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The potential of *Strychnos* spp L. Utilization in Food Insecurity Alleviation: A review

Kiana K. van Rayne[a], Oluwafemi A. Adebo[b], Obiro C. Wokadala[c], and Nomali Z. Ngobese[a]

[a]Department of Botany and Plant Biotechnology, University of Johannesburg, Johannesburg, South Africa; [b]Department of Biotechnology and Food Technology, University of Johannesburg, Johannesburg, South Africa; [c]Postharvest Technology Programme, Faculty of Agricultural and Natural Sciences, University of Mpumalanga, Nelspruit, South Africa

ABSTRACT

Southern Africa has a vast resource of edible fruits, which can be useful in combating food and nutritional insecurity. However, many of these fruits are underutilized. An example of such underutilized fruit are the *Strychnos* fruits (monkey oranges). This review aims to highlight *Strychnos* spp as a potential food source to aid in the alleviation of food insecurity. This may promote more in-depth research on their nutritional value and processing procedures. Data bases such as Science Direct, Springer Link, Wiley online library and NCBI were used to construct this review. From the literature reviewed, there are numerous advantages within this genus, such as high fruit yields, drought tolerance and time of fruit maturity. Furthermore, little is known about the nutritional value of the fruit components (seeds, rind and pulp) and information regarding seed propagation is sparse, which has also hindered domestication of the genus. However, the genus appears to be a rich source of fibre, vitamin C and essential minerals such as iron. By expanding the knowledge surrounding the fruit of these species, their potential as a new food source may be exploited for its thickening properties, high micronutrient content and medicinal potential.

KEYWORDS
Domestication; edible fruit; food security; medicinal plants; South Africa; strychnine

CONTACT Nomali Z. Ngobese ngobesen@uj.ac.za Department of Botany and Plant Biotechnology, University of Johannesburg, Johannesburg, South Africa

Introduction

The global population is growing at a rapid rate and is expected to surpass 9 billion people by the year 2050.[1] Within Africa, the continuous growth will place pressure on the food system thus increasing the demand on food production. By exploiting underutilized edible plants as alternatives or food supplements, the increasing pressure placed on the current food staples may be drastically reduced. Additionally, food and nutritional security is defined by the successful attempts in repeatedly obtaining safe, affordable, and nutritious food supplies to sustain individuals through their daily activities. A prominent issue arising from food and nutritional insecurity is malnutrition, defined as the undernourishment, over nourishment, or poor balanced intake of nutrients.[2,3] While food security, malnutrition and obesity are three of the major components causing detrimental effects on health and livelihood globally, the current pandemic caused by the rapid out break of the Coronavirus Disease 2019 (COVID-19) further amplifies the impact of these components on communities which have already been battling food and dietary constraints. Due to the enforcement of multinational lockdowns aimed in controlling the spread of COVID-19, food availability and accessibility have been negatively impacted, which thus has had a knock on effect on food security, resulting in increased malnutrition and in turn increases vulnerability to non-communicable diseases (i.e diabetes) and illnesses (i.e COVID-19).[4] Thus, highlighting flaws within the current food system and reinforcing the need for a more robust and sustainable food system.

Majority of the world's food supply is based on the agro-industrial food system, which originated during the green revolution. This system does not include a large diversity of food crops and is centred around the production and development of high-yielding, energy-dense and nutrient-poor crops, such as maize, wheat and rice, which proved to be beneficial in providing food for a large majority of the population. However, a number of complications arose from the dependency on these key crops (maize, wheat and rice) which led to detrimental effects on the environment (soil erosion, water depletion, pollution and pest resistance), reduction of biodiversity (due to the expansion of agricultural land)[5] and malnutrition (due to the dependence on nutrient-poor crops).[6] Moreover, this dependency has left the global food system vulnerable to economic and environmental changes as the above-mentioned crops are not resilient to climate change.[3] By expanding the diversity of crops on which the current food systems are based on, positive effects may be observed on the environment, dietary nutrition and livelihoods, both locally and globally. Environmental benefits include reduction in carbon dioxide, conservation of local biodiversity, improvements in soil quality and water security. Nutritional benefits include diversified diets, mitigation of micronutrient deficiencies and availability of important vitamins. Livelihood benefits include the reduction in poverty, employment opportunities, improved household food security, and gender empowerment.[7] Thus, the inclusion of indigenous food crops may transform the current food system as well as contributing to global initiatives such as the sustainable development goals (SDGs). These are a set of 17 goals developed in 2015, which aims for global sustainable development by alleviating poverty, protection of the planet and ensuring prosperity. The utilization of indigenous food crops may contribute to seven of the SDGs, this incluseds 1. The alleviation of poverty, 2. the alleviation of hunger, 3. improvement of health and wellbeing, 12. responsible consumption and production, 13. climate action, 15. life on land, and 17. partnership for the goals.[8]

