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Nutritional Constraints of Legumes and the Role of Novel Food Processing Technologies to Enhance Their Nutritional Values

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Abstract: Legumes contain high amount of essential nutrients. It is the cheapest source of protein for the millions of people in developing countries. However, this interesting crop contains nutritional constraints, which reduce the bioavailability of both macronutrient and micronutrient, and limits its utilization in household and industrial level. The main nutritional constraints commonly found in legumes are trypsin inhibitor, protease inhibitor, oxalate, phytic acid, saponin, tannins, polyphenol lectins, and flatulence causing oligosaccharides. Some of this nutritional constraint reduces mineral bioavailability and absorption, protein and starch digestibility. This causes both macronutrients and micronutrients malnutrition among people those consumed as stable food. Furthermore, continuous consumption of nutritional constraints threats health of consumer. To eliminate the problem of nutritional constraints and enhance nutritional values of legumes, various processing techniques and method are used. These techniques are soaking, boiling, roasting fermentation and germination, were used since ancient time. Today, besides them the novel food processing technology such as microwave cooking, autoclaving cooking, and extrusion cooking are used. However, still further research is needed to reduce the level of to reduce the level of nutritional constraints in legumes food. Therefore, this review aimed to update information of nutritional constraints of legumes and role novel food processing technologies to enhance their nutritional values of legumes.

Keywords: Nutritional Constraints, Novel Food Processing Technology, Nutritional Values

1. Introduction

Legumes (Leguminosae) are the predominant important source of food crops for human in nutritional, health benefits and together with economical point of view due to its served as staple foods for millions of people living around worlds [160]. The term legume has been mainly derived from Latin word 'legumen' that mean the seeds that are born in pods [18, 1]. The legume seeds are easy to harvest and store which makes them a suitable crop to grow in different areas [39]. The dried legumes are consumed after processing into different products such as *dhal*, roasting, puffing into snack and powder forms for preparation of different other types of food products [54].

Legumes ranked as third largest family of flowering plants having more than 19500 species and classified into around 750 genera. It is a well-known crop with a long history of cultivation and utilization. The evidences suggested that they have been cultivated for thousands of years and eating was dated back to 5500 BC [50]. Nowadays legumes are occupied the second position next to cereals in terms of consumption in the world although less cultivated as compared to cereals crop [124].

Many of different legumes are grown the over the world. Of these, the major ones in terms of global production and consumption quantities are chickpea (*Cicer arietinum*), common bean (*Phaseolus vulgaris*), grass pea (*Lathyrus sativus*), lentil (*Lens culinaris*), mung bean (*Vigna radia*ta), urad bean (*Vigna mungo*), pea (*Pisum sativum*), pigeon pea (*Cajanus Cajan*), and soybean (*Glycine max),* broad bean (*Vicia faba L*) and cowpea (*Vigna unguiculata L)* [117].

Currently, the mean annual world legumes production trienniums ending of 2014 is 77 (Mt) and the legumes yields of this year is 929 (k/ h) [117]. In the period from 2011 to

2013, 60% of the total legumes world production is attributed to seven legumes producing countries, from which India led with 24.3% of total production followed by Myanmar (7.3%), Canada (7.0%), China (6.3%), Nigeria (4.6%), Brazil (4.2%), Australia (4.2%), and Ethiopia (3%) [44].

The nutritional composition of legumes can provide a high proportion of proteins, carbohydrates, dietary fibers, B-group vitamins, and minerals. They are also high in dietary fiber and folate [50]. Legumes, commonly beans are low in fat [150]. The amount of proteins in legumes varies highly depending on the cultivar, location of growth, environmental factors, and soil type in which legumes grown, and ranges between 20 and 35% [129]. The protein content is high as compared with cereals and is rich in the amino acid lysine and sulfur amino acids, which are limited in most plant foods [95]. It is an inexpensive source of protein, particularly in the developing world where meat, dairy products, and fish are economically inaccessible [50] and known as the poor man's meat.

Several observational epidemiologic data have shown that legumes has ability to prevent and lower a severe disease of today's world like cardiovascular diseases, obesity, certain cancer, and diabetes mellitus, and gut health due to legumes has high soluble and insoluble fiber, oligosaccharide, phenolic contents and phytochemicals [141]. According to reports of WHO [162], adopting eating habits of legume, prevents 80% of heart disease, stroke, type 2 diabetes, and some cancers.

Apart from having high nutritional value legumes foods are often associated with a series of compounds known nutritional constraints, which generally interfere with the nutrients bioavailability of the legumes [140]. Nutritional constraints are substance that generated by normal metabolism of species in the natural food stuffs act to reduce nutrient intake, digestion, absorption and utilization, and provoke toxicity if consumed in excess amount [80]. They are also limits extensive utilization of legumes at household and industrial level [5]. The most commonly reported nutritional constraints of legume seeds are trypsin inhibitor, protease inhibitor, phytic acid, saponin, tannins, polyphenol lectins and flatulence causing oligosaccharides [147, 12, 79].

