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Review article

Nutraceutical and antimicrobial potentials of Bambara groundnut (*Vigna subterranean*): A review

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ABSTRACT

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) [BGN] is an easy-to-cultivate vegetable crop neglected over the past years. It is a drought-tolerant crop with nutritional and medicinal values and as a result, the crop is referred to as nutraceuticals. Based on this, there exist a need to review the beneficial potential (nutraceutical value) of this neglected and underutilized crop to protect and promote its cultivation for food (source of nutrients) and medicines especially among rural poor communities in sub-Saharan Africa. This review systematically examines the background information and uses of BGN. The antimicrobial properties of BGN were also considered and examined to ascertain its nutraceutical importance. BGN has been reported as a crop possessing antioxidant and antimicrobial properties. Clinically, the extracts of BGN have been reported to exhibit antimicrobial activities against bacteria such as *Klebsiella pneumoniae* subsp. *pneumoniae* ATCC 700603, *Pseudomonas aeruginosa* ATCC 27853, *Staphylococcus aureus* subsp. *aureus* ATCC 33591, *Escherichia coli*, *Bacillus cereus*, yeast (*Candida albicans*) and mold (*Aspergillus niger*). This review outlines the uses of BGN as a functional food crop as well as its nutraceutical and antimicrobial potentials. However, there exist paucity of knowledge and literature on the crop's antimicrobial activities especially against plant pathogens of economic importance. Hence, this review proposes that more research be geared towards assessing the nutraceutical value and antimicrobial potentials of this crop against plant pathogens of economic importance and the promotion of the crop's cultivation.

1. Introduction

Leguminous plants are known for their nutritional value and economic significance in the world [1]. Even though legumes are regarded as the poor man's meat, they play a crucial function in the diets and wellbeing of humans especially in poor rural African communities in sub-Saharan Africa because of the high protein and carbohydrates content and assorted phenolic compounds being released when consumed (cooked or uncooked) [2]. Carbonaro *et al.* [3] reported that legume seeds contain proteins and peptides that could be grouped as nutraceuticals. According to Pandey, Verma, & Saraf, [4], nutraceuticals are synthetic substances or chemical compounds (usually concentrated in powder, capsule or pill form) that can provide therapeutic or wellbeing benefits to humans, including the promotion of disease prevention and treatment. Sasi [5] refers nutraceuticals as any functional food extract with health and medical benefits especially to humans. Also, López-Gutiérrez *et al.* [6] reported phytochemicals as non-nutritive compounds in plants with disease-preventive properties. Plant-based nutraceuticals have drawn the attention of most researchers in recent years due to the presence of a vast variety of phytochemicals (some undiscovered) with health benefits and disease-preventive properties.

One of the major causes of premature death killing about 50000 people daily in the world is infectious diseases [7]. Due to the resistance of human pathogenic microbes to drugs, a subsequent rise in the infectious diseases has been reported leading to increase in mortality rates [7]. This has resulted in an increased pursuit for plants phytochemicals with the potency to inhibit the proliferation of microbes that have shown or developed resistance to conventional drugs or antibiotics. Plants with one or more of their organs containing bioactive compounds that can be used to synthesize drugs are referred to as medicinal plants according to the World Health Organisation [8]. Vats *et al.* [9] reported that plants are used traditionally as antimicrobials. Hence, plants could be regarded as alternatives to the cure of infectious diseases as the incidence of microbes resistant to antibiotics has been on the increasing side.

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Bambara groundnut [BGN] is mainly cultivated for its seed in most rural areas in sub-Saharan Africa [10]. Mayes *et al.* [11] reported BGN as a crop that researchers have ignored despite its nutritional value. This could be attributed to less knowledge of the plant's phytochemical composition and their associated nutraceutical properties including its antimicrobial and antioxidant potentials. In sub-Saharan Africa, BGN is grown locally to sustain families by providing a source of protein, carbohydrates and nutrients (functional food) and income for households especially in rural communities [12]. Bambara groundnut has been a research focus as a functional food alternative as well as characterization of its phytochemical properties since the identification of its nutritional and nutraceutical values. For example, Bambara groundnut cultivars from Zambia were reported to exhibit antioxidant potency similar to lentils, common beans and chickpeas [13]. Furthermore, the presence of flavonoids, tannins and alkaloids in BGN cultivars were found in Nigeria and the alkaloids were reported to possess analgesic properties [14]. In addition, work done by many other researchers has shown that BGN possesses antioxidant and antimicrobial properties and are used to treat many ailments [15, 16, 17, 18, 19]. However, literature is scant on the uses and potential nutraceutical and antimicrobial properties of BGN especially against plant pathogens of economic importance. Therefore, this review examined the background information on the cultivation and uses of BGN. The nutraceutical and antimicrobial properties of BGN were also considered and examined to ascertain the medicinal uses of the plant especially its antimicrobial potentials for control and management of both human and plant pathogens.

