Methods for Processing Pulses to Optimize Nutritional Functionality and Maximize Amino Acid Availability in Foods and Feeds

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ABSTRACT

Pulses are a versatile group of nutrient-dense leguminous seeds. Alternatives to animal protein are required to meet the protein demands of a continuously growing human population. While pulses boast a protein content that is double that of cereal grains, their digestibility is lower than that of animal proteins, and they tend to be limiting in either sulfur amino acids (AA) or tryptophan. Additionally, pulses contain antinutritional factors (ANFs [e.g., phytate]) that impact the absorption of nutrients; therefore, pulses cannot be consumed in their native state and must be processed before consumption. Common processing methods can include, but are not limited to, dehulling, milling, soaking, and cooking (e.g., boiling and roasting). Many processing methods and conditions can improve protein content and digestibility, the indispensable AA content of pulses, and reduce or eliminate ANFs. However, it appears that processing conditions and pulse type can affect the degree to which processing modifies protein and AA contents, digestibility, and, ultimately, protein quality. Thus, depending on the food application, specific processing methods may be more beneficial compared with others and should be considered independent of the pulse chosen for the formulation of foods and feeds.

Pulses are a group of leguminous seeds that are consumed globally as a staple food. Pulses are defined by the Food and Agriculture Organization of the United Nations (16) as "crops harvested solely for dry seed, excluding crops harvested green for food (e.g., green beans), oil extraction (e.g., soybean or peanuts), or crops grown and harvested exclusively for sowing purposes (e.g., alfalfa seeds)" and are classified into 11 main categories (Table I) (16).

The global population is expected to increase to 8.1 billion by 2025, and 9.6 billion by 2050 (33). Due to continuous growth in the global population and a potential imbalance in food production due to climate change, there is a risk for future food shortages. Furthermore, both developed and developing countries are encountering nutritional concerns that require solutions. In developing countries, protein energy malnutrition is of particular concern, while the imbalance of macro- to micronutrient intake and excessive calorie intake are the primary issues in developed countries (8). Consequently, there is enormous potential and drive in the agri-food industry to investigate alternative protein sources, including plant-based proteins (2).

Pulses are a source of plant protein. However, the digestibility of proteins in pulses is generally lower in their natural form compared with animal sources (38). Pulses also contain antinutritional factors (ANFs [e.g., phytate]) that can reduce the availability and utilization of nutrients. Additionally, pulses cannot be consumed in their raw state, and must be processed and/or cooked before consumption. Different processing techniques exist on household and industrial scales, including, but not limited to, dehulling, boiling, roasting, and extrusion. These techniques affect the nutrient composition and digestibility of pulses (23) and result in different products that may require additional

Table I. Classification of pulses[a]

Pulse Class	Common Name	Botanical Name
Beans, dry (*Phaseolus* spp. and *Vigna* spp.)	Kidney, haricot	*P. vulgaris*
	Lima, butter bean	*P. lunatus*
	Adzuki bean	*V. angularis*
	Mung bean, golden, green gram	*V. radiata*
	Black gram, urd	*V. mungo*
	Scarlet runner bean	*P. coccineus*
	Rice bean	*V. umbellata*
	Moth bean	*V. acontifolia*
	Tepary bean	*P. acutifolius*
Broad beans (faba), dry (*Vicia* spp.)	Horse bean	*V. faba equina*
	Broad bean	*V. faba*
	Field bean	*V. faba*
Peas, dry (*Pisum* spp.)	Garden pea	*P. sativum*
	Field pea	*P. arvense*
Chickpeas	Chickpea, Bengal gram, garbanzos	*Cicer arietinum*
Cowpeas, dry	Cowpea, blackeye pea/bean	*V. unguiculata*
Pigeon peas	Arhar/toor, cajan pea, Congo bean	*Canjanus cajan*
Lentils	Lentil	*Lens culinaris*
Bambara beans	Earth pea	*V. subterranea*
Vetches	Common vetch	*Vicia sativa*
Lupins	Lupin	*Lupinus* spp.
Pulses NES (not elsewhere specified, minor pulses)	Lablab or hyacinth bean	*Lablab purpureus*
	Jack or sword bean	*Canavalia ensiformis*
	Winged bean	*Canavalia gladiate*
	Guar bean	*Psophocarpus teragonolobus*
	Velvet bean	*Mucuna pruriens* var. *utilis*
	Yam bean	*Pachyrrizus erosus*

[a] Data source: Food and Agriculture Organization of the United Nations (16).

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processing. Thus, this article aims to address various methods used to process pulses and the effects of processing on nutritional functionality, amino acid (AA) bioavailability, and ANFs in foods and feeds.

