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Functional Uses of Peanut (*Arachis hypogaea* L.) Seed Storage Proteins

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Abstract

Peanut (*Arachis hypogaea* L.) is an important grain legume crop of tropics and subtropics. It is increasingly being accepted as a functional food and protein extender in developing countries. The seed contains 36% to 54% oil, 16% to 36% protein, and 10% to 20% carbohydrates with high amounts of P, Mg, Ca, riboflavin, niacin, folic acid, vitamin E, resveratrol and amino acids. Seed contains 32 different proteins comprised of albumins and globulins. The two-globulin fractions, arachin and non-arachin, comprise approximately 87% of the peanut seed proteins. Peanut worldwide is mainly used for oil production, consumption as raw, roasted, baked products, peanut butter, peanut flour, extender in meat product formulations, confectionary and soups. Peanut proteins have many properties such as good solubility, foaming, water/oil binding, emulsification that make them useful in various food products. Very limited studies have been carried out in peanut functional properties, which has been reviewed in the present article. Adequate modifications can be done in protein functionality that are influenced by pH, temperature, pressure etc. However, some individuals develop severe IgE-mediated allergies to peanut seed proteins. Thus, methods to improve nutrition and reduce allergenicity have also been discussed. Within the last decade, manipulations have been done to alter peanut chemistry and improve nutritional quality of peanuts and peanut products. Hence, improved comprehensive understanding of functional properties and nutritional chemistry of peanut proteins can generate better source of food grain to meet nutritional requirement of growing population. In the present review, composition of peanut seed proteins, functional properties, nutritional components and nutraceutical value have been discussed with respect to beneficial aspects to health, reducing hunger and usage in food end products.

Keywords: seed proteins, albumin, globulin, nutritional value, functional properties

1. Introduction

Peanut, or groundnut, of genus *Arachis* is a member of the legume family (Fabaceae). Cultivated peanut (*Arachis hypogaea*), an allopolyploid with AABB genome composition, is the second-most important grain legume crop worldwide after soybean [1]. The genus *Arachis* is endemic to South America [2] and the probable center of origin of *Arachis hypogaea* has been recognized in Gran Panatanal (Mato Grosso, Brazil) and also on the eastern slopes of the Bolivian Andes [3].

Peanut has now become one of the major global oil-seed crops covering approximately 26 million ha land area in about 120 countries [4–6]. According to FAO, world production of groundnut is above 45 million tons, averaging about 1.8 t/ha. Significant level of annual peanut production has been recorded in India amounting to approximately seven million tons [7]. China leads in production of peanuts, with a share of about 41% of overall world production, whereas India has 14% share and the United States has (7%) [8]. *Arachis hypogaea* has been divided into two subspecies *A. hypogaea* ssp. *hypogaea* and *A. hypogaea* ssp. *fastigiata* [9]. Morphological variations in branching and flowering patterns, pod and seed traits are used to characterize different botanical varieties [10]. The varieties are further distinguishable into a number of market types or cultivars like Virginia (large seeded), Runner (small seeded), Peruvian runner, Valencia and Spanish type. Some market types or cultivars are more preferred for some particular uses due to differences in flavor, oil content, size, shape, and disease resistance [11].

Peanut is accepted as a potential source of food grade protein and an energy dense food. The seed typically contains 36% to 54% oil, 16% to 36% protein, and 10% to 20% carbohydrates as well as high amounts of macro minerals, trace elements, vitamins riboflavin, niacin, folic acid, fiber and vitamin E, resveratrol, phytoosterols. It is also known as poor man's nut and being seen as potential functional food. A 100 g of peanut kernels provide 567 kcal of energy and 8.5 g of dietary fiber [12]. Consumption of peanuts can reduce risk of inflammation and diseases like diabetes, cancer, gallstone and alzheimer's [12, 13].

Peanuts are consumed all over the world in a wide variety of forms such as raw, boiled or roasted, and are widely used to prepare a variety of packaged foods (peanut butter, candies, confections, and snack products) in the United States. Peanuts and peanut butter contain monounsaturated fatty acids besides plant proteins, minerals like magnesium, potassium, fiber, arginine and various bioactive components. The by-product of the oil extraction is a meal that is also high in proteins, dietary fiber, antioxidants, vitamins, and minerals, and can be utilized as animal feed or processed further for human consumption. The defatted protein flour after oil extraction in peanuts, has immense uses and has been exploited in meat-like products that can be used to formulate cholesterol-free vegetarian alternatives [14]. Peanut flour is used in composite flours with non-wheat cereals to improve the nutritional value of bread [12]. Peanut bars, peanut milk and fermented peanut are also different forms of consumption. Protein energy malnutrition in third world developing countries is a problem due to dependence on animal proteins which are expensive and thus, affordable plant proteins with its additional benefits are being exploited such as peanut proteins, which can be used to combat protein-energy malnutrition. Partially defatted peanut flour, is a protein-rich, inexpensive and underutilized product that offers the same health and dietary benefits of peanut with less fat and can be utilized for making value added products to eradicate malnutrition among children [15]. Peanut proteins play an important role in many food products because of their properties such as nutritional value, contribution to food texture, solubility etc., among others. Huge tons of by-products obtained from peanut industries can be utilized to generate a reasonably high quantity of protein, that could be further used in a variety of food formulations due to its properties such as water and oil absorption, gel formation, foaming, emulsification etc. Functional properties depend upon extraction procedure and use of adequate modification methods [16].

