14 Crops – Legumes

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14.1 Introduction

Legumes belong to the family Leguminosae and consist of oilseeds such as soybeans, peanuts, alfafa, clover, mesquite, and pulses, including the dry grains of peas, chickpeas, lentils, peas, beans, and lupins. Production and use of legumes date back to ancient cultures in Asia, the Middle East, South America, and North Africa. They are cultivated throughout the world for their seeds, harvested and marketed as primary products. Grain legumes are grouped into pulses and oilseeds. The pulses are different from the leguminous oilseeds, which are primarily utilized for oil (Schneider, 2002). There are about 1300 species of legumes, with only about 20 commonly consumed by humans (Reyes-Moreno & Paredes-Lopez, 1993). Notable amongst legume species are chickpeas (*Cicer arietinum*), pigeon pea (*Cajanus cajan*), lentil (*Lens culinaris*), mung bean (*Vigna radiata*), soybean (*Glycine max*), winged bean (*Psophocarpus tetragonoloba*), cowpea (*Vigna unguiculata*), pea (*Pisum sativum*), groundnut (*Arachis hypogaea*), and black gram (*Vigna mungo*), to mention but a few. Some of the most important legumes in the world are peas, beans, peanuts, soybeans, and chickpeas (Reyes-Moreno et al., 2000).

Canada is the leading producer of peas in the world, with about 3,379,400 metric tonnes (MT) produced in 2009 (FAO, 2009). In 2010, the US was the leading global producer of soybeans and the second and third top producer of peas and lentils, respectively (Table 14.1). In the same year, the US was also the fourth leading producer of dry beans and peanuts. Canada again tops the production of lentils and is the seventh and ninth leading producer of soybeans and chickpeas. Similarly, production of dry beans and chickpeas in Mexico is high and the country ranks fifth and eighth in global production, respectively. Brazil was the leading producer of dry beans in 2009. The leading producer of chickpeas in 2009 was India with 7,060,000 MT. Cutting-edge research in plant breeding and agronomic practices in the last several decades has allowed suitable varieties and cultivars for the North American climate to be identified, which has resulted in marked increases in legume production in the region. Although a large percentage of the legumes produced in North America are exported, there is growing interest in expanding domestic consumption, due to increased awareness of their health benefits.

Legumes have a special place in the diet of humans, because they contain nearly 2–3 times more protein than cereals (Reyes-Moreno & Paredes-Lopez, 1993). Cowpeas, for example, contain about 25% protein (Annor et al., 2010). Legumes are also excellent sources of complex carbohydrates and have been reported as beneficial for cardiovascular diseases and diabetes by some researchers (Hu, 2003; Jacobs & Gallaher, 2004), probably due to the large amounts of water-soluble fiber and a large content of phenolics (Enujiugha, 2010). Legumes are also a good source of vitamins (thiamine, riboflavin, niacin, vitamin B_6, and folic acid) and certain minerals (Ca, Fe, Cu, Zn, P, K, and Mg), and are an excellent source of polyunsaturated fatty acids (linoleic and linolenic acids) (Augustin et al., 1989). Indeed, several studies suggest that increased consumption of legumes may provide protection against diseases such as cancer, diabetes, osteoporosis, and cardiovascular diseases, among others (Hu, 2003; Pihlanto & Korhonen, 2003; Tharanathan & Mahadevamma, 2003). Legumes further offer a practical avenue for diet diversification as consumers look for greater balance between plant and animal food sources. With growing concerns about the impact of agricultural practices on the environment,

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Table 14.1 Production of legumes in North America and top 20 global production ranking

	USA		Canada		Mexico	
Legume	Rank	Production (MT)	Rank	Production (MT)	Rank	Production (MT)
Beans, dry	4	1442470	15	253700	5	1156250
Chickpea	15	87952	9	128300	8	131895
Groundnut, with shell	4	1885510				
Lentil	3	392675	1	1947100		
Pea, dry	2	645050	1	2862400		
Soybean	1	90605500	7	4345300		

MT, metric tonnes.
Source: http://faostat.fao.org/site/339/default.aspx.

addition of legumes in crop rotation cycles can have beneficial impacts as they have the capacity to fix nitrogen in soils, thereby reducing the need for chemical fertilizers.

Peanuts are the most commonly consumed (by humans) and convenient of the legumes as they form part of the mainstream diet and can be easily obtained and consumed as roasted seeds or in the form of peanut butter. In the US, for example, peanuts and peanut butter comprise over two-thirds of all nut consumption (www.peanut-institute.org/peanut-facts/history-of-peanuts.asp, accessed 18 November 2013). Soybeans and pulse legumes, on the other hand, are more alien to the North American diets. Factors that have limited their consumption in North America include the longer time required for their preparation, the possible gastrointestinal (GI) discomfort due to the presence of indigestible carbohydrates which ferment in the GI tract causing gas and bloating, and their typical beany flavor. Extensive research in breeding, food quality, and processing has helped to overcome some of these limitations, increasing the acceptability of legumes in the North American diet and facilitating their use in food formulation.

Although legumes are rich in proteins, the quality of their protein is not nutritionally adequate. This is because they lack sulfur-containing amino acids such as methionine and cysteine. These limiting amino acids are, however, complemented by the use of legume cereal blends in diets. Cereals, being rich in sulfur-containing amino acids, complement the legume proteins, hence improving the quality of the protein. Other factors such as low protein digestibility, presence of antinutritional factors such as trypsin inhibitors, lectins, phytates, polyphenols, and flatulence factors make some legume seeds underutilized (Enujiugha, 2005; Mubarak, 2005; Ragab et al., 2010). Most of these antinutritional factors can, however, be reduced or eliminated by various processing techniques. In this chapter, we discuss different processing technologies applied to legumes, which are grouped as traditional and modern processing technologies.

14.2 Technologies involved in legume processing

The processing of legumes can be conveniently grouped into traditional and modern, depending on the complexity of the processing steps involved and the types of equipment used. Traditional methods include simple technologies and simple equipment that can be used at household level, whereas modern processing includes much more sophisticated processes and equipment at industrial level.

Legumes can be cooked and consumed as fresh beans or after drying, which is done to extend their shelf life. The term "pulse," for example, specifically refers to the dried grains of pea, chickpea, bean, lentil, and lupin, which distinguishes them from the fresh beans. Cooking of legumes inactivates antinutritional factors such as trypsin and amylase inhibitors, thus improving their nutritional quality. As is done in Asia and other parts of the world, in North America, fresh soybeans in the pod, peas, green beans, sugar snap beans, and string beans can be cooked and eaten as a side dish or with salads. Peanuts and soybeans are also roasted whole and consumed as is or used to prepare peanut butter and soybean butter. Increasingly, peas have been subjected to similar processing and are roasted for consumption as a snack or further processed to obtain pea butter.

