Role of Banbara Nuts as Nutraceutical and its Potential in Green Synthesis of Nanoparticles: Ability of Bioactive Compounds

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Abstract
Bambara nut (*Vigna subterranea* (L.) Verdc.) is a vegetable crop that is easy to cultivate which has been underutilized over time. It is referred to as nutraceuticals due to its nutritional and medicinal values. The crop is tolerant to drought. Accordingly, it is important to explore the nutraceutical imp0rtance of this underutilized and neglected crop to safe guard and encourage its production for food as medicinal and nutritional source, particularly among the poor and rural societies in Africa and also to discuss its application and potentials in the synthesis of nanoparticles. This review specifically looked into the usefulness of banbara nut. The effect against microbes were also taken into consideration and studied to evaluate its nutraceutical advantages. Antimicrobial activities of banbara nut extracts have been observed in clinical settings against a variety of bacteria, *Candida albicans* and *Aspergillus niger* which was found to also possesses antioxidant properties. Banbara nut possess high bioactive compounds which include phenols and flavonoids that possess special chemical ability that can both effectively serve as capping and reducing agents on nanoparticles. Green synthesized zinc and silver oxide nanoparticles utilizing the post-harvest leaves of banbara nut and their antioxidant, anti-inflammatory and antimicrobial potentials have been reviewed. Likewise, the effect of nano-structured shell of bambara nut as filler have also been discussed. The potential applications of banbara nut as nutraceuticals and in green synthesis of nanoparticles are reviewed in this paper.

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1. Introduction

The world's legume plants are valued for their nutritional content and economic importance [1]. Despite being known as the meat for a poor man, legumes such as banbara nut (*Vigna subterranean*) are essential to human nutrition and health, particularly in impoverished remote sub-Saharan African communities [2]. This is due to their high protein and carbohydrate content as well as the various phenolic compounds they release when consumed, whether cooked or raw. Proteins and peptides found in legume seeds may be categorized as nutraceuticals [3].

Because it has implications for the development of medications and dietary supplements for human wellness and health, the study of phytochemicals and mineral content in medicinal plants has gained interest in the pharmacological and nutritional science sectors [151]. Nutraceuticals are synthetic materials or chemical compounds (often found and concentrated in the form of capsule, pill, or powder) which can offer wellbeing or therapeutic advantages to human, and also promote the prevention of disease and their treatment [4]. Nutraceuticals are also defined by Sasi [5] as any functional food extract that has advantages for human health and medicine. Additionally, phytochemicals were described by Lopez-Gutierrez *et al.* [6] as substances found in plants which are non-nutritive and have the ability to prevent disease.

Recently, the majority of researchers' attention has focused on plant-based nutraceuticals since they include a wide range of phytochemicals, some of which are yet to be identified, that have been shown to have health advantages and the ability to prevent disease. Likewise, an enco-friendly procedures for nanoparticles' synthesis that is gaining popularity in the fields of biochemistry, biology, and chemistry technologies is called "green synthesis." This trend has a number of roots, one of which is the demand for more environmentally friendly ways to offset the increased expenses and energy demands of chemical and physical processes. This is why researchers look for less expensive synthesis techniques. The other reason is that standard techniques of synthesizing nanoparticles typically involve multiple procedures in the process of synthesis, which involves treatments with heat, and use harmful reductants like sodium borohydride or hydrazine, which frequently result in hazardous by-products. The goals of green chemistry are to reduce waste, use less energy, use renewable resources, and use risk-reducing techniques. The three primary ideas for creating nanoparticles using a green synthesis strategy include selecting a solvent medium (water is preferred) and using an environmentally friendly capping and reducing agents to stabilize the nanoparticles [7]. Then, it seems that the biological systems are the best factory for achieving these kinds of natural chemical conditions which can be found also in legumes such as banbara nuts. The use of plants to produce nanoparticles has sparked a lot of research in the field of green synthesis in more recent times [8]. Plant extracts contain bioactive compounds that can serve as capping and reducing agents to create stable, shaped nanoparticles. Enzymes, alkaloids, Proteins, phenolics, polysaccharides, amino acids, terpenoids, flavones, and alcoholic compounds are among the main substances that influence the capping and reduction of the nanoparticles. But reports have also included chlorophyll pigments, quinol, caffeine, linalool, methyl chavicol, eugenol, ascorbic acid, theophylline, and other vitamins [9–16]. Nontoxic Bioactive compounds, such as the phenols and flavonoids, possess a special chemical ability that can both effectively serve as reducing and capping agents on nanoparticles, preventing them from clumping together. Metals can bind to the carboxyl and hydroxylic groups present in the bioactive compounds [17].

When compared to major income crops, banbara nuts are comparatively underutilized and are typically connected with small-scale subsistence farming, where women are the primary processors and producers [18, 19]. The lack of knowledge on how to improve seed systems, processing, agronomic techniques, and utilization—particularly with regard to the synthesis of nanoparticles using banbara nut are among the obstacles to the full potential of bambara nuts. Given the abundance of bioactive chemicals found in bambara nuts, this work explores their potential involvement in the eco-friendly synthesis of nanoparticles and the methods used while providing an outline of their nutraceutical usefulness.