Protein and AA Composition of Pulses

The protein content of pulses is generally between 15 and 30% but can be higher in certain types of pulses (e.g., 32–44% in lupin) (22,32). Pulses contain almost double the amount of protein compared with cereal grains (32). The AA profile of pulses tends to be similar across different pulse types. Compared with animal proteins, plant proteins tend to contain lower levels of one or more indispensable AAs. Pulses have a higher lysine content compared with cereal grains, in which lysine tends to be the limiting AA (32,38). Conversely, pulses are relatively poor in sulfur AAs (methionine and cysteine) and tryptophan; in comparison, cereal grains tend to be sufficient in these AAs (38). Since pulses tend to be poor in one or more indispensable AAs, they often have a lower protein quality than that of animal protein sources (38).

ANFs in Pulses

Although pulses possess a robust nutritional composition, they also contain ANFs. Common ANFs in pulses include protease and amylase inhibitors, lectins, phytate, phenolic compounds, phytosterols, and saponins (31). Of the ANFs intrinsic to pulses, trypsin and chymotrypsin inhibitors, tannins, and phytate can all decrease nutrient availability (20). The inhibitors of serine proteases (trypsin and chymotrypsin) are the most important enzyme inhibitors in pulses with respect to protein availability (7). These enzyme inhibitors decrease the digestibility of proteins and, subsequently, the availability of AA for absorption (31). Phytate, while primarily associated with minerals, can also bind and decrease the availability of proteins in the gastrointestinal tract (31). Tannins also can negatively affect protein digestibility through the precipitation of proteins in the gastrointestinal tract (20,31).

Processing and Its Effects on Protein, AAs, and ANFs

Dehulling. The effects of dehulling on protein and indispensable AA contents and in vitro protein digestibility are presented in Table II. Dried pulses can be consumed whole or can undergo dehulling to remove the seed coat (30). Pulses can be dehulled using either a dry or wet method. The method employed to dehull pulses is often dictated by pulse type (30). The purpose of dehulling dried seeds is to improve digestibility and reduce cooking time (30). In general, dehulling results in an increase in protein content (3,19,25,34,35) and has been reported to increase in vitro protein digestibility by 2–16% in a variety of pulses (3,19).

Soaking and Cooking via Boiling and Pressure Cooking. The effects of soaking, boiling, and pressure cooking on protein and indispensable AA contents and in vitro protein digestibility are presented in Table III. Soaking is a common pretreatment for most pulses prior to cooking. Traditionally, pulses are soaked in cold water for 8–12 hr prior to cooking (boiling and pressure cooking) (22). However, other methods of soaking involve high-temperature soaking and soaking in salt or alkali solutions (22). The most common methods of cooking pulses involve boiling or pressure cooking. Soaking and cooking of pulses appears to impact protein content differently depending on method and the specific pulse. There is conflicting data on the effects of soaking and cooking pulses, with increases reported in the protein contents of black gram, peas, chickpeas, beans, and lentils (10,28,35,36,37), whereas other studies have reported no changes and decreases in the protein contents of black gram, chickpeas, peas, kidney beans, faba beans, and mung beans. (1,14,24,28). Most changes appear to be marginal, however.

Table II. Effects of dehulling on protein and amino acid contents and in vitro protein digestibility in a variety of pulses

		Effects of Processing			
Pulse	Processing Parameters	Protein Content (% Change)	IAA[a] Content (% Change)	In Vitro Protein Digestibility (% Change)	Reference
Chickpea	Dehulled after germination via dehusker (versatile dhal mill)	Increased (5%)	–	Increased (13.4%)	19
Cowpea	Dehulled after germination via dehusker (versatile dhal mill)	Increased (2.7%)	–	Increased (13.4%)	19
Faba bean	Manual removal	Increased (4%)	–	No change	3
Field peas	Six varieties of peas dehulled using grain testing mill	Increased all varieties (1–2%)	–	–	35
Green gram	Dehulled after germination via dehusker (versatile dhal mill)	Increased (2.2%)	–	Increased (16.7%)	19
Horse gram	Twelve varieties dehulled manually after soaking	Increased in 3 of 12 varieties (0.15–3%; no change in 9 of 12 varieties	–	–	25
Kidney bean	Manual removal	Increased (1.5%)	–	Increased (3.5%)	3
Lentil	Dehulled after germination via dehusker (versatile dhal mill)	Increased (3.1%)	–	Increased (13.2%)	19
	Four varieties dehulled using a grain testing mill after increasing moisture content	Increased (0.5–1%)	–	–	34
	Eight varieties dehulled using a grain testing mill after increasing moisture content	Increased all varieties (0.5–2%)	–	–	36
Mung bean	Manual removal postsoaking	No change	Slight increase in all IAA	Increased (4.1%)	24

[a] Indispensable amino acids.