Thus, the present chapter focuses on the peanut seed storage proteins composition, nutritional value, bioactive components, functional properties, its usage and methods to reduce allergenicity.

2. Peanut proteins

Seed storage proteins are present as one or more groups of proteins in high amounts in seeds to provide a store of amino acids for use during germination and seed growth. The peanut seed contains 32 different proteins comprised of albumins and globulins. The seed storage proteins are mainly composed of arachin (legumin), conarachin (vicilin) - I, II fractions [17]. Many papers have highlighted the composition of seed storage proteins (SSPs) using one dimensional and two dimensional PAGE [18–21]. The different fractions of seed proteins by SDS PAGE in groundnut cultivars is shown in **Figure 1**. SSPs in peanut are composed of families of 2S, 7S, and 11S proteins that can be subdivided in homology groups. 11S proteins are more diverse than 2S and 7S proteins in peanut seeds, but 2S and 11S subgroups are very similar in the A and B genomes of *Arachis* [20].

However, peanut proteins is also a source of severe IgE-mediated allergies in some individuals. Due to peanut being recognized as one of the potent allergens, the immunological protein names with prefix *Ara* with different numbers have also been designated from Ara h 1 to Ara h 17.

2.1 Globulins

Globulins (7S and 11S) comprise of the majority of the total protein in many seeds that are consumed by humans. Vicilins (7S globulins) and legumins (11S globulins) share similar folds and belong to the cupin superfamily of proteins.

Ara h 1, a 7S vicilin, exists as trimer formed by three identical monomers and is also a glycoprotein. It comprises approximately 12–16% of peanut proteins [22]. When analyzed in SDS PAGE, the Ara h 1 vicilin shows two isoforms at 69 and 66 kDa [23]. 11S globulin seed protein is a hexamer (360–380 kDa) formed by two trimers [24], with each monomer having four linear epitopes [25]. Ara h 3 is a legumin-like seed storage protein that has high sequence similarity to glycinin, the major 11S globulin seed storage protein family in soybean. Ara h 3 and related proteins belong to the 11S globulin storage protein family that is characterized by three common features. The first one is that they contain an acidic and basic chain separated

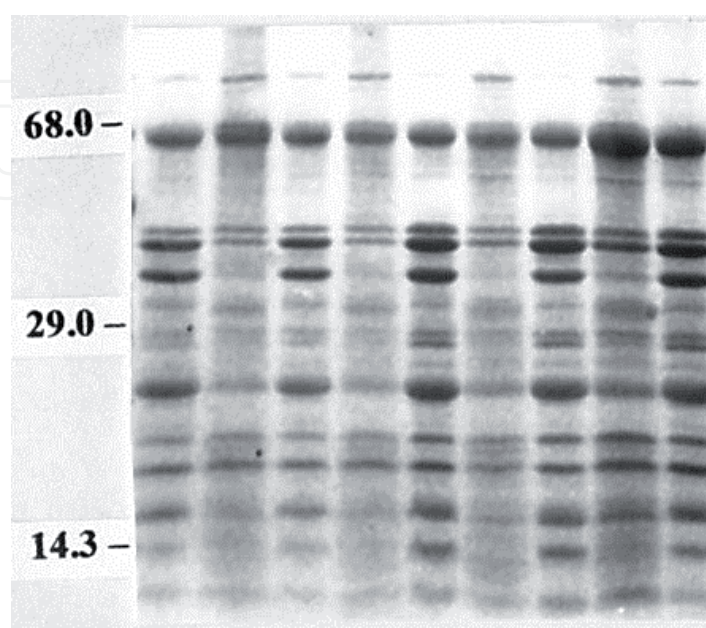


Figure 1.
SDS PAGE analysis of Total Seed Storage Proteins in Peanut (*Arachis hypogaea*) cultivars along side a marker (adapted from [19]).

by a conserved Asn-Gly (N-G) peptide bond. Second, the formation of intra and inter-disulfide bonds is observed due to four conserved cysteine residue. Third, an Asn-Gln (N-Q) peptide bond is present that serves as a potential proteolytic cleavage site. It also functions as a trypsin inhibitor [24, 26, 27]. Ara h 3 and soybean glycinin result in a sequence identity of 47.2%. Mature Ara h 3 is a hexamer (360–380 kDa) formed by a head-to-head association of two trimers [25, 28]. Ara h 3 was originally identified as 14 kDa [28]. Later, it was found to be of 60 kDa [24]. This Ara h 3 is post translationally modified and cleaved into 43 kDa acidic and 28 kDa basic subunits. In SDS PAGE, several fragments can be identified as 14, 25, 42 and 45 kDa.