Fig 1: Banbara nut

2. Description of Bambara nut and their cultivation

A natural crop that is extensively grown throughout most of sub-Saharan Africa is the bambara nut. The west, central, east, and southern subregions of the continent are among the agro-ecological zones where it is extensively farmed [20–23]. Banbara nut is an indigenous legume from Africa that is a member of the Faboideae and Fabaceae families, respectively. In the continent, banbara nuts have some common names such as Nzama in Malawi, Ntoyo in Ci Bemba, or Katoyo in Zambia, Njugo in South Africa. In Nigeria, it is known as Okpa (the Igbo speaking half) and Gurujia (the Hausa speaking section) [24]. According to Stephens [25], the banbara nut is also referred to as the underground bean, baffin pea, voandzou nzama (in Malawi), and indhlubu. The annual leguminous plant known as the bambara nut has a robust taproot, trifoliate leaves, and a long, green petiole [26, 27]. The blooms are carried on long, hairy peduncles that emerge from the stem nodes [28]. The plant produces 3.0-3.7 cm-long, oval or spherical pods [9]. The landraces of Bambara nuts are made up of numerous genotypes with varying capacities to withstand environmental stress [27, 9, 30]. The plant takes 110–150 days to reach full maturity in well-drained soil, 5.0–6.5 pH sandy loams, with a mean temperature of 20–28^o C [27]. The color of the seed can range from red, brown, or black and occasionally be speckled with many colors [22, 11]. Before they are eaten, the hulls are frequently removed. The removed shells are considered a waste material. Nonetheless, research by Klompong and Benjakul [18] has demonstrated that the hulls are a source of useful chemicals and nutraceuticals. Because of its resilience to severe environmental stress including low and variable rainfall and soils lacking in nitrogen, it is free from total crop failure [10, 12, 13]. The plant can thrive in humid regions and low-nutrient soil circumstances, where most other non-leguminous plants might not be able to survive [11]. According to Tibe *et al.* [14], banbara nuts are a drought and disease-resistant crop that can help minimize pests in agricultural settings. Its capacity to fix atmospheric nitrogen through the process of biological nitrogen fixation reduces the need for costly, environmentally harmful synthetic fertilizers or manures, particularly in African's nutrient-poor soils, where resource-poor farmers cultivate the crop. Work by Mohale *et al.* [15] on the symbiotic nitrogen nutrition effectiveness of the plant growing in the Lowveld region (Mpumalanga Province) of South Africa provided evidence for the nitrogen-fixing capacity of banbara nuts. The researchers discovered that the Banbara nut provided Nitrogen (33–98%) to the poor nutrient of the soils that are in the area and was found to be highly dependent on symbiotic fixation (4–200 kg N-fixed ha1) for its Nitrogen nutrition [15]. The use and cultivation of banbara nuts is of interest in sub-Saharan Africa's arid savannah regions. 90% of farmers in Botswana (the bulk of them are women) grow banbara nuts. Of these, 63% grow the crop for personal use, 12% grow it for financial gain, and 25% grow it for both profit and food [16]. Given the crop's resilience to extreme environments, including drought and low-nutrient soils in the event of climate change, it is viewed as a crop capable of mitigating poverty and poor nutrition, particularly in impoverished sub-Saharan African's rural communities.

Fig 2: Cultivation of Banbara nuts

3. Nutritional importance of Banbara Nut

Farmed locally by the rural population, bambara nuts are source of protein for consumers and are primarily cultivated by them to feed their immediate families in most of the countries in sub-Saharan African region. According to study, the seeds of this crop may include 49–63.5% carbs, 15–25% protein, 4.5–7.4% fat, 3.2–4.4% fiber, 0.7% ash, and 0.01% cholesterol per 100 g dry weight [24, 11, 29]. Mwale *et al.* [18] noted that because the protein content is similar to that of other legumes, it is considered a valuable addition to diets based on cereal. The Banbara nut are cultivated below the ground, and the pods is hard and wrinkled when dried which contain at least one or two seeds. As a functional food, the dried seeds can be boiled and eaten. Additionally, the food crop can be eaten immature as a snack after roasting or steaming with a salt tincture [25] or matured as porridge [22]. The seeds are nutrient-dense and a complete food due to their chemical makeup [12, 31, 32]. The Banbara nut are produced below the ground, and the pods contain minimum of one or two seeds which are observed to be wrinkled and hard when dried. As a functional meal, the dried seeds can be cooked and eaten. Furthermore, the food crop can be eaten as porridge when it is mature [22] or as a snack when it is immature and has been roasted or sweltered with a salt tincture [25]. The seeds are a wholesome and complete diet because of their biomolecules [12, 31, 32]. Furthermore, the food crop can be consumed as porridge when matured [22] or the immature form as a snack after roasting or sweltering with a tincture of salt [25]. The biomolecules of the seeds make them nutritious and a complete food [12, 31, 32]. Sesay [30] further stated that Banbara nuts are carbohydrates and protein sources to consumers and also provides extra cash for rural subsistence farmers in the majority of West African nations. Numerous researches have reported on the seed's biochemical composition [31-36]. Some regions of the Congo still harvest oil from the seed, despite the fact that it is said to contain little fat [37]. In East Africa, bambara nuts are roasted, pulverized, and added to cuisine without any sauces [37, 38]. Banbara nut flour is used to make part of the bread in Zambia [39]. The nuts are used in Botswana to make stiff porridge and pastries [34, 36]. Banbara nut flour is also used in Nigeria to make steamed foods like "okpa," [37]. Murevanhema and Jideani [40] defined "okpa" as a cooked substance, similar to gel, made from banbara nut paste, wrapped in banana leaves, and allowed to bubble until ready to use. Furthermore, the use of matured black landrace seed is used for therapeutic purposes [26]. The flavor and content of vegetable milk made from banbara nuts was found to be the best; also, people liked the lighter color of this milk over that of cowpea, soybean milk and pigeon pea [12]. Antioxidants are generally reported to be present in most legumes [40]. Antioxidants have the ability to preserve food quality by preventing the oxidative lipids degradation [41]. Additionally, Adelakun *et al.* [42] described antioxidants as components that shield human tissues and cells from free radicals (reactive nitrogen /oxygen species, or RNS/ROS). Antioxidants are abundant in most leguminous nuts' seed coats and there have been reports of differences in antioxidant levels between the light- and dark-seeded landraces of banbara nuts [40]. Onyilagha *et al.* [43] sta ted that the antioxidants in the black and red seed coat of banbara nuts contain antioxidants who's their mechanisms of antioxidation differ from those of other leguminous plant and were found to possess more nutrients and minerals than the light-seeded landraces. In Botswana, the light-seed landrace is preferred for consumption due to its superior flavor and less cooking time, while the dark-seeded landrace is used for the treatment of impotence. Curiously, different African tribes use banbara nut for different purposes. For instance, some tribes in kenya make use of it to treat diarrhoea and nausea [44], in Nigeria it is to treat venereal diseases [40], Pregnant women's nausea and vomiting in South Africa and cataracts in Senegal [40]. In conclusion, banbara nuts serve a variety of purposes, such as supplying minerals and nutrients as functional foods, improving human and animal health (because of their antioxidant qualities), and acting as a commodity to help those in rural sub-Saharan Africa make a living. Therefore, it is necessary to protect and encourage the growth of this crop in order to continue providing the people in the majority of rural African communities with the benefits of it.

