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The Role of Legumes in Human Nutrition

Yvonne Maphosa and Victoria A. Jideani

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Abstract

Legumes are valued worldwide as a sustainable and inexpensive meat alternative and are considered the second most important food source after cereals. Legumes are nutritionally valuable, providing proteins (20–45%) with essential amino acids, complex carbohydrates ($\pm 60\%$) and dietary fibre (5–37%). Legumes also have no cholesterol and are generally low in fat, with $\pm 5\%$ energy from fat, with the exception of peanuts ($\pm 45\%$), chickpeas ($\pm 15\%$) and soybeans ($\pm 47\%$) and provide essential minerals and vitamins. In addition to their nutritional superiority, legumes have also been ascribed economical, cultural, physiological and medicinal roles owing to their possession of beneficial bioactive compounds. Research has shown that most of the bioactive compounds in legumes possess antioxidant properties, which play a role in the prevention of some cancers, heart diseases, osteoporosis and other degenerative diseases. Because of their composition, legumes are attractive to health conscious consumers, celiac and diabetic patients as well as consumers concerned with weight management. The incorporation of legumes in diets, especially in developing countries, could play a major role in eradicating protein-energy malnutrition especially in developing Afro-Asian countries. Legumes could be a base for the development of many functional foods to promote human health.

Keywords: legumes, nutrition, bioactive compounds, food security, proteins, micronutrients, malnutrition

1. Introduction

Legumes are plants belonging to the family Leguminosae also called as Fabaceae that produce seeds within a pod [1, 2]. Leguminosae is a large family with over 18,000 species of climbers, herbs, shrubs and trees of which only a limited number is used as human food. Common legumes used for human consumption include peas, broad beans, lentils, soybeans, lupins, lotus, sprouts, mung bean, green beans and peanuts and are referred to as grain legumes or food legumes [3, 4]. A variety of legumes are shown in **Figure 1**.



Figure 1. A variety of legumes [5].

Food legumes are divided into two groups, namely oil seeds and pulses. The former being legumes with high oil content such as soybean and peanuts and the latter being all dry seeds of cultivated legumes used as traditional food [4]. The Food and Agriculture Organisation of the United Nations [5] recognises 11 primary leguminous classes (**Table 1**). Legumes are believed to be one of the first crops cultivated by mankind and have remained a staple food for many cultures all over the world [2]. These seeds are valued worldwide as an inexpensive meat alternative and are considered the second most important food source after cereals [2]. Legumes are nutritionally valuable, providing proteins with essential amino acids, complex carbohydrates, dietary fibre, unsaturated fats, vitamins and essential minerals for the human diet [6–8]. In addition to their nutritional superiority, legumes have also been ascribed economical, cultural, physiological and medicinal roles owing to their possession of beneficial bioactive compounds [9].

The consumption of legumes has also been reported to be associated with numerous beneficial health attributes [10] such as hypocholesterolemic, antiatherogenic, anticarcinogenic and hypoglycemic properties [11].

Legumes have proven to be a cheap source of nutrients as well as a potential source of income for subsistence farmers who cultivate legumes at household level. They are excellent crops for

	Class	Examples of legumes
1	Dry beans (mainly species of <i>Phaseolus</i> and some beans classified as <i>Vigna</i>)	Kidney, haricot bean (<i>Ph. vulgaris</i>), lima, butter bean (<i>Ph. lunatus</i>), adzuki bean (<i>Ph. angularis</i>), mungo bean, golden, green gram (<i>Ph. aureus</i>), black gram, urd (<i>Ph. mungo</i>), scarlet runner bean (<i>Ph. coccineus</i>), rice bean (<i>Ph. calcaratus</i>), moth bean (<i>Ph. aconitifolius</i>), tepary bean (<i>Ph. acutifolius</i>)
2	Dry broad beans (<i>Vicia faba</i>)	Horse-bean (<i>Vicia faba equina</i>), broad bean (<i>Vicia faba major</i>), field bean (<i>Vicia faba minor</i>)
3	Dry peas (<i>Pisum spp.</i>)	Garden pea (<i>Pisum sativum</i>), field pea (<i>P. arvense</i>)
4	Chickpeas	Chickpea, Bengal gram, garbanzos (<i>Cicer arietinum</i>)
5	Dry cow peas	Cowpea, blackeye pea/bean (<i>Vigna sinensis</i> ; <i>Dolichos sinensis</i>)
6	Pigeon peas	Pigeon pea, cajan pea, Congo bean (<i>Cajanus cajan</i>)
7	Lentils	Lentils (<i>Lens culinaris</i>)
8	Bambara beans	Bambara groundnut (<i>Vigna subterranean</i> (L.) Verdc), earth pea (<i>Voandzeia subterranea</i>)
9	Vetches (<i>Vicia sativa</i>)	Spring/common vetch
10	Lupins (<i>Lupinus spp.</i>)	Bitter lupin, sweet lupin
11	Minor pulses (Legumes not identified separately due to their minor relevance at international level)	lablab or hyacinth bean (<i>Dolichos spp.</i>), jack/sword bean (<i>Canavalia spp.</i>), winged bean (<i>Psophocarpus tetragonolobus</i>), guar bean (<i>Cyamopsis tetragonoloba</i>), velvet bean (<i>Stizolobium spp.</i>), yam bean (<i>Pachyrrhizus erosus</i>)

Table 1. Classification of legumes.

local farmers that do not afford expensive irrigation systems and fertilisers. This is because legumes thrive in poor soils and adverse weather conditions, are highly disease and pest resistant, are cover crops; therefore, reduce soil erosion and have a symbiotic relationship with the nitrogen-fixing rhizopus resident in their root nodules, thus making them excellent rotation crops [12, 13].

