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The physical, chemical and sensory properties of soymilk, tofu and doughnut made from specialty full-fat soy flours

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The physical, chemical and sensory properties of soymilk, tofu and doughnut made from specialty full-fat soy flours

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Signatures have been redacted for privacy

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ABSTRACT

Several specialty soy flours were used to make soymilk, tofu and doughnuts. Low lipoxygenase and low stachyose (LPLS)-, low lipoxygenase- and regular soy flours yielded 10 - 30% more soymilk and produced 50% less waste (okara) than soy chips, soy flakes, and soybeans, using the Takai Automated Soymilk and Tofu System (steam injection cooking). Use of soy flour reduced the soymilk processing time while producing good quality soymilk with 83.6 - 86.8% and 84.3 - 86.1% solids and protein recoveries, respectively. Soymilk made from soy flours, chips and flakes had significantly less fat (0.54 - 1.04%) than soymilk made from the whole beans (1.45%). The lowest fat content was found in the LPLS-soy flour soymilk (0.54%).

Despite better yield, tofu made from soy flour did not have a smooth texture (cracks) as did tofu made from other soy ingredients. Curds were incompletely formed with milky whey left behind after coagulation and pressing.

No significant difference in "beaniness" was found between all the soymilk samples, while the LPLS-tofu was rated as less beany than the flake tofu.

When roasted full-fat soy flours of 30 and 44 PDI (protein dispersibility index) and defatted soy flours of 20 and 70 PDI were used to replace 30% non-fat dry milk and or eggs in doughnuts, the color, texture, moisture, fat and protein contents, fat absorption, and the sensory attributes of the doughnuts were very similar among all the samples including the control (no soy).

With the exception of the full-fat low stachyose soy flour, other soy flours did not produce significant soy flavor and off-flavors in doughnuts (up to 10% soy flour addition). Although the defatted 70 PDI soy flour reduced the overall fat absorption by 40%, the doughnuts were less preferred by the panelists than doughnuts with full-fat soy flour added. Drier and less tender attributes occurred at the higher addition levels which could be the reasons for lower preference. The full-fat 44 PDI soy flour reduced the fat absorption by 13% (overall), while preserving the sensory attributes of doughnuts in this study.

GENERAL INTRODUCTION

Soybeans are rich in protein (30-40%) and oil (20%) (Wilson, 1995). Due to shortage of meat and dairy products in many Asian countries, food uses of soybeans contribute significant protein and fat requirements to people of Asia (Sipos, 1988). With the recent attention on the protective effects of soy isoflavones in cancer prevention, the benefits of eating soy is rising which may increase the popularity of soyfoods.

Although soybeans have been cultivated in China since 2800 B.C. (Wilson, 1995), the United States is the world largest world soybean producer today. Between September 1993 and April 1994, the United States had about 43.4% of the total world soybean production. The preliminary data for the share in 1994/95 was 50.4% (Soya Bluebook Plus, 1995).

More than one-third of U.S. soybeans are exported while the rest are used domestically mainly for the production of food oil, feed meal, soy flours, soy protein concentrates and isolates. Countries such as China, Taiwan, Japan, Korea and other Asian countries import soybeans from the U.S. for preparation of traditional soyfoods, e.g., soymilk, tofu, soy sauce, miso, tempeh, etc., and for oil and meal production (Liu et al., 1995).

Although the consumption of soy in the U.S. is still not as popular with the majority of people, mainly due to the flavors, soyfood sales have soared by about 30% in 1995 after years of steady 10-15% growth. It is predicted that the value of total soyfoods market will double by the beginning of the next century. This includes soy proteins, tofu, soymilk, tempeh, miso, soy sauce, soynuts and other products marketed primarily as soyfoods, except soy oils (Kuhn, 1996). Continuous improvement in soy flavor and soy utilization are important for increasing consumption.

Thesis Organization

This thesis contains two main studies. The first part is about utilization of soy flours in soymilk and tofu manufacture which includes the introduction, materials and methods, results and discussion and conclusion. The second part discusses the utilization of soy flour in doughnut production. Similarly, this part contains the introduction, materials and methods, results and discussion, conclusions plus recommendations. All references cited in the literature review and both studies are listed at the end of the thesis.

The appendices for sensory scorecards, additional tables and figures, and preliminary data for doughnut study are included after the General Conclusions.

LITERATURE REVIEW

Soy Applications - Limitations and Improvements

The use of soy in the United States has been mainly limited by its flavor. Other concerns include abdominal discomfort (flatulence) and the presence of trypsin inhibitor and other biologically active compounds (Liener, 1981) such as hemagglutinins, goitrogens, phytate, allergen (2S-globulin) and antivitamins. Nevertheless, most of these compounds are readily destroyed to significant levels by moist heat treatment without detriment to the nutritional quality.

Flavor problems

The distinctive flavors of soymilk, tofu and other traditional soy products such as miso and tempeh are widely accepted in many Asian countries since the soybean has a very long history in the Oriental diet. In the Western part of the world, people perceive the flavors of soy as "beany", "green", "grassy", "painty" and "bitter" (Wolf, 1975; Rackis et al., 1979; Wilson, 1996). Oriental consumers are less likely to perceive the flavors of soy as a problem while it is unacceptable to many consumers in the West.

The undesirable flavors in soy are caused by the production of hexanal and other volatile aldehydes compounds by hydroperoxidation of *cis-cis* 1,4-pentadiene-containing fatty acids, mainly linoleic and linolenic acids, by lipoxygenase in soybeans. The reaction occurs when soybeans are damaged, crushed, ground, or rehydrated during processing and/ or storage (Wolf, 1975;

Rackis et al., 1979; Wilson, 1996; Zhu et al., 1996). The soy flavor has caused a repulsive reaction from the consumers towards soy foods and negative perception of soy-containing foods. To overcome the flavor problems, many investigators have tried several methods to inhibit lipoxygenase activity and to minimize beany flavors in soy proteins (Table 1 and 2).

Table 1. Methods to prevent or inhibit lipoxygenase activity.

Genetic modification of soybeans: lipoxygenase null lines
Wet blanching: water or steam
Dry heating
Grinding at acidic pH
Grinding with H_2O_2 plus calcium cloride
Grinding in hot water (100°C)
Grinding with solvent azeotropes
Grinding and heating in a vacuum
Inhibition by acetylene compounds
Addition of antioxidants
Soaking and heating after alkaline treatment

Wilson, 1996.

Table 2. Methods used to minimize beany flavors in soy proteins.

Azeotrope extraction
Enzymatic treatment
Masking the beany flavor with added desirable flavors
Single-solvent extraction
Steam treatment
Vacuum treatment
Supercritical CO_2 extraction
Replacement with another protein source

Wilson, 1996.

Application of heat is common in soymilk preparation. Heat is used not only to inhibit lipoxygenase, but also to destroy trypsin inhibitor, urease and other biologically active components (Savage et al., 1995). However, the solubility, nutritional value and functionality of soy protein are greatly decreased by excessive heat treatment (Wolf, 1975; Borhan and Snyder 1979; Savage et al., 1995). Other methods may be too costly for industrial production, and none of these methods totally remove the undesirable flavors in soy. Until 1980s and early 1990s, researchers have shifted their attention from processing method to genetic alternation of soybean to produce one isozyme null (L-1 or L-2 or L-3 null), double-null (L-1, L-3; L-2, L-3; L-1, L-2), and triple-null soybean (Davies et al., 1987; Hildebrand et al., 1990; Wilson, 1996). Davies et al. (1987) concluded that the removal of L-2 isozyme produced soymilk with less beany, rancid and oily flavors and aromas. Similarly, less beany flavor and hexanal production were also found by Lee (1995) in soymilk made from the L-2 null soybeans. Wilson (1996) studied the sensory attributes of tofu made from L-2 null varieties and also found less beany flavor in these treatments.

The applications of triple-null soybean, soy flour and soy proteins in traditional soy foods and other food products are still in the early stage. Although the removal of lipoxygenase may eliminate the beany flavor, the usage is uncertain due to the blandness in flavor. Wilson (1996) stated that blandness may be undesirable to traditional soy food consumers (soymilk and tofu) in other countries. In addition, astringency may become more noticeable in a bland soy product.

Flatulence

Soybean carbohydrates are made up by sugar, dextrins, pentosan, galactans and cellulose (Pyler, 1988). Starch, if present, will be less than 1% (Wilson et al., 1978). The amount of individual sugar and polysaccharide components in defatted soy flour are listed as follows (Pyler, 1988):

Sucrose	7-8%
Stachyose	5.6-6.6%
Raffinose	1.4-2.0%
Pentosans	5.6-6.6%
Galactans	4.3-6.0%
Total carbohydrates	~26.6%

Oligosaccharides, mainly stachyose and raffinose, are known to be responsible for the cause of flatulence. This occurs when the microbial floral in the lower intestinal tract of humans ferment these sugars and produce gas that causes the abdominal discomfort. Humans do not have α-galactosidase in the digestive tract, hence are incapable of digesting the oligosaccharides (Rackis et al., 1970; Thananunkul et al., 1976; Mudgett and Mahoney 1985).

Gas is produced by anaerobic bacteria when stachyose and raffinose are broken down to monosaccharides. Continuous gas production occurs during fermentation of monosaccharides (Rackis et al., 1970). The gas production is positively correlated to the amount of oligosaccharides ingested, hence the more soy is consumed the more gas is produced. The sequence of sugars in the oligosaccharides is as shown in Figure 1.

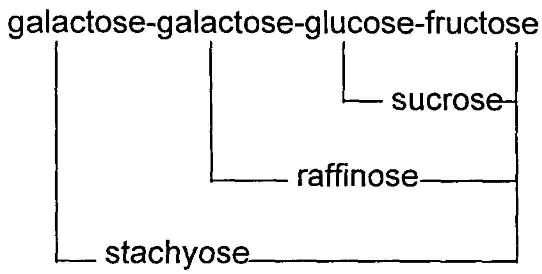

Figure 1. The sequence of sugars in soy oligosaccharides (Rackis et al., 1970).

Researchers have tried to eliminate the problem by adding α-galactosidase from bacteria, yeast and fungi (Cruz and Park, 1973; Thananunkul et al., 1976; Mudgett and Mahoney, 1985; Mulimani and Ramalingam, 1995) into soymilk for enzymatic hydrolysis of stachyose and raffinose. Most recently, the low-stachyose soybean has been produced by genetic modification by DuPont and was used in this study.

Trypsin inhibitor

The amino acid patterns, amino acid availabilities (digestability) and the contents of biologically active compounds determine the nutritional qualities of soy proteins (Del Valle, 1981). Trypsin inhibitors (protease inhibitors) in soybeans lower the nutritional value of soy proteins by complexing with trypsin and chymotrypsin, thus effectively impairing the digestability of soy proteins (Del Valle, 1981; Liener, 1981). Inhibition of trypsin activity can lead to pancreatic hypertrophy (enlargement of pancreas) due to an increase in secretory activity of the pancreas in response to low trypsin level (Liener, 1981). Pancreatic hypertrophy draws sulfur-containing amino acids from the body in order to produce more trypsin and chymotrypsin, thus causes growth depression in young animals (Liener, 1981; Snyder and Kwon, 1987). The pancreatic secretion of trypsin is regulated by a feedback mechanism (Figure 2).

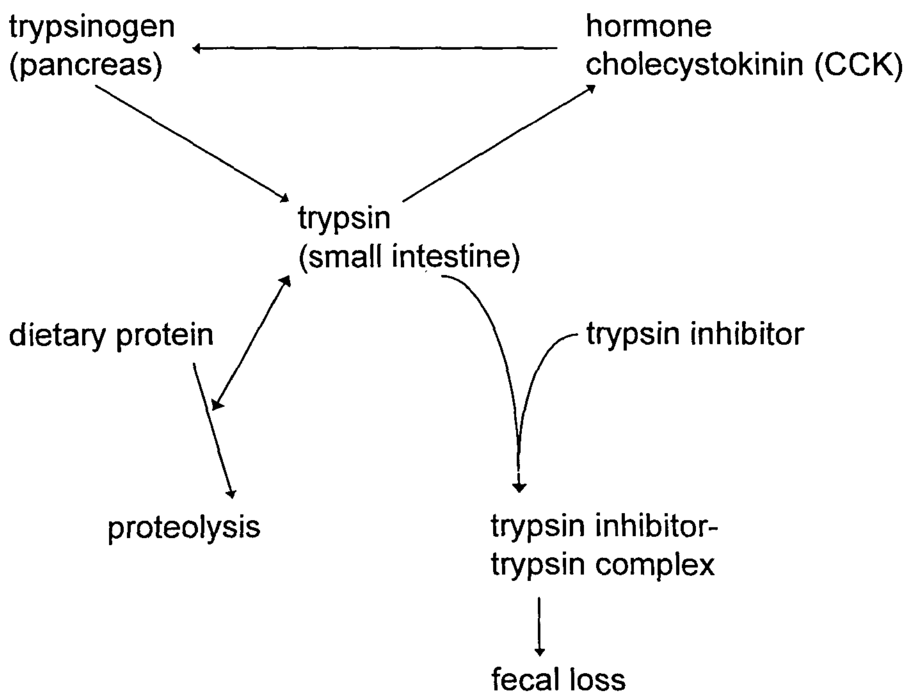

Figure 2. Regulation of the secretion of trypsin by the pancreas, CCK and trypsin inhibitor (Liener, 1981; Snyder and Kwon, 1987).

