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EDITED BY

Benedicta Essel Ayamba,
Council for Scientific and Industrial
Research (CSIR), Ghana

REVIEWED BY

Mustapha Mohammed,
University for Development Studies,
Ghana
Debasis Mitra,
National Rice Research Institute,
(ICAR), India

*CORRESPONDENCE

Michael Abberton
m.abberton@cgiar.org

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Potentials of underutilized legumes in food security

Modupe S. Ayilara^{1,2}, Michael Abberton^{2*}, Olaniyi A. Oyatomi²,
Olu Odeyemi³ and Olubukola O. Babalola¹

¹Food Security and Safety Focus Area, Faculty of Natural and Agricultural Sciences, North-West University, Mmabatho, South Africa, ²Genetic Resources Centre, International Institute of Tropical Agriculture, Ibadan, Nigeria, ³Department of Microbiology, Obafemi Awolowo University, Ile-Ife, Nigeria

Adopting underutilized legumes in tackling food security is essential, especially in this era of climate change. Underutilized legumes are embedded with inherent potentials such as the ability to survive in extreme conditions (such as temperature, drought, pH, saline, etc.), high nitrogen-fixing potential, weed and disease control ability, and high nutrient status. Underutilized legumes can improve the yield of companion crops in an intercropping system and as a subsequent crop (due to their residual effects). They possess symbiotic and non-symbiotic organisms in their nodules, and also have different organisms in their bulk soil, rhizoplanes and rhizosphere, which can fix nitrogen, solubilize phosphorus or produce exudates which help in improving plant growth. Also, they contain some phytochemicals, including alkaloids, saponin, amino acids, organic and inorganic minerals, and compounds that help improve human health and prevent diseases. Hence, this review discusses the current status, role, challenges and the prospects of underutilized legumes in food security.

KEYWORDS

orphan crops, nitrogen fixation, phytochemicals, rhizobium, anti-nutrients

Introduction

Food security is a global challenge in recent years, especially with the ever-growing population and crop yield reduction, making it difficult to feed the increasing populace. Food security is when there is physical, economic, and social accessibility of sufficient and nutritious food for everyone (1, 2). About 850 million of the world population are extremely hungry, leading to economic challenges and difficulties in the achievement of the sustainable development goals (SDG) (3). Food security is affected by factors such as economy, climate change, environment, lack of storage and processing facilities (leading to postharvest loss), underutilization of some crops with essential values, seed quality, and soil nutrient status (4–12). The utilization of underutilized crops (orphan crops), especially legumes, will go a long way in alleviating food insecurity; this is because of their inherent properties, such as the ability to survive drought, their high nutrient status, and most especially, their high nitrogen-

fixing potentials which consequently increase plant growth, crop yield and food production (13, 14). Underutilized legumes are crops that are well known in their countries of origin owing to their economic, cultural, or agronomic values but are generally abandoned by plant breeders, policymakers, consumers, agricultural researchers, donors, extension services, and technology providers (15, 16). This reduces their general acceptability and information available on them and makes it impossible to unleash the potential embedded in them. Nitrogen is the most crucial nutrient in the soil, and its presence enhances crop yield (17); it accounts for 78-79% of the total gas in nature in an inert state and unabsorbable by plants. Plants use ammonium and nitrate forms of nitrogen which are easily lost from the soil through denitrification, crop harvesting, and leaching (17). Legumes are nitrogen-fixing plants from the family Leguminosae that form a symbiotic relationship with a group of bacteria collectively called rhizobia. Rhizobia are concealed in a specialized structure on the root of legumes (nodules), and they fix air nitrogen into a plant usable form (ammonia) using nitrogenase complex enzyme (18, 19). Therefore, the intervention of legumes capable of fixing nitrogen will help to significantly improve food security (20, 21). Thus, it is important to create awareness and understand the mechanism adopted by underutilized legumes in ensuring food security in a bid to ensure the maximum utilization of their potentials; hence this review.