It is of utmost importance to increase the utilisation of legumes and to introduce new legume-based products that will be affordable to low-income groups as a way to reduce poverty and alleviate malnutrition. Protein-energy malnutrition (PEM) is a major nutritional syndrome affecting over 170 million preschool children and lactating women in developing African and Asian countries [1, 12, 14]. The prevalence of PEM can be attributed to many factors such as the high price of animal protein (eggs, meat and milk), the staple cereal-based diet and the ever increasing price of food commodities becoming unaffordable to the lower income groups. Although, high protein legumes such as soybean and cowpea are available to consumers, their consumption rate surpasses their production rate; thus, an ever increasing demand has been observed [12]

The nutritional demand of legumes is increasing worldwide because of increased consumer awareness of their nutritional and health benefits. Furthermore, recent years have seen more people substituting animal protein with vegetable protein; thus, further increasing the demand for legumes as they are the chief source of plant proteins. To meet this demand,

there is a need to direct attention to the nutritional profiling of various legumes, increase the utilisation of underutilised legumes, produce cheap, innovative value-added products from legumes, educate consumers on the nutritional value of legumes as well as find new ways of encouraging the use of existing legumes. **Figure 2** shows a comparison of the proximate composition of five common cereal grains and five common legumes. From the graph, it is evident that legumes have higher amounts of protein and dietary fibre than cereals.

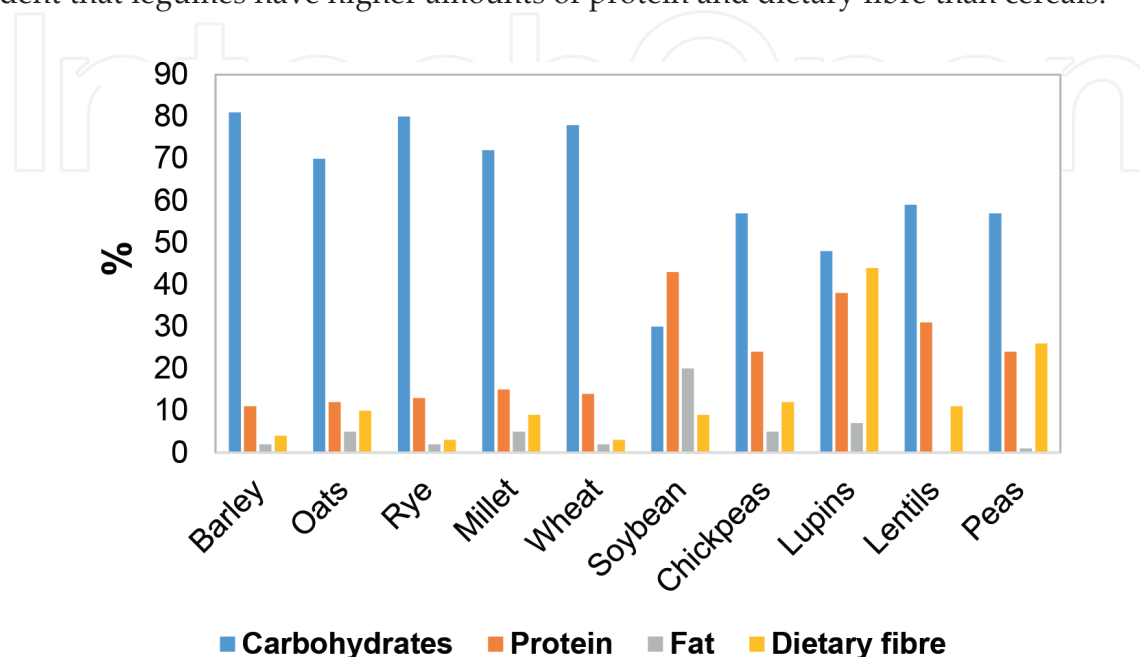


Figure 2. A comparison of the proximate composition of some common cereal grains and legumes [15, 16].

2. Protein content of legumes

Legumes are an excellent source of good quality protein with 20–45% protein that is generally rich in the essential amino acid lysine [9]. Peas and beans are on the lower side of the range with 17–20% proteins while lupins and soybeans are on the higher end of the range with 38–45% protein [2, 15]. Legumes have higher protein content than most plant foods with about twice the protein content of cereals (**Figure 2**) [2, 17, 18]. The high protein content of legumes can be attributed to their association with the activity of the nitrogen-fixing bacteria in their roots, which converts the unusable nitrogen gas into ammonium which the plant then incorporates into protein synthesis.

Leguminous proteins, except soy protein (**Table 2**), are however low in the essential sulphur-containing amino acids (SCAA), methionine, cystine and cysteine as well as in tryptophan (**Table 2**) and are therefore considered to be an incomplete source of protein [2]. The main fractions of leguminous protein are albumins and globulins which can be divided into two groups, namely vialin and legumin. Vialin is the major protein group in most legumes and is characterised by a low content of SCAA, thus explaining the low levels of SCAA in legumes [18]. The low level of SCAA in legumes is not completely a negative factor as it results in increased calcium retention. Hydrogen ions produced from the breakdown of SCAA cause the demineralisation of the bone and thus excretion of calcium in the urine. Therefore, leguminous

