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Functional Properties of Soybean Food Ingredients in Food Systems

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1. Introduction

The food system is the transformation of raw materials into healthy food products within biophysical and socio-cultural contexts which results in production, processing, distribution, preparation and consumption of food. Food systems include components of food availability, access and utilization which underpin food security (Gregory et al., 2005). The expanding world population has resulted to a greater pressure for the consumption of plant products in foods with aesthetic and organoleptic appeal; consequently resulting in a great emphasis on the need for food ingredients with multiple functional properties. The role of soybean as a traditional food item in Far East is well recognized where it is used to make tofu, tempeh and soymilk. Advances in food technology resulted in the development of a variety of edible soy products including concentrates, isolates and extruded-expanded products; the consequence of which is increased soy consumption by populations of technically developed regions of the world (Young and Scrimshaw, 1979). Soybean is crushed into oil and defatted meal. The meal is usually used as an animal feed; a smaller percentage is further processed into food ingredients including soyflour, concentrates, isolates and textured protein. These are soy protein products used as food ingredients because of their multiple functional properties. Functional properties have been defined as “those physical and chemical properties that influence the behavior of proteins in food systems during processing, storage, cooking and consumption” (Kinsella 1976). The functional behavior of proteins in food is influenced by some physicochemical properties of the proteins such as their size, shape, amino acid composition and sequence, net charge, charge distribution, hydrophobicity, hydrophilicity, type of structures, molecular flexibility/rigidity in response to external environment such as pH, temperature, salt concentration or interaction with other food constituents (Damodaran 1997). The functional properties are the intrinsic physicochemical characteristics which affect the behavior of a food ingredient in food systems during processing, manufacturing, storage and preparation. Such functional properties include water holding, oil binding, emulsification, foam capacity, gelation, whipping capacity, viscosity and others. Functional properties are important in determining the quality (nutritional, sensory, physicochemical and organoleptic properties) of the final product as well as facilitating processing such as improved machinability of cookie dough or slicing of processed meats (Kinsella, 1979). Therefore functional properties

of food proteins are important in food processing and food product formulation (Wu et al. 2009). However, these properties vary with the type of food products; for example, proteins with high oil and water binding are desirable for use in meats, sausages, bread and cakes, while proteins with high emulsifying and foaming capacity are good for salad dressing, sausages, bologna, soups, confectionery, frozen desserts and cakes (Ahmedna et al. 1999). This chapter presents a compilation of the functional food ingredients from soybean, their composition and structure and conformation in order to understand the mechanism of particular functional traits. The role of sprouting in soybean functionality will also be discussed.

2. Food ingredients from soybean

Foods made from soybean may be divided into four classes namely, soy ingredients, traditional soy foods, second-generation soy foods, and foods where soy is used as a functional ingredient (US Soybean Export Council 2008). These food products are outlined in Figure 1. Traditional soy foods include soy milk, tofu, tempeh, natto, miso and soy sauce. Soy milk is a protein-rich, milky liquid obtained from the soaking and grinding of whole soybeans with water, or from hydrating whole, full-fat flour, cooking the resultant slurry, and filtering all or part of the soy pulp or fibre from the cooked liquid. Second-generation soy foods include meat extenders, soy burgers, soy sausage, imitation chicken and soy cheese. Foods in which soy is used as functional ingredient include baked goods to which soy flour is added. Soy ingredients are the processed soybean protein products which include soy flour (defatted and full fat), soy concentrates, soy isolates, texturized vegetable soy protein and hydrolyzed soy protein. These soy ingredients (Figure 2) are the object of our discussion.

Soy Flour

Mature, whole, yellow soybeans are used for human food production. Soy flour is flour produced from hulled soybean seeds and is then ground into a fine powder; at least 97% of the product must pass through 100-mesh standard screen and contain 50% protein (Berk, 1992). The production of edible soybean flours and grits may take place either as an independent industrial activity or as a by-product of oil-mill operations. Soy grits are similar to soy flour except that the soybeans have been toasted and cracked into coarse pieces (US Soybean Export Council, 2010; Pyler, 1994; Lusas and Riaz, 1995). They are usually classified into three groups according to particle size: coarse 10 to 20 mesh; medium 20 to 40 mesh and fine 40 to 80 mesh (Berk, 1992). There are four forms: enzyme-active, natural or full-fat, defatted, and lecithinated (Figure 2). Further classification of the commercial soy flours and grits is in terms of their Nitrogen Solubility Index (NSI) or Protein dispersibility Index (PDI). Each of these tests indicates the percentage of total soluble nitrogen in water, with a range of values from 0 to 100 (Dubois, 1980). These parameters indicate the extent of protein denaturation and hence the intensity of heat treatment which has been applied to the starting material. The PDI decreases with higher levels of heat treatment. The NSI method gives lower values and has been related to PDI by the formula $PDI = 1.07(NSI) + 1$ (Lusas and Riaz 1995; Central Soya Company 1988). Flours made from white flakes have NSI of about 80%, while those from toasted flakes show NSI values of 10-20%. High PDI soy ingredients are more soluble and have highly active enzymes and anti-nutritional factors (Lusas and Riaz 1995).

Enzyme-active flours

Enzyme-active soy flour is produced from defatted soybeans that have been processed in such a manner as to preserve the activity of the enzyme lipoxidase. As early as 1934 it was reported that ground soybeans could be used for bleaching the carotene pigments of wheat flour during bread making (Wolf 1975). One method of preparing the bleaching agent involved grinding washed beans, removing the hulls, and mixing the resulting full-fat flour with four parts of corn flour; between 0.75 and 2% of the soy-corn flour mixture was sufficient for bleaching. This action is as a result of the activity of lipoxygenase in soybean. However, many studies have reported that increased addition of raw soybean in food products results in undesirable bean flavor. In addition to bleaching the pigments, lipoxygenase is also reported to cause oxidation of gluten proteins resulting in finer crumb. In the US enzyme active soy flour preparation are used at 1% level on wheat flour basis. In some continuous bread baking process, the lipoxygenase preparation is incubated with cottonseed or soybean oil and the peroxidised oil is then used in the dough formula resulting in improved bread flavor.

To obtain the enzyme active flour soybean seeds are cleaned, sorted into uniform size to minimize variations in processing, equilibrated to 10-12% moisture, preheated to 55°C (enhances loosening of hulls from the cotyledons during cracking and aids the removal by aspiration) and cracked into six to eight pieces by using corrugated rolls. The raw cotyledons are milled into full-fat enzyme active flours. Active-defatted soy flour could be obtained by defatting the obtained flour with hexane at 66-71°C (Lusas and Riaz 1995).

