NUTRITIONAL COMPOSITION, FUNCTIONAL ATTRIBUTES, AND BIOACTIVE POTENTIAL OF INDIGENOUS MORAMA BEAN (TYLOSEMA ESCULENTUM) FROM BOTSWANA: A REVIEW

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Abstract

Morama bean (Tylosema esculentum [Burch.] A. Schreib.) is a perennial wild legume indigenous to the Kalahari Desert that grows in Botswana, Namibia and South Africa. Although it is one of the most nutritionally valuable legumes available, seeds have 29–39% protein and 48–24% lipid on a dry weight basis, and are among the most underutilised legumes in sub-Saharan Africa. The fatty acid content is very similar to olive oil with oleic acid being the major acid (42–49%) and with linoleic acid as another major acid (19–26%), whereas the phytochemical content includes phenolic acids, flavonoids, phytosterols and the unique compound benzofuranone called griffonilide. This bean is used and eaten by indigenous people in Botswana for centuries but it has been neglected from modern food system. The review provides a summary of the existing peer-reviewed scientific literature related to Morama bean's nutritional and nutritional bioactive components, traditional food utilization, antinutritional factors, and commercial potential, targeting future research and policy needs to unlock its potential applications for food security and the UN Sustainable Development Goals (SDGs).

Keywords: Tylosema esculentum; Morama bean; legume; nutritional composition; phytochemicals; antioxidant; Botswana; food security; underutilised crops; bioactive compounds

1. Introduction

Within sub-Saharan Africa, food insecurity is a major concern, especially for farmers living in rural areas who are reliant on a limited number of crop species that are sensitive to drought, soil degradation, and climate variability. In these settings, legumes are known to be a keystone of food protein, but food systems are dominated by a few domesticated species, especially soybean, cowpea, groundnut and common bean, which poses high nutritional and ecological risk [1, 2].

In this context Tylosema esculentum, known as the Morama bean, is one of the most nutritious of the wild plants in southern Africa. It is a perennial vine that grows on the sandy veld in the Kalahari Desert of Botswana, building a large underground tuber up to 12 kg, which acts as its root system [3]. The local names for the bean include Morama or Marama (Setswana), qhwii (Sesarwa/Khoi San), riqhama (Sekgalagadi) and ombanui (Otjiherero) [4]. The Basarwa, Bakgalagadi, and Ovaherero peoples of Botswana have traditionally collected, consumed and passed down information on this plant, but it has not been domesticated nor commercially developed on a large scale [5].

The quality of the nutrition evidence that makes this oversight particularly striking. The protein content of Morama bean is similar to that of soybean, its fat content is close to peanut, and its fatty acid profile is similar to olive oil [3, 6]. Its phytochemical content has been studied and it is known that it has strong antioxidant, anti-microbial, anti-viral and anti-inflammatory properties [5, 7]. This review collates information from studies done since 1969, arguing for a greater investment and research into this under-researched legume.

2. Botanical Description and Ecology

Tylosema esculentum is a non nodulating, perennial leguminous vine that grows under some of the most adverse conditions it is possible to imagine. It grows at temperatures between 28–37 °C, can withstand annual rainfall of as little as 100 mm and can grow in sandy soil with low organic matter, nitrogen and phosphorus content [3]. This ecological resilience is particularly important in the context of climate change and the expansion of dryland agroecosystems.

The vine grows to be 3-6 m long and has a leathery grey-green color when mature, though young leaves are a soft reddish-brown. The leaves are bi-lobed. Golden-yellow flowers appear in the middle of summer, followed in the fall by pods with 1 to 3 oval reddish-brown seeds [3, 9]. The natural populations are found in Botswana's Kweneng, Ghanzi, Southern and Central districts, and in sandy veld of Namibia. Attempted domestication has been made in Australia, Israel, Kenya and the USA, but has met varying levels of success, thus demonstrating the difficulty of domestication [3, 19].

3. Nutritional Composition

3.1 Proximate Composition

The nutritional composition of Morama bean has been documented over the past over 50 years, from Wehmeyer et al., 1969 [10] to the most recent surveys [4, 5]. What emerges from this is an extra-ordinarily energy dense, protein rich seed. The comparative proximate composition of Morama bean with soybean and groundnut is presented in table 1.