Table III. Effects of soaking and cooking (boiling and pressure) on protein and amino acid contents and in vitro protein digestibility in a variety of pulses

		Effects of Processing			
Pulse	Processing Parameters	Protein Content (% Change)	IAA[a] Content (% Change)	In Vitro Protein Digestibility (% Change)	Reference
Soaking					
Black gram	50 g of seed soaked in 1,250 mL of distilled water at room temperature for 4 hr; after soaking, boiled at a 1:5 (w/v) ratio	No change	–	–	28
	50 g of seed soaked in 1,250 mL of distilled water at room temperature for 4 hr; after soaking, cooked in an autoclave (1:5, w/v) at 121°C for 10, 20, 40, 60, and 90 min and at 128°C for 20 min	Increased at 20, 40, 60, and 90 min at 121°C and at 20 min at 128°C	–	Increased	28
Chickpea	Soaked in distilled water (1:5, w:v) at 30°for 16 hr	Decreased (0.2%)	–	Increased (1%)	1
	50 g of seed soaked in 1,250 mL of distilled water at room temperature for 4 hr; after soaking, boiled at a 1:5 (w/v) ratio	No change	–	–	28
	50 g of seed soaked in 1,250 mL of distilled water at room temperature for 4 hr; after soaking, cooked in an autoclave (1:5, w/v) at 121°C for 10, 20, 40, 60, and 90 min and at 128°for 20 min	Increased at 20, 40, 60, and 90 min at 121°C and at 20 min at 128°C	–	Increased	28
Cowpea	Soaked in tap water at room temperature (1:5, w/v) until maximum seed weight and hydration achieved	–	Increased total IAA	Increased	22
Faba bean	Soaked in distilled water (1:5, w:v) at 30°for 16 h	Decreased (0.2%)	–	Increased (1%)	1
	Soaked for 12 hr at 30°C in double deionized water (1:5, w/v)	No change	–	Increased (0.5%)	3
Field peas	Varieties of peas soaked for 24 hr at room temperature (1:4, seed/water, w/w)	Increased in 4 of 6 varieties (0.5–1%)	–	–	35
Kidney bean	Soaked in distilled water (1:5, w:v) at 30°C for 16 hr	Decreased (0.2%)	–	Increased (1%)	1
	Soaked for 12 hr at 30°C in double deionized water (1:5, w/v)	No change	–	Increased (3.3%)	3
	Soaked in tap water at room temperature (1:5, w/v) until maximum seed weight and hydration achieved	–	Increased total IAA	Increased	22
Lentil	50 g of seed soaked in 1,250 mL of distilled water at room temperature for 4 hr; after soaking, boiled at a 1:5 (w/v) ratio	No change	–	–	28
	50 g of seed soaked in 1,250 mL of distilled water at room temperature for 4 hr; after soaking, cooked in an autoclave (1:5, w/v) at 121°C for 10, 20, 40, 60, and 90 min and at 128°C for 20 min	Increased at 20, 40, 60, and 90 min at 121°C and at 20 min at 128°C	–	Increased	28
Mung bean	Soaked in distilled water (1:10, w/v) for 12 hr at room temperature	Decreased (0.5%)	Decreased isoleucine, tryptophan, total sulfur AA, and lysine	Increased (7.2%)	24
Pea	Soaked in distilled water (1:5, w:v) at 30°C for 16 hr	Decreased (0.2%)	–	Increased (1%)	1
	Soaked in tap water at room temperature (1:5, w/v) until maximum seed weight and hydration achieved	–	Increased total IAA	Increased	22

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[a] Indispensable amino acids.