The majority of soybean and pulses produced in North America are dried post harvest. For pulses, the seeds can be subsequently dehulled and split, which reduces cooking time. Details on the techniques used for primary processing of legumes (e.g. harvesting, cleaning, sorting, dehulling, splitting) are described elsewhere (Erskine et al., 2009; Snyder & Kwon, 1987; Subuola et al., 2012; Tiwari et al., 2011).

Dry legume seeds (e.g. soybeans, alfalfa, clover, pea, beans, chickpeas, lentils) are sometimes allowed to germinate after soaking and sold in the sprouted form. Sprouted legumes are of interest nutritionally, as the germination process helps to increase protein digestibility and mineral bioavailability, and in some instances can reduce the concentration of tannins, phytic acid, and indigestible carbohydrates (Boye et al., 2012). Sprouting will be discussed later in this chapter.

Another technique used to preserve and extend the shelf life of legumes, particularly pulses, is canning, which will be discussed later in this chapter. Whole seeds are first soaked, blanched, and cooked and then packaged in cans with a variety of sauces, which eases their use in food preparation. A wide variety of canned legumes can be found in North American supermarkets, with the most popular perhaps being canned baked beans.

Another growing market for both household use and in the food service sector is the frozen precooked legumes category. Frozen vegetables are perceived by some consumers to have higher nutritional value than canned foods. Rickman et al. (2007) point out that this perception may not always be true, as the effects of processing, storage and cooking are highly variable by commodity. Nevertheless, there is a growing market for precooked frozen legumes, which offer convenience when they can be quickly warmed on stove-top or in the microwave prior to consumption. The export market for frozen vegetables in North America was valued at US$292 M in 2011 (www.icongrouponline.com, accessed 18 November 2013). Individually quick-frozen (IQF) vegetables may be classified as ready-to-use, reheat-and-serve foods. They are first blanched/cooked prior to quick-freezing, which helps to preserve physical and nutritional quality.

Infrared heating is another technique applied to whole pulse seeds to decrease the time required for cooking. The process is sometimes called micronization. A company located in Canada, Infraready Products Ltd. (www.infrareadyproducts.com, accessed 18 November 2013), uses this technique to precook pulses (i.e., peas, beans, chickpeas and lentils). Described benefits of micronization include shorter cooking times, increased water and moisture absorption and retention, decreased microbial and enzymatic activity, increased shelf life, softer texture and flavor enhancement due to the addition of toasted notes to finished food products. Pulses can also be fully precooked in water and then dehydrated and sold as is or ground into flour, which will be discussed later in this chapter.

A variety of food products can be processed directly from dried legume seeds. In traditional markets, soybeans are processed into soymilk, tofu, yuba, miso, natto, sufu, and tempeh (Keshun, 1997). With the growing migrant population and the increasing trend towards exotic foods, these traditional products are now available in North America. Similarly, whole pulses are typically used to prepare soups, sauces, fried and baked products in places like India, Africa, and South America; these food products are now being made from pulses in North America. Research is further exploring novel uses and promising application areas of legumes for the North American market (Figure 14.1).

14.3 Traditional processing technologies

The traditional processing of legumes is labor intensive and is mostly done by women, especially in developing countries in Asia and Africa. The major traditional techniques used in the processing of legumes are soaking, dehulling, milling, boiling/cooking, roasting, pounding and grinding, frying, steaming, germination, fermentation, and popping, among others. Irrespective of the type of food that is prepared from legumes, they are taken through at least one of these processes. In this section, we discuss what some of these technologies are and the principles behind them.

14.3.1 Soaking

Legumes are primarily soaked in water and/or salt solutions (0.25–1%) to soften the cotyledon, which then hastens cooking (Silva et al., 1981). Soakaing involves adding water and/or salt solution to the legumes and discarding the water after a period of time or cooking with the soak water. Sodium chloride, acetic acid, and sodium bicarbonate solutions have been used in the soaking of legumes (Huma et al., 2008). Different soaking times have also been reported (Huma et al., 2008; Xu & Chang, 2008), but in most cases, the soaking is done overnight. Soaking