Mechanism used by underutilized legumes to boost food security

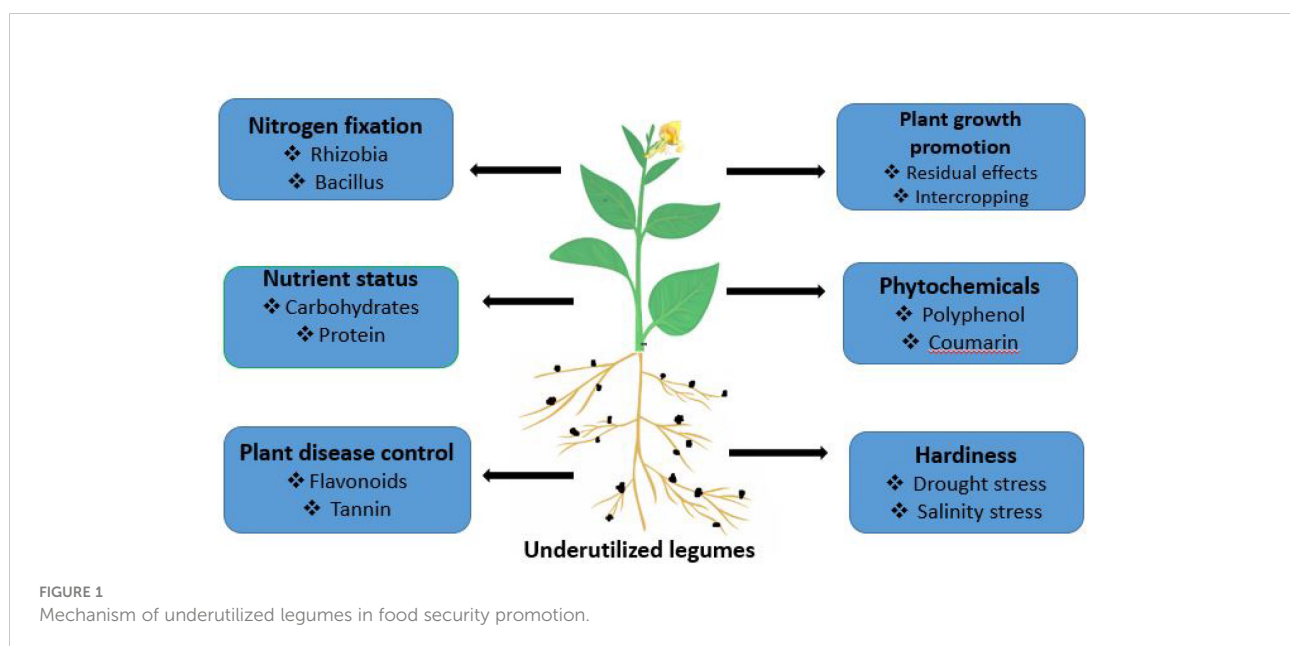
Underutilized legumes can improve food security due to their high nutrient status, ability to improve soil nutrient,

potentials to alleviate climate change effects, resilience to adverse effects of climate change such as (erosion, disease emergence, etc.), plant disease control potential, and weed control (13, 19, 22) (Figure 1).

Nutritional status of underutilized legumes

Malnutrition (including protein and micronutrient malnutrition) has been reported to be the leading cause of stunted growth (especially in children below 5 years) as well as child and infant death globally (23). Malnutrition which could be in form of undernutrition (leading to stunted growth, underweight, mineral and vitamin deficiency) or over nutrition (resulting in cancer, diabetes mellitus, stroke, and heart disease) leads to poverty and a reduction in economic growth and productivity (24). According to WHO, around 115 million children below five years of age are stunted, 462 million adults are underweight, 41 million children are overweight and obese, and 1.9 billion adults are overweight and obese, hence, a reduction in malnutrition would help to decrease diseases globally by 32% (24). Malnutrition, especially protein deficiency has been reported to impede fetal brain development, resulting to an abnormal brain physiology and anatomy (25). Malnutrition leads to a high mortality rate, increased cost for diseases treatment and a low rate of recovery from sickness (26–29). Worldwide, malnutrition is responsible for 45% of death in children (30).

Many underutilized legumes are very high in nutrients and can promote good health and ensure food security (31). They are very affordable and rich in protein, one of the most essential



nutrients needed for good living, especially in this era where animal protein sources pose a health threat to humans and are being discouraged. This has led to the promotion and recommendation of plant-based protein to fulfill the nutritional needs of the ever-growing population (32). Soetan and Adeola (33) researched to reveal the nutritional properties of different underutilized legumes which include Bambara groundnut (*Vigna subterranean*), Jack bean (*Canavalia ensiformis*), Lima bean (*Phaseolus lunatus*) and sword bean (*Canavalia gladiata*). These researchers observed that these plants are rich in protein, fiber, fat, calcium, phosphorus, sodium, potassium, iron and magnesium. *Cassia hirsuta* L. has equally been reported to contain high protein, lipid, potassium, fiber, carbohydrates, and energy contents (34), while velvet bean (*Mucuna pruriens*) has been reported to have optimum crude

protein, lipid, fiber, carbohydrate, energy, calcium, potassium, phosphorus, zinc, manganese and magnesium content which is capable of supplying human nutritional needs (35). Examples of other underutilized legumes and nutrient composition are listed in Table 1 below:

Some underutilized legumes have multiple edible parts; for instance, different parts of winged bean which include the flower, seeds, pod case, immature pods, tuberous roots, and leaves (62), similarly, the seeds and leaves of fenugreek are edible (63), also, marama bean produces edible grains and tubers beneath their root (49), zombie pie produces edible seeds and tubers (16) and African yam bean produces edible tubers and seeds (64). The edibility of multiple parts of underutilized legumes gives a chance for the human nutritional requirements to be satisfied through different diets, especially for picky eaters, making it

TABLE 1 Underutilized legumes and their nutritional composition.