A reliable food system is one which not only provides nutritious food for all but is also environmentally, socially, and economically acceptable. A system that will not have detrimental effects of the food supply for future generations.[3] By incorporating a qualitative increase in food production coupled with a drastic reduction in food waste in the food system, food security may be attained. Furthermore, the inclusion of underutilized crops may greatly benefit this endeavour, as Africa alone is home to over 4000 underutilized vegetables and fruit trees.[1] The incorporation of these food plants into the food system may alleviate food insecurity and poverty, especially in the rural regions of South Africa. Thus, the commercialization of underutilized indigenous food crops will contribute to the development of agro-diversity and build a resilient food system.[3] A number of studies have indicated that South Africa is home to a large variety of indigenous edible plants that may be used to produce food and beverages, for both the local and international market.[6,9,10] However, the potential of these underutilized plants has not been fully realized, as in-depth research on their incorporation in the value chain remains scanty. Past research has revolved around their identification, listing as well as documentation of their potential as a food source. The lack of knowledge, with regards to phytochemical, nutritional and functional properties, of underutilized fruit species hinders domestication initiatives that may promote food security.[11] In an effort to expand the knowledge of these underutilized food plants, recent studies have focused on determining their nutritional compositions.[12–15] However, there are many more edible underutilized fruit trees which have the potential to be commercialized for consumption. This review aims to highlight *Strychnos* spp as a potential food source to aid in the alleviation of food insecurity. This may promote more in-depth research on their nutritional value and processing procedures. Data bases such as Science Direct, Springer Link, Wiley online library, Taylor & Francis Online and NCBI were used to construct this review.

Strychnos spp

Species within this genus are highly valued amongst communities in rural areas, as they have proven to be a reliable source of food especially in times of scarcity of staple crops or crop failure. Their reliability is based on their seasonality and yields.[16,17] The morphological structure of species in this genus consists of trees, shrubs, and woody climbers, often consisting of small clusters of white or creamy white flowers. While the fruits may be categorised into three size groups, namely small, medium and large fruits. Species such as *S. mitis, S. potatorum, S. usambarensis, S. decussata* and *S. henningsii* produce the smaller class of globose or subglobose fruit, ranging between 12 mm to 20 mm in diameter, with thin-fleshy rinds. *S. cocculoides* and *S. gerrardii* may be categorised as medium sized globose fruit (50–70 mm in diameter), with thick woody rinds. The larger class of globose fruits are produced by the species *S. madagascariensis, S. pungens* and *S. spinosa* (80–120 mm in diameter) and are also comprised of thick woody rinds.[18–20] The monkey orange fruits (Fig. 1) typically reach maturation and are harvested near the end of the dry season (lean season, July – September), when many other crops are not available. While the fruits of *S. madagascariensis* reach maturation and fall from the tree between December and March, in Madagascar. The monkey orange trees also produce large fruit yields (300–700 fruits per tree).[16,17,25,26] Majority of the species found within this genus are considered to be poisonous, due to the presence of alkaloids, strychnine and brucine. These toxic compounds are typically restricted to the seeds, while the fruit pulp remains edible.[26] The genus *Strychnos* is a pantropical genus, and species are split across four geographical regions, namely American, African, Asian and Australian regions.[27] According to Ngadze,[21] 75 *Strychnos* species have been reported to occur within Africa and of these species, 20 (occurring primarily in southern Africa) produce edible fruits. Within Africa, most widely distributed species include, *S. spinosa; S. innocua; S.usambarensis; S. decussata; S. henningsii; S. madagascariensis* and *S. mitis*. An additional commonly consumed fruit is *S. cocculoides*. In particular, *S. madagascariensis* and *S. spinosa* densely populate the UMkhanyakude district, in KwaZulu-Natal, South Africa where these species are acclimatized to unfavorable conditions such as drought and low soil fertility.[28] Although little is known about the nutritional value of monkey orange fruits and seeds, some belonging to the *S. innocua, S. madagascariensis, S. cocculoides* and *S. spinosa* species are frequently consumed.[27] The succeeding section of this review highlights such uses of the *Strychnos* spp.

Permission was granted to make use of images from the respective authors. Images 1C and 1c were provided by Godfrey Elijah Zharare, images 1d and 1f were provided by Ruth T. Ngadze and images 1E, 1e and 1 H were provides by Adekunle Adebowale and Ashley Nicholas.

Indicators of fruit maturity

The fruits produced by the monkey orange trees are typically harvested during the ripening stage (i.e. yellow/ orange fruit) of the fruit (Table 1). These stages are visually determined through color changes of the fruit rind (Fig. 2). The table below documents color changes that occur in the fruits of popular *Strychnos* species, from mature unripe to mature ripe. These color changes may be used as maturity indicators in determining the stage at which fruits are ready to be harvested and consumed.