These nutritional constraints affect human and animal nutrition by reducing the bioavailability of the nutrients present in food legumes and or decreasing absorption and utilization of other nutrient by body [17]. This problems causes protein and mineral deficiency particularly in Afro-Asian countries [50]. Reduction or elimination of this nutritional constraints and improving the bioavailability of macronutrient and micronutrient of legume is an interested area of studies [53].

To reduce or eliminate this nutritional constraints various simple processing methods such as milling, soaking, boiling, roasting, fermentation, and germination have been used since ancient time [136]. Recently, novel food is processing technologies such as irradiation, microwave, autoclaving, and extrusion cooking have been developed to remove nutritional constraints and enhancing nutritional quality of legumes. Therefore, the aim of this review to compiles updated information about nutritional constraint of legumes and the role of novel food processing technologies to enhance their nutritional value of legumes.

2. Methodology

This review paper is written using secondary data published in different journals, research gate, and annual reports studied by various researcher, institution, and organization. The mainly sources used to acquire this secondary published data were electronic data such as *Web of Science, GRIS (agris.fao.org), Scopus, Research Gate, Science Direct, Taylor, and Francis.*

3. Literature Reviews

3.1. Nutritional Constraints in Legumes

Nutritional constraints in legumes are primarily associated with compounds or substances of natural or synthetic origin, which interfere with the absorption of nutrients or reduce nutrient intake, digestion, and utilization and may cause other adverse effects [116]. They are found in legumes in different amounts based on types of legumes, mode of its propagation, chemicals used in growing crop as well as those chemicals used in storage and preservation of the legumes [145].

Nutritional constraints can be classified as protein and non-protein origin [44]. Protein origins are lectins, cyanogenic glycosides, protease inhibitors, and toxic amino acids and they are heat-labile. Non-protein origin like phytic acid, condensed tannins, alkaloids, saponins, and α-galactosides are heat stable [64]. Many of these nutritional constraints are capable of reducing nutritional values of legumes by limiting digestibility of proteins and carbohydrates (enzyme inhibitors, lectins and tannins) or diminishing bioavailability of minerals (phytates and oxalates) and a-galactoside causing flatulence in human [109].

3.1.1. Tannin

Tannins are group of plant polyphenols present in all higher plants including leguminous plants, forages, flowers, fruits, grasses, and leguminous trees [24]. Seguim used the word tannin in scientific literatures to describe the process of transforming animal hide into durable leather by using compound present in various plants extracts [37]. The term tannin is refers to any polyphenolic compound that contains sufficient hydroxyl and other suitable groups to form strong complex with protein and macromolecules [102]. This polyphenolic compound precipitates proteins from aqueous solution [22] and thereby reduces the protein digestibility of legumes food.

Tannins are accountable for the astringency, bitterness of foods due their interaction with protein and various other organic compounds such as amino acids and alkaloids, which cause depression in the intake of legumes food. Tannins are water-soluble compounds with a molecular weight of 500 to 3000 Daltons [37]. It also inhibits the activities of digestive enzymes such as trypsin, chemotrypsin, amylase, and lipase

[42]. While consuming food contain tannins induces toxic in monogastric animals including human as a result, decrease feed intake, nutrient digestibility, protein availability as well as interfere with dietary iron absorption [66]. The presence of tannins in the legumes also decreases the availability of vitamins A and B12 [157].

The tannins content of legume seed depend on genetic and environment conditions during plant growing and postharvest storage methods. Tannins content of seed also different based its colors. Red-colored beans contain most tannin, and white colored beans have the least [79]. The tannins content of legumes ranged from 0.75 to 4.78% [86]. It commonly found in the dicotyledons of Leguminosae and when ingested, it form complexes with proteins, which causes inactivate many digestive enzymes and decrease protein digestibility [68].

In nature, there are two different types of tannins. These are hydrolyzable tannins and condensed tannins [124]. The former consists of polyphenols (gallic acid and ellagic acid) that can be easily hydrolyzed by heating with weak acid; on the other hand, condensed tannins are flavonoid polymers (catechins or proanthocyanidins) linked by carbon-carbon bonds that oxidize with hot mineral acid [63].

Condensed tannins are polymerized products of flavan-3-ol and flavan-3,4-diol or a mixture of both. Condensed tannins are capable of precipitating proteins and form soluble or insoluble complexes with various molecules [4, 48]. Condensed tannins have molecular weight higher than hydrolysable tannins and thus have more impacts digestibility than hydrolysable tannins [82].