Legume	Species name	Nutrient composition	References
Adzuki bean	<i>Vigna angularis</i>	Adzuki bean contains lysine, minerals, protein, fat, iron, fiber, and calcium.	(36)
Chickpea	<i>Cicer arietinum</i> L.	Chickpea is rich in protein, calcium, carbohydrate, fiber, and phosphorus.	(37)
Cluster bean	<i>Cyamopsis tetragonoloba</i>	Cluster bean is a good source of ascorbic acid, vitamin A, iron, phosphorus, calcium, and protein.	(38)
Common bean	<i>Phaseolus vulgaris</i>	Common bean is rich in vitamins, protein, carbohydrates, minerals, and unsaturated fatty acids (majorly oleic and linoleic acids).	(39)
Faba bean	<i>Vicia faba</i> L.	Faba bean has an appreciable amount of potassium, calcium, sulfur, manganese, protein, cadmium, fiber, magnesium, and energy.	(40)
Fenugreek	<i>Trigonella foenum-graecum</i> L.	Fenugreek seeds have a high amount of protein, phosphorus, amino acids, magnesium, biogenic elements, sulfur, lipids, fatty acids and calcium but have a low amount of manganese, copper, and zinc.	(41)
Grass pea	<i>Lathyrus sativus</i> L.	Grass pea is a good source of carbohydrates, protein, copper, zinc, phosphorus, iron, potassium, carotene, arginine, flavonoids, and tryptophans.	(42, 43)
Horsegram	<i>Macrotyloma uniflorum</i>	Horsegram contains protein, zinc, iron, calcium and fiber.	(44)
Kersting's groundnut	<i>Kerstingiella geocarpa</i>	Kersting's groundnut is highly rich in protein, essential amino acids, and carbohydrates.	(45)
Lablab bean	<i>Lablab purpureus</i>	Lablab bean is a rich source of fat, carbohydrates, amino acids, fibers, calcium, lysine, and iron but has low sulfur, methionine, and cysteine content.	(46)
Lentil	<i>Lens culinaris</i> Medik	Lentil has a significant quantity of protein, minerals, vitamins, and low-digestible carbohydrates.	(47)
Lima bean	<i>Phaseolus lunatus</i>	Lima bean contains an appreciable level of carbohydrate, fiber, protein, sodium, and potassium with a low-fat content.	(48)
Marama bean	<i>Tylosema esculentum</i>	Marama bean contains fat, carbohydrates, amino acids, protein, fibers, and minerals such as magnesium, copper, chromium, iron, zinc, calcium, iodine, and vitamins B6 and B12.	(49)
Moth bean	<i>Vigna aconitifolia</i> L.	Moth bean seed comprises carbohydrates, fat, moisture, fiber and protein.	(50)
Mung bean	<i>Vigna radiata</i> L.	Mung bean has a high protein, calcium, fiber, iron, potassium, and carbohydrate content with a low fat level.	(51–53)
Narrow-leafed lupin	<i>Lupinus albus</i>	Narrow-leafed lupin is a good source of protein, methionine, lipids, carbohydrates, calcium, manganese, potassium, phosphorus, sodium, and fiber.	(54)
Pigeon peas	<i>Cajanus cajan</i>	Pigeon pea is a rich source of minerals, protein, iron, fiber, vitamins, and zinc	(55)
Red clover	<i>Trifolium pratense</i>	Red clover contains calcium, fiber, carbohydrate, protein, fat and magnesium.	(56)
Rice bean	<i>Vigna umbellata</i>	Rice bean seeds are rich in protein, fat, minerals, vitamins (riboflavin, ascorbic acid, niacin, and thiamine), and amino acids (valine, tryptophan, tyrosine, methionine, and lysine).	(57)
Urad bean	<i>Vigna mungo</i>	Urad bean is rich in potassium, protein, calcium, Vitamin A, B1 and B3, phosphorus, and sodium.	(58)
Vetch	<i>Vicia sativa</i> L.	Vetch is a good source of fatty acid, protein, linoleic, and linolenic acid.	(59)
Zombie pea	<i>Vigna vexillata</i>	Zombie pea is rich in Ca, Mg, Fe, Zn, Mn, sulphur-amino acids, cystine, and methionine.	(60, 61)

possible for the same or similar nutrients to be supplied from different parts of the same plant.

Phytochemicals and compounds in underutilized legumes

The concept of food security involves the existence of safe and nutritious food for all people to meet their dietary needs and promote healthy life (65). Hence, other medicinal or health benefits which can be provided by food is essential to promote food security. Underutilized legumes contain some phytochemicals which can help to prevent diseases in humans; example of such include winged bean, sword bean, velvet bean, jack bean, and scarlet bean, which are rich in antioxidants and phenols and are capable of promoting health status in humans (66).