Full-fat flours and grits

Conventional processing method for full-fat flours and grits is shown in Figure 3. Natural or full-fat flour contains natural oils (18-20%) found in the soybean. Inactivation of lipoxygenase is a key step in the preparation of good flavored full-fat soy flours. Methods that have been reported include (1) conditioning of soybeans at 13-14% moisture in hot air (100°C) or steaming of dehulled beans and subsequent drying and grinding to full-fat flour; such flour; (2) microwave heating before cracking and dehulling and (3) extrusion cooking in which the soybeans were cracked and dehulled followed by a dry-heat preconditioning to inactivate lipoxygenase and other enzymes (Wolf, 1975; Kanzamar et al. 1993; Lusas and Riaz 1995). The treated seeds are tempered to 15-20% moisture after cooling and extrusion cooked. The extruded material is dried, cooled and milled into flour (Mustakas et al 1971).

White flakes

White flakes are produced by cleaning, heating and cracking soybeans, removing the hulls by aspiration; flaking the chips to about 0.25-0.30 mm thickness and extracting the oil by hexane to 0.5-1.0% oil. While the oil is removed by extraction, the carotenes are removed as well and the extracted residue gets a typical white colour, hence the name white flakes (Anon, 2008a). Processors produce white flakes with PDIs of 20, 70 and 90. Flaking ruptures the cotyledon cells allowing the oil to flow together, becoming accessible to lipases in the presence of heat and moisture. Beany flavor in defatted soy flours has been reduced significantly by preheating the soybeans before dehulling or flaking for the PDI objective of the specific product where appropriate (Lucas and Riazs 1995). White flakes have uses and is sold as an intermediate form for other products. White flakes and defatted soy flour with a high PDI serve as raw material for the manufacture of most protein concentrates, isolated

soy protein and texturised soy flour. They are also used alone or in combination with whole soybeans, as a starting material for the production of soy sauce (Berk 1992).

Defatted flours and grits

Defatted flour and grits have the oils removed during processing, contains less than 1% oil (Berk, 1992). The defatted flour or grits actually consists of a range of products rather than a single one. The important variable in the processing is the toasting step- a moist cooking with steam under atmospheric or pressurized conditions (Figure 2). Toasting is omitted if the soy flour is to be used as a bleaching agent in bread where activity of the oxidative enzymes is required. For some food uses, toasting improves the flavor and destroys anti-nutritional factors. However, despite the advantages of toasting, intermediate degrees may be desirable in order to retain adequate levels of functional properties since some of which are destroyed progressively on toasting. Therefore, the particular potential uses of the product determine the degree of toasting required.

Lecithinated soy flour

Lecithinated is flour whose normal lecithin content of 0.5 to 1.5% has been augmented to 15% in order to increase its emulsifying properties. It is obtained by spraying lecithin and vegetable oil on 70 and 20 PDI soy flour resulting to a good emulsifier that can be used for partial or total replacement of egg (Riaz, 2006).

Soy protein concentrate

Soy protein concentrate (SPC) is protein (70%) produced by extraction of sugars, soluble carbohydrate material, mineral matter and other minor constituent from defatted soy flour (US Soybean Export Council, 2008). The objective in producing SPCs is to remove strong-flavour components and the flatulence sugars (stachyose and raffinose). At the same time both the protein and dietary fibre contents are increased (Lucas and Riaz 1995). Three processes may be used: (1) heating the white flakes resulting in denaturation of the protein and they become water insoluble before the extraction process begins. The drawback is that the protein has lost most of its functional properties; this method is no longer used today; (2) extraction with water at isoelectric pH (4.5) where the soy protein has its lowest possible solubility characteristics. The neutral pH can be restored after extraction by neutralization and the protein regains its original solubility characteristics and functional properties. This process results in the best tasting and most functional SPCs that have found applications in the preparation of fat emulsions; (3) extraction with aqueous (70-90%) ethyl alcohol for the extraction of the oligosaccharides. This is the most popular process because it results in the most bland tasting and nutritionally most attractive SPCs. This process is based on the (irreversible) alcoholic denaturation of the protein. Mild heat drying conditions are used to retain high PDIs and NSIs (Lusas and Riaz 1995; Anon 2008a). A variety of granulations (from grits to ultrafine flours) may be obtained if the SPC was made from white flakes, extracted and dried with minimum breakage (Beery 1989).

Soy protein isolate

High PDI (70-90%) white flakes and flour milled to 200 mesh are used in making soy protein isolates (SPIs) (Lusas and Riaz, 1995; US Soybean Export Council, 2010). The production consists of an aqueous solubilization of protein and carbohydrates at neutral or alkaline pH and the recovery of the solubilized protein, separation and, optionally washing and neutralization before drying (Moure et al., 2006). Three steps are involved in the process of

making SPIs. (1) the soy flakes or flour are slurried with water under alkaline conditions (pH 6.8-10 at 27-66°C using sodium hydroxide and other alkaline substances approved for food use) so that the protein as well as the oligosaccharides can go into solution. The protein solution is then separated from the insoluble residue by centrifugation (Lusas and Riaz, 1995; Anon, 2008b); (2) the supernatant containing the protein and the sugars in solution is acidified to pH 4.5 (isoelectric point of proteins where their solubility is minimal), by using hydrochloric acid or phosphoric acid. This results in the precipitation of the protein as a curd. Typical process includes several extractions of white flakes or flour and washing of the curd; (3) The solubility of the precipitated protein is restored by neutralizing to alkaline pH 6.5-7.0 after re-dilution with fresh water or spray dried in its acidic form and packed in multilayer paper bags (Anon 2008b; Lusas and Riaz, 1995).

Textured soy protein

Texturization means the development of a physical structure that will when eaten provide a sensation of eating meat (Berk, 1992). Textured soy protein product is obtained either by spinning in into a fibre and then combining the fibre in layers to achieve the desired texture, or a thermoplastic extrusion process (US Soybean Export Council, 2010). Spun fibre is obtained using soy protein isolate as starting material; extrusion or steam texturised products from flour, concentrate or isolated protein (Berk, 1992). These products known as textured vegetable protein can simulate meat fibre structures (Anon, 2008b). Another possibility is the hydrolysed soya protein. The degree of hydrolyzation determines the functionality of the end products. Low degree of hydrolyzation results in highly functional foaming agents and high degree of hydrolyzation results in hydrolysed vegetable protein (HVP) which are used in soups and sauces as flavor enhancers (Anon, 2008a).

