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Review

A Review on the Potential Food Application of Lima Beans (*Phaseolus lunatus* L.), an Underutilized Crop

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Abstract: The world is facing the global challenges of insecurity, poverty and climate change, which can impede food availability, production and nutritional security. Due to these factors, the production and availability of crop species such as legumes, pulses and cereals are declining, while some are gradually becoming extinct, which affects consumption. To meet global food demands, efforts should be geared towards promoting the cultivation and utilization of underexploited and neglected crops, which have the potential to improve food and nutrition security. However, the exploitation and utilization of crops mostly depend on existing knowledge. Therefore, this review gives an overview of the current knowledge regarding lima beans (*Phaseolus lunatus* L.), an underutilized legume that can serve as a promising potential food crop. While there are some studies on lima beans, they cannot compare to the abundance of studies on other legumes. It is essential to exploit the nutritional and health properties of this crop, as well as to explore processing techniques such as cooking, soaking, fermentation and germination for transforming them into other food forms. Despite the dearth of information on this crop compared to other legumes, there is a case for the promotion of lima beans, especially where there are incessant food shortages, as they will allow for dietary diversity. This is vital considering the vulnerability of world food systems, coupled with an ever-growing population, necessitating a focus on other neglected crops to improve food security.

Keywords: food security; legume; underutilized crop; nutritional benefits

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1. Introduction

Legumes, belonging to the Leguminosae family, also known as Fabaceae, play a significant role in food and nutrition worldwide. The Leguminosae family is large, containing more than 18,000 species of shrubs, herbs, trees, and climbers, of which only a few are used in the human diet. Legumes are also known to be the second-most significant source of food after cereals [1]. Legumes are essential sources of nutrients such as minerals, carbohydrates, vitamins, and dietary fiber, and serve as excellent sources of inexpensive plant proteins, in comparison to animal products [2]. Despite increasing interest in these crops, their application and cultivation is relatively small. According to Popoola et al. [3], legumes are grouped into minor and major species. The minor legumes are considered to be neglected, underutilized, and less exploited, for example, the lima bean, winged bean, marama bean, rice bean and Bambara groundnut. The major legumes such as cowpea, common bean, soybean, chickpea, groundnut and others are known for their well-recognized agronomic practices, cultivation, utilization and domestication [3].

Underutilized and neglected legumes could contribute to enhancing livelihoods in various ways, by diversifying production systems, improving nutrition, guaranteeing food security, establishing new markets, stabilizing ecosystems and providing replacements for crop survival under stress conditions [4]. However, several legumes have been underutilized. One such underutilized legume are lima beans (*Phaseolus lunatus* L.). Lima beans, also known as 'butter beans', are green or white, medium-to-large sized beans [5]. Considering the current challenges to food security we are facing as a planet, exploring

the cultivation, domestication and use of an underutilized legume such as the lima bean could help to ameliorate the current global over-dependence on other legumes such as soybeans and common beans. Such an over-dependence can have a negative ecological, nutritional, economic and agronomic impact. As few scientific reviews exist on lima bean utilization [6–9], this review provides updated information on this crop as a vital, yet underutilized legume crop for improving food and nutrition security. Available literature was sourced from major databases (Scopus, Web of Science and Google Scholar). In addition to providing up-to-date information, this review also describes the nutritional, anti-nutritional and health composition of the crop, an overview of its microstructure, the impact of food processing on these constituents and the utilization of the lima bean for food use.

2. Taxonomy, Origin and Description of Lima Bean

According to Temegne et al. [10], the taxonomic description of the lima bean is as follows: Domain: Eukaryota, Kingdom: Plantae, Phylum: Spermatophyta, Subphylum: Angiospermae, Class: Dicotyledonae, Order: Fabales, Family: Fabaceae, Genus: *Phaseolus*, Species: *Phaseolus lunatus*. The genus *Phaseolus* consists of 50 species, of which only five {*Phaseolus lunatus* L., (lima bean), *Phaseolus acutifolius* A. Gray (tepary bean), *Phaseolus dumosus* Macfad (year bean), *Phaseolus vulgaris* L. (common bean), and *Phaseolus coccineus* L. (scarlet runner bean)} have been domesticated [11]. The lima bean is the second-most agronomically and economically-significant legume species for humans in tropical regions after the common bean [12]. According to Bonita et al. [9], the origin and taxonomy of the lima bean can be confusing. It appears to have originated in the tropical area of Central and South America [13], and after the discovery of the Americas by the Europeans, it rapidly spread into Asia, Europe and Africa as new varieties were selected or evolved [14]. Figure 1 shows the current geographical distribution and concentration of this crop, where it is particularly found in South America, Africa, Asia and Australia. Other geographical records of this crop include Aldabra, the Caribbean, Central America and Comoros Island [15]. Wild forms are only found in other parts of the world [10]. Indigenous names for lima beans include amaijalero (Uganda), bakla, kaisam bali-pati, loba, lobia (India), bonchi, bonchi-kai, dambala, dara-dambala, potu-bonchi (Sri-Lanka), frijol, frijol de lima, frijol de media luna, frijol de monte, frijol de rat, frijolillo (Nicaragua, Mexico), gros pois (Marituis), guaracara (Venezuela), Haricot De Lima (French), haricot de Madagascar, kabaro, kalamaka, konoka (Madagascar), kratok, kacang kara, kekara (Indonesia), haricot de sieva, mange-tout (Rwanda), hereboontjies (South Africa), papala (Nigeria), and tubabu soso (Senegal) [15]. Other common names include Burma bean, broad bean, butter bean, Carolina bean, civet bean, common bean, dwarf bean, frash bean, French bean, garden bean, green bean, haba bean, Hibbert bean, sugar bean, pallar beans, Madagascar bean and guffin bean [15,16].

The lima plant has a hood shape of twinning keels and typical flowers, and it is an annual to perennial growing plant, which can reach about 600 cm in height [10,17]. The crop tolerates warm temperate climates (16–27 °C), a precipitation range of 800–1500 mm and tends to prefer well-drained soil with a pH > 6 [18–20]. The increasing growing habits of wild lima bean species show more variation, with protracted flowering periods as well as the production of larger pods than the domesticated varieties [21]. Their roots are thin and the plants can be up to 2 m in length, while the leaves are trifoliated with egg-shaped leaflets of about 1–11 cm and 3–20 cm in width and height, respectively. [10,22]. The fruits are dehiscent pods (oblong-falcate, large flat with a crescent moon-shape) and can measure up to 12 cm in height, containing between two and four seeds [20,22,23].