3.1.2. Phytic Acid

Phytic acid refers to phytate (myo-inositol hexaphosphate), is made up of myo- inositol ring with six phosphate ester groups, and can be abbreviated as IP6 [79]. Phytate is formed during maturation of the plant seed and in dormant seeds represents 60–90% of the total phosphate [85]. Usually legume based food items contain higher amounts phytate than do cereal based food items [79]. According to different authors the total inositol phosphates content ranged from 0.2 to 1.9% in Ph. *vulgaris,* from 0.15 to 2.34% in Lens *esculenta,* from 0.4 to 1.1% in Cicer *arietinum,* from 0.2 to 1.3 in P. *sativum* or from 0.5 to 1.1% in V. *faba* [28].

The myo-inositol phosphates, IP6 and IP5, have the worst antinutritional effects, as the smaller molecules (IP4, IP 3, IP 2, and IP 1) have a lower capacity to complex with inorganic cations. The major inositol phosphate in legumes is IP6 [25].

The major part of phosphorous contained within phytic acid is primarily unavailable to humans and monogastric animals owing to absence of enzyme phytates within the digestive tract of them [61]. [133] reported that in dry mature legumes, 99% phytate found in water-soluble form. Phytate rapidly accumulates in the seeds during the ripening period and accumulation site of phytic acid is in the dicotyledonous seeds of globoid (which is inclusions of protein body) [49]. Nevertheless, in monocotyledons like wheat and rice, phytate is present in germ of corn or bran layer [138].

Plant based food contain more nutritional constraints of phytic acids than animal based foods. As result, vegetarian in developing countries ingests high levels of phytic acid [84]. Phytates are negatively charged and they strongly bind to divalen cations like Zn^{2+}, $Fe^{2+/3+}$, Ca^{2+}, Mg^{2+}, Mn^{2+} and Cu^{2+} and impede their absorption in animal and human food [61, 58]. Among them, bioavailability of Zn^{2+} was reported to be the most adverse affected minerals [85]. Not all minerals are the same affinity to phytates. Phytate exhibits stability and their affinity for all polyvalent cations in decreasing order of $Cu^{2+} > Zn^{2+} > Ni^{2+} > Mn^{2+} > Fe^{3+} > Ca^{2+}$ [31].

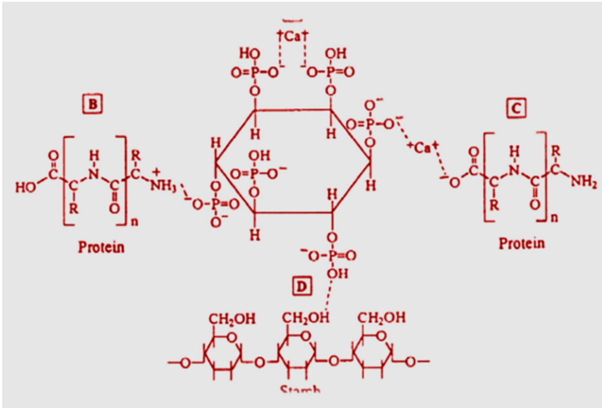

Figure 1. *Possible interaction of Phytate with Minerals, Protein, and Starch [44].*

Phytates has capability to form strong complexes with multivalent cation at physiological pH makes it serious nutritional constraint in the legumes [25]. However, at neutral and alkaline pH, net charge of both phytate and proteins is negative and hence dissociates each other [133]. Phytic acid is able to complex with proteins also, decreasing protein solubility. Phytates therefore influence enzyme activity and there is evidence of negative effects on key digestive enzymes including lipase, a-amylase, pepsin, trypsin, and chymotrypsin [25]. Among all nutritional constraints phytic acid considered as the one of main concern for human health [79].

3.1.3. Trypsin Inhibitors

Proteinases are enzyme that improves the nutritional and functional properties of various protein molecules [122]. They are widely distributed in the plant kingdom including the seeds of most legumes and cereals crops. It becomes an important research area due to their effective way of limiting enzyme activity by forming protein–protein interaction. Trypsin and chemotrypsin enzymes are mainly inhibited by protease inhibitors and thus interfering with the digestion of proteins and leading increasing pancreatic secretion and hypertrophy of the pancreas [88]. Trypsin inhibitors are found in most legumes in variable amounts and most legume species contain less than 50% of the trypsin inhibitor of soybeans [130]. When humans and monogastric animals are ingested significant amount of legumes, they disrupt the digestive process and may lead to undesirable physiological reactions [138].

