# Chapter 13
# The Legume Grains: When Tradition Goes Hand in Hand with Nutrition

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## 13.1 Legume Grains and Tradition

### *13.1.1 Nomenclature and Classification*

The word "legume" is derived from the Latin word *legumen,* which means seeds harvested in pods. Their seeds usually fall into one of two main classes: one in which the principal storage material is a polysaccharide, usually starch, and another in which the principal storage material is fat, often described as oilseeds (Kingman 1991). In many parts of the world, legume grains are also called "pulses", a word derived from the Latin term *puls*, meaning pottage or pulp. The latter is the word most commonly used in most English-speaking countries to describe legume seeds which have a low content of fat, such as kidney beans, broad beans, peas or lentils (Aykroyd et al. 1982).

All members of the *Leguminosae* share the characteristic of producing pods, but their growth habits can vary from being small, herbaceous plants to full-grown trees. They comprise 18,000–19,000 species belonging to about 670 genera and are distributed worldwide, with woody genera mostly in the southern hemisphere and the tropics; herbaceous genera are mostly present in temperate regions and are very numerous in Mediterranean-climate areas (Langran et al. 2010).

The majority of the most commonly consumed legume grains originated from Asia, Africa and, to a lesser extent, the Mediterranean region and India. Bean, chickpea and lentil, crops commonly consumed in the Mediterranean region, originated in this area but are now widespread in temperate regions throughout the world

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(Aykroyd et al. 1982). Soybean, which is now mostly produced in the United States, originated as a wild crop in East Asia, was domesticated in China and was later brought to other countries (Guo et al. 2010).

### *13.1.2 Origins and Production*

Legumes have been consumed by humans since the earliest practice of agriculture and have been used both for their medicinal, cultural as well as nutritional properties (Phillips 1993). Other parts of the plant besides the grain, such as leaves, shoots, flowers, immature pods and tubers, in addition to sprouted seeds (Aykroyd et al. 1982) are commonly consumed.

The species grown include important grain, pasture and agroforestry species. Their wide agricultural distribution makes them important crops in numerous parts of the world, such as Africa, Latin America, Asia and Mediterranean regions. Legumes are one of the world's most important sources of food supply, especially in developing countries, in terms of food energy as well as nutrients (Reyes-Moreno and Paredes-López 1993; Wang et al. 2003). In Africa and Latin America, they are especially valuable as a source of dietary protein to complement cereals, starchy roots and tubers (Phillips 1993). Their domestication for human food and animal feed have been reported back to as early as 9500 years before present (BP) in the Fertile Crescent of the Near East (Phillips 1993). Jatobá, also known as guapinol, or Brazilian cherry, is a member of the *Fabaceae*, genus *Hymenaea*, which was used as a food source in Amazonian prehistory (Roosevelt et al. 1996). Beans of several species were domesticated in tropical America thousands of years ago, and *Phaseolus* identified in archaeological sites in Mexico and Peru indicated the presence of domesticated beans as early as 10,000 years ago (Kaplan and Lynch 1999). There is evidence for the cultivation in Mexico of common beans, *P. vulgaris*, and teparies, *P. acutifolius*, before about 2500 BP in the Tehuacán Valley (Kaplan and Lynch 1999). In the Peruvian Andes, there are reports of domesticated common beans and lima beans by about 4400 BP and by about 3500 BP, respectively, and lima beans by about 5600 BP in the coastal valleys of Peru. Reports on chickpea indicate as possible origin the fertile crescent of the Mediterranean, though some ethnobotanists report early findings in the Himalayas (Kaplan and Lynch 1999).

The use of legumes in pastures and for soil improvement dates back to the Romans, with Varro (37 BC), cited by Graham and Vance (2003) noting "Legumes should be planted in light soils, not so much for their own crops as for the good they do to subsequent crops". This was intuitive information from farmers that later on was explained by the fact that legumes can fix atmospheric nitrogen through a symbiotic interaction with *Rhizobia* and, by doing so, are able to reduce atmospheric nitrogen to ammonia, resulting in high protein content of the soil. Because of this ability to "fix" nitrogen, legumes help stabilize soil and prevent erosion and are essential for healthy ecosystems and agriculture.

Legumes species can be adapted to climates ranging from temperate to tropical and humid to arid. The dry mature seeds, which have high food value and store well for long periods of time, play an important role in the diets of the peoples of the world. In rank order, dry bean (*Phaseolus vulgaris*), pea (*Pisum sativum*), chickpea (*Cicer arietinum*), fava bean (*Vicia faba*), pigeon pea (*Cajanus cajan*), cowpea (*Vigna unguiculata*) and lentil constitute the primary dietary legumes. Peanut (*Arachis hypogaea*) and soybean (*Glycine max*) are dominant sources of cooking oil and protein. They are also major food sources in many regions (National Academy of Science 1994).

