Consortium for Educational Communication

Module on

STRUCTURE AND COMPOSITION OF LEGUMES

By

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TEXT

1. INTRODUCTION:

Legumes belong to the order Leguminosae (legumes or the bean family). The Leguminosae (also known as Fabaceae) encompasses about 750 genera and 19,000 species of herbs, shrubs, trees, and climbers. They are among the three largest families of flowering plants. This large family is divided into four subfamilies— the Mimosoideae, Caesalpinoideae, Papilionoideae, and Swartzioideae. Many agricultural shrubs including grain, pulses, and forage crops belong to legumes. The Papilionoideae, with a worldwide distribution, are the largest subfamily and include the most important species for human food. Legume crops are extensively produced in temperate climate areas for their seeds. These legume seeds are used for human and animal consumption or for the production of oils for industrial uses. They are often used in crop rotation and intercropping. The importance of legumes is due to their significance in human nutrition. Some of the widely used legumes include beans, black beans, fava beans, chickpeas, kidney beans, lima beans, lentils, lupins, peas, soybeans, and peanuts (groundnuts). And common food products made from legumes include tofu, peanut butter, and soymilk.

2. NUTRITIONAL IMPORTANCE

Grain legumes are second only to cereals as a source of human food. Nutritionally, legume seeds are two to three times richer in protein than cereal grains (National Academy of Sciences, NAS, 1979). They are considered as a significant source of protein, dietary fiber, carbohydrates, and micronutrients. Perhaps they are best known for their high protein content; due to the nitrogen fixation through symbiotic relationship with bacteria. In many developing countries where animal protein is expensive, legumes are an important source of cheap protein. The literature data reveals that the acidic amino acids (Aspartic acid and Glutamine) dominate amino acid composition of legumes and usually account for 30-40% of the total amino acids. On the other hand, they are deficient in the essential amino acid methionine. When legumes and cereals are eaten together, they provide complete protein nutrition. Cereals are deficient in lysine but contain adequate amounts of methionine. For this reason, when cereals are consumed with legumes, they complement each other thus improving the nutritive value of both. Thus, a combination of legumes with grains forms a well-balanced diet for vegetarians. Common examples of such combinations are dal (lentils) with rice, dal with wheat, and beans with corn tortillas, tofu with rice, and peanut butter with wheat bread (as sandwiches).

Most of the legumes are low in fat except for soybeans and peanuts which are considered to be rich in oil. Legumes also contain health protective compounds such as phenolics, inositol phosphates, and oligosaccharides. As a result they can be used not only as meat replacers but also as components of rational nourishment and food for vegetarians.

3. LEGUME IDENTIFICATION

Plants in the Leguminosae family have characteristic pods that help to identify them as legumes. A legume fruit develops from a simple carpel and usually dehisces (opens along a seam) on two sides. A common name for this type of fruit is a pod. All legumes have similar fruits, called 'pods', as shown in Fig. 1. The structure and morphology of a pod (Pisum sativum) is also shown in Fig. 2. However, the most dependable way to identify the legume subfamilies is by examining the plant's reproductive structure (i.e., the flower).