Amino acid	BGN	CP	SB	AB	LP	LB	LT	CK	BB	KB
Arginine	4.0	1.6	7.2	1.3	3.9	2.2	2.2	1.8	0.7	1.5
Aspartic acid	5.0	2.8	11.7	2.4	3.9	2.9	3.1	2.3	0.8	2.9
Histidine	2.2	0.7	2.5	0.5	1.0	0.6	0.8	0.5	0.2	0.7
Serine	3.2	1.2	5.1	1.0	1.9	1.1	1.3	1.0	0.3	1.3
Glutamic acid	16.5	4.5	18.7	3.1	8.7	4.2	4.4	3.4	1.3	3.6
Proline	3.2	1.1	5.5	0.9	1.5	1.0	1.2	0.8	0.3	1.0
Glycine	3.3	1.0	4.2	0.8	1.5	1.1	1.1	0.8	0.3	0.9
Alanine	3.5	1.1	4.3	1.2	1.3	1.1	1.2	0.8	0.3	1.0
Lysine*	3.0	1.6	6.4	1.5	1.9	1.8	2.0	1.3	0.5	1.6
Threonine*	2.5	0.9	3.9	0.7	1.3	0.9	1.0	0.7	0.3	1.0
Valine*	3.8	1.1	4.8	1.0	1.5	1.2	1.4	0.8	0.3	1.2
Isoleucine*	3.8	1.0	4.5	0.8	1.6	1.0	1.2	0.8	0.3	1.0
Leucine*	6.8	1.8	7.8	1.7	2.7	1.8	2.0	1.4	0.6	1.9
Tyrosine*	3.2	0.8	3.1	0.6	1.4	0.7	0.8	0.5	0.2	0.7
Phenylalanine*	4.3	1.4	4.9	1.1	1.4	1.1	1.4	1.0	0.3	1.3
Tryptophan*	0.7	0.3	1.3	0.9	0.3	0.3	0.3	0.2	0.1	0.3
Cystine**	0.5	0.3	1.3	0.2	0.4	0.4	0.4	0.3	0.1	0.3
Methionine**	2.0	0.3	1.3	0.2	0.3	0.3	0.2	0.3	0.1	0.4

BGN: Bambara groundnut; CP: Cowpea; SB: soybean; AB: Adzuki bean; LP: Lupins; LB: Lima beans; LT: Lentils; CK: Chickpea; BB: Broad beans; KB: Kidney beans.
 Essential amino acid.
 Essential, sulphur-containing amino acid.

Table 2. Amino acid profiles of 10 legumes expressed as g/100 g protein [5, 17, 19, 20].

protein may improve calcium retention in comparison with high SCAA proteins of animal or cereal origin. Legume protein has also been reported to contribute to the reduction of low density lipoproteins, a known factor in the development of coronary heart diseases [9].

Legumes and cereals complement each other in terms of protein as cereals are high in SCAA (low in legumes) and have low in lysine (high in legumes) [1]. As such, protein quality is significantly improved when legumes are eaten in combination with cereals [18]. For nutritional balance, legumes and cereals are to be consumed in the ratio 35:65 [4]. Legumes are particularly important in vegetarian diets as they are the chief source protein and also provide vitamins and minerals [18]. For vegetarians to get a good balance of amino acids, their diets need to combine legumes with cereals. Common examples of such combinations are *dhal* with rice in India, beans with corn tortillas in Mexico, tofu with rice in Asia, peanut butter with bread in the USA and Australia [17], samp and beans (South Africa), Bambara groundnut and maize kernels (Zimbabwe), maize meal *pap* with beans (Southern Africa) and rice and beans (Southern Africa, Latin America). **Table 2** shows the amino acid profiles of several legumes.

3. Classification of carbohydrates in relation to legumes

Legumes are a source of complex, energy giving carbohydrates [17] with up to 60% carbohydrates (dry weight). Leguminous starch is digested slower than starch from cereals and tubers. As such, legumes have a low glycemic index (GI) rating for blood glucose control [9, 14] making them suitable for consumption by diabetic patients and those with an elevated risk of developing diabetes. Furthermore, legumes are gluten free, making them suitable for consumption by celiac disease patients or individuals sensitive to the proteins gliadin and glutenin [18]. Generally, legumes are important for individuals seeking a healthy, disease free lifestyle [8]. Legume starch isolates have been employed as thickeners in soups and gravies in the food industry [9].

Legumes are also a valuable source of dietary fibre (5–37%), containing significant amounts of both soluble and insoluble dietary fibre [2, 9, 17]. The monomers in legume dietary fibres include glucose, galactose, fucose, arabinose, rhamnose, xylose and mannose. Legumes also contain significant amounts of resistant starch and oligosaccharides, mainly raffinose, which have been reported to possess prebiotic properties [2]. These are fermented by probiotics to short chain fatty acids improving colonic health and reducing the risk of colon cancer. High dietary fibre diets are associated with many health benefits. These include the prevention and possible treatment of diseases and conditions like constipation, obesity, diabetes, heart complications, piles and some cancers [21–23]. In addition, dietary fibre, particularly soluble dietary fibre, has the ability to lower blood cholesterol, improve glucose tolerance and reduce glycaemic response by forming a protective gel lining along the intestinal walls thus reducing glucose and cholesterol assimilation into the bloodstream [22, 24, 25]. Insoluble dietary fibres are porous, have low densities, increase faecal bulk and promote normal laxation [26–28]. As such, legumes are an invaluable component of the human diet. Dietary fibre fractions from legumes have found use in the bakery, meat, extruded products and beverage industries as stabilisers, texturing agents, fortifiers, bulking agents, fat replacers and emulsion stabilisers [9, 10, 15, 17].