Legumes are second only to the *Graminiae* in their importance to humans (Graham and Vance 2003), with soybean being the biggest produced legume crop. In fact, the Food and Agriculture Organization statistics for 2012 (http://faostat.fao.org/site/339/default.aspx) show that about 276 million metric tons of soybean were produced across the world, ranking it seventh on the world's top food and agriculture commodities (the largest being milk). Soybean came right after rice and wheat, which ranked second and sixth (http://faostat.fao.org/site/339/default.aspx), respectively. Figure 13.1 shows that the world's top producer of soybean in 2013 was the United States, with a production of 89 million metric tons, followed by Brazil and Argentina. It is noticeable that Ukraine, which is listed as the ninth biggest soybean producer in the world, is the only European country in the top 10 list, followed by Italy, in 15th place.

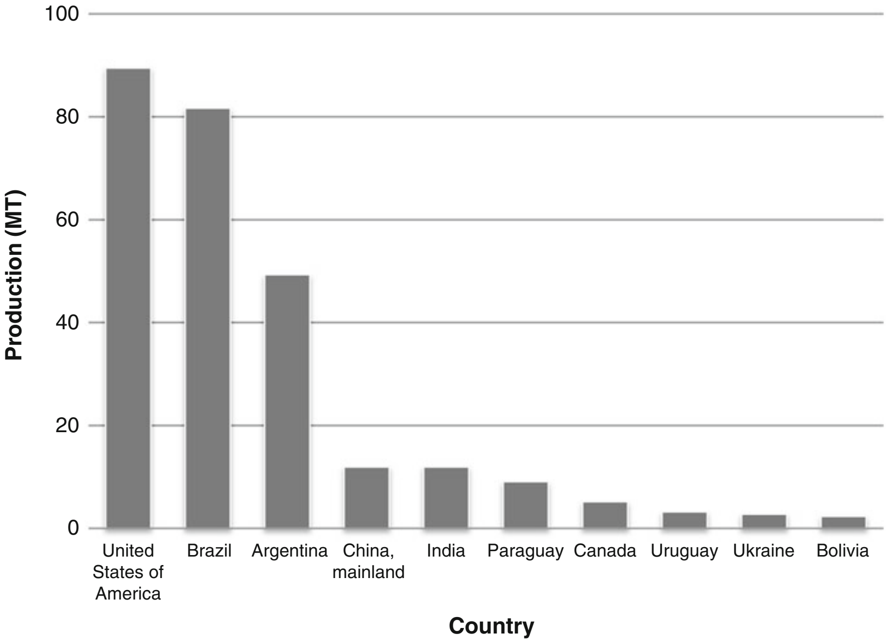


**Fig. 13.1** World's top 10 soybean-producing countries (million metric tons). *Source*: FAOSTAT (2013)

Common bean (*Phaseolus vulgaris*, $2n=22$) is the world's most important grain legume for direct food consumption, especially in Latin America and Africa (Pedrosa-Harand et al. 2006). The world's top bean producers are Brazil and India, with a production of 3.4 and 1.1 million metric tons in 2008, respectively, according to FAO statistics.

Grain quality of the legumes is determined by factors such as acceptability by the consumer, soaking characteristics, cooking quality and nutritive value. Acceptability characteristics include a wide variety of attributes, such as grain size, shape, colour, appearance, stability under storage conditions, cooking properties, quality of the product obtained and flavour (Reyes-Moreno and Paredes-López 1993). In addition to traditional food and forage uses, legume grains can be milled into flour (Loayza Jibaja and Bressani 1988); used to make bread, doughnuts, tortillas, chips, spreads and extruded snacks; or used in liquid form to produce milks, yoghurt and infant formula. Legume grains can also be used as a source of food additives. Gums for thickeners (e.g. arabic gum, guar gum and tragacanth gum) are derived from legumes, and soybean derivatives (e.g. soybean lecithin) are used extensively in processed foods.

Many more nonedible uses of legume grains exist, such as in the production of plastics, biodiesel, cosmetics, dyes, insecticides, etc., but these would fall out of the scope of this chapter.

### *13.1.3 Legume Grains in the Mediterranean Diet*

The Mediterranean diet can be described as the dietary pattern found in the olive-growing areas of the Mediterranean region, in the late 1950s and early 1960s, when the consequences of World War II were overcome, but the fast-food culture had not reached the area yet (Trichopoulou 2001).

Recent studies, capturing the evidence accumulated over the last three decades, have documented that the traditional Mediterranean diet meets several important criteria for a healthy lifestyle (Trichopoulou 2001). Although it is difficult to describe the "typical" traditional Mediterranean diet, one can define eight aspects that tend to characterize it, of which two of the most important ones are a high ratio of monounsaturated/saturated fat and a high intake of legumes (including beans, lentils, peas and chickpeas) (Trichopoulou et al. 2003b, 2009). Although variable, it is estimated that the average person following a Mediterranean diet ingests about 102.5 g of legumes per day (Martinez-Gonzalez et al. 2002).

Total lipid consumption may be moderately high in the populations consuming Mediterranean diets, reaching around 40 % of total energy intake in Greece and around 30 % of total energy intake in Italy (Trichopoulou 2001), but the ratio of monounsaturated to saturated dietary lipids is much higher than in other places of the world, including northern Europe and North America (Trichopoulou 2001).