Table III. *(Continued from previous page)*

Red kidney bean	50 g of seed soaked in 1,250 mL of distilled water at room temperature for 4 hr; after soaking, boiled at a 1:5 (w/v) ratio	No change	–	–	28
	50 g of seed soaked in 1,250 mL of distilled water at room temperature for 4 hr; after soaking, cooked in an autoclave (1:5, w/v) at 121°C for 10, 20, 40, 60, and 90 min and at 128°C for 20 min	Increased at 20, 40, 60, and 90 min at 121°C and at 20 min at 128°C	–	Increased	28
White kidney bean	50 g of seed soaked in 1,250 mL of distilled water at room temperature for 4 hr; after soaking, boiled at a 1:5 (w/v) ratio	No change	–	–	28
	50 g of seed soaked in 1,250 mL of distilled water at room temperature for 4 hr; after soaking, cooked in an autoclave (1:5, w/v) at 121°C for 10, 20, 40, 60, and 90 min and at 128°C for 0 min	Increased at 20, 40, 60, and 90 min at 121°C and at 20 min at 128°C	–	Increased	28
Cooking: Boiling and pressure					
Bengal gram	Boiled for 30 min in open vessel	–	Decreased methionine, cysteine, threonine, tryptophan, and lysine	–	18
	Pressure cooking (15 lb of pressure) for 10 min at 120°C	–	Decreased methionine, cysteine, threonine, tryptophan, and lysine	–	18
Black gram	Boiled for 30 min in open vessel	–	Decreased methionine, cysteine, threonine, tryptophan, and lysine	–	18
	Pressure cooking (15 lb of pressure) for 10 min at 120°C	–	Decreased methionine, cysteine, threonine, tryptophan, and lysine	–	18
Chickpea	Soaked seeds drained, mixed with oil and salt, and boiled for 3 hr	Increased (4.51%)	Decreased lysine (0.38%)	–	10
	Soaked prior to boiling (1:10, w/v) for ~90 min	No change	–	Increased (4.91%)	14
	Soaked in tap water (1:10, w/v) at 15 lb of pressure prior to autoclaving at 121°C for ~35 min	No change	–	Increased (5.79%)	14
	Soaked seeds drained and cooked in boiling water bath (predetermined cook time by variety)	Increased (0.5–1%)	–	–	37
Cowpea	Soaked seed (4 hr; 1:5, w/v) boiled (1:5, w/v) until 50% of seeds soft	–	Increased total IAA	Increased (5%)	22
	Seeds autoclaved with distilled water (1:5, w/v) at 15 psi and 121°C for 20 min	–	Increased total IAA	Increased (8%)	22
Field peas	Seven varieties of peas; soaked seeds drained and cooked in boiling water bath (predetermined cook time by variety)	Increased (0.5–2%)	–	–	35
Great northern bean	Soaked seeds drained and cooked in boiling water bath (predetermined cook time by variety)	Increased (0.9%)	–	–	37
Green gram	Boiled for 30 min in open vessel	–	Decreased methionine, cysteine, threonine, tryptophan, and lysine	–	18
	Pressure cooking (15 lb of pressure) for 10 min at 120°C	–	Decreased methionine, cysteine, threonine, tryptophan, and lysine	–	18
Kidney bean	Soaked seeds drained, mixed with oil and salt, and boiled for 3 hr	Increased (4.83%)	Decreased all IAA (0.1–0.33%), except histidine	–	10
	Soaked seed (4 hr; 1:5, w/v) boiled (1:5, w/v) until 50% of seeds soft	–	Increased total IAA	Increased (5%)	22

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Table III. *(Continued from previous page)*

	Seeds autoclaved with distilled water (1:5, w/v) at 15 psi and 121°C for 20 min	–	Increased total IAA	Increased (8%)	22
	Soaked seeds drained and cooked in boiling water bath (predetermined cook time by variety)	Increased (1%)	–	–	37
Lentil	Soaked seeds drained, mixed with oil and salt, and boiled for 3 hr	No change	Decreased isoleucine (0.13%), leucine (0.11%), and valine (0.26%) Increased lysine (0.34%) and phenylalanine (0.22%)	–	10
	Eight varieties; soaked seeds drained and cooked in distilled water (predetermined cook time by variety)	Increased all varieties (0.5–1%)	–	–	36
	Soaked prior to boiling (1:10, w/v) for ~90 min	Decreased (0.7%)	Decreased isoleucine, tryptophan, total sulfur AA, and lysine Increased leucine	Increased (7.6%)	24
Mung bean	Soaked prior to autoclaving in tap water (1:10, w/v) at 15 lb of pressure at 121°C for ~35 min	Decreased (0.8%)	Decreased isoleucine, tryptophan, total sulfur AA, and lysine Increased leucine	Increased (8.5%)	24
Pea	Soaked seed (4 hr; 1:5, w/v) boiled (1:5, w/v) until 50% of seeds soft	–	Increased total IAA	Increased (5%)	22
	Seeds autoclaved with distilled water (1:5, w/v) at 15 psi and 121°C for 20 min	–	Increased total IAA	Increased (8%)	22
Pinto bean	Soaked seeds drained and cooked in boiling water bath (predetermined cook time by variety)	Increased (1.5%)	–	–	37
Red gram	Boiled for 30 min in open vessel	–	Decreased methionine, cysteine, threonine, tryptophan, and lysine	–	18
	Pressure cooking (15 lb of pressure) for 10 min at 120°C	–	Decreased methionine, cysteine, threonine, tryptophan, and lysine	–	18