Table 1. Comparative proximate composition per 100 g dry matter [6, 11]

Component	Morama Bean	Soybean	Groundnut
Protein (%)	29–39	33–46	22–30
Lipid (%)	24–48	17–20	45–55
Carbohydrate (%)	19–24	14–18	16–22
Ash (%)	3.19	4.50	3.80
Calcium (mg/100 g)	241	~200	~60
Iron (mg/100 g)	3.95	~9	~2

Protein content of 29% – 39% of dry matter is similar to that of soybean and is substantially higher than most common legumes [3, 6]. The lipid fraction (24–48%) is of particular interest and more than soybean, and is one of the highest fat contents found in legumes [3, 4]. Most of the carbohydrate fraction is in the form of insoluble dietary fibre, which has some important implications for glycaemic response and for gut health [12].

3.2 Fatty Acid Profile and Lipid Quality

Morama bean oil has a light golden colour, a pleasant nutty aroma, and a fatty acid composition that closely mirrors olive oil [3]. Oleic acid (18:1) dominates at 42–49% of total fatty acids, followed by linoleic acid (18:2) at 19–26%. Saturated fats, principally palmitic acid (12–14%) and stearic acid (7–10%), are present in proportions consistent with cardiovascular benefit [1, 13]. Long-chain unsaturated fatty acids collectively account for approximately 75% of total fat content.

Phytosterol analysis identified beta-sitosterol as the dominant sterol (84.50 mg/g), alongside stigmasterol and campesterol, compounds with established cholesterol-lowering properties [3]. Total tocopherols have been reported at approximately 199 µg/g, with gamma-tocopherol as the primary isomer (59–234 µg/g), levels of potential anticarcinogenic and anti-inflammatory significance [4, 12].

3.3 Protein Quality and Amino Acid Profile

The protein fraction is dominated by globulins (53%), with albumins (23.3%) and prolamins (15.5%) making up most of the remainder [14]. All essential amino acids are present, with lysine (5.5%), leucine (5.9%), and arginine (6.3–7.3%) as the most abundant, reflecting a profile broadly comparable to casein [3]. The well-known limitation of low methionine (0.8%) and cysteine (0.8%) content can be addressed through dietary complementarity with cereals such as sorghum [4, 1].

3.4 Micronutrient Content

Despite growing in impoverished sandy soils, Morama bean accumulates an impressive mineral profile. Calcium reaches 241 mg/100 g, nutritionally significant in populations with limited dairy access [6]. Magnesium (274.5 mg/100 g), zinc (6.2 mg/100 g), and iron (3.95 mg/100 g) are present at meaningful concentrations, particularly relevant given the high prevalence of iron-deficiency anaemia and zinc deficiency across rural Botswana [4, 3]. Potassium (757–1316 mg/100 g) and phosphorus (334–554 mg/100 g) are also abundant. B vitamins including B6 (1.56 mg/100 g), B12 (0.043 mg/100 g), and folate further strengthen the bean's credentials as a whole-diet nutritional resource [6, 4].

4. Phytochemical Composition and Bioactive Potential

4.1 Phenolic Acids

The seed coat of Morama bean is greatly enriched with phenolic compounds compared to the cotyledon with approximately 2,038 mg/100 g and 317 mg/100 g, respectively [3]. In the seed coat, the phenolic acids are most abundant in this form, with the presence of sinapic acid (543 mg/100 g) and protocatechuic acid (153 mg/100 g) [3, 1]. Gallic acid, caffeic acid, ferulic acid, vanillic acid and p-coumaric acid are other phenolics. Gallic acid has special significance in the area of anticancer, antimicrobial, and anti-mutagenic attributes [1, 5].

The seed coat has significantly higher antioxidant activity than the cotyledon (ABTS radical scavenging), which can be correlated with the phenolic distribution [3]. The total phenolics were reported to be 1.72 mg GAE/g [4]. The values emphasize the whole-seed consumption and the seed coat as a possible functional ingredient.

4.2 Flavonoids

Myricetin is the predominant flavonoid in Morama bean, accounting for as much as 10,582 mg per 100 g of the bean's seed coat [3]. It is one of the highest reported, and the highest recorded, concentrations for any legume, and is especially relevant because of the proven antioxidant, anticarcinogenic and anti-mutagenic activity of myricetin [3, 1]. Other flavonoids include rutin (602 mg/100 g), naringin (492 mg/100 g), hesperidin

(434 mg/100 g), fisetin (481 mg/100 g), quercetin (331 mg/100 g), and kaempferol (98 mg/100 g) [3, 4]. In Table 2, key phytochemicals and their reported biological activity are summarised.