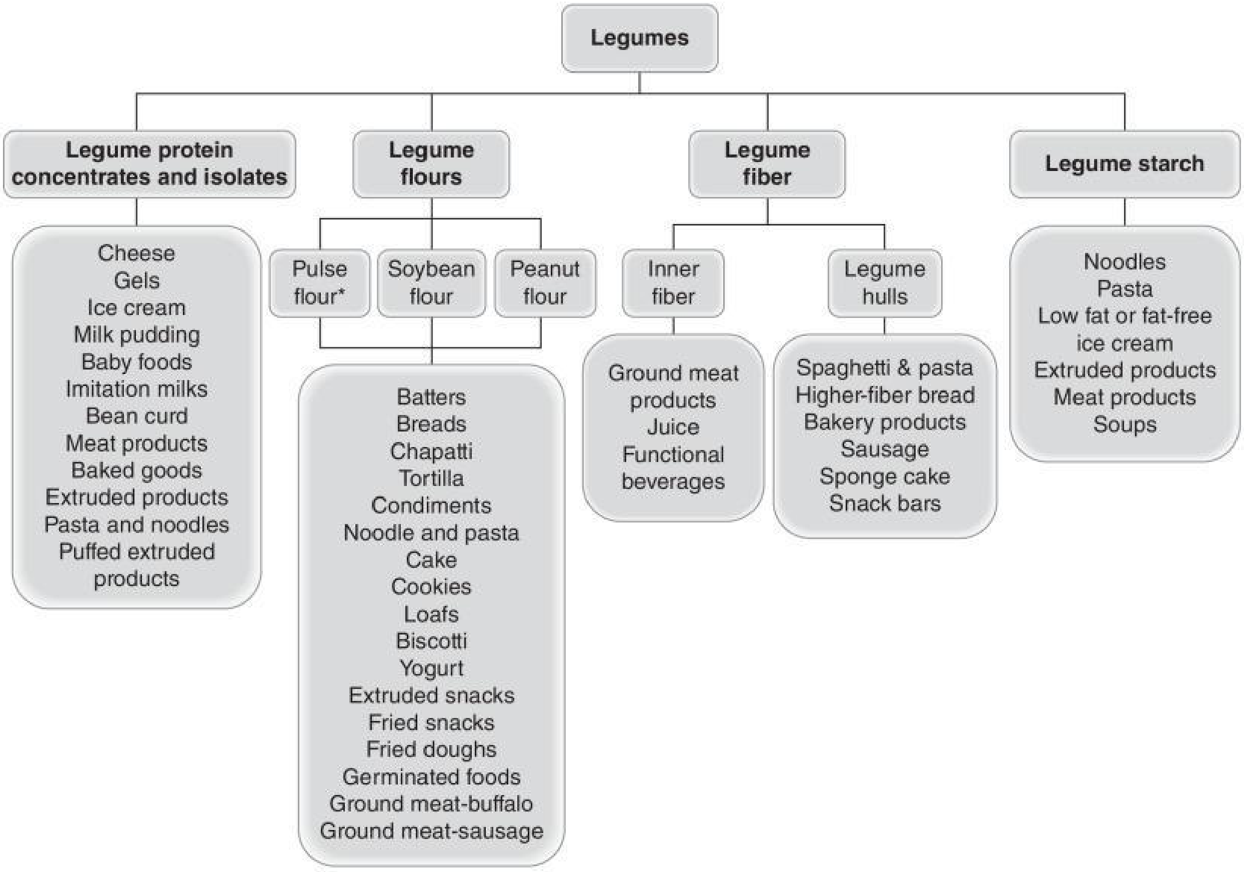

Figure 14.1 Potential and current food applications of legume flours and fractions. *Pulse flours include flours prepared from yellow pea, green gram, cowpea, navy bean, faba bean, field pea, lupin, lentils, great northern bean, pinto bean, red bean, white bean, black bean, winged bean, and pigeon pea.

of legumes can be done in either warm water or water at ambient temperature. Beside its primary role of shortening the cooking times of legumes, soaking has been reported to significantly reduce the phytate and phytic acid contents of legumes (Toledo & Canniatti-Brazaca, 2008). This was observed when legumes were not cooked with the soaking water. The flatulence factors in legumes are also reduced by soaking, as a result of the leaching out of stachyose and raffinose (Shimelis & Rakshit, 2005). These oligosaccharides are used as substrates by microorganisms in the large intestines, resulting in the production of carbon dioxide, leading to flatulence and intestinal discomfort. The addition of sodium bicarbonate to the soak water results in significant reduction in stachyose and raffinose. Soaking also increases the protein digestibility of legumes (Toledo & Canniatti-Brazaca, 2008), as confirmed in chickpeas, lentils, and different types of legumes (Martín-Cabrejas et al., 2009).

Soaking further results in the reduction of the mineral contents of legumes, due to the loss in the soaking water, especially when the water is discarded; however, their bioavailability is increased after soaking (Martín-Cabrejas et al., 2009). The increase in the bioavailability of minerals may be attributed to the reduction in antinutritional factors during soaking. These antinutritional factors are known to bind to the minerals in legumes, making them unavailable to the human body. Generally, soaking and cooking legumes without the soaking water reduces their carbohydrate contents (Martín-Cabrejas et al., 2009).

14.3.2 Cooking

The cooking of legumes has been practiced for years. It is one of the most common processing techniques applied to legumes, and involves boiling the legume seeds in water till they are soft. Traditionally, determination of the required softness of cooked legumes is done by pressing the legumes with the thumb. Several changes occur during the cooking of legumes apart from softening: gelatinization of starch, denaturation of proteins, and browning of the seeds (Enujiugha, 2005: Onigbinde & Onobun, 1993). Besides reducing the antinutritive factors in legumes, cooking reduces the amounts of stachyose and raffinose. The longer cooking times required have, however, been an obstacle to legumesuse. To reduce the legume cooking times, potash has been used traditionally to help soften the legume cotyledons. Sodium bicarbonate, trisodium phosphate, and ammonium carbonates have also been exploited to reduce the cooking times of legumes (Bueno et al., 1980).

14.3.3 Fermentation

Solid-state fermentation (SSF) is one of the alternative technologies for processing a great variety of legumes and/or cereals with the aim of improving their nutritional quality and obtaining edible products with palatable sensory characteristics (Reyes-Moreno et al., 2004). The advantages of fermentation include the development of flavor, texture, taste, reduction in product volume and the increase in product stability and shelf life through the preservation of the foods (Steinkraus, 2002). Legumes have been fermented into a variety of products. Notable among these products are tempeh and soy sauce, which are particularly popular in Asian countries.

Tempeh is a traditional fermented food produced with different strains of *Rhizopus* species (*R. oligosporus, R. stolonifer, R. oryzae, R. arrhizus*) fermenting boiled and dehulled soybeans (Annor et al., 2010: Keuth et al., 1993). It has a pleasant mushroom-like aroma and a nutty flavor, making it an excellent option for meat, fish and poultry products (Pride, 1984). During the fermentation process, stachyose and raffinose are broken down to digestible sugars. The fermentation process also improves the flavor, nutritional and functional properties of the product (Bavia et al., 2012). Even though soybeans are the main legumes used for the preparation of tempeh, other substrates have been used, e.g. cowpeas (Annor et al., 2010) and chickpeas (Reyes-Moreno et al., 1993). The process variables for the production of tempeh from chickpeas were optimized by Reyes-Moreno and colleagues (1993). According to their study, the optimum combination of process variables for production of optimized chickpea tempeh flour through the SSF process was incubating at 34.9 °C for 51.3 h. The chickpea tempeh was prepared by soaking the chickpeas at 25 °C for 16 h in four volumes of acetic acid solution (pH 3.1). The seeds were then drained and their seed coats removed. The cotyledons were then cooked for 30 min and then cooled to 25 °C, packed in polyethylene bags and fermented with a suspension of *R. oligosporus* spores.

Soy sauce is a traditional Asian fermented soybean product that has gained international acceptance as a condiment or seasoning sauce due to its distinctive flavor. A combination of soybeans and wheat is normally used as the raw material. The soybeans and wheat are first fermented with *Aspergillus oryza* and then yeast and lactic acid bacteria are added later, after the addition of brine solution (8%) (Zhao et al., 2013). Two types of fermentation for soy sauce can be used: low-salt solid state and high-salt liquid state. The fermentation times for these two different types of fermentations differ significantly; while the former takes about 1 month, the latter takes as long as 6 months. Different concentrations of brine are also used for the different fermentation types. For the low-salt solid state fermentation, about 8% is used, while about 17% is used for the high-salt liquid state fermentation. The different fermentation types result in different tastes and flavors, with the high-salt liquid state fermented soy sauces having an edge over the taste and flavor of the low-salt solid state fermented product. Soy sauce has been reported to have antihypertensive properties, due to the presence of angiotensin I-converting enzyme, which was found to decrease blood pressure in hypertensive rats (Kinoshita et al., 1993).