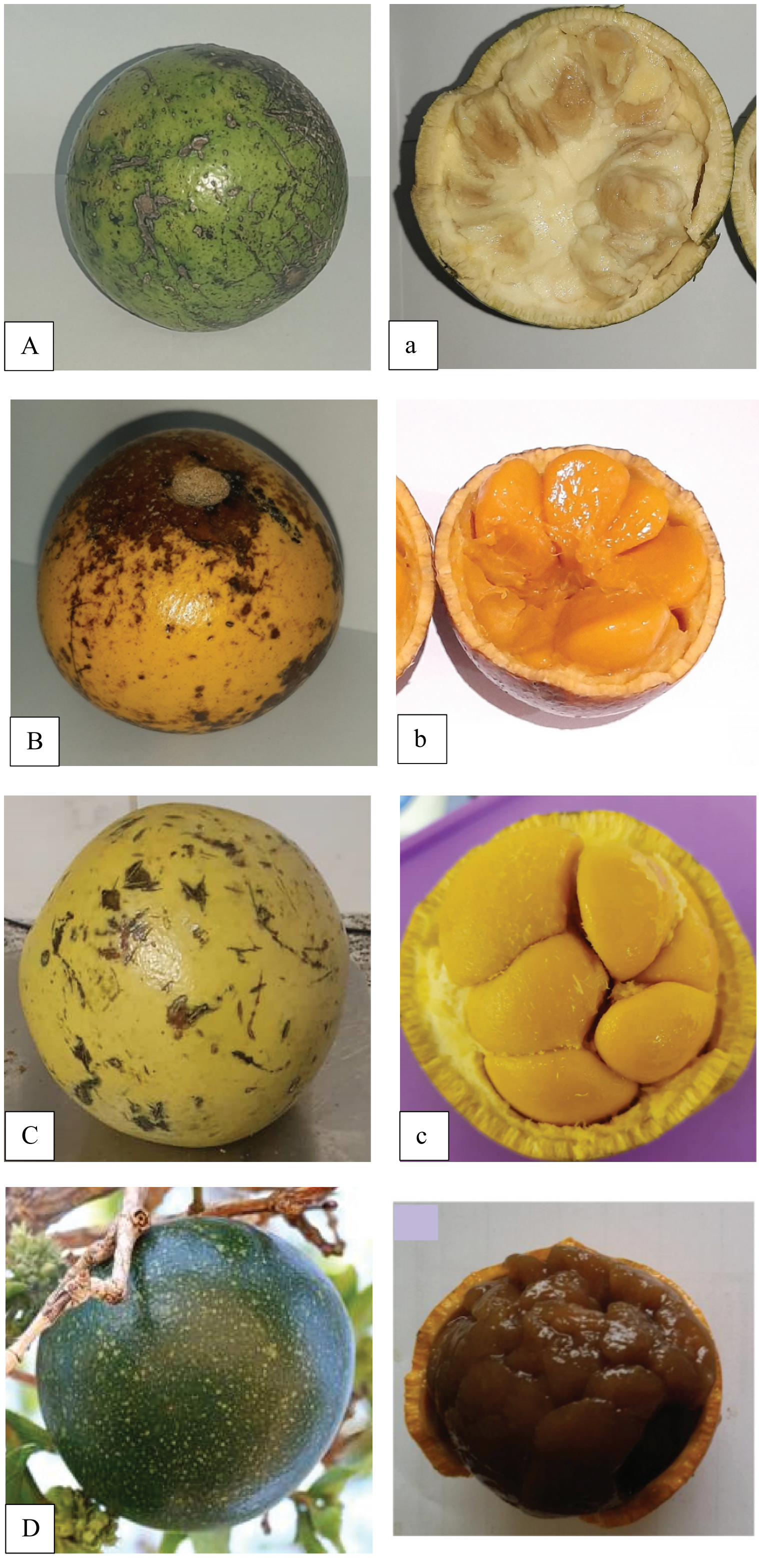

Figure 1. The above images are (A) *S. spinosa*, (B) *S. madagascariensis*, (C) *S. pungens*, (D) *S. cocculoides*,[21,22] (E) *S. gerrardii*, (F) *S. innocua*[21,23] (G) *S. nux-vomica*[24] and (H) *S. decussata*.