Although trypsin inhibitor (TI) activity can cause hypertrophy of the pancreas in many young animals, this symptom is less likely to happen in adult humans as human trypsin is weakly inhibited by the inhibitor (Liener, 1981). Nonetheless, concerns arise when infants are fed with soy-based formula as the effects of TI were observed in young animal studies. Despite the inhibitory effect of TI, lately Kennedy (1994) found anticarcinogenic properties in Bowman-Birk trypsin inhibitor derived from the extract of soybeans.

Adequate destruction (>80%) of TI could be achieved by a moist heat treatment at 100°C for 10 minutes while preserving the nutritional quality (PDI ~ 3.0) of the soybean protein diet (Rackis, 1974). Figure 3 shows the effect of moist heat treatment on TI activity and protein efficiency ratio of soybean meal.

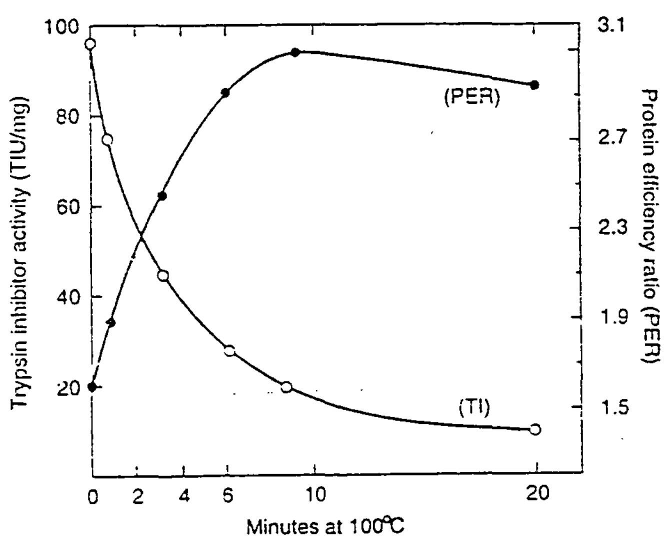

Figure 3. The effect of moist heat treatment on trypsin inhibitory activity and protein efficiency ratio of soybean protein (Rackis, 1974).

Another study found that no pancreatic hypertrophy occurred when rats were fed with soy flour in which only 55-69% of TI activity had been destroyed (Rackis and McGhee, 1975). Optimum conditions were observed when the rats were fed soy flour with 79-87% of the TI inactivated.

Most recently, Bai (1997) studied the trypsin inhibitor activity in soymilk (using XLRB soy flakes from Mycal Corporation of America, Jefferson, IA) prepared from an electric jacketed kettle and a commercial automatic soymilk machine. Only 15.51% and 13.47% trypsin inhibitor residues (percent of origin) were found in the two systems after heating at 95°C for 7 minutes. In another study, soymilk obtained from the same commercial automatic soymilk machine at the same processing parameters with Vinton 81 soybeans, was used to prepare a soymilk-based diet for an animal study. The protein efficiency ratio (PER) of the diet was found to be 2.39, which was the same as the casein diet (Lihono and Serfass, 1996). No pancreatic hypertrophy was found in the study, which indicated that the heat treatment adequately destroyed the trypsin inhibitors (>80%) while retaining the protein quality of the soymilk. The same processing system was used in this research.

Soymilk and Tofu

The cultivation of soybeans was first recorded in 2838 B.C. in China. From China, soybean cultivation was spread into other Asian countries (The Soybean Fact Book, 1993). Soymilk and tofu are popular traditional soy foods to many people in China, Japan, Korea, Hong Kong, Malaysia and Indonesia. These foods have been part of the diet in these countries for many thousand years and they are relatively inexpensive.

Soymilk preparation

There are many ways to prepare soymilk and tofu, in the home or on a industrial scale. Cultural differences, flavor preferences and cost of production are some of the factors that lead to variation in processing methods. For instance, Chinese-style homemade soymilk is usually thinner than the Japanese-style homemade soymilk, and has 10% lower yield of nutrients due to different preparation methods (Shurtleff and Aoyagi, 1983). Chinese prepare soymilk by filtering the bean-water puree (slurry) before cooking; while Japanese filter the bean-water puree after cooking. It is believed by the authors that unheated puree does not pass as easily through the pressing sack, thus lowers the nutrient retention in the Chinese-style soymilk.

Despite the differences, soybeans are the common starting materials in traditional soymilk and tofu manufacture. In the traditional Chinese method, soybeans are soaked in water overnight, ground with water, filtered and boiled for 10 minutes to make soymilk, then coagulated and pressed to make tofu (Liu et al., 1995). The Japanese method is similar except for the heating prior to filtration (Wilson, 1995). As indicated by Wilson (1995), utilization of MicroSoy® flakes (Mycal Corporation of America, Jefferson, IA) in soymilk and tofu production is another alternative in recent years. The preparations of refrigerated and shelf-stable soymilk (Japanese-style) using soybeans or soy flakes are shown in Figure 4.

Soymilk can also be prepared from powdered soymilk and soy flour at home, for convenience, but the costs are higher than the whole soybeans (Shurtleff and Aoyagi, 1983). Even though the powdered soymilk may not taste as good as the soymilk made from the whole soybeans, the preparation time is much less without the need to soak and grind the beans and filter the slurry.

Utilization of soy flour in commercial soymilk production is not as common. Johnson et al. (1981) made soymilk from soy flours using the "Steam-Infusion

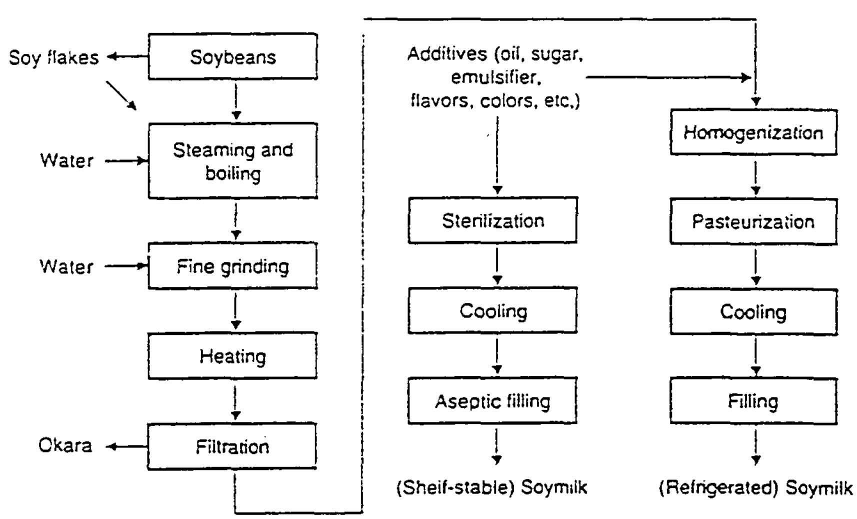

Figure 4. Steps in refrigerated and shelf-stable soymilk production (Wilson, 1995).

Cooking" method and recovered 86% of the solids and 89% of the protein as soymilk when the soy flour slurry was heated at 154°C for 40 seconds (pH = 6.7) in the steam-infusion cooker. The trypsin inhibitors were adequately destroyed (less than 8% residue) during the process. No sensory test was conducted for the soymilk made in this study. The high yields were believed to be due to optimum heat treatment and extreme shearing process during the steam-infusion cooking which created a more stable emulsion.

Lee (1995) found that soymilk made from the "Steam-Infusion Cooking" method (or "Rapid Hydration Hydrothermal Cooking" method) had significantly less "raw bean flavor" but was less "smooth" than soymilk made from the conventional method. Since the beans were not soaked and the water contact time was short during the process, less volatiles were developed with less lipoxygenase activity. Failure in the filtration step after the process accounted for the gritty attribute.

Tofu preparation

Tofu is prepared by coagulating soymilk, molding, pressing, cutting and chilling the curds in water (Wilson, 1995). Factors that affect the coagulation process are: (1) type and concentration of coagulants, (2) coagulation temperature, and (3) the method of mixing the coagulant with soymilk (Liu et al., 1995). All these factors plus the percent solids in soymilk are critical factors as they influence the texture and yield of the tofu (Wilson, 1995). The five most commonly used coagulants are magnesium chloride, magnesium sulfate, calcium chloride, calcium sulfate and glucono-δ -lactone (Liu et al., 1995). The use of calcium sulfate (calcium sulfate dihydrate, $CaSO_4 \bullet 2H_2O$) and glucono-δ-lactone are becoming popular as both are GRAS (generally recognized as safe) (Wilson, 1995) and the calcium based coagulants provide dietary calcium.

Although soybeans are commonly used in tofu production, soy flakes (Mycal Corporation of America, Jefferson, IA), which were introduced recently, can be used as well (Wilson, 1995). Without the need of soaking and grinding, use of soy flakes significantly reduces time for production. As reported by Wilson (1995), there is a 20 to 40% savings in cost when flakes are used in soymilk and tofu manufacture.

Depending on the type of tofu desired, firm tofu can be made by coagulating 5-8% solids soymilk at 90-95°C (194-203°F), with vigorous mixing during the coagulation step. A softer tofu can be produced by coagulating 10-13% solids soymilk at 70-80°C (158-176°F), with a minimum of stirring ("only enough to thoroughly disperse the coagulant in the soymilk") (Wilson, 1995).

Composition and nutrient content

Soymilk is rich in protein (~3.0%, except for the amino acid, methionine) and is generally low in fat (<2.0%). Tofu contains 105-205mg/100g (Soya Bluebook Plus, 1995) of calcium mainly contributed by the added coagulant, calcium sulfate. The composition and nutrient content of soymilk and tofu are given in Table 3.

Soy Flour

Applications

Use of soy flour in the baking industry began in 1926, when it was first manufactured in the United States (Tremple and Meador, 1958). It is used in many foods beside bakery products such as infant formulas, milk replacers, meat balls, meat patties, soups, sauces, candies, confections, desserts, dietary items and pet foods. In Japan, soy flour is also used to prepare homemade soymilk (Shurtleff and Aoyagi, 1983).

The high protein content and relatively low price of soy flour, make it very attractive to many developing countries, such as India, for fortifying purposes in bread and cereal products (Gupta et al., 1977; Gandhi et al., 1985).

Functional properties

The wide applications of soy flour in the food industry are attributed to its numerous functional properties (Table 4).

Emulsification

Soy protein has two important characteristics that are responsible for its emulsifying properties. It has a hydrophobic and a hydrophilic region that associate with oil and water, respectively, in an oil-water emulsion. The emulsion capacity depends on the solubility of soy protein. Therefore, the more soluble the protein in the aqueous phase when emulsion is formed, the more stable the

Table 3. Composition and nutrient content for 100g edible portions.

Soyfood	Water g	Kcal	Protein (nx5.71) g	Fat g	Carbo-hydates g	Crude fiber g	Calcium mg	Iron mg	Zinc mg	Thiamin mg	Ribo-flavin mg	Niacin mg	Vit. B6 mg	Folacin mcg
Soymilk	93.3	33	2.8	1.9	1.8	1.1	4	0.58	0.23	0.16	0.07	0.15	0.04	1.5
Tofu, raw, firm	69.8	145	15.8	8.7	4.3	0.2	205	10.47	1.57	0.16	0.10	0.38	0.09	29.3
Tofu, raw, regular	84.6	76	8.1	4.8	1.9	0.1	105	5.36	0.80	0.08	0.05	0.20	0.05	15.0

adapted from Soya Bluebook Plus, 1995.