4. Fat and fatty acid composition of legumes

Legumes have no cholesterol and are generally low in fat, with $\pm 5\%$ energy from fat [10] with the exception of peanuts ($\pm 45\%$), chickpeas ($\pm 15\%$) and soybeans ($\pm 47\%$). The fat in legumes constitutes of significant amounts of mono- and polyunsaturated fatty acids (PUFA) and virtually no saturated fatty acids [2]. The highest amount of PUFA (71.1%) and monounsaturated fatty acids (34%) are reported in kidney beans and chickpeas, respectively [2]. The PUFAs present in some legumes include the essential omega-6 linoleic acid (C18:2, ω 6) and omega-3 alpha-linolenic acid (C18:3, ω -3). These PUFAs are essential for human health and since the human body cannot synthesise them, they must be included in the diet [18].

5. Clustering of legumes depending on their proximate composition

Using K-means cluster, 22 legumes were grouped into 3 cluster centres as shown in **Table 3**. Cluster 1 represented legumes that are high in carbohydrates ($\pm 63.8\%$), average in protein ($\pm 25.4\%$), low in fat ($\pm 2.6\%$) and low in dietary fibre ($\pm 9.3\%$). Cluster 2 represented legumes that are average in carbohydrates ($\pm 37.1\%$), high in protein ($\pm 36.1\%$), average in fat ($\pm 14.1\%$) and high in dietary fibre ($\pm 17.7\%$). Cluster 3 represented legumes that are low in carbohydrates ($\pm 19.3\%$), low in protein ($\pm 18.7\%$), high in fat ($\pm 55.0\%$) and average in dietary fibre ($\pm 13.3\%$).

Of the 22 legumes, 6% of the legumes fell into cluster 1, 18% into cluster 2 and 5% into cluster 3. Sword bean fell into clusters 1 and 2, hyacinth fell into clusters 1 and 3 and groundnut fell into clusters 2 and 3. It can be concluded that the majority of legumes are high in carbohydrates hence are high in energy, are a source of protein because even the cluster that is “low” in protein provides up to 19% protein which is significantly high and are low in fat with the exception of groundnut, hyacinth, lupins, soybean and sword bean.

	Cluster		
	1	2	3
Carbohydrate (%)	63.78	37.10	19.33
Protein (%)	25.44	36.09	18.73
Fat (%)	2.58	14.11	55.03
Dietary fibre (%)	9.32	17.72	13.28
Legumes	Adzuki bean, Green gram, Black gram, Pigeon pea, Cowpea, Lima bean, Broad bean, Kidney bean, Mung bean, African yam bean, Bambara groundnut, Lentil, Sword bean, Black velvet bean, White velvet bean, Pinto, Chickpea, Hyacinth	Sweet lupin, Bitter lupin, Soybean, Sword bean, Groundnut	Groundnut, Hyacinth

Table 3. Cluster centres for 22 legumes.

6. Micronutrients in legumes

Legumes are a good source of B-group vitamins such as folate, thiamin and riboflavin but are a poor source of fat soluble vitamins and vitamin C [2]. Folate is an essential nutrient and has also been reported to reduce the risk of neural tube defects like spina bifida in newly born babies [10, 18]. Legumes are also sources of the essential minerals zinc, iron, calcium, selenium, phosphorus, copper, potassium, magnesium and chromium [2, 29]. These micronutrients play important physiological roles such as bone health (calcium), enzyme activity and iron metabolism (copper), carbohydrate and lipid metabolism (chromium, zinc), haemoglobin synthesis (iron) as well as antioxidative activity, protein synthesis and plasma membrane stabilisation (zinc) [30]. Generally, legumes are low in sodium and this is desirable considering the recent trends encouraging sodium reduction [17, 31]. Although, legumes have high iron contents, the bioavailability of the iron is poor hence diminishing the value of legumes as a source of iron [10]. However, if legumes are consumed in combination with vitamin C rich foods, the absorption of iron is increased. In this manner, the high iron content would play a major role in the prevention of anaemia especially in women of reproductive age.

7. Bioactive compounds and non-nutrients in legumes

Legumes contain non-nutrient bioactive compounds such as phytochemicals and antioxidants [18]. These include isoflavones, lignans, protease inhibitors, trypsin and chymotrypsin inhibitors, saponins, alkaloids, phytoestrogens and phytates. Most of these chemicals are termed 'anti-nutrients' and although they are non-toxic, they generate adverse physiological effects and interfere with protein digestibility and the bioavailability of some minerals [32]. Most of these anti-nutrients are heat labile and since legumes are consumed after cooking, they do not pose a health hazard [32]. Legumes can also be detoxified by dehulling, soaking, boiling, steaming, sprouting, roasting and fermentation prior to processing [11].

Research has shown that most of these non-nutrients are phytochemicals with antioxidant properties which play a role in the prevention of some cancers, heart diseases, osteoporosis and other chronic degenerative diseases [8, 10]. The quantities of some non-nutrients present in legumes are given in **Table 4**. The antioxidant capacity of legumes allows them to inhibit or slow down oxidative processes which are largely responsible for degenerative diseases by interacting and scavenging free radicals and reactive oxygen species, chelating metal catalysts, activating antioxidant enzymes as well as inhibiting oxidases [22]. As such, the incorporation of legumes into human diets all over the world could offer protection against chronic diseases [33]. Therefore, legumes, especially underutilised legumes, should be explored for the development of innovative, value-added products (**Figure 3**).