4. Nutraceuticals importance of banbara nut

The chairman and founder of the Foundation for Innovation in Medicine, Stephen DeFelice, originated the phrase "nutraceutical" in 1989, combining the words "nutrition" with "pharmaceutical" [45]. DeFelice defines a nutraceutical as a food or component of a food that in addition to offering essential nutrients, has therapeutic benefits, such as the ability to prevent or treat disease or illness [46, 47]. Nutraceuticals can also be defined as non-toxic food ingredients that have been shown by science to have or produce health benefits, like prevention or treatment of disease [48]. The search for potent and innovative antimicrobial chemicals has been spurred by the gradual rise in microorganism resistance to newly developed antibiotics. Researchers have turned their attention to plant-based medicine in their hunt for potent antimicrobial chemicals because of its historical use in the treatment of both infectious and non-infectious disorders, particularly in developing and underdeveloped nations [49]. These medicinal herbs are ingested as teas, elixirs, or juice concoctions for the purpose of treating respiratory infections [50]. Numerous studies [59-53] have demonstrated the importance of these medicinal plants as key sources of chemicals with antibacterial, anticancer, and antioxidant properties. These compounds can be combined to create novel antibiotics that are not resistant to harmful microbes. For instance, Kumar *et al.* [54] investigated the anti-tubercular activity of five plants which are legumes (*Ceasalpinia mimosoides*, *Kingiodendron pinnatum*, *Indigofera cassioides*, *Derris scandens*, and *Humboldtia brunonis*). They found that the leguminous plants contained terpinoids, flavonoids, anthro-quinones, saponins, and phlabotanins. Several studies' results [55, 37, 56] demonstrated that bacteria which are Gram-positive were more vulnerable to plant extracts than Gram-negative bacteria. According to Goli *et al.* [37], the lipopolysaccharides of Gram-negative bacteria's outer membrane are what allow them to withstand plant extracts. But according to a recent study by Ajiboye and Oyejobi [55] employing the method of agar-well diffusion observed that the majority of the extracts were able to stop Gram-negative bacteria from growing. In his work, Taahir [57] used the direct bioautography method and found that brown and red hulls of banbara nut extracts inhibited Gram-negative bacteria more (Pseudomonas aeruginosa ATCC 27853, pneumoniae ATCC 700603 and Klebsiella pneumoniae subsp.) than bacteria that are Gram-positive bacteria (Staphylococcus aureus subsp. aureus ATCC 33591), supporting the findings of Ajiboye and Oyejobi [55]. Because brown and red banbara nut hulls linked well with high content of tanin and flavonoid, the ability of the hulls' extracts was attributed to their high content of phenolic compounds [58, 59]. Using the agar diffusion method, Klompong and Benjakul [60] found that extracts from the coat of banbara nuts showed antibacterial activity against wide range of bacteria, which include Bacillus cereus, Escherichia coli, and Staphylococcus aureus as well as *Candida albicans*, *Aspergillus niger*, yeast, and mold, in a manner that is dose-dependent. Using the Kirby-Baurer diffusion method. Anthony [61] discovered that the extracts of banbara nut showed inhibitory activities against *Candida albicans*, Escherichia coli Staphylococcus aureus, and Pseudomonas auriginosa. All things considered, banbara nuts are a potent antibacterial that can stop prokaryotic and eukaryotic cells from proliferating. The cytoplasmic membrane is a common site of entry for antimicrobial agents, and when this membrane's permeability is disrupted, the membrane itself is destroyed [62]. As a result, the cell deforms, lyses, and dies due to cytoplasmic leakage and coagulation [63]. This substance stops spore germination and mycelial growth in fungus [64]. The phytochemicals found in banbara nuts possess both hydrophilic and hydrophobic properties, which promote their accumulation in cell membranes. This alteration in permeability results in the seepage of intracellular components, weakening of the enzyme systems of microorganisms, and ultimately, their death [63]. It is obvious that the type of organisms being studied and the extract's concentration affect the antibacterial properties of banbara nuts. But no research has determined the exact dosage of banbara nut extracts for treating any human illness in sub-Saharan Africa presently. Banbara nuts have historically been utilized for the treatment of various ailments, and as such, there are numerous chances for additional research on the crop's therapeutic value and potential applications [ss]. Legumes have been found to contain phytochemicals with antioxidant properties by a number of authors [57-73]. Of particular, the hull of the banbara nut has been found to contain phenolic compounds in large quantities, with nutraceutical and functional ingredients than other parts of the plant [68]. It has been observed that the content and kind of phenolics in banbara nuts can be influenced by the pre-processing and extraction methods [72]. Using methanolic extraction optimization, it was found that cooking red banbara nuts improved their nutraceutical profiles by increasing their free radical scavenging speed by a factor of ten when compared to their uncooked counterpart [72]. According to research on the phytochemical components of banbara nuts by Mbagwu *et al.* [74], the crop has more alkaloids than other legumes, and variations in the hulls of different landraces of banbara nuts have been observed [72]. For example, it has been observed that boiling dry beans reduces the phenolic content (protease inhibitors) by 80% to 90%, that treating banbara nut flour with 60% ethanol improves its nutritional quality, and that dehulling can lower the tannin level by up to 92% [80]. Higher concentrations of tanins and flavonoids were discovered in both brown and red banbara nut landraces in a study intended to determine the therapeutic qualities of banbara nut [72]. The flavonoid compounds found in the hull of brown banbara nuts included higher concentrations of myricetin (1.800 mg g^{-1}) and rutin (24.458 mg g^{-1}), while the highest tannin compounds found in the hull of red banbara nuts were 0.105 mg g^{-1} of ellagic acid and 0.115 mg g^{-1} of chlorogenic acid [58]. Furthermore, two market classes of banbara nuts that are often farmed in Zambia were shown to have polyphenols, particularly higher epicatechin and catechin [72]. Table 1 lists a Some bioactive compounds and chemical components in Bambara nut.

Table 1: Some Bioactive compounds and chemical components in Bambara nut.

Type/Class of Nutraceutical	Raw	Cooked	References
Phenolic compounds (mg/g)			
Quercitrin	2.05	1.58	[77]
Rutin	0.427–24.46	3.16	
Quercetin	0.007–6.39	3.94	[77; 78]
Isoquercitrin	0.42	0.29	
Kaempferol	0.052–2.18	3.15	[77; 78]
Myricetin	0.062–1.800	-	
Gallic acid	0.05–1.03	0.41	
Luteolin	1.09	1.67	[77]
Cholorogenic acid	0.03–2.37	0.50	
Catechin	0.01–2.34	-	
Ellagic acid	0.005–1.09	1.42	
Epicatechin	1.15	0.39	
Caffeic acid	-	3.75	[77; 78]
Dietary fiber			
Ursonic acid (%of IDF)	10.6–11.5	-	[79]
Insoluble dietary fibre, IDF (%of TDF)	9.60–10.00	-	
Total dietary fibre, TDF (% of seed)	1.61–10.30	-	[80; 81; 82]
Soluble dietary fiber (% of TDF)	3.00–7.00	-	[82]
Amino acids (%of protein	3.21–21.38	-	
Glutamic acid	3.21–21.38	-	
Leucine	1.33–10.22	-	[82; 83]
Arginine	1.20–8.25	-	[82; 83]
Lysine	0.99–8.54	-	
Isoleucine	0.89		[83]
Fatty acids (mg/100g)			
Saturatedfattyacids	1690	-	
Polyunsaturatedfatty (PUFA)	2100	-	
Monounsaturatedfatty (MUFA)	1073	-	[83]
Tocopherols and tocotrienol (mg/100g)			
γ-Tocopherol	1.05	-	
α-Tocopherol	0.26	-	[83]
δ-Tocopherol	6,64	-	
α-Tocotrienol	0.10	-	
γ-Tocotrieno	0.18	-	
Phytosterols (% of total sterol)			
β–Sitosterol	1.89–2.23	-	
Campesterol	0.73–3.93	-	[84]
Stigmasterol	0.68–1.78	-	