Table 2. Key phytochemicals in Tylosema esculentum and reported biological activities [3, 1, 4]

Compound	Class	Location	Biological Activity
Myricetin	Flavonoid	Seed coat	Antioxidant, anticarcinogenic
Rutin	Flavonoid	Seed coat, tuber	Antimicrobial, antidiabetic, anticancer
Gallic acid	Phenolic acid	Seed coat	Anticancer, antimicrobial, anti-mutagenic
Protocatechuic acid	Phenolic acid	Cotyledon	Anti-inflammatory, anti-hyperglycemic
Quercetin	Flavonoid	Seed coat	Antioxidant, anti-inflammatory
Beta-sitosterol	Phytosterol	Seed	Cholesterol-lowering, anti-inflammatory
Griffonilide	Benzofuranone	Tuber	Anti-nociceptive, cytotoxic, antibacterial

4.3 Unique Compounds: Griffonilide and Lignans

Two compounds found in the Morama bean tuber, griffonilide and griffonin (also called lithospermoside) are unique with respect to the bean and are one of the most structurally distinctive phytochemicals in the plant. [15, 1] Griffonil has been shown to have anti-nociceptive, cytotoxic, antimicrobial, antioxidant, and anti-amyloid properties, while griffonin has been shown to be antimicrobial. The results of these data are preliminary and should be pursued in dedicated pharmacological research.

Lignans, secoisolariciresinol (305-406 µg/100 g) and lariciresinol (614-825 µg/100 g), are also high in morama bean compared to soybean [3, 12]. These lignans are converted to enterolignans in the intestine and have oestrogenic, anti-oestrogenic and antioxidant properties that may have a protective effect against some forms of cancer and cardiovascular disease. Morama contains no isoflavones, and their effects on oestrogen are not a confounding factor with Morama, unlike with soybean [3].

5.The antimicrobial, antiviral and anti-inflammatory properties.

The biological activity of Morama bean polyphenols has been studied using mainly in vitro models, with generally positive results. Polyphenolic fractions of the seed coat and cotyledon have been found to exhibit strong antibacterial and antifungal effects against both gram-positive and gram-negative bacteria and Candida species [7, 16]. The implications of these findings are that Morama bean compounds could potentially be used in developing new antimicrobial agents at a time when antibiotic resistance is a health emergency.

Of particular clinical relevance is the antiviral activity against rotavirus (RV) which is the major cause of childhood diarrhoeal disease in the world. Ethanolic seed coat extracts at concentrations of 0.01–0.001 mg/mL showed significant inhibition of rotavirus replication in in vitro system, and gallic acid was found to be a major active ingredient [4, 5]. This is in line with the tradition of the Basarwa to give Morama (preparations) to babies and young children as a protective food [4]. There is also some evidence for anti-influenza, anti-herpes, anti-hepatitis and some anti-coronavirus activity, with quercetin and epigallocatechin known to play a role in the early stages of viral replication being inhibited [4]. Protective effects against free radical induced erythrocyte haemolysis have been reported by protocatechuic acid, sinapic acid and the total phenolics [1, 5].

6. Traditional Knowledge and Indigenous Information.

Morama bean is most prolific in sand veld ecological zones of Kweneng, Ghanzi, Southern and Central districts in Botswana which is the same area where conventional agriculture is most problematic [4]. Gwamba et al. [4] conducted a survey research in these districts with 221 respondents who recorded detailed indigenous knowledge about the processing methods and medicinal uses in four major communities: 36.3% Basarwa, 35.2% Bakgalagadi, 19.5% Bangwaketse and 4.5% Ovaherero.

The most common method of preparation was roasting in heated sand (96.8%) [4]. The sand is placed in a traditional cast iron pot and heated over an open fire, the dry beans are added in and stirred very gently for 2–3 minutes until they start to darken in colour, and release the characteristic flavour of a nutty aroma. Other methods such as boiling of fresh green beans, compositing with samp or dried melon (lengangale) and also traditional oil extraction method by grinding and water-boiling are also widely used [4, 3]. Medicinally, Morama is used by all the age groups and particularly given to infants, pregnant women, lactating mothers and the elderly [4]. Traditional birth attendants have used concoctions of Morama and wild cucumber to induce lactation; the tuber is used in combination with Devil's Claw and other plants to treat diarrhoea, headache, stomach cramps and hypertension [4].