Saponins and glycosides are another group of bioactive compounds present in legumes such as lentils, chickpeas, soy bean and peas. These compounds form insoluble complexes with 3- β -hydroxysteroids and form micelles with bile acid and cholesterol; thus, facilitating their

Legume	Polyphenols (%)	Phytic acid (%)	Tannins (%)	α -Galactosides (%)
Common bean (white)	0.3	1.0	0	3.1
Common bean (Brown)	1.0	1.1	0.5	3.0
Pea	0.2	0.9	0.1	5.9
Lentils	0.8	0.6	0.1	3.5
Faba bean	0.8	1.0	0.5	2.9
Chickpea	0.5	0.5	0	3.8
Soybean	0.4	1.0	0.1	4.0
Pigeon pea	0.2	0.1	0	0

Table 4. Some non-nutrients present in common legumes (% dry matter) [34, 35].

excretion from the human body. These compounds have also been reported to possess hypocholesterolemic and anticarcinogenic activity [2].

Other important bioactive compounds found in legumes include polyphenols and their derivatives such as flavanols, flavan-3-ols, anthocyanins/anthocyanidins, condensed tannins/proanthocyanidins and tocopherols [32]. The concentration of polyphenols such as glutathione and tocopherols in legumes ranges from 321 to 2404 $\mu\text{g}/100\text{ g}$. Although, tannins are generally considered undesirable because they render protein indigestible, recent studies have shown

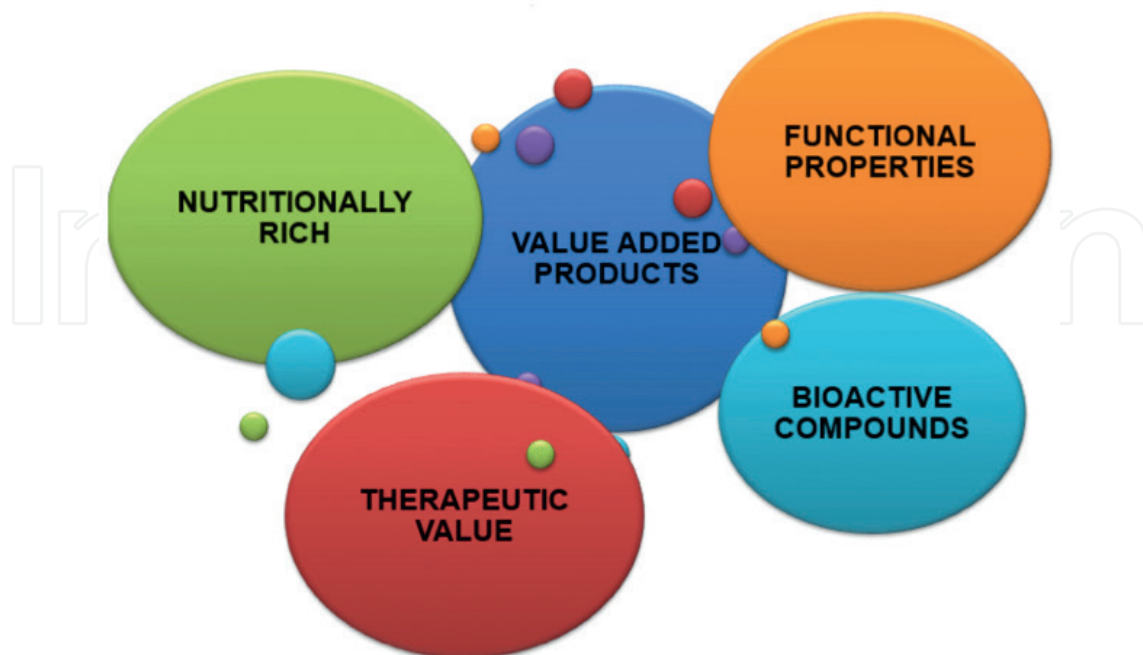


Figure 3. Potential of legumes in the production of value-added products.

their consumption to have an inverse correlation to the incidence of biological molecule (DNA, lipids and proteins) damage due to their reducing nature [11]. Legumes with coloured seed coats such as Bambara groundnut, black bean, red kidney bean and black gram, have long been associated with antioxidant and anticarcinogenic activity [2]. It is believed that the denser the colour of the seed coat, the higher the antioxidant activity.

7.1. Oligosaccharides

Most legumes contain up to 50 mg/g total oligosaccharides. Oligosaccharides are responsible for flatulence widely associated with the consumption of legumes. The absence of an α -galactosidase enzyme in the human gastrointestinal tract to cleave the α -1,6 galactose linkage in galactoside-containing oligosaccharides such as raffinose and stachyose means these oligosaccharides pass undigested to the colon where they are metabolised by bacteria forming large amounts of carbon dioxide, hydrogen and methane. These gases may cause bloating and gastric discomfort and are expelled from the body as flatulence. However, although the oligosaccharides in legumes are viewed negatively, their beneficial attributes outweigh their negative properties [10]. Oligosaccharides are prebiotic in nature and therefore, promote the growth of the probiotics, *Bifidobacteria* spp, which play a major role in the maintenance of a healthy colon. In Japan, soybean oligosaccharides have been suggested as a substitute for table sugar [10].