3. Classification of functional properties of food ingredients

Functional properties may be classified according to the mechanism of action on three main groups (Figure 4). These groups are (1) properties related with hydration (absorption of water/oil, solubility, thickening, wettability); (2) properties related with the protein structure and rheological characteristics (viscosity, elasticity, adhesiveness, aggregation and gelling), and (3) properties related with the protein surface (emulsifying and foaming activities, formation of protein-lipid films, whippability) (Kinsella, 1979; Moure et al. 2006). These properties vary with pH, temperature, protein concentration, protein fraction, prior treatment, ionic strength and dielectric constant of the medium as well as other treatments such as interactions with other macromolecules in the medium, processing treatments and modifications, physical, chemical and enzymatic methods (Kinsella, 1979).

Functional properties related with hydration mechanisms

Some functional properties can be interpreted as a result of the thermodynamically favourable protein-water interactions (wettability, swelling, water retention, solubility) or unfavourable (foaming, emulsification) (Moure et al., 2006). The interactions of protein with water are important in relation to dispersibility, water absorption and binding, swelling, viscosity, gelation and surfactant properties as these properties influence the important functions of proteins in meat, bakery and beverage systems (Moure et al., 2006). Ease of dispersibility or wettability is important in food formulations and is affected by surface polarity, topography, texture and area, and by the size and microstructure of the protein particles (Kinsella, 1979).

Bound water includes all hydration water and some water loosely associated with protein molecules following centrifugation, ranging from 30 to 50 g per 100 g protein (Riaz, 2006). Soy isolate having the highest protein content among soy protein products has the highest water-binding capacity, approximately 35 g/ 100 g (Hettiarachchy and Kalapathy, 1998). Soy concentrates contain polysaccharides, which absorb a significant amount of water. Generally, processing conditions can affect the amount of water that can be absorbed; these conditions can be varied to influence how tightly the water is bound by the protein in the finished food product (Endres, 2001).

Water holding capacity is the ability to retain water against gravity, and includes bound water, hydrodynamic water, capillary water and physically entrapped water (Moure et al., 2006). The amount of water associated to proteins is closely related with its amino acids profile and increases with the number of charged residues (Kuntz and Kauzmann, 1974), conformation, hydrophobicity, pH, temperature, ionic strength and protein concentration (Damodaran, 1997; Kinsella, 1979). Defatting increases the protein solubility and water and oil absorption capacities of the meals. Germination, fermentation, soaking or thermal treatments (toasting/autoclaving) significantly improves water absorption capacity (Moure et al., 2006).

Proteins swell as they absorb water and it is an important functional property in foods like processed meat, doughs and custards where the proteins should imbibe and hold water without dissolving and concurrently impart body, thickening and viscosity. Viscosity and swelling are closely related important properties in processed meats (Kinsella, 1979). Factors which affected swelling also influences viscosity; protein concentration, pH and temperature positively affects swelling and viscosity whereas sodium chloride depresses both (Kinsella, 1979).

Protein solubility is influenced by the hydrophilicity/hydrophobicity balance, which depends on the amino acid composition, particularly at the protein surface (Moure et al., 2006). The presence of a low number of hydrophobic residues; the elevated charge and the electrostatic repulsion and ionic hydration occurring at pH above and below the isoelectric pH favour higher solubility. Protein solubility is also influenced by production method and in particular by denaturation due to alterations in the hydrophobicity/hydrophilicity ratio of the surface. A highly soluble protein is required in order to obtain optimum functionality required in gelation, solubility, emulsifying activity, foaming and lipoxygenase activity (Riaz, 2006). Soluble protein preparations are easier to incorporate in food systems, unlike those with low solubility indices which have limited functional properties and more limited food uses.

Functional properties related with protein structure and rheology

Solubility, hydrodynamic properties, hydrophobicity and microstructure of proteins have been reported to play an important role in the rheological properties of proteins (Krause et al., 2001; Krase et al., 2002). Apparent viscosity of soybean isolates depends on interaction between soluble and insoluble proteins with water and between the hydrated particles (Añón et al., 2001). Due to the increased interactions of hydrated proteins, the water absorption and swelling, viscosity increases exponentially with protein concentration (Kinsella, 1979). Knowledge of the viscosity and flow properties of protein dispersions are of practical importance in product formulation, processing texture control and mouthfeel properties and in clarifying protein-protein interactions and conditions affecting conformational and hydrodynamic properties (Kinsella, 1979).

Protein gels are three-dimensional matrices or networks of intertwined, partially associated polypeptides with entrapped water; and are characterized by a relatively high viscosity, plasticity and elasticity (Kinsella, 1979). The ability of protein to form gels and provide a structural matrix for holding water, flavours, sugars and food ingredients is useful in food applications, and in new product development and provides an added dimension to protein functionality. Gelling property is important in comminuted sausage products and is the basis of many Oriental textured food e.g. tofu. Factors known to affect gelation include pH, ionic strength, reducing agents, urea, temperature, the presence of non-protein components and the mechanical forces applied to the system (Sathe, 2002). Properties of the gel are determined by the interactions between solvent and the molecular net resulting in transparent or coagulant gels. Coagulant gels are formed by proteins containing non-polar residues (Shimada and Matsushita, 1980), while those containing hydrophilic amino acids form transparent ones (Moure et al., 2006). Soy flour and concentrates form soft, fragile gels, whereas soy isolates form firm, hard, resilient gels. Protein gelation is concentration dependent; a minimum of 8% protein concentration is necessary for soy isolates to form a gel. The general procedure for producing soy protein gel involves heating the protein solution at 80 to 90°C for 30 minutes followed by cooling at 4°C (Riaz, 2006). The ability of the gel structure to provide a matrix to hold water, fat, flavour, sugar, and other food additives is very useful in a variety of food products (Kinsella, 1979; Hettiarachchy and Kalapathy, 1997).

Functional properties related to protein surface

Important properties of foods involve the interaction(s) of proteins and lipids, e.g. emulsions, fat entrapment in meats, flavor absorption, lipoprotein complexes in egg yolk, meats, milk, coffee whiteners, dough, and cake batters (Kinsella, 1979). Emulsions and foams are two phase systems commonly found in food systems, whose formation is significantly affected by protein surface activity (Moure et al., 2006; Kinsella, 1979). Emulsions are generated by mixing two immiscible liquids e.g. oil and water. The liquids are immiscible because of their relative polarities. When liquid of low polarity such as fat is mixed with water a strong driving forces limits the contact between the two liquids resulting to phase separation. Droplet size of emulsion significantly affects the stability of emulsions; emulsions with precisely controlled droplet size exhibit better stability. Reduction in droplet size also improves stability of an emulsion to separation due to gravity (McClements, 1999). The goal in food processing is to stabilize the emulsion thereby giving it a reasonable lifetime. The dispersed system can be stabilized against coalescence and phase separation by adding a component that is partially soluble in both phases. Such components are phospholipids (emulsifiers) which when mixed with lipid in an aqueous environment; the fatty acid portion of the molecule is inserted into the oil phase, while the phosphate ester head group remains in contact with the aqueous phase. The result is that the two immiscible phases are not in contact with each other and the total energy of the system is lower. Emulsifiers or foaming agents therefore reduce the interfacial tension and help to stabilize the oil-water and air-water interfaces (Moure et al., 2006). In decreasing the interfacial tension of emulsions low molecular weight surfactants (phospholipids, mono and diglycerides or monoesterates) are more effective than high molecular weight ones (proteins and hydrocolloids) (Damodaran, 1997). Despite the lower efficiency of proteins the emulsions and foams formed with proteins are more stable, hence proteins are preferred