The legumes in the Mediterranean diet can have a significant impact in plasma carotenoid levels. It was found that amongst different components of the

Mediterranean diet, fruits and vegetables tended to increase levels of some carotenoids, whereas olive oil had no apparent effect (Trichopoulou et al. 2003a).

Also, although soybean is not a traditional component in the Mediterranean diet, researchers have found that a daily intake of 40 mg of soy isoflavones together with a Mediterranean diet and exercise can reduce insulin resistance in postmenopausal women (Llaneza et al. 2010).

Some of the best described health benefits of the Mediterranean diet are the lower incidence of osteoporosis (Puel et al. 2007) and different types of cancer such as gastric adenocarcinoma (Buckland et al. 2009), cancers of the upper aerodigestive tract (Bosetti et al. 2009), colorectal cancer (Bingham et al. 2003; Stamatiou et al. 2007), prostate cancer (Itsiopoulos et al. 2009) and other types of cancer (Materljan et al. 2009). The prevention of these diseases through dietary means is linked to specific food items that contain a complex array of naturally occurring bioactive molecules with antioxidant, anti-inflammatory and alkalinising properties (Puel et al. 2007). As legume grains are high in compounds such as proteins, mono- and di-unsaturated fatty acids, phenolic compounds, trypsin inhibitors, phytates and oligosaccharides components known for having important antioxidant and anti-inflammatory activities, it is probable that their consumption is linked to lower prevalence of these ailments.

As an example, certain legume grains, such as lentils, fava beans and split beans, are known to be very fibre rich (Table 13.2); high fibre intakes are related to lower rates of colon cancer. In fact, in populations with low average intake of dietary fibre, an approximate doubling of total fibre intake from foods could reduce the risk of colorectal cancer by 40 % (Bingham et al. 2003).

## 13.2 Legume Grains and Nutrition

Legumes are important sources of adequate proportions of different nutrients, such as protein, minerals, lipids, vitamins, starch, sugars and other non-starch polysaccharides, which have made them targets of justified nutritional interest (Table 13.2). Bearing in mind that diet and fat ingestion are the factors most directly related to high cholesterol levels and the increase of arteriosclerosis and fatal coronary diseases in various countries, the quantity and type of fat in pulses is another factor to be considered when evaluating the nutritional importance of these substances. Some of these nutrients and their impact on human and animal health will be discussed next.

Table 13.1 shows the typical nutritional content of a selected number of legume grains, in terms of water, proteins, fat, energy, sugars, fibre and carbohydrates. One can observe that there is a substantial variability in terms of protein content, with soybean having the highest amount per 100 g FW basis. Of these grain legumes, chickpea has the lowest amount of protein but, on the other hand, shows the highest amount of total sugars in the grain. The fattiest legume grain, by far, is the peanut, with almost half its fresh weight corresponding to total lipids. The legume showing the highest fibre content is lentil, followed by split pea and fava bean (Table 13.1).

**Table 13.1** Nutrient content of selected legume grains, mature seeds, raw, per 100 g fresh weight (FW) basis

| Legume | Water (g) | Protein (g) | Total lipid (fat) (g) | Fibre (g) | Energy (kcal) | Sugars, total (g) | Carbohydrate by difference (g) |
|---|---|---|---|---|---|---|---|
| Soybean (*Glycine max*) | 8.54 | 36.49 | 19.94 | 9.3 | 446 | 7.33 | 30.16 |
| Chickpea (*Cicer arietinum*) | 11.53 | 19.30 | 6.04 | 17.4 | 364 | 10.70 | 60.65 |
| Lentils (*Lens culinaris*) | 10.40 | 25.8 | 1.06 | 30.5 | 353 | 2.03 | 60.08 |
| Split pea (*Pisum sativum*) | 11.27 | 24.55 | 1.16 | 25.5 | 341 | 8.00 | 60.37 |
| Groundnut (*Arachis hypogaea*) | 6.50 | 25.80 | 49.24 | 8.5 | 567 | 3.97 | 16.13 |
| Fava bean (*Vicia faba*) | 10.98 | 26.12 | 1.53 | 25.0 | 341 | 5.70 | 58.29 |
| Black beans (*Phaseolus vulgaris*) | 11.02 | 21.60 | 1.42 | 15.2 | 341 | 2.12 | 62.36 |

*Source*: USDA (2010)

More and more new crops are being identified which seem to have a good combination in terms of nutrient composition, being very well balanced not just in one nutrient category but for several. The morama bean (*Tylosema esculentum*), for example, is a leguminous oilseed native to the Kalahari Desert and neighbouring sandy regions of Botswana, Namibia and South Africa that has recently been reported to be an excellent source of good quality protein (29–39 %), rich in mono- and di-unsaturated fatty acids and a good source of micronutrients (calcium, iron, zinc, phosphate, magnesium and B vitamins including folate) (Jackson et al. 2010).

Moreover, it is also reported to be a potential source of phytonutrients (phenolic compounds, trypsin inhibitors, phytates and oligosaccharides), components which have been shown to be important in the prevention of noncommunicable diseases such as cardiovascular diseases (CVDs), diabetes and some cancers (Jackson et al. 2010).