The authors of that study also demonstrated that heating boosted the nutraceutical and antioxidant properties of these nuts. Additionally, novel phenolic chemicals such as Medioresinol, catechin dimer, GC-hexoside, Quinic acid, catechin glucoside, caffeic acid derivative, p-coumaric acid, and salicylic acid were discovered using HPLC-PDA-ESI-MS profiling in cooked banbara nut seeds [72]. Fascinatingly, when the two market classes of banbara nuts were examined, variations in phenolic compounds were observed [54]. This suggests that there may be room to find more unique phytochemical components of banbara nuts, which might turn the crop into a source of nutraceuticals. The research is lacking on the relationship between the type, content, and medicinal efficacy of banbara nut extracts for the majority of disorders, despite the fact that phenolic chemicals such as flavonoids, alkaloids, lignans, tannins and phenolic acids) are known to treat some illnesses. Moreover, there is a paucity of research on the impact of extraction methods and pre-processing strategies for optimizing the nutraceutical potential of banbara nuts. Thus, additional research is required to evaluate this crop's potential as an antibacterial and nutraceutical.

5. Analysis of Bioactive compounds in banbara nut

The structure, wetness, plasticity, and content of the material will determine the recovery of chemicals from the matrix of the sample. The sample may be fresh or dried, depending on the target compounds. Therefore, it is crucial to prepare the sample matrix before extraction, particularly since certain compounds a ratio of 1:5 to 1:10 solvent/sample (solid vegetal material) for extraction using ultrasonic bath is appropriate [87]. When producing a concentrated extract, such high ratios might be sufficient. To guarantee that, preparation procedures like sifting, drying, and homogenization is important. By removing interferences, raising the concentration of analyte in the mixture, and producing the ideal size of particle, sample preparation not only maintains the matrix chemicals but also guarantees the extraction efficiency [85]. Due to their effect on the cavitation phenomena and the extracts' final concentration, the ratios of sample quantity to solvent and particle size should likewise be put into account in order to optimize extraction yield [86]. For the recovery of bioactive chemicals from plants, it has been proposed that the compounds of interest were completely extracted from the matrix of the sample and a larger sample concentration of solvent (1:50, 1:100 and above) would be needed if the extraction's goal is to prepare sample for quantitative analysis of bioactive compounds. The literature reports the solid/solvent ratio ranges; however, it is sometimes unclear if the data are presented based on a dry or wet sample. It is recognized that fresh material, not dry stuff, is typically referred to. To enable the solubilization of the compounds of interest in the case of dry material, the matrix must be hydrated; as a result, the ratio may need to be increased. Sequential extraction procedures can increase efficiency because each extraction will have a new solvent available, improving solubility. Nevertheless, extra procedures like centrifugation or filtration will be needed in between extractions. The major factor in any process of extraction is unquestionably the selection of solvent. The strength and solubility of the matrix interactions with the solvent should be the primary considerations when selecting the extraction solvent. Viscosity, Polarity, specific gravity, surface tension, pH, melting and boiling points, vapor pressure, density, and the impact on the extracted compound's activity and purity are some of the properties of the solvent that need to be monitored [88].

Because they lower the cavitation threshold and make it more difficult to remove the chemicals from the matrix, these aspects should be carefully considered [89]. The suitability of the solvent for the extraction parameters, the intermediate and final products to be employed, and the capacity of the solvent to react with the target chemicals under conditions of extraction should all be taken into account. The solvents' physicochemical and biological characteristics are crucial because they not only interact with the extracted substances and treated material but also define the medium's nature. Generally speaking, bioactive chemicals are extracted from plant matrices like herbs, industrial waste, stems, or seeds using organic solvents (methanol, ethanol, acetonitrile, petroleum ether, acetone), water, and combinations of these solvents. Bioactive chemicals from plant sources have long been extracted using organic solvents such ethanol, methanol, acetone, and isopropanol combined with different amounts of water; some extractions employ either 100% organic solvent or water. The stability of the bioactive chemical and the efficacy of the therapies may be significantly impacted by possible modifications to the solvents used during the extraction procedure [89].

According to certain research, acidifying extraction solvents can protect delicate bioactive substances from oxidative deterioration [90]. Free radicals that might be created during ultrasonication are stabilized by the hydrogen ions (H+) produced by the acids [89]. So many researches have shown that organic solvents, such as methanol, very effective at extracting bioactive compounds because of their polarity. In other to reduce the environmental effect of organic solvents while providing comparable or even higher function, biodegradable and non-toxic substitutes, including ethanol, are being investigated in extraction techniques to some extend [91]. New substitutes for harmful solvents include eutectic or ionic solvents that contain the citric acid and lactic acid as well as systems that are multiphasic like cloud point extraction [92, 95] By changing the ionic strength, which impacts the solubility of the chemicals and the sample matrix interactions, the extraction performance can also be affected due to the pH of the solvent. The ideal pH for removing flavonoids from plant matrices has been assessed in a number of research. Mai *et al.*, [96] examined how pH of the solvent affected the recovery of flavonoids in *Euonymus alatus* and found that there were high recoveries in acidic pH ranges (2.5–3.5) and fell as the pH ranges increases. The extraction of polyphenols from the peel of pomegranate is influenced by the pH of the solvent, with the optimum outcomes being seen in an acidic medium, according to another study that examined polyphenols in this instance [97]. Lower extraction yields were observed at pH values higher than 7.0. Higher flavonoid yields are typically generated in acidic media, according to reports found in the literature. The breakdown of phenolics attached to the polymers carbohydrate and proteins is supported by an acidic pH, which explains this trend for polyphenols [98]. At lesser pH values, phenols are protonated which transforms them into molecules that are hydrophobic to interact more strongly with micellar surfactant that are hydrophobic and pass through the micelles easily [99]. Higher pH levels allow protons to become more active, deprotonating phenols and making them more ionic. This decreases the solubility of hydrophobic phenolic compounds in micelles. Consequently, more phenols are extracted when the pH is decreased (99; 100).