Ara h 4 is also arachin, an isoform of Ara h 3. Ara h 4 is no more used but it is renamed as Ara h 3.02 [29]. Five different genes were found to encode for isoforms of Ara h 3 [30].

2.2 Albumins

Ara h 2, a 2S albumin is a glycoprotein and accounts for approximately 6 to 9% of total peanut protein [31] with a molecular weight of approximately 17 kDa [32]. Ara h 2 also known as conglutin and functions as a trypsin inhibitor. Structurally, Ara h 2 has five α -helices arranged in right-handed super helix connected by several extended loops with four conserved disulfide bridges and 10 highly exposed epitope binding sites [33].

Ara h 5 (15 kDa) belongs to the profilin family and regulates the polymerization of actin [34]. It is presented at low levels in peanut extracts. Ara h 6 is a 15 kDa protein and belongs to the conglutin family [35]. It is 59% homologous to Ara h 2 and has similar allergenicity [36, 37]. Ara h 6 is a heat and digestion stable protein and showed resistance to proteolytic treatment [38, 39]. Ara h 7 is also a 15 kDa protein and belongs to the conglutin family [35]. The sequence identity between Ara h 2 and Ara h 6 is 35%.

2.3 Other proteins

Ara h 8 (17 kDa) is a Pathogenesis related protein. It is homologous to Betv1 proteins. Ara h 9 and Ara h 17 (9.8 kDa, 2 isoforms) are nonspecific lipid-transfer (nsLTPs) proteins of type 1 category. Ara h 16 is an nsLTP of type 2 category (approx. 7 kDa) [40].

Ara h 10 (16 kDa, 2 isoforms) and Ara h 11 (14 kDa) belong to oleosin. Ara h 14, Ara h 15 are peanut oleosins with amphiphilic structural proteins. Ara h 12 and Ara h 13 are defensin, with molecular weight ranging from 5 to 12 kDa [35]. Oleosins are also abundant in peanut seeds.

3. Importance as a functional food

Peanut is increasingly recognized as a functional food. The protein quality is based on amino acid pattern and percent digestibility. According to Protein Digestibility Corrected Amino Acid Score (PDCAAS), the plant protein peanut is nutritionally equivalent to animal proteins such as meat and eggs. The PDCAAS for peanuts has been estimated to be about 0.70 out of 1, whereas, for whole wheat PDCASS is 0.46. After the oil is extracted, the protein content in peanut cake can reach upto 50% [41]. All the protein components are highly digestible.

3.1 Amino acids content

Peanuts contain all the twenty amino acids, including 9 essential amino acids, necessary for normal body growth and metabolism [12]. They also show high levels of arginine and histidine. The remaining amino acids were present in substantial quantities except methionine, tryptophan and cystine that were considered low [42].

Comparisons across common tree nuts and peanuts show that all are naturally high in both acidic and basic amino acids, in addition to also being naturally high in hydrophobic amino acids, including leucine, glycine and valine, among others [43]. Peanut has a high percentage of arginine (12.5%), which gives added benefit with its overall high protein content, making peanut an important dietary source of this amino acid whose consumption has been directly linked to various cardiovascular health promoting activities [14]. The arginine is highest in peanuts among foods [44]. The amino acid profile of the peanut meals shows that it can be an ingredient for protein fortification [45]. Being a leguminous plant protein, it also has additional components that have positive health benefits like fiber and unique bioactive components besides amino acids (Tables 1 and 2). They also contain many important functional components including coenzyme Q10 [46], and polysterols, which make it a functional food [47, 48].

Amino acid data for blanched seed (without peanut skin or testa) is ultimately most relevant to peanut nutrition as the skin only accounts for approximately 3% of the total seed weight after shelling and skins are relatively low in total protein compared with the blanched seed, i.e., approximately 15% versus 25%. For blanched seed, asparagine/aspartic acid and glutamine/glutamic acid residues predominate, accounting for approximately 35% of the amino acids, which is in good agreement with data from other sources [43, 49].

3.2 Fats, vitamins and minerals

In the fats, peanut contains 50% monounsaturated fatty acids (MUFAs), 33% polyunsaturated fatty acids (PUFAs) and 4% saturated fatty acids [50]. PUFA needs to be given through diet and cannot be synthesized. This way presence of high MUFAs and PUFAs reduce heart stress. So, the oils of peanuts are very important and healthy.