over low molecular weight surfactants for emulsification purposes in foods (Moure et al, 2006). Surface activity of proteins is related to their conformation and ability to unfold at interfaces determined by molecular factors (flexibility, conformational stability, distribution of hydrophilic and hydrophobic residues in the primary structure) and external factors (pH, ionic strength, temperature, possible competitive adsorption of other proteins or lipids in the interface) (Vliet et al., 2002). Highly insoluble proteins are not good emulsifiers as they can generate coalescence (Kato and Nakai, 1980). Emulsion stability is not only influenced by the presence of salts and pH (Tsaliki et al., 2004), but also by several physical interdependent processes such as cream formation, flocculation or aggregation and coalescence (Damodaran, 1997) resulting in phase separation.

Foams are gaseous droplets encapsulated by a liquid film containing soluble surfactant protein resulting in reduced interfacial tension between gas and water. Capacity of proteins to form stable foams with gas by forming impervious protein films, is an important property in cakes (angel, sponge), soufflés, whipped toppings, fudges, etc (Kinsella, 1979). Properties of good foaming proteins include (1) solubility in the aqueous phase and rapid adsorption during shipping and bubbling; (2) concentrate at the air-water interface and unfolding to form cohesive layers of protein around air droplets with reduction of surface tension; and (3) possess sufficient viscosity and mechanical strength to prevent rupture and coalescence (Kinsella, 1979; Hettiarachchy and Ziegler, 1994).

Functional properties related to organoleptic/kinesthetic

The contribution of proteins to food flavours is known as it affects the sensory properties (appearance, colour, flavor, taste and texture) of foods. Proteins may modify flavor by binding flavours and off-flavours to generate flavors on cooking and to release reactants that may produce flavours, especially following hydrolysis or proteolysis (Kinsella, 1979). These are important factors considered in fabricating foods from soy proteins.

4. Functional properties of soybean food ingredients in food systems

The food systems where soy protein products find application are outlined in Table 1. These include (1) comminuted meat sausages, such as frankfurters and bologna; (2) low-viscosity emulsions, such as milk, coffee whitener and liquid whipped topping; (3) high-viscosity emulsions, such as mayonnaise or salad dressings; (4) Bakery, pasta and food bars; (5) Confectionery and (6) Infant formulas.

Meat and dairy based systems

Solubility, water binding, swelling, viscosity, gelation and surfactant properties are important functional properties of soy proteins in meat and dairy based systems. Comminuted meats (sausage, bologna, luncheon meats) usually contain more fat than normal meat, hence soy proteins are used to enhance and stabilize fat emulsion, improve viscosity, impart texture upon gelation following cooking and improve moisture retention and overall yields (Table 2). Heat-treated soy flour is commonly used as well as soy concentrates. However, there use results in poor flavor and mouthfeel as well as poor texture, dryness and flavour associated with flours and concentrates added above 10% (Kinsella, 1979). This is resolved by using soy isolates in meat loaves, sausage-type products for their emulsion-stabilizing effects, gelation, moisture retention and improved effects on texture.

Textured protein products in use both in the meat and vegetarian meat analog industry include texture soy flours, textured soy protein concentrates, and textured soy protein materials comprised of various blends of isolated soy protein, soy protein concentrate, soy flour, wheat flour, vital wheat gluten, rice flour, soy fibre, assorted starches etc. Textured soy flours are less functional with regard to water-holding capabilities compared to other textured vegetable protein ingredients (Riaz, 2006).

Texturized soy protein products are used as meat extenders in comminuted meat products such as patties, fillings, meat sauces, meat balls, etc. As much as 30% of the meat can be replaced by hydrated texturized soy products without loss of eating quality. In addition to offering economic savings, textured soy products offer certain product improvement- water and fat absorption resulting in increased product juiciness and use of meat with higher fat content (Berk, 1992).

Low-viscosity systems

In a low-viscosity, low fat emulsion, creaming is the usual form of breakdown and the contribution of protein to the whitening effect of the emulsion is important (Puski, 1976). Solubility is the most important criterion of soy protein product for beverages (Kinsella, 1976). Other requirements of the soy protein product include: formation of a clear or translucent solution that is bland, low viscosity, stability over pH range, ionic strength and temperature conditions and storage in liquid, concentrate or powder form. Solubility of the protein in acidic range is necessary in carbonated beverages. This is achieved by using protein hydrolysates (Kinsella, 1976), although the presence of bitter peptides is a problem with hydrolysate.

Beverages containing soy protein can be classified according to their position in the marketplace (Table 3). Soy protein products in ready-to-drink beverages affect sensory attributes in diverse ways. That is the type of protein is related to certain functionality characteristics in beverages. In general, soy proteins with good solubility will produce better beverage mouthfeel and suspension stability. The relationship between protein physical properties and beverage functional attribute are detailed in Table 4 (Riaz, 2006).

Physical properties of soy protein products differ from each other as a result of differences in component composition (protein, fat and fibre content), preparation, and processing. In addition, the physical properties differ within the same group to a great extent. Good functional proteins in beverage system are those with high solubility, high emulsification, and proper viscosity for the targeted market (Riaz, 2006). Proteins with high foaming and high gelling properties would have a negative impact on beverage quality.

High viscosity systems

The role of soy proteins in high-viscosity products includes emulsification and colloidal stability to heat. Soy isolates show a greater (6-fold) emulsifying capacity compared to soy protein concentrate (Kinsella, 1979) often depending on method of preparation. There is a close relationship between emulsifying properties and solubility of soy protein products especially in low viscosity emulsions (milk, salad dressing, coffee whitener). However, this is less important in viscous emulsions for example in comminuted meats where soy proteins with 50% solubility can ensure adequate emulsifying capacity and the thermal stability in preventing fat separation. Creaming is less important in high viscosity emulsions. However, coalescence and inversion into water-in-oil emulsions are the most likely breakdown problems.