Coumarin, polyphenol, and flavonoid are available in abundant quantity in fenugreek and have been reported to cure cardiovascular and other chronic diseases (67). Common bean, chickpea, lablab bean, winged bean, faba bean, and pigeon peas contain saponin that have antioxidative, antidiabetic, antitumor, hyperlipidemia, hepatoprotective, anticarcinogenic, antiviral, hypocholesterolemic, and antihepatic effects on humans (68). Common bean contain some level of lectin and lectin-related compounds (69). African yam bean has polypeptides embedded in its albumin fraction with a size not less than 26 kDa sizes (70). Bambara groundnut contains flavonoids, steroids, and saponins which were reported to be responsible for its anti-tubercular nature (71, 72). Amino acids are found in almost all underutilized legumes, and are very helpful in gene expression, treating genetic disorders, boosting the immune system (by producing cytokinins, immunoglobulins, etc.), and regulating the metabolic activities in the body; for instance, arginine prevents oxidation stress, enhances glucose and fatty acid metabolism and prevents non-communicable diseases (47). Similarly, amino acids such as valine, alanine, isoleucine, leucine, serine, threonine, proline, etc., produce signal molecules or hormones that regulate lymphocyte multiplication (lymphocytes carry the memory for invading pathogens and reduce pathogen infiltration) (47). Branched chained amino acids (valine, leucine, and isoleucine) also help to maintain blood sugars and promote reproduction in women by normalizing the embryo implantation, blastocyst development, and fetal development through the production of hormones; it as well enhances the function of the mammary gland (73). In addition, amino acid oxidases from L-isomers of leucine, tyrosine, phenylalanine and tryptophan have antimicrobial properties, which helps to boost the human immune system and fight pathogens (74). Further research should be carried out to test plant extracts from the leaves, flower, roots, and stem bark of underutilized legume in the laboratory for antimicrobial and diseases (e.g. cancer) control potentials, and if successful, they

should be further developed into orthodox medicine for human use.

Nitrogen fixation by underutilized legumes

Nitrogen is the most crucial nutrient in the soil, and its presence enhances crop yield (17); it accounts for 78-79% of the total gas in nature, which is in an inert state and unabsorbable by plants. Plants use ammonium and nitrate forms of nitrogen are lost from the soil through denitrification, crop harvesting, and leaching (17). The intervention of legumes capable of fixing nitrogen will help in significantly in improving food security (20, 21). Legumes are nitrogen-fixing plants that form a symbiotic relationship with a group of bacteria called rhizobia. These rhizobia are concealed in a specialized structure on the root of legumes (nodules), and they fix air nitrogen into a plant usable form (ammonia) using nitrogenase complex enzyme contained in them (18). *Rhizobium* are gram-negative, aerobic, motile, rod-shaped, non-sporing bacteria; they live in water, soil, and plants, and they multiply through cell division using acids, alcohol, and sugar as their energy source (75). Nodulation is the development of nodules on the root of leguminous plants. Firstly, flavonoid (a plant metabolite) is dispersed into the root zone of legumes (76). This attracts infective *rhizobium* cells to the root of a susceptible legume seedling; the legume provides them with food and shelter, leading to an increase in rhizobial population and plant's root hair colonization. When the root hair curls, a *rhizobium* enters, multiplies and forms an infection thread, the infection thread enters the root cortex, where other root cell infection takes place; thereafter, cell division increases, leading to the formation of an embryonic nodule (77). Variations occur in the shape, size, texture, location, and color of nodules and the effectiveness of the nodules is essential to assess the outcome of the legume-*rhizobium* symbiotic relationship. Nodule color reflects the nitrogen-fixing potentials of nodules; effective nodules appear deep red or pink in color arising from the leghemoglobin pigment (78). Hassen et al. (79) reported the production of effective nodules isolated from Bambara groundnut landraces which are pink in color. When legumes are fertilized using synthetic chemicals, the effective *rhizobia* strain produces small nodules which remain passive until the synthetic nitrogen are exhausted (77). Effective nodules are large and clustered on the plant's primary and upper lateral roots and usually evaluated by weight or volume during the late plant flowering stage, while ineffective nodules are usually tiny, many and widely distributed on leguminous roots.

Nitrogen fixation potentials has been reported in underutilized legumes such as Bambara groundnut, Kersting's groundnut, African yam bean and winged bean (80). *Rhizobium* belonging to the strain KUL-Z₃, KUL-GP, KUL-JN and KUL-BH were isolated from winged bean (81). Equally, Ribeiro et al. (82)

discovered novel strains of rhizobium lineage in common bean, the strains discovered were majorly *Rhizobium leguminosarum*, *Rhizobium etli* and *Rhizobium phaseoli*. If well investigated, these rhizobia could probably be capable of promoting food security better than others that have been previously identified from well-known legumes. For instance, they could have the ability to produce antibiotics or other metabolites which can promote the growth of plants by enhancing the release of nutrients or by controlling or preventing plant diseases.