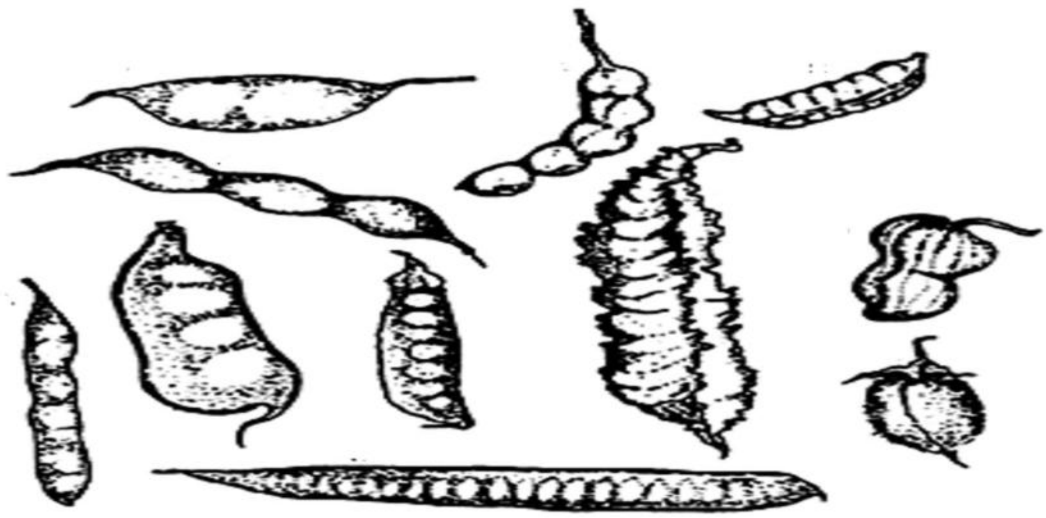

Fig 1: Legume pods

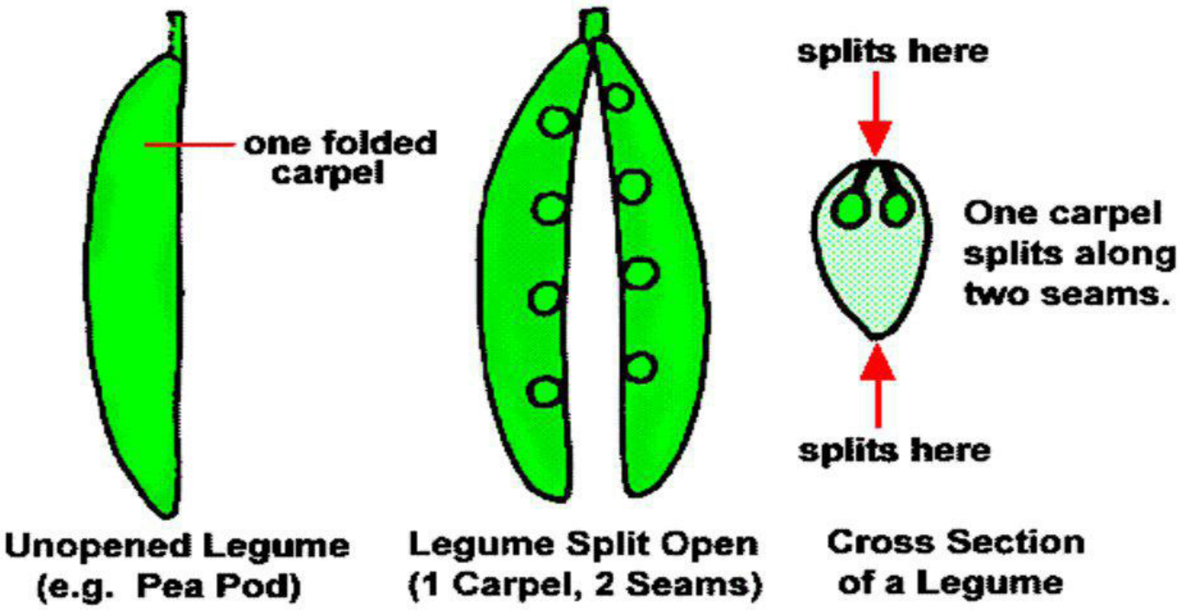

Fig 2: Structure and morphology of pods

4. SEED STRUCTURE

Legume seeds have a characteristic structure consisting of three major parts: seed coat (testa or hull), the cotyledons, and hypocotyl (including plumule) as shown in Fig. 3. In many of the legumes, the cotyledons constitute about 90% of the seed. However, most of the legume seeds have very little endosperm at maturity, as the cotyledons of the embryo make up a majority of the seed weight and contain the necessary stores for growth. The cotyledons are part of the embryo and are not therefore analogous to the endosperm of cereals. Although, legume seeds have an endosperm at an early stage of development, but in the mature seed it is vestigial, and the reserves for the early growth of the seedling are stored in the cotyledons. Cotyledons provide a majority of the nutritional components to food value, with the exception of fiber and calcium, of which a significant portion is found in seed coat. The seed coat is the next largest fraction, but because of high fiber content, it contains an insignificant part of the total food value of the whole seed. Outer layers of the seed coat are also known to contain tannins. The compositions of the hull and cotyledon are different, as would be expected. It has been therefore demonstrated that the cotyledons account for most of the food value of the whole seed. The seed coat contains very little nutrient material except for soybeans that contain 35% of the calcium in whole seed.