8. Legume consumption around the world

Legumes play an important role in many diets all over the world and are especially important in developing/third world countries in Africa, Latin America and Asia. Legumes have been labelled the 'poor man's meat' and this statement seems to hold some truth as observed in the consumption distribution in different regions, with an inverse relation between legume consumption and income being observed [10]. Emerging research is however changing the label of legumes to "health food", encouraging their inclusion in the diets of even affluent people [2]. Legumes have been used in the production of various commercial products such as textured vegetable protein (TVP), tofu, soy sauce, soy paste and curry. Some by-products of legumes include dietary fibre, single cell proteins, citric acid and enzymes. Legumes can be incorporated in various ways to increase their acceptance in balanced nutritious diets [8] as shown in **Table 5**.

Common name	Food uses
Soybean (<i>Glycine max</i>)	Asian dishes (tofu, natto miso), roasted snacks, milk, yoghurt, sprouted beans, curd, yuba, soy sauce, soy paste, TVP
Black gram (<i>Vigna mungo</i>)	Dhal, fermented products (idli, dosa, papad)
Lentils (<i>Lens culinaris</i>)	Dhal, papadums
Peas (<i>Pisum sativum</i>)	Soup, dhal
Peanut/Groundnut (<i>Arachis hypogaea</i>)	Peanut butter, peanut bar, flour, roasted/boiled snacks
Adzuki beans (<i>Vigna angularis</i>)	Japanese desserts and confections, soup ingredients for therapeutic purposes
Anasazi beans (<i>Phaseolus vulgaris</i>)	Boiled meal, snack, soup

Common name	Food uses
Black-eyed peas (<i>Vigna unguiculata</i>)	Boiled snack/part of meal, fried cake <i>akara</i> , steamed pudding <i>moi moi</i> in West Africa
Chickpea (<i>Cicer arietinum</i>)	Middle Eastern and Mediterranean foods such as falafel and hummus, Boiled/fried/cooked/crushed snacks, dhal, curry, flour used in bread making, fermented food (<i>dhokla</i>)
Kidney beans (<i>Phaseolus vulgaris</i>)	Ingredient in Mexican chili; most-consumed legume in America
Lentils (<i>Lens culinaris</i>)	Soups and stews; most important legume in India
Lima beans (<i>Phaseolus lunatus</i>)	Cooked whole
Mung beans/Green gram (<i>Vigna radiate</i>)	Bean sprouts, cooked whole or with sugar into a dessert, soup, flour used for baking, transparent noodles, patties, sweets
Navy beans (<i>Phaseolus vulgaris</i>)	Baked beans
Black turtle beans (<i>Phaseolus vulgaris</i>)	Bean soup popular in latin American cuisine
Pinto beans (<i>Phaseolus vulgaris</i>)	Fried beans
Bambara groundnut (<i>Vigna subterranean</i> (L). Verdc)	Boiled whole or split, soups, milk, yoghurt, boiled/fried/cooked/crushed snacks, commercially canned in gravy, flour used in bread making
Yam bean (<i>Pachyrhizus</i> spp)	Tubers used as vegetables
Lupins (<i>Lupinus</i> spp)	High protein seeds
Rice bean (<i>Vigna umbellate</i>)	Boiled seeds, fodder
Winged bean (<i>Psophocarpus tetragonalobus</i>)	Boiled seeds
Faba bean (<i>Vicia faba</i>)	Whole food
Sword bean (<i>Canavalia gladiate</i>)	Mature beans and dried seeds used as food and for medicinal purposes
Hyacinth bean (<i>Lablab purpureus</i>)	Popular in south Asian dishes
Velvet bean (<i>Mucuna monosperma</i>)	Seeds used as food and for pharmaceutical application
African Yam bean (<i>Sphenostylis stenocarpa</i>)	Bean seeds usually eaten alone or in combination with other foods
Tamarind (<i>Tamarindus indica</i>)	Pulp used for food and beverage preparation, flour used as soup thickener, remedy in diarrhoea and dysentery
Marama bean (<i>Tylosema esculentum</i>)	High nutritional value food

Table 5. Various ways in which legumes are eaten around the world [2, 19, 36–39].

9. Role of legumes in human health and food security

Many diseases of lifestyle are a result of a poor diet, high in animal products and low in plant matter. Legumes are high in dietary fibre, high in complex, low glycemic carbohydrates, high in bio-active compounds, low in saturated fat and no cholesterol (**Figure 4**). These dietary components promote health and longevity by decreasing insulin production and preventing chronic diseases

such as diabetes, cancer, cardiovascular disease and obesity. As such, a legume-based diet can result in a longer, healthier life.

Although, legumes are the second most important crops after cereals, the inadequacy of the knowledge of their nutritional and functional benefits has resulted in them not being given enough attention. Therefore, future studies should look into harnessing the many desirable properties (**Figure 4**) of legumes in the development of inexpensive legume products that are available to all income groups [39]. Most legumes are cultivated by low-income groups at household level. The increased use of legumes would increase their demand and in turn would encourage local farmers to increase legume production, hence resulting in increased financial stability and food security. The functional properties (**Figure 4**) of legumes such as water binding, oil binding, emulsion stabilisation and gelling could be harnessed in the development of various food products. There is urgent need to educate communities worldwide about the nutritional value of legumes, methods of detoxifying legumes of anti-nutrients and various methods of making legumes more attractive to consumers. In addition, genetic modification could be explored in developing transgenic leguminous species that cook faster and have low levels of anti-nutrients.

Taking their nutritional superiority into consideration, it is expected that dieticians and nutritionists encourage the public through mass media such as television, press and radio, to increase their consumption of legumes.