Nitrogen fixation has also been demonstrated in Kersting's groundnut, where high nitrogen-fixing ability was expressed by *Bradyrhizobium kavangense* 14-3^T, *Bradyrhizobium elkanii*, *Bradyrhizobium pachyrhizi* PAC48^T, *Bradyrhizobium vignae* 7-2^T, and *Bradyrhizobium subterraneum* 58-2-1^T. These microsymbionts enhanced plant growth promotions *via* increased leaf chlorophyll, nodulation and photosynthesis, which all helps to increase plant yield (83). Likewise, the lablab bean's ability to associate with nitrogen-fixing rhizobia such as *Mesorhizobium ensifer* and *Bradyrhizobium species* has been reported (84). However, there could be variability in the nitrogen-fixing potentials of different rhizobia, for instance, Hailu Gunnabo et al. (85) carried out research that revealed that of all the *Rhizobium species* isolated from the common bean in Ethiopia, only *Rhizobium phaseoli* and *Rhizobium etli* were predominant. This could be due to the ability to out-compete other organisms.

Non-symbiotic bacteria and cyanobacteria residing in the bulk soil, rhizosphere or rhizoplane of plants can fix nitrogen by using nitrogenase enzymes at normal temperature and pressure (86). Free-living bacteria utilize soil nitrogen for their metabolic activities and are active only under specific conditions; they use high molecular weight nitrogen by releasing proteases and chitinases enzymes which break down the complex nitrogen for plant use (87). Examples of free-living nitrogen-fixing bacteria include *Azotobacter species*, *Bacillus species*, and *Azospirillum species*, with *Azospirillum* sp. being one of the most efficient free-living nitrogen-fixing diazotrophs (88, 89). Zoundji et al. (90) reported that *Rhizobium species* was able to increase the dry shoot matter of Bambara groundnut. Similarly, *Rhizobium species* and *Pseudomonas species* were able to increase the biomass and yield of common bean by 25% and 15% respectively (91). *Aspergillus species* and *Penicillium species* significantly increased the root length, shoot dry weight, height, nodule number, pod number, 50 seed weight, nodule dry weight and phosphorus content of *Phaseolus vulgaris* L. (92). The two fungal species (*Aspergillus species* and *Penicillium species*) reported by Elias et al. (92) were able to increase the yield and yield parameters of *Phaseolus vulgaris* because they have phosphorus solubilizing ability. Few studies have been carried out on the endophytes living in different organs other than the roots of underutilized legumes such as the flower, seeds, root, and stem. Endophytes are organisms that help plants to store nutrients, recycle nutrients, and in soil bioremediation

(93). Chimwamurombe et al. (94) reported the presence of endophytes belonging to the species *Chitinophaga* sp., *Rhizobium* sp., *Massilia species*, *Microbacterium species*, *Burkholderia species*, *Kosakonia species*, *Mucilaginibacter species*, *Curtobacterium species*, *Bacillus species*, *Pseudorhodofera species*, *Methylobacterium species*, *Caulobacter species*, *Sphingomonas, species*, and *Pantoea species*. in the seed of marama bean. These researchers reported the presence of exudates such as protease, siderophores, indole acetic acid (IAA), endoglucanase, and 1-aminocyclopropane-1-carboxylic acid (ACC deaminase), which enhanced the nitrogen-fixing and phosphorus solubilizing abilities of the endophytes (94). Parsa et al. (95) also assessed common beans for fungal endophytes and realized that the prevalent species were *Fusarium oxysporum*, *Cladosporium cladosporioides* and *Xylaria species*. Some of the microbes mentioned above can be used in bioremediation process, which can rejuvenate the soil and make it available for plant growth and for other purposes.

There are records of free-living microbes from the rhizosphere and bulk soil of underutilized legumes. Some of them are embedded with other attributes aside from nitrogen fixation. For example, the rhizosphere and bulk soil of marama bean has been found to contain bacteria from the species *Klebsiella*, *Bacillus*, *Acinetobacter*, *Kosakonia*, *Raoultella*, *Arthrobacter*, *Burkholderia*, these organisms are embedded with the ability to solubilize phosphorus, and to produce catalase, ammonia, hydrogen cyanide, protease as well as ACC deaminase activity (96). In another research which involved lima bean, the presence of a high population of microbes was reported in the rhizosphere, and they belong majorly to the species *Gaiella*, *Streptomyces*, *Nitrososphaeraceae*, *Acidobacteria*, *Rhizobium*, *Conexibacter*, *Bacillus*, *Burkholderiaceae*, *Novosphingobium* and *Synechococcus* (Cyanobacteria) (97). However, there is a research gap in literature regarding the quantification of nitrogen fixed and the existence of non-symbiotic nitrogen-fixing bacteria inhabiting the nodules, rhizosphere, bulk soil and rhizoplane of many underutilized legumes; hence, further researches should be carried out to unravel these information. If the amount of nitrogen fixed by specific underutilized legumes in intercrops and as subsequent crops are confirmed, the deficient nitrogen needed by crops can be complimented using synthetic nitrogen source; this will reduce the application of synthetic fertilizer and the greenhouse gases emission associated with them.