Winged bean (*Psophocarpus tetragonolobus*), also known as the Goa bean, is an important underexploited legume of the tropics. All the plant parts, viz., seeds, immature pods, leaves, flowers and tubers are edible. Mature seeds contain 29–37 % protein, 15–18 % oil and fairly good amounts of phosphorus, iron and vitamin B. Its essential amino acid composition is very similar to that of soybean, and the fatty acid composition is very much comparable to groundnut (Kadam and Salunkhe 1984). The trypsin inhibitor in winged bean has been shown to be heat resistant.

These less commonly used crops, given their desirable nutritional aspects, should be considered more carefully, and their utilization should be pondered in non-native environments.

### 13.2.1 Carbohydrates

Carbohydrates in the legumes can be divided into water-soluble components such as sugars and certain pectins and insoluble ones such as starch and cellulose (Aykroyd et al. 1982). Both of these groups include carbohydrates that are very useful in energy production, but also the more indigestible ones, that cannot be so effortlessly utilized because they are not easily "breakable" by the digestive enzymes. In general, legumes are richer in fibre than most cereals and include cellulose, hemicellulose, lignin and galactomannans (Aykroyd et al. 1982). The primary action of fibres in the human organism occurs in the gastrointestinal tract, presenting different physiological effects. It has been demonstrated that diets rich in these nondigestible fermentable carbohydrates favour the development of beneficial species in detriment of pathogens in the gut (Grizard and Barthomeuf 1999). According to various investigations, metabolites from the fermentation of complex carbohydrates can be beneficial to health because they show a protective effect against colon or rectal cancer; decrease infectious intestinal diseases by inhibiting putrefactive and pathogenic bacteria (*Clostridium perfringens*, *Escherichia coli*, *Salmonella*); increase mineral bioavailability such as that of calcium; aid in the decreases of hypercholesterolemia, hyperlipoproteinemia and hyperglycaemia; and stimulate the immune system (Grizard and Barthomeuf 1999).

The carbohydrate content of legumes varies roughly between 16 and 60 g/100 FW basis (Table 13.2). Legume starches are particularly rich in the unbranched moiety amylose. Thus, they are particularly prone to retrogradation and the devel-

**Table 13.2** Lipid content of selected legume grains, mature seeds, raw, per 100 g FW basis

| Legume | Lipids (total) | | | |
|---|---|---|---|---|
| | Saturated (g) | Monounsaturated (g) | Polyunsaturated (g) | Phytosterol (mg) |
| Soybean (*Glycine max*) | 2.884 | 4.404 | 11.255 | 161 |
| Split peas (*Pisum sativum*) | 0.161 | 0.242 | 0.495 | 135 |
| Chickpea (*Cicer arietinum*) | 0.626 | 1.358 | 2.694 | 35 |
| Lentil (*Lens culinaris*) | 0.156 | 0.189 | 0.516 | nd[a] |
| Peanut (*Arachis hypogaea*) | 6.834 | 24.429 | 15.559 | 220 |
| Fava bean (*Vicia faba*) | 0.254 | 0.303 | 0.629 | 124 |
| Black beans (*Phaseolus vulgaris*) | 0.366 | 0.343 | 0.610 | nd[a] |

*Source*: USDA (2010)

[a]*nd* no available data

opment of resistant starch after heat treatment. Legume starch may also resist digestion due to entrapment within thick-walled cells, leading to the commonly reported issues of flatulence associated with the ingestion of legume grains (Phillips 1993). Legume starch is more slowly digested than starch from cereals and tubers and produces less abrupt changes in plasma glucose and insulin upon ingestion.

### *13.2.2 Proteins*

Protein calorie malnutrition is prevalent in many developing countries of the tropics and subtropics (Kadam and Salunkhe 1984). In many countries, human nutrition is highly dependent on grain legumes for protein. It is estimated that about 20 % of food protein worldwide is derived from legumes (National Academy of Science 1994). The highest consumption occurs in the former Soviet Union, South America, Central America, Mexico, India, Turkey and Greece.

Different legumes, such as common bean (Reyes-Moreno and Paredes-López 1993), pea (Casey et al. 1984) or soybean (Xu and Chang 2009a; Young et al. 1979), are very high in protein content (Table 13.2). Besides the grain, the nutritive value of sprouts as an important source of protein and other nutrients has also been recognized (Ribeiro et al. 2011; von Hofsten 1979). Soy milk is also an excellent dietary protein source for common consumers, vegetarians and people with lactose intolerance and milk allergy (Xu and Chang 2009a).

Protein contents in legume grains range from 19 to 40 % (Table 13.2), contrasting with 7–13 % of cereals and being equal to the protein contents of meats (18–25 %) (Genovese and Lajolo 2001). However, although quantitative profiles are similar, the same does not apply from a qualitative profile point of view. It is estimated that the protein in legume grains is generally rich in lysine (Phillips 1993) but, compared with meat, which is the main source of protein, it is deficient in sulphur-containing amino acids (Wang et al. 2003), such as cystine (Bertagnolli and Wedding 1977) and methionine (National Academy of Science 1994). On the other hand, cereal-grain proteins are low in lysine but have adequate amounts of sulphur amino acids. Therefore, the supplementation of cereals with legumes has been advocated as a way of combating protein-calorie malnutrition problems in developing countries, and in some countries such combination is part of the food cultural heritage.