6. Plant-mediated nanoparticle synthesis

Numerous bioactive substances present in plants, such as alkaloids, phenols, terpenoids, flavonoids, proteins, steroids, alcohols, saponins function as reducing agents during nanoparticles synthesis. A variety of nanoparticles have been synthesized utilizing plants such as post-harvest leaves of banbara nut, *Ficus benghalensis*, *Acalypha indica*, *Zingiber officinale*, *Centella asictica*, *Plumbago zeylanica*, *Parthenium hysterophorus*, *Passiflora foetida*, *Sapindus rarak*, *Acalypha indica*, and others [75, 111, 114]. Plant extracts are more advantageous than microorganisms when synthesizing green nanoparticles, due to their one-step, nonpathogenic, and economical procedure [115, 116]. Bioactive natural compounds have been found to have great potential in this regard and are used to improve the stability, activity, and biodistribution of metal nanoparticles [118], while the extracted bioactive compounds help reduce size and shape-controlled nanoparticles [119]. The green chemistry approach has been constantly used for the synthesis of functional nanomaterials to reduce waste, environmental hazards, and the use of toxic chemicals, among other reasons.

In addition to helping the size of the nanoparticles to be fine-tuned, it also helps to remove dangerous byproducts. Numerous studies have demonstrated formulation of nanoparticles employing different parts of plants, such as seeds, callus, fruit, flower, and stem likewise the production using byproducts. The synthesis of nanoparticle using plant extract start by Weighing a precise quantity of plant material in grams, then clean and boil the chosen plant portion in distilled water. Syringe filter tube or a muslin cloth is then used to squeeze and filter the extract. The salt solution that is added during the filtration process is determined by the type of nanoparticle that will be generated. The solution exhibits a hue shift, signifying the development of nanoparticles that may subsequently be isolated. The main sign indicating that nanoparticles have been synthesized is the noticeable color change (figure 4). If there is no color change in the mixture, it may be because of the medium been high in acidity. To get around this problem, an alkaline solution can be made by a solution of NaOH. To properly synthesize nanoparticles, salt extract must be applied gradually through a syringe at a moderate volume. The nanoparticle generated may be in the form of colloidal and the synthesis of nanoparticle is verified by a peak at a particular range in nanometer with a decrease in the plasmon absorbance intensity [117].

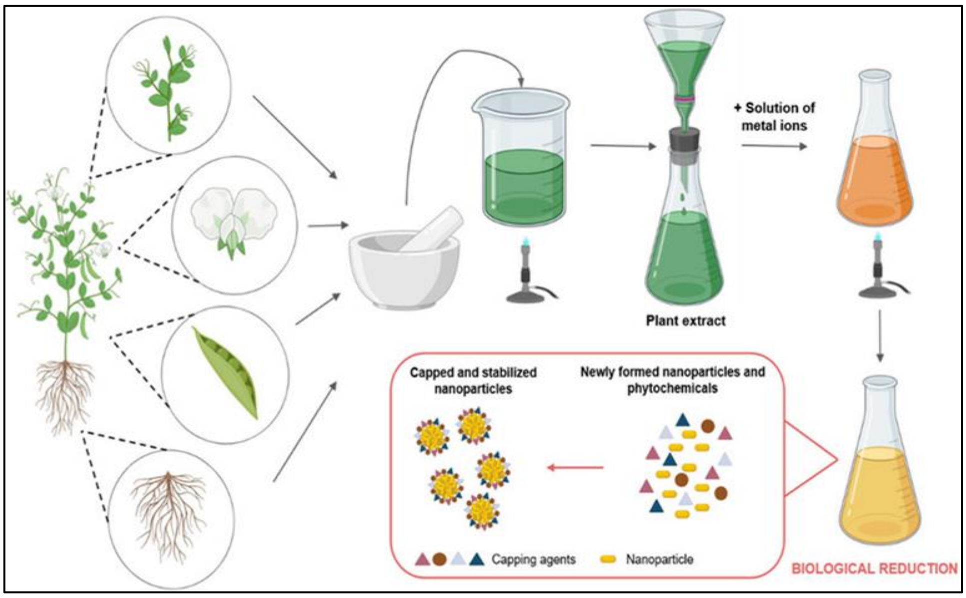

Fig 4: Representation of plant-mediated synthesis of nanoparticles

7. Methods of Nanoparticles Synthesis

The most popular technique for nanoparticles synthesis is the Physical (top-down) method, which starts with the fragmentation of bulk material and progresses to the formation of nanoparticles. To create different nanoparticles, the Biological and Chemical (bottom-up) approach collects atoms and molecules. The top-down method greatest advantage is its ability to quickly and efficiently produce a huge number of nanoparticles. Nonetheless, the primary merits of using the bottom-up method are that it produces nanoparticles having distinct crystallographic characteristics and a larger specific surface area [101]. It is not possible to synthesize the required shape using a physical method. Nevertheless, unwanted materials can be removed and fewer nanoparticles can be produced by employing a bottom-up strategy One of the primary techniques for producing nanoparticles utilizing the bottom-up method is the chemical reduction method. Generally speaking, there are three components to the creation of nanoparticles: biological or green, chemical and physical methods [102] as shown in figure 4. Furthermore, this technique was proposed as the most important and popular way to create nanoparticles. The physical method uses energy, pressure, and temperature to produce Nanoparticles [103]. Atomic condensation, sol-gel, chemical etching, spray-mediated pyrolysis, sputtering and laser pyrolysis are the processes used in the chemical technique to produce Nanoparticles. Chemical and reaction ratios can change the nanoparticles' morphologies. The produced nanoparticles may face challenges with bioaccumulation, toxicity, regrowth, reuse, and recycling after synthesis [104,105]. Green-synthesized Nanoparticles on the other hand, have been shown to be non-toxic [106]. Numerous applications in biomaterials research have made use of the green synthesis of nanoparticles with different shapes and sizes [107,108]. In the pharmaceutical industry, nanoparticles have been created for a different use, which include the treatment of bacterial and viral illnesses [109]. Because it can be produced in large quantities using environmentally friendly methods, the biosynthetic approach offers several advantages over other traditional synthesis protocols. For the amalgamation of nanomaterials, the great bio-diversity and readily available sources of plant output have been extensively studied. These biologically produced nanomaterials have important uses in a number of domains, including treatment, diagnosis, surgical device manipulation, and other product forms. In the treatment of different chronic illnesses, nanomedicine has demonstrated encouraging clinical outcomes. Furthermore, environmentally friendly ways of acquiring Nanoparticless were identified as essential resources for future generations to guard against a number of illnesses [110].