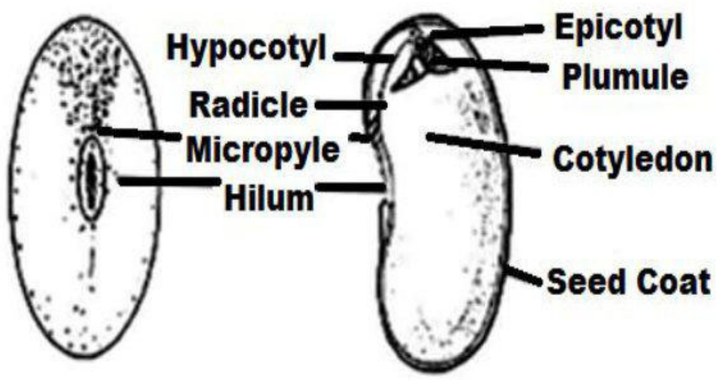

Fig 3: Structure of a legume seed (soybean)

Legume seeds are highly organized structures when examined at the sub cellular level. The major constituents, proteins, lipids, and starch (when present) are neatly packaged in a grain legume. Protein storage sites are called protein bodies. Protein bodies are about 5μm in diameter. The starch granules are oblong and vary in size with species and stage of maturity. Surrounding the protein bodies and starch granules are membranes containing lipid bodies. The lipid deposits are called spherosomes. These are particularly prominent in the oily legumes such as soybean. In the oil-bearing legumes, protein bodies and starch granules are the prominent structures. In some legumes, globoids containing phytate are present in the protein bodies. These sub-cellular structures are not uniformly distributed throughout seed. The outer layers of the cotyledons of chickpeas, kidney beans, and soybeans were found to contain larger concentrations of protein and more trypsin inhibitor than the inner layers. Fig. 4 exemplifies the structure of protein bodies and starch granules at cellular level.

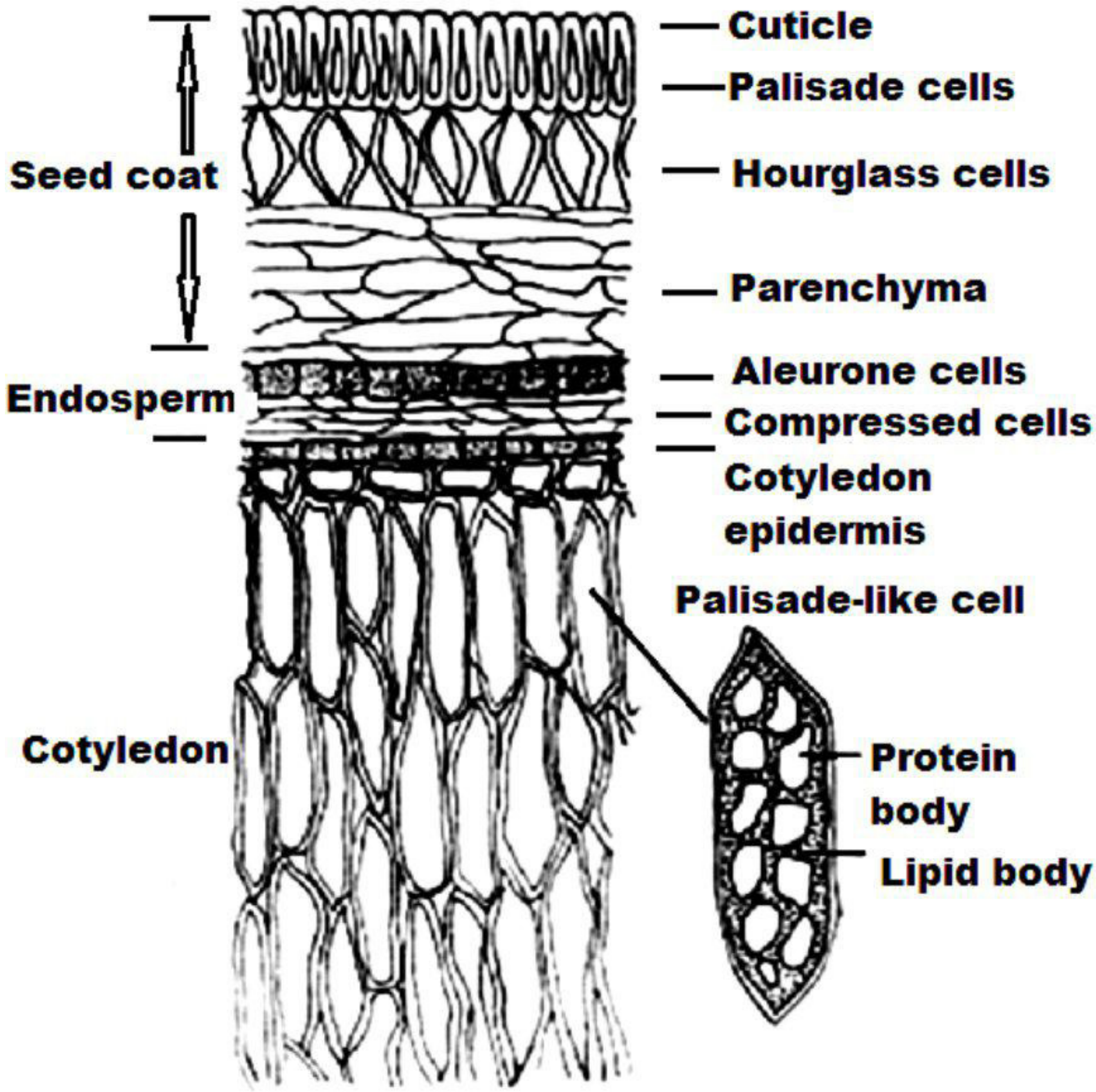

Fig 4a: Cross section of a legume seed (soybean)