2. Bambara groundnut description and cultivation

Bambara groundnut (BGN) is a native crop widely cultivated in most countries in sub-Saharan Africa. In sub-Saharan Africa, the countries where BGN is widely grown cut across different agro-ecological regions in the continent including the west, central, east and southern subregions [20, 21, 22, 23]. The crop is an indigenous African legume that belongs to the family and sub-family of *Fabaceae* and *Faboidea* respectively. The common names of BGN vary across the continent. In Nigeria, it is called Okpa (Igbo speaking part) and Gurujia (Hausa speaking part), Njugo in South Africa, Nzama in Malawi, Ntoyo in Ci Bemba or Katoyo in Zambia [24]. Stephens [25] also indicated that BGN is also known as voandzou nzama (in Malawi), baffin pea, indhlubu, and underground bean.

Bambara groundnut is an annual leguminous plant [26, 27] with strong taproot and trifoliate leaves that have long and green petiole [27]. Massawe *et al.* [28] pointed out that the flowers are borne on long, hairy peduncles arising from the stem nodes. The plant has oval or spherical pods that are about 3.0–3.7 cm long [29]. Bambara groundnut landraces comprise of many genotypes with diverse strength to endure environmental pressure [27, 29, 30]. The developmental period of the plant ranges from 110-150 days under a mean temperature of 20–28 °C, well-drained soil and sandy loams with 5.0–6.5 pH values [27]. Bambara groundnut seed colouration varies from black, brown or red and sometimes stippled with numerous colours [22, 31]. The hulls are often removed before they are consumed. The removed hulls are regarded as a waste product. However, the work done by Klompong and Benjakul [18] has shown the hulls to be a source of nutraceuticals and functional ingredients. BGN is free from complete crop failure because of its ability to thrive well under harsh environmental stress conditions like low and uncertain rainfall and nitrogen-deficient soils [30, 32, 33].

The plant is capable of surviving in wet climates, and poor-nutrient soil conditions that most non-leguminous plant may not survive [31]. Tibe *et al.* [34] indicated BGN as a pest, disease, and drought-resistant crop capable of reducing pest in the field. The ability of BGN to fix atmospheric nitrogen through the process of biological nitrogen fixation reduces the necessity to apply manures or expensive environmentally unfriendly synthetic fertilizers especially in nutrient-poor soils in Africa, where the crop is cultivated by resource-poor farmers. This nitrogen-fixing ability of BGN was supported by work done by Mohale *et al.* [35] on the symbiotic nitrogen (N) nutrition efficiency of BGN grown in the Lowveld region (Mpumalanga Province) in South Africa. The authors found that BGN was significantly dependent on symbiotic fixation (4–200 kg N-fixed ha^{-1}) for its N nutrition and contributed N (33–98%) to the nutrient-poor soils in the region [35]. In the dry savannah regions in sub-Saharan Africa, BGN is a point of interest for utilization and cultivation. In Botswana, 90% of farmers (majority are women) cultivate BGN and 63% of the farmers grew the crop for consumption, 12% of them grew the plant for making a profit and 25% for both feeding and making a profit [36]. Based on the crop's ability to strive well in harsh conditions such as poor-nutrient soils and drought under future climate change scenarios, the crop is seen as a poverty and poor nutrition remediation crop that can enhance food and nutrition security especially in poor rural communities in sub-Saharan Africa.

3. Bambara groundnut nutrition and uses

Bambara groundnut serves as a source of protein to the consumers and is grown locally by the rural population to provide food for their immediate families especially in most countries in sub-Saharan Africa. The works done by researchers have shown that seeds of BGN per 100 g dry weight may contain carbohydrates (49–63.5%), protein (15–25%), fat (4.5–7.4%), fibre (3.2–4.4%), ash (0.7%), and cholesterol (0.01%) [24, 31, 37]. Mwale *et al.* [12] pointed out that the protein content of BGN is comparable to other legumes and as a result, it is regarded as a worthy supplement for cereal-based diets. Sesay [38] further pointed out that BGN is a source of protein, and carbohydrates to consumers (thus servings as a functional food), and additional income to subsistence farmers in rural areas in most West African countries. The fruits of BGN are produced underground and the pods containing at least one or two seeds are noticeably hard and wrinkled when dried. The dried seeds can be boiled and consumed as a functional food. Further, the food crop can be consumed matured as porridge [22] or immature form as a snack after sweltering or roasting with a tincture of salt [25]. The seeds' chemical content makes them nutritious and a complete food [32, 39, 40].

Biochemical composition of the seed has been reported by many researchers [39, 40, 41, 42, 43, 44]. Although the seed is reported to have little fat, some parts in Congo still extract oil from the seed [45]. Bambara groundnut is roasted, crushed and used in food making without condiments in East Africa [45, 46]. Some of the Zambian bread is made from BGN flour [47]. In Botswana, the nuts are used in making cakes and stiff porridge [43, 45]. Goli *et al.* [45] also reported the use of BGN flour in making steamed products like "okpa" in Nigeria. Murevanhema and Jideani [48] clarified "okpa" as a cooked mixture like gel produced using BGN paste enveloped by banana leaves and bubbled till prepared for utilization. Further, Heller *et al.* [26] revealed the application of matured black landraces seed for medicinal purposes. Vegetable milk produced from BGN was ranked first in flavour and composition; and the lighter colour of the milk was most preferred than cowpea, pigeon pea, and soybean milk [32].