Table 4. The functional properties of soy flours.

Functional Property	Food Product
Emulsification	
Formation	frankfurters, bologna, sausages, breads, cakes, soups, whipped toppings, frozen desserts
Stabilization	frankfurters, bologna, sausages
Fat absorption	
Prevention	doughnuts, pancakes
Promotion	frankfurters, bologna, sausages, meat patties
Water absorption	
Promotion	breads, cakes, macaroni, confections
Retention	breads, cakes
Dough formation	baked goods
Cohesion	baked goods, macaroni
Color control	
Bleaching	breads
Browning	breads, pancakes, waffles
Aeration	confections, chiffon mixes, whipped toppings
Texturization	
Viscosity	sauces, gravies, chili
Formation	simulated meats

adapted from Smith and Circle, 1972.

emulsion (Snyder and Kwon, 1987).

Fat absorption

Prevention

Addition of soy flour in doughnuts and pancakes prevents excessive fat absorption. It is believed that the denaturation of protein during the frying process forms a protective surface barrier limiting the penetration of frying oil (Wolf and Cowan, 1975; Sipos, 1988). This explains the reason that high NSI (nitrogen solubility index) soy flour is more effective in preventing fat absorption than low NSI soy flour in which the protein is already denatured during manufacturing process (Wolf and Cowan, 1975).

Promotion

In meat products, soy proteins promote absorption and retention of fat. The reported absorption capacity of textured soy flours is 65 - 130 percent of their dry weight in oil. However, the mechanism of fat binding by soy protein is not yet completely understood. The fat-binding property of soy protein is due to the formation and stabilization of the emulsion and the formation of a gel matrix which prevents fat from migrating to the surface (Wolf and Cowan, 1975).

Water absorption and retention

The hydrophilic region of soy protein associates with water readily. Therefore, when soy proteins are present in foods, they absorb and retain moisture which promotes tenderness and prolongs product shelf life. This water absorption characteristic is very important in baked products as it also increases dough yield and improves dough handling. In meat products, the water absorption and retention properties give a chewy meat-like texture upon hydration and minimize shrinkage during cooking (Wolf and Cowan, 1975).

Dough formation

Lipoxygenase in soy flour increases mixing tolerance (resistance towards overmixing and subsequent breakdown after reaching peak development) and improves the rhelogical properties of dough (Faubion and Hoseney, 1981). The oxidative effect of lipoxygenase on the sulfhydryl groups of protein improves the gluten development in dough (Frazier et al., 1973; Faubion and Hoseney, 1981).

Cohesion and elasticity

Soy protein added to macaroni in the form of treated soy flour limits the uptake of water and retains the cohesiveness and elasticity. In frankfurters and bologna, soy protein gives cohesive and adhesive properties (Wolf and Cowan, 1975). In the cohesion-adhesion process, soy protein acts as an adhesive material while elasticity is created by disulfide links in deformable gels (Kinsella, 1979).

Color control

Under the Standards of Identity for Bread Products, soy flour can be used up to 3% on a flour weight basis in breadmaking while enzyme-active soy flour is permitted at a level of 0.5% flour weight basis (Pyler, 1988). Lipoxygenase in soy flour is responsible for bleaching carotenoids in bread hence makes whiter crumb color (Dubois and Hoover, 1981; Pyler, 1988). Use of low-lipoxygenase soy flour can improve crust color (darker brown) due to the Maillard reaction between lysine and reducing sugars (Sipos, 1988).

Aeration

Soy proteins can form films to entrap gas in an air-liquid interphase. This property allows soy proteins to be used in confections, whipped toppings, icings, frozen desserts and various types of cakes (Kinsella, 1979).

Texturization

Upon addition of water, textured soy proteins form a meat-like texture hence enhancing their applications in meat products. Use of soy proteins improves texture, retains moisture and reduces the production cost (Sipos, 1988).

Types

The common types of soy flours available in the market are in the forms of enzyme-active, full-fat, low-fat, defatted and refatted or lecithinated soy flours (Soy Protein Council, 1987; Lusas and Rhee, 1995). Each type has its specific applications based on its functionality. The uses for each type are summarized in Table 5.

Among all these applications, defatted toasted soy flour is the most common one being used in the food industry. With various protein dispersibility index

Table 5. Types of soy flours and uses.

Type	Characteristics	Uses
Enzyme-active	(1) full-fat: protein: 42 ± 1% fat: 21 ± 0.5% (2) defatted: protein: 52 - 54% fat: 0.5 - 1%	increasing mixing tolerance and bleaching in bread
Full-fat	protein: 41% fat: 20.5% PDI: 20-35	being used in cakes, cake doughnuts and sweet goods
High-fat	protein:46% fat: 14.5%	being used in cakes, cake doughnuts and sweet goods
Low-fat	protein: 52.5% fat: 4%	being used in cakes, cake doughnuts and sweet goods
Defatted	protein: 53% fat: 0.6% PDI: 10-90	being used in a wide range of foods depends on the protein solubility as indicated by PDI (Table 3)
Refatted or lecithinated	protein: 51% added fat: 1- 15% added lecithin: 3-15%	increasing dispersibility in confection and cold beverage products

adapted from Wantanabe and Kishi, 1984; Soy Protein Council, 1987; Pyler, 1988; Lusas and Rhee, 1995.

(PDI) levels available based on the degree of heat treatment, defatted soy flour are widely used in several products (Table 6).

Manufacture

The manufacture of soy flour is very often a proprietary process. An overview of the production of enzyme-active, full-fat, low fat and defatted soy flour are shown in Figure 5.

Table 6. Applications of defatted soy flours in foods.

PDI	Application
90+	bleaching agent in white bread fermentation
60-75	fat and water absorption and control; doughnut mixes, bakery mixes, pastas, baby foods, meat products, cereals
30-45	fat and water absorption and control, nutrition, emulsification; meat products, bakery mixes
10-25	baby foods, protein beverages, comminuted meat products, soups, sauces, gravies, hydrolyzed vegetable proteins

adapted from Lusas and Rhee, 1995.

Full-fat soy flours are commonly made by an extrusion process and Mustakas et al. (1970) are the pioneers in this area (Mustakas et al., 1970; Wolf, 1975; Lusas and Rhee, 1995). The extrusion process of Mastakas et al. (1970) was outlined by Wolf in 1975 where whole soybeans were cracked, dehulled, preconditioned with dry-heat, tempered with water in an extruder-cooker, dried, cooled, then milled to produce full-fat soy flour.

The interrupted 'cut' flight extruder is one of the extruders used in this production (Figure 6). The making of extruded full-fat soy flour is shown in Figure 7.

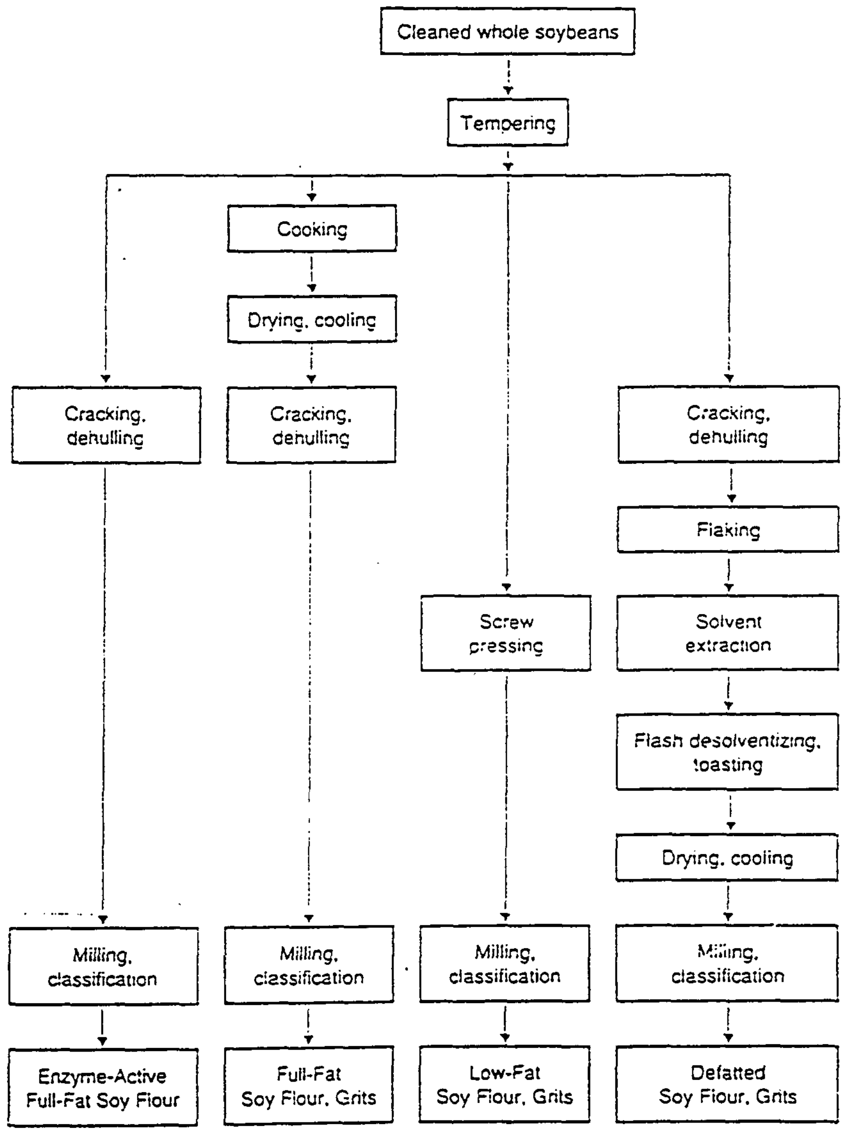

Figure 5. Flow diagram for manufacture of enzyme-active, full-fat, low-fat and defatted soy flours (Lusas and Rhee, 1995, p.130).

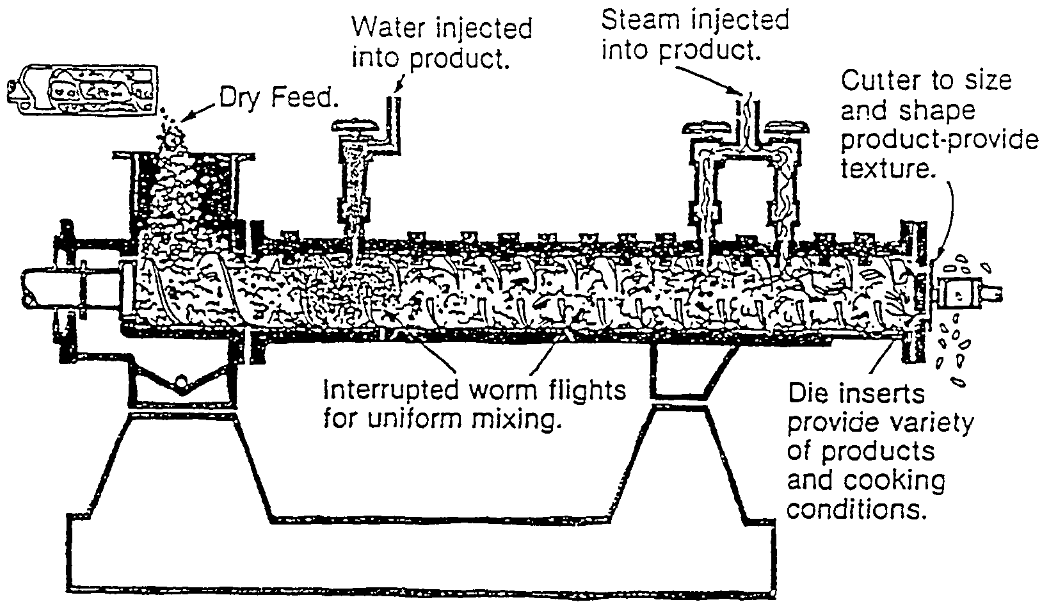

Figure 6. Cross-section of interrupted-flight extruder used for production of toasted full-fat soy flour (Lusas and Rhee, 1995, p.125).