7. Antinutritional Factors and Food Safety

As with all grain legumes, Morama bean has anti-nutritional compounds, most noteworthy of which is a trypsin inhibitor which makes up about 20% of the Morama bean protein when raw [14]. This inhibitor is heat sensitive: the activity of the trypsin inhibitor dropped from 251 to 3 TUI/mL extract after 20 minutes of dry heating at 150 °C and to ca. 70 % after 30 minutes of baking at 140 °C [8]. The traditional ways of roasting and boiling are therefore already effective mitigation practices in indigenous food practices.

Morama bean is important in that it lacks cyanogenic glycosides and the enzymes needed to produce HCN, unlike some legumes [12]. No cross reactions were detected with the major peanut and lupin allergens through immunological testing [3]. In Gwamba et al. [4] 89.9% of the respondents strongly disagreed that Morama is bitter when cooked properly. Tannins and saponins give the raw seeds a bitter taste, but roasting gets rid of this bitter taste. Phytate and oxalate content is still not systematically characterized and there is a gap in the literature [4].

8. Value-Added Food Products and Commercialisation

There have been a variety of food products that are developed from Morama and undergone evaluation, many of which have been part of the EU-supported MARAMA and MARAMA II research projects [3]. The protein (1.5%), fat (3.1%) and unsaturated fatty acid (68.5%) content of Morama milk (an aqueous extract of shelled beans) is higher than soymilk and dairy milk, respectively [3]. Partially defatted Morama flour has 50-53% protein on dry matter basis and their incorporation into composite sorghum porridge greatly enhances the nutritional quality of the porridge [8, 17]. Both mechanical (~20% yield) and hexane solvent extraction (~48% yield) yields of Morama oil are appreciated for their sensory profile and consumer acceptability in fried food applications, compared to sunflower and olive oil.

Awareness of the commercial potential of Morama is high but market infrastructure is very weak. Some of the main constraints are low raw material availability, manual dehulling which is labour-intensive, lack of post-harvest infrastructure, and lack of formal linkages in the supply chain [4, 18]. Finding appropriate mechanical processing equipment and institutionalizing value chains between rural harvesters and urban and export markets are still important priorities.

9. Domestication, Breeding and Genomic Perspectives.

Its most important limitation for Morama bean is that it is a species that is harvested exclusively from the wild. The genome is relatively small (around 1 Gb, 2n = 42) and microsatellite markers have been used to confirm a wide genetic diversity among geographically distinct populations [19, 9]. Morama bean was selected for the African Orphan Crops Consortium genome sequencing programme and several genes associated to self-incompatibility and cysteine proteases have been identified using genomic tools [9, 20]. A possible alternative to conventional breeding is de novo domestication by CRISPR/Cas9 technology, which could be achieved more quickly than conventional breeding, for traits like seed shattering, pod maturation synchrony and yield [2].

Socio-economic barriers also play a role. In Botswana, survey data from the community shows a concern for soil quality, labour needs, access to water and slow returns in cash [3, 4]. The cultural

understanding of Morama as not an agricultural crop but a gift from the gods is an important constraint that needs to be addressed in a sensitive and respectful way in any research programme with the Basarwa (San). Community participatory processes and structures that safeguard IPPR and secure equitable benefit sharing are not nice to have, but requirements for ethical and sustainable development [4, 18].

10. Conclusion

Morama bean is one of the most nutritionally outstanding wild plants in sub-Saharan Africa. Not only is the plant capable of growing in soil that is too poor, too dry, and too hot for many other food crops, its combination of high-quality protein, lipids with an olive oil-like fatty acid profile, micronutrient density, and an abundance of bioactive phytochemicals is unusual, even among legumes. In fact, this is a fact that the Basarwa, Bakgalagadi and Ovaherero communities of Botswana have known for generations. There is a gap in science and policy.

Important and urgent research needs are the validation of health claims based on in vitro studies, rigorous in vivo and clinical studies, the development of low-cost mechanical harvesting systems for the small-scale rural producers, comprehensive characterization of the antinutrient and bioavailability properties of the food, and inclusive supply chain development that ensures the retention of community harvesters within the commercial value chain. The evidence reviewed here is a strong case for Morama bean to not only be incorporated into Botswana's food security policy, but into the larger international debate on crops that are nutritious and resilient to climate change and uncertain futures.

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