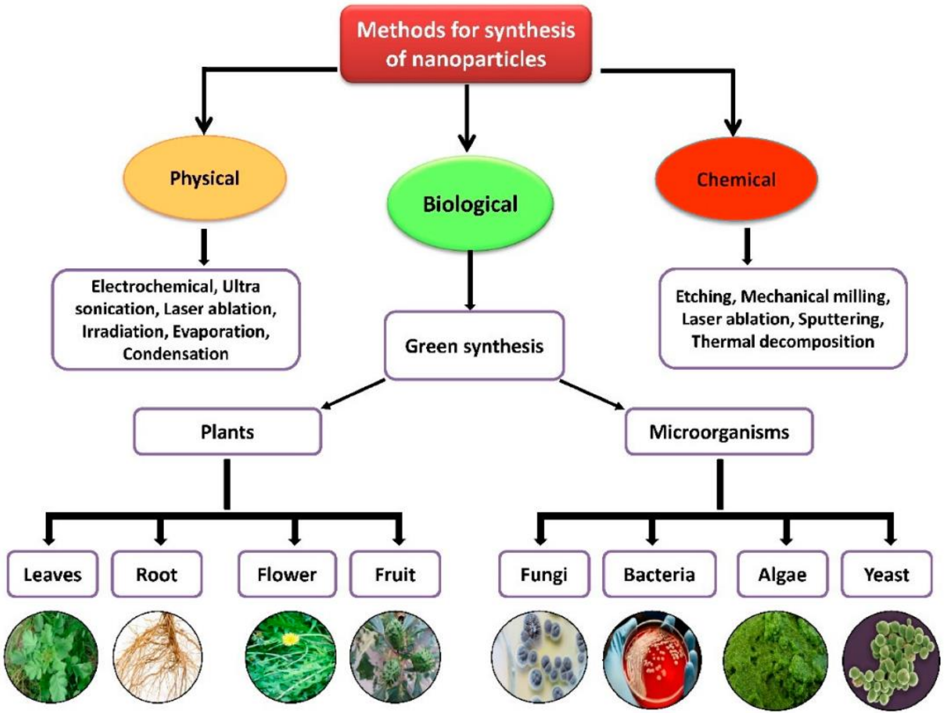

Fig 5: methods for synthesis of Nanoparticle

The use of harmful chemicals in conventional synthesis raises serious concerns since they have a negative effect on plants, soil, and agricultural products when they are discharged into the environment. A volume/high surface ratio is a feature of biological synthesis, and using biological components has been found to have positive ecological effects. They are regarded as non-toxic since they are known to produce little or no environmental contamination when discharged into the environment (Table 2).

Table 2: Major advantages and disadvantages identified for conventional and biological/green nanomaterials

Materials	Advantages	Disadvantage
Conventional Nanomaterials	– NMs are smaller and chemically simpler –They have reliable size, shape, and properties –they follow a standard synthetic process – full-scale use is possible	– The toxicity is unknown when released to the environment –Extremely reactive or potentially unstable -The effect on health of human is unknown –The life cycle of the product is known.
Biological/green nanomaterials	–the procedure for synthesis is eco-friendly –it avoids using solvents that are hazardous – capping agent functions as stabilizers of unstable nanomaterials –it employs Recyclable biological sources	–they are Larger and more chemically complex – feasibility is un-known for large-scale applications –Wide variations in sizes, shapes, and surface properties - – unknown life cycle

5. Uses and application of banbara nut extract in the synthesis of nanoparticles

A study was recently carried out by Ogbuagu *et al.*, [75] who green synthesized nanoparticles of silver and zinc oxide utilizing the post-harvest leaves of banbara nut and their antioxidant, antimicrobial and anti-inflammatory potentials. The aqueous leaves extract of the plant was observed to be suitable for the green synthesis of zinc and silver nanoparticles. Due to the reduction of Ag^+ to Ag^0, spherical-shaped leaves nanoparticles with sizes between 20 and 60 nm and rectangular-shaped roots nanoparticles with sizes between 55 and 85 nm were formed. The UV-vis spectroscopy spectroscopic investigation reveals that the nanoparticles' visible section of the spectrum λ peak absorption falls between 434 and 460 nm. The development of amorphous nanoparticles was verified by XRD analysis, which produced diffraction peaks that were not clearly defined. The produced nanoparticles contained functional groups directly involved in the bio-reduction Ag and Zinc ions to metallic silver and zinc nanoparticles. The produced nanoparticles have extremely low toxicity, according to the toxicity analysis. The results of the antimicrobial activity experiment conducted on Salmonella typhi and Staphylococcus aureus showed that the produced zinc and silver nanoparticles exhibit antibacterial properties [75]. These nanoparticles may be employed in treatments for illnesses brought on by bacteria and other microbes. The nanoparticles may find use in anti-inflammatory therapy as the anti-inflammatory analysis shown high activity for increasing concentrations. At various doses, the activity of anti-oxidant utilizing 2,2-diphenyl-2-picrylhydrazyl (DPPH) demonstrated notable scavenging action. These plants could be used because they are rich in bioactive compounds. Recently research conducted by Eze *et al.*, [76] examined the effect of nano-structured bambara nut shell as filler on the mechanical, morphological and physical properties of epoxy matrix. The amount of bambara nut shell fillers in the epoxy matrix has a major impact on the mechanical and physical properties of the matrix. The ideal composite characteristics were attained at filler loadings up to 15 weight percent, within the parameters of variance in this investigation. Most properties were shown to decline above this filler threshold load. With 15 weight percent of the nano filler, the maximum tensile strength of 80.20 MPa was achieved; however, when the filler loading was increased to 20 weight percent, the strength performance significantly decreased, reaching as low as 39.5 MPa. In a similar vein, the modulus of elasticity decreased for both the 15 and 10 weight percent, going from 138.5 MPa to 118 MPa. It is evident from other mechanical characteristics examined in this study, such as flexural strength and impact energy, that the ideal bambara nut shell nano filler for epoxy matrix is not greater than 15% weight percent. Physical characteristics such as the composite's density showed its highest value at 5 weight percent (0.8g/cm3) filler loading. As the filler volume increased above 5 weight percent, composites with lower densities resulted, indicating that the Bambara nut shell nano filler is a light-weight agricultural material appropriate for uses requiring both high strength and low weight. This implies that the composite can be used for both residential and industrial applications at the ideal filler loading, particularly in situations where light weight, high impact energy, and good tensile strength are important considerations [76].