The location of protease inhibitors in legumes depend on types of seeds. For instance, in soy and faba beans protease inhibitors is concentrated mostly in the cotyledon (>90%) whereas in other legumes like chickpea and they are found three parts, cotyledon (77.2% to 75.8%), embryonic axis (11.9% to 15.5%), and seed coat (10.9% to 8.7%) [154]. The nutritional constraint activity of protease inhibitors is associated inhibiting proteases, which are resistant to digestion in the small intestine and so ensures their removal through excretion. They form enzyme-trypsin inhibitor complex, which decrease in protein digestibility. Protease inhibitors inhibit the enzyme activity through the catalytic mode by blocking the active site of the enzymes. The Nitrogen- or Carbon-terminus and the exposed loop of protease inhibitors are often considered important structural features for the inhibition of enzyme activity [110].

Legumes protease inhibitors are grouped into two families depend on their molecular weight and cystine contents. These are Kunitz and Bowman-Birk inhibitors. Two families are capable of inhibiting trypsin and chymotrypsin. Kunitz protease inhibitor has a molecular weight of 20 kDa with two disulphide bridges whereas Bowman-Birk inhibotor has a molecular weight of 8–10 kDa with seven disulphide bridges. Kunitz protease inhibitor mainly found in soybean but the rest is commonly found in common bean, cowpea, and lentils [88].

3.1.4. Lectins (Hemagglutinins)

Lectins (haemagglutinins) are glycoproteins, which are able to reversibly bind to specific sugars, and glycoproteins on the surface of cells in the gut wall, thus interfering with nutrient breakdown and absorption [101]. Lectins are present in almost all biological systems including viruses, bacteria, fungi, unicellular organisms, animals, and plants [115]. The term ‘lectin’ is originated from Latin word “legere”, which means to select. As it, selectively bind carbohydrates [138].

It has ability to agglutinate erythrocytes with specifically reversible binding to monosaccharides, oligosaccharides, and glycoconjugates, which are chemically inseparable, and lectins contain one non-catalytic domain for binding specific carbohydrates [132].

Lectins activities have been determined in more than 800 varieties of the legume family. About 2-10% of total protein, legume seeds are lectins [64]. Many types of beans contain lectins including green beans, red kidney beans, and white kidney beans. In plant, based food lectin can be named as phytohemagglutinins (PHA). The content and composition of lectin varies in different legumes. It mainly concentrated in the seeds as one of the components of seed storage proteins and mainly present in the cotyledons of seeds and appears during the maturation of seed [82]. In legumes lectins ranges from 0.6% in garden pea, 2.4 to 5% in kidney bean, and 0.8% in Lima and soya bean with respective to total protein content [165].

Lectins (hemagglutinins) have the ability to directly bind to the intestinal muscosa, interacting with the enterocytes, and interfering absorption and transportation of simple sugar and digested product causing epithelial lessions within intestine. It diminishes the bioavailability of the nutrients by inactivating digestive enzymes. This nutritional constraint has different interactions on the toxicity, blood groups, mitogenesis, digestion, and agglutination [101].

3.1.5. Saponin

Saponins are naturally occurring compounds that exist in a wide variety of edible legumes [133]. Saponin is composed of carbohydrate and non-carbohydrate or aglycone portion. This aglycone portions are usually referred to as sapo-genins [72]. Saponin contents depend on the age of the plant and the part of the plant and the levels of saponins in germinated seeds are higher than in dry seeds [135]. Saponins have been reported in many edible legumes, and they have been found in lupins, lentils and chickpeas, as well as soy, various beans and peas.

The term of saponin is derived from the Latin word “sapo” which means ‘soap’, because of the saponin molecules form, soap-like foams when dissolved in the water [133]. It has nonpolar aglycones fixed with one or more monosaccharide moieties. This combination of polar and non-polar structural elements in their molecules proved their soap-like behaviour in aqueous solution [106]. The concentrations of saponin in legumes range from 0.01 to 5.6% on a dry weight basis and Soybeans have highest saponin content of all bean varieties (5.6%) [74, 133]. Saponin decreases the bioavailability of nutrients by inhibiting various digestive enzymes like trypsin and chymotrypsin [87].

3.1.6. Oxalates

Oxalates bind minerals, such as calcium and magnesium, and interfere with their metabolism. The insoluble calcium oxalate has the tendency to precipitate in the urinary tract and form calcium oxalate crystals with sharp edges, leading to the formation of kidney stones when the levels are high enough [103]. Oxalate is a nutritional constraint that under normal conditions is confined to separate compartments, but when it is processed and or digested, it encounters the nutrients in the gastrointestinal tract [105]. When released oxalate binds with nutrients rendering them unavailable to the body. The oxalate content of legumes can vary based on the variety, growth, season, soil conditions, time of harvest, and many other factors [165]. Soybeans and other legumes such as lentils, red kidney beans, and white beans have been found to contain oxalates [98].

Moreover, oxalate forms insoluble salts with minerals, mostly the insoluble chelate complex with dietary calcium [8]. About 75% of all kidney stones are composed primarily of calcium oxalate and hyperoxaluria is a primary risk factor for this disorder [8]. Furthermore, the nutritional constraints oxalic acid has been shown to impair the absorption of magnesium, zinc, iron, and calcium in the intestine by complexation [105].