The list of fermented legume foods is endless, with soybean arguably being the most fermented legume. Some of the products are *dawadawa*, from the African locust bean (*Parkia tilicoidea*), natto from soybeans, tempe *kedelee* from soybeans, *oncomhitam* from peanuts, *ketjap* (soy sauce) from black soybeans and *channakiwaries* prepared from bengal gram (*Cicerarietinum L.*) and black gram (*Vignamungo*) flour.

14.3.4 Dehulling

Dehulling involves the removal of the hulls of grain seeds, in this case legume seeds. It is one of the basic processing steps in legume processing. Dehulling can be done traditionally with mortar and pestle, which makes the process laborious and time consuming (Ehiwe & Reichert, 1987). The dehulling of legumes results in reduction of fiber and tannin content, and, most importantly, affects the appearance, texture, cooking quality, digestibility, and palatability of the grains (Deshpande et al., 1982). It has been demonstrated that there are marked differences in the dehulling efficiency of legumes (Reichert, 1984). Soybeans (*Glycine max*), faba beans (*Vicia faba equine* L.) and field peas (*Pisum sativum* L.) have better dehulling efficiencies (about 70%) compared to the others. These dehulling efficiencies were attributed to the resistance of seed splitting during dehulling and also to fact that the seed coat of these legumes is loosely bound to their cotyledons (Ehiwe & Reichert, 1987).

14.3.5 Germination/sprouting

Germination is one of the most common and effective legume processing methods, with the aim of improving nutritional quality. It can be defined as the transformation of seeds (herein referred to as legumes) from their dormant state to a metabolically active state, involving the mobilization of stored reserves of these seeds. As a result, there is a rapid increase in respiration, synthesis of proteins and nucleic acids, and the elongation and division of cells (Kadlec et al., 2008). Germination is normally preceded by soaking. During germination, the degradation of stored carbohydrates in the seeds by enzymes takes place. This results in significant changes in the physicochemical characteristics of the legumes, including the modification of antioxidant activities (López-Amorós et al., 2006). The process of germinating legumes, as is traditionally practiced, involves soaking seeds in water for 24 h at room temperature, draining and then spreading them on a damp cloth for about 48 h. In some cases where traditional germination is done on a large scale, large wet baskets are used.

14.3.6 Puffing

Puffing is one of the traditional technologies used to process legumes. It is commonly applied to chickpeas and peas, resulting in a light and crispy product. Puffed legumes are commonly eaten as snack foods, though they can also be milled into flour and used for other purposes. Traditionally, puffed legumes are prepared by soaking the legumes in water for about 15–20 min, followed by draining the water. The wet grains are then tempered in a closed vessel for about 4 h, after which they are cooked in sand, heated to about 200 °C for about a minute. This normally results in the expansion of the grains, leading to the splitting of the husk of the legumes. Puffed legumes are known to retain all the nutrients and also result in improved protein and carbohydrate digestibility (Baskaran et al., 1999).

14.4 Modern processing technologies

Modern processing technologies for legumes involve the use of sophisticated equipment and result in the mass production of products. Some of these technologies include extrusion cooking, high-pressure cooking, air classification, agglomeration, and canning. In this section, some of these technologies as applied to the processing of legumes and their effects on the nutritional and physical characteristics of legumes are discussed.

14.4.1 Extrusion cooking

Extrusion cooking is a high-temperature, short-time process that can be applied to foods to modify and/or improve their quality attributes. It consists of the thermomechanical cooking of foods at high temperatures, pressure and shear, generated inside a screw-barrel assembly (Battacharya & Prakash, 1994). Extrusion has been applied to legumes for the production of ready-to-eat products. Attempts to use extrusion cooking as a means to decontaminate aflatoxin in peanuts (Grehaigne et al., 1983; Saalia & Phillips, 2011) and canavanine in jack beans (Tepal et al., 1994) have been mentioned.

Extrusion has several effects on the nutritional properties of the resulting extruded products. Improvements in the protein and starch digestibility of extruded faba and kidney beans were reported by Alonso et al. (2000). According to Phillips (1989), the conditions used in extrusion cooking result in physical and chemical transformations such as protein cross-linking (Stanley, 1989), isopeptide bonding (Burges & Stanley 1976), or amino acid racemization, that directly influence the nutritional composition of extruded products. Extrusion cooking has also been effectively used in the production of textured vegetable protein (TVP) and textured soy protein (TSP), used extensively as food ingredients.

The extruder consists of a sturdy screw or screws rotating inside a smooth or grooved cylindrical barrel. The barrel can be heated externally for certain applications. For the production of extruded legume products, legume flour, which is conditioned to a moisture content of about 20–25% with live steam, is fed into the extruder. As the flour-water mixture goes through the barrel, it is heated rapidly by friction and external heat; coupled with high pressures, temperatures as high as 150–180 °C are attained. The legume flour-water mixture then goes through a process called thermoplastic "melting," also known as thermoplastic extrusion. The intense heat and pressure conditions applied to the product result in the denaturation of the soy proteins and puffing of the mixture. The extrudate is then cut and dried.

14.4.2 High-pressure cooking

High-pressure cooking involves the application of hydrostatic pressure of several hundred MPa to foods for the purpose of sterilization, protein denaturation, and control of enzyme and chemical reactions, amongst others (Estrada-Giron et al., 2005). It basically involves the cooking of food in a high-pressure cooker. High-pressure cooking, also commonly referred to as high hydrostatic pressure (HHP) cooking, is gaining worldwide interest, especially in Japan, the US and Europe, because of its advantages over most processing methods. In the US, consumers can purchase HHP-processed sauces, oysters, and guacamole (Estrada-Giron et al., 2005). HHP results in significant inactivation of microorganisms (Knorr 1993), improved food quality and retention of ingredients in the products (Cheftel, 1991). HHP can also be used in the modification of texture, whipping, emulsification and dough-forming properties of foods (Hoover, 1989). HHP has been applied to the processing of legumes, especially soybeans. HHP-produced tofu was found to have a much longer shelf life due to the significant reduction in its microbial population (Prestamo et al., 2000). The solubilization of protein from whole soybean grains, subjected to pressure of up to 700 MPa, has also been reported (Omi et al., 1996). The activity of lipoxygenase, an enzyme which is responsible for the off-flavors produced in soybeans, has been found to be sensitive to high pressures (Ludikhuyze et al., 1998).