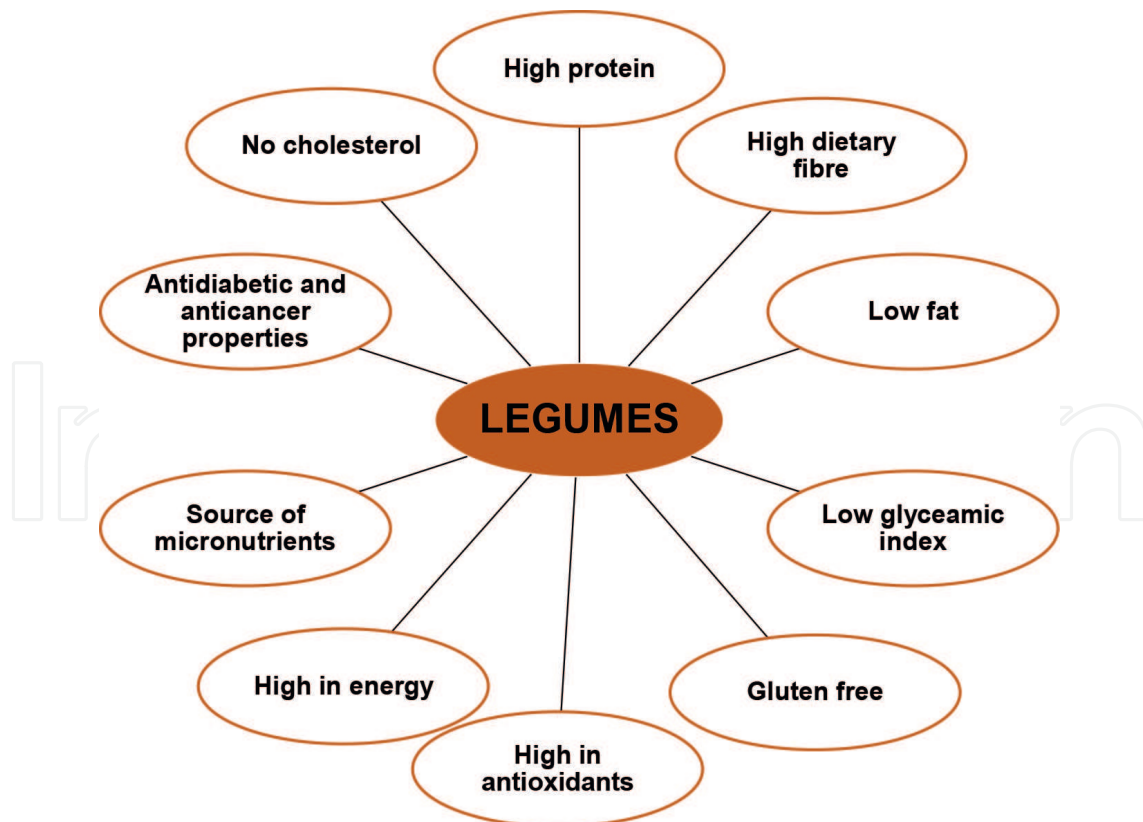


Figure 4. Desirable attributes of legumes.

10. Why underutilised legumes should be given more attention

Underutilised legumes also known as orphan crops, neglected crops or lesser crops such as Bambara groundnut, African locust bean, African yam bean, pigeon pea, kidney bean, lima bean and marama bean deserve to be given more attention [40]. Most of these underutilised legumes thrive in adverse conditions, are nutritionally superior and yield more than common legumes [40].

There is a pressing need in developing/poor countries such as those in sub Saharan Africa, for readily available, affordable, nutritional rich food supplements to cater for the ever increasing population. Underutilised legumes could be the answer to this demand. Most are cultivated only at household level as secondary crops. As such effort should be directed towards conducting extensive research to extend both technical and practical knowledge about these legumes so that their full potential may be achieved. These legumes' high nutritional could largely contribute to combating malnutrition [13]. It is envisaged that underutilised legumes could have an abundant amount of undiscovered bioactive compounds that could be employed in the production of therapeutic, affordable, functional foods. The increased use of underutilised legumes could reduce the overutilisation of common legumes such as soybean.

11. Constraints associated with the utilisation of legumes and possible solutions

Several factors contribute to the limited use of legumes. These include the presence of anti-nutrients, myths about legume consumption, their association with bloating and flatulence as well as their hard-to-cook phenomenon. There is a need to educate consumers about methods in which these negative properties of legumes can be reduced or removed completely. Processing methods such as soaking, germination, fermentation and cooking have been reported to detoxify the legume seed. Soaking prior to cooking also softens the seeds, significantly reducing cooking time.

Low yields, poor seed availability, lack of market, significant labour requirement at maturity, lack of awareness of indigenous legumes and the lack of convenient food applications also contribute to the low utilisation of some legumes [9]. The development of new legume products could lead to a higher demand of legumes hence prompting local farmers to increase the production of these legumes for commercial purposes [37]. To overcome the discomfort and embarrassment associated with bloating and flatulence caused by oligosaccharides, commercial digestive aids such as Beano (AkPharma Inc, Pleasantville, NJ) have been developed. These digestive aids contain the enzyme α -galactosidase, which breaks down the oligosaccharides, therefore avoiding gas production in the large intestines. Rinsing legumes and changing the boiling water several times also significantly reduces the amount of oligosaccharides in legumes. Several methods of overcoming constraints that limit the use of legumes are given in **Table 6**.