Generally, most legumes are noted to possess antioxidants [48]. White and Xing [49] reported antioxidants as ingredients with the potential of protecting the quality of food by impeding the oxidative breakdown of lipids. Furthermore, Adelakun *et al.* [50] referred to antioxidants as ingredients that protect the cells and tissues of human against free radicals (reactive oxygen/nitrogen species (ROS/RNS)). The seed coats of most leguminous nuts are rich in antioxidants, and differences in amounts of antioxidants in the dark-seeded and light-seeded landraces of BGN have been reported [48]. Onyilagha *et al.* [51] reported that the red and black seed coat of BGN contains antioxidants whose antioxidative mechanisms were different from other legumes and were noted to contain more nutrient and mineral content than the light-seeded landraces. In Botswana, the light-seed landrace is preferred for consumption because of less time to cook and superior flavour while the dark-seeded landrace is used to treat impotence [48]. Interestingly, in Africa, BGN is used by different tribes for the treatment of different diseases. For example, some tribes used BGN to treat nausea and diarrhoea (in Kenya) [16], venereal diseases (in Nigeria) [48], nausea and vomiting in pregnant women (in South Africa) [15] and cataract (in Senegal) [48]. In summary, BGN has different usages, which includes provision of functional food (nutrients and minerals) and health benefits (due to their antioxidant properties) for humans and animals, and as a commodity to generate income or financial support for people in rural communities in sub-Saharan Africa. Hence, there exists the need to preserve and promote the growth of this crop for the continuous supply of the crop's benefits to the populace in most rural communities in Africa.

4. Bambara groundnut nutraceuticals

The progressive increase in the resistance of microorganisms to recently available antibiotics has prompted the quest for effective and novel antimicrobial compounds. This quest for effective antimicrobial compounds has directed researchers to focus on plant-based medicine because of their historical use for curing infectious and non-infectious diseases especially in developing and under developed countries [52]. Rojas *et al.* [53] pointed out that these medicinal plants are consumed as elixirs, teas, or juice preparations for respiratory infection treatments. Works done by many researchers [53, 54, 55, 56] have shown these medicinal plants as major sources of antimicrobial, antioxidant and anticancer compounds that can be used to produce new antibiotics that pathogenic microbes are not resistant to. For example, Kumar *et al.* [57] examined five leguminous plants (*Kingiodendron pinnatum*, *Humboldtia brunonis*, *Indigofera cassioides*, *Derris scandens* and *Ceasalpinia mimosoides*) for anti-tubercular activity and observed that the legumes contained saponins, steroids, anthro-quinones, terpinods, flavonoids and phlabotanins that showed potential for anti-tubercular activity.

The findings of some researchers [8, 45, 58] have shown that Gram-positive bacteria were more susceptible to extracts from plants than the Gram-negative bacteria. Gao *et al.* [45] reported that the ability of Gram-negative bacteria to resist plant extracts is an attribute of the lipopolysaccharides in their external membrane. However, a recent work done by Ajiboye and Oyejobi [8] using an agar-well diffusion method showed that most of the extracts used inhibited the growth of Gram-negative bacteria. Taahir [59] observed in his work, where he used direct bioautography method, that Gram-negative bacteria (*Klebsiella pneumoniae* subsp. *pneumoniae* ATCC 700603, and *Pseudomonas aeruginosa* ATCC 27853) were more inhibited than Gram-positive bacteria (*Staphylococcus aureus* subsp. *aureus* ATCC 33591) by BGN extracts from red and brown hulls confirming the work of Ajiboye and Oyejobi [8]. The ability of BGN extracts from red and brown hulls was attributed to the high phenolic content of the hulls as red and brown BGN hulls correlated well with high flavonoid and tannin content [60, 61]. Klompong and Benjakul [18] observed that BGN seed coat extracts exhibited antimicrobial properties against bacteria (*Staphylococcus aureus*, *Escherichia coli*, *Bacillus cereus*), yeast (*Candida albicans*) and mold (*Aspergillus niger*), in a dose-dependent manner using agar diffusion method. Anthony [62] found out that BGN nut extracts exhibited inhibitory properties against *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas auriginosa* and *Candida albicans* using the Kirby-Baurer diffusion method. In sum, BGN can be considered as an efficient antimicrobial agent that can inhibit the proliferation of both prokaryotic and eukaryotic cells. A typical antimicrobial agent's mechanism of action is through the penetration of the cytoplasmic membrane, disruption of the permeability of the membrane leading to the destruction of the membrane [63]. Consequently, cytoplasm leakage and coagulation occur causing the deformation, lysis and death of the cell [64]. In fungi, this agent prevents mycelial growth and spore germination [65]. The hydrophilicity and hydrophobicity of BGN phytochemicals enhance its accumulation in cell membranes leading to the change in permeability of the membrane, seepage of intracellular components, weakening enzyme systems of microbes and consequently, their death [64]. Clearly, the antimicrobial activities of BGN depend on the concentration of the extract and nature of tested organisms. However, no study has so far quantified the dosage of BGN extracts for treatment of any human disease in sub-Saharan Africa.