6. Other potential applications of banbara nut-derived nanoparticle

Due to their numerous applications in industries, electronics, the environment, energy, and, more specifically, biomedical fields, NPs such as the well-known Ag and Au NPs have been thoroughly studied in this field and are highly intriguing for biological applications. In general, plant-derived green NPs are also less likely to cause serious side effects in humans when compared to chemically synthesized NPs, and they have a wide range of potential uses, including but not limited to:

Drug Delivery

Therapy Usually entails delivering drugs to a specific target site; if an internal route for drug delivery is not available, external therapeutic methods, such as radiotherapy and surgery, are used. These techniques are frequently used interchangeably or in combination to treat diseases, with the aim of therapy being to always remove the tumors or the cause of illness in a long-lasting manner [120]. Nanotechnologies are making a compelling contribution in this area by developing novel drug delivery methods, some of which have been proven effective in a clinical setting and are used in clinical settings [121]. For instance, doxorubicin, a drug with high toxicity, can be delivered directly to tumor cells using liposomes (Doxil®) without affecting the kidneys or heart, and paclitaxel incorporated with polymeric mPEG-PLA micelles (GenexolPM®) is used in chemotherapeutic treatment of metastatic breast cancers [122]. Improved in vivo distribution, reticuloendothelial system evasion, and favorable pharmacokinetics contribute to the success of nanotechnologies in drug delivery [123]. A perfect drug delivery system consists of two components: controlled drug release and targeting ability. By specifically targeting and killing harmful or cancerous cells, side effects can be minimized, and drug efficiency can be ensured. Controlled drug release can also reduce drug side effects [124]. Nanoparticle drug delivery systems have the advantage of reduced irritant reactions and improved penetration within the body due to their small size, allowing for intravenous and other delivery routes. Attaching nano-scaled radioactive anti bodies that complement antigens on the cancer cells with drugs enables the specificity of nanoparticle drug delivery systems. These methods have yielded positive outcomes [125], including enhanced (i) drug bioavailability, (ii) targeted drug delivery, and (iii) uptake of low solubility drugs [126].

Environment

The environment has been significantly impacted by modern technological innovations. However, advancements in nanotechnology have given us confidence that, with appropriate use, we can restore the ecosystem that was once harmed. By offering rapid and affordable evaluation and management to eliminate contaminants from water, nanoparticles can help address the issue of having clean, accessible water. For instance, a low quantity of copper in drinking water was achieved by using filter paper manufactured from Cu NPs during water purification, which also assisted in reducing the bacteria E. coli [127]. Cleaning up oil spills has also been shown to benefit from nanoparticles. The carbon particles were able to provide stabilized oil in water emulsions with the aid of tailored surface chemistry [128]. Furthermore, in brine shrimp, the carbon black [CB] NPs demonstrated non-toxic effects and the ability to absorb benzene. Since heavy metals like mercury, lead, thallium, and others seriously harm the environment and living things, nanoparticles like carbon nanotubes, nano zeolites, and metal oxides were successful in eliminating them. Nanoscale zero-valent iron is the most practical media since it is inexpensive, readily available, and non-toxic [129]. Bimetallic nanoparticles, which combine elemental iron or any other metal with catalysts like silver, gold, nickel, etc., could be used as an alternative to speed up the reduction process.

Bio-Sensing Applications

Analytical tools called biosensors are used to identify an analyte based on its concentration and occurrence. As seen in figure 6, biosensors are made up of three parts: a transducer, a reader tool, and an element that detects the analyte and produces a signal. A nano-biosensor is a biosensor that functions within the range of nanoscale. They are often used in the clinical setups, for quality assurance, livestock, drug production, biomedical, farming, agricultural, military and defense sectors industrial pollution management, forestry bacterial and virus diagnostics [149, 150]. For the benefit of humanity, the utilization of nanoparticles for biological material sensing is highly beneficial [130]. These biosensing applications employ a variety of nanoparticles [131]. A study demonstrated the application of Green synthesized mesoporous graphene oxide/silica nanocomposites from rich husk ash (RH-GO/SBA-15) for the removal of RhB in aqueous media [8]. Another study examined cancer using the green production of Au-Ag alloy mediated by chloroplasts [132]. PtNPs mediated by S. myriocystum were employed to identify asthma and allergies [133]. AuNPs produced by Hypnea valencia were utilized to identify pregnant individuals [134]. Additionally, the production of AgNPs mediated by Noctiluca scintillans was assessed to identify problems with oral discharge and gum disease [135].

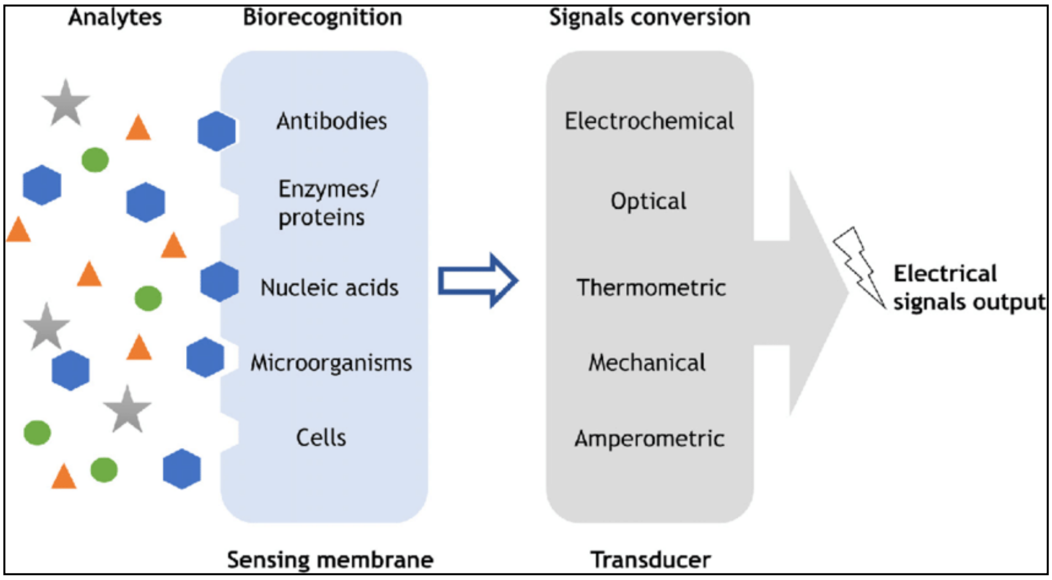

Fig 6: Schematic illustration of biosensor with its three main components: (a) Sensing membrane (detector), (b) transducer and (c) signal output system.