With respect to the impact on AA composition, boiling- and pressure cooking-induced changes in the indispensable AA contents of pulses appear to vary. Boiling and pressure cooking are reported to decrease indispensable and dispensable AA in beans (10,24) and decrease lysine, methionine, and threonine contents in chickpeas and Bengal gram, respectively (10,18). Boiling is also reported to decrease leucine, isoleucine, and valine but increase lysine and phenylalanine in lentils (10). In contrast, Khattab et al. (22) reported increases in the total indispensable AA contents of boiled and pressured-cooked Canadian and Egyptian pigeon peas, kidney beans, and peas.

With respect to ANFs, soaking can reduce phytate (4–32% reduction) and tannin (3–70% reduction) contents depending on duration, solution, and pulse type (26). Cooking pulses, either by boiling or pressure cooking, is effective at reducing phytate (3.7–66% reduction), tannins (8–93% reduction), and trypsin inhibitor activity (45–100% reduction), ultimately improving the nutritional status of the pulse (26).

Fermentation. The effects of fermentation on protein and indispensable AA contents and in vitro protein digestibility are presented in Table IV. Fermentation is another traditional method employed to optimize digestibility of pulses (23). The microorganisms used during fermentation produce enzymes capable of breaking down protein into AA and peptides (13). Chitra et al. (12) reported an increase in in vitro protein digestibility in chickpeas, pigeon peas, mung beans, and urd beans fermented with lactic acid bacteria. Active yeast fermentation improved the protein chemical score and increased the total indispensable AA contents of cowpeas, peas, and kidney beans (22). Conversely, fermentation with *Lactobacillus plantarum* reduced the sulfur AA content of a pea protein concentrate (9). Fermentation is reported to decrease phytate, tannin, and trypsin inhibitor activity, thereby improving nutritional status in a variety of pulses (26). These results suggest that selection of bacterium is important and that microorganisms that metabolize sulfur AA to a lesser extent should be considered to reduce ANFs and improve AA composition of fermented pulse products.

Germination. The effects of germination on protein and indispensable AA contents and in vitro protein digestibility are presented in Table V. Germination, or sprouting, of pulses is primarily employed to improve nutritional content. Germination involves soaking the whole seed (12–24 hr), draining, and allowing the seeds to germinate (23). Protein content is generally reported to increase during germination (11,17,21); however, El-Adawy et al. (15) reported a decrease in the protein contents of germinated mung beans, peas, and lentils, and Pal et al. (25) reported no change or decreases in the protein content of horse gram. Germination of pulses has also been reported to increase in vitro protein digestibility and reduce trypsin inhibitor activity and phytate (12,25). Contrasting results have been reported for the effects of germination on AA content in pulses. Researchers have reported increases in the indispensable AA contents of germinated pinto beans, lupin, and mung beans (5,11,24), whereas Fouad and Rehab (17) reported an increase

Table IV. Effects of fermentation on protein and amino acid contents and in vitro protein digestibility in a variety of pulses

Pulse	Processing Parameters	Effects of Processing			Reference
		Protein Content (% Change)	IAA[a] Content (% Change)	In Vitro Protein Digestibility (% Change)	
Black gram	Soaked dhal (4 hr, 31°C) ground and transferred to tightly covered bowl overnight (16 hr) to ferment at room temperature (31°C); postfermentation, batter steamed for 5 min	–	Decreased methionine, cysteine, threonine, tryptophan, and lysine	–	18
Chickpea	Soaked and ground dhal mixed with 1.5% (w/v) inoculum (lactic acid bacteria) and fermented for 24 hr in an incubator at 30°C	Increased (0.5%)	–	Increased	12
Cowpea	Dry active yeast (3 g/100 g of seeds) dissolved in water and added to ground seeds and fermented for 24 hr at room temperature	–	Increased total IAA	Increased (3%)	22
Kidney bean	Dry active yeast (3 g/100 g of seeds) dissolved in water and added to ground seeds and fermented for 24 hr at room temperature	–	Increased total IAA (except in Canadian variety)	Increased (2–3%)	22
Mung bean	Soaked and ground dhal mixed with 1.5% (w/v) inoculum (lactic acid bacteria) and fermented for 24 hr in an incubator at 30°C	Increased (0.7%)	–	Increased	12
Pea	Dry active yeast (3 g/100 g of seeds) dissolved in water and added to ground seeds and fermented for 24 hr at room temperature	–	Increased total IAA (except in Canadian variety)	Increased (2–3%)	22
Pea protein concentrate	Pea protein concentrate inoculated with *Lactobacillus plantarum* and fermented for 11 hr under anaerobic conditions at 32°C	–	Decreased sulfur AA score from 0.84 to 0.66	Increased (3%)	9
Pigeon pea	Soaked and ground dhal mixed with 1.5% (w/v) inoculum (lactic acid bacteria) and fermented for 24 hr in an incubator at 30°C	Increased (1.5%)	–	Increased	12
Urd bean	Soaked and ground dhal mixed with 1.5% (w/v) inoculum (lactic acid bacteria) and fermented for 24 hr in an incubator at 30°C	Increased (0.3%)	–	Increased	12