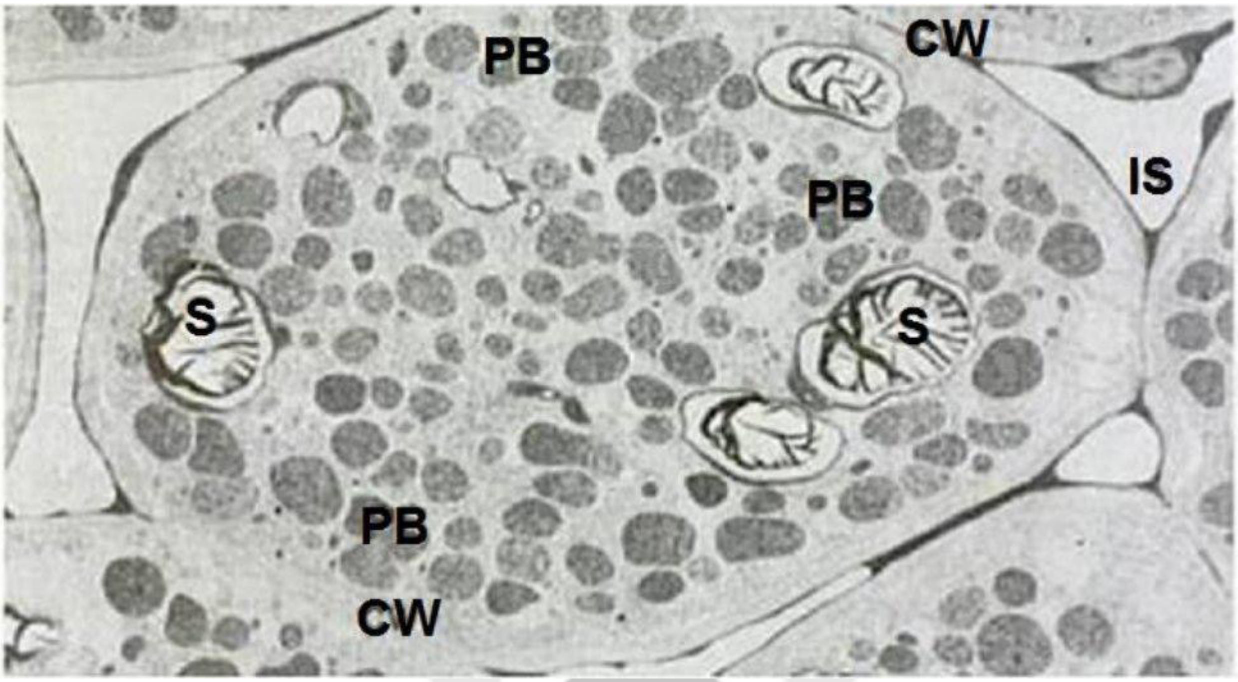

Fig 4b: Sub cellular structure of a mature pea (S: starch grains, PB: protein body, CW: cell wall, IS: intercellular space)

5. CHEMICAL COMPOSITION

5.1. Proximate composition

Food legumes vary greatly in their nutrient composition, depending on the type and variety of seed, soil conditions, and environmental factors. The proximate composition of some major food legumes grown in India are presented in Table 1. The protein content of the selected legumes ranges from 19.4% to 35% of the edible portion. Although crude protein has been reported to range between 15% and 45%.The Carbohydrate content ranges from 21.6% to 65.4%, and appears to be inversely related to the lipid content. Legume seeds high in carbohydrates have low lipid content, and vice versa. A classical example is peanut, which has a very high lipid content and relatively low carbohydrate content (16.13%). Potassium is by far the most abundant mineral in most food legumes, with soybeans containing as much as 1.80 g/100 g edible portion. Phosphorous, copper, iron, calcium, and magnesium are some of the important minerals found in significant amounts in legumes. Niacin and pantothenic acid account for the most quantitatively important vitamins in legumes, and most are also a good source of folate.