The sprouts and young pods of the lima bean may be consumed, but the crops are mostly grown commercially for their seeds [24]. The matured green seeds are utilized as a vegetable for canning, freezing, or fresh market use [14,25]. Seeds vary in terms of color, eye appearance, size, and shape, while their size is usually smaller than that of the common bean (*Phaseolus vulgaris*) [17,26]. The average weight of the seeds is around 146 g, with a thickness of 0.72 cm, a width of 0.8–1.50 cm and a length of 1–15 cm, depending on the cultivar [22,27]. The weight of the seeds is higher than those of other legumes such

as *Phaseolus vulgaris* L. [28], *Phaseolus coccineus* L. var. (purple scarlet runner) [29] and *Vicia fabae* var. (broad bean) [30]. The shapes of the seeds tend to be spherical, curved, or kidney-like. Lima seeds are mostly green or cream in color, although some varieties are speckled and mottled red, black, purple, white, dark or light brown (Figure 2). Lima bean seeds tend to have a remarkably starchy flavor [16].

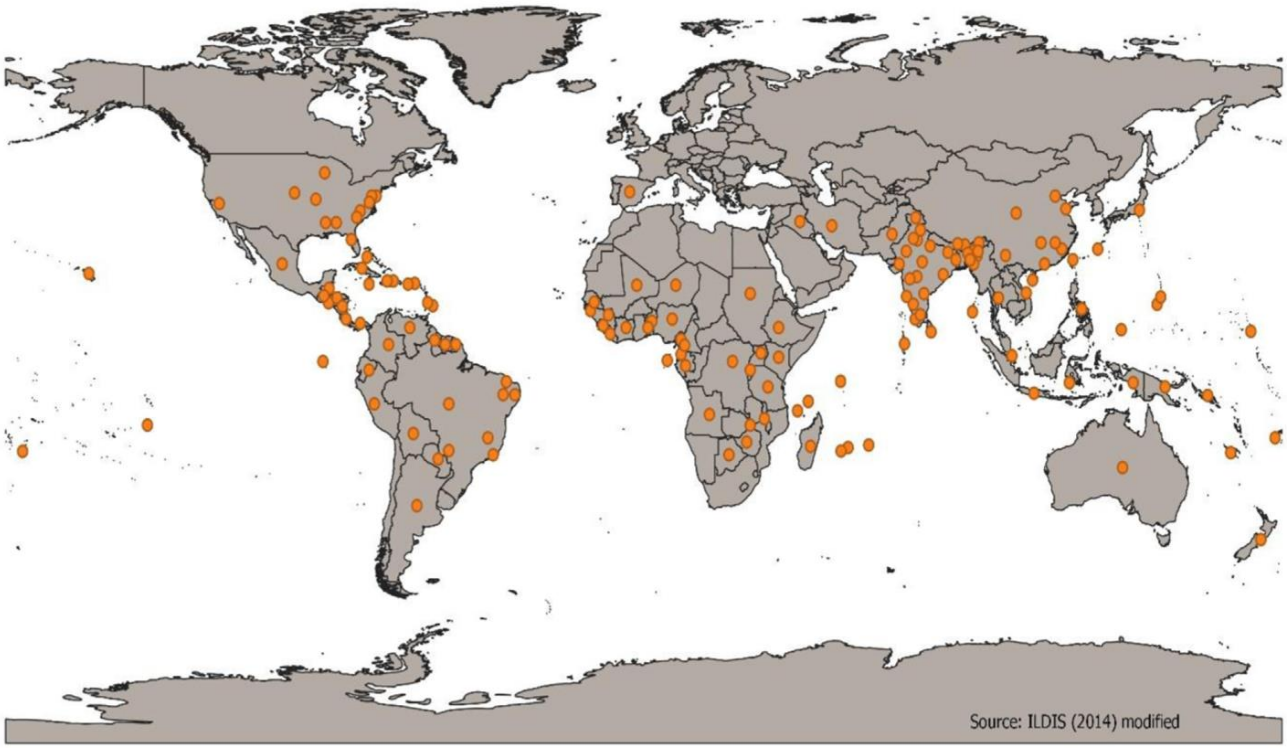


Figure 1. Distribution of lima bean. (Source: [31–34]).



Figure 2. (**A**) Lima bean pods and leaves (**B**) Flower (**C**) Lima bean seeds and pods [10] (**D**) Lima bean seeds variability [35].

Three morphotypes have been distinguished in *Phaseolus lunatus*, namely, the Big lima, which has a big flat seed, the Sieva, which has a medium flat seed, and the Potato, which has small, rounded seeds [36]. Botanical varieties of lima beans identified are the var. lunatus (domesticated types) and var. silvester (wild types); however, it has been posited that only the *Phaseolus lunatus* species name should be retained, as the domesticated and wild groups cannot be strictly differentiated [37]. Domesticated and wild lima beans have been discovered in a wide range of climatic conditions [18,38]. According to genomic data, the wild types are structured into three major gene pools, namely, one Andean (AI) and two Mesoamerican (MI and MII), as well as gene pools with one domestication that occurs in each of them [17,39]. While AI is constrained to southern Ecuador and northern Peru, where these species actually originated, and MI mainly occurs in central-western Mexico, MII is widely more distributed, from southern Mexico and Central America to tropical South America [39,40]. Lima bean seeds are usually planted between April and June and harvested about 5 months later, then stored in silos or, in a kitchen-crop setting, tied and hung up in a kitchen to be dried by smoke [41]. Lima beans adapt well in poor soils, and in areas such as tropical lowland rainforests, where most crops struggle, they tolerate both drought and heat conditions [25,42,43]. They are grown from sea level to above 2000 m elevation. Ideal temperatures range from 16 to 27 °C, and the bean is frost intolerant [25].