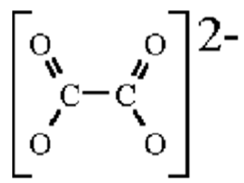

Figure 2. *Structure of oxalates.*

3.1.7. Raffinose Family Oligosaccharides

Raffinose oligosaccharides are complex sugar containing chain of α-galactose, which are unable to be digested by human upper intestine due to absence of α-galactosidase, the enzyme required to break the link in α-galactose chain [114]. Therefore, the RFOs passes into large intestinal tract where it metabolized anaerobically microflora present in large intestinal tract and produce high amounts of carbon dioxide, hydrogen, and small amounts of methane gas, which cause flatus production [101]. These gases cause abdominal pain owing to a flatus effect and sometimes result in diarrhea [142].

Raffinose family oligosaccharide is present in all parts of the legumes although, it accumulates in the seeds and roots during developments and the highest amount in the matured seeds. There are considerable RFOs in the soybean, lentils, lupins, faba beans chickpea, cowpea, pigeon pea, black gram, horse gram, and green gram which, cause production of flatulence when human ingested [60]. The concentration of raffinose family oligosaccharides in legumes is 0.1-2.6% raffinose, 0.13-5.5%stachose and 0-4.5% verbascose in dry basis [94].

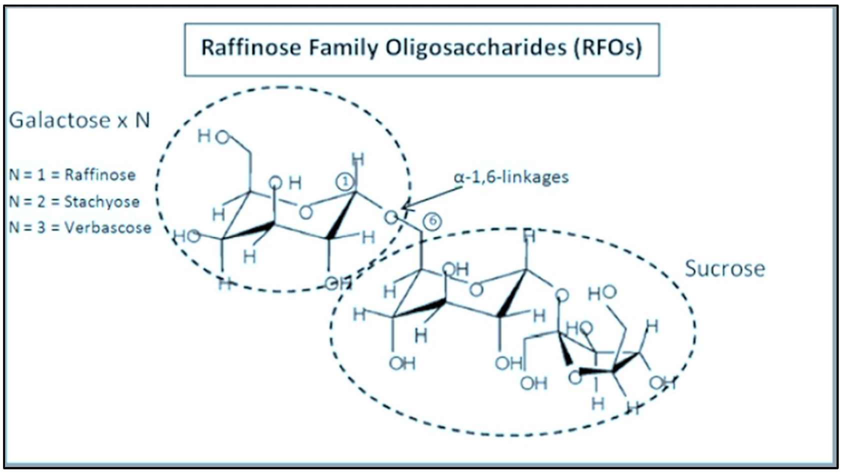

Figure 3. *Molecular structure of raffinose oligosaccharides [94].*

Table 1. *Shows nutritional constraints and their main impacts on nutritional values.*

Nutritional constraints	Their main impacts	References
Phytates	Reduces bioavailability of vital minerals	[149]
Oxalates	Decrease calcium absorption and causes kidney stone formation	[8]
Lectins	Prevent absorption of digestive end products in the small intestine	[53]
Protease inhibitors	Inhibit protein digestive enzymes	[85]
Tannins	Reduce digestibility of dietary protein	[22]
Saponins	Hemolytic activity	[86]
Oligosaccharides	Flatulence in human	[94]

3.2. The Role of Novel Food Processing Technologies for Enhancing Nutritional Quality of Legumes

Food processing techniques bring about changes in the biochemical, nutritional, and sensory characteristics in legumes that enhance their nutritional value by increasing essential amino acids, protein digestibility, amino acid availability, and certain B vitamins. The nutritional profile of legumes is generally improved from approximately 40% up to 98% [36]. It also proves beneficial in reducing nutritional constraints that otherwise would cause interference in the metabolism of certain essential nutrients.

3.2.1. Traditional Processing Methods

(i) Milling

In nature the outer bran in coarse grains are fibrous, bitter, astringent, or colored. Thus, milling is commonly used to separate the bran layer, which is composed of fibrous, bitter, and astringent from the grains to improve its desirability for consumer. Milling is defined as an act or process of grinding, particularly grinding grain into flour or meal [20]. It is an important and intermediate step in post-production of grain. Removing the bran layer from the grain is used to reduce nutritional constraint such as phytic acid, lectins, tannins that are present in the bran of legumes. Since tannins are located mostly in the seed coat of dry seeds, milling process can be removed it easily and improve in the nutritional quality of the protein. However, over milling legumes remove aleuronic layers and germ, which is rich in protein, vitamins, and minerals [61].