14.4.3 Canning

Canning is a heat sterilization process applied to foods to ensure they are commercially sterile (i.e. the products are free from microorganisms capable of growing in the food at normal non-refrigerated temperatures). Properly sealed and heated canned foods should remain stable and indefinitely unspoiled in the absence of refrigeration. The effectiveness of the canning process is determined by the type of food, pH, container size and consistency or bulkiness of the food, but heating of food for longer than necessary is undesirable, as the nutritional and eating quality of foods are affected negatively by prolonged heating (Brock et al., 1994). Canning, like many other food processes, is applied to legumes to improve their shelf life. Canning of legumes is mainly composed of two processes: soaking/blanching and thermal processing/heat sterilization. Soaking is done before canning to remove foreign material, facilitate cleaning, aid in can filling through uniform expansion, ensure product tenderness, and improve color. Soaking also results in the reduction of antinutritive factors in the legumes, due to their leaching out (Uebersax et al., 1987). Blanching inactivates enzymes, which might produce off-flavors, but also softens the product and removes gases to reduce strain on can seams during retorting (Beckett, 1996). Afoakwa et al. (2006) optimized the preprocessing conditions for the canning of Bambara groundnuts. They concluded that soaking time of 12 h, blanching time of 5 min and sodium hexametaphosphate salt concentration of 0.5% gave the best quality canned product from Bambara groundnut with acceptable quality characteristics.

Conditions for heat sterilization of low-acid foods are defined to ensure that all spores of *Clostridium botulinum* are destroyed and to prevent the spoilage of the product by heat-resistant, non-pathogenic organisms. Sterilization should normally be performed at 121 °C for at least 3 min (Beckett, 1996). In the case of legumes, additional sterilization would also provide adequate softening of the seeds (van Loggerenberg, 2004). Canning has significant effects on the nutritional properties of legumes. Wang et al. (1988) found that canning decreased the protein content of drained beans, with the exception of one cultivar. Canning results in nitrogenous components, such as amino acids and small chain polypeptides, leaching from bean tissue into brine (Drumm et al., 1990); crude protein also leaches into the canning medium (Lu & Chang, 1996). Canning of legumes also causes mineral losses. Iron, magnesium, manganese, potassium, and zinc losses occur during soaking, blanching and/or thermal processing, but phosphorus and copper levels remain the same in canned beans. The sodium and chloride levels increase in canned beans, due to the sodium chloride (NaCl) added to the filling medium of cans (Lopez & Williams, 1988).

14.4.4 Air classification

Air classification is a technique for the dry separation of particles from finely ground powders and flours, according to their size, shape, and density. Air classification is typically applied to pulse products and is a relatively simple technique that allows expansion of product offerings. It has been proven as an effective method for the production of starch-rich and protein-rich fractions of meals (King & Dietz, 1987). Air classification has been carried out on pea (*P. sativum*), faba bean (*V. faba*), mung bean (*Vigna radiata*), green lentil (*Lens culinaris*), navy bean (*Phaseolus vulgaris*), baby lima bean (*Phaseolus lunatus*), and cowpea (*Vigna unguiculata*) (Tyler et al., 1981). The first process of air classification involves milling. Tyler et al. (1981) used a pin mill when they studied the air classification of legumes. In their study, dehulled legume seeds were milled with a pin mill and then fractioned into starch fraction and protein concentrate using an air classifier. These fractions were remilled several times and air classified again to increase the quality and also the yield of the protein concentrates. Air classification, aside from separating the starch and protein fractions, results in enrichment of the fractions.

14.4.5 Agglomeration

Agglomeration, in general, can be defined as a process during which primary particles are joined together so that bigger porous secondary particles (conglomerates) are formed (Palzer, 2005). According to this definition, even caking of hygroscopic raw materials during storage can be regarded as a kind of undesired agglomeration. Agglomeration is a physical phenomenon and can be described as the sticking of particulate solids, which is caused by short-range physical or chemical forces among the particles themselves due to physical or chemical modifications of the surface of the solid. This phenomenon is triggered by specific processing conditions, or binders and substances, which adhere chemically or physically on the solid surfaces to form a bridge between particles (Pietsch, 2003). The basic principle of the process of agglomeration is that powdery flour is dispersed in a humid atmosphere to wet the surface of the flour particles, resulting in the particles adhering to each other. This process has been used in the preparation of cous-cous in North Africa. Agglomeration enhances the swelling and dispersion properties of legume flours.

14.5 Ingredients from legumes

14.5.1 Oil

Due to their high oil content, soybeans and peanuts have served as important raw materials for oil production. Soybean oil production in the US in 2011 was 8.4 million MT (www.soystats.com, accessed 18 November 2013), whereas peanut oil production is more limited and was 89 thousand MT in 2012 (www.indexmundi.com, accessed 18 November 2013). Even though Mexico and Canada rank seventh and 15th in global production of soybean oil, respectively, there is hardly any peanut oil production in Canada.

Hydraulic pressing, expeller, solvent extraction and combinations of these techniques are the main processes used for vegetable oil extraction. With a few exceptions, the process for extracting oil from soybeans and peanuts is very similar (Figure 14.2). Typically, the oilseed is first cleaned to remove foreign materials, dried if needed to facilitate dehulling and cracking, which allows the seeds to be broken into smaller pieces, followed by conditioning and flaking. The flaking process involves passage of the broken pieces between rolls, which ruptures the oil cells and expands the surface area for solvent penetration and subsequent oil extraction.

Hexane is the most common solvent used for oil extraction. The miscella obtained after solvent extraction contains a mixture of oil and solvent, which is passed through a solvent recovery system to remove solvent. The crude oil remaining is subjected to further refining to obtain edible oil and other derived products. The defatted flakes are passed through a desolventizer/toaster to remove residual solvent. The meal obtained is rich in protein, and can be used as is or further processed downstream to extract protein. Lui (1997) provides further detail on soybean oil extraction processes. Concerns about trace remnants of hexane in solvent-extracted defatted oilseed meals have spurred research on alternative defatting techniques such as the use of other solvents, mechanical extraction, enzyme-assisted aqueous extraction, and supercritical extraction (Russin et al., 2011).

14.5.2 Flours

Whole, dehulled and defatted legume seeds, flours, and flakes can be milled to obtain a variety of flour products. Subuola et al. (2012) and Tiwari et al. (2011) provide an overview of the methods used to obtain flours from soybean, pulses, and peanuts. The major component found in legume flours is carbohydrate, which can range from 25% to 68%. Depending on whether flours are defatted or not, protein content can range from 17% to 56%. Table 14.2 presents the composition of legume flours prepared using a variety of processing techniques.