3. Nutritional, Anti-Nutritional and Health Beneficial Constituents of Lima Beans

Lima beans have a good nutritional profile and are an excellent source of proteins, amino acids (AA), minerals, dietary fiber and B-complex vitamins (folate, B6 and niacin). An advantage the seeds have over other legumes is their fat-free protein quality [44], There is, however, variation within species in terms of nutritional composition [45,46], which can be attributed to fluctuations in climate and growing stages [36]. Its nutritional composition, such as fat, protein, carbohydrate and ash, ranges from 0.21 to 3.12%, 8.61 to 26.02%, 50.44 to 77.39% and 2.35 to 6.12%, respectively [45–48] (Table 1). The lima bean hulls also have a higher protein content than most cereals [49], which means that lima beans are a good source of dietary protein that can be used to complement other food crops such as cereals.

Table 1. Nutritional composition (%) of lima bean reported in literature.

Protein	Ash	Fat	Fibre	Carbohydrate	Reference
22.24	4.68	1.22	6.85	58.56	Farinde et al. [16]
15.93	3.67	1.15	* 27.87	68.89	Palupi et al. [27]
24.98	4.14	2.03	* 22.72	NR	Granito et al. [45]
23.17	2.78	0.21	* 18.40	71.14	Ezeagu, and Ibegbu [46]
25.91–30.29	3.08–3.41	2.04–2.65	2.57–2.80	61.68–65.61	Seidu et al. [47]
26.02	3.05	3.03	7.12	60.78	El-Gohery [48]
23.8–27.3	3.4–3.6	1.5–2.1	2.4–2.7	53.4–57.3	Giami [50]
24.07	3.40	3.77	5.10	NR	Chel-Guerrero et al. [51]
24.90–25.01	4.31–5.64	2.92–3.05	1.98–2.07	50.44–51.64	Fasoyiro et al. [52]
21.6–24.0	4.3–4.4	1.3–2.3	NR	60.0–63.1	Bello-Perez et al. [53]
24.65–25.55	6.12–6.69	1.60–1.62	4.98–5.00	49.42–52.71	Obiakor [54]
21.20	3.00	1.51	4.20	68.51	Iheanacho [55]
8.61	3.29	2.19	2.00	72.56	Adebayo [56]
20.69–23.08	4.39–5.61	0.59–1.14	4.06–6.86	54.31–59.64	Yellavila et al. [57]
24.6	3.2	2.8	6.8	57.3	Jayalaxmi et al. [58]
19.50	5.12	0.52	4.52	55.06	Adebayo and Okoli [59]
22.72	4.82	1.68	4.27	57.31	Oraka and Okoye [60]
17.53–22.69	3.43–4.94	1.31–1.86	6.24–7.84	50.68–54.92	Chukwunyere and Abtew [61]
23.98–24.76	3.14–3.35	2.78–2.94	5.59–6.09	53.17–54.40	Gemede and Birhanu [62]
26.67	4.1	1.72	5.83	61.68	N'zi et al. [63]
14.23	2.35	3.12	16.05	57.70	Ogungbemi et al. [64]
16.62–22.47	3.51–4.28	1.27–1.72	* 19.21–21.93	72.75–77.39	Sahasakul et al. [65]
24.46	3.37	5.93	2.51	54.43	Oke et al. [66]

* Total dietary fiber; NR- not reported.

In general, lima seeds have two folds of added protein compared to cereals [9,67] and are rich in lysine, an essential amino acid (AA). As reflected in Table 2, lysine levels can range between 4.2 and 101.4 g/100 g. Other notable essential amino acids (which have to be sourced from food as the body cannot produce them) of benefit to humans present in lima beans are phenylalanine (2.8–128.3 g/100 g), leucine (1.42–156.7 g/100 g), valine (0.81–98.3 g/100 g), threonine (0.84–102.7 g/100 g), isoleucine (0.77–90.8 g/100 g) and histidine (0.09–62.4 g/100 g) (Table 2). These AAs are important biological components needed in the human body for biosynthesis, neurotransmission and other metabolic activities, and studies indicate that lima beans are a good source of these components. The amino acid (AA) levels of lima beans are similar to that of cowpea and soybean crops [68]. Levels of essential Aas, such as phenylalanine, arginine and leucine, are higher than the FAO recommended daily allowances (RDA) in lima seeds (Table 2), with the exception of methionine, which is reported to occur in low levels [46,48]. Palupi et al. [27], however, reported an increase in methionine and concluded that methionine is part of the limiting Aas of pulse proteins. This is not unexpected, as low levels of methionine are a common trend in legumes [48]. The few available studies conducted on the AA composition of lima beans (summarized in Table 2) suggest that more research efforts should be geared toward this.

Table 2. Amino acid composition (g/100 g) of lima bean reported in literature.

Ala	Ile	Glu	Arg	Gly	Asp	Lys	Leu	Phe	Val	Met	Tyr	Cys	His	Thr	Pro	Ser	Trp	Reference
75.5	90.8	213.8	135.5	88.5	172.6	101.4	156.7	128.3	98.3	7.8	55.5	1.9	62.4	102.7	73.6	142.4	NR	Palupi et al. [27]
4.34	5.06	14.54	6.42	4.14	12.51	6.42	8.30	6.05	5.58	1.01	4.24	1.25	2.74	4.30	4.90	6.56	1.38	Ezeagu, and Ibegbu [46]
4.15–4.71	4.12–4.55	NR	5.87–6.36	4.22–4.50	NR	6.85–7.25	8.20–8.64	5.63–6.24	4.16–5.11	1.12–1.17	3.21–3.54	0.24–0.54	4.24–5.14	4.36–4.82	4.42–5.13	7.20–7.78	3.21–7.78	Seidu et al. [47]
4.03	4.67	13.64	6.22	4.63	12.94	7.97	9.36	4.14	5.73	1.15	3.68	3.93	3.63	4.87	3.89	5.52	NR	El-Gohery [48]
4.82	3.86	NR	6.37	4.46	NR	7.10	8.65	6.22	4.40	0.81	3.77	0.55	3.08	4.46	2.84	7.97	0.97	Domínguez-Magaña [69]
0.85	0.77	2.14	0.54	0.74	1.89	0.80	1.42	0.91	0.81	0.08	0.21	0.08	0.09	0.84	0.87	1.13	0.02	Palupi et al. [70]
NR	4.2	NR	2.0	NR	NR	4.2	4.8	2.8	4.2	2.2	NR	NR	2.4	2.6	NR	NR	1.4	* RDA [71]

Ala—alanine; Arg—arginine; Asp—Aspartic acid; Cys—cysteine; Glu—glutamic acid; Gly—glycine; His—histidine; Ile—isoleucine; Leu—leucine; Lys—lysine; Met—methionine; Phe—phenylalanine; Pro—proline; Ser—serine; Thr—threonine; Trp—tryptophan; Tyr—tyrosine; Val—valine. ND—not detected; NR—not reported. * RDA Source [71].