(ii) Soaking

Soaking is the first step, followed by many subsequent treatments, such as cooking, germination, and fermentation. It consists of hydrating the seeds in water, usually until they reach maximum weight. The medium in which they are hydrated can be discarded or retained, depending on the subsequent procedure [69]. Numerous studies indicate that soaking can reduce the levels of total sugars, α-galactosides, minerals, phytic acid, and proteolytic enzyme inhibitors because of metabolic processes taking place that usually affect the soluble carbohydrate metabolic processes and riboflavin contents [129].

Effects of soaking in reduction of nutritional constraints during soaking depends on temperature, pH, types of soaking media, type of legumes and time of soaking and solubility of components [36]. Soaking legumes in distilled water, 1% NaHCO3 and mixed salt solutions reduced total phenols, tannins, and phytates by 33%, 35%, and 21% respectively [36]. However, [144] reported that soaking legumes in simple tap water not reduce the tannin contents. Overnight soaking of chickpea reduces the concentration of α –galactosides by 16 - 27% [47].

(iii) Cooking / Boiling

Cooking is usually done prior preparation and consumption of legumes. It imparts a tender and soft texture, enhances palatability, and digestibility of the seeds. It also facilitates the leaching of nutritional constraints into the cooking medium and then the leached nutritional constraint is discarded with cooking water [143]. Cooking decrease, the phytic acid content of the legumes in that way enhances the bioavailability of iron, zinc, and calcium for absorption by body. Moreover cooking successfully decrease heat-labile nutritional constraints such as trypsin inhibitor, lectin and volatile compounds present legumes thereby enhancing protein quality of the cooked product [134]. Increasing temperature during cooking unfolds protein structure for this reason, it susceptible to digestive enzymes.

Cooking soybean for 30 min effectively reduce up to 82.2% compared to raw soybean of trypsin inhibitor (23.73 mg/100 g) [35]. The other finding shows cooking for 60 min resulted in mean decrease of 49.6% and 46.3% reduction of RFOs in horse gram and green gram respectively. [62] found that cooking peas at 100°C for 40 min enhances IVPD as compared to uncooked because of the complete elimination of the trypsin inhibitor and reduction of tannins and phytic acid contents. [120] found that 40% reduction of tannins after pressure-cooking. On the other hand, cooking for long time can reduce protein quality and causes loss of vitamins minerals, and protein quality itself. Therefore, processing parameters for plant protein cooking are usually set to around 100°C and time varies from 10 to 60 min to maintain nutritional values [11].

Boiling of legumes usually done at 100°C for some minutes in order to make the seed tenderize and improve sensory properties of legumes and makes more acceptable for consumer. Boiling process eliminates thermo-labile nutritional constraints like trypsin inhibitors, hemagglutinin tannins present in legume seeds [113]. [33] was studied the effects of boiling pigeon peas with high heat on lectins, tannins, and protease inhibitors. They observed that boiling pigeon peas for 80 minutes reduced protease inhibitors by 70%, lectins by 79% and tannin by 69%. [107] observed that boiling successfully reduces oxalate and saponin contents of lima bean (*Phaseolus lunatus*) flour as compared to raw lima bean flour. Thus, cooking and boiling great role in enhancement of nutritional quality of legumes by reducing nutritional constraints specially those are eat heat liable and water-soluble.

(iv) Roasting

This process involves use of dry heat to legume seeds using a hot pan or dryer at a temperature of 150 -200°C in the presence or absence of salt or ash for a short time, relying on the seed. The reason of roasting legumes prior consumption is to enhance its palatability and edibility as well as to develop unique color, flavor, texture, and appearance of seeds. It is also an essential system to reduce nutritional constraints found in the legumes specially that are heat liable. Different author was reported that roasting method partially or fully eliminate nutritional constraints such as trypsin inhibitor, hemagglutinin, goitrogenic agents, cyanogenic glucosides, alkaloids, and oligosaccharide [153].

This process also reduces unwanted microorganisms and inactivates the enzymes that promote deterioration of the product during storage. It also improves in vitro digestibility of protein (IVPD) and in vitro digestibility of starch of legumes [69]. It was reported that roasting reduces in vitro digestibility of proteins and starch (formation of resistant starch), and decreases the content of riboflavin, thiamine, and niacin. Thus, roasting enhances the nutritional quality and increases the shelf life of the roasted legumes [69].

(v) Fermentation

Fermentation is an anaerobic and catabolic process where complex molecules are transformed into simple ones by the activities of microorganisms and their enzymes. It is the oldest method of food processing and preservation practiced extensively over the world. At home, fermentation process is accelerated by addition of a starter culture of selected microbes or using back-slopping [65]. Fermentation process creates optimum pH (generally below pH 4.5) which is suitable for the activity of phytases. The optimum pH of phytase for fungal and bacterial origin is between 4.5 to 5.5 and 6.5 to 7.5 respectively [61]. At their optimum condition, phytases degrade the hexa form of phytic acid into IP5, IP4, IP3, IP2, IP1, and myo-inositol. The lowered form of phytic acid (IP-1 to IP-4) has no negative effect on bioavailability of iron, zinc, and calcium [56].