Asparagine accounts for 50–70 % of the nitrogen in translocatory channels serving fruit and seed of white lupin (*Lupinus albus* L.) (Atkins et al. 1975). The nutritional quality of legume protein is limited by the presence of heat labile and heat stable antinutrients as well as an inherent resistance to digestion of the major globulins. In addition to its nutritional impact, legume protein has been shown to reduce plasma low density lipoprotein (LDL cholesterol) when consumed.

On the down side, many legume seeds have been proven to contain high amounts of lectin. Lectin is a sugar-binding protein present in plants and animals. These proteins have the ability to agglutinate erythrocytes, acting as haemagglutinins (Grant et al. 1983). As described before in this chapter, soybean is the most important grain legume crop, the seeds of which contain high activity of soybean lectins. These are able to disrupt small intestinal metabolism and damage small intestinal villi via the ability of lectins to bind with brush border surfaces in the distal part of the small intestine (Imberty and Perez 1994). Heat processing can reduce the toxicity of lectins, but low temperature or insufficient cooking may not completely eliminate their toxicity, as some plant lectins are resistant to heat. In addition, lectins can result in irritation and oversecretion of mucus in the intestines, causing impaired absorptive capacity of the intestinal wall. Other protein non-nutritional compounds include protease inhibitors—Kunitz trypsin inhibitor (KTI) and Bowman-Birk inhibitor. Protease inhibitors represent 6 % of the protein present in soybean seed. Approximately, 80 % of the trypsin inhibition is caused by KTI, which strongly inhibits trypsin and therefore reduces food intake by diminishing their digestion and absorption. Another effect of KTI is the induction of pancreatic enzyme, hyper secretion and the fast stimulation of pancreas growth, hypertrophy and hyperplasia.

However, reports have shown that germinating or soaking in 0.5 % sodium bicarbonate can decrease most antinutritional factors such as phytic acid, tannin, trypsin inhibitor and haemagglutinin activity, at least in soybean, lupin and bean seeds (el-Adawy et al. 2000). Furthermore, efforts have been made to use selection and breeding to improve antinutritional factors content in legumes, and low antinutritional factor lines with acceptable seed size have been developed (Mikić et al. 2009). However, environment and agricultural management influences such quality of legumes to a considerable extent, and this should be noted while breeding for antinutritional factor lowering potential.

### *13.2.3 Lipids*

The legume grains, in particular soybean and groundnut (peanut), are often used to extract edible oils. Of all edible oils, that from soybean is the second most important, with an estimate world production of 36 million metric tonnes in 2009 (FAO stats), followed by palm oil, which produced 41 million metric tonnes in the same year. Groundnut oil is the sixth most important edible oil of vegetable origin and had an annual production of about 5.2 million metric tonnes in 2009 (FAO stats). In contrast to the leguminous oilseeds, most pulses contain only a small amount of fats (usually less than 2 %, Table 13.2). Chickpeas are unusual amongst the pulses as they have a relatively high fat percentage (around 6 %, Table 13.2). Whereas soybean and groundnut have around 20 and 50 g of total lipids per 100 g FW basis, respectively, split peas and lentils have only about 1 g of total lipids per 100 g FW basis. However, even in the high fat legumes, the lipid component is highly unsaturated. Table 13.3 gives more detailed information on the types of lipids present in the legume grains. Of the total lipid content in soybean and groundnut, over 85 % are comprised of unsaturated fat, with peanut having more polyunsaturated fat and soybean more monounsaturated fat. Even though peanuts are high in fat, their

**Table 13.3** Vitamin content of selected legume grains, mature seeds, raw, per 100 g FW basis

| Legume | Vitamin | | | | | |
|---|---|---|---|---|---|---|
| | Vitamin A (IU) | Vitamin E (alpha-tocopherol) (mg) | Vitamin C (mg) | Thiamine (mg) | Riboflavin (mg) | Vitamin B-6 (mg) |
| Soybean (*Glycine max*) | 22 | 0.85 | 6 | 0.874 | 0.870 | 0.377 |
| Split peas (*Pisum sativum*) | 149 | 0.09 | 1.8 | 0.726 | 0.215 | 0.174 |
| Chickpea (*Cicer arietinum*) | 67 | 0.82 | 4 | 0.477 | 1.541 | 0.535 |
| Lentil (*Lens culinaris*) | 39 | 0.49 | 4.4 | 0.873 | 0.211 | 0.540 |
| Groundnut (*Arachis hypogaea*) | 0 | 8.33 | 0 | 0.640 | 0.135 | 0.348 |
| Fava bean (*Vicia faba*) | 53 | 0.05 | 1.4 | 0.555 | 0.333 | 0.366 |
| Black beans (*Phaseolus vulgaris*) | 0 | 0.21 | 0 | 0.900 | 0.193 | 0.286 |

*Source*: USDA (2010)

consumption is viewed as a significant contribution to a healthy diet. They contain important nutrients and bioactive constituents that can provide a wide range of health benefits, such as phytosterols (Shin et al. 2010). More recently, peanuts have also been studied in satiety control and body weight management.