As shown in Table 1, lima beans are low in fat but contain substantial amounts of linoleic acids [72]. They are also free from cholesterol, which is crucial in terms of dietary recommendations. Lima beans have moderately high carbohydrate levels (50.44–77.39%, Table 1), and so the bean could be used to produce starch and its byproducts. As documented in previous studies [27,45,53], starch is the major carbohydrate component of lima beans, constituting between 37 and 41.96%. As observed on scanning electron microscopy, the starch granules are reported to have oval, heterogeneous and spherical shapes (Figure 3A,B) [73,74], with small pores near the granule's equatorial region (Figure 3A). However, a study by Okekunle et al. [74] indicated that lima bean starch showed no evidence of pores or fissures in the different varieties investigated (Figure 3B).

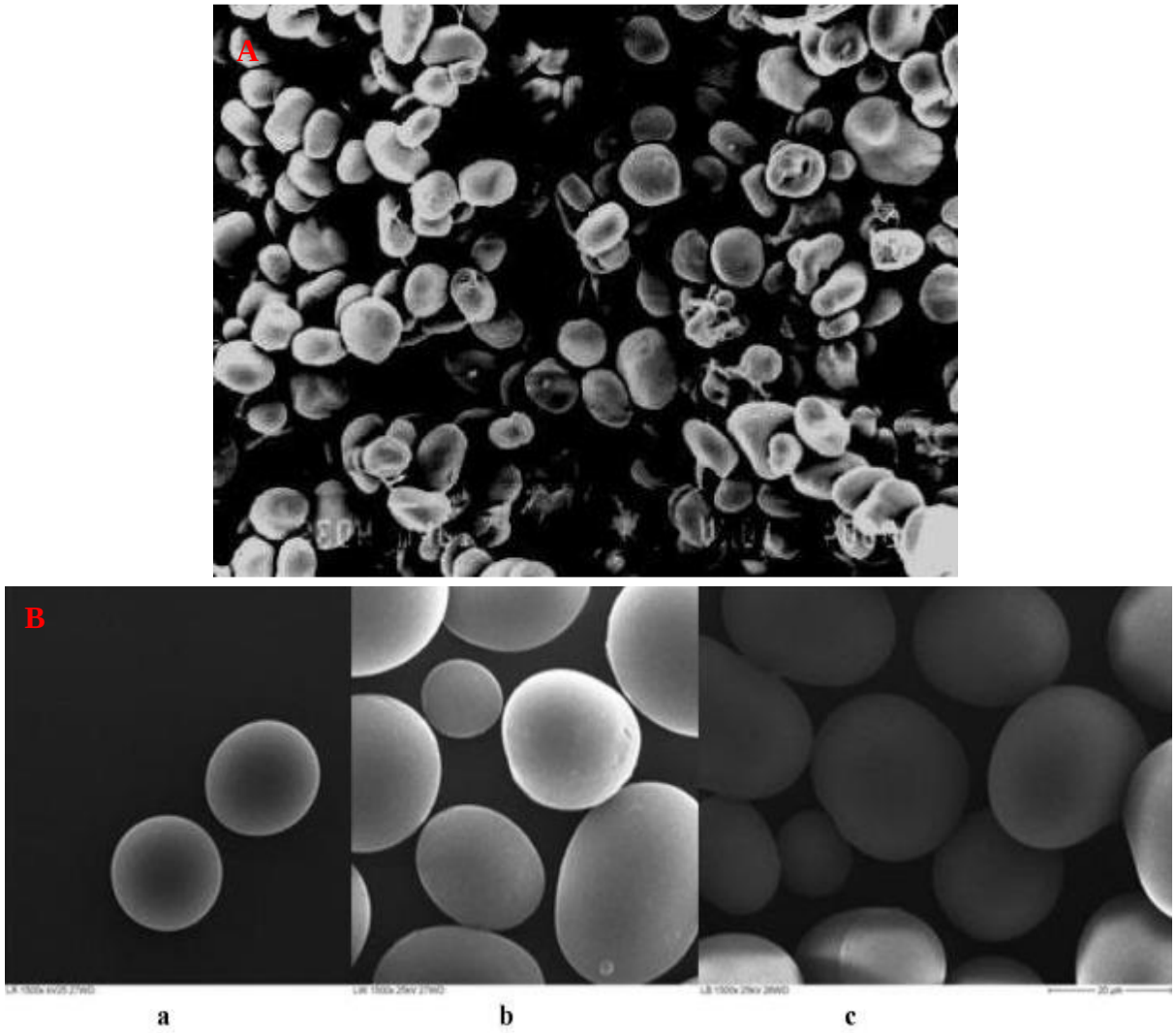


Figure 3. (**A**): Scanning electron microscope of lima bean starch at 200× magnification [73]. (**B**): Scanning electron microscope of lima bean starches at 1500× magnification (**a**) red native starch (**b**) white native starch (**c**) brown native starch [74].

Lima beans are a source of dietary fiber, as the grain consists of insoluble and soluble dietary fractions. Like other legumes, the seeds are rich in vitamins including niacin, riboflavin and thiamin [75]. The varying levels of minerals in the lima bean (Table 3) show high levels of calcium, iron, zinc, phosphorus and potassium. These are minerals known to assist with muscle movement, keeping the nervous system healthy, and building strong bones and teeth. High levels of potassium and phosphorus in lima beans, with levels up to

1181.7 and 4080 mg/100 g, respectively, suggest that the lima bean is a food source that can provide the body with these essential food components.

Table 3. Mineral composition (mg/100 g) of lima beans reported in literature.