Composition and nutritional quality

The proximate composition and nutrient content of selected soy flours are given in Table 7 (Soya Bluebook Plus, 1995). The composition, nutritional quality and functional property of soy flour are highly dependent on the variety, the manufacturing process such as dehulling, heat treatment, oil extraction, and the storage conditions particularly the temperature and relative humidity. Kinsella (1979) pointed out that the protein solubility and water absorption properties of soy flours are affected by their extent of heat treatment. The longer and more intense the heat treatment, the lower the solubility of protein. However, using the degree of solubility such as PDI and NSI (nitrogen solubility index) solely as an indicator for functionality may be misleading since solubility is pH dependent (Kinsella, 1979).

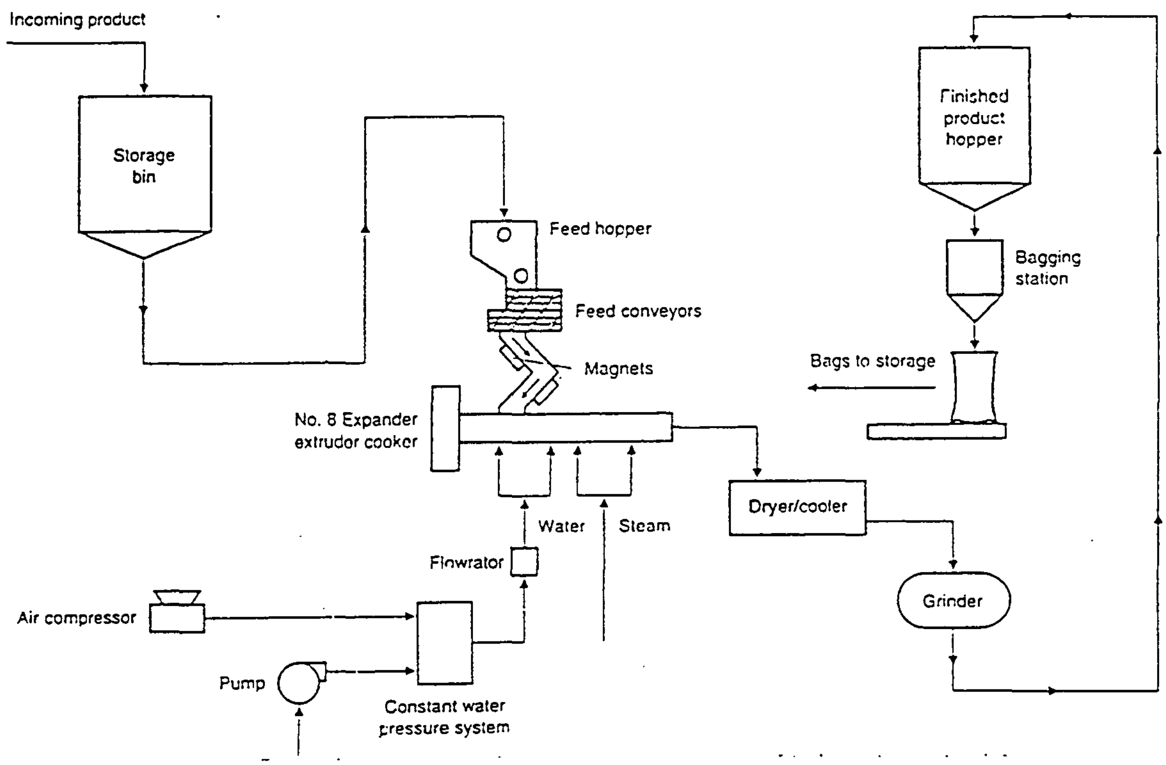

Figure 7. Flow diagram for making extrusion-cooked full-fat soy flour (Lusas and Rhee, 1995, p.126).

To preserve the functionality and nutritional value of soy flours, many investigators, included Jansen et al. (1978) and Ferrier and Lopez (1979), used high temperature short time procedure in making soy flour. The full-fat soy flour prepared by Ferrier and Lopez (1979), had PDI's of 55 and 42 when the

Table 7. The proximate composition and nutrient content in selected soy flours in 100g edible portions.

Type	Water g	Kcal	Protein (Nx5.71) g	Fat g	Total CHO[a] g	Crude fiber g	Ash g	Ca mg	P mg	Fe mg	Na mg	K mg	Vit.A IU	Zn mg	Thiamin mg	Ribo-flavin mg	Niacin mg	Vit.B6 mg	Folacin mcg
Full-fat raw	5.16	436	34.54	20.56	35.20	4.72	4.46	206	494	6.37	13	2,515	120	3.9	0.58	1.16	4.32	0.46	345.00
Full-fat roasted	3.81	441	34.80	21.86	33.67	2.23	5.86	188	476	5.82	13	2,041	110	3.6	0.41	0.94	3.29	0.35	227.40
Low-fat	2.70	326	46.53	6.70	37.98	4.23	6.09	188	593	5.99	18	2,570	40	1.2	0.38	0.29	2.16	0.52	410.00
Defatted	7.25	329	47.01	1.22	38.37	4.27	6.15	241	674	9.24	20	2,384	40	2.5	0.70	0.25	2.61	0.57	305.40

[a] CHO = carbohydrates. Adapted from Soya Bluebook Plus, 1995.

soybeans were heated at 99° and 110°C with 82% destruction of trypsin inhibitor activity. The selected soy flours were blended in water for flavor evaluation. There was no significant difference in flavor and off-flavor when compared to commercial soy flour. The samples were also added on a 12% flour weight basis in bread to test the functional properties. The external and internal appearance, flavor and texture were not significantly different between the soy-wheat blend bread and the 100% wheat bread. The relationships between heat processing and nutritional quality are shown in Table 8.

Storage stability

The extractability of proteins (solubility) decreases during storage of flour (Kinsella, 1979). Chiba et al., (1981) in Japan studied the effects of storage

Table 8. Processing and Nutritional Parameters of Heat-Treated Soy Flours.

Heat[a] min	NSI[b]	TI TIU/mg[c]	PER[d]	Pancrease wt 9/100g body wt
0	97.2	96.9	1.13	0.68
1	78.2	74.9	1.35	0.58
3	69.6	45.0	1.75	0.51
6	56.5	28.0	2.07	0.52
9	51.3	20.5	2.19	0.48
20	37.9	10.1	2.08	0.49
30	28.2	8.0		

Lusas and Rhee, 1995.
[a] Live steam at 100°C.
[b] NSI = nitrogen solubility index
[c] TI = trypsin inhibitor; TIU = trypsin inhibitor units.
[d] PER = protein efficiency ratio corrected on a basis of PER = 2.5 for casein.

temperature and relative humidity (RH) on the quality of soybeans and defatted soy flour stored for five months. They found that storage under 37°C and 65% RH, and 37°C and 85% RH significantly lowered the protein extractability, increased the aldehyde content and enhanced the browning of both beans and flour. No changes were found after storage at 37°C and 35%RH, and at 5°C and 65%RH. This indicates that one of the parameters has to be low when the other is high. Both materials were kept "air tight" and under "dark" condition but no information about the packaging material was reported.

The storage stability of full-fat soy flour and a blend with wheat flour (80% wheat and 20% soy flour) has been studied in India (Gupta, 1977; Gandhi, 1985). The moisture content of full-fat soy flour kept in polyethylene bags (700 gauge) and metallic tins remained unchanged (8%) after a 10-month period (April, 1981 to January, 1982) under ambient conditions (exact temperature and RH were not stated) where the RH was 80%-90% in four months. No insect infestation was observed (Gandhi, 1985).

When soy flour was blended with wheat flour, the moisture and free fatty acid contents increased after four months of storage but these values were lower than the values in wheat flour alone (Gupta et al., 1977). There was no significant difference in moisture and free fatty acids contents in soy flour after four months of storage. They concluded that blending of soy flour with wheat flour enhanced the keeping quality during storage.

A 8-month storage study of soybeans conducted by Thomas et al. (1989) showed that the amount of protein extracted from soybeans into soymilk decreased by 14% overtime at all four storage conditions (20°C - 85%RH, 30°C - 85%RH, 20°C - 65%RH and 30°C - 65%RH). Narayan et al. (1988) studied the changes in the quality of soybeans after 1, 2, 3 and 9 years of storage. The moisture, fat, water-soluble nitrogen, nitrogen solubility index, sugars, trypsin inhibitor activity, available lysine, pigment contents and lipoxygenase activity decreased during storage while the non-protein nitrogen, extent of browning, free fatty acid content and peroxide value increased.

Table 9 shows the effect of relative humidity and temperature on the moisture content in whole soybeans (Perkins, 1995). All this information is very important for determining the quality of soybeans for later use.

Soy Flour Application in Doughnut Manufacture

Full-fat and defatted soy flours have been used in doughnut manufacture to control fat absorption during frying, improve crust color, shape and tenderness, and increase moisture content for longer shelf life (Johnson, 1970; Anonymous, 1978; Sipos, 1988). Lecithinated soy flour is used in doughnut formulas for partially replacement of egg yolks. For economical and fortifying reasons, full-fat and defatted soy flours have also been used as a substitute for nonfat dry milk solids in several bakery items. Most commercial doughnut mixes have soy flour added for functional purposes. This includes mixes from the Iowa

Table 9. Effect of relative humidity and air temperature on the percent moisture in whole soybeans.

Relative humidity of air (%)	0°C 32°F	5°C 41°F	10°C 50°F	15°C 59°F
40	9.0	8.5	8.0	7.5
50	10.5	10.0	9.5	9.0
60	12.0	11.5	10.5	10.0
70	14.0	13.0	12.0	11.5
80	16.0	15.0	14.5	13.5

Perkins, 1995.

Donut Supply (Urbandale, IA) and Dawn Food Products, Inc. (Jackson, MI).

Protein solubility

The solubility of soy flour, a way of assessing the degree of heat treatment, is commonly expressed as percent nitrogen solubility index (NSI) or percent protein dispersibility index (PDI). The formulas are (Wolf and Cowan, 1975):

1. NSI = (%WSN x 100) / %total nitrogen in sample;

where WSN (water soluble nitrogen) = (ml alkali x N x 0.014 x 100) / wt of sample

2. PDI = (%WDP x 100) / (%total nitrogen in sample x 6.25);

where WDP (water dispersible protein) = (ml alkali x N x 0.014 x 100 x 6.25) / wt of sample

The relationship between NSI and PDI is (Lusas and Rhee, 1995):

PDI = 1.07 (NSI) + 1

Generally, 3 to 10% soy flour addition based on flour weight basis was recommended for doughnut mixes. Higher addition is limited due to soy flavors which are unacceptable to many consumers. This occurs when high NSI soy flour (80%) is used (Johnson, 1970). Although higher NSI soy flour is more efficient in reducing fat absorption during frying, only soy flour with NSI in the range of 50-65% is recommended for use in doughnut manufacture for improved functionality while preserving the flavor of doughnuts.

Reduction in fat absorption

An earlier study found that doughnut mixes with 4% (flour weight basis) replacement of 60- and 80-NSI soy flour had lesser fat absorption than the wheat mix (Table 10; Wolf and Cowan, 1975).

As mentioned earlier, the control of fat absorption by soy protein is believed due to the formation of protective coat by denaturation of protein during frying (Wolf and Cowan, 1975).

Table 10. Control of fat absorption in doughnuts with soy flour.

Mixes	NSI of soy flour	Fat absorption g fat/100g dry mix
Wheat flour mix	--	27.6
Wheat + 4% soy flour	60	22.8
Wheat + 4% soy flour	80	11.1

Wolf and Cowan, 1975.

Martin and Davies (1986) also studied the effect of soy flour on fat absorption by cake doughnuts. They concluded that when the PDI level is 50 or above, the fat absorption is a function of the amount of soy protein being added. At high PDI levels, there was little or no difference in fat absorption between PDI-soluble and PDI-insoluble protein (PDI of 80, 69 and 30 were tested at 2, 6 and 10% replacement of doughnut mix). Only at a PDI of 30, the insoluble soy protein loses the functionality in reducing fat absorption.

Cake doughnuts fortified with 65- and 22-NSI defatted soy flours at 18, 22 and 26% protein levels were prepared for sensory and analytical evaluation by Lawhon et al. (1975). Similarly, they found lower fat absorption in high NSI soy flour-fortified doughnuts. The high NSI soy doughnuts also retained more moisture than the low NSI soy doughnuts. When compared to doughnuts fortified with other oilseed flours (glandness cottonseed, deglanded cottonseed and peanut flours), soy doughnuts contained more moisture and absorbed less fat than the others. Greater moisture is due to greater water absorption by soy flour. All fortified doughnuts received significantly lower scores for acceptability, flavor and texture than the control (containing wheat flour only). This is not surprising as the subsitution levels are way too high! For the soy doughnuts, the substitution levels were 14.8, 24.3 and 33.8% (flour weight basis) for 18, 22 and 26% total protein levels.