Carbohydrates that contain fiber or starch, these two types of carbohydrates have a slower, less pronounced effect on blood sugar. The American Diabetes Association ranks peanuts and other nuts as diabetes superfoods. Peanut have a low glycemic index (GI) and glycemic load (GL) [51]. On a 100 –point scale, the GI of peanuts is 14, and the GL of peanuts is one. Mature groundnut kernels were reported to contain 9.5–19% carbohydrates in which starch and sucrose are the major constituents.

The peanut is also a good source of minerals like Magnesium, Calcium, Phosphorus, potassium, iron, zinc, iron, copper, selenium and vitamins as well as dietary fibers (Table 1). Minerals like calcium and phosphorus are important for normal growth and development of bones and muscles. While minerals required in trace amounts like zinc, selenium whose daily requirement can be met by 100 g of peanuts [12, 52].

Peanuts are a vital source for introducing most of the water soluble vitamins into the human body along with vitamin E which is fat soluble [1, 12]. A 100 g peanuts consumption is capable of providing up to 75% recommended dietary allowances (RDA) of Niacin, 60% RDA of folate, 53% RDA of thiamin, 10% RDA of Riboflavin, 35% RDA of pantothenic acid, 27% RDA of pyridoxine, 55.5% RDA of vitamin E [12, 52]. In 42 g of peanuts, more than 10% provide recommended dietary allowances (RDA) for niacin, pantothenic acid, and total folate is present.

Another important vitamin which is supplemented in the body by the intake of peanuts is vitamin B3 [53] (known as Niacin or Niacinamide or Nicotinamide), to an extent of 13.525 mg. The vitamin B5 pantothenic acid is also provided by peanuts [52]. This vitamin plays an important role in the normal functioning of the respiratory chain and participates in hydrogen transfer, and electron transfer reactions through its coenzymes, Nicotinamide adenine dinucleotide (NAD) and Nicotinamide adenine dinucleotide phosphate (NADP). Roasted peanuts will provide B6 to the human body to the extent of 0.256 mg. Vitamin B9, more commonly known as folate or folic acid, is a water-soluble vitamin that is part of the B vitamin family and required for normal

functioning. Folate (vitamin B9) present in peanuts to an extent of 145 µg may also help protect against cancers of the lung, colon, and cervix [12].

Peanut flour which is most commonly used for fortification contains protein ranging in between 47% - 55% i.e. a good amount of protein. Peanut flour has been

COMPONENTS	CLASS	TYPES	AMOUNT (per 100gm of dry roasted peanuts)
Lipids	Fatty acids	Saturated	6.893 gm
		Monosaturated	24.640 gm
		Polysaturated	15.694 gm
Vitamins	Fat soluble	E (tocopherol)	8.2 mg (raw), 4.1 mg/ 100 g roasted
	Water soluble	B2 (Riboflavin)	0.098 mg
		B1 (Thiamine)	1.0 mg
		B5 (Panthothenic acid)	1.395 mg
		B3 (Niacin)	13.525 mg/
		B6 (Pyridoxine)	0.256 mg
		B9 (Folate)	145 mg
		Choline	55.3 mg
Minerals	Macro	Potassium	658 mg
		Sodium	Approx.5.56 mg
		Calcium	54 mg
		Magnesium	175 mg
		Phosphorus	358 mg
	Micro	*Selenium	7.5 mg
		*Copper	0.671 mg
		*Manganese	Approx.2.06 mg
		Iron	2.26 mg
		Zinc	3.31 mg
Amino acids	Essential	(* antioxidant minerals)	
		Tryptophan	0.230 gm
		Leucine	1.535 gm
		Isoleucine	0.833 gm
		Methioione	0.291 gm
		Phenyalanine	0.304 gm
		Valine	0.993 gm
		Lysine	0.850 gm
		Threonine	0.811 gm
	Non- essential	Glycine	1.427 gm
		Alanine	0.941 gm
		Cysteine	0.304 gm
		Tyrosine	0.963 gm
		Arginine	2.832 gm
		Histidine	0.599 gm
		Aspartic acid	2.888 gm
		Glutamic acid	4.949 gm
		Proline	1.045 gm
		Serine	1.167 gm
Others	Total carbohydrates		21.51 gm
	Dietary fibers		8.0 gm
	Functional components	Coenzyme Q10	
	Total Sugars		4.18 gm

(Adapted from Source USDA 2011)

Table 1.
Nutrient components in Peanut.

BIOACTIVE COMPOUNDS	TYPE	AMOUNT (per 100 gm of dry roasted peanuts)
Isoflavonoid	Daidzein	49.7 mg
	Genistein	82.6 mg
Phenolic acids	p-coumaric acid	6.9 mg
Phytosterols	b-sitosterol	61 mg to 114 mg
Stilbenes	Resveratrol	0.48 mg to 3.96 mg

Table 2.
Composition of bioactive compounds.

used to replace animal proteins in a variety of products. Peanut flour blends well with cereal flour to yield products with excellent flavor texture and color [12].