Sodium	Magnesium	Potassium	Calcium	Phosphorus	Iron	Manganese	Copper	Zinc	Reference
110.22	312.12	986.90	225.10	295.28	8.70	NR	NR	4.50	Farinde et al. [16]
NR	183.93	38.21	11.04	74.95	10.19	NR	NR	NR	Palupi et al. [27]
NR	266.84	1881.70	158.76	NR	11.98	NR	NR	4.18	Granito et al. [45]
182.4	111.5	817.4	95.3	ND	3.20	3.26	1.03	3.29	Ezeagu, and Ibegbu [46]
7.53–80.73	30.15–67.13	7.53–360.80	11.13–20.14	11.50–17.20	11.30–18.17	0.13–0.18	0.26–0.82	2.24–3.13	Seidu et al. [47]
53.87	268.04	1373.29	360.73	355.63	18.54	1.07	1.74	4.17	El-Gohery [48]
NR	NR	NR	NR	NR	6.7–7.5	NR	NR	NR	Giami [50]
40–50	NR	140–300	200–380	260–340	2–4	NR	NR	NR	Fasoyiro et al. [52]
NR	NR	NR	NR	83.00–85.00	85.64–87.33	NR	12.17–13.73	4.17–4.18	Obiakor [54]
3980	7019.99	4920	3910	4080	NR	NR	NR	NR	Adebayo [56]
19.99–21.33	NR	50.04–52.08	NR	154.98–172.77	2.45–2.67	NR	NR	NR	Yellavila et al. [57]
27	123.10	1295.13	326.46	153.36	5.40	2.63	4.30	2.64	Jayalaxmi et al. [58]
285.10	148.75	390.65	471.35	486.28	4.71	6.83	4.62	2.62	Adebayo and Okoli [59]
51.66–60.66	19.88–37.27	32.39–37.03	68.67–81.15	4.30–10.98	91.62–128.47	NR	NR	5.91–9.47	Gemede and Birhanu [62]
14.74	137.13	1425.90	101.11	503.97	11.75	NR	2.78	4.97	N'zi et al. [63]
248.31	NR	212.24	310.22	NR	234.01	170.35	NR	NR	Ogungbemi et al. [64]
19.59–33.34	115.46–138.76	990.13–1375.48	86.40–100.47	NR	4.12–4.75	NR	NR	1.93–2.05	Sahasakul et al. [65]
73.62	195.33	136.76	234.72	184.29	3.24	NR	NR	NR	Oraka and Okoye [76]
0.43	0.26	0.69	0.35	0.98	0.02	ND	0.000331	0.01	Adeparusi [77]
9.5	115.5	1629.6	351.7	579.6	6.1	NR	NR	NR	Bolade et al. [78]

ND–not detected; NR–not reported.

Generally, legumes are consumed with their hulls, which conserves the micronutrient content, unlike most cereals which are polished before being consumed [79]. However, high levels of minerals do not necessarily mean a corresponding high bioavailability [80]. Regrettably, despite a high nutritional content, the lima bean also contains antinutrients such as lectins (particularly phytohaemagglutinins), tannins, trypsin inhibitors, thioglucosides, oxalate and cyanide-producing glucosides, which inhibit the absorption and utilization of essential minerals and decrease the nutritive component of foods, protein digestibility and can cause deleterious effects.

Also known as anti-nutritional factors (ANFs), antinutrients are found in all legumes and act as metabolic functions, while the consequences in the body can be negative, positive, or both [78,81]. According to Gemede and Ratta [82], protease inhibitors reduce the digestion of protein, phytates reduce the absorption of iron and calcium, phytohaemagglutinins prevent the absorption and digestion of end products in the small intestine, oxalates encourage the formation of kidney stones and reduce the absorption of calcium, while cyanide inhibits respiration. Maturity stage, cultivars, agroecology, and environmental conditions are some of the parameters that affect ANF content. Anti-nutritional factors, such as phytohaemagglutinin, trypsin inhibitor, tannins, oxalate and phytic acids have been reported to be present in lima beans (Table 4) [46,54,83]. Levels of phytic acids, tannins, trypsin inhibitor, oxalate and hydrogen cyanide reported in lima beans range from 0.02 to 47.2 mg/g, 0.01 to 78.9 mg/g, 3.4 to 184.1 Tiu/mL, 0.01 to 5.42 mg/g and 0.01 to 5.68 mg/g (Table 4) [46,52,54,83,84]. Consuming raw or inadequately processed lima beans, as with any other legume, is believed to cause countless detrimental effects. Elimination or deactivation of ANFs will enhance the nutritional quality of lima beans and increase their acceptance and application as a valuable food [48]. Most of these ANFs can be reduced or removed completely by using different processing methods such as fermentation, dehulling, cooking and soaking.

Table 4. Anti-nutritional factors (mg/g) of lima beans reported in literature.

Tannin	Phytic Acid	Oxalate	Trypsin Inhibitor Activity (Tiu/mL)	HCN	Hemagglutinin (HU/g)	Protease Inhibitor	Saponin	Alkaloid	Lectin	Reference
0.10	1.41	0.01	24.82	0.08	NR	NR	NR	NR	0.01	Farinde et al. [16]
NR	11.57	NR	36.07	0.03	NR	NR	16.84	NR	NR	Palupi et al. [27]
NR	0.08	0.69	29.7 (Tiu/mg)	NR	NR	NR	NR	NR	NR	Ezeagu, and Ibegbu [46]
5.58	8.57	NR	4.28 (mg/g)	NR	NR	NR	NR	NR	NR	El-Gohery [48]
4.99	4.15	5.42	NR	NR	NR	NR	NR	NR	NR	Adebayo [56]
59.2–78.9	36.7–47.2	NR	20.40–26.98 (Tiu/mg)	NR	NR	NR	NR	NR	NR	Fasoyiro et al. [52]
0.1	3.36	0.13	16.5 (TIU/100 g)	NR	NR	NR	0.26	NR	NR	Jayalaxmi et al. [58]
0.29–1.16	0.91–1.11	0.04–0.05	NR	NR	NR	NR	NR	NR	NR	Gemede and Birhanu [62]
0.72	0.66	2.27	NR	0.10	NR	NR	NR	NR	NR	N'zi et al. [63]
1.39	0.19	NR	NR	NR	NR	NR	0.45	NR	NR	Ogungbemi et al. [64]
0.02	8.6	NR	29.3	0.05	61.4	NR	NR	NR	NR	Bolade et al. [78]
0.59	2.34	NR	3.4	0.42	NR	NR	NR	NR	NR	Egbe and Akinyele [83]
9.8	6.5	2.7	184.1	NR	NR	NR	162.9	12.3	NR	Oraka and Okoye [76]
0.01	0.02	1.61	NR	5.68	NR	NR	15	NR	NR	Adegbehingbe, [84]
NR	10.36	NR	NR	0.01	NR	NR	NR	NR	NR	Palupi et al. [70]
0.34	26.48	3.22	NR	NR	NR	NR	38	23	NR	Adegbehingbe, and Daramola [85]
0.11	0.22	NR	NR	NR	NR	0.04	NR	NR	NR	Oke et al. [66]
0.02	0.03	NR	28.36	0.01	NR	NR	NR	NR	NR	Adeniran et al. [86]