Another study showed that cake doughnuts with 3% added commercial defatted soy flour scored favorably in sensory attributes when compared with the control (containing wheat flour only) (McWatters, 1982).

Doughnut

There are two types of commercial doughnuts: cake doughnuts, leavened by baking powder through chemical reaction that produces carbon dioxide for dough rising, and yeast-raised doughnuts, leavened by yeast enzymes through fermentation of sugar that produces carbon dioxide and ethyl alcohol (Lawhon et al., 1975). However, for this research, only cake doughnuts were made for physical, chemical and sensory evaluations.

Doughnut mixes

Ingredients and their functional properties in commercial doughnut mixes are listed in Table 11 (Murphy-Hanson, 1992).

Production and control

The production of cake doughnuts is a controlled process. Besides consistency and uniformity of mixes, there are several critical control points which are important for assuring the quality of doughnut (Table 12).

The batter temperature can be affected by the temperatures of the mix, room, water and friction. The water temperature is calculated as:

Water temperature = (3 x desired batter temperature) - (room temperature + mix temperature + friction*)

*friction = 5°F, (Dixon, 1983)

Table 11. Ingredients and their functional uses in cake doughnut.

Ingredient	Amount	Use
Flour	55-65% (mix weight basis)	structure and framework of doughnut
Sugar	22-30%	sweetness, tenderness, moisture retention, browning and spread control
Shortening	3-9%	tenderness, shelf life improvement and lubricating protein structure
Dried egg yolks	0.5-3%	richness and tenderness
Non-fat dried milk	3-5%	crust color, shelf life improvement, gas retention, structure binder and builder
Leavening agent	1.75-3%	gas production
Salt	0.75-1.5%	flavor enhancer
Potato starch	2%	water absorption, shelf life improvement, coating and reduction in fat absorption
Soy flour	3%	water binding, fat absorption control, gas retention, color and volume control
Lecithin	0.5%	fat absorption and batter flow control and symmetry
Cottonseed flour	0.15-0.3%	crumb color
Emulsifier		shelf life and eating qualities improvement

adapted from Murphy-Hanson, 1992.

Table 12. The critical control points for doughnut manufacturing.

Factor	Recommendation
Batter temperature	76-78°F (24.4-25.6°C)
Mixing sequence	consistent mixing order and timing
Floor time (rest time)	10-15 minutes
Cutters	proper setting
Frying temperature	370-375°F (187.8-190.6°C)
Frying time	60-90 seconds
Fat level	adequate amount
Free fatty acids (FFA)	0.3-0.75% FFA

adapted from Dixon, 1983.

If the water temperature is too cold, a low volume and tough doughnut will be obtained. If it is too hot, the doughnut will appear to be flat with increased fat absorption. Consistent mixing order and time are important for uniformity, good texture and proper fat absorption. Before frying, 10-15 minutes rest or floor time is necessary for hydration and initial leavening reaction. Insufficient or lengthy floor time will reduce the volume of the doughnut. Cutters have to be set properly for desired size and weight.

Frying temperature affects the volume, spread, crust color and fat absorption of doughnut. Over heating will give a brittle and dark crust doughnut with excessive fat absorption; while low heating temperature will give a poor shape doughnut with increased fat absorption due to the spread of batter. An underfried doughnut has a low volume, enlarged center hole and a cracked surface that causes excessive fat absorption. If the frying time is too long, the fat absorption will increase and batter will overexpand.

A misshapen and/ or a flat doughnut with rough surface and excessive fat absorption will be obtained if the fat level is too low. However, if the level is too high, doughnuts may float over flight bars and not turn properly (Dixon, 1983).

Hydrogenated vegetable shortenings are less susceptible to oxidative changes, hence are suitable for frying. It is critical to note the turnover rate of the frying fat. Physical indicators for disposal are darkening of color, foaming, smoking, presence of undesirable odor, and the presence of flavor, odor and greasiness in the fried products (Murphy-Hanson, 1992). One way to measure the changes in fat quality is the free fatty acid (FFA) level. The recommended FFA level for doughnut frying is 0.3-0.75%. Excessive smoking occurs when the FFA level is 1.0% (Dixon, 1983).

The moisture content of cake doughnuts is inversely related to the amount of fat absorbed. Extreme undermixing and long frying times tend to increase the fat absorption of doughnuts (Wheeler and Stingley, 1963).

PART I. THE PHYSICAL, CHEMICAL AND SENSORY PROPERTIES OF SOYMILK AND TOFU MADE FROM LOW LIPOXYGENASE AND LOW STACHYOSE-, LOW LIPOXYGENASE- AND REGULAR FULL-FAT SOY FLOURS

INTRODUCTION

Use of soy flour in soymilk and tofu preparation is not as common as the use of soybeans. Higher yield and less waste are expected when soy flour is used since the hull (8% of soybean seeds) has been removed. Johnson et al. (1981) recovered 86% of the solids and 89% of the proteins as soymilk when the soy flour slurry was heated at 154°C for 40 seconds in the steam-infusion cooker.

Despite greater yield, the quality of soymilk and tofu made from soy flour is a concern. Lee (1995) showed that soymilk made from soy flour using a steam-infusion cooker had less "raw bean flavor" but was less "smooth" than soymilk made from the conventional method. The storage stability and cost of soy flour as compared to soybeans, are also important factors that influence the value of soy flour.

The undesirable flavors in soy caused by hexanal and other volatile aldehydes produced by the hydroperoxidation of soybean lipoxygenase in *cis-cis* 1,4-pentadiene-containing fatty acids (linoleic and linolenic acids) are common problems in soy applications. However, recent studies have shown that the undesirable flavors could be improved by genetic modifications. Davies et al. (1987), Lee (1995) and Wilson (1996) found less beany flavor in soymilk or tofu made from L-2 null varieties. "Triple-null" soybeans would be expected to have even less beany flavor, and they are currently being studied in Japan and in the

U.S. (Wilson 1996).

Fermentation of soy stachyose and raffinose by the microbial floral in the lower intestinal tract of humans produces gas that causes abdominal discomfort. Humans do not have α-galactosidase in the digestive tract, hence are incapable of digesting the oligosaccharides (Rackis et al., 1970; Thananunkul et al., 1976; Mudgett and Mahoney 1985). Soybean breeders (e.g., DuPont) have developed new varieties with low stachyose concentration in the seeds.

The objectives of this study were to evaluate the yield, ease of processing, waste produced and the qualities of soymilk and tofu made from several specialty soy flours, and to compare these products to those made from the soybeans, soy chips, soy grits and soy flakes. Low lipoxygenase and low stachyose-, and low lipoxygenase soy flours were also included in order to examine for any added flavor advantages in soymilk and tofu.

MATERIALS AND METHODS

Soy Ingredients

Soymilk

Six types of soy ingredients were used in soymilk preparation:

1. Low lipoxygenase and low stachyose full-fat soy flour (LPLS) (low lipoxygenase isozyme-2; 8-9% sucrose; variety of Optimum Quality Grains, trademark of DuPont).
2. Organic low lipoxygenase full-fat soy flour (LP) (low lipoxygenase isozyme-2; non-variety specific).
3. Regular full-fat soy flour (SF) (Pioneer 9305).
4. Soy chips (CH) (Pioneer 9305; 6-8 pieces per soybean).
5. Soy beans (BN) (Pioneer 9305).
6. MicroSoy® organic flakes (F).

All the soy ingredients were supplied by the Natural Products, Inc., Grinnell, Iowa, except the MicroSoy® flakes, which was obtained from the Mycal Corporation of America, Jefferson, Iowa. The regular full-fat soy flour, soy grits, soy chips, and soybeans were from the same variety. All ingredients were from the 1996 crops.

Tofu

Five types of soy ingredients were used in tofu preparation:

1. Low lipoxygenase and low stachyose full-fat soy flour (LPLS) (low

lipoxygenase isozyme-2; 8-9% sucrose; variety of Optimum Quality Grains, trademark of DuPont).

2. Regular full-fat soy flour (SF) (Pioneer 9305).
3. Soy grits (G) (16-mesh, 1.18 mm; Pioneer 9305).
4. Soy beans (BN) (Pioneer 9305).
5. MicroSoy® organic flakes (F).

Soymilk Preparation

Soy flour

Three and a half kilograms of soy flour were rehydrated with 30 liters of water (10 - 15°C) in three batches using a heavy-duty stirrer (Fisher brand, cat. no. 14-509-1, 1983) to prevent the formation of clumps (about 5 minutes). The soy slurry was allowed to pass through a 0.2- mm cutter head in the Stephan grinder (A. Stephan u. Sohne GmbH & Co., Germany) to make a homogeneous slurry. The soy slurry was agitated in the slurry tank of Takai Automated Soymilk and Tofu System (Takai Tofu and Soymilk Equipment Co., Ishikawa-ken 921, Japan) for 10 minutes, steam-injected into the cooker where it was cooked at 95°C, and held for 7 minutes. Soymilk was extracted by a 120- and a 100-mesh roller extractor and collected in a 80-L stainless steel coagulation tub (Figure 8).

Soy chips

Three and a half kilograms of soy chips were soaked in 10 liters of water three hours prior to grinding. The chips and soaking water were ground in the

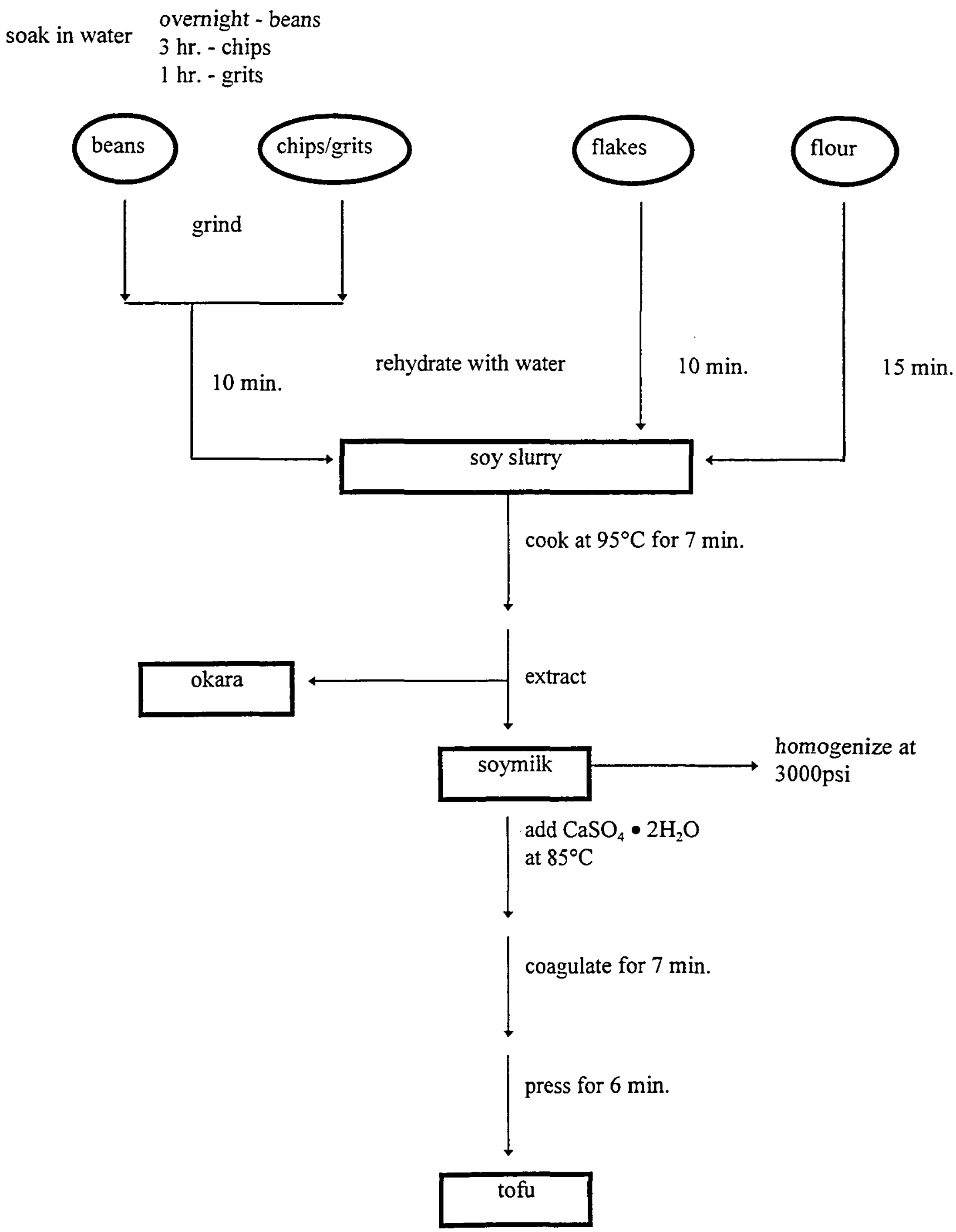

Figure 8. Soymilk and tofu production flow chart.