Bakery, pasta and food bars

Soy ingredients that have unique functional applications in bakery products include soy flours, soy grits, soy protein concentrates, soy protein isolates, textured soy protein, soy brans, and soy germs (Riaz, 2006). Soy bran is obtained by toasting and grinding the seed coat portion of the soy bean (US Soybean Export Council, 2008; Dubois, 1980). Soy germ comprises 2% of the total soybean and is used in baked and extruded products as well as in cereal-based products as adjunct to other soy ingredients to increase isoflavone levels. Inclusion rates are usually 1 to 2% of the total formulation of the product because of its high isoflavones content (Riaz, 2006).

Soy protein ingredients are important in determining the quality of the product as well as facilitating such processing requirements as in improving machinability of cookie dough for instance. The extent of heat treatment during processing determines the use of soy proteins in bakery products (Table 5).

Soy proteins are rapidly insolubilized by heat, moist heat in particular during processing. However, heat is necessary during soy protein production as it is needed to desolventize, inactivate anti-nutrient compounds and to improve soy flour flavors. On the other hand, non-heated soy flours have bitter, beany flavour and limited applications while containing high lipoxygenase activity. To balance enzyme activity, flavor quality and solubility requirements, defatted soy flours with a range of solubilities as well as concentrates and isolates from minimally heat-treated flours possessing good solubility are produced (Riaz, 2006). Protein solubility is a measure of the percentage of total protein that is soluble in water under controlled conditions and is a measure of the degree of heat treatment to which the soy flour has been subjected (Riaz 2006). Soy flours with high NSI or PDI are used in bakery and cereal products and are added directly to the dough (Endres, 2001). Enzyme-active soy flour has a minimum water solubility of 70% (Schryver, 2002). Soy flours subjected to minimal heat treatment (PDI 80) show high lipoxygenase activity and are used at 0.5% to bleach flour and improve the flavour of bread. Flours with a PDI of approximately 60 are commonly used for improving water-binding capacity (1 to 2% in bread, 10% in waffles and pancakes). Some functional properties of soy protein products in baked goods are detailed in Table 6.

Soy protein ingredients are used to aid formation and stabilization of emulsion for many food products including cake batters. Generally, the emulsifying capacity of soy protein products increases with increasing solubility and interfacial tension is progressively reduced as concentration is increased (Riaz, 2006).

The capacity of proteins to form stable foams with gas by forming impervious protein films, is an important property in some food applications including angel and sponge cakes (Riaz, 2006). Soy protein products differ in their foaming ability, with soy isolates being superior to soy flour and concentrates. Soy protein foaming ability is closely correlated to its solubility.

Soy proteins addition to wheat flour dilutes the gluten proteins and starch while exhibiting a strong water-binding power that provides some resistance to dough expansion, the effect being proportional to quantity of soy flour. The water-binding power of soy flour is related to its high water absorption capacity, 110% by weight in defatted product. That is defatted soy flour will absorb an amount of water equal to its weight when mixed with wheat flour to normal dough consistency. However, with full-fat flour, no measureable increase in dough absorption results from normal use levels of the soy product (US Soybean Export Council, 2008). Water holding capacity of protein is very important as it affects the texture, juiciness, and taste of food products and in particular the shelf-life of bakery products. All

SPCs, irrespective of the processing method, have certain fat and water- holding characteristics (Endres, 2001). There is no reason for using SPC in bakery products, unless higher protein fortification levels are necessary. Soy flour does the same job of nutritional and functional improvement more economically (Berk, 1992).

Food bars are combinations of ingredients that provide food in a solid, low-moisture form and are consumed as a source of nutrients, as opposed to confectionery bars, which are consumed as sweet products (Raiz, 2006). The basic formulations of food bars are outlined in Table 7. All food bars use similar combinations of ingredients but their positioning varies widely as well as the nutrient profile. The largest proportion of soy protein in bars is in the form of isolates. Two main functional types are used in food bars. The first type has high gel strength, with its solution having high viscosity forming rigid, thermostable gels at moderate concentrations. The highly gelling soy isolate makes firmer bars with a drying mouthfeel, with shorter texture, similar to that of a cookie. The second forms solutions with much lower viscosities and will not form gels at any concentration. The low viscosity soy proteins produce much softer, chewier nutritional bars. Water-holding capacity, viscosity and wettability all play a role in determining the texture of the end product (Riaz, 2006).

Confectionery

Lecithinated soy flour improves the dispersion of the flour and other ingredients in confections and cold beverage products as well as improving water retention in baked goods and extending their shelf lives (Riaz, 2006). Partially hydrolysed soy proteins possess good foam stability properties and can be used as whipping agents in combination with egg albumen or whole eggs in confectionery products and deserts (Berk, 1992).

Infant formula

Soy protein isolate is the preferred ingredient in infant formulas where milk solids are replaced. This is because of its bland taste, absence of flatus-producing sugars and negligible fibre content (Berk, 1992).

5. Effect of sprouting on functional properties of soybean food ingredients

Sprouting is the practise of soaking, draining, and leaving seeds or grains until they germinate or sprout. The increasing interest in functional and healthy food products has promoted the use of germinated soya bean flour in the manufacture of foods for human consumption (Farrera-Rebollo & Calderon-Dominguez, 2007). It is known that germination induces increase in free limiting amino acids and available vitamins with modified functional properties of seed components (Akpapunam, 1996; Jideani and Onwubali, 2009). The nutrient composition of soy bean sprout is affected by sprouting conditions such as times and temperatures, presence or absence of light during the sprouting process, the composition of the soaking and rinsing water as well as post-sprouting handling. Sprouts in general are high moisture and low calorie products and good sources of protein and other nutrients (Jideani and Onwubali, 2009). On the basis of mineral bioavailability, the significant reduction of phytic acid during sprouting makes sprouts nutritionally more attractive than their non-sprouted seed.

Jideani and Onwubali (2009) reported that sprouted soy bean flour resulted in increased loaf volume, a firmer, spongy and more elastic loaf in wheat bread. A combination of yeast (2.4%) and sprouted soy bean flour (10.6%) produced an optimal loaf.

In our research we observed that sprouting of soybeans seeds at 25°C resulted in maximum values of vitamin C and lipase at 48 h; amylase activity 36 h. Equal mixtures of the flour obtained at these times were studied for its functional properties. The flour possessed a higher emulsification capacity compared to whole egg powder. There was no significant difference between the whole egg powder and the sprouted flour in oil absorption. Hence, sprouted soybean flour could find use in fried foods and food systems where egg is required to minimize oil absorption (Murevanhema, 2009). Soy bean are rich source of phenolic antioxidants, which occur naturally bound to carbohydrates (McCue and Shetty, 2004). Free phenolic antioxidants have higher antioxidant activity than their carbohydrate-bound forms. McCue and Shetty (2004) reported that water extracts of dark-sprouted soybean contained high levels of free phenolics and antioxidant activity, alpha-Amylase being the major enzyme responsible for driving carbohydrate metabolism to phenolic synthesis in dark-sprouted soybean. Therefore, sprouted soybean flour in addition to having improved functionality may have important antioxidant effects in stabilizing lipids in formulated foods.