The use of BGN traditionally to treat many human diseases is prominent across sub-Saharan Africa countries (South Africa, Botswana, Kenya, Nigeria and Senegal) and therefore provides many opportunities for more study on the therapeutic importance and application of the crop [17]. Several authors [59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72] have reported the presence of phytochemicals with antioxidant properties in legumes, and in particular, higher amounts of phenolic compounds including nutraceutical and functional ingredients have been found in the hull of BGN compared to other parts of the plant [67]. Table 1 summarises the nutraceuticals reported to be present in BGN and their functions. It is noted that the pre-processing techniques and

Table 1. Summary of the nutraceuticals in BGN and their functions.

Nutraceuticals	Functions	References
Alkaloid compounds (e.g. 9-Octadecenamide, (Z)-, ethanol 1-methoxy- benzoate, 1-Monolinoleoylglycerol trimethylsilyl and ether butylated hydroxytoluene)	Antimicrobial and antioxidants activity	Taahir [59]
Flavonoid compounds (e.g. rutin and myricetin). Tannin compounds (e.g. chlorogenic acid and ellagic acid)	Anti-inflammatory activity, oestrogenic activity, enzyme inhibition, antimicrobial activity antiallergic activity, antioxidant activity, vascular activity and cytotoxic antitumour activity	Cushnie and Lamb [66] Taahir *et al.* [67]
Sphingolipids	Involved in protein sorting, apoptosis and calcium regulation	Spassieva and Hille [68] Tsamo *et al.* [69]
Fatty acids	Anti-inflammatory, antimicrobial and cytotoxic Activities	Tsamo *et al.* [69] Farag *et al.* [70]
t-Ferulic acid	Exhibits a wide variety of biological activities such as antioxidant, anti-inflammatory, antimicrobial, antiallergic, hepatoprotective, anticarcinogenic, antithrombotic, increase sperm viability, antiviral and vasodilatory actions, metal chelation, modulation of enzyme activity, activation of transcriptional factors, gene expression and signal transduction	Nyau *et al.* [71] Kumar and Pruthi [72]
p-Coumaric acid	High free radical scavenging, anti-inflammatory, antineoplastic, and antimicrobial activities	Nyau *et al.* [71] Ferreira *et al.* [74]
Catechin and Epicatechin	Involved in antioxidant activities	Nyau *et al.* [71] Bernatoniene and Kopustinskiene [75] Schwarz *et al.* [76]
Salicylic acid	Performs anti-inflammatory functions through suppression of transcription of genes for cyclooxygenase	Nyau *et al.* [71] Randjelović *et al.* [77]

extraction methods can affect the concentration and type of phenolics in BGN [73]. For example, boiling dry beans have been reported to reduce the phenolic content (protease inhibitors) by 80%–90% and treatment with 60% ethanol improved the nutritional quality of BGN flour and dehulling was reported to reduce the tannins content by up to 92% [67]. Cooking red BGN was reported to enhance its nutraceutical profiles as the free radical scavenging speed was increased by 10-fold compared to the uncooked using methanolic extraction optimisation [73]. The work done by Mbagwu *et al.* [19] on the phytochemical components of BGN showed the presence of more alkaloids in the crop than other legumes and differences among the hulls of BGN landraces have been noted [67]. In a study aimed at identifying the medicinal properties of BGN, Harris et al. [67] found higher amounts of flavonoids and tannins in the hulls of both brown and red BGN landraces. Among the flavonoid compounds present in the hull of brown BGN, higher amounts of rutin (24.458 mg g^{-1}) and myricetin (1.800 mg g^{-1}) were reported, and in the hull of red BGN, chlorogenic acid (0.115 mg g^{-1}) and ellagic acid (0.105 mg g^{-1}) were the highest tannin compounds reported [67]. In addition, a previous study found polyphenols (especially more catechin and epicatechin) in nuts of two market classes of BGN commonly grown in Zambia and the authors showed that their nutraceutical and antioxidant activities are enhanced after processing by cooking [73]. Furthermore, HPLC-PDA-ESI-MS profiling revealed new phenolic compounds (Quinic acid, (E) GC-hexoside, catechin glucoside, medioresinol, p-coumaric acid, salicylic acid, caffeic acid derivative and catechin dimer) in cooked seeds of BGN [73]. Interestingly, differences in phenolic compounds were noted when the two market classes of BGN were compared [57], which implies that there is potential do discover more novel phytochemical components of BGN making the crop a potential source of nutraceuticals. Although phenolic compounds (alkaloids, flavonoids, lignans, phenolic acids and tannins) in BGN are noted to treat some diseases, however, literature is scant on the correlation between the phenolic compound type, its content and remedy potency of BGN extracts for most ailments. Furthermore, literature is scant on the effect of pre-processing techniques and extraction methods of optimisation to fully utilise the nutraceutical potential of BGN. Therefore, there is need for more research geared towards assessing the nutraceutical value and antimicrobial potentials of this crop.