Stephan grinder with an additional 20 liters of water using a 0.5-mm and then a 0.05-mm cutter head. The soy slurry was poured into the slurry tank of the Takai system and processed in the same way as the soy flour slurry.

Soybeans

Four kilograms of whole beans were washed and soaked in 10 liters of water overnight at room temperature. Soaking water was drained and the weight of beans was determined. The water uptake was calculated by subtracting the initial weight of the unsoaked beans from the weight of the soaked beans. Additional water (30 liters minus the amount of water uptake) was added during grinding to make up a total of 30 liters of water. Beans and water were ground through a 0.5-mm and then a 0.05-mm cutter head, and processed in the Takai system.

Soy flakes

Three and a half kilograms of flakes were rehydrated with 30 liters of water in the Takai slurry tank and agitated for 10 minutes, followed by the same cooking process.

Collected soymilk was homogenized at 3,000 psi using a laboratory homogenizer (Model 15M-8TA, Gaulin Corporation, Everett, MA) and kept at 41°F (5°C) before used. The soymilk yield and waste produced (okara) were calculated. The °Brix or percent soluble solids, color, pH, viscosity and proximate analysis for moisture, fat and protein were determined. Soymilk samples were evaluated by trained panelists on the day after processing. Soymilk was made once a week with a total of three replications in three weeks. Color measurement and proximate analysis were also conducted on the raw ingredients.

Tofu Preparation

Upon extraction, soymilk was coagulated at 85°C with calcium sulfate ($CaSO_4 \cdot 2\ H_2O$) in a 80-L stainless steel coagulation tub for 7 minutes with vigorous mixing during the addition of coagulant. Curd breaking (after 2 minutes) was necessary during coagulation for proper dispersion and release of whey. Depending on the percent solids, calcium sulfate was added at the range of 0.2 to 0.3% of the volume of the soymilk produced.

The curds were air pressed (CKD Co., Japan) from 2 to 4 to 6 kg/cm^2 in a stainless steel press-box (2125 cm^2) for 6 minutes. Tofu was weighed and cooled immediately in water (10 - 15°C) and stored at 5°C (41°F) before use. The tofu yield and waste produced (okara) were calculated. The color, hardness and proximate analysis for moisture, fat and protein were determined. Tofu samples were evaluated by trained panelists on the day after processing. Tofu was made once a week with a total of three replications in three weeks. Color measurement and proximate analysis were also conducted on the raw ingredients.

Processing Data

Yield

The yield of soymilk (sm/raw) and tofu (tofu/raw) were calculated as the amount of soymilk or tofu produced per kg of raw ingredient used:

sm/raw = total soymilk produced (L) / total raw ingredient used (kg)

E.g. 32.87L/ 3.5kg = 9.39 L/kg

tofu/raw = total tofu produced (kg) / total raw ingredient used (kg)

E.g. 10.41kg/ 3.5kg = 2.97 kg/kg

Waste/ Okara

The waste or okara produced was calculated as the amount of okara produced per kg of raw ingredients used:

oka/raw = total okara produced (kg) / total raw ingredient used (kg)

E.g. 1.2kg/ 3.5kg = 0.34

Percent solids recovery (%SR)

The percent solids recovery is determined as the total solids recovered in soymilk or tofu from the total solids in raw ingredient x 100%:

$\%SR = [(\text{product}^{a} \times \%S^{b}) / (\text{raw ingredient (kg)} \times \%S_{raw})] \times 100\%$

[a] soymilk (L) or tofu (kg);

[b] %S of soymilk or tofu.

Percent protein recovery (%PR) in dry basis

The percent protein recovery is determined as the total proteins recovered in soymilk or tofu from the total proteins in raw ingredient x 100%:

$$\%PR = [(product^{a} \times \%S^{b} \times \%P^{c}) / (raw\ ingredient\ (kg) \times \%S_{raw} \times \%P_{raw\ in\ dry\ basis})] \times 100\%$$

[a] soymilk (L) or tofu (kg);

[b] %S of soymilk or tofu;

[c] %P of soymilk or tofu in dry basis.

Physical Analyses

Color

The color of soymilk and tofu was measured using a 6100 Hunterlab Labscan Spectro Colorimeter (Hunterlab, VA). The instrument was standardized with a black and a white (X = 78.67, Y = 83.31, Z = 86.40; D65) tile, under white cool fluorescent light, with a 10° observation angle. Soymilk or tofu was filled into a 5.2-cm diameter plastic transparent petri dish (1 mm head space) and placed on the reflectance port under a 1-cm (~ 0.375-inch) aperture to measure the L, a and b values. Three measurements were made for each sample at each replication.

pH

The pH of soymilk was measured using a 340 pH meter (Corning, NY) in a 600-ml beaker with continuous stirring. Two repeated measurements were made for each sample and each replication.

Viscosity

The Brookfield Digital Viscometer model DV-II+, version 2.0 (Brookfield, MA) was used to measure the viscosity of soymilk. The sample was filled into a 600-ml beaker and allowed to just cover the grove of the cylindrical spindle no. 1. The speed was set at 100 rpm and the viscosity was measured at 8°C and 20°C (±0.1°C) separately. Five continuous readings were taken for each sample at each replication. The viscosity was expressed as milliPascal-second (mPas) (1 mPas = 1 cp or centipoise).

°Brix or percent soluble solids

A bench top refractometer (Bausch and Lomb Optical Corp., Rochester, NY) was used to measure the percent soluble solids of soymilk. Approximately 2 drops of soymilk were taken for each reading and two measurements were made for each soymilk at each replication.

Hardness

Tofu was cut into one-half inch cube for hardness determination on a Instron Universal Testing Machine (Model 1122, Instron Corp., Canton, MA) equipped with a 50-kg compression head. The scale, crosshead speed and chart speed were set at 5 kg load, 200 mm/min and 200 mm/min, respectively. Three cubes were measured for each sample at each replication.

Proximate Analyses

Moisture

The AOAC Official Method 945.39 (AOAC, 1995) was used to analyze the percent moisture in all soy ingredients. Beans were ground before drying using a Cyclone Sample Mill (UD Corporation, CO).

Approximately 20 g of soymilk and 8 g of tofu were dried in an aluminum weighing dish at 75°C in an air dry oven until a constant weight (approximately 10-12 hours) was obtained. Three sets were prepared for drying for each sample at each replication.

Fat

Approximately 2 g of dried sample were wrapped in a 15-cm Whatman® no. 1 filter paper, inserted into a thimble and extracted using a Goldfisch extractor (AACC 30-25, 1984) for 4 hours. Three sets were prepared for each sample at each replication. The fat contents were expressed in wet (Fwb) and dry basis (Fdb).

Protein

The percent protein was measured by the Kjeldahl method (AOAC method 955.04, 1995) where the total nitrogen was multiplied by 6.25. Kjeltabs Tct (K_2SO_4 = 94.34%, $CuSO_4 \bullet 5H_2O$ = 2.83%, TiO_2 = 2.83%) (Fisher Scientific, PA) was used as the catalyst for environmental reason. Three sets were prepared for each sample at each replication. Similarly, the protein contents were expressed as a wet weight (Pwb) and a dry weight basis (Pdb).

Carbohydrate and ash

By substracting the percent moisture (%M), fat (%F)and protein (%P) from 100%, the percent carbohydrate and ash (%C + A) on a wet basis can be determined as follow:

$$\% C + A = 100\% - \%M - \%F - \%P$$

Sensory Evaluation

Soymilk

Soymilk was evaluated on the day after processing. Ten panelists were trained in three 1-hour sessions to be familiar with the 15-cm unstructured line scales for yellowness, brownness, nuttiness/ pasta/ cereal flavor, beaniness and astringency of soymilk (Appendix 1). Samples were marked with 3 digit random codes in 3-oz white plastic cups and served at room temperature under white fluorescent light in individual sensory booths.

To minimize "fatigue" of tasting six samples simultaneously, soymilk was given in two sets randomly for flavor evaluation, where the flake soymilk was given in both sets for data normalization (i.e., four in the first set, and three in the second set). Panelists spent 5 to 10 minutes to evaluate the color of six samples at the same time before tasting the second set. A total of three replications were conducted.

Tofu

One-half inch tofu cubes were steamed for a minute before serving under white fluorescent light in individual sensory booths. Eleven panelists were trained in three 1-hour sessions for yellowness, brownness, surface smoothness, firmness and beaniness of tofu using the 15-cm unstructured line scales (Appendix 2). Five samples were evaluated simultaneously.

Statistical Analysis

All data were subjected to the GLM (General Linear Model) procedure using the SAS package (Statistical Analysis System, release 6.06, 1997). The fixed-effects model was used except for the sensory test, a mixed-effects model was used in which the fixed factor was the type of raw ingredient and the random factor was the panelists (Lyman Ott, 1993; Lawless and Heymann, 1998).

RESULTS AND DISCUSSION

Processing

Soymilk

Among the soy ingredients used, soy flour on average yielded about 30% and 20% more soymilk than soybeans and flakes, respectively. Use of soy flour significantly reduced the waste (okara, i.e., insoluble residues) produced, when compared to the use of flakes, chips and beans (Table 13).

Soybeans contain about 8% hull, 90% cotyledons, and 2% hypocotyl (Perkins, 1995). Removal of the hull during soy flour manufacture explains the reduction in waste when used in soymilk preparation.

It was believed that the grinding process in soy flour production has reduced the size of insoluble polysaccharides (cellulose, hemicellulose and pectins) and proteins in soybeans to very fine sizes, which eventually passed through the 120-mesh roller press of the soymilk machine, and went into the soymilk extract, hence giving more soymilk and less okara. This was supported by the fact that more solids (83.6 – 86.8%) and proteins (84.3 – 86.1% dry basis) were recovered in soymilk made from the soy flours. The similarity in °Brix (soluble solids, i.e., measured as percent sucrose) in all samples (Table 15), despite differences in yields, also supported that higher solids recovery in soymilk made from the soy flours were due to greater insoluble solids retention.

All three soy flours were not significantly different in yield, okara produced,

Table 13. The yield, okara produced, percent solids recovery and percent protein recovery of soymilk[z].

Sample	sm/raw (L/kg)	oka/raw (kg/kg)	%SR	%PR (dry basis)
LPLS	10.46[a] *±0.32*	0.33[b] *±0.08*	86.84[a] *±4.10*	86.11[a] *±4.77*
LP	10.04[a] *±0.18*	0.28[b] *±0.08*	83.58[a] *±3.16*	84.27[a] *±1.79*
SF	10.16[a] *±0.43*	0.38[b] *±0.04*	84.93[a] *±2.50*	85.97[a] *±7.34*
CH	9.11[ab] *±0.21*	0.71[a] *±0.14*	66.78[b] *±0.73*	76.45[b] *±2.00*
BN	7.64[c] *±0.44*	0.77[a] *±0.07*	57.23[c] *±2.85*	67.28[c] *±2.94*
F	8.23[bc] *±1.71*	0.81[a] *±0.06*	62.25[bc] *±5.09*	66.35[c] *±3.97*

[z] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).
LPLS = low lipoxygenase and low stachyose soy flour;
LP = low lipoxygenase soy flour; SF = regular soy flour;
CH = soy chips; BN = soybeans; and F = soyflakes.

solids and protein recoveries, regardless of the variety. However, when comparing the soymilks made from the regular soy flour, chips and beans (same variety), the soy flour soymilk had the greatest yield, solids and protein recoveries and produced the least amount of okara. As the size of the soy ingredient decreased (from soybean to soy flour), the yield, solids and protein recoveries increased.