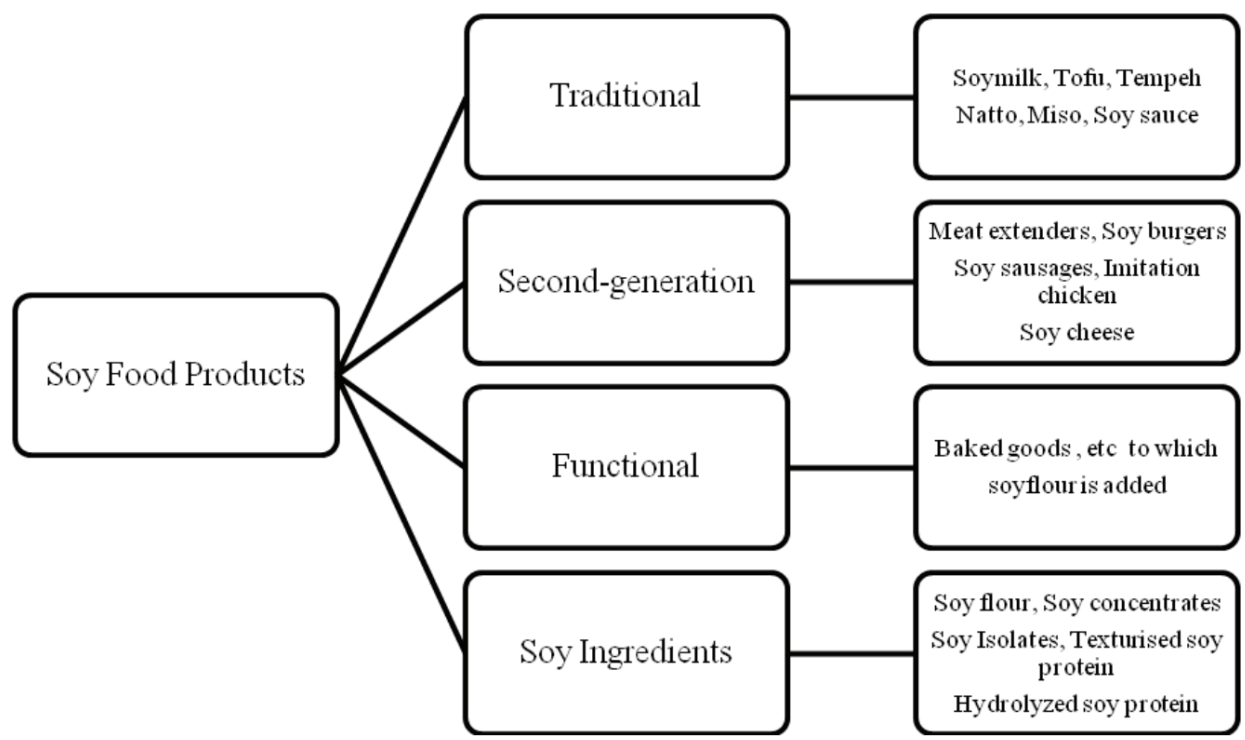


Fig. 1. Categories of soy food products (Adapted from US Soybean Export Council, 2008)

