs connected to the intake and use of beans (Table 4).

Morama bean bitterness

According to the respondents, morama bean is not consumed raw (Table 4). Uncooked beans are bitter and unpalatable. Therefore, they must be cooked before consumption. When asked to use the Likert scale to rate the bitterness and unpalatability of cooked morama beans, the respondents showed a strongly low perception (mean = 1.25, σ = 0.81) toward the Likert item. A high proportion of respondents (89.9%) strongly disagreed that the bean is bitter and unpalatable when cooked or roasted (Table 4). This suggests that the consumers of morama beans do not experience bitterness when the bean is cooked. This also implies that morama bean potentially contains natural components that contribute to bitterness. Therefore, the cooking or roasting processes may be responsible for reducing these bitter components. A study by Jackson [45] reported bitterness and a slimy texture of raw morama beans.

Although not entirely clear, components such as tannins and saponins are attributed to the unpalatability and unpleasant slimy texture of morama bean [7]. Previous research has shown that the bitter taste of peptides is caused by several amino acids, including phenylalanine, tryptophane, tyrosine, isoleucine, proline, and histidine [62, 63]. Tryptophan, an essential amino acid, is said to be the most bitter amino acid [64]. Previous studies have reported 0.68 mg/100 g of tryptophan in morama beans [14]. Thus, the bitterness could be due to the tryptophan found in morama bean. The bitter, astringent, and sour properties of soybean and its byproducts are known to be caused by L-phenylalanine, phenolic acids (syringic), and bitter isoflavone glycosides like genistin and daidzein [65]. These imply that the caustic and bitter flavor of morama bean may be caused by several of its ingredients. According to the respondents in this study, when morama beans are roasted well, the consumer does not experience bitterness except when the beans are overly roasted and burnt. Nonetheless, the beans may taste bitter for a less regular consumer, or if consumed for the first time, this could be the reason for the 10.1% of respondents who indicated that the bean was bitter.

Challenge of the bean's hard shell

The difficulty of cracking the hard morama shell emerged as the biggest concern, even though respondents generally did not appear to identify significant obstacles (mean = 1.91) related to morama bean use. Notwithstanding, respondents seemed to face a challenge (mean = 3.07, σ = 1.64) in breaking the morama bean shell to obtain the bean. Traditionally, morama bean users use stones to break open the shell to obtain the bean. However, the exercise is labor-intensive, time-consuming, and may hinder prospective value-addition efforts. Therefore, this might necessitate developing and creating effective equipment or machinery to help break the shell to obtain the bean.

Current barriers and opportunities for the commercialization of morama bean

Current barriers to the commercialization of morama bean and its products

As this study revealed, the respondents had high awareness that morama beans can be processed into value-added products (Table 4). However, based on observations, a few households generate revenue from selling morama beans in the present. Plant-based milk, oil, and canned beans are just a few of the value-added products that may be made from morama beans [41]. However, the market availability of these products remains a concern. Legwaila et al. [66] noted that apart from products developed from morula (*Sclerocarya birrea*), many products made from indigenous traditional food plants are only available in Botswana's informal markets. Similarly, Kgosikoma et al. [41] noted that morama bean and its products are currently limited to sale in informal local markets mainly by women and children. The income is used for children's school fees, uniforms, and other home expenses [66].

Morama beans and other indigenous traditional plant products in Botswana are facing challenges. This includes market constraints, infrastructure, and inadequate product supply [41, 66]. As a result, this opens a massive market for exploitation, which may call for the food industry to produce products that can be sold domestically and outside. Several factors have been identified as the main factors restricting the exploitation of morama beans and commercialization. Among others, limited raw materials, declining morama bean density in the wild, seasonality of the bean, poor accessibility to areas where the bean grows, unavailability of plowing land, climate change,

drought, land privatization, poor post-harvest operations such as limited skills and poor market infrastructure [17, 41, 66]. In addition to the previously mentioned, inadequate supply of products is among factors that have been pointed to be hindering the market and commercialization of morama bean and other indigenous traditional plants of Botswana.

Opportunities for growth and commercialization

The market viability of morama products is positive and has the potential to grow. As Kgosikoma et al. [41] found, consumers are willing to purchase morama bean products. In addition, the author states that the products can compete with exotic similar products or replace them. Emphasis on the commercial potential of some morama-made products, Faria et al. [17] pointed out that either a commercially fortified product or a fortified supplemental food product for feeding programs using morama bean and sorghum has high potential. Therefore, among others, it is suggested that availing land and domestication of morama bean may help accelerate the commercialization efforts of morama bean products [41]. In addition, land redistribution policies, domestication of the bean, viable processing skills, promoting and upgrading marketing skills, and availing necessary machinery and equipment can accelerate commercialization efforts. Additional actions that have been proposed include providing sufficient and convenient access to information and financial support, which could hasten the use and commercialization of morama beans and their products [17, 41].