4. Presence of secondary metabolites

Peanut is a reservoir of secondary metabolites like flavonoids, polyphenols, phytosterols, stilbenes (**Table 2**). The evaluation of peanuts role in a heart-healthy diet has increased in the last decade [54]. Extraction procedures would play a big role in getting these bioactive components since extracting solvent, isolation procedures, purity of active compounds, as well as the test system and substrate to be protected by the antioxidant affects its function [55].

The flavonoid content in peanuts was determined, which is second only to walnuts [56]. Studies [57, 58] reported that peanut seeds had an isoflavonoid content of daidzein and genistein in the greatest amounts with a content of 49.7 mg/100 g and 82.6 mg/100 g, respectively. A-type proanthocyanidins was determined in peanuts [59]. Luteolin was the principal antioxidative component from the methanolic extracts of peanut hulls [60]. Mature, red peanut skins contain about 17% by weight of procyanidins, nearly 50% of which are low molecular weight oligomers [61]. Catechins, A-type and B-type procyanidins dimers, trimers, and tetramers were also detected in chemically purified peanut skin aqueous and ethanol extracts [45]. Furthermore, higher concentrations of compounds mentioned were observed in raw peanut skins than roasted peanut skins.

The polyphenolic content of raw and dry roasted peanut samples containing varying levels of oleic acid (normal, mid, and high) were determined [62, 63]. Normal oleic acid peanuts had higher concentrations of individual polyphenolics than mid- and high-oleic peanuts. Free p-coumaric acid, three esterified derivatives of p-coumaric, and two esterified derivatives of hydrobenzoic acid were identified as the predominant polyphenolics. Whole raw peanuts had a mean of 25 mg/kg of p-coumaric acid (from a range of 8 to 66 mg/kg among cultivars) and the value increased to an average of 69 mg/kg when peanuts were roasted at 175 °C for 10 min.

Peanuts as a source of phytosterol has been getting a lot of attention with new research findings identifying phytosterols like beta-sitosterol, sitosterol in peanuts and peanut products as cancer growth inhibitors, as well as protectors against heart diseases [64]. The phytosterol contents of peanuts and peanut products were analyzed. Results show that among the four cultivars studied, the Valencia peanuts in raw, dry roasted, and oil roasted, contained the highest phytosterol concentration [65]. Studies with sitosterol or mixtures of plant sterols have shown that they reduce serum cholesterol levels in humans by approximately 10%. This discovery has resulted in subsequent research to evaluate the effects of sitosterol derivatives on cholesterol absorption and serum cholesterol levels [48].

Stilbenes contain two phenyl compounds connected by a 2- carbon methylene bridge. They occur in nature in a rather restricted distribution. Stilbenes like isoflavonoids, are also classified as phytoestrogens. Most stilbenes in plants act as antifungal phytoalexins, compounds that are usually synthesized only in response to infection or injury. The most studied one is resveratrol. Resveratrol is one of the major stilbene phytoalexin compounds produced by grape berries and peanuts in response to stress like fungal infection, the presence of heavy metal ions, or ultra-violet (UV) irradiation [66]. Resveratrol was found to be present in substantial amounts in the leaves, roots, and shells of peanuts, but very little was found in developing seeds and seed coats of field-grown peanuts [67]. The phytoalexin content of peanuts, however, increases during germination and is enhanced by microbial infection, postharvest induction procedures such as soaking and drying; wounding (slicing and incubation); UV light exposure, among others. Raw peanuts soaked in water for about 20 hours and dried for 66 hours increased the resveratrol content between 45 and 65 times after the soaking treatment [66]. Boiled peanuts contain more resveratrol than peanut butter and roasted peanuts. Resveratrol has been associated with reduced CVD and reduced cancer risk. Resveratrol has been shown from in vitro, ex vivo, and animal studies to have many attributes that may provide protection from atherosclerosis, antiproliferative, and proapoptotic properties against breast, colon, prostatic, and leukemia cells [68].

5. Industrial properties and applications

Functional properties affect the behavior of proteins during processing, storage and in preparation of food and food components (Table 3). Among different proteins, glycinin is nutritionally superior to the 7S con-glycinins [69], and possesses superior intrinsic functional properties for processed foods [70]. Processing technology has the capability of altering the protein structure, function, and physicochemical properties of peanuts [71–76].