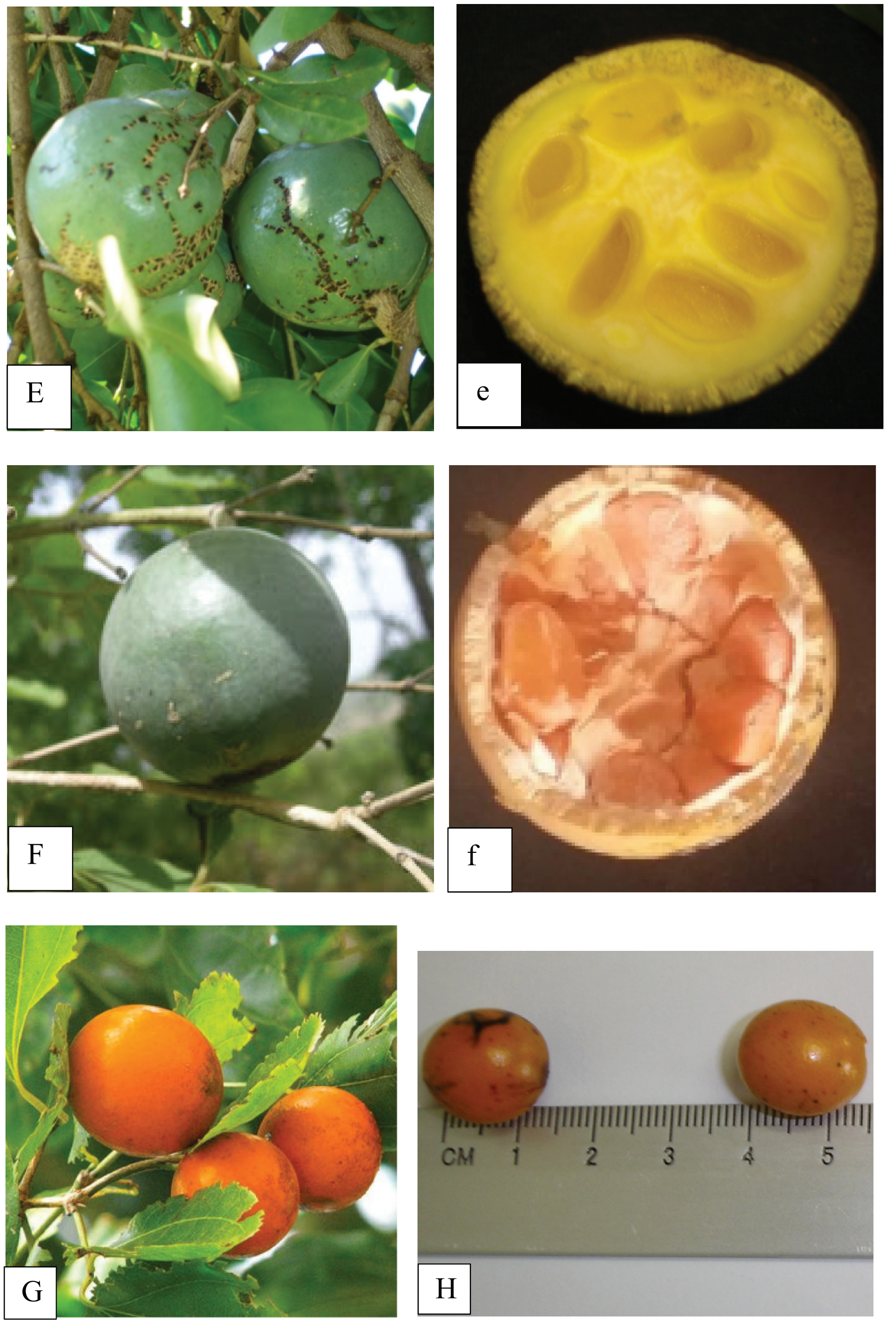

Figure 1. Continued

-: not available

Based on a study conducted by Sitrit[29] on the characterization of *Strychnos spinosa* as a potential new crop, the fruit of *S. spinosa* requires approximately 100 days to reach full size. Color break in the fruits begins at 20–25 days after harvest. However, this period may be reduced through the exposure to ethylene as the fruits are climacteric and increased exposure to ethylene may trigger chlorophyll degradation during the ripening process. Little is known

Figure 2. The image above shows the color changes occurring in *S. madagascariensis* fruits during ripening of mature fruit.

about the maturation process and ripening of *S. madagascariensis* fruit and how these physiological changes influence the nutritional quality of the fruit pulp and seeds. Nonetheless, an overview of its nutritional constituents is provided in the ensuing section.