Table 1: Energy and Selected Nutrients in Legumes

(Composition per 100 g edible portion of dried mature whole seeds)

Legume	Water (%)	Energy (Kcals)	Protein (g)	Fat (g)	Carboh ydrate (g)	(g)	(mg)	Iron (mg)	Thiamin (mg)
Black gram	10.6	344	21.0	1.6	63.4	3.4	110	6.4	0.58
Broad beans	13.8	328	25.0	1.2	56.9	3.1	104	4.2	0.45
Chick pea	11.0	362	19.4	5.6	60.9	3.1	114	2.2	0.46
Cow pea	11.5	340	22.7	1.6	61.0	3.2	110	6.2	0.59
Groundnut	7.3	548	23.4		21.6	2.4	58	2.2	1.00
Kidney beans	12.1	336	20.3	1.2	62.8	3.6	86	6.9	0.45
Lentils	12.0	340	20.2	0.6	65.0	2.1	68	7.0	0.46

Lima beans	10.5	346	19.8	1.3	65.4	3.0	90	5.6	0.46
Mung beans	10.6	341	22.9	1.2	61.8	3.5	105	7.1	0.53
Peas	13.6	330	22.2	1.4	60.1	2.7	54	4.4	0.77
Pigeon peas	11.5	339	20.4	1.2	63.4	3.5	103	4.9	0.49
Soybeans	10.2	400	35.1		32.	5.0	120	10.0	0.30

5.2. Moisture

The moisture content is an important characteristic for the legume grain to remain nutritious and edible. Moisture has a major impact on storage of legumes. The available literature states that legumes at a moisture content as high as 13% can be safely stored to prevent risk of microbial spoilage. However to prevent the shrinkage of legume seeds a higher moisture of about 15-19% is desirable. Table 1 shows the prescribed levels of moisture content for various legumes. The recommended moisture content for some legumes is listed in Table 2. The recommended moisture content is higher than prescribed so as to preserve quality characteristics and prevent shrinkage.

Table 2: Moisture contents of legume seed

Recommended Moisture Content (%)

Legume	**Climate, Long Term**	**Moderate climate, Short Term**
Bean	15	19
Lentil	15	16
Chickpea	14	16

Pea		15	18

5.3. Carbohydrates

The total carbohydrates vary greatly, ranging from 24% in winged bean seeds to 61% found in cowpea. Carbohydrates may be divided into water-soluble components such as sugars and certain pectins, and insoluble ones such as starch and cellulose. These carbohydrate components differ in their functionality with each component having a particular impact on human health. Such carbohydrates contain groups that are utilized as sources of energy by man, and also those that cannot be so utilized because they are resistant to human digestive enzymes. The value of carbohydrates in legumes is of little use from a nutritional point of view, as it is obtained by deducting the sum of protein, fat, moisture, and ash from the total sample weight, and thus includes dietary fiber, starch, and soluble carbohydrates. Since legumes contain substantial amounts of dietary fiber, more so than cereals, such values are particularly difficult to interpret.

5.3.1. Soluble carbohydrates

Legume seeds contain significant levels of water soluble carbohydrates, including trace amounts of monosaccharides, such as glucose and arabinose in soybeans, and measurable concentrations of disaccharides and oligosaccharides, often including sucrose, raffinose, stachyose, verbascose. Food legumes significantly vary in their total soluble sugar content and composition. Wrinkled peas may have about 10.2-15.1% total soluble sugar whereas soybean may contain 5% total soluble sugar. Legumes have a larger content of sugar than cereals which contain 1-2%. Sucrose is the major sugar and unlike cereals, legumes contain appreciable quantities of oligosaccharides. These are indigestible to mammalian enzymes are, therefore, implicated in the production of flatus from grain legumes. Legumes contain only small amounts of glucose.

5.3.2. Insoluble Carbohydrates a)
Starch

Starch is the primary component of legume carbohydrates. Values for the starch content of selected legumes can be seen in Table 3. Legume seeds vary greatly in their starch content. California small white beans contain 57.8% of starch, while soybeans contain as little as 0.2% of starch. Some legume seeds such as leguminous oilseeds or those containing gum have been reported to lack starch. In general, soybean, lupine, and winged beans are known to have a lower starch level. However, soybeans have been shown to contain some starch granules. The starch granule is composed of mixture of amylose and amylopectin. The legume starches may have a high amylose concentration and differ significantly in their amylose and amylopectin ratios. The amylose content of legumes varies from 5.3% in smooth pea to 43.9% in black gram. The amylose content of selected legume starches can be seen in Table 3. High amylose content delays starch gelatinization and affects normal cooking properties. The gelatinization temperature of various legume starches generally ranges from 60 to 90°C. A substantial amount of amylopectin promotes the gelatinization process while the degree of amylopectin branching in the starch varies the gelatinization temperatures.