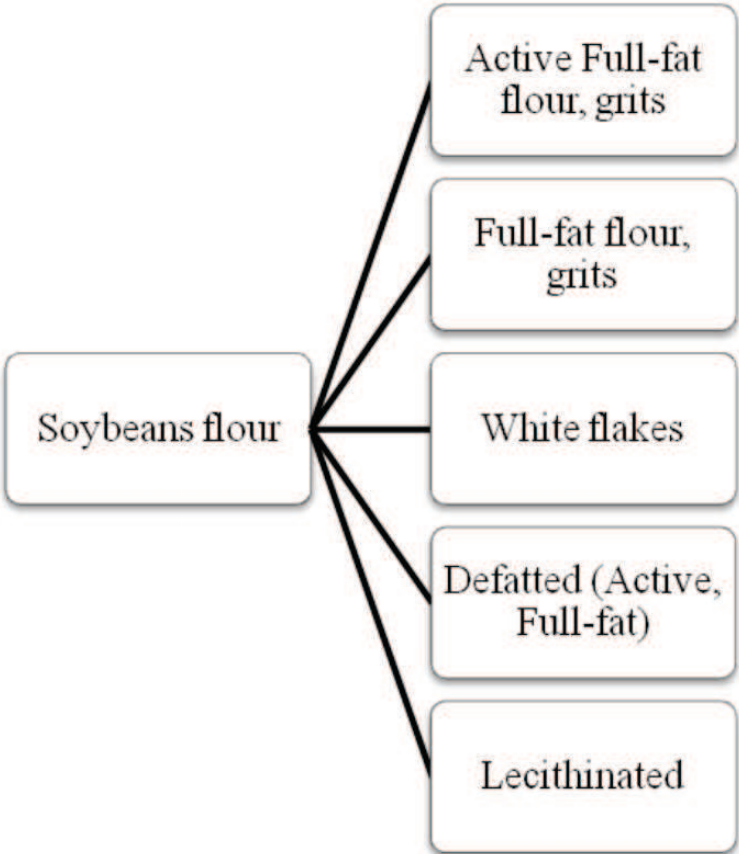


Fig. 2. Flour products from soybeans

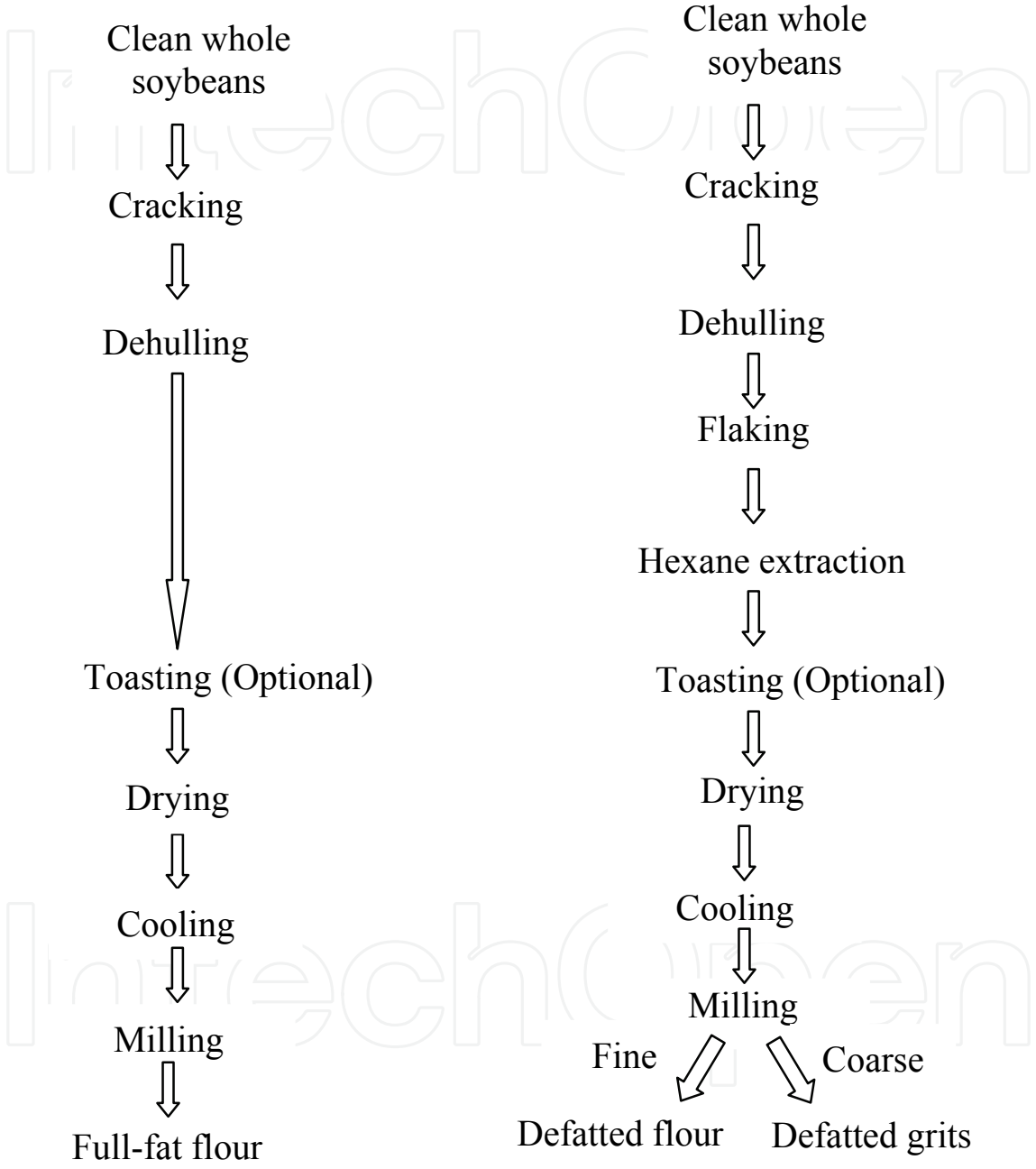


Fig. 3. Conventional processes for producing full-fat and defatted soybean flour/ grits (Mutakas, 1971).

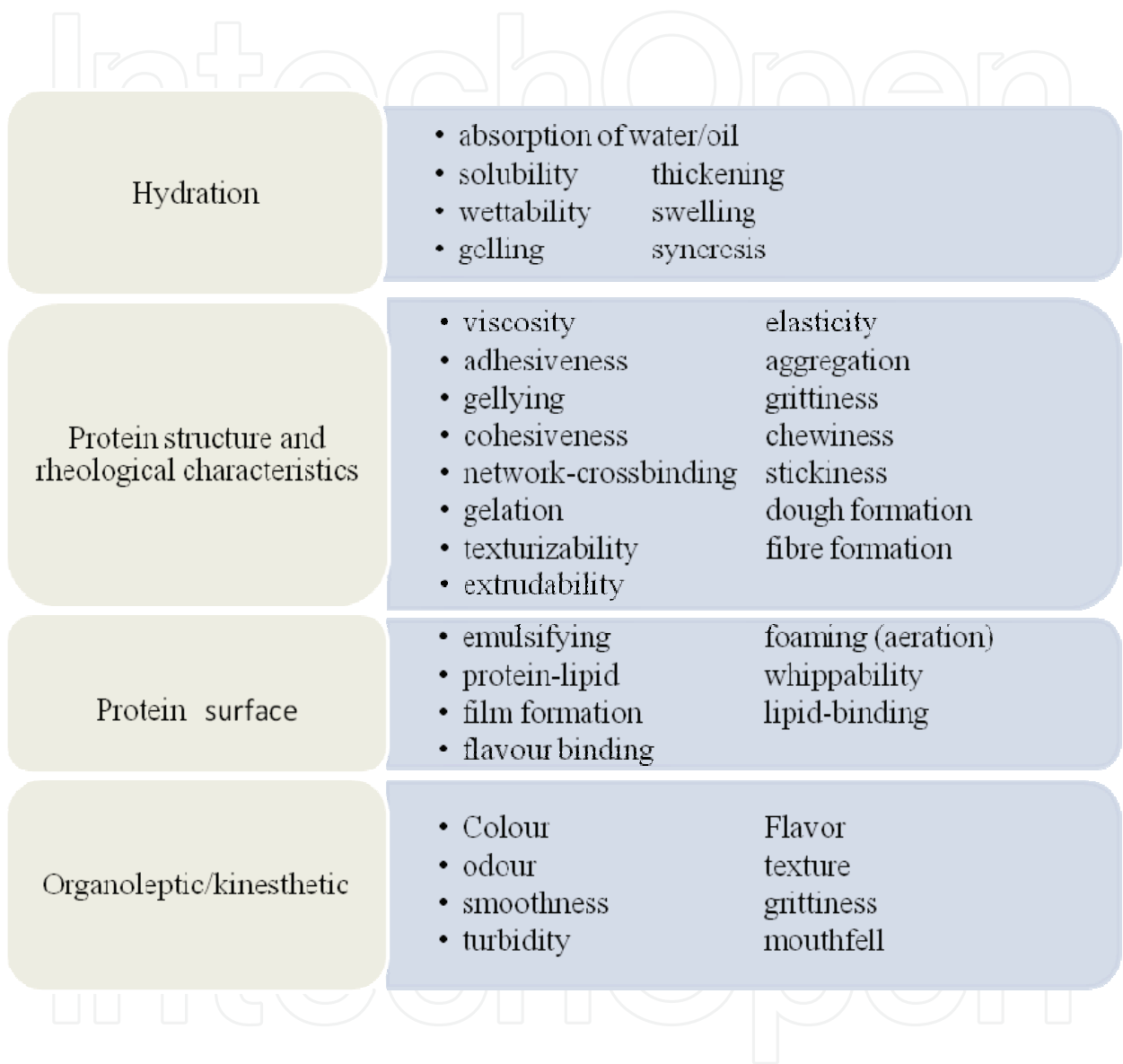


Fig. 4. Functional properties of food ingredients in food systems (Adapted from Moure et al. 2006; Kinsella, 1979)