It is believed that the presence of hull in whole beans helped remove some of the insoluble residues in soymilk during filtration, thus lowering the total solids recovery in soymilk. In addition, more water was bound to the okara of the soybeans, which decreased the yield as well.

Johnson et al. (1981) recovered 86% solids and 90% proteins when making soymilk from the soy flour using the "Steam-Infusion Cooking" method. They believed having optimum heat treatment (154°C, 40 seconds) and extreme shearing during the steam infusion and flashing process might have given more stable emulsion (increased in protein solubility) and hence greater yield.

Tofu

Although the soy flours, especially the LPLS-variety, produced more tofu and less okara (Table 14), the overall quality of the tofu was not as good as those made from the grits, beans, and flakes. The major problem was the tofu texture. The soymilk made from the soy flour did not coagulate as fast nor form a smooth intact tofu curd upon pressing as the other treatments. Although higher calcium sulfate concentration (0.25 - 0.30% of the soymilk volume) was added, and soymilk was allowed to coagulate for longer time, the whey was still milky after 10 minutes of coagulation.

The protein in soy flour could have been physically altered in size and structure that made the proteins incapable of forming 3-dimensional matrixes during the gelation process. More calcium sulfate was added to the soymilk

Table 14. The yield, okara produced, percent solids recovery and percent protein recovery of tofu[z].

sample	tofu/raw (kg/kg)	oka/raw (kg/kg)	%SR	%PR (dry basis)
LPLS	3.20[a] ±0.15	0.23[c] ±0.02	56.87[a] ±1.74	66.92[a] ±1.99
SF	2.85[ab] ±0.32	0.38[b] ±0.05	45.55[b] ±5.66	56.64[b] ±5.94
G	2.54[b] ±0.25	0.79[a] ±0.03	41.94[b] ±1.52	56.61[b] ±3.24
BN	2.36[b] ±0.17	0.79[a] ±0.02	39.77[b] ±4.14	54.38[b] ±3.81
F	2.48[b] ±0.34	0.79[a] ±0.04	41.20[b] ±1.04	55.95[b] ±3.69

[z] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).
LPLS = low lipoxygenase and low stachyose soy flour; SF = regular soy flour; G = soy grits; BN = soybeans; and F = soyflakes.

due to greater protein recovery, however, “chalkiness” was a concern when too much calcium sulfate was added. The presence of insoluble carbohydrate particles could have interfered in the gelation process. Snyder and Kwon (1987) pointed out that the particle size of the suspended solids in the original soymilk is one of the factors that will affect the gel formation. When soymilk powder was used to make tofu, a milky whey was obtained (Shurtleff and Aoyagi, 1983). Therefore, this could be the reason that soy flour is not commonly used in tofu manufacture in many Asian countries. The tofu manufacturers prefer using beans, flakes and grits as they may help in removing the insoluble solids during the filtration process.

Ease of Processing

Use of soy flour eliminated the time for soaking (10 hours or overnight for beans; about 3 hours for chips) and grinding, and produced less okara. However, proper mixing (5 minutes) and hydration (10 minutes) were necessary before cooking the soy flour slurry. In addition, homogenization at higher psi was necessary to prevent sedimentation.

More coagulants and longer time were needed for coagulating soymilk made from the soy flours. The tofu also tended to fall apart when held or cut (not cohesive).

Physical Analyses

Color

Soymilk made from the LP-soy flour was the most yellow. There was no significant difference in the L, a and b values in soymilk made with the regular soy flour, chips and beans as they were from the same variety. The degree of yellowness in soymilk can be predicted from the color (b values) of the soy flours (Table 15) as they are more uniform than the chips, flakes and beans.

The LPLS-soy flour and the flakes produced tofu that was most "yellow" in color (higher b values). Although there were differences in the Hunter L, a and b values among samples, the differences were small mainly due to the variety

Table 15. The Hunter L, a and b values, pH, viscosity and °Brix of soymilk[z].

Sample	L	a	b	pH	Viscosity (mPas) 8°C	Viscosity (mPas) 20°C	°Brix
LPLS	83.86[a]	-1.38[b]	11.99[b]	6.67[ab]	21.01[a]	18.08[a]	7.87[a]
	±0.75	±0.10	±0.16	±0.05	±1.90	±1.73	±0.23
LP	85.11[a]	-1.15[ab]	13.19[a]	6.64[ab]	21.44[a]	18.77[a]	7.97[a]
	±0.11	±0.11	±0.20	±0.01	±1.94	±0.90	±0.21
SF	84.47[a]	-1.22[ab]	9.87[c]	6.68[a]	20.91[a]	18.24[a]	7.83[a]
	±0.44	±0.09	±0.51	±0.03	±1.31	±0.92	±0.72
CH	85.30[a]	-1.24[ab]	9.51[c]	6.69[a]	18.83[b]	16.69[b]	7.87[a]
	±0.93	±0.08	±0.08	±0.01	±0.73	±0.28	±0.35
BN	85.09[a]	-0.99[a]	10.42[c]	6.63[ab]	20.64[a]	18.13[a]	8.30[a]
	±1.32	±0.26	±0.69	±0.06	±0.81	±0.58	±0.30
F	84.09[a]	-1.34[b]	11.97[b]	6.61[b]	21.01[a]	18.03[a]	7.80[a]
	±1.62	±0.28	±1.08	±0.01	±2.29	±1.71	±0.78

[z] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).
LPLS = low lipoxygenase and low stachyose soy flour; LP = low lipoxygenase soy flour;
SF = regular soy flour; CH = soy chips; BN = soybeans; and F = soy flakes.

difference and they did not affect the overall quality of the products (Table 16).

pH, viscosity and °Brix

The pH's of all the soymilks were very similar. The viscosity of soymilk was affected by the temperature. The viscosity at 20°C was significantly lower than the viscosity at 4°C for all samples. Soymilk made from the chips was lower in viscosity than soymilk from the other treatments. There was no significant difference in the °Brix for any of the samples (Table 15).

Table 16. The Hunter L, a, b values, and hardness of tofu[z].

Sample	L	a	b	Hardness (N)
LPLS	85.60[b]	0.40[a]	13.78[a]	46.06[a]
	±0.53	*±0.06*	*±0.30*	*±10.88*
SF	85.43[b]	0.23[b]	12.78[b]	37.04[b]
	±0.91	*±0.24*	*±0.90*	*± 7.74*
G	86.39[a]	0.09[c]	11.70[c]	23.42[c]
	±0.81	*±0.06*	*±0.52*	*± 6.08*
BN	86.00[ab]	0.36[a]	12.56[b]	23.42[c]
	±0.55	*±0.11*	*±1.07*	*± 6.17*
F	86.09[ab]	0.05[c]	13.48[a]	33.12[b]
	±0.58	*±0.05*	*±0.27*	*±13.13*

[z] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).
LPLS = low lipoxygenase and low stachyose soy flour;
SF = regular soy flour; G = soy grits; BN = soybeans; and F = soyflakes.

Hardness

Tofu made from the soy flours and flakes was significantly harder than tofu made from the grits and beans. The LPLS-tofu was the hardest sample (Table 16). Higher calcium sulfate concentration and greater carbohydrate retention (Table 17) could be the reasons. As mentioned by Snyder and Kwon (1987), when the amount of added calcium salt increases, the gel strength also increases. There was no significant difference in hardness between the tofu made from the grits and the tofu made from the beans.

Proximate Analyses

Moisture

The moisture content of soymilk made from the soy flour was significantly lower than the other treatments. The percent solids was 7.65 -7.71% compared to 6.52, 6.90 and 7.19% found in soymilk made from the chips, beans and flakes, respectively (Table 17).

The LPLS-tofu was significantly drier than tofu made from the regular soy flour, grits and beans (16.44% solids after drying). Other tofus were similar in the moisture contents (84.7 - 85.3%) (Table 18).

Fat

Soymilk made from the soy flours, chips and flakes had significantly less fat than soymilk made from the whole beans (1.45%). The lowest fat content (0.54%) was found in the LPLS-soy flour soymilk.

Table 17. The proximate analysis of soymilk^{y}.

sample	%M	%S	%Fdb	%Fwb	%Pdb	%Pwb	%C+Adb^{z}
LPLS	92.35^{c}	7.65^{a}	7.08^{d}	0.54^{c}	44.93^{abc}	3.43^{a}	47.97^{a}
	±0.33	*±0.33*	*±1.53*	*±0.09*	*±3.40*	*±0.17*	*±4.74*
LP	92.30^{c}	7.70^{a}	12.73^{c}	0.98^{b}	43.59^{c}	3.35^{ab}	43.67^{b}
	±0.15	*±0.15*	*±1.86*	*±0.15*	*±2.62*	*±0.16*	*±3.56*
SF	92.29^{c}	7.71^{a}	12.01^{c}	0.92^{b}	40.89^{d}	3.14^{bc}	47.10^{a}
	±0.39	*±0.39*	*±1.58*	*±0.09*	*±2.59*	*±0.12*	*±3.99*
CH	93.48^{a}	6.52^{c}	16.03^{b}	1.04^{b}	45.88^{ab}	2.99^{c}	38.10^{c}
	±0.14	*±0.14*	*±1.67*	*±0.11*	*±1.19*	*±0.11*	*±1.79*
BN	93.10^{ab}	6.90^{bc}	19.48^{a}	1.45^{a}	46.47^{a}	3.21^{abc}	33.93^{d}
	±0.13	*±0.13*	*±3.38*	*±0.38*	*±1.06*	*±0.10*	*±3.40*
F	92.81^{b}	7.19^{b}	12.68^{c}	0.92^{b}	44.21^{bc}	3.18^{bc}	43.11^{b}
	±1.01	*±1.01*	*±1.01*	*±0.18*	*±1.64*	*±0.46*	*±1.41*

^{y} Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).

^{z} %C+Adb = 100%-%Fdb-%Pdb.

%M = percent moisture; %S = percent solids; %Fdb = percent fat in dry basis; %Fwb = percent fat in wet basis; %Pdb = percent protein in dry basis; %Pwb = percent protein in wet basis and %C+Adb = percent carbohydrates and ash in dry basis. LPLS = low lipoxygenase and low stachyose soy flour; LP = low lipoxygenase soy flour; SF = regular soy flour;CH = soy chips; BN = soybeans; and F = soy flakes.

Table 18. The proximate analysis of tofu[y].

sample	%M	%S	%Fdb	%Fwb	%Pdb	%Pwb	%C+Adb[z]
LPLS	83.57[b]	16.44[a]	24.46[b]	3.98[bc]	53.11[ab]	8.68[a]	22.17[a]
	±1.03	*±1.03*	*±1.87*	*±0.47*	*±1.53*	*±0.66*	*±3.15*
SF	85.16[a]	14.84[b]	26.48[b]	3.93[bc]	51.91[b]	7.70[b]	21.62[a]
	±1.44	*±1.44*	*±0.63*	*±0.43*	*±2.18*	*±0.75*	*±2.19*
G	85.27[a]	14.73[b]	29.44[a]	4.37[ab]	55.37[a]	8.13[ab]	15.48[b]
	±1.21	*±1.21*	*±1.40*	*±0.23*	*±2.24*	*±0.41*	*±3.43*
BN	84.84[a]	15.16[b]	31.45[a]	4.76[a]	54.31[a]	8.22[ab]	14.25[b]
	±0.85	*±0.85*	*±1.85*	*±0.14*	*±2.49*	*±0.12*	*±4.26*
F	84.72[ab]	15.29[ab]	25.35[b]	3.89[c]	55.10[a]	8.42[a]	19.55[a]
	±1.51	*±1.51*	*±3.15*	*±0.72*	*±2.56*	*±0.83*	*±5.21*

[y] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).

[z] %C+Adb = 100%-%Fdb-%Pdb.

%M = percent moisture; %S = percent solids; %Fdb = percent fat in dry basis; %Fwb = percent fat in wet basis; %Pdb = percent protein in dry basis; %Pwb = percent protein in wet basis and %C+Adb = percent carbohydrates and ash in dry basis. LPLS = low lipoxygenase and low stachyose soy flour; SF = regular soy flour; G = soy grits; BN = soybeans; and F = soy flakes.

Less fat in soy flour soymilk could be the result of hull removal which contained about 0.3% of the total fat of whole beans (Perkins, 1995) and some loss during the soy flour manufacturing process. Moizuddin et al. (1997) suggested that the soybean hull might have acted as a filter aid, allowing the passage of the oil ("channels") into the soymilk, while the absence of hull would cause caking of the insoluble matter that would block the release of oil into the soymilk.