5. Conclusion

There is an increasing knowledge of the benefits of nutraceuticals which have attracted the interest of researchers globally. Although limited works have been done on BGN, some works done on BGN have demonstrated their potentials as a source of nutraceuticals. This review examined the uses of BGN and found that the crop has varieties of uses which cut across medical and nutritional uses. However, it was noted that limited works have been done on the nutraceutical value of the crop and the effect of pre-processing techniques on the quantity and quality of phytochemicals including the methods of extraction for their optimisation. Most of the identified antimicrobial potentials of the crop were mainly against human pathogens placing the crop as a potential natural product that can be used in the future to synthesize drugs. This review suggests further research work is needed on the nutraceutical value and antimicrobial potentials of BGN.

Declarations

Author Contribution statement

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The authors declare no conflict of interest.

Additional information

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References

[1] I.B. Baoua, L. Amadou, D. Baributsa, L.L. Murdock, Triple bag hermtic technology for post-harvest preservation of Bambara groundnut (Vigna subterranea (L.) Verdc.), J. Stored Prod. Res. 58 (2014) 48–52.
[2] R.N. Tharanathan, S. Mahadevamma, Grain legumes a boon to human nutrition, Trends Food Sci. Technol. 14 (2003) 507–518.
[3] M. Carbonaro, P. Maselli, A. Nucara, Structural aspects of legume proteins and nutraceuticals properties, Food Res. Int. 1 (2014) 1–12.
[4] M. Pandey, R.K. Verma, S.A. Saraf, Nutraceuticals: new era of medicine and health, Asian J. Pharm. Clin. Res. 3 (1) (2010) 11–15.
[5] S. Sasi, Nutraceuticals–a review, Int. J. Ind .Biotechn. Biomat. 3 (1) (2017) 25–29.
[6] N. López-Gutiérrez, R. Romero-González, P. Plaza-Bolaños, J.L.M. Vidal, Identification and quantification of phytochemicals in nutraceuticals products from green tea by UHPLC-Obitrap-MS, Food Chem. 173 (2015) 607–618.
[7] E. Scio, F. Mendes, E.V.S. Motta, P.M.Q. Bellozi, D.M.O. Aragão, J. Mello, R.L. Fabri, J.R. Moreira, Antimicrobial and antioxidant activities of some plant extracts, in: RaoVenketeshwer (Ed.), Phytochemicals as Nutraceuticals – Global Approaches to their Role in Nutrition and Health, Technol, 2012.
[8] A.A. Ajiboye, G.K. Oyejobi, In vitro antimicrobial activities of Vigna subterranean, J. Antimicro. Agents 3 (2017) 1–4.
[9] S. Vats, R. Tiwari, A. Alam, K.K. Behera, R. Pareek, Evaluation of phytochemicals, antioxidant and antimicrobial activity of in vitro culture of Vigna unguiculata, Researcher 11 (2012) 70–74.
[10] A.S. Karunaratne, S.N. Azam-Ali, I. Al-Shareef, A. Sesay, S.T. Jørgensen, N.M.J. Crout, Modelling the canopy development of Bambara groundnut, Agric. For. Meteorol. 150 (2010) 1007–1015.
[11] S. Mayes, S. Basu, O. Molosiwa, E. Redjeki, N. Ahmad, F. Khan, J. Roberts, Molecular analysis of Bambara goundnut, an under-utilised African legume crop as part of the bamlink project-what lessons can we learn, in: 2nd International Symposium on Underutilized Species: Crops for the Future-Beyond Food Security, 979, Acta Horticulture, Kuala Lumpur, 2013, pp. 451–458.