Legume flours are of interest in food processing due to both their nutritional and functional properties. Functional properties that aid in food formulation and processing include protein solubility, water holding

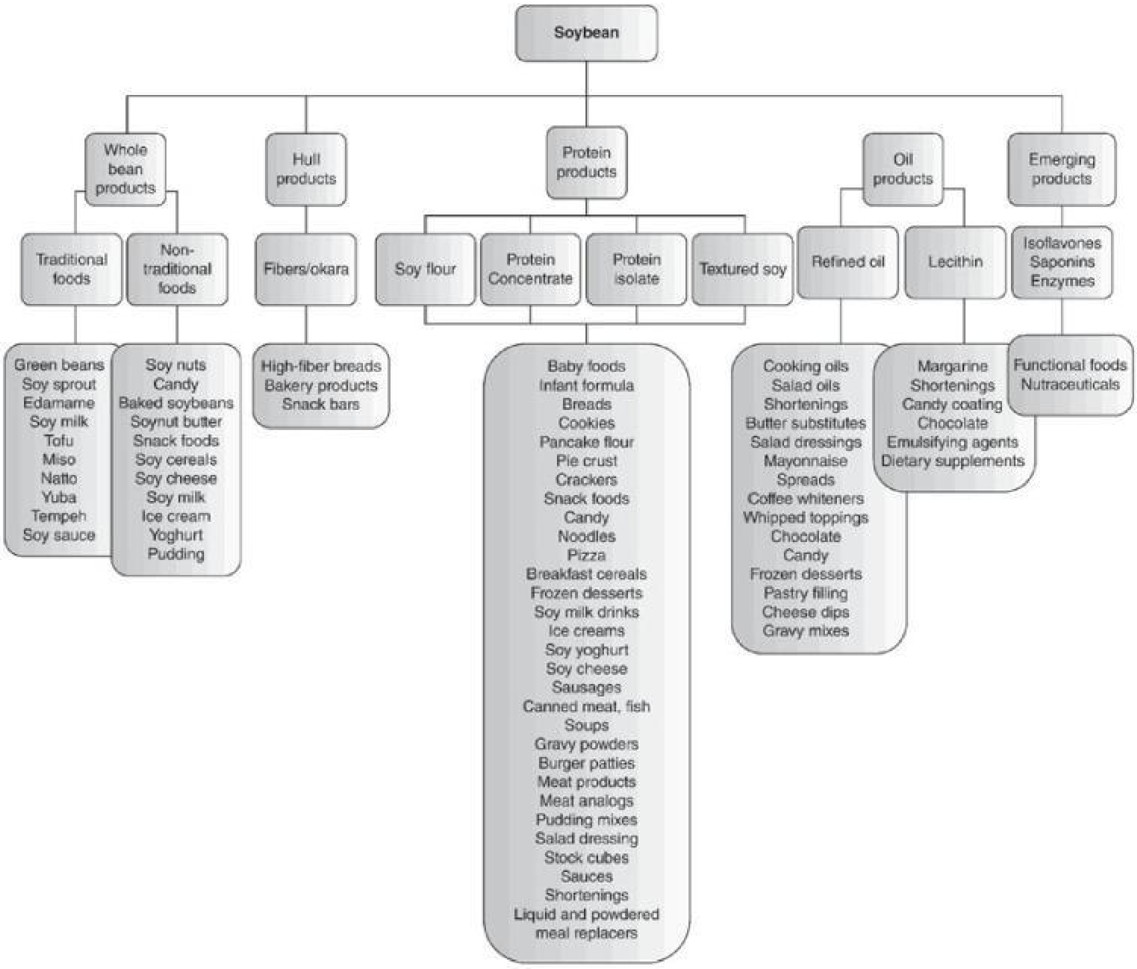

Figure 14.2 Soybean foods and ingredients. Reprinted from L'Hocine & Boye (2007), with permission from Taylor & Francis.

Table 14.2 Chemical composition of legume flours and legume protein concentrates/isolates

	Processing techniques	Protein (%)	Fat (%)	Carbohydrates (%)	Moisture (%)	Ash (%)	Starch (%)	Crude fiber (%)	References
Legume flours									
Full-fat Desi chickpea flour	Centrifugal mill (5-mesh sieve with 1.5 mm pore size)	22.3	5.16	39.19	db	3.37			(Mondor et al., 2010)
Full-fat Kabuli chickpea flour	Centrifugal mill (5-mesh sieve with 1.5 mm pore size)	18.9	6.70	71.24	db	3.16			(Mondor et al., 2010)
Kabuli chickpea flour	Centrifugal grinding mill and dehulling	16.71	7.34	61.14	12.06	2.76			(Boye et al., 2010a)
Desi chickpea flour	Centrifugal grinding mill and dehulling	20.52	5.23	61.94	9.26	3.04			(Boye et al., 2010a)
Defatted chickpea flour	Grinding and sieving (80-mesh sieve), defatted (10% w/v hexane) and air dried	17.2	0.3			2.8		1.1	(Paredes-López et al., 2006)
Chickpea flour	Grinding with a coffee mil, sieving through a 60- mesh sieve	21.37	7.17	58.92	7.40	2.98		2.16	(Bencini, 2006)
Chickpea flour	NR	22.9	6.4		10.4	2.83	40.4		(Marconi et al., 2000)
Bengal gram flour (*Cicer arietinum*)	Dehulling, grinding and sieving (40- or 60-mesh)	21.2	5.6	66.1	3.2	2.6		1.8	(Nagmani & Prakash, 1997)
Whole pea flour	Grinding and passing through a 4 mm screen	23.7			13.9	3.28	52.7	5.5	(Maaroufi et al., 2000)
Pigeon pea flour	Boiling, dehulling and dry milling	22.4	2.63	59.4	5.24	5.76		3.82	(Oshodi & Ekperigin, 1989)
Pea flour	NR (Fernández-Quintela et al., 1997)	23.93	3.12	59.39		2.58		8.77	
Yellow pea flour	Centrifugal grinding mill and dehulling	21.09	2.01	60.29	14.19	2.42			(Boye et al., 2010a)
Field pea flour	Commercial	25.0	1.1		db	2.7	55.7	1.9	(Sosulski & McCurdy, 1987)