NR–not reported.

The nutritional composition of dry beans such as lima beans can provide health benefits in a way that few other foods can match [80]. Lima beans can be used to maintain the function of the digestive system, including in diverticulosis and irritable bowel syndrome [87]. It also contains insoluble fiber, which prevents constipation and improves stool bulk. Lima beans have also been reported to promote cardiovascular health, control blood sugar levels due to its low glycemic index, manage blood glucose and reduce cholesterol, as it is rich in fibre [61,88,89]. According to Ezeagu and Ibegbu [46], lima beans are reported to contain trace amounts of isoflavones (daidzein and genisten) which can assist in preventing breast and colon cancer. Studies have also shown that lima bean seeds have lunatusin (a 7 kDa peptide) which has shown inhibited proliferation in the breast cancer cell line MCF-7 [90]; lectins in lima beans have also been described to have anticancer activities [9]. Lima beans also help to replenish iron stores [54]. This can be beneficial to children, adolescents and women, especially during a menstrual period, when many women are iron deficient. A diet high in lima beans can assist with menstrual iron deficiency, as iron is an integral element of hemoglobin, as well as a part of the main enzyme system for energy metabolism and production [54]. Studies have also indicated the presence of gastroprotective, antimicrobial, antioxidant, antiviral and antihypertensive activities in lima beans [91–94].

4. Impacts of Certain Processing Methods on the Nutritional, Anti-Nutritional Profile and Techno-Functional Properties of the Lima Bean

Prior to consumption, the lima bean has to undergo food processing to improve its palatability and make it edible. Lima beans can also be utilized as a functional ingredient to enhance the dietary value of other foods. As with other legumes, lima beans can be prepared using different processing methods [95]. Some of these traditional processing methods (such as cooking, soaking, fermentation, and germination) will be briefly discussed with regard to their impact on the nutritional composition, ANFs and the techno-functional properties of the lima bean.

4.1. Soaking

According to Uwaegbute and Nnanyelugo [96], soaking reduces the levels of surface contaminants and toxic substances through the leaching of these undesirable constituents into the soaking medium. Soaking the seeds before cooking can also be used to moisten and soften the cotyledon and lower the cooking time. During the soaking process, water disperses into the starch granules and protein fractions, which enables the subsequent gelatinization of starch and protein denaturation during further processes, softening the bean texture [97]. The conditions to be considered when soaking lima bean seeds are temperature, time, pH, and type of media/solution (water is a common medium).

Soaking lima bean seeds in water for 24 h has been reported to cause a reduction in phytates, tannins, oxalates, saponins and trypsin inhibitors [58]. The loss in phytase may be attributed to the leaching of phytase ions into the soaking water due to variances in the chemical potential, which controls the diffusion rate [98,99]. Tannin reduction during soaking, on the other hand, has been linked to the leaching of polyphenols into the soaked bean water [100]. However, a study by Adebayo [56] on the effect of soaking time (12–48 h) on the proximate compositions of lima beans, showed no significant differences in the protein and ash of soaked and unsoaked lima beans. All the reported minerals (potassium, sodium, calcium, phosphorus and magnesium) in the study increased upon soaking, and this might be equated to the reduction in the ANFs with an increase in soaking time [56].

4.2. Dehulling

The hull or seed coat of legumes has a bitter taste and is indigestible, and so legumes are sometimes dehulled of their seed coat to improve the taste. Dehulling is also used to reduce cooking time, as the seed coat impedes water uptake during cooking [101]. A comparison of the nutritional composition of undehulled and dehulled lima seed flours showed that carbohydrates, crude fiber, ash and protein contents were lower in the dehulled sample, while crude fat was higher in the undehulled sample [41]. The authors of this study concluded that the obtained values for fat were acceptable because lima beans have a low-fat content [41]. They also found that functional properties (oil absorption, foam and emulsion capacity) were higher in the dehulled lima bean, while bulk density and water absorption capacity were lower in the dehulled sample [41].

According to another study, the protein content of the dehulled lima bean is lower than that of the undehulled sample. This could be attributed to the numerous distributions of protein within some legumes, as proteins in legumes can be spread across the endosperm, hulls, or bran [102]. A further study found that the fiber and fat content of undehulled lima bean samples were higher than those of a dehulled Christmas lima bean sample [102]. This indicates that dehulling lima bean seeds could reduce the fat content. The reduction in fat during dehulling can be linked to the leaching out of oil or fat molecules from the cotyledons [103].

The ash and carbohydrate contents of undehulled lima beans appear to have no significant difference from dehulled lima beans [103]. In a study, dehulled samples had lower viscosity, swelling index, and oil and water absorption capacity than the undehulled samples. Low water absorption capacity could be due to the lower availability of polar amino acids [104]. The low oil absorption capacity may be attributed to the large proportion of polar (hydrophilic) amino acids on the protein molecule's surface [104,105]. Dehulling increased the gelation capacity of dehulled samples in studies, and this may be linked to the higher protein content reported in dehulled samples as well as seed coat removal [103].