	Food system	Functional property for all products	Soy ingredients ¹
1.	Meat and dairy		
	Meat, sausages, bologna	Water absorption, binding, elasticity, cohesion-adhesion, emulsification, fat adsorption	F, C, I
	Simulated meats	Flavour-binding	C, I,H
	Cheese, curds	Gelation	C, I
2.	Low viscosity		
	Beverages	Solubility, emulsifying, gelation	F, C, I, H
	Whipped toppings, frozen desserts	Foaming, emulsifying, dispersibility	I, W, H
	Imitation dairy	Emulsifying, colloidal stability	
3.	High-viscosity		
	Retortable sauces	Emulsifying, colloid stability to heat	
	Mayonnaise and salad dressing		
4.	Bakery and pasta	Solubility, emulsifying, gelation, colour control, cohesion-adhesion	F, C, I
5.	Confectionery	Foaming, solubility	I, W
6.	Infant formula	Nutrition, solubility, emulsification, colloidal stability to heat	

¹F, C, I, H, W are soy flour, concentrate, isolate, hydrolysate and soy whey, respectively.

Table 1. Functional properties of soy protein products in food systems

Improves uniform emulsion formation and stabilisation. Reduces cooking shrinkage and drop by entrapping-binding fats ans water. Prevents fat separation. Enhances binding of meat particles without stickiness. Improves moisture holding and mouthfeel. Gelation improves firmness, pliability and texture. Facilitates cleaner, smoother slicing. May impart antioxidant effects. Improves nutritional value.

Source: Kinsella (1979)

Table 2. Functions of soy protein in meat-based product

Ready-to-drink product	Description	Market
Milk-plus	Contain cow’s milk plus soy protein.	Mainstream consumer
Milk alternatives	Contain either no dairy ingredients or at least no lactos, are possess approximate composition of cow’s milk.	Lactose-intolerant consumers
Soymilks/Soy beverages	Based on all-vegetable ingredients, with soy as the sole protein source.	Ethnic and religious groups, vegetarians, and health conscious consumers, have become a widening part of the mainstream consumer.
Pharmaceutical/nutritional	Scientifically formulated and clinically tested for specific human diseases or developmental states.e.g. infant formula, adult nutritional supplements, and enteral feeding formula.	Sold via medical referral within pharmacies
Meal replacers/weight loss	Provide balanced nutrition as par to an overall diet plan.	Weigh conscious or obese consumers
Cream alternatives	e.g coffee whiteners and whipped toppings dairy-like cream alternatives without casein.	Religious, ethnic, and dietary needs demanding replacement of casein in toppings.
Fortified juice	Fruit-flavoured drink with soy protein included (<1.5%) for nutrient fortification.	Children, women, and helath-conscious adults
Fruit smoothies	Fruit-type drink with a higher protein addition (1.5 to 3%). Two subsets: semblance of drinkable yogurts; blended fruit shakes popular at smoothie bars.	Health conscious and active adults seeking added nergy and more nutrition in tasty, fruity flavours.

Adapted from Riaz (2006).

Table 3. Beverages containing soy protein products

Physical property	Beverage functional attribute
Solubility	Appearance, mouthfeel, sediment, suspension stability
Emulsification	Suspension stability, mouthfeel, appearance, colour
Viscosity	Mouthfeel, stability, flavour
Flavour binding	Flavour
Particle size	Mouthfeel, colour and appearance
Heat stability	Colour, suspension

Source: Riaz (2006)

Table 4. Relationship between physical properties of proteins and beverage attributes

Application	Protein dispersibility index (PDI)
Emulsifying, foaming	>90
Lipoxygenase bleaching of flour and bread	>85
Water absorption in bakery products	60
Waffles	30
Crackers, cereals	15

Source: Riaz (2006).

Table 5. Soy protein solubility requirement for selected bakery applications

Functional property	Mode of action	Baking system	Protein form
Emulsification			
Formation	Formation and stabilization of fat emulsions	Breads, cakes	Flour, concentrates, isolates
Fat Adsorption			
Prevention	Binding of free fat	Doughnuts, pancakes	Flour, concentrates
Water Absorption and Binding			
Uptake	Hydrogen bonding of water, entrapment of water, no drip	Breads, cakes	Flour, concentrates
Retention	Hydrogen bonding of water, entrapment of water, no drip	Breads, cakes	Flour, concentrates
Dough formation	-	Breads, cakes	Flour, concentrates, isolates
Cohesion-adhesion	Protein acts as adhesive material	Breads, cakes	Flour, concentrates, isolates
Elasticity	Disulphide links in deformable gels	Breads, cakes	Flour, concentrates, isolates
Flavour-binding	Adsorption, entrapment, release	Breads, cakes	Concentrates, isolates, hydrolyzes
Foaming	Forms stable films to trap gas	Whipped toppings, chiffon desserts, angel cakes	Isolates, soy whey, hydrol
Colour control			
Bleaching	Bleaching of lipxygenase	Breads	
Browning	Maillard, caramelization	Breads, pancakes, waffles	

Source: Riaz (2006).

Table 6. Selected functional characteristics of soy protein in baking systems

Category		Description
1.	Athletic bars	Includes energy bars.
2.	Lifestyle or wellness bars	Includes the 40:30:30 concept of balanced calorie intake from carbohydrates, protein and fat)
3.	Diet bars	Includes meal replacement bars and high-protein, low-carbohydrate bars
4.	Carbohydrate energy endurance bars	Used by backpackers, climbers, cyclists, etc. for an energy boost.

Adapted from Riaz (2006)

Table 7. Basic formulations of food bars

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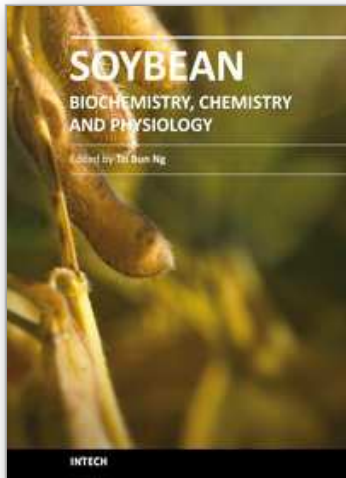
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Soybean is an agricultural crop of tremendous economic importance. Soybean and food items derived from it form dietary components of numerous people, especially those living in the Orient. The health benefits of soybean have attracted the attention of nutritionists as well as common people.

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