Green lentil flour	Centrifugal grinding mill and dehulling	23.03	0.82	63.08	10.68	2.39			(Boye et al., 2010a)
Red lentil flour	Centrifugal grinding mill and dehulling	25.88	0.53	63.10	9.27	2.34			(Boye et al., 2010a)
Lentil flour	Grinding of whole flours	20.6	2.15	56.1	11.2	2.80		6.83	(de Almeida Costa et al., 2006)
Lentil flour	Dehulling and grinding into powder by passing through a 0.4 mm screen	32.38–33.39	1.95–2.10	47.04–51.49	7.98–10.37	2.70–3.78		2.43–4.13	(Suliman et al., 2006)
Lentil flour	Dehulling, grinding and sieving (40- or 60-mesh)	26.0	0.8	65.2	5.0	2.3		0.7	(Nagmani & Prakash, 1997)
Common bean flour	Grounding the whole flours	20.9	2.49	54.3	9.93	3.80		8.55	(de Almeida Costa et al., 2006)
Black gram flour (*Phaseolus mungo*)	Dehulling, grinding and sieving (40- or 60-mesh)	23.2	1.4	67.9	3.3	3.3		0.8	(Nagmani and Prakash, 1997)
Green gram flour (*Phaseolus aureus*)	Dehulling, grinding and sieving (40- or 60-mesh)	25.6	1.3	67.7	1.3	3.3		0.8	(Nagmani & Prakash, 1997)
Common bean flour	NR	20.8	2.6		10.4	3.68	37.9		(Marconi et al., 2000)
Defatted peanut flour	Dehulling, flaking and defatting (using butane and propane)	55.88	1.50	25.14	8.12	4.85			(Wu et al., 2009)
Defatted soybean flour	Grinding flakes to pass through 100-mesh or finer, and defatting	50.5	1.5	34.2		5.8		3.2	(Wolf, 1970)
Soybean flour	Commercial	48.2	0.9		db	5.8	2.4	4.2	(Sosulski & McCurdy, 1987)
Ranges		16.71–55.88	0.3–7.34	25.14–67.9	1.3–14.19	2.34–5.76	2.4–55.7	0.8–8.77	
Legume protein concentrates									
Soybean protein concentrate	Aqueous alcohol washing, IEP and leaching	66.2	0.3		6.7				(Wolf, 1970)

(*Continued*)

Table 14.2 (*Continued*)

	Processing techniques	Protein (%)	Fat (%)	Carbohydrates (%)	Moisture (%)	Ash (%)	Starch (%)	Crude fiber (%)	References
Full-fat Desi chickpea protein concentrate (IEP)	Alkaline extraction/ IEP	78.6	11.37	6.88	db	3.18			(Mondor et al., 2010)
Full-fat Kabuli chickpea protein concentrate (IEP)	Alkaline extraction/ IEP	69.9	21.55	5.39	db	3.16			(Mondor et al., 2010)
Defatted Desi chickpea protein concentrate (IEF)	Alkaline extraction/ IEP	86.9	3.71	5.92	db	3.47			(Mondor et al., 2010)
Defatted Kabuli chickpea protein concentrate (IEF)	Alkaline extraction/ IEP	85.6	10.44	0.59	db	3.37			(Mondor et al., 2010)
Peanut protein concentrate (IPPPC)	Acid extraction/IEP	72.35	1.13	17.97	1.48	3.05			(Wu et al., 2009)
Peanut protein concentrate (AAPPC)	Aqueous alcohol precipitation	69.54	0.70	16.06	1.51	2.06			(Wu et al., 2009)
Peanut protein concentrate (IAPPC)	IEP and alcohol precipitation	71.49	0.84	16.46	1.49	2.03			(Wu et al., 2009)
Ranges		66.2–86.9	0.3–21.55	0.59–17.97	1.48–6.7	2.03–3.47			
Legume protein isolates									
Micelle chickpea protein isolate	Micellization (NaCl extraction and ultrafiltration) from defatted flour	87.8	1.8			2.3		0.2	(Paredes-López et al., 2006)
Isoelectric chickpea protein isolate	IEP (alkaline extraction) from defatted flour	84.8	1.9			2.7		0.2	(Paredes-López et al., 2006)

Peanut protein isolate	IEP (pH 4.5) and alcohol precipitation	96.65	0.20	0.36	1.61	2.22			(Wu et al., 2009)
Soybean protein isolate	Alkaline extraction from defatted flour or flask, IEP, centrifugation/ filtration	92.8	<0.1		4.7				(Wolf, 1970)
Soybean protein isolate	Commercial	82.3	0.4		db	4.0	1.8	0.6	(Sosulski & McCurdy, 1987)
Field pea protein isolate	Alkaline extraction and IEP	80.3	1.7		db	4.4	2.7	1.3	(Sosulski & McCurdy, 1987)
Faba bean protein isolate	Acid extraction and IEP	86.3	2.0		db	3.9	1.8	0.6	(Sosulski & McCurdy, 1987)
Pea protein isolate	Dehulling, alkaline extraction, centrifugation and lyophylizing	84.09	3.32	6.57		7.88		5.01	(Fernández-Quintela et al., 1997)
Faba bean protein isolate	Dehulling, alkaline extraction, centrifugation and lyophylizing	81.24	3.83	8.47		7.89		6.90	(Fernández-Quintela et al., 1997)
Soybean protein isolate	Dehulling, defatting, alkaline extraction, centrifugation and lyophylizing	82.16	1.46	5.64		7.73		3.17	(Fernández-Quintela et al., 1997)
Ranges		80.3–96.65	0.1–3.83	0.36–8.47	1.61–4.7	2.22–7.89	1.8–2.7	0.2–6.90	

db, dry basis; IEP, isoelectric precipitation; NR, not reported.