Ability to survive extreme conditions

Underutilized legumes can survive in extreme conditions due to the presence of soil microflora in their rhizosphere and nodules and some inherent traits they possess, a term referred to as hardiness (Figure 1). Underutilized legumes have peculiar

physiological makeup and harbor microbes that can survive and be active in extreme conditions such as saline, drought, extreme pH, temperature, etc. (16, 98, 99). Degefu et al. (100) carried out an experiment on pigeon pea and revealed that *Bradyrhizobium elkanii* and *Bradyrhizobium japonicum* survive in saline and drought soils in Ethiopia, where they help the plant to alleviate the stress conditions. In mung beans, strains of *Pseudomonas* and *Rhizobium* which produces auxin and ACC deaminase helped the plant to survive in saline environment by inducing salinity tolerance (101). Common bean was also evaluated for the ability to survive in a saline condition and it was detected that the presence of different *Rhizobium species* designated as PvMb1, ISRA352, PvNk7, and PvNk8 helped it to alleviate salinity stress and enhanced plant growth and osmolyte content (glycine, betaine and proline) (102). Similarly, *Rhizobium radiobacter* from mung beans produced extracellular polymeric substances which was used to bioremediate arsenic and increased the survival and stress tolerance of the plant to arsenic pollutant (103).

In addition, salt and pH tolerance was recorded in common bean which accommodates *Rhizobium species*. in their nodules, the effective isolates recovered were HUCRM3B, HUCRM2D, HUCRM5C and HUCRM9C, the species helped common bean to alleviate pH and salt stress (104). The presence of microflora in soil with high salinity content and soil with extreme pH indicates that the microbes utilizes the salt and pH for their growth and can thus be developed into commercially available products which can be used in bioremediation; hence, helping to put to use land that are neglected because of their natural extreme chemical properties or high chemical properties arising from human activities and pollutions.

Plant disease control

The use of plant extract from underutilized legumes to control plant diseases has not been extensively explored. Some phytochemicals are found in underutilized legumes; these chemicals, which are also present in some other plants, have been reported to be capable of controlling plant diseases (Figure 1). African yam bean contains tannin (16); although

tannin is an antinutrient which prevent the absorption of nutrient during consumption, on the other side its potential to control plant disease could be an advantage. Equally, Adegboyega et al. (105) reported the presence of tannin and phytate in the seeds and tubers of winged beans. Flavonoids, tannin, and phenols were also reported to be present in common beans with an increased concentration in a water-stressed condition (67). Fenugreek contains coumarin, polyphenol, and flavonoid in abundant quantity (67), and saponin in common bean, chickpea, lablab bean, winged bean, faba bean, and pigeon peas has also been established (68). Sparvoli et al. (69) and Ajibola et al. (106) has equally reported the presence of lectin in common bean and the presence of polypeptides in African yam bean, respectively. Bambara groundnut also contains flavonoids, steroids, and saponins which were reported to be responsible for its anti-tubercular nature (71, 72). Many of the phytochemicals that are produced by the aforementioned underutilized legumes have been reported to be used in curing some plant diseases. The causative agent of diseases they cure and the mechanism of action of the plant diseases they control are detailed in Table 2 below. Research should be intensified to unravel some other existing and novel phytochemicals in underutilized legumes which can be useful in the control of plant diseases. The presence of all these aforementioned phytochemicals from other plants has been reported by some other researchers to be capable of controlling plant diseases (Table 2). The ability of these chemicals from underutilized legumes to control plant diseases should as well be tested and the mechanisms underlying their production in underutilized legumes should be properly understood; perhaps it could be used to increase the level of phytochemical production by underutilized legumes for plant disease control.

Promotion of companion/subsequent plant growth

Legumes are capable of fixing nitrogen for themselves; however, other plants can as well benefit from this fixation (115). A neighboring plant in an intercropping system (116) or a succeeding plant (117) can utilize the nitrogen fixed biologically

TABLE 2 Phytochemicals found in underutilized legumes and their potentials against plant diseases.