[12] S.S. Mwale, S.N. Azam-Ali, F.J. Massawe, Growth and development of Bambara groundnut (Vigna subterranea) in response to soil moisture 1. Dry matter and yield, Eur. J. Agron. 26 (2007) 345–353.
[13] V. Nyau, S. Prakash, J. Rodrigues, J. Farrant, Antioxidant activities of Bambara groundnuts as assessed by FRAP and DPPH assays, Am. J. Food Nutr. 3 (2015) 7–11.
[14] A.A. Olaleye, E.I. Adeyeye, A.J. Adesina, Chemical composition of Bambara groundnut (V. subterranean L. Verdc) seed parts, Bangladesh, J. Sci. Ind. Res. 3 (2013) 167–178.
[15] Anonymous, Production Guideline for Bambara Groundnuts, 2011.
[16] C.H. Mkandawire, Review of Bambara groundnut (Vigna subterranea (L.) Verdc.) production in sub-sahara Africa, Agric. J. 4 (2007) 464–470.
[17] P. Mølgaard, J.G. Holler, B. Asar, I. Liberna, L.B. Rosenbæk, C.P. Jebjerg, L. Jørgensen, J. Lauritzen, A. Guzman, A. Adsersen, H.T. Simonsen, Antimicrobial evaluation of Hulliche plant medicine used to treat wounds, J. Enthnopharm. 138 (2011) 219–227.
[18] V. Klompong, S. Benjakul, Antioxidative and antimicrobial activities of the extracts from the seed coat of Bambara groundnut (Voandzeia subterranea), R. Soc. Chem. Adv. 5 (2015) 9973–9985.
[19] F.N. Mbagwu, V.U. Okafor, J. Ekeanyanwu, Phytochemical screening on four edible legumes (Vigna subterranean, Glycine max, Arachis hypogea, and Vigna uniguiculata) found in eastern Nigeria, Afr. J. Plant Sci. 5 (2011) 370–372.
[20] S.M. Mpotokwane, E. Gaditlhatlhelwe, A. Sebaka, V.A. Jideani, Physical properties of Bambara groundnuts from Botswana, J. Food Eng. 89 (2008) 93–98.
[21] A.R.S.M. Eltayeb, O.A. Ali, A.A. Abou-Arab, F.M. Abu-Salme, Chemical composition and functional properties of flour and protein isolate extracted from Bambara groundnut (Vigna subterranean), Afr. J. Food Sci. 5 (2011) 82–90.
[22] V.A. Jideani, C.F. Diedericks, Nutritional, therapeutic, and prophylactic properties of Vigna subterranea and Moringa oleifera, in: O. Oguntibe (Ed.), Antioxidant-Antidiabetic Agents and Human Health, 9, Janeza Trdine, Rijeka, Croatia, 2014, pp. 187–201, 51000.
[23] V. Nyau, S. Prakash, J. Rodrigues, J. Farrant, Identification of nutraceutical phenolic compounds in Bambara groundnuts (Vigna subterranea L. Verdc) by HPLC-PDA-ESI-MS, Br. J. Appl. Sci. Technol. 6 (2014) 77–85.
[24] S.I. Okonkwo, M.F. Opara, The analysis of Bambara nut (Voandzeia subterranean (L.) thouars) for sustainability in Africa, Res. J. Appl. Sci. 6 (2010) 394–396.
[25] J.M. Stephens, Bambara Groundnut-Voandzeia subterranean, (L.) Thouars, University of Florida, Gainesville, Florida, 2012. http://edis.ifas.ufl.edu/mv014. (Accessed 19 March 2015).
[26] J. Heller, F. Begemann, J. Mushonga, Bambara groundnut. Vigna subterranea (L.) Verdc. Promoting the conservation and use of underutilised and neglected crops. 9, in: Proceedings of the Workshop on Conservation and Improvement of Bambara Groundnut (Vigna subterranea(L.) Verdc.), 14–16 November 1995, Harare, Zimbabwe, Institute of Plant Genetics and Crop Plant Research, Gatersleben/