Table 14.3 Functional properties of legume flours, protein concentrates, and isolates

	Protein content (%)	PS (%)	WHC	FAC	LGC	BD (g/mL)	FE	FC	FS	EC	EA (%)	ES	References
Legume flours													
Red kidney bean flour	23.32		2.25 (g/g)	1.52 (g/g)	10 (%)	0.556		45.7 (mL/100 mL)	41.2 (mL/100 mL)	55.0 (mL/100 mL)		52.4 (mL/100 mL)	(Siddiq et al., 2010)
Small red kidney flour	20.93		2.65 (g/g)	1.23 (g/g)	10 (%)	0.526		38.2 (mL/100 mL)	43.3 (mL/100 mL)	60.5 (mL/100 mL)		62.3 (mL/100 mL)	(Siddiq et al., 2010)
Cranberry flour	23.62		2.41 (g/g)	1.48 (g/g)	12 (%)	0.539		49.6 (mL/100 mL)	54.9 (mL/100 mL)	53.4 (mL/100 mL)		52.4 (mL/100 mL)	(Siddiq et al., 2010)
Black bean flour	23.24		2.23 (g/g)	1.34 (g/g)	12 (%)	0.515		37.4 (mL/100 mL)	39.4 (mL/100 mL)	45.6 (mL/100 mL)		48.2 (mL/100 mL)	(Siddiq et al., 2010)
Yam bean flour	20.43		131.9 (%)	0.6 (mL/g)	14.3 (%)			40.2 (%)		50.7 (%)			(Obatolu et al., 2007)
Green gram flour	NR		1226 (g/kg)	900 (g/kg)		0.69		16 (%)		48 (mL oil/g of sample)	54.0	51.8 (%)	(Ghavidel & Prakash, 2006)
Bengal gram flour	NR		1362 (g/kg)	788 (g/kg)		0.73		12 (%)		185 (mL oil/g of sample)	51.6	49.4 (%)	(Ghavidel & Prakash, 2006)
Pigeon pea flour	22.4		138 (%)	89.7 (%)	12% (w/v)			68 (%)	20 (%)	49.4 (%)			(Oshodi & Ekperigin, 1989)
Cowpea flour	NR		1285 (g/kg)	993 (g/kg)		0.65		40 (%)		69 (mL oil/g of sample)	51.9	50.1 (%)	(Ghavidel & Prakash, 2006)
Field pea flour	25.0	80.3 (%)	0.78 (g /g)	0.41 (g oil/g sample)						34.6 (mL oil/0/1 g sample)			(Sosulski & McCurdy, 2006)
Lentil flour	NR		974 (g/kg)	857 (g/kg)		0.85		22 (%)		58 (mL oil/g of sample)	50.5	48.1 (%)	(Ghavidel & Prakash, 2006)
Lentil flour	NR		3.20 (mL/g)	0.95 (mL/g)	8.0 (%)	0.91		40.0 (%)			47.4		(Aguilera et al., 2009)
Desi chickpea flour	20.6–24.3		1.34–1.39 (g/g)	1.05–1.17 (g/g)	10–14 (%)						59.6–68.8	76.6–81.3 (%)	(Kaur and Singh, 2005)
Kabuli chickpea flour	26.7		1.33 (g/g)	1.24 (g/g)	10 (%)						58.2	82.1 (%)	(Kaur & Singh, 2005)
Chickpea flour	NR		2.10 (mL/g)	1.10 (mL/g)	8.0 (%)	0.71		24.0 (%)			22.9		(Aguilera et al., 2009)
Faba bean flour	29.2	85.9 (%)	0.72 (g /g)	0.47 (g oil/g sample)						34.6 (mL oil/0.1 g sample)			(Sosulski & McCurdy, 2006)
Peanut flour	52.73		1.67 (mL/g)	2.67 (mL/g)				0.06 (mL/g)		87.08 (mL/g)			(Yu et al., 2007)
Soybean flour	48.2	20.6 (%)	1.75 (g/g)	0.56 (g oil/g sample)						37.2 (mL oil/0.1 g sample)			(Sosulski & McCurdy, 2006)

Legume protein isolates													
Field pea protein isolate	80.3	38.1 (%)	2.52 (g /g)	0.98 (g oil/g sample)						36.6 (mL oil/0.1 g sample)			(Sosulski & McCurdy, 2006)
Faba bean protein isolate	86.3	40.0 (%)	2.16 (g /g)	1.78 (g oil/g sample)						38.6 (mL oil/0.1 g sample)			(Sosulski & McCurdy, 2006)
Micelle chickpea protein isolate	87.8	72.5 (%)	4.9 (mL/g)	2.0 (mL/g protein)			43.3 (%)		59.2(%)		63.7	94.3 (%)	(Paredes-López et al., 2006)
Isoelectric chickpea protein isolate	84.8	60.4 (%)	2.4 (mL/g)	1.7 (mL/g protein)			47.5 (%)		66.6(%)		72.9	85.0 (%)	(Paredes-López et al., 2006)
Soybean protein isolate	82.3	30.6 (%)	2.65 (g /g)	1.03 (g oil/g sample)						45.1 (mL oil/0.1 g sample)			(Sosulski & McCurdy, 2006)
Soybean protein isolate	NR	21.2 (%)	5.7 (mL/g)	1.9 (mL/g protein)			41.8 (%)		53.2(%)		50.8	99.7 (%)	(Paredes-López et al., 2006)
Soybean protein isolate	90.2	22.2 (%)	584 (%)	144 (%)							75.1		(Naczk et al., 1986)
Cowpea protein isolate	95.7		2.20 (mL/g)	1.10 (mL/g)	6 (%)	0.82					50		(Ragab et al., 2004)
Legume protein concentrates													
Soybean protein concentrate	69.6	31.5 (%)	445 (%)	157 (%)							59.4		(Naczk et al., 1986)
Peanut protein concentrate	77.82		1.11 (mL/g)	0.90 (mL/g)				0.02 (mL/g)		87.50 (mL/g)			(Yu et al., 2007)
P. angularis	79.6		5.05 (g/g)	4.38 (g/g)				80.4–140.1 (%, pH 2–10)			54.7–57.0 (pH 2–10)	93.2–96.7 (%, pH 2–10)	(Chau et al., 1997)
P. calcaratus	78.0		5.28 (g/g)	4.71 (g/g)				80.2–130.0 (%, pH 2–10)			54.5–57.7 (pH 2–10)	94.5–97.3 (%, pH 2–10)	(Chau et al., 1997)
D. lablab	85.0		5.08 (g/g)	4.77 (g/g)				60.5–140.2 (%, pH 2–10)			53.0–57.9 (pH 2–10)	94.9–97.1 (%, pH 2–10)	(Chau et al., 1997)
Soybean protein concentrate	78.7		3.46 (g/g)	3.06 (g/g)				50.8–100.2 (%, pH 2–10)			54.5–58.1 (pH 2–10)	94.6–97.8 (%, pH 2–10)	(Chau et al., 1997)
Pea protein concentrate	55.5		153.0 (%, V/W)	113.0 (%, V/W)		0.45					22.4		(Conc & Blend, 1981)

BD, bulk density; EA, emulsifying activity; EC, emulsifying capacity; ES, emulsifying stability; FAC, fat absorption capacity; FC, foaming capacity; FE, foaming expansion; FS, foaming stability; LGC, least gelation concentration; NR, not reported; PS, protein solubility; WHC, water-holding capacity.