Nutritional value

As previously mentioned in Section 2, the fruits of certain *Strychnos* species are highly valued amongst communities in the rural regions of southern Africa due to their reliability and abundance. Furthermore, nutritional analysis (Table 2) supports its popularity as it revealed that *S. innocua* fruit pulp is a rich source of lipids (6.0–20%), carbohydrates (61–75.53%), potassium (28.67–256.33 mg/100 g), copper (2.37 mg/100 g) and zinc (28.73 mg/100 g).[31,32] The seeds of *S. madagascariensis* are also valuable sources of reducing sugars (41%), fiber (53%), iron (15.78 mg/100 g) and manganese (9.86 mg/100 g).[33] The fruit pulp of *S. spinosa* is a good source of fiber (16.7–23.96%), carbohydrates (42.1–59.82%) and vitamin C (880 mg/100 g).[12,30] The fiber content of all three fruit species (especially *S. spinosa* and *S. madagascariensis*), which ranges between 25–30%[30] as mentioned in Table 2, may aid in the daily recommended intake (DRI) for adults. With regards to the vitamin and mineral content, the *Strychnos* spp fruit may greatly contribute to the DRI of Zn (42 mg/day), Fe (6.7 – males, 11.4 mg/day females), Mn (2.5–2.8 mg) and vitamin C (75–90 mg/day) in adults.[30,33] There is a lack of information surrounding the nutritional contents of other popular *Strychnos* species (*S. pungens* and *S. cocculoides*), which indicates a need for further research to fill this gap. Moreover, knowledge of the effects of processing on the nutritional value of *Strychnos* species is limited, which further impedes utilization of the genus as a food source and emphasizes the need for further investigation.

P: phosphorus; Ca: calcium; Mg: magnesium; Fe: iron; K: potassium; Na: Sodium; Cu: coper: Mn: manganese; Zn: zinc; Vit. C: vitamin C; -: not available; *: wet weight

The techniques or methods used for the quantification of various nutritional components of S. spinosa, *S. innocua* and *S. madagascariensis*, as depicted in Table 2, are as follows. Proximate analysis of ash, protein, fats and fibre (for *S. spinosa* and *S. innocua*) were determined through the methods set out by the Association of Official Analytical Chemists, AOAC (1990). While the proximate analysis of *S. madagascariensis* was done as follows, protein was determined by multiplying the total nitrogen content by the conversion factor 6.25, ether extraction was used for fats, and fiber was determined through acid/neutral detergent analysis.[33] The total carbohydrate content was calculated through difference while the total energy component was calculated using the protein, fat and carbohydrate

Table 1. Color changes that occur during the ripening of *Strychnos* spp.

	Common name	Immature fruit color	Mature ripe fruit color	Fruit pulp at maturity	References
S. madagascariensis Poir.	Black monkey orange	Pale green-blue	Yellow	Orange	[35]
S. spinosa Lam.	Green monkey orange	Bright green	Initially yellow, then brown/black	White – yellow – dark brown. Fruit falls off the tree when mature.	[16]
S. pungens Soler.	Spiny-leafed monkey orange	Bluish-green	Yellow	Pale yellow. Fruit falls from tree when ripe.	[16]
S. cocculoides Baker.	Corky-bark monkey orange	Green	Orange	Yellow-brownish. Fruit falls from tree before ripening.	[16]
S. mittis S. Moore	Yellow bitterberry	Green	Yellow-orange	-	[20]
S. potatorum Linn	Black bitterberry	Green	Blue-black	Whitish	[20]
S. decussata (Pappe) Gilg	Cape-teak	Green	Orange-red	-	[20]
S. gerrardii N.E.Br.	Coastal monkey orange	Green	Orange-yellow	Orange	[20]
S. henningsii Gilg	Red bitterberry	Yellow-orange	Purple-black	-	[20]
S. usambarensis	Blue bitterberry	Bluish-green	Yellow-orange	-	[20]

contents. The method of analysis used for the quantification of the mineral components of *S. spinosa* and *S. innocua* is atomic absorption spectrophotometry (AAS), while mineral analysis for *S. madagascariensis* was done through inductively coupled plasma-optical emission spectrometry (ICP-OES).[12,32,33] The vitamin C contents of both *S.spinosa* and *S. innocua* were determined through the titration method.[12,32]

A recent study conducted by Ngadze *et al*,[34] on the utilization of monkey orange (*S. cocculoides*) juice to fortify maize based diets revealed a number of beneficial effects. Initial findings showed that maize porridges fortified with processed monkey orange juice had a much higher organic acid content in comparison to unfortified maize porridge. Malic acid (54.7 mg/100 g, FW) was identified as the predominant organic acid, followed by fumaric acid, citric acid and formic acid (23.1 mg/100 g; 0.9 mg/100 g and 0.1 mg/100 g, respectively). The study also showed that the addition of monkey orange juice in maize porridges significantly increased the bioavailability of both phenolic compounds and minerals. Furthermore, the fortified porridge showed lower levels of starch hydrolysis which may be caused by the high phenolic compound content.

Fruit processing and product development

Based on the availability and beneficial effects of *Strychnos* fruits, rural communities have further exploited the use of these species through fruit processing and product development. Table 3 indicates some of the food products developed from *Strychnos* species. The common processing methods used are drying or exposing the plant components to heat as a way of creating products which may last longer.