Department of Research & Specialist Services, Harare/International Plant Genetic Resources Institute, Rome, Italy, 1997, p. 166.
[27] S.N. Basu, J.A. Roberts, S.N. Azam-Ali, S. Mayes, Bambara groundnut, Genome Mapp, Mol. Breed. Plants 3 (2007) 157–173.
[28] F.J. Massawe, M. Dickinson, J.A. Roberts, S.N. Azam-Ali, Genetic diversity in Bambara groundnut (Vigna subterranean (L.) Verdc), Genome 45 (2002) 1175–1180.
[29] A.C. Zeven, Landraces: a review of definitions and clarifications, Euphytica 104 (1998) 127–139.
[30] H.I. Amadou, P.J. Bebeli, P.J. Kaltsikes, Genetic diversity in Bambara groundnut (Vigna subterranea L.) germplasm revealed by RAPD makers, Genome 44 (2001) 995–999.
[31] I.A. Onimawo, A.H. Momoh, A. Usman, Proximate composition and functional properties of four cultivars of Bambara groundnut (Voandezeia subterranean), Plant Foods Hum. Nutr. 53 (1998) 153–158.
[32] S.H. Brough, S.N. Azam-Ali, A.J. Taylor, The potential of Bambara groundnut (Vigna subterranean) in vegetable milk production and basic protein functionality systems, Food Chem. 47 (1993) 277–283.
[33] E.A. Baryeh, Physical properties of Bambara groundnuts, J. Food Eng. 47 (2001) 321–326.
[34] O. Tibe, J.O. Amarteifio, R.M. Njogu, Trypsin inhibitor activity and condensed tannin content in Bambara groundnut (Vigna subterranea (L.) Verdc) grown in southern Africa, J. Appl. Sci. Environ. Manag. 11 (2007) 159–164.
[35] K.C. Mohale, K.B. Alphonsus, D.D. Felix, Symbiotic N nutrition, C assimilation, and plant water use efficiency in Bambara groundnut (Vigna subterranean L. Verdc) grown in farmers' fields in South Africa, measured using 15N and 13C natural abundance, Biol. Fertil. Soils 50 (2013) 307–319.
[36] V.A. Jideani, S.M. Mpotokwana, Modeling of water absorption of Botswana Bambara varieties using Peleg's equation, J. Food Eng. 92 (2009) 182–188.
[37] H.K. Adu-Dapaah, R.S. Sangwan, Improving Bambara groundnut productivity using gamma irradiation and in vitro techniques, Afr. J. Biotechnol. 3 (2004) 260–265.
[38] A. Sesay, Influence of flooding on Bambara groundnut (Vigna subterranea L.) germination: effect of temperature duration and timing, Afr. J. Agric. Res. 4 (2009) 100–106.
[39] O.S. Ijarotimi, T.R. Esho, Comparison of nutritional composition and antinutrient status of fermented, germinated and roasted Bambara groundnut seeds (Vigna subterranea), Br. Food J. 111 (2009) 376–386.
[40] A.G.A. Mahala, A.A. Mohammed, Nutritive evaluation of Bambara groundnut (Vigna subterranean) pods, seeds and Hulls as Animal Feeds, J. Appl. Sci. Res. 6 (2010) 383–386.
[41] A.P. Alobo, Production and organoleptic assessment of akara from Bambara groundnut (Voandzeia subterranean (L.) Thouars), J. Plant Food Hum. Nutr. 53 (1999) 313–320.
[42] K.O. Adebowale, T.A. Afolabai, O.S. Lawal, Isolation, chemical modification and physicochemical characterisation of Bambara groundnut (Voandzeia subterranean) starch and flour, Food Chem. 78 (2002) 305–311.
[43] S.O. Lawal, K.O. Adebowale, Y.A. Adebowale, Functional properties of native and chemically modified proteins concentrates from bambarra groundnut, J. Food Res. Int. 40 (2007) 1003–1011.
[44] C.A. Nti, Effects of Bambara groundnut (Vigna subterrenea) variety and processing on the quality and consumer appeal for its products, Int. J. Food Sci. Technol. 44 (2009) 2223–2242.
[45] A.E. Goli, F. Begemann, N.Q. Ng, Characterisation and evaluation of IITA's Bambara groundnut (Vigna subterranean (L.) Verdc. Proceedings of the workshop on conservation and improvement of Bambara groubdnut (Vigna subterranean (L.) Verdc). 14–16 November 1995, Harare, Zimbabwe, Int. Plant Genet. Resour. Inst. (1997) 101–118.
[46] P.O. Uvere, A.C. Uwaegbute, E.M. Adedeji, Effect of malting on the milling performance and acceptability of Bambara groundnut (Voandzeiza subterranean Thouars) seeds and products, Plant Foods Hum. Nutr. 54 (1999) 49–57.
[47] A.R. Linnemann, Cultivation of Bambara Groundnut (Vigna Subterranean (L.) Verdc.) in the Western Province, Zambia, in: Report of Field Study of Tropical Crops, Department of Tropical Science. Wageningen Agric. University, Netherlands, 1990.
[48] Y.Y. Murevanhema, V.A. Jideani, Potential of Bambara groundnut (Vigna subterranea (L.) Verdc) milk as a probiotic beverage-A review, Crit. Rev. Food Sci. Nutr. 53 (2013) 954–967.
[49] P.J. White, Y. Xing, Antioxidants in Food: Source of Natural Antioxidants, Woodhead Publishing Limited, Boca Raton, 2001.
[50] O.E. Adelakun, O.J. Oyelade, B.I.O. Ade-Omowaye, I.A. Adeyemi, M. Van De Venter, Chemical composition and antioxidative properties of Nigeria okra seed (Abelmoschus esculentus Moench) flour, Food Chem. Toxicol. 47 (2009) 1123–1126.
[51] J.C. Onyilagha, S. Islam, S. Ntamatungiro, Comparative phytochemistry of eleven species of Vigna sp. (Fabaceae), Biochem. Systemat. Ecol. 37 (2009) 16–19.