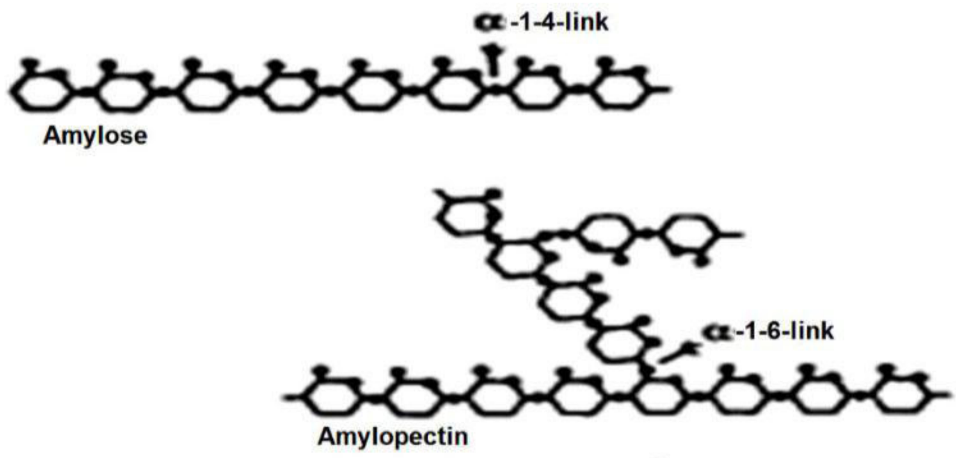

Table 3: Starch and amylose contents of various

legume seeds		
Legume	**Starch**	**Amylose**
Lentil	34.7-52.8	20.7-45.5
Broad bean	41.2-52.7	22.0-35.0
Soy bean	0.2-0.9	15.0-20.0
Red gram	40.4-48.2	38.6
Mung bean	37.0-53.6	13.8-35.0
Black gram	32.2-47.9	43.9
Red kidney	31.9-47.0	17.5-37.2
bean		

*Values are reported in g/100g on a dry weight basis

b) Dietary fiber

Dietary fiber is defined as the skeletal remains of plant cells that are resistant to hydrolysis by the enzymes of man. It includes cellulose, hemicelluloses (water soluble and insoluble, including pectin) and lignin. Legume seeds are excellent sources of dietary fibers. The fiber concentration ranges from 1.2% to 25.6%. A wide range of unusual storage dietary fibers are commonly associated with legumes and many of them are water soluble polysaccharides, which swell to a gel in water, e.g. guar gum from the cluster bean. Many of these substances have been shown to be composed solely of D-mannose and D-galactose (the galactomannans), and are found only in legume seeds. Black gram has been shown to contain an unusual gum containing 20% protein; the presence of this material may account for certain unique cooking characteristics of this legume.

Table 4: Dietary Fiber Components of Four Pulses

Hemicellulose + pectin

Legume	Water insoluble (%)		Water soluble (%)	Cellulose (%)	Lignin (%)	Total dietary Fiber (%)
Pigeon pea	1.4	8.7		7.3	2.9	20.3

Chickpea 0.9	8.1		13.7	2.9	25.6
Black					
2.4	8.3		5.0	3.8	19.5
gram					
Mung					
1.5	7.0		4.6	2.2	15.3
bean					

5.4. Fats

Of all edible oils, that from soybeans is the most important. Various studies report an estimated world production in 2030 to about 371.3 million tons. Groundnut oil is the fifth most important edible oil of vegetable origin, with an annual production that hovers around 34 million tons per year in the current scenario.

In contrast to the leguminous oilseeds, most pulses contain only small quantities of fats (less than 3%). For this reason, no doubt, little research has been carried out on their fatty acid composition. Chickpeas are unusual among the pulses in being relatively high in oil (5.6%). Oleic and linoleic acids are the main unsaturated fatty acids, and palmitic the saturated fatty acid. For human nutrition, linoleic acid is considered as an essential fatty acid in comparison to oleic acid. Oils from temperate zone legumes tend to have more unsaturated components than those of the tropics, and some legume species contain a considerable proportion of linolenic-acid. The presence of this in soybeans limits their usefulness in food to some extent, as it is thought to be responsible for the development of undesirable 'beany' flavors in the stored oil and food products containing the oil. Genetic breeding has solved the problem by introducing newer varieties of lower content of linolenic-acid.