[a] Indispensable amino acids.

in lysine content but a reduction in sulfur AA content in germinated lentils.

Thermal Treatments. *Micronization.* Pulses may also be exposed to high-temperature cooking, including micronization, roasting, and extrusion. The effects of micronization on protein and indispensable AA contents and in vitro protein digestibility are presented in Table VI. Micronization is a relatively new processing method that employs high-intensity infrared radiation to heat and cook seeds in a short period of time (23). Micronization of pea protein flour had no effect on protein content (29). When Canadian and Egyptian varieties of cowpeas, kidney beans, and peas were micronized, the indispensable AA contents (except for Canadian peas) and protein quality parameters (e.g., protein quality score) increased (22). In the same study, micronization decreased in vitro protein digestibility, which was attributed to Maillard reactions between reducing sugars and protein, as well as to thermal cross-linking of AA (22). Micronization has been reported to significantly decrease phytate and trypsin inhibitor activities and decrease tannin content, although significant decreases in tannin content appear to be dependent on pulse type (26).

Roasting. The effects of roasting on protein and indispensable AA contents and in vitro protein digestibility are presented in Table VII. Roasting or toasting of pulses is achieved by exposing the seeds to a dry heat between 150 and 200°C (23) and has been reported to increase the protein contents of pinto beans, chickpeas, peas, and lentils (5,6). Similar to micronization, roasting of Canadian and Egyptian cowpea, kidney bean, and pea varieties increased indispensable AA content (except Canadian kidney beans) (22). There are conflicting reports on the effects of roasting on in vitro protein digestibility and indispensable AA content, with both increases and decreases reported (12,18,22). Roasting of pulses decreases phytate and trypsin inhibitor contents, and, similar to micronization, significant decreases in tannin content appear to be pulse dependent (26).

Extrusion. The effects of extrusion on protein and indispensable AA contents and in vitro protein digestibility are presented in Table VIII. Extrusion is often utilized when pulses are used as an ingredient in food products such as snack foods (23). Extrusion involves continuous high-pressure and high-temperature cooking, which denatures proteins and inactivates enzymes (23). The effects of extrusion on protein content vary; changes generally appear to be based on processing conditions and pulse type (1,3,4,22). Extrusion has been determined to decrease phytate, tannin, and trypsin inhibitor activities in a variety of pulses, including chickpeas, faba beans, kidney beans, and peas (1,3,4). Alonso et al. (4) reported decreases in the indispensable AA histidine, methionine, and tryptophan in peas. Additionally, extrusion is effective at increasing in vitro protein digestibility in faba beans, kidney beans, and lentils (3,27).

Considerations and Conclusions

In this article we discussed common processing methods utilized for pulse ingredients. Pulses are an attractive protein alternative to animal proteins as the agri-food industry moves toward sustainable sources of proteins. Pulses are nutrient-dense seeds that have high protein contents. Generally, pulses require some form of processing prior to consumption to improve their nutri-

Table V. Effects of germination on protein and amino acid contents and in vitro protein digestibility in a variety of pulses