5.1 Protein solubility, emulsification

Protein solubility is the first and foremost property that is determined in testing a new protein isolate. The functional properties of proteins are often affected by

Functional Property	Food type
Solubility	Beverages
Water absorption and binding	Meats, Sausages, breads, cakes
Viscosity	Soups, gravies
Gelation	Meats, curds, cheese
Cohesion –adhesion	Meats, Sausages, baked goods, cheeses, pasta products
Elasticity	Meats, bakery products
Emulsification	Sausages, bologna, Soup, cakes
Fat absorption	Meats, sausages
Flavor binding	Simulated meats, bakery goods
Foaming	Whipped toppings, chiffon deserts, angel food cakes

Table 3.
Uses of protein functional properties in food types (adapted from [70]).

protein solubility and those most affected are foaming, emulsification and gelation. The solubility of a protein is the thermodynamic manifestation of the equilibrium between protein–protein and protein solvent interactions [77]. These properties are affected by the intrinsic factors of protein such as molecular structure and size, and many other factors including the method of protein separation, production, pH, ionic strength and the presence of other components in the food system. The importance of these properties varies with the type of food products in which the protein concentrate is used.

Interactions of water and oil with proteins are very important in food systems because of their influence on the flavor and texture of foods. Proteins with high oil and water binding are desirable for use in meats, sausages, breads, and cakes [78]. Emulsification of proteins is closely related to the conformation of proteins and interaction of adsorbed molecules at the oil/water interface. Proteins with high emulsifying and foaming capacity are good for salad dressing, sausages, bologna, soups, confectionery, frozen desserts, and cakes [78]. Researchers [79–81] have determined the functional properties of several plant proteins concentrates using alkali solutions with isoelectric precipitation produced from peas and beans. The functional properties of peanut proteins have been subjects of limited studies that focused mainly on peanut flour [82–84]. According to some, protein isolates (PPI) have higher purity of proteins and better functional properties than other peanut protein products, such as flour or concentrate [82].

5.2 Influence of extraction procedure, pH, temperature

Functional properties of protein are influenced by many factors. For the end product uses, pH, temperature and ionic strength of the food system are important factors to consider. For initial extraction of proteins, methods and conditions of protein extraction, as well as downstream processing of extracted proteins such as purification, drying are the factors that are important [82]. Methods used to develop plant protein isolate/concentrate include isoelectric precipitation, alcohol precipitation, alkali solution and hot water extraction [83].

Peanut protein concentrates were isolated from defatted peanut flour by various methods such as isoelectric precipitation, alcohol precipitation, combined isoelectric and alcohol precipitation, and combined alkali solution with isoelectric precipitation [80]. Their functional properties (protein solubility, water holding/oil binding capacity, emulsifying capacity and stability, foaming capacity and rheology) were evaluated. Protein prepared by alcohol precipitation was found to have better functional properties particularly water holding/oil binding capacity, which were significantly different from other protein products such as of isoelectric and alkali precipitates [80]. The study concluded that it could be effectively used for making protein concentrates and suitable for use in various food formulations such as weaning foods, dry mixes, baked foods, whipped toppings and salad dressings owing to its high water and oil binding capacities.

Heating destroys anti-metabolites such as trypsin inhibitor in beans and nuts [85] and amylase inhibitors in legumes, thus improving the bioavailability or digestibility of the protein [86]. Roasting of peanuts significantly decreased protein solubility in peanut flour in the pH range 3.5–10.0 compared to that in raw peanut flour. Heating of peanut in water at 100–120 °C for 15 min decreased the protein solubility [16]. This might be due to the increase of surface hydrophobicity of protein via unfolding of molecules upon heat. The pH range also had a significant effect on the solubility of peanut protein [16]. The minimum protein solubility was observed at pH 3.5–4.5 and maximum solubility at pH 10 or higher [16]. The study suggested that solubility was pH dependent with the lowest solubility being

observed for both raw and roasted peanuts, at the isoelectric point of pH around 4.0. Protein solubility reduced as pH increased until reached an isoelectric point. At pH above the isoelectric point an increase in protein solubility was observed.

5.3 Gel forming ability or foaming

The abilities of protein to form gels and to provide a structure for holding water, flavors, sugars, and food ingredients are useful in food applications, and in new-product development that provide an added dimension of protein functionality. Foams are 2 phase systems composed of air bubbles surrounded by a continuous liquid lamellar phase [87]. Defatted peanut flour is not a good foaming agent, with a foaming capacity of only 6 ml/100 ml liquid, whereas, roasted peanuts showed half of the raw peanuts foaming capacity. Therefore, defatted peanut protein isolates may not be suitable in the food system that requires foaming such as cake and ice cream. Overall, roasting decreased functionality of peanut protein isolates, while fermentation significantly increased all functional properties of both raw and roasted peanut flours [16].

Recent studies have shown that high pressure treatment can change not only the functional characteristics of food proteins, but also their physical and chemical properties as well as molecular conformation [88–90]. In peanut protein isolates, high pressure treatment from 50–200 MPa, a non-thermal processing, significantly improved water binding capacity (WBC) and oil binding capacity (OBC). Additionally, pressure treatment could result in intensity denaturation of conarachin II fraction [91]. It was evident by SDS PAGE (Figure 2). This way protein isolates can be used as food supplementary material with improved characteristics.