Phytosterols are unsaponifiable triterpenes found in the lipid fraction, possessing a cyclopentanoperhydrophenanthrene ring structure and are sometimes referred to as 4-desmethyl sterols. Several other legume grains besides peanuts are rich in phytosterols, in particular soybean, split peas and fava beans (Table 13.3). The health benefits of phytosterol consumption as natural components of a regular diet include anticarcinogenic, anti-osteoarthritic (Gabay et al. 2009), anti-coronary heart disease (Escurriol et al. 2009; Teupser et al. 2010) and hypocholesterolemic (Demonty et al. 2009; Hernandez-Mijares et al. 2010; Lin et al. 2009) actions. Due to the importance of phytosterols in human health, genetic engineering approaches have been utilized and have been successful in generating transgenic plants with increased phytosterol content in the seeds (Harker et al. 2003; Hey et al. 2006). However, these tests were conducted in tobacco plants, which are highly amenable for transformation and should be repeated for these crops.

Also, modulating endogenous levels of novel fatty acids of oils has gained significant attention in recent years, due to the increasing awareness of consumers of the impact that dietary lipids have on health (Clemente and Cahoon 2009).

Commodity soybean oil is composed of five fatty acids (palmitic acid, stearic acid, oleic acid, linoleic acid and linolenic acid) with average percentages of 10 %, 4 %, 18 %, 55 % and 13 %, respectively (Clemente and Cahoon 2009). This fatty acid profile sometimes results in low oxidative stability that limits the uses of soybean oil in food products and industrial applications. Therefore, there is an interest in utilizing genetic transformation techniques to modulate the fatty acid composition of soybean oil.

### 13.2.4 Vitamins

The vitamin content of different legume grains is quite variable (Table 13.4). Vitamin A concentration is highest in split pea, whereas groundnut has no trace of this particular vitamin. However, groundnut is very rich in alpha-tocopherol, having 8.33 g per 100 g FW basis. Alpha-tocopherol is quantitatively the major form of vitamin E in humans and animals and has been extensively studied (Jiang et al. 2001). It is a class of compounds that may have vitamin E activity and function as an antioxidant protector of the organism. Oxidative damage is a major contributor to the development of cancer, CVD and neurodegenerative disorders. Antioxidant vitamins defend against oxidative injury and are therefore believed to provide

**Table 13.4** Mineral content of selected legume grains, mature seeds, raw, per 100 g FW basis

| Legume | Minerals (mg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Calcium (Ca) | Iron (Fe) | Magnesium (Mg) | Phosphorous (P) | Potassium (K) | Copper (Cu) | Zinc (Zn) |
| Soybean (*Glycine max*) | 277 | 15.7 | 280 | 704 | 1797 | 1.66 | 4.89 |
| Split peas (*Pisum sativum*) | 55 | 4.4 | 115 | 366 | 981 | 0.866 | 3.01 |
| Chickpea (*Cicer arietinum*) | 105 | 6.2 | 115 | 366 | 875 | 0.847 | 3.43 |
| Lentil (*Lens culinaris*) | 56 | 7.5 | 122 | 451 | 955 | 0.519 | 4.78 |
| Groundnut (*Arachis hypogaea*) | 92 | 4.6 | 168 | 376 | 705 | 1.144 | 3.27 |
| Fava bean (*Vicia faba*) | 103 | 6.7 | 192 | 421 | 1062 | 0.824 | 3.14 |
| Black beans (*Phaseolus vulgaris*) | 123 | 5.0 | 171 | 352 | 1483 | 0.841 | 3.65 |

*Source*: USDA (2010)

protection against various diseases. In the form of food supplement, alpha-tocopherol can be found under the label E307.

Another key vitamin also found in the legume grains but in smaller amounts is vitamin C (also called L-ascorbic acid or L-ascorbate). Vitamin C is also an important antioxidant, protecting the body against oxidative stress. In the legumes, the germinated seeds are richer in this vitamin than the grains, as the vitamin degrades rapidly after long storage (Aykroyd et al. 1982).

Starchy legumes are valuable sources of dietary fibre as well as thiamine and riboflavin. Starchy legumes are a valuable component of a prudent diet, but their consumption is constrained by low yields, the lack of convenient food applications and flatulence (Phillips 1993). In a study where chicks were fed test diets containing 35 % soybean meal (control) or raw (40 %) or dehulled (35 %) lupine seed meal lupin diet, all broilers fed with lupine-based diets had significantly higher ($P<0.001$) riboflavin in the plasma (Olkowski et al. 2005).