According to Ngadze et al.,[17] *Strychnos spp*. fruit pulp should be immediately consumed or processed after the fruit is cracked open as the pulp is highly susceptible to microbial spoilage and enzymatic browning. Thus, the fruit is typically processed per household in an effort to extend the shelf life of the produce. The pulp is generally dried, juiced or processed into jams and other related products. Drying of the pulp is typically done over a fire or direct sunlight, the dried fruit pulp is then made into fruit rolls, leathers, or pounded into a flour which is added to maize porridge or sauces. Juicing is initiated by soaking the pulp in water to separate the pulp attached to the seeds. The mixture

Table 2. Nutritional values of *Strychnos* spp. fruit. Values are calculated based on 100 g DW of fruit.

Species	Plant part	Ash (%)	Crude protein (%)	Fat (%)	Fiber (%)	Total carbohydrate (%)	Energy (kJ/100 g)	Minerals (mg/g)									Vitamin (mg/100 g)	References
								P	Ca	Mg	Fe	K	Na	Cu	Mn	Zn	Vit. C	
Strychnos spinosa	Fruit pulp	4.1 – 4.6	3.3–11.7	1.9 – 31.2	16.7–24.0	42.1–59.8	1923	0.66–1.68	0.15–1.3	0.43–1.41	0.00–0.14	1.37–19.68	0.02–0.25	0.00	0.03	0.00–0.01	880	[12,30]
Strychnos innocua	Fruit pulp	0.5 – 3.7	4.0–11.5	6.0–20.0	17.9	61.0–75.5	1390–2084	2.11–2.60	0.06–6.67	1.63–10.67	0.06–9.77	28.67–256.33	0.46–153.33	2.37	2.50	28.73	*18	[31,32]
Strychnos madagascariensis	Seeds	-	8.3	1.0	53.0	89.9	791	94.20	148.03	79.25	15.78	594.36	16.45	0.72	9.86	1.36	-	[33]

Table 3. Food products developed from popular *Strychnos* spp.

Species name	Plant part	Processing	Food product	References
S. madagascariensis	Fruit pulp	Eaten raw	Snack	[32,35–37]
		Pounded and sundried	Flavoring in porridge, jams, juices, fruit roles, wine and beer	
	Seeds	Roasted on an open fire	Sweet treats	
	Root, bark and leaves	Crushed and mixed with cold water	Tea (for the treatment of diarrhoea)	
S. spinosa	Fruit pulp	Eaten raw	Snack	[12,22]
		Sundried	Food preserve (jams, jellies, juices, fruit roles, powders, wine, beer, fritters and muffins)	
S. pungens	Fruit pulp	Eaten raw	Snack	[38,39]
S. cocculoides	Fruit pulp	Eaten raw	Snack	[34,38,40,41]
		Juiced	Fruit juice,	
			Porridge supplement	
S. innocua	Fruit pulp	Eaten raw	Snack	[32]

is then heated (92°C, for 3 minutes) and stained using a cloth. Lastly, jams, sauces, pickles or chutneys are generally produced through heating and pasteurization of the fruit pulp. However, the type of food product and methods used is species dependant.[14] Furthermore, little is known about the effects of these processing methods on the nutritional composition and functional properties of the fruit.

Based on the medicinal uses of some of the species mentioned later, in Table 4, these species may hold antibacterial and antifungal properties which may aid in food preservation. However, further research is required to determine the antibacterial and antifungal efficacy of these species on foodborne pathogens as well as determining the effects of processing on these properties and nutritional quality.

Potential food hydrocolloid/thickener application of *Strychnos* spp

As mentioned in Table 4, the seeds of *S. potatorum* may be used for water purification due to its coagulation properties. This has been utilized in the rural regions of South Indian states as traditional water clarification methods. These coagulation properties are suggested to be the result of numerous -OH groups along the backbones of polysaccharide moieties, galactan and galactomannan, of the seed extracts.[55] Furthermore, studies have shown that the protein coagulant fraction, of 12 kDa, has a high potential in the treatment of turbid water.[55] Galactan and galactomannan polysaccharide fractions are also present in *S. innocua* and *S. nux-vomica* seeds, with ratios of 0.2 and 2.0 respectively.[56] Galactans and galactomannans are a particularly important polysaccharide for their utilization in industrial applications as food gums. They possess coagulant properties valuable in the treatment of water. They are also contributing components to the gelling and thickening properties of food sources such as legumes.[57] According to van Rayne,[33] the seeds of *S. madagascariensis* fruit contains high amounts of sugar (41 g/100 g), this fraction of the seeds may contain the polysaccharide fractions responsible for its thickening properties. Thus, the seeds of certain *Strychnos* species may be a valuable addition to the food industry, not only for their nutritional and medicinal properties but also for the functional properties they may impart in food products.