Constraint	Negative effect	Solution
Trypsin inhibitors and amylase inhibitors	Decreases protein digestibility and starch digestibility	Boiling dry beans generally reduces the content by 80–90% Fermentation
Phytate	Chelates with minerals resulting in poor mineral bioavailability	Dehulling, soaking, boiling, steaming, sprouting, roasting and fermentation, autoclaving, gamma irradiation
Lectins, saponins	Reduced bioavailability of nutrients	Most destroyed by cooking, soaking, boiling, sprouting, fermenting
Oligosaccharides	Flatulence and bloating	Digestive aids such as Beano, changing boiling water, soaking, cooking, germination
Hard-to-cook phenomenon	Energy and time consumption	Soak legumes before cooking them
Lack of convenient food applications	Boredom of eating the same food repeatedly	New product development of innovative legume products as well as increased utilisation of lesser legumes
Low levels of sulphur-containing amino acids	Incomplete protein source	Consumed in combination with cereals (high in sulphur-containing amino acids)
Lack of awareness, understanding and knowledge of nutritional value of legumes	Low intake of legumes	Increasing consumer awareness of the nutritional profile of legumes
Beliefs and taboos—for example, eating groundnuts can cause stomach upset	Low intake of legumes	Increasing consumer awareness of the nutritional profile of legumes and of methods to get rid of anti-nutrients and oligosaccharides
Reluctance to try a new kind of food or to change eating habits	Low intake of legumes	Development of innovative, attractive legume-based products to entice consumers
Low iron bioavailability	Poor source of iron	Consumed in combination with vitamin C rich foods, the absorption of iron would be increased

Table 6. Utilisation problem of legumes and possible solutions.

12. Role of legumes in weight management and satiety

Several studies have suggested that the consumption of legumes could aid in weight loss. This could be attributed to the low fat and high dietary fibre nature of legumes. The low GI nature of legume carbohydrates also aids in stabilising blood sugar and insulin levels resulting in the consumer feeling satiated for increased periods of time [18]. This in turn results in less and infrequent eating which is ideal for weight management. In a US National Health and Nutrition Examination Survey [41], it was concluded that eating legumes was associated with decreased body mass index (BMI), reduced waist circumference and reduced risk of obesity. More studies in Iran concluded that the risk of suffering from obesity was reduced in men who consumed at least 30 g of legumes a day [41]. More studies have reached the conclusion that the consumption of 3–5 cups of legumes as part of an energy-controlled diet results in the loss of 3.6–8.1 kg of body mass over 6–8 weeks [41].

13. Novel, healthy legume-based products

There are various products developed from legumes both at household level (**Table 5**) and commercially. Legumes provide high protein meat-substitutes for vegetarians, low fat substitutes for health conscious individuals and low cost products for low-income groups. One of the most utilised legumes is soybean [3]. Its high oil content makes it a suitable raw material for oil extraction [42]. From soybean, products such as milk, tofu, temper, soy sauce, yoghurt and cheese have been commercially produced (**Table 5**). Soymilk, cheese and yoghurt are excellent dairy substitutes for vegans and lactose intolerant individuals. Soy-corn milk, a product produced from a mixture of soymilk and sweet corn is also available [42]. Blending sweet corn with soymilk helps in masking the beany flavour associated with legume milk as well as enhances its nutritional value [42]. Dairy substitutes have also been produced from Bambara groundnut. Bambara groundnut milk was patented by Ref. [38], these researchers also reported the production of yoghurt from Bambara groundnut milk.

Other leguminous products include texturised vegetable protein (TVP), canned beans, groundnuts/peanuts and flour. The term 'TVP' loosely refers to extruded defatted soy flour or concentrate with a meat-like chewy texture when cooked or hydrated [42]. This product is very popular amongst vegetarians. Canned legumes are a common sight in many supermarkets and small stores. Most legumes are canned in brine, sugar solution or tomato purees. Although, this technology preserves legumes allowing for their availability all year round, it increases their cost [42]. Groundnuts are another popular group of legumes. Commercially, they are used in the extraction of oil as well as in the manufacture of peanut butter or are sold as salted, boiled, roasted, shelled or unshelled (**Table 5**). Legumes are sometimes ground into flour for use as thickeners in soups, emulsion stabilisers or for baking [37]. Legume flour available in the food market includes that from cowpea, soybean, pigeon pea and African yam bean [42].

Research has begun exploring the technological function of leguminous ingredients in the formation of novel, healthier foods. Dietary fibres from legumes have high water binding, oil binding, swelling capabilities making them suitable for use as thickeners in soups, fat replacers in meat products, stabilisers in emulsions, texturisers in bread as well as in improving body and mouthfeel in products such as yoghurt [37]. In addition, dietary fibres extracted from legumes such as Bambara groundnut possess prebiotic properties and could be used in the production of prebiotic supplements [22]. Starch from legumes was reported to positively improve the stability and rheological properties of oil-in-water emulsions [43]. Soy protein finds use in protein shakes common amongst physically fit individuals [42].

14. Conclusions

Legumes are a sustainable and inexpensive source of protein, unsaturated fat, dietary fibre, complex carbohydrates, micronutrients and important bioactive phytochemicals, therefore their consumption could contribute to a healthier lifestyle. Their composition makes them attractive to health conscious consumers, celiac and diabetic patients as well as consumers concerned with

weight management. To harness the nutritional benefits of legumes, they should be incorporated into children and infants' diets at home and through school feeding programs, especially in developing countries to reduce poverty and malnutrition. Furthermore, legumes could be a base for the development of many functional foods as well as a range of feed and raw material for industrial products.

Author details

Yvonne Maphosa* and Victoria A. Jideani

Address all correspondence to: yvonmaphosa@gmail.com

Department of Food Science and Technology, Cape Peninsula University of Technology, Bellville, South Africa

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