### 13.2.5 *Minerals*

Legume seeds are also an important source of dietary minerals, with the potential to provide all of the essential minerals required by humans (Grusak 2002). The plants contain 14 mineral elements defined as essential for plant growth and reproductive success, which are N, S, P, K, Ca, Mg, Cl, Fe, Zn, Mn, Cu, B, Mo and Ni. However, iron bioavailability is not always favourable amongst the different legume seeds; it has been shown to be quite low for lupin, soybean (Macfarlane et al. 1988, 1990) and urd bean (Chitra et al. 1997), whereas in chickpea it is reported to be the highest (Chitra et al. 1997).

It seems that the amount of available nutrients in the legumes is influenced by processing methods (Chau and Cheung 1997; Xu and Chang 2009b). Cooking, as well as autoclaving the seeds of, e.g. *Phaseolus* brings about a more significant improvement in the digestibility of both protein and starch as compared with soaking and germination (Chau and Cheung 1997). This is an important factor for these particular nutrients but not as much for the minerals, because mineral bioavailability seems to be relatively undisturbed with different processing methods (Trugo et al. 2000). Therefore, using natural variation can be one of the possible options to help reduce the problems associated with lower bioavailability of minerals. Phytic acid is one of the chief antinutrients present mainly in seeds of grain crops such as legumes and cereals and has the potential to bind mineral micronutrients in food and reduce their bioavailability. Germination can reduce or eliminate appreciable amounts of phytic acid in legumes and hence improves mineral bioavailability (Sutardi and Buckle 1985). Perlas and Gibson (2002) demonstrated that soaking can be used to reduce the inositol penta- and hexaphosphate (phytic acid) content of complementary foods based on mung bean (legume) flour and thus enhance the bioavailability of iron and zinc. Low phytic acid lentils have been identified in Saskatchewan that have low phytic acid concentrations, making them a promising material to be used in regions with widespread micronutrient malnutrition (Thavarajah et al. 2009).

Legume grains, given their high micronutrient status, should be considered priority picks in food dietary choices, both for human food and animal feed.

### *13.2.6 Nutraceuticals*

Some research works have reported bioactive components in plant foods with nutraceutical properties related to the maintenance of health or prevention of chronic disease. Selection of the right legume varieties combined with a suitable germination process could provide good sources of bioactive compounds from legumes and their germinated products for nutraceutical applications (Lin and Lai 2006; Xu and Chang 2009b). Amongst these substances are proteins, carbohydrates, antioxidant molecules, polyunsaturated fatty acids and inositol derivates (Ribeiro et al. 2011).

Legume seeds contain two major classes of soluble α-galactosyl: the raffinose family oligosaccharides and the galactosyl cyclitols (Ribeiro et al. 2011). Legumes are also a unique source of natural products such as flavonoids, isoflavonoids, alkaloids and saponins, many of which have documented antimicrobial, pharmaceutical and/or nutraceutical properties (Leia et al. 2011). Soybeans and soy foods contain significant amounts of health-promoting components of these isoflavones, flavon-3-ols and phenolic compounds (Xu and Chang 2009a) with important antioxidant activities. The dark-coat seeds, such as azuki beans, black soybeans (Lin and Lai 2006) and the hulls of *Phaseolus vulgaris* (Oomah et al. 2010), contain high amounts of phenolic compounds with high antioxidative ability. Flavonoids are widely present in plants, usually in the form of water-soluble glycosides (Wollenweber and Dietz 1981). Isoflavones are polyphenolic compounds found mainly in legumes, the benefits of which have been widely studied and attributed in particular to their phytoestrogenic activity (Romani et al. 2011).

Besides the grain and grain derivatives, seed sprouts have also been used as a good source of nutraceutical compounds (Ribeiro et al. 2011). The high nutritional value of seeds derives from the deposition of compounds during development. Bean sprout, for example, is an important source of proteins, sucrose, glucose and myo-inositol (Ribeiro et al. 2011), antioxidants and phytoestrogens (Diaz-Batalla et al. 2006). Additionally, bean sprouts have low levels of raffinose, an antinutritional compound for flatulence symptoms when ingested in high quantities (Ribeiro et al. 2011).

Legume grains have also been used traditionally for their antifungal activity in traditional medicine. Extracts obtained from seeds of *Psoralea corylifolia* (Fabaceae), a commonly occurring medicinal plant in South India where it is known as *babchi*, showed several degrees of antifungal activity, having important anti-dermatophytic properties (Rajendra Prasad et al. 2004). The seeds of this legume plant are also used as stomachic, deobstruent and diaphoretic in febrile conditions and also in leucoderma and other skin diseases (Rajendra Prasad et al. 2004).

Other examples of the medicinal uses of species from the *Fabaceae* come from the Mayan populations, which used them routinely for the treatment of diarrhoea and eye infections. These properties seem to be associated to the presence of flavonoids and quinones that showed strong activity against both bacteria and fungi (Rosado-Vallado et al. 2000). The tropical forage legume *Clitoria ternatea* (L.) also has shown to have insecticidal and antimicrobial activities (Kelemu et al. 2004).

Finally, early studies of the effects of dietary carbohydrates on plasma lipid levels identified leguminous seeds as potential hypocholesterolaemic agents.