Domestication of *Strychnos* spp

Indigenous fruit bearing trees (IFBT's) in Sub-Saharan Africa (SSA) are typically regarded as food for animals or the poor and have only recently been made priority to aid in food security. IFBT's have many benefits over commercial crops, apart from their great distribution they provide a large diversity of produce to aid in food security; their fruiting seasons vary allowing for a constant availability of produce throughout the year; they have successfully adapted to the local climates and tend to show a greater tolerance towards droughts, fire and pests. Furthermore, commercial crops are greatly

Table 4. A summary of the distribution, habitat, uses and poisonous components in popular *Strychnos* species.

Species	Common name	Distribution	Habitat	Uses	Possible medicinal uses	Poisonous components	References
S. madagascariensis Poir.	Black Monkey Orange	Botswana, South Africa (Limpopo, North-west, Mpumulanga, KwaZulu-Natal), Eswatini	Savanna	Edible fruits, edible oils made from seed coat,	Seed coat and fruit pulp possess anti-diabetic properties. Root used to treat sore eyes	Seeds and unripe fruit are believed to be poisonous	[18,21,28,33,35,38,42–45]
S. cocculoides Bak.	Corky-bark Monkey Orange.	Botswana, Zimbabwe, Zambia, northern Namibia, Angola, Tanzania, Mozambique, Kenya	Savanna	Edible fruits	Roots are used for abdominal pains and to treat gonorrhea, it is also used as an aphrodisiac	Seeds and bark are poisonous	[18,22,38]
S. spinosa Lam.	Spiny or Green Monkey Orange	South Africa (Eastern Cape, KwaZulu-Natal), Mozambique, Swaziland, Zimbabwe, Botswana, Namibia	Savanna	Wood may be used for general carpentry, Leaves used as fodder.	leaves; roots; bark and fruit (seeds) are used medicinally for the treatment of snake bites, abdominal pains and gonorrhea	Seeds, bark and unripe fruit contain strychnine	[18,22,46,47]
S. decussata (Pappe) Gilg	Cape teak	South Africa (Eastern Cape, Knysna, KwaZulu-Natal, Gauteng)	Costal forest	No documented edible uses	Roots, leaves and bark are used medicinally for stomach ailments	Unripe fruits and bark are poisonous	[18,48]
S. nux-vomica L.	Strychnine tree, poison nut	United States, European Union, Fujian, Guangdong, Guangxi, Hainan, North Australia, Taiwan, Asia	Forest	Production of rodenticides	Dried seeds used to treat neurodisorders, arthritis and vomiting	Seeds and unripe fruit	[49–52]
S. potatorum L.f.	Clearing nut tree	India, Sri Lanka, Burma	Wet forest	Seeds, may be used in the treatment of wastewater, Fruits used as fish poison	Leaves, roots, bark and seeds are used as traditional medicine to treat various ailments	Unripe fruits	[18,27,53,54]
S. gerrardii N.E.Br.	Coastal monkey orange	KwaZulu-Natal	Coastal and dune forest	Edible fruits	No documented medicinal uses	Not documented	[20]

dependant on additional inputs such as fertilizers, herbicides and pesticides, whereas IFBT's may be less dependent on these inputs if domesticated.[58] Domestication of indigenous food plants with potential economic value is typically subjected to a selection criterion to identify priority species. This criterion encompasses aspects such as cash value, food provision, medicinal value, harvest period, ease of propagation and drought tolerance.[53] A study conducted by Sato,[59] revealed that the seeds of *S. madagascariensis* have a high germination rate (98%, after the pulp has been separated from the seeds). Additionally, Govender,[35] reports that the species may be easily cultivated from seed similar to that of *S. spinosa*,[60] thus further promoting this species for domestication. The focus of such aspects has been placed on more popular species within this genus, such as *S. cocculoides* and *S. nux-vomica*. According to Mkonda,[61] the domestication of *S. cocculoides* was initiated by the domestication program developed by the International Centre for Research in Agroforestry. This initiative was developed for the incorporation of valuable indigenous fruit trees into agroforestry, to increase the availability of food in rural regions. *S. cocculoides* was chosen as it ranked third in preferred fruit trees by farmers. Their studies indicated that the seeds of *S. cocculoides* germinate well without any additional treatments, while variation in germination success is based on phenotypical variation within the species. *S. cocculoides* is reported to have an 80% germination rate within three weeks in summer and nine weeks in winter. However, the survival rate of seedlings may decline drastically. The tree is reported to produce fruit five years after sowing from seed.[40] *S. nux-vomica* is highly valued for its homoeopathic uses and source of drugs in Asia and India. Similar to that of *S. cocculoides*, the success of germination of the seeds of *S. nux-vomica* varies with phenotypical variation within the species. Larger seeds prove to germinate more successfully than smaller seeds.[62] Le Roux,[46] reports that the seeds of *S. spinosa* grow well in cultivation, provided that they receive moderate amounts of water and are planted in warm climates. A study conducted by Nkosi *et al.*,[60] revealed that *S. spinosa* ranked first for the most preferred indigenous fruit tree in KwaZulu-Natal, this was due to the species ease of propagation, value added products, market demand, yield, pest tolerance and drought tolerance. However, further research is required to expand the knowledge around the less popular *Strychnos* species for their consideration in domestication programs.