[52] S. Yagi, N. Drouart, F. Bourgaud, M. Henry, Y. Chapleur, D. Laurain-Mattar, Antioxidant and antiglycation properties of Hydnora johannis roots, South Afr. J. Bot. 84 (2013) 124–127.
[53] J.J. Rojas, V.J. Ochoa, S.A. Ocampo, J.F. Muñoz, Screening for antimicrobial activity of ten medicinal plants used in Colobian folkloric medicine: a possible alternative in the treatment of non-nosocomial infections, BMC Compl. Alternative Med. 6 (2006) 10.
[54] B. Abu-Shanab, G. Adwan, D. Abu-Safiya, N. Jarrar, K. Adwan, Antibacterial activities of some plant extracts utilized in popular medicine in Palestine, Turk. J. Biol. 28 (2) (2004) 99–102.
[55] J.K. Patra, N.K. Dhal, H.N. Thatoi, In vitro bioactivity and phytochemical screening of Suaeda maritima (Dumort): a mangrove associate from Bhitarkanika, India, Asian Pacific J. Trop. Med. 1 (2011) 727–734.
[56] M.M. Iwu, A.R. Duncan, C.O. Okunji, New antimicrobials of plant origin, Afr. Trad. Herb Res. Clin. 9 (2014) 51–57.
[57] J.K. Kumar, A.G.D. Prasad, V. Chaturvedi, Phytochemical screening of five medicinal legumes and their evaluation for in vitro anti-tubercular activity, Ayu 35 (2014) 98–102.
[58] A. Branter, Z. Male, S. Pepelinfak, A. Atolic, Antimicrobial activity of Paliurus spina. Chrisfi mill, J. Ethnopharmacol. 52 (1996) 119–122.
[59] H. Taahir, Bambara Groundnut (Vigna subterranean) from Mpumalanga Province of South Africa: Phytochemical and Antimicrobial Properties of Seeds and Product Extracts (MSc. Thesis), Facultly of Applied Sciences, Cape Peninsula University of Technology, 2017.
[60] C. Celis, A. Garcia, G. Sequeda, G. Mendez, R. Torrenegra, Antimicrobial activity of extracts obtained from Anacardium excelsum against some pathogenic microorganisms, Emir. J. Food Agric. 3 (2011) 249–257.
[61] A. Carraturo, K. Raieta, I. Tedesco, J. Kim, G.L. Russo, Antibacterial activity of phenolic compounds derived from Ginkgo biloba sarcotestas against food-borne pathogens, Br. Microbiol. Res. J. 1 (2014) 18–27.
[62] W.W. Anthony, Evaluation of Phytoconstituents, Antioxidants Potential, Cytotoxic, Antimicrobial Activities and mineral Composition of Vigna subterranea (L) Verdic. Extracts (MSc thesis), Jomo Kenyatta University of Agriculture and Technology, 2018.
[63] S.N. Weerakkody, N. Caffin, S.M. Turner, A. Dykes, In vitro antimicrobial activity of less-utilized spice and herb extracts against selected food-borne bacteria, Food Contr. 21 (2010) 1408.
[64] F. Lv, H. Liang, Q. Yuan, C. Li, In vitro antimicrobial effects and mechanism of action of selected plant essential oil combinations against four food-related microorganisms, Int. J. Food Res. 44 (2011) 3057.
[65] V.R. Kannan, C.S. Sumathi, V. Balasubramanian, N. Ramesh, Elementary chemical profiling and antifungal properties of cashew (Anacardium occidentale L.) nuts, Bot. Res. Int. 2 (2009) 253.
[66] T.P. Cushnie, A.J. Lamb, Antimicrobial activity of flavonoids, Int. J. Antimicrob. Agents 26 (2005) 343–356.
[67] T. Harris, V. Jideani, M. Le Roes-Hill, Flavonoids and tannin composition of Bambara groundnut (Vigna subterranea) of Mpumalanga, South Africa, Heliyon 4 (2018), 00833.
[68] S. Spassieva, J. Hille, Plant sphingolipids today-are they still enigmatic? Plant Bio. 5 (2003) 125–136.
[69] A.T. Tsamo, P.P. Ndibewua, F.D. Dakora, Phytochemical profile of seeds from 21 Bambara groundnut landraces via UPLC-qTOF-MS, Food Res. Int. 112 (2018) 160–168.
[70] M.A. Farag, H.A. Gad, A.G. Heiss, L.A. Wessjohann, Metabolomics driven analysis of six Nigella species seeds via UPLC-qTOF-MS and GC–MS coupled to chemometrics, Food Chem 151 (2014) 333–342.
[71] V. Nyau, S. Prakash, J. Rodrigues, J. Farrant, Domestic cooking effects of Bambara groundnuts and common beans in the antioxidant properties and polyphenol profiles, J. Food Res. 6 (2017) 24.
[72] N. Kumar, V. Pruthi, Potential applications of ferulic acid from natural sources, Biotechn. Rep. 4 (2014) 86–93.
[73] V. Nyau, S. Prakash, J. Rodrigues, J. Farrant, Domestic cooking effects of Bambara groundnuts and common beans in the antioxidant properties and polyphenol profiles, J. Food Res. 6 (2) (2017) 24–37.
[74] P.S. Ferreira, F.D. Victorelli, B. Fonseca-Santos, M. Chorilli, A review of analytical methods for p-coumaric acid in plant-based products, beverages, and biological Matrices, Crit. Rev. Anal. Chem. 49 (1) (2019) 21–31.
[75] J. Bernatoniene, D.M. Kopustinskiene, The role of catechins in cellular responses to oxidative stress, Molecules 23 (4) (2018) 965.
[76] N.A. Schwarz, Z.J. Blahnik, S. Prahadeeswaran, S.K. McKinley-Barnard, S.L. Holden, A. Waldhelm, (–)-Epicatechin supplementation inhibits aerobic adaptations to cycling exercise in humans, Front. Nutr. 5 (2018) 132.
[77] P. Randjelović, S. Veljković, N. Stojiljković, D. Sokolović, I. Ilić, D. Laketić, RandjelovićD, N. Randjelović, The Beneficial Biological Properties of Salicylic Acid, 2015.