Pulse	Processing Parameters	Effects of Processing: Protein Content (% Change)	Effects of Processing: IAA[a] Content (% Change)	Effects of Processing: In Vitro Protein Digestibility (% Change)	Reference
Bengal gram	Soaked for 8 hr then spread on trays and covered with thick moist cloth; germinated in dark room at room temperature (31°C) for 16 hr	–	Decreased methionine, tryptophan, and lysine	–	18
Chickpea	Seeds soaked in distilled water for 12 hr at room temperature, drained, and transferred to dish lined with wet filter paper; germinated until uniform sprouts measured 1.5 cm	Increased (6%)	–	Increased	12
	Soaked in distilled water (1:10, w/v) for 12 hr at room temperature, drained, and transferred between thick layers of cotton cloth; germinated for 72 hr	Increased (1.89%)	–	Increased (4.02%)	14
	Washed and soaked (4–5 vol water) at 22–25°C for 12 hr; seeds drained and germinated under wet muslin cloth for 24 hr	Increased (2.1%)	–	Increased (9.2%)	19
Cowpea	Washed and soaked (4–5 vol water) at 22–25°C for 12 hr; seeds drained and germinated under wet muslin cloth for 24 hr	Increased (1.5%)	–	Increased (9.1%)	19
Faba bean	Rinsed with bi-deionized water, transferred to wet filter paper, and germinated in aired dark incubator for 24, 48, and 72 hr at 25°C	No change	–	Increased (2–8%)	3
Green gram	Washed and soaked (4–5 vol water) at 22–25°C for 12 hr; seeds drained and germinated under wet muslin cloth for 24 hr	Increased (1.4%)	–	Increased (11.7%)	19
Horse gram	Washed and soaked seeds (1:5, w/v) for 12 hr at 25–30°C; seeds drained and germinated under wet muslin cloth for 48 hr	Decreased in 1 of 12 varieties (2%); No change in 11 of 12 varieties	–	–	25
Kidney bean	Rinsed with bi-deionized water, transferred to wet filter paper, and germinated in aired dark incubator for 24, 48, and 72 hr at 25°C	Increased at 72 hr (0.7%)	–	Increased (5–10%)	3
Lentil	Seeds soaked in tap water for 12 hr at room temperature (3:10, w/v) then germinated between thick layers of cotton cloth for 72 and 120 hr in the dark at room temperature	Decreased (1–4%)	–	–	15
	Soaked in distilled water (1:10, w/v) for 12 hr at room temperature, drained, and transferred between thick layers of cotton cloth; germinated for 3, 4, 5, and 6 days (watered every day)	Increased (2–3%)	Increased lysine (0.2%) Decreased sulfur AA (0.3–0.5%)	–	17
	Washed and soaked (4–5 vol water) at 22–25°C for 12 hr; seeds drained and germinated under wet muslin cloth for 24 hr	Increased (2%)	–	Increased (9.5%)	19
Lupin	10 g of seeds soaked in 50 mL of distilled water for 6 hr then germinated in the dark for 48, 72, and 96 hr at 15 and 24°C	–	Increased IAA	–	11
Mung bean	Seeds soaked in distilled water for 12 hr at room temperature, drained, and transferred to dish lined with wet filter paper; germinated until uniform sprouts measured 1.5 cm	Increased (4%)	–	Increased	12
	Seeds soaked in tap water for 16 hr at room temperature (3:10, w/v) then germinated between thick layers of cotton cloth for 72 and 120 hr in the dark at room temperature	Decreased (2–4%)	–	–	15
	Soaked in distilled water (1:10, w/v) for 12 hr at room temperature, drained, and transferred between thick layers of cotton cloth; germinated for 72 hr	Increased (2.5%)	Slight increase in total IAA	Increased (8.9%)	24
Pea	Seeds soaked in tap water for 19 hr at room temperature (3:10, w/v) then germinated between thick layers of cotton cloth for 72 and 120 hr in the dark at room temperature	Decreased (2–4%)	–	–	15

(Continued on next page)

[a] Indispensable amino acids.

Table V. *(Continued from previous page)*

Pigeon pea	Seeds soaked in distilled water for 12 hr at room temperature, drained, and transferred to dish lined with wet filter paper; germinated until uniform sprouts measured 1.5 cm	Increased (2.5%)	–	Increased	12
Pinto bean	Seeds arranged in layers of sawdust and wetted daily; seeds were picked when sprouts measured 1 cm	Increased (0.5%)	Increased IAA except isoleucine and leucine	–	5
Urd bean	Seeds soaked in distilled water for 12 hr at room temperature, drained, and transferred to dish lined with wet filter paper; germinated until uniform sprouts measured 1.5 cm	Increased (2.5%)	–	Increased	12

Table VI. Effects of micronization on protein and amino acid contents and in vitro protein digestibility in a variety of pulses

		Effects of Processing			
Pulse	Processing Parameters	Protein Content (% Change)	IAA[a] Content (% Change)	In Vitro Protein Digestibility (% Change)	Reference
Cowpea	Tempered seeds heated to 90°C using a small experimental benchtop micronizer	–	Increased total IAA	Decreased (2%)	22
Kidney bean	Tempered seeds heated to 90°C using a small experimental benchtop micronizer	–	Increased total IAA	Decreased (2–3%)	22
Pea	Tempered seeds heated to 90°C using a small experimental benchtop micronizer	–	Increased total IAA (except in Canadian variety)	Decreased (2–3%)	22
Yellow pea flour	Tempered peas exposed to infrared heat using laboratory-scale micronizer at 110–115°C and subsequently milled	No change	–	–	29

[a] Indispensable amino acids.