4.3. Cooking, Roasting and Autoclaving

Cooking is one of the oldest methods used for making food edible prior to consumption. Generally, legumes are subjected to three different types of cooking, namely, pressure-cooking, ordinary cooking and microwave cooking. Nutrients, convenience, texture, flavor, safety, and cost are factors that consumers take into consideration when choosing food for cooking at home, with flavor being the most significant factor [106–108]. The effects of

cooking on nutritional composition and ANF have been reported to lower the iron, copper and zinc content of lima beans [109]. Egbe and Akinyele [83] investigated the effect of cooking time (60–160 min) on the ANFs of lima beans and reported that the conventional method of preparing meals, which includes discarding and changing the cooking water several times, may decrease the level of ANFs, particularly HCN, and increase the nutrient digestibility of this legume. Cooking was also reported to have reduced the protein, ash, fiber and fat contents in lima beans, but increased the carbohydrate content [59].

A study comparing different heat treatments (boiling, roasting and autoclaving) determined that the crude protein, ash, fiber and fat contents of lima bean flours were significantly lower in boiled and autoclaved samples compared to roasted samples [60]. Tests on the ANFs of the flours showed that levels of trypsin inhibitors, saponins, oxalates, alkaloids, tannins and phytates were reduced significantly during autoclaving and boiling treatments compared to the roasting sample. Likewise, the saponin content was moderately higher in boiled samples compared to roasted and autoclaved samples [60]. Functional properties such as the solubility index, foam capacity, bulk density, swelling capacity, and water and oil absorption capacity were higher in roasted flours than in boiled and autoclaved samples [76]. Flours with a better water absorption capacity would be more appropriate for use in the preparation of baby or complementary foods [76]. In a similar manner, flours with a good foam capacity are required for the preparation of salad dressings and whipped cream [76]. A study on the effect of different processing methods (roasting cooking, soaking, germination, autoclaving and decortication) showed that all the processing methods were effective in reducing antinutrients and improving the nutritional value of lima beans, thus increasing its benefit in foods and food formulations [58].

4.4. Fermentation

Fermentation is a traditional food processing technique that improves the nutritional content of foods through the biosynthesis of essential amino acids, and vitamins, and through antinutrient degradation [63,110,111]. A decline in the protein content of lima bean flour, however, was reported by N'zi et al. [63], with authors attributing this to an increase in the catabolism of the protein matrix by microorganisms during fermentation. The same authors ascribed fat reduction during the fermentation of the bean to the hydrolysis of lipids by lipases, which are produced by fermenting microorganisms [63]. The fermentation of lima beans also has a decreasing effect on iron, copper, calcium and phosphorus, possibly linked to the reduction in phytate, tannins and HCN [54,63].

In a study, ground lima beans were fermented with starter cultures (*Rhizopus stolonifera*, *Saccharomyces cerevisiae* and *Aspergillus fumigatus*), and their nutritional and anti-nutritional compositions were investigated [84]. Significant reductions were seen in all the anti-nutritional factors (oxalate, saponin, phytic acid, tannin, and cyanide) of the starter culture fermented samples over the naturally fermented samples [84]. Significant reductions in anti-nutrients in the starter culture-fermented samples indicate that the fungi *Rhizopus stolonifera*, *Saccharomyces cerevisiae* and *Aspergillus fumigatus* were liable for these reductions [84]. Variations in the mineral contents of the starter cultures and naturally fermented samples were observed, but these were significantly lower than in the raw samples. The starter culture-fermented samples contained high fat, ash and protein contents, and low carbohydrate and crude fiber, over the naturally fermented samples [84].

The reported decrease in carbohydrate and crude fiber contents of starter culture-fermented samples over the naturally fermented samples could be attributed to the secretion of extracellular enzymes, for example, hemicellulases ligninases and cellulases by the fungi [112] These fungi are able to hydrolyze carbohydrates and crude fiber into simple sugars, while the organisms could be used as a carbon source to convert them to other macromolecules such as fats and proteins [113]. The substantial quantity of ash content in the starter culture fermented sample over the naturally fermented sample could indicate that these fungi might have played unique roles through hydrolytic or biosynthetic mechanisms to enhance the inorganic mineral elements in the samples [84].

4.5. Germination

Germination has been defined as a controlled bioprocessing step, normally adopted to alter inherent food grain composition for desirable characteristics, including the biosynthesis of health-promoting compounds [114]. During this process, the inherent physical attributes of protein, including its composition, structure, conformation and amino acid sequence, are affected and have been linked to an increase in the protein content of the germinated lima bean, noted in a study conducted by Adebayo and Okoli [59]. The changes or mechanisms occurring during the fermentation or germination of lima beans have been determined to be similar, with slight modifications in their mechanisms.

According to Farinde et al. [16], a reduction in fat, protein, fiber and ash was observed in lima beans after germination, with an increase in the carbohydrate content. However, compared to other food processing methods (roasting, fermentation, cooking), germination produces the lowest carbohydrate content [16]. The high carbohydrate content in the processed lima bean samples could be due to processing methods that soften the cellulose, causing starch granules to break down and make the starch readily available [115]. The lower carbohydrate content in germinated samples might be due to the breaking down of carbohydrates in the seed into simple sugars as the embryo is the bean's major energy source for growth [16].

The minerals zinc, sodium, phosphorous, iron, calcium, potassium and magnesium increase with germination [16]. Likewise, all the processing methods discussed, including germination, significantly reduce the antinutrient content in lima beans. Tannins and other polyphenols in legumes may be lessened during germination, and this could be a result of the formation of polyphenol complexes with proteins, and gradual oligosaccharide degradation [116]. Germination is reported to have the lowest reduction effect (among tested processing methods) on trypsin inhibitors in the lima bean. This gives an indication that heat treatment, specifically moist heat, is more efficient at reducing trypsin inhibitors to acceptable minimal levels [16]. It should be noted that these processing methods can be combined or used singly during the preparation of lima beans.

4.6. Drying

Matured lima beans are usually processed into dried form through an open sun drying method [117]. Although the sun drying method is easy and cheap, it can be subjected to several environmental disruptions such as rain, dust, birds, insects and so on [117]. Lima beans also reduce in quality due to solar radiation [117]. To overcome such disadvantages, a controlled, closed environment should be used. Some food industries use mechanical dryers powered by either excessive electrical energy or fossil fuels to dry lima beans, which has resulted in the development of solar dryers.