It is the only traditional processing method, which helps in decreasing the phytate content by 90-95% as it creates favorable situation for activity of enzyme phytase [55]. Fermentation also offered optimum pH conditions for enzymatic degradation of tannins, which form complex with protein. It reduces nutritional constraints such as trypsin, amylase inhibitor, phytic acid, and tannins [61]. Fermentation of legumes by lactic acid bacteria reduces more phytatic acid and tannins contrast to spontaneous fermentation [128]. Fermentation, enhances the levels of vitamins (thiamin, riboflavin, niacin, ascorbic acid), minerals (zinc, iron), protein and amino acids, and improves protein digestibility of legumes food [128].

(vi) Germination

The process of germination is an ancient popular practice in many parts of world. It is a natural catabolic process of all higher plants by which the seed comes out of its dormancy when dry seed uptake water using the reserved substances in the cotyledon for embryo development and growth [127]. During germination, reserved nutrients of seed such as protein and starch are breakdown by enzymes. It activates enzymes such as phytase, polyphenol-oxidase, amylases, and proteases naturally found in legumes. These enzymes bring biochemical changes, structural change, and enhance the nutritional value of legumes by reducing many proteinaceous nutritional constraints such as haemagglutinin, amylase, and trypsin inhibitors. It was reported that 18-40% and 33% reduction of α-galactosides in lentils and pigeon pea respectively after germinated for 3 to 4 days [21].

In their study, [71] also reported that green gram, bengal gram and horse gram showed 64.6, 65.1 and 66.2% of IVPD and after germination (72h). As result of reduction of phytate, the bioavailability of mineral improved in germinated legumes. According to [137], germinating of legume seeds for (96 h) caused maximum reduction of trypsin inhibitor (96.33%) > tannin (93.59%) >phenolics (92.43%) >phytic acid (88.06%) and thereby enhances the nutritional quality of legumes.

3.2.2. Novel Food Processing Methods

(i) Extrusion Cooking

Extrusion cooking technology is mainly used for the production of several ready-to-eat products. It is process that combine thermal and mechanical process produce precooked product such as snacks, breakfast cereals, meat and cheese analogues, supplement foods, infant foods and other textured foods [64]. Extruded products are consumer eye-catching due to their convenience, pleasant appearance, and texture. It also applied for producing an array of ready-to-eat legume-added foods [111]. Extrusion cooking is high temperature, short time processing technology in which moistened, expansive, starch and proteinaceous food are plasticized and cooked in a tube by a combination of moisture, pressure, temperature and mechanical shear, ensuing in molecular transformation and chemical reactions [137].

In this method, cooking takes place within an extruder where the product produces its own friction and heat owing to pressure. It is versatility, high productivity, and low operating costs, energy save, and short times cooking method of novel food processing technology [1]. It has ability to break the covalent bonds in biopolymers and structural disruption, which facilitates modification of functional properties of food ingredients and giving texture for them [26]. As compared to other processing techniques, it has little effect on nutritional quality of extruded products.

Owing to heat and powerful mechanical stress extrusion cooking technology, reduces nutritional constraints in legumes such as tannins, phytic acid, trypsin inhibitors, and lectins. Besides this extrusion cooking increase digestibility of starch and proteins of extruded products [57, 112]. In their study [31] also reported that extrusion cooking is the best method to eliminating trypsin, chymotrypsin, a-amylase inhibitors, and hemagglutinin activity without modifying protein content of the legumes. It was found by reductions in phytic acid of 26.73% and 20.75% in extruded faba beans and green bean because of hydrolyzing phytic acid to inositol penta, tetra, and triphosphates [31]. [31] was also similarly found that extrusion cooking significantly ($P<0.05$) reduce the levels of phytic acid, condensed tannins and polyphenols. It considerably increases in vitro digestibility of starches [12].

(ii) Microwave Cooking

Microwave cooking is a heat treatment in which food is passes through microwave radiation. It one of means of cooking food especially in developed countries as it require coast and electricity which my difficult for developing countries. Microwave cooking is high temperature short time (HTST) processing technology. It is faster than pressure-cooking thus used for determination of cooking quality for legumes seed. Microwave heating is increasing and its use for cooking is becoming popular due to the reduction of processing time [62].

Microwave cooking destruct nutritional constraints of the legumes without affecting its original nutritional value of foods like vitamin [36]. Even though it is not studied broadly, microwave cooking reduces nutritional constraints in soybean consequently improved the protein digestibility and quality [71]. The microwave cooking of legume for 15 min resulting in reducing the levels of raffinose family oligosaccharides of tested legumes [10]. Microwave cooking is effective mean of reduction in tannins content of oilseed than other cooking methods [51]. It was found that some nutritional constraints like trypsin inhibitor, a-amylase inhibitor, and lectin were greatly reduced by heat [62].