Phytochemicals	Disease/Pathogen	Diseases caused by the pathogen	References
Coumarins and pyrenes	<i>Alternaria solani</i>	Early blight	(107)
Flavonoides and isoflavonoide	<i>Gymnosporangium yamadai Miyabe</i>	Rust diseases	(108)
Lectins and polypeptides	<i>Pseudomonas syringae</i>	Citrus blast and black pit	(109, 110)
Phenolics	<i>Fusarium oxysporum</i>	Fusarium wilt	(111)
Saponins	<i>Penicillium italicum</i>	Blue mold disease	(112)
Steroids	<i>Colletotrichum musae</i>	Anthracnose	(109, 113)
Tannin	<i>Curvularia lunata</i>	Leaf blights	(114)

by legumes. When legumes are planted in a monocropping system and harvested, only the seeds are harvested. The other parts, e.g., the roots, stems, and other non-edible portions, are left behind, and they decompose to release nutrients. In an intercropping system, the roots of the plants grow and die several times during the life cycle of the plants and lead to the release of nitrogen by mineralization, nitrogen is also made available by mycorrhizae fungi and the root exudates released during intercropping (118). Mycorrhizae network between roots of legumes and companion crops also mediates nitrogen transfer and uptake respectively (119). More research is needed on the mechanism of nutrient transfer between nodulating underutilized legumes and non-nodulating plants, as this would enhance tapping into the potentials of underutilized legumes for improved food security. In a study by Giller et al. (120), the transfer of nitrogen from common bean to maize which was the companion crop during intercropping was recorded, though the quantity transferred was not too significant.

In contrast, in a previous research carried out by Egbe et al. (121), it was reported that the weight and nodule number of Bambara groundnut, when intercropped with maize decreased, while the nodules numbers increased and the weight was indifferent when Bambara groundnut was intercropped with cowpea. The researchers as well reported that the nitrogen-fixing potentials decreased with a lower planting density of Bambara groundnut when it was intercropped with cowpea and maize. Also, nitrogen fixation (using root yield nitrogen) measured was not different when Bambara groundnut was intercropped with both cowpea and maize (121). Owing to the different reports on nutrient transfer during intercropping, it is necessary to understand the principles underlying the transfer of nutrients during intercropping as this will help to maximally tap into the potentials of increasing nitrogen transfer from legumes to cereals.

Asides intercropping, underutilized legumes could make nitrogen available for subsequent crops through decomposition, a process referred to as residual effect (Figure 1). A study by Uher et al. (122) revealed that the forage quality from maize intercropped with common bean led to a high crude protein as well as a reduced amount of neutral and acid detergent fiber, consequently a higher nutrient digestibility, even though different densities of intercropping was used. Gebremichael et al. (123) also noted that the yield of sorghum planted in an intercropping system and as a subsequent crop using pigeon peas had an increased grain yield. This indicates that intercropping using underutilized legumes have a positive effect on the nitrogen-fixing potentials, nutritional outputs, forage, and grain yield which all have an effect on food security. It is therefore very vital to carry out more studies to determine the compatibility of different accessions and species of underutilized crops as intercrops and preceding crops, as this will help farmers to choose the best option to realize their desired output (i.e. forage, grain yield, etc.).

Factors impeding the usage of underutilized legumes for food security

The utilization of underutilized legumes in promoting food security are hindered by different factors, which include the presence of anti-nutrients, long cooking duration, low demand by the populace, shattering of the pod, high cost of production and poor digestibility (16, 37). Some climbing underutilized legumes require staking, which incurs additional costs for farmers; for instance, African yam bean requires staking, which may be too expensive for farmers (124). The production of some other underutilized legumes is also laborious; for example, bambara groundnut is a shrub and the manual weeding, milling and harvesting could be stressful or expensive if the farmer employs people to carry out the maintenance operations (125). Long cooking duration is another problem associated with underutilized legumes (126). Most of the underutilized legumes take several hours to cook, making it impossible for them to serve immediate hunger needs. In a study by Owusu et al. (126), the long cooking duration of lima bean was reported. However, some methods have been used to hasten the cooking time of underutilized legumes and these include presoaking, dehulling, and molecular techniques such as Genome-Wide Association Study and Quantitative Trait Loci, which can be used to identify the loci which controls the cooking duration and can be altered to reduce the cooking duration (127). Equally, novel breeding techniques such as transcription activator-like effector nucleases (TALENs), clustered regularly interspaced short palindromic repeats (CRISPR/Cas9) and zinc finger nucleases (ZFNs) are available to insert the desired traits into plants (127). The use of organic tenderizers can also be experimented as organic tenderizers are natural and not associated with harmful side effects compared to their chemical counterparts; such tenderizers include unripe pawpaw, kiwi, etc. Enhancing the cooking time of underutilized legumes will go a long way in promoting their acceptability and utilization.