The drying behavior of lima beans was investigated in a study comparing recirculatory, vacuum and tray dryers [118]. Drying behavior is a function of temperature and time. The beans, when dried in tray, recirculatory and vacuum dryers, took 220, 265 and 300 min, respectively, to dry in ranges of 40 to 80 °C. Drying at 80 °C using recirculatory dryers was determined to be the most appropriate method for drying lima beans [118].

5. Utilization of Lima Bean

In comparison to other legumes, lima beans are an underutilized crop, and this could perhaps be associated with a relatively low awareness of the nutritional and health potentials of the crop and the best preparation methods. Lima beans are commercially grown for their tender green pods, which are used as green vegetables, and are used dried as a pulse, and, due to their subtle flavor, have broad applications in different dishes [119]. Conventionally, the beans are usually cooked before consumption and can be eaten fresh, fried, boiled, canned, frozen, baked, dried, or roasted [7,120]. Dishes include salads, casseroles, soups and stews [119] (Figure 4).

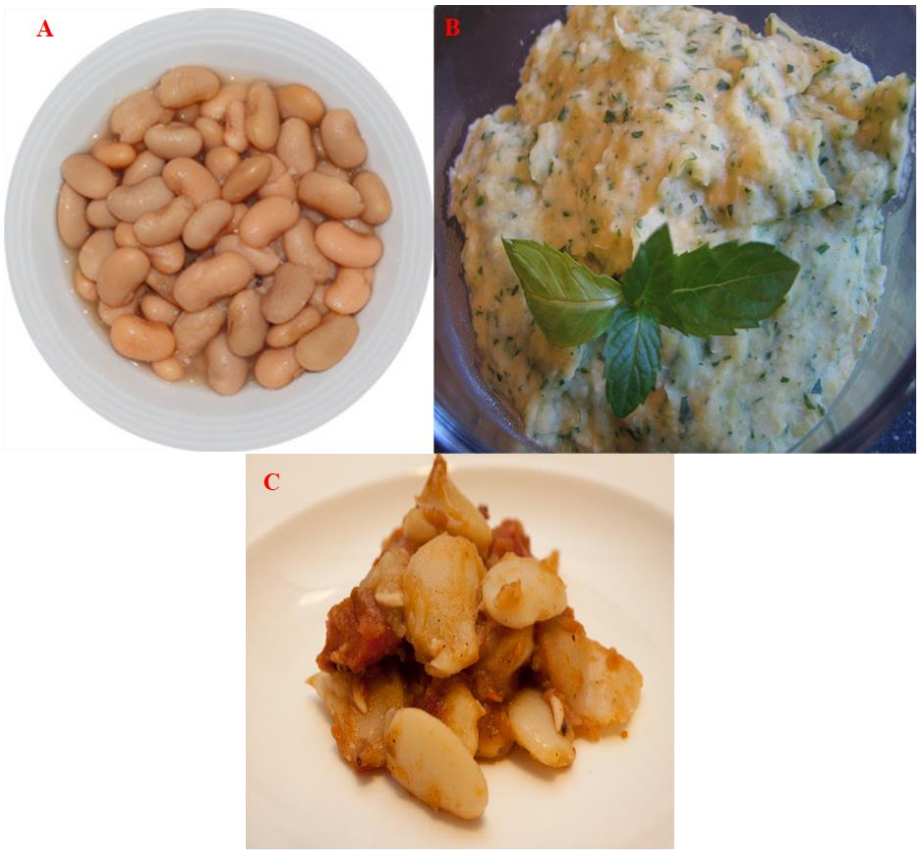


Figure 4. Foods from lima beans (**A**) Canned lima bean [5] (**B**) Lima beans dip [121] (**C**) Baked lima beans [122].

The bean also has medicinal applications [123] and could be eaten in combination with other crops such as roots, tubers and cereals [109,124]. It can be mixed with cereals such as sorghum to produce bread [125], with maize to produce blend extrudate [126] and can be processed into flour [56]. Lima beans can be used as a thickener in soups [25], to produce biscuits [48], moi-moi [54], succotash [119], protein isolate [51] and protein fractions. These are promising food ingredients, particularly once their functionalities have been determined [127]. Native or oxidized starches can also be produced from lima beans, and these might be of great assistance in the food industries in meeting an increasing demand for starch [74]. Lima beans show promising potential in the fortification of traditional weaning and adult foods [124]. The bean has also been used as a substitute during the production of '*daddawa*' (a Nigerian fermented condiment) [86,128].

According to Lim [25], lima bean leaves and young pods are sometimes consumed in Malawi and Ghana as they have a bitter taste. The Yoruba tribe in Nigeria processes the seeds into cakes, porridge and puddings, while the Japanese cook the dry seeds as "*nimame*" (a boiled bean sweetened with sugar). In Java, lima beans are regularly eaten as a side dish with rice, and the young pods are cooked or steamed [25]. Lima beans also have other uses apart from their utilization in food. The leaves and stems can be turned into hay or silage, it may be planted as a green manure and cover crop and the crop is sometimes used as fodder. However, use in its raw form may lead to hydrogen cyanide poisoning [25]. The lima seeds are difficult to cook, particularly after they have been stored for a long-time, and contain toxic elements known as cyanogenic glycosides, which are the major limitations of cultivation and utilization. However, the commercialization of agricultural products such as lima beans is an important process in increasing food security and improving nutrition and crop productivity and reducing poverty [129,130]. The commercialization of lima beans into value-added products will further improve the livelihood of farmers and assist household consumers and food industries in dietary diversification.

6. Conclusions

A review of the overall nutritional quality and the anti-nutritional factors from various studies on lima beans shows that there is an untapped potential regarding its domestication and utilization. Lima beans have been found to be a good source of protein, fiber and carbohydrates, and provide energy, essential minerals and balanced essential amino acids which could be useful during food formulation. Lima beans also have certain antinutrients that could affect the body, either positively or negatively. The potential health benefits encourage the promotion of lima beans in our diet to take advantage of its components, which are nutritious and promote health. However, it is recommended that for the successful utilization of this bean, further detailed analyses of its overall components should be considered, including the techno-functional properties, in order to increase our depth of understanding. Studies should also be geared toward the domestication, development, application, processing and preservation of lima beans, particularly into value-added products that would boost the economy and help solve food insecurity challenges. Further research using in vivo studies could uncover more beneficial effects of lima beans for human health.

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