Effect of membrane processing were analyzed on the functional properties, structural changes, subunit profile and sensory attributes of the groundnut protein concentrate [92]. Results indicated an increase in the nitrogen solubility and foaming capacity of the protein concentrate over pH ranges of 2–10, acid precipitated protein isolate. Protein concentrate also showed higher emulsion stability index, less hydrophobicity but reduced nutty flavor as compared to control flour and acid protein isolate. Thus, membrane technology could give a protein concentrate with improved functionality and sensory characteristics similar to roasted wheat and improved digestibility, which will have potential application in the development of

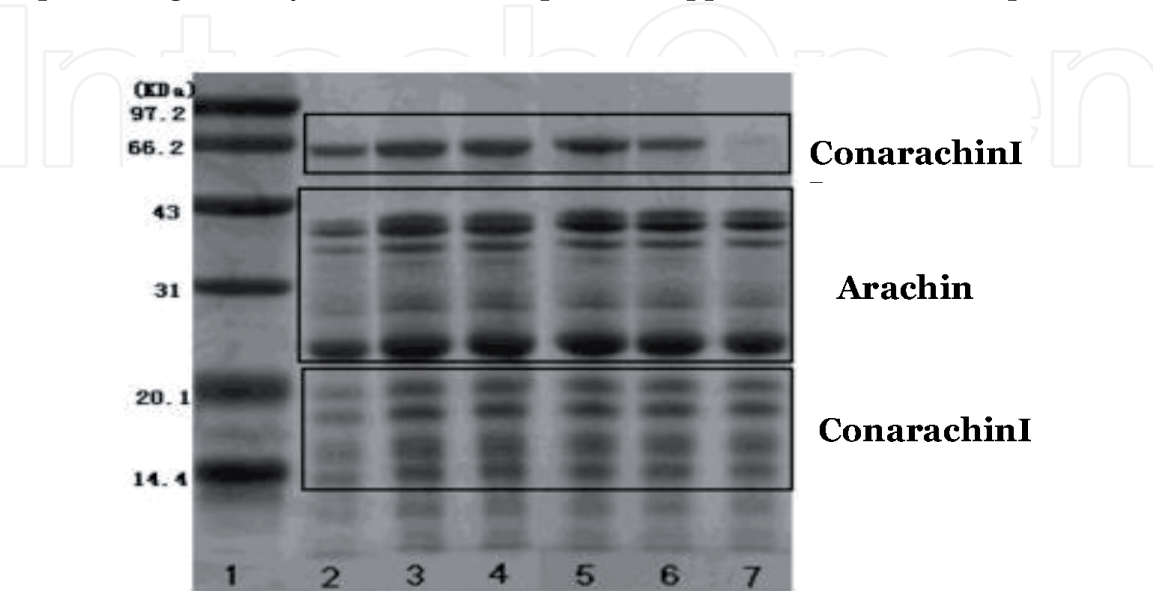


Figure 2. Effect of high pressure on protein concentrates lanes 2(untreated) and 3–7(treated with 50–100 MPa). (adapted from [91]).

food product formulations. Increased thermal stability, protein solubility at 4.5–6 pH, improved foaming and emulsifying properties were noticed by conjugating protein isolates (PPI) with dextran [84].

5.4 Water holding capacity and oil binding capacity

Hydration or rehydration is the first and perhaps most critical step in imparting desirable functional properties to proteins in a food system. Water retention is defined as the ability of the food material to hold water against gravity [93]. Water holding capacity and oil absorption capacity both were significantly higher in raw peanut protein isolates [16]. Intrinsic factor affecting the water binding capacity of food proteins includes amino acid composition, protein conformation, and surface polarity/hydrophobicity [94]. The water retention capacity is the sum of bound, hydrodynamic and physically entrapped water [95]. During roasting, peanut proteins were denatured by high temperature, exposing more hydrophobic sites, which explained the reduced water retention of peanut protein [96]. With respect to water-holding capacity, the denatured proteins bind more water through exposure of hydrophilic groups [97].

Oil binding capacity and water holding capacity are increased by high pressure treatment [91]. Both properties are important for food texture and flavor. They are high in raw peanut proteins but affected by high temperatures.

6. Role in hunger management

The peanut protein isolates with improved functional food properties are critically needed in many developing countries, because animal protein is more expensive and is getting beyond the reach of many people in developing countries. Abundant proteins in peanuts are cheaper sources of proteins that would serve the purpose. Research data show that peanut and peanut butter consumption improved the feeling of fullness and satisfied the consumers better than the carbohydrates snacks like rice cakes in equal quantities [98]. Another study has shown that peanut consumption can curb the appetites due its fullness effect [99]. Evidence has emerged in favor of type of healthy monounsaturated fat in peanuts that may stimulate a hormone which helps a person to feel satisfied after consumption [100]. Apart from this, it has been seen that daily nutrition peanut consumption leads to long term health benefits. Compared to well-known foods like green tea and red wine, peanuts have higher antioxidant capacity [101].