## 13.3 Legume Grains for Animal Feed

Forage legumes are also widely used in many grassland farming areas of the world; their importance arose principally because of their ability to fix atmospheric nitrogen biologically and secondly because of their nutritional value. They can reduce nitrate leaching and reduce global warming potential of livestock farming systems. In animal feeding, they can be used as green forage, forage dry matter, forage meal, silage, haylage, immature grain, mature grain and straw, while some species may be used for grazing too (Mikić et al. 2009). Forage legumes can sustain high animal performances and improve the nutritional quality of ruminant products. This, by itself, can indirectly improve human health, as ruminant products are part of the diet of large segments of the population. These benefits have been shown in research conducted in a wide range of situations in Europe (Rochon et al. 2003). Amongst the most commonly used legume grains for animal feed are soybean (Solanas et al. 2005), pea (Yanez-Ruiz et al. 2009), chickpea (Yanez-Ruiz et al. 2009), alfalfa (Hoffman et al. 1999; McAllister et al. 2005; Tongel and Ayan 2010), crown vetch (McAllister et al. 2005), white clover (*Trifolium repens*, also known as Dutch White, New Zealand White or Ladino) (Lacefield and Ball 2000; Rochon et al. 2003; Smith and Valenzuela 2002) and several *Lotus* species (McAllister et al. 2005). White clover (*Trifolium repens*) is the main legume to be found in pastures and meadows of temperate regions and is adapted to survive in a range of grassland environments (Rochon et al. 2003).

The plants of the genus *Medicago* L. (*Fabaceae*) belong to 50 species of annual or perennial herbs, rarely shrubs, of which *Medicago sativa* L. (alfalfa) is one of the best known, as it is used as a forage crop widely (Alessandra et al. 2010). Lucerne, or alfalfa, is sometimes called “queen of forage crops” in Turkey, as it is the most promising forage crop for Turkish farmers, producing high-quality feed during summer on lowland fields (Tongel and Ayan 2010).

Feed legumes have a great significance in animal feeding as one of the most quality and least expensive solutions for a long-term demand for plant protein in animal husbandry. Forages help meet the protein requirements of ruminants by providing degraded substrate for microbial protein synthesis plus protein that escapes ruminal degradation (Broderick 1995). The potential of different legume seed species, including recently new developed varieties as protein supplements to low-quality forages, has been evaluated with positive outcomes (Yanez-Ruiz et al. 2009). Due to a different amino acid composition between species, each of the feed legumes may easily find its useful place in animal feeding, supplementing and replacing each other (Mikić et al. 2009). Evidence from numerous feeding studies with lactating dairy cows indicates that excessive ruminal protein degradation may be the most limiting nutritional factor in higher-quality temperature legume forages (Broderick 1995). Condensed tannins found in legumes are known to decrease protein degradation, either by altering the forage proteins or by inhibiting microbial proteases (Broderick 1995). Compared to soybean meal, beans and peas showed similar suitability as protein supplements for sustaining in vitro fermentation of low-quality forages (Yanez-Ruiz et al. 2009). In order to increase protein digestibility, one common strategy is to mix grain legumes with cereals (Chauhan et al. 1988; Geervani et al. 1996; Mupangwa et al. 2000; Solanas et al. 2007) and grasses (Hoffman et al. 1999; Roffler and Thacker 1983).

Legumes are also important forages because of their ability to convert atmospheric nitrogen through a symbiotic interaction with *Rhizobia*. During this interaction, atmospheric nitrogen is reduced to ammonia which is incorporated in amino acid biosynthesis and ultimately results in high protein content. It was estimated that $7–10 billion worth of nitrogen is fixed by legumes annually and a proportion returned to the soil for subsequent crops. Thus, even modest use of alfalfa (*Medicago sativa*) in rotation with corn could save farmers $200–300 million in nitrogen fertilizer costs annually (Leia et al. 2011).

## 13.4 Conclusions

Legume grains have been grown for thousands of years and have a long tradition of cultivation in many parts of the world, including the Mediterranean region, where they are part of the staple diet. The grain legumes are cultivated primarily for their grains and are used either for human consumption or for animal feed. However, plant sources rich in proteins, used for feeding, are still highly deficient in Europe. Covering this deficit requires massive imports of soya bean meal that is mainly produced in the United States. These imports demand transport over long distances, resulting in adverse environmental impacts. Legumes have the potential to positively contribute to sustainable agriculture, as they can lower the needs for mineral nitrogen, which is an expensive, unavailable resource in many countries. It allows producing human food and animal feed with very limited ecologically harmful inputs, reducing greenhouse gas emissions. Grain legumes are more adapted than grasses to global changing environments, some being less susceptible to drought and others more productive under high temperatures. In spite of the importance of legumes in agriculture, increases in yield over the past few decades have lagged behind those of cereals, mainly because of numerous stresses such as salinity, acidity, nutrient limitations and various diseases and pests. However, on the whole, introducing grain legumes into European crop rotations offers interesting options for reducing environmental burdens, especially in a context of depleted fossil energy resources and climate change. Moreover, the heavily substantiated and proven health benefits associated to the legume grains make them ideal choices when faced with the increased available dietary items in the market.

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