Table 5: Fatty Acid and Phytosterol Composition of some legumes

Fatty Acids of Interest

Legume	16:0	18:1	18:2 -ed	18:3	Saturat	MUFA	PUFA	
Pisum sativum	0.125	0.232	0.411	0.084	0.161	0.242	0.495	135
Vicia faba	0.204	0.297	0.581	0.046	0.254	0.303	0.627	124
Phaseolus vulgaris	0.343	0.123	0.332	0.278	0.366	0.123	0.610	-

*Values are per 100 g edible portion

5.5. Protein

Legumes are relatively rich sources of protein as the seeds contain 200-250 g protein/kg. Many studies have shown an increase in total protein contents in various legumes by dry weight after germination. This may be attributed to the use of carbohydrates and lipids as energy sources for the germinating seeds, thus allowing for protein to contribute a greater proportion of the remaining weight, and the production of enzymes. The protein content of cooked legume seed (70-100 g/kg cooked food) is similar to that of bread (80-90 g/kg), but still much higher than for potato (15-22 g/kg). Legume seeds are rich in lysine and poorer in sulfur containing amino acids (methionine and cysteine) compared to cereals. Lysine is the first limiting amino acid in cereals so it is important that legumes complement cereals in lysine balance. Legume proteins are composed of several thousand specific proteins. About 70-80% of the crude protein in legume seeds is storage protein. The non-storage proteins are enzymes, enzyme inhibitors, hormones, transporting, structural, and recognition proteins. The main protein fractions of legume seed are albumin and globulin, which can be separated into two major fractions, vicilin, and legumin. The relative proportion of legumin to vicilin varies with genotype. But vicilin is the major protein fraction in all legumes except Vicia faba. Vicilin contains low sulfur containing amino acids; this is the main cause of the relatively poor amino acid composition of pea. The main globulin fractions differ in their amino acid composition, molecular weight of protein subunits, and physico-chemical properties. Some soybean varieties contain about 50% protein.

5.5.1. Classification

Most of the protein in legumes is located in the cotyledons and embryonic axis, with the seed coat containing very little protein. Legume seed proteins can be classified based on their functionality into structural and storage proteins. Structural proteins, sometimes referred to as enzymatic proteins, are made up of protease inhibitors, lectins, lipoxygenases, and amylase inhibitors. Together they make up a small percentage of the total protein in the seeds, are found in the cotyledon, and are responsible for cell metabolism. These structural proteins are albumins that are soluble in water, and influence the postharvest taste and digestibility of food legumes. The storage proteins, which make up the bulk of legume seed proteins, are insoluble in water but soluble in salt solution and belong to the globulin class of proteins. Storage proteins are found primarily in the parenchyma cells of the cotyledons and are contained in small membrane bound organelles called protein bodies, and range in size from 2-20 μm in diameter. Storage proteins provide the carbon and nitrogen building blocks necessary for seed growth during germination. They are further classified based on their sedimentation coefficients into four main fractions: 2S, 7S, 11S, and 15S. Fractions with higher sedimentation coefficients (up to 18S) have been reported in some soybean strains. None of the fractions are, however, homogenous. The 2S and 15S fractions are made up mainly of enzyme inhibitors and allergenic factors. The 7S globulins together account for 50% of proteins in some soybeans, but usually contribute more than 70% of total proteins in most soybean and legume seeds. Some legumes, e.g., French bean and cow pea, have a predominance of 7S globulins as the storage protein.

5.5.2. Protein quality

It is well known that legume proteins are low in essential sulfur containing amino acids such as methionine, while being especially rich in lysine. The second limiting amino acid in legume protein is tryptophan, but in a few legumes (cow pea, lentils, and green peas) it was the most limiting amino acid. The effect of these deficiencies is observed more markedly on growth than on protein requirements for maintenance. The digestibility of proteins varies greatly, from 51% to 92%, and is influenced by the presence of anti nutritional factors.

5.6. Other nutrients

Among the fat soluble vitamins, only vitamin A and vitamin E have received much attention. Most legumes contain only small amounts of carotenoids (provitamin A). The amount of vitamin E (tocopherol) is present in the oil. The water soluble vitamins (the thiamin) content of legumes is equivalent to, or slightly exceeds, that of whole cereals. Reported values range from 0.3-1.6 mg/100g; much of the variation between and within species is doubtless due to differences in methods of estimating thiamin.

Legumes contain little riboflavin; representative values range from 0.1 to 0.4 mg/100g. Legumes are a good source of nicotinic acid, containing on average about 2.0 mg/100g. Groundnuts are exceptions, containing an average of over 16 mg/100 g.