Groundnut-based ‘Plumpy’nut, a ready to use therapeutic food, has helped save the lives of thousands of malnourished children in Niger, by UNICEF [102].

Recent research studies suggest that boiling enhances antioxidant concentration in the peanuts. It has been found that boiled peanuts have 2–4 folds increase in isoflavone antioxidants biochanin A and genistein content, respectively [103].

7. Methods to improve nutrition and manage allergenic properties

Seed storage peanut proteins (such as Ara h 3 and Ara h 4) are less severe in allergenicity compared to their vicilin (Ara h 1) and conglutin (Ara h 2) type seed storage proteins [104–107].

Many methods are tried in peanut protein extracts to reduce their allergenic effect. Among them, roasting, boiling or another heat treatments are most common and require less labour and effort. Though heat treatments sometimes

affect secondary antioxidants due to Maillard reaction products [108]. Some novel processing approaches such as high-pressure processing, pulsed ultraviolet light, high intensity ultrasound, irradiation, and pulsed electric field have been performed toward reducing the immunoreactivity of peanut. Covalent and non-covalent chemical modifications to proteins also have the tendency to alter peanut allergenicity.

The heat or plasma treatment has shown to reduce allergenicity. Roasting lowered allergenicity by 600–700 fold than in native form. The autoclaving decreased immunoreactivity by 50 folds. Among the chemical methods used, it was found that tannic acid (1–2 mg/ml) reduced allergenicity [109]. But it hampers protein digestibility. Use of magnetic beads has also been shown to that it covalently attaches to phenolics.

Conventional Breeding has been reported and varieties missing in isoforms of Ara h 2 or 3 were crossed. Some lines lacking in both Ara h 2 and Ara h 3 were produced [110]. In conventional breeding, large seeded varieties suitable for food have been conventionally bred such as Asha (ICGV 86564) and Namnama (ICGV 90320) in the Philippines [111]. Groundnuts are bred for high oleic to linoleic ratio (O/L ratio) to improve the oil quality. Gorbet and Knauff registered the first high oleic line, SunOleic 95R [112], and it was followed by another variety, Hull with high O/L ratio and resistance to TSWV [113].

Heavy ion beam radiations H1B1 has been used (100 Gy amount) to generate some hypoallergic mutants [114]. Though irradiation affected the production of bioactive compounds. Chung and Champagne [115] have treated protein extract from roasted raw peanuts with POD (peroxidase) and TGA (transglutanasase) at 37 °C. They found TGA was not effective but POD was effective for Ara h 1/ Ara h 1 reduction. Different enzyme treatments of alcalase and flavourzyme in Ara h 1, 2 and Ara h 3 have also been done [116]. Pepsin, trypsin and chymotrypsin digestion has also been implemented to reduce allergenicity [117, 118].

RNA interference or genetic engineering techniques have also been suggested to remove allergenic groups of proteins when diversity of seed proteins was analyzed in *Arachis hypogaea* and related species [20]. Three independent transgenic lines have been generated for Ara h 1 and Ara h 6 proteins by using RNA interference [119, 120].

8. Conclusions

The high energy, protein and carbohydrate contents suggest that groundnut or peanut could be of great importance in alleviating protein energy malnutrition and hunger. The minerals analyzed in groundnut were similar to those of other nutritious foods consumed globally, the good levels of fatty acids and amino acids which make them a healthy food for human, and animal nutrition. The low levels of anti-nutrients could enhance absorption of nutrient in groundnut. Also, the functional properties can be modified by simply boiling or roasting and different methods of processing such as heat, pressure, membrane filtering, use of conjugates etc. Though the efforts are ongoing to reduce allergenicity which is generally found more in 2S albumin components and very less in globulins, much research is needed to generate hypoallergic cultivars. On the other hand, peanuts are a rich source of medicinally important phytochemicals of diverse nature. Due to this reason peanut cultivation in developing countries can benefit local communities. Various studies have also increasingly linked peanut consumption with improved human health and with decreased risks of life threatening diseases.

9. Future prospects

Peanut seed storage proteins can be used for different food and feed purposes, and also to make peanut protein biopeptides, hydrolysates, protein films etc. These have variety of industrial applications. In future, research should be aimed at modifying or improving the functional properties and nutritional chemistry to generate food end products. It has been well established with number of studies, that peanut can meet the increasing demand for protein rich healthy food with several benefits and thus, awareness should be spread in many more countries to exploit peanut or groundnut as vegan source of protein. Moreover, new cultivars need to be developed with hypoallergic proteins and improved nutrition.

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