Toxicity of *Strychnos spp.*

Although the fruits of *S. madagascariensis, S. cocculoides, S. pungens* and *S. spinosa* are only safe for consumption once they have ripened, as the unripe fruits are believed to contain strychnine and other toxic alkaloids (such as brucine), they are still regularly consumed by the rural communities and are highly valued for their nutritional contributions to daily diets.[21,42,43] Strychnine and brucine are part of a group of secondary metabolites, that are used by plants to deter herbivorous animals and insects. Plants containing these secondary metabolites are also considered poisonous to humans if accidentally consumed.[43] The lethal dosage of strychnine is reported to range between 30–120 mg (for adults) and 15 mg (for children), per day. Consumption of this alkaloid in these quantities may lead to convulsions of the central nervous system and death (induced by spinal paralysis or cardiac failure).[44] The toxicity of brucine is not as severe, in comparison to strychnine, as its lethal dosage much higher (1000 mg for an adult).[44] Information regarding the chronic toxicity of these alkaloids after long term consumption has not been documented. Due to the presence of these alkaloids, the seeds of many *Strychnos* species are avoided for consumption. Govender[35] reports that although the seeds of *S. madagascariensis* are bitter in taste, they are still often consumed in rural areas as sweet treats. However, Shaffer[63] reports that only the fruit pulp of *S. madagascariensis* is consumed as the seeds are believed to contain strychnine. According to van Rayne,[33] the seeds of *S. madagascariensis* were found to contain moderate amounts of strychnine (0.08% on a dmb), while the seeds of *S. nux-vomica* contains 1.25–2.5% strychnine and 1.5–1.7% brucine,[44] suggesting that the seeds of *S. madagascariensis* are substantially less toxic in comparison to the popular medicinally important species *S. nux-vomica*. However, further research is required around the toxicity of the seeds and how processing may affect its toxicity.

Medicinal uses of *Strychnos spp.*

The use of medicinal plants for the treatment of a large rage of ailments has been the center of communities and cultures for centauries and still maintains it value to date. The use of traditional medicinal plants is gaining popularity both internationally and locally to meet the primary health care needs. Medicinal plants hold particular value in developing countries such as South Africa due to the vast variety of plant species.[49] It has been estimated that around 80% of residents in developing countries are dependent on medicinal plants while 90% of residents in certain African countries are solely dependent on these plants·[45] The medicinal value of many *Strychnos* species may be attributed to the alkaloid content, of which this genus is popular for. *S. nux-vomica* is considered to be an important medicinal plant around the world, despite its highly toxic characteristic. A critical step in the use of *S. nux-vomica* seeds for therapeutic purposes is the processing or detoxification step in order to reduce its alkaloid content. Various pharmacopoeias describe a range of detoxification procedures, including the use of cow's urine, milk, ghee, Kanji, castor oil, ginger, sand and vinegar.[44] However, heat treatments allow for the use of *S. nux-vomica* seeds as a medicinal treatment as it lowers the strychnine and brucine content, as well as increasing the isostrychnine, isobrucine, strychnine N-oxide and brucine N-oxide contents.[44] Due to its medicinal importance, this species is cultivated in the United States, European Union, Fujian, Guangdong, Gauangxi, Hainan, North Australia, Taiwan and Asia. Moreover, it is particularly popular in Indian and Chinese herbal remedies.[64] However, many of the medicinal properties of this genus have not been scientifically supported, thus requiring further research on the effectiveness of this alkaloid, as well as identifying other compounds which may contribute to the medicinal value of these species.

Conclusions

In conclusion, *Strychnos* spp are only valued in the rural communities as lack of knowledge surrounding their nutritional value and potential strychnine content has hindered their integration into the general food system. Recent studies have classified certain species as priority species due to their popularity, fruit yields, drought tolerance and cash value. However, less popular species within this genus may prove to be valuable to the food system once their nutritional compositions and cultivation potential has been fully explored. Furthermore, the addition of underutilized indigenous fruit trees, such as those found in *Strychnos* spp, may aid in alleviating food and nutrition insecurity as well as assisting in creating other food products for consumption.

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ORCID

Oluwafemi A. Adebo http://orcid.org/0000-0002-3757-5137

Author contributions

Conceptualization, K.K.V.R and N.Z.N.; investigation, K.K.V.R.; software and formal analysis, K.K.V.R. and N.Z.N.; data curation, N.Z.N.; writing—original draft preparation, K.K.V.R.; supervision, O.W., O.A.A. and N.Z.N.; project administration and funding acquisition, N.Z.N. All authors have read, edited and agreed to the published version of the manuscript.

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