(iii) Autoclaving

Autoclaving involve cooking foods under pressure. It commonly practiced in many areas of the world for cooking seeds. This novel food processing technology uses heat treatment application. Most food becomes health under this treatment as it destroys food spoilage microorganisms. It is shortened time of cooking. Autoclaving is simple method of deactivating or removing nutritional constraints of the legumes. It reported that autoclaving enhances nutritional quality of legumes by reducing nutritional constraints [121].

Autoclaving considerably decrease tannins, phytic acid, trypsin inhibitors, and oligosaccharides content of legumes [31]. In Autoclaved of Jackbeans for 30 minutes at 121°C and 15 psi were observed maximum the reduction of total free phenolics (78%), tannin (83%), oligosaccharides like raffinose (76%), stachyose (82%), verbascose 980%) and trypsin inhibitor activity (74%) compared to that of raw seeds [32].

Other finding haven shown that, autoclaving cause greater reduction (67%) on polyphenols content followed by roasting (52%), germination (48%), and cooking (44%) [108]. Other previous finding shows that autoclaving at121°C for 60 min reduced the nutritional constraints of rapeseed products from 9 to 43% for phytic acid and from 41 to 67% for tannins [93]. The oxalate content of the raw lima bean flour of 0.27%, was drastically reduced to 0.02% by autoclaving followed by boiling compared to the roasting (0.03%) [7].

(iv) Irradiation

Irradiation process involves exposing food to ionizing radiations like gamma rays emitted from radioisotopes 60 Co and 137 Cs, or high-energy electrons and X-rays produced by machine sources. Gamma irradiation has been recognized as a reliable and safe method for improving the inactivation of nutritional constraints in foods. When soybean was subjected to a radiation dose of 10 kGy, lectin was reduced by 50% [41] which is a significantly higher reduction than with normal processing techniques such as germination, soaking and dehulling (Liener, 1994a). Siddhuraju *et al*. [136] reported that irradiation dose levels of up to 10 kGy on the reduction of various nutritional constraints and improve the nutritional values of foods.

Table 2. *Shows summary of processing and their effects on nutritional constraints.*

Process	Temperature	Time (min)	Legumes type	Reduction in protease inhibitor	Reduction in tannins	Reduction in phytate	Reduction in lectins	References
Autoclave	121°C	-	Legumes seeds	-	33.1-45.7	28-51.6%	-	[120]
Irradiation	-	-	Soybean	-	-	-	50%	[136]
Boiling	100°C	90min	Chickpea	82.27%	48.04%	28.93%	100%	[36]
Soaking	20°C	12hr	Mung bean	15.8%	39.4%	26.7%	49.1%	[120]
Extrusion	High temp	-	Vicia faba	-	54.4	26.7%	-	[12]
Microwave	High temp	15min	Chickpea	80.5%	48.45%	38.02%	100%	[36]
Germination	-	92hr	legume seeds	93.59%	96.33%	88.06%	-	[137]
Fermentation	-	-	Legumes	-	-	83%	-	[31]

4. Conclusion and Future Prospects

Although legumes are indispensable food in terms of nutritional, medicinal and economical point of view for the all population of the worlds; their extensive utilization, and consumption is hindered because of the presence of nutritional constraints. These nutritional constraints reduce the mineral absorption, protein digestibility, and causing toxicity and health disorder when eaten in high concentration. All this makes the consumption of legumes in human and animal senseless if intervention is not taken. Different studies have shown processing legumes, seeds before consumption have effects on the level nutritional constraint found in the legumes. Traditional food processing can reduce nutritional constraints, yet some of those such as milling, roasting and cooking can be negatively affect heat sensitive nutrients.

Different review retrieved has shown among various processing techniques fermentation and germination has significant effects in enhancing the bioavailability and digestibility of proteins by reducing of nutritional constraints of legumes. Microwave, extrusion, and autoclave cooking are cost effective in saving time and energy required for cooking and reduces nutritional constraint found in the legumes. However, there is limited information, about different novel food processing technologies roles in reduction nutritional constraints of legumes and improving their nutritional values. Thus, more studies need to provide reliable and quantitative information on role novel food processing technologies roles in legumes.

Generally, this review provides key information on nutritional constraints of legumes and role novel food processing on reduction of nutritional constraints at same time their role improving nutritional values of legumes foods.

List of Abbreviations

UN	United Nation
DM	Dry matter
RFO	Raffinose family oligosaccharide
FAO	Food and Agricultural Organization
Mt	Million ton
WHO	World Health Organization

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