A considerable variation in vitamin content occurs in various varieties of legumes. Legumes contain less pantothenic acid than cereals, but in comparison with most common foods, they are good sources of folic-acid.

With the exception of germinated seeds, legumes as consumed are almost devoid of ascorbic acid (vitamin C). Small amounts have been found in a few varieties, but the vitamin oxidizes after long storage. Furthermore, the prolonged cooking which most dry legumes need and the habit followed in some countries of cooking them in sufficient quantities to last for several meals would remove or destroy any ascorbic acid they contained.

Legumes are considerably richer in calcium than most of the cereals; a typical value is about 100 mg/100g, as compared with 10 and 16 mg for milled rice and low extraction wheat flour respectively. Soybeans, horse gram and a few other species contain over 200 mg/100g. Groundnuts have a content well below the average. Calcium content varies widely within species, being dependent on such factors as variety, climate, cultural methods and the mineral content of the soil. The considerable content of phytic-acid in legumes may affect the absorption and utilization of their calcium, but even when this is taken into account, a daily intake of 50 g of legumes can make a useful contribution to calcium needs. The same conclusion can be probably applied to Iron. Legumes are moderately good sources of this nutrient, containing on average about 7 mg/100g, with a range of 2-10mg. As with other nutrients, widely varying values for iron, due to factors already mentioned, are reported in the literature. Typical legume intake provides 2-8 mg of iron daily, which represents a considerable fraction of daily requirements.

5.7. Toxic constituents in legumes

Legumes contain a wide range of toxic components such as trypsin-inhibitors, lectins or haemagglutinins, cyanogens, saponins, and toxic amino acids. The amounts vary with species and variety, but in general legumes tend to contain more toxic materials than cereals. The toxic components are antinutritional factors that have coincidental involvement in human nutrition. Inspite of the presence of toxins, legumes can be safely eaten and provided they are adequately prepared.

A) Cyanogens

Cyanogens are mainly in the form of glucosides. The Lima bean has the highest concentration of cyanogens of all food legumes.

B) Favism

Favism is associated with faba beans. Its principal clinical manifestations are haemolytic-anaemia.

C) Phytate

Phytate chelates with certain metal ions such as calcium, magnesium, zinc, copper and iron, form insoluble complexes that are not readily broken down and may pass through the digestive tract unchanged. It also forms strong complexes with proteins, which may lead to their reduced digestibility.

D) Trypsin-inhibitors

They are low molecular weight peptides (4,000-20,000 Da) that are soluble in water. Usually they are isomers of one peptide. Trypsin-inhibitors contained in the diet irreversibly inactivate trypsin in the small intestine that reduces protein digestion. They also cause the hypertrophy of pancreas. Levels of trypsin-inhibitor (expressed in trypsin inhibitor units - TIU) are species-dependent. They are the highest in soybean seeds (43-84 TIU/mg protein), lower in chickpea seeds (15-19 TIU/mg protein) and pea (6-15 TIU/mg protein), and the lowest in lentil and Faba bean (3-8 TIU/mg protein and 5-10 TIU/mg protein, respectively).

E) Other toxic factors

Amylase-inhibitors, which interfere with the starch digestion, have been extracted from beans. Cowpeas, chickpeas, and lentils are however free from them.

A number of anti-vitamins have been found in legumes. Examples of anti-vitamins are lipoxidase which destroy carotenoids and is responsible for the beany flavor; anti-vitamin E in soybeans and peas; anti-thiamin in mung beans, and an anti-vitamin B_{12} in soybeans.

Goitrogenic activity from plant foods is usually associated with the presence of thioglycosides (Glucosinolates). These are broken down by enzymes to isothiocyanate, which can lead to the development of goitre. Various studies have reported that soybean enlarged the thyroid of rats but the effect was reduced considerably when soybeans were processed to infant food and isolates. Also, several cases of goiter in infants have been reported that indicated insufficient heat treatment during its preparation.

Oestrogens have been found in soybeans, groundnuts, and chickpeas. However, their activity is weak

Legumes are rich in serotonin and dopamine. They can cause strong physiological activity.

Tannins are polyphenolic and high molecular weight compounds that are shown to inhibit enzyme activity particularly that of trypsin and amylase.

5.8. Method of detoxification

Traditional methods of domestic preparation of legumes have largely overcome the problem of toxicity. Most legumes when cooked until soft are safe to eat. However, it is advised that moist heat at 100°C should have penetrated right through the grain which is not always the case with slow cooking methods.

5.9. Nutraceutical components

Antioxidant content of germinated legumes is of particular interest. Isoflavones in soybeans are of much importance in decreasing the incidence of chronic diseases. There are also reports of phenolic content in mung bean.