The shattering of the pods of underutilized legumes is another challenge that impedes their production and reduces their yield (127). The presence of anti-nutrients and properties such as hydrogen cyanides, saponins, oxalates, phytates, alkaloids, flatulence factors, tannins and heamagglutinins in underutilized legumes reduce their acceptability (128). However, many solutions have been prescribed to reduce the anti-nutrient factors in legumes, and these include autoclaving, parching in hot sand, soaking in water, microwave treatment, boiling in water, fermentation, dehulling, soaking in acidic or alkaline solution, roasting, simmering, pounding, baking, air-drying, steaming, and soaking in lime solutions (129). The purpose or proposed use of underutilized legumes could be

considered before deciding to reduce their anti-nutrients. For instance the anti-nutrients are chemicals of interest for the pharmaceutical industries; hence, if the crops are meant to be used for drug production, antinutrients should be enhanced and not reduced but for consumption purposes, the reduction of antinutrients is very important.

Prospects, recommendations and research gaps in underutilized legumes

A lot of microorganisms are associated with the nodules, rhizosphere, rhizoplane, and bulk soil of legumes generally, with few studies reporting these in underutilized legumes. Since underutilized legumes have the potentials to host novel microbes with desirable characteristics and traits to improve crop yield (such as the ability to survive in extreme temperature, pH, salinity and water stressed situation, their insecticidal and pesticidal ability and the potential to fix high nitrogen), such microbes should be developed into products such as inoculum, biofertilizers, biochar, biopesticides, bioinsecticides, etc. to increase the growth and yield of both leguminous and non-leguminous plants. Plant extracts can also be produced using different parts of underutilized legumes such as the roots, stems, pods, leaves, etc., and tested for their ability to treat plant diseases and drive away pests and insects.

Underutilized legumes should be incorporated into different planting system so as to determine the best planting system that suits them and fully unleash their potentials to improve food security. Furthermore, the compatibility of underutilized crops with other crops, the principles underlying the transfer of nitrogen from nitrogen-fixing underutilized legumes to companion crops and the yield outcome during intercropping should be well understood in order to maximize the advantages associated with their intercropping.

In addition, research should be intensified on the application of legumes to adapt and mitigate climate change effects which include pests, erosion, drought, salinity and diseases; this will help to maximize land resources. Also, organic tenderizers such as unripe pawpaw and kiwi which are being used locally as tenderizers to soften beefs while cooking, should be tested for their ability to reduce the cooking time of underutilized legumes by softening them, as organic tenderizers are natural and not associated with harmful side effects compared to their chemical counterparts.

Due to the high nutritional and medicinal properties of many underutilized legumes, essential nutrients can be extracted from them and made into nutritional supplements or tablets for the treatment and prevention of ailments. Other edible products such as cooking oil can be extracted from underutilized legumes since

similar legumes (e.g., soybean are processed into oil) are used to produce cooking oil and some underutilized legumes have high lipid contents. The processing of underutilized legumes into flour will prolong their shelf life and prevent spoilage; the flowers can therefore be incorporated in baking of breads and other pastries.

Finally, creating awareness of underutilized legumes will help to reduce the problem of low demand. If well publicized, many people, even if they do not like the taste of underutilized legumes, can feed on them for their health benefits. If underutilized legumes are used as raw materials in industries (e.g. for oil and medications), demand from such will help to increase the production and encourage more farmers to produce them; hence, prevent them from going into extinction and promoting food security.

Conclusion

The intervention of underutilized legumes in tackling food insecurity should be emphasized owing to their important characteristics. Many research has been carried out on the nitrogen-fixing potentials of well-known legumes. Hence, adequate awareness and information from researchers on the nitrogen-fixing potentials of underutilized legumes will remarkably enhance their utilization; perhaps there may be some of them that fix more nitrogen than many well-known legumes, which will promote their usage as preceding crop or in an intercrop in a view to improving food security. This will reduce the application of fertilizers by farmers, consequently reducing the cost of farmer's production and alleviating the effects of climate change since a reduction in fertilizer application will lead to the reduction in the release of greenhouse gases. In addition, underutilized legumes can bioremediate the soil and survive in extreme environments owing to the presence of rhizobia and other plant growth promoting microbes in them, which produces or enhances the production of metabolites which makes the environment more conducive for the plants. Equally, underutilized legumes are very high in nutrients, making them a good source of satisfying human nutritional needs. However, underutilized legumes are faced with challenges such as long cooking duration, low demand, anti-nutrient factors etc. Some methods have been reported to tackle these challenges, for instance, organic tenderizers and the use of molecular techniques such as TALENS, ZFNs, etc. has been recommended to reduce the cooking time, antinutrient factors are also reduced through different processing such as dehulling, soaking, etc., also the knowledge of the underutilized legume's health benefit will help to promote their demand. Hence, it is very necessary to carry out more research to unravel the potentials embedded in underutilized legumes and promote their use to improve food security.

Author contributions

MSA managed the literature searches and wrote the manuscript's first draft. OAO, MA, OB, and OO were involved in the conceptualization, reviewing of the drafts and proofreading of the manuscripts. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

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