Antimicrobial Activity

The scientific community is in danger due to the sharp rise of antibiotic resistance. Thus, it is necessary to create a substance that shows great promise and becomes more effective against strains of bacteria that are resistant to antibiotics. In the past, traditional remedies were made from metals such as iron, copper, silvergold, etc. [136]. The researchers used this prior knowledge to determine that nano-based metallic oxide nanoparticles (NPs) have inherent antibacterial activity. Numerous biocidal actions against both Gram-positive and Gram-negative bacteria and eukaryotes were demonstrated by the metallic nanoparticles produced from plants [137]. Additionally, it demonstrated that metallic nanoparticles (NPs) effectively inhibited resistant strains, including methicillin-resistant S. aureus [MSRA], ampicillin-resistant E. coli, and others [138]. Currently, plants are used to include metallic nanoparticles' antibacterial properties against bacteria and fungi. Additionally, it is thought that NPs interact with the cell membrane more readily because they have a larger surface-to-volume ratio than their bulk counterparts [139]. The cell wall and cell membrane make up the structure of fungi. Phospholipids make up the cell membrane, while mannoproteins, β-1,3-D-glucan and β-1,6-D-glucan proteins, chitin, proteins, lipids, and polysaccharides (such as mannan or galactomannan, glucan, and chitin) make up the cell wall. Through interactions with the cell wall and membrane, the metallic nanoparticles function. Inhibiting β-glucan synthase, a crucial component of the cell wall, comes after the diffusion [140]. Oxidative stress, which interacts with macromolecules and results in cell lysis, comes after ROS [141].

Wound Healing

An injury to the skin tissue caused by trauma or stimulation is called a wound. Numerous treatment approaches are used, including vascular surgery, plant-based therapy, chemotherapeutics, and dressings; however, each method has drawbacks. The use of nanoparticles in wound healing is becoming more popular. It consists of two groups, one of which functions as a delivery agent for repair and the other as a medication that aids in wound healing [142]. For example, in albino Wistar male rats' excision wounds. Garg *et al.* [143] showed that silver nanoparticles have antimicrobial and healing properties [144]. The silver nanoparticles were synthesized using Arnebia nobilis root extract. Rats were given the hydrogel-based formulation. The rats exhibited no harmful effects from NPs, and the cells re-epithelialized. The application of NPs to wound healing is still in its infancy. To fully utilize the therapeutic potential of NPs, more thorough research is necessary to better understand the molecular mechanism and the body's reaction to them.

Anticancer Property

Because of its high death rate, cancer is one of the primary causes of death. The current chemotherapeutics lose their effectiveness, meaning that the patient develops resistance to the medications after a few cycles. Because of their small size, large surface area, tumor selectivity, and apoptotic activity—that is, their ability to cause cell death and exhibit cytotoxic properties—metallic nanoparticles are showing promise in the treatment of cancer. NPs use a variety of ways to achieve their anticancer effects. The first is apoptosis, in which high ROS levels cause oxidative stress, which in turn causes DNA breakage and cell lysis [145]. An additional one is the way that NPs interact with cell membranes and alter cell permeability [146]. The silver nanoparticles (PgAg NPs) were synthesized from fresh Panax ginseng leaves. In A549, MCF7, and HepG2 cancer cell lines, these nanoparticles showed cytotoxic effects that resulted in oxidative stress [147]. A549 cells showed increased phosphorylation of EGF receptors as a result of its inhibition of EGF. Furthermore, PgAg NPs increased the apoptotic process and disrupted the shape of the cells. It is possible that PgAg NPs' anticancer action is due to this interlinkage. The use of NPs to treat cancer is a new field, and further in vivo research is needed to fully comprehend the processes that NPs work.

Vaccines

While inactivated pathogen vaccines usually result in a modest immune response, conventional vaccines based on live-attenuated pathogens carry the danger of reverting to pathogenic virulence. Nanoparticle-based vaccines are a novel strategy that has demonstrated significant promise in overcoming the drawbacks of traditional vaccinations.

Recent developments in chemical and biological engineering have made it possible to precisely manipulate the size, shape, functionality, and surface characteristics of nanoparticles, which improves antigen presentation and boosts immunogenicity. [148]

Other Applications

Nanostructured bambara nut shell as a filler on the mechanical, morphological, and physical characteristics of epoxy matrix is another possible use of this legume plant [76]. According to anti-inflammatory study, green synthesized silver and zinc oxide nanoparticles made from post-harvest banbara nut leaves may also be used in anti-inflammatory therapy because their anti-inflammatory properties improve with concentration [75].

6. Summary and prospects for research

The benefits of nutraceuticals and the search for greener methods for the synthesis nanoparticles are becoming more widely known, and this has piqued the interest of researchers around the world. Recently, nanoscience has gained researchers' interest due to its significant applications in medical diagnosis, pharmacy, disease curing, electronics, agriculture, space, and chemical industries. The biologically mediated nanoparticles are gotten through plants, bacteria, fungi, actinomycetes, and yeast. Plant extracts are more advantageous than other bio-sources of nanoparticles due to their one-step, non-pathogenic, and economical procedure. Because of bioactive substances found in plants, such as phenols, alkaloids, flavonoids, terpenoids, steroids, saponins, alcohols, and proteins which function as reducing agents and during the synthesis of nanoparticle with less harmful consequences, bio-mediated nanoparticles have been employed extensively to treat a variety of pathogenic disorders. Nanoparticles, which have a number of hazardous qualities for the environment and human health, are produced via non-biological techniques like physical and chemical procedures. Certain characteristics of bio-mediated nanoparticles include increased surface area, increased reactivity, nontoxicity, and biocompatibility. While there hasn't been much research done on the nutraceuticals and synthesis of nanoparticles from banbara nut plants extract, the few researches that has been done has shown the crop's potential as a source of nutraceuticals and nanoparticles due to the presence of bioactive compounds. This review found that the crop has a variety of uses outside of medicine and nutrition. However, very little research has been done on how different nanocomposite are synthesized and their divers' biotechnological applications. Also, there is need to improve the pre-processing techniques, the quantity and quality of phytochemicals including extraction methods for the optimization of the bioactive compounds and the nanoparticles. The majority of the crop's found antimicrobial potentials were mostly against human diseases, indicating that it has the potential to be a natural product that is eventually used to make pharmaceuticals especially when nanoparticles are involved for target delivery and quick response. This review suggest that more investigation is necessary to fully understand the antibacterial potential, nutraceutical benefit and techniques for the synthesis of nanoparticles from banbara nut which is tagged as underutilized legumes with their various applications.

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