Developing morama bean products and upgrading skills that can be used to process the beans that would benefit local communities is essential. As pointed out by Faria et al. [17], there are threats associated with ethnic and social disparities that could widen. Hence this could lead to the very poor, such as the *San* not profiting from their natural indigenous plants such as morama bean. The lipid level of morama beans is higher than that of soybeans, although the protein content is comparable [13]. This suggests that morama beans can be used as an alternative to soy in products that currently contain soy.

Limitations, recommendations, and future research directions

In this study, respondents pointed out several health claims associated with consuming morama beans. Chingwaru et al. [57] study and findings somewhat support this health claim. The bioactive constituents found in morama beans showed great potential as a source of therapeutic agents against major human diseases. However, there remains a lack of robust scientific studies in the literature using in vitro, in vivo, and clinical trials that may help ascertain health claims associated with consuming morama beans. This highlights gaps around morama bean research that could further enhance its importance in food and nutrition product formulations.

Creating food items from morama beans and, more crucially, advancing research on the health effects of its components remains crucial. It is recommended that intensive research focus on ascertaining the therapeutic health potential and sustainable domestic breeding or domestication since currently the bean is collected from the wild. It is also important to develop effective equipment or machinery that can assist in breaking the hard morama shell to obtain the bean, replacing the labor-intensive and time-consuming traditional methods. Lastly, coordinated relationships with the communities where native plants like morama bean are found remain essential for sustainable usage, preservation of indigenous knowledge, and protection or conservation of these resources.

Conclusions

This study has revealed that morama bean has major important uses for the livelihoods of marginalized communities in Botswana where it is distributed in large quantities, particularly for domestic consumption and income generation. The fresh beans are mainly boiled with water while dry beans are commonly roasted on hot sand in a traditional pot over an open wood fire. Processing by roasting improves the bean's palatability, appearance, and aroma, which increases its acceptability as a food source. Besides being a standalone food, morama bean is incorporated into other foods to improve their nutritional quality and taste. For example, the Basarwa in the Central District of Botswana boil fresh morama beans in milk or pound dry or fresh beans, then sieve and prepare them as porridge using milk. The Bakgalagadi and Basarwa tribes mix powdered morama beans with several traditional edible plants to improve appetite, especially for undernourished children, pregnant and lactating women, and adults with appetite problems. While all districts shared similarities in morama bean processing methods, using milk to cook the beans was only observed in the Central district. This could indicate the influence of variations in regional customs and ethnic or local preferences. This study has shown that morama bean has huge untapped potential for developing food products. Conversely, the low knowledge observed from participants and limited research about the bean's medicinal properties present an opportunity for further studies. The legume grows under harsh environmental conditions where most staple food crops would not survive. Thus, it is a good candidate for contributing to food and nutrition security among vulnerable groups.

Acknowledgements
This study was made possible by the support of Jomo Kenyatta University of Agriculture and Technology, Botswana University of Agriculture and Natural Resources, and Regional Universities Forum for Capacity Building in Agriculture. Special acknowledgments are extended to the village chiefs in all study areas for giving consent to survey with their subjects. Finally, the participants who generously contributed their information and knowledge made the study possible. Therefore, I extend special appreciation to everyone who participated in this study.

Author contributions
All the authors designed and contributed to this study. JG conducted the survey and drafted the manuscript. MVRM is a sociologist who assisted with editing, structuring study questionnaires, and data analysis. SI, JK, and AO contributed to the design and preparation of the study, reading, and editing of the manuscript.

Funding
The Botswana University of Agriculture and Natural Resources provided financial assistance for this study.

Availability of data and materials
The research data is provided in this manuscript. Additional details supporting the findings may be provided upon request from the corresponding author.

Declarations

Ethics approval and consent to participate
The study was granted ethical approval by the Institutional Review Board (IRB) of Mount Kenya University (Ethical clearance application Reference Number MKU/ISERC/4451 and IRB Approval Number 3173). In each study area, the village chief was consulted to request consent for the survey to be carried out with the subjects. Participants were asked for consent to take part in the study. In addition, they were made aware that the information gathered would only be used for academic purposes and would be held strictly confidential.

Consent for publication
Not applicable.

Competing interests
The authors declare that there is no competing conflict of interest.

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Received: 3 June 2024 Accepted: 9 December 2024
Published online: 03 February 2025

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