Table VII. Effects of roasting on protein and amino acid contents and in vitro protein digestibility in a variety of pulses

		Effects of Processing			
Pulse	Processing Parameters	Protein Content (% Change)	IAA[a] Content (% Change)	In Vitro Protein Digestibility (% Change)	Reference
Bengal gram	Roasted on iron pan for 10 min at 160°C	–	Decreased methionine, cysteine, threonine, tryptophan, and lysine	–	18
Black gram	Roasted on iron pan for 10 min at 160°C	–	Decreased methionine, cysteine, threonine, tryptophan, and lysine	–	18
Chickpea	Whole seeds roasted in sand bath at 200°C for 2 min	No change	–	Increased	12
Cowpea	Roasted on sand bath at 180°C for 15 min	–	Increased total IAA	Decreased (4–5%)	22
Green gram	Roasted on iron pan for 10 min at 160°C	–	Decreased methionine, cysteine, threonine, tryptophan, and lysine	–	18
Kidney bean	Roasted on sand bath at 180°C for 20 min	–	Increased total IAA (except in Canadian variety)	Decreased (5–6%)	22
Mung bean	Whole seeds roasted in sand bath at 200°C for 2 min	Decreased (0.4%)	–	Increased	12
Pea	Roasted on sand bath at 180°C for 15 min	–	Increased total IAA	Decreased (4–5%)	22
Pigeon pea	Whole seeds roasted in sand bath at 200°C for 2 min	Decreased (0.6%)	–	Increased	12
Red gram	Roasted on iron pan for 10 min at 160°C	–	Decreased methionine, cysteine, threonine, tryptophan, and lysine	–	18
Urd bean	Whole seeds roasted in sand bath at 200°C for 2 min	Decreased (0.6%)	–	Increased	12

[a] Indispensable amino acids.

ent profile. While ANFs may impact protein digestibility and AA availability, most processing methods will reduce ANF content, consequently improving the nutritional status of the pulse. Many pulse processing methods result in improved protein and indispensable AA contents, digestibility, and protein quality. However, this is not the case for all pulses, with processing conditions and pulse type influencing changes. Processing conditions can also affect nutrient, protein, and AA levels, as well as digestibility, differently due to differences among pulse types. Additionally, while some processing methods can decrease protein and indispensable AA contents, the reduction or destruction of ANFs is generally greater compared with changes in the nutrient content, potentially resulting in a net positive change in protein and AA contents. Pulses are a viable food option that

Table VIII. Effects of extrusion on protein and amino acid contents and in vitro protein digestibility in a variety of pulses

Pulse	Processing Parameters	Effects of Processing			Reference
		Protein Content (% Change)	IAA[a] Content (% Change)	In Vitro Protein Digestibility (% Change)	
Chickpea	Single-screw extruder; temperature at cooking zone 140 or 180°C; feed zone temperature 100°C (for all treatments)	Decreased at 180°C (0.2%)	–	–	1
Faba bean	Twin-screw extruder; moisture at 25%; temperatures at 152 and 156°C	No change	–	Increased (16%)	3
	Single-screw extruder; temperature at cooking zone 140 or 180°C; feed zone temperature 100°C (for all treatments)	Decreased at 180°C (0.2%)	–	–	1
Kidney bean	Single-screw extruder; temperature at cooking zone 140 or 180°C; feed zone temperature 100°C (for all treatments)	Decreased at 180°C (0.2%)	–	–	1
	Twin-screw extruder, moisture at 25%; temperatures at 152 and 156°C	No change	–	Increased (14%)	3
Lentil	Twin screw extruder; moisture at 14, 18, and 22%; temperature between 140 and 180°C	–	–	Increased (31–49%)	29
Pea	Single-screw extruder; temperature at cooking zone 140 or 180°C; feed zone temperature 100°C (for all treatments)	Decreased at 180°C (0.2%)	–	–	1
	Twin-screw extruder; 25% moisture and 145°C	No change	Decreased histidine (1.5%), methionine (3.5%), and tryptophan (1.4%)	Increased (3%)	4

[a] Indispensable amino acids.

align well with global priorities regarding population growth, health, and climate change that emphasize increased use of plants as sources of protein and other nutrients. Thus, depending on the food or feed application, the methods used to process pulses and pulse ingredients may require optimization to maximize nutrient and protein levels and decrease ANFs.

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