Similarly, tofu made from the soy flours and flakes had significantly less fat (3.9 - 4.0% wet basis) than tofu made from the beans (4.8%), while there was no statistical difference in the fat content between tofu made from the grits and from the beans.

Protein

The protein contents of soymilk ranged from 3.0 to 3.4% (wet basis) and 7.7 - 8.7% in the tofu. With addition of calcium sulfate, proteins were concentrated and aggregated by the divalent calcium cations.

Carbohydrates and ash

The carbohydrate and ash contents calculated by difference were significantly higher in soymilk made from the soy flours and flakes (43.1 - 48.0%) than from the chips (38.1%) and beans (33.9%) (Table 17).

Greater carbohydrate and ash contents were also found in the tofu made from the soy flours and flakes (19.6 - 22.2%, dry basis). No significant difference was found between tofu made from the grits and tofu made from the beans (15.5% and 14.3%, respectively) (Table 18). As the size of the soy particles decreased (from bean to flour), the carbohydrate and ash contents increased in both soymilk and tofu (Figure 9).

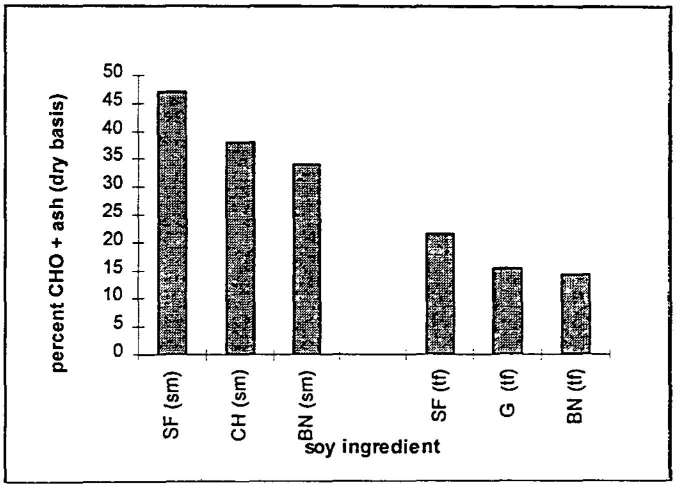

Figure 9. The percent carbohydrates and ash (dry basis) in soymilk and tofu. SF (sm) = regular soy flour used in soymilk production; SF (tf) = regular soy flour used in tofu production; CH = soy chips; and BN = soybeans.

The grinding process in soy flour production could have physically reduced the size of insoluble polysaccharides that eventually went into the soymilk (not filtered out), hence giving a greater amount of total carbohydrate retention. Soybeans contain approximately 35% carbohydrates of which 10% are soluble carbohydrates (Perkins, 1995; Synder and Kwon, 1987). Therefore, if the insoluble parts were not filtered out, they would have added to the total carbohydrates in the soymilk.

Sensory Evaluation

Soymilk

Panelists found no significant differences in nuttiness, beaniness and astringency among all the samples (Table 19). Partial genetic modification of lipoxygenase profile (low in lipoxygenase isozyme-2) in the LPLS- and LP-varieties did not significantly decrease the intensity of beaniness in the soymilk.

Table 19. The sensory evaluation of soymilk[y].

Sample	Yellowness	Brownness	Nuttiness[z]	Beaniness	Astringency
LPLS	4.0^{b}	1.4^{ab}	6.0^{a}	3.2^{a}	2.9^{a}
LP	4.9^{a}	1.7^{a}	5.3^{a}	3.8^{a}	3.7^{a}
SF	2.0^{c}	0.9^{b}	5.9^{a}	3.8^{a}	3.5^{a}
CH	1.5^{c}	0.9^{b}	5.0^{a}	4.0^{a}	3.8^{a}
BN	1.9^{c}	1.7^{a}	6.1^{a}	3.2^{a}	2.9^{a}
F	4.0^{b}	1.4^{ab}	5.7^{a}	3.5^{a}	3.6^{a}

[y] Means of 3 replications with 10 panelists (N = 30). Means with the same letter(s) within a column are not significantly different ($P < 0.05$).

[z] also pasta/ cereal flavor;

0 = white, no brownness, no nuttiness/ pasta/ cereal flavor, no beaniness, no astringency;

15 = yellow, intense brownness, intense nuttiness/ pasta/ cereal flavor, intense beaniness, intense astringency.

LPLS = low lipoxygenase and low stachyose soy flour; LP = low lipoxygenase soy flour; SF = regular soy flour; CH = soy chips; BN = soybeans; and F = soyflakes.

In contrast to the studies in whole soybeans, less beany flavor and hexanal production were found by Lee (1995) in soymilk made from the L-2 null soybeans. Wilson (1996) studied the sensory attributes of tofu made from L-2 null varieties and also found less beany flavor in these treatments. The study conducted by Davies et al. (1987) concluded that the removal of L-2 isozyme produced soymilk with less beany, rancid and oily flavors and aromas.

However, Davies et al. (1987) found no significant difference in beany flavor when tasting the soy flours of L-2 null variety and the control. Similar results were found when the LPLS- and LS soy flours were used to make soymilk in this study. Autooxidation could have occurred in soy flours which would produce hexanal and other volatiles (rather than by the hydroperoxidation of lipoxygenase), thus masking the effect of the L-2 null soy flours (unchanged beany flavor in soymilk).

The variety used in this study was also different from those used in other studies. Davies et al. (1987) and Wilson (1996) used soybeans to make soymilk and tofu, respectively, in their studies. Intact beans were less susceptible to autooxidation than soy flours. Although Lee (1995) used soy flours to prepare soymilk, the samples were used within an hour after grinding, therefore less autooxidation occurred. The short heating process (40 seconds by steam-infusion cooking) with less water contact time also reduced the activation of lipoxygenase, hence giving less beany flavor in the soymilk.

Addo et al. (1983) evaluated the hexanal, hexenal and hexanol production in bread dough containing 3% full-fat soy flours with different sets of lipoxygenase isozymes (with missing either L-1 or L-2 or L-3 isozyme) and found those volatiles in all soy-containing dough, but less in the one with L-2 null soy flour. None of these studies completely eliminated the beany flavor or hexanal production. This suggested the beany flavor was not only caused by the L-2 isozyme but also by the L-1 and L-3 isozymes. Therefore, even with little L-2 activity in the LPLS- and LP- varieties (where L-1 and L-3 were still exist), the beany flavor was still above human detectable level.

Although the LPLS-variety is a little higher in sucrose concentration (8-9%) than the regular variety (6-8%; Pyler, 1988; Perkins, 1995), panelists tasted no difference in sweetness during the training sessions.

Soymilk made from the LPLS- and LP- soy flours was significantly more yellow than the soymilk made from the regular soy flour, chips and beans. The intensity of yellowness was highly correlated to the b values of the soymilk (made from soy flours) and the soy flours (r = 0.9975; r = 0.9984).

Tofu

Although there were significant differences in yellowness and brownness among samples, they were all rated at about or below one-tenth of the color scales. Again, tofu made from the LPLS-soy flour was significantly more yellow than the tofu made from the regular soy flour, grits and beans (Table 20).

Tofu made from the soy flours were significantly less smooth (appearance) than tofu made from the grits and beans. The flake tofu was firmer than the bean tofu, however, this may due to the variety difference. Panelists found less beany flavor in the LPLS-tofu than in the flake tofu.

Table 20. The sensory evaluation of tofu[z].

Sample	Yellowness	Brownness	Surface smoothness	Firmness	Beaniness
LPLS	1.7[a]	0.6[c]	4.8[c]	6.7[ab]	2.8[b]
SF	1.1[b]	1.1[ab]	5.7[bc]	7.1[ab]	3.4[ab]
G	1.1[b]	0.8[bc]	7.5[a]	6.6[ab]	3.2[ab]
BN	1.0[b]	1.2[a]	7.5[a]	6.0[b]	3.0[ab]
F	1.3[ab]	0.9[abc]	6.6[ab]	7.2[a]	3.9[a]

[z] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).
0 = no yellowness, no brownness, very rough, very soft and no beaniness;
15 = intense yellow, intense brownness, very smooth, very firm and intense beaniness.
LPLS = low lipoxygenase and low stachyose soy flour; SF = regular soy flour; G = soy grits; BN = soybeans; and F = soy flakes.

Cost Analysis

The cost of soy ingredients are given as follows (based on 3,000lbs quantities):

LPLS full-fat soy flour (Natural Products, Inc.)	$0.33/ lb
Organic LP full-fat soy flour (Natural Products, Inc.)	$0.48/ lb
Regular full-fat soy flour (Natural Products, Inc.)	$0.28/ lb
Soy chips (Natural Products, Inc.)	$0.29/ lb
Soy grits (Natural Products, Inc.)	$0.29/ lb
Soy beans (Natural Products, Inc.)	$0.12/ lb

MicroSoy® organic flakes (Mycal Corp.) $0.50/ lb

From a economic standpoint, use of soy flour is beneficial with lower cost (compared to the flakes), greater yield and less waste than the use of other soy ingredients. Thus, it can be used as an alternative source for soymilk manufacture.

CONCLUSIONS

Soy flour yielded 10 - 30% more soymilk and produced 50% less waste than chips, flakes and beans, using the Takai Automated Soymilk and Tofu System. Use of soy flour reduced the soymilk processing time while producing good quality soymilk. The LPLS- soy flour produced soymilk with significantly less fat (0.54%) than the soymilk made from other soy ingredients. Nevertheless, soy flour made unacceptable tofu in this system due to poor texture quality.

No significant difference in "beaniness" was found among all the soymilk samples, while the LPLS-tofu was rated as less beany than the flake tofu.

PART II. THE PHYSICAL, CHEMICAL AND SENSORY PROPERTIES OF CAKE DOUGHNUTS CONTAINING ROASTED FULL-FAT-, FULL-FAT LOW STACHYOSE- AND DEFATTED SOY FLOURS

INTRODUCTION

Most of the commercial doughnut mixes today contain about 3% soy flour for crust color improvement, water binding, fat absorption control, improvement in shape and tenderness, and longer shelf life (Johnson, 1970; Anonymous, 1978; Sipos, 1988). These functional properties vary with the type, the solubility and the addition level of soy flour used.

Soy flour contains about 5-8% sucrose and 40-50% protein, hence it can be used for partial replacement of non-fat dry milk (NFDM) and egg, which reduces the cost of mixes.

Defatted soy flour is more commonly used in doughnut mixes compared to full-fat soy flour. With fat removal, the shelf life of defatted soy flour is longer, which is one of the reasons that it is used more frequently.

The objectives of this study were to compare the quality of doughnuts made with full-fat and defatted soy flours, either by partial substitution for NFDM and or egg, or by addition. The effect of PDI level on fat absorption was also evaluated.

MATERIALS AND METHODS

Soy Flour

Roasted full-fat low stachyose soy flour with 19 PDI (FLS19) and soy flours of 30 and 44 PDI (F30, F44) (Natural Products, Inc., Grinnell, IA), and two defatted soy flours of 20 and 70 PDI (D20, D70) (Cargill, Cedar Rapids, IA) were used in doughnut production. The fat and protein contents of these soy flours were as follows (each lot was tested and data were provided by the manufacturers):

Table 21. The fat and protein contents of soy flours.

Soy flour	%fat	%protein
FLS19	21.05	44.01
F30	22.88	40.27
F44	23.99	39.69
D20	0.50	50.00
D70	0.50	50.00

FLS19 = full-fat low stachyose with 19 PDI;
F30 = full-fat 30 PDI; F44 = full-fat 44 PDI;
D20 = defatted 20 PDI and D70 = defatted 70 PDI.

Doughnut Formula

The doughnut formula and ingredients used are listed in Table 22.

Mixing and Frying Procedure

Sucrose and soybean oil were mixed and beaten for one minute at speed 1 using a KitchenAid (model K5SS, KitchenAid, Denver, CO) counter top mixer.

Table 22. Doughnut formula and ingredient brand names[a].

Ingredients	Amount
Sucrose (Domino®, Domino Sugar Corp., New York, NY)	300.00g
Soybean oil (Crisco, Procter & Gamble, Cincinnati, OH)	90.00ml
Flour, all-purpose (Gold Medal, General Mills, Inc., Minneapolis, MN)	781.36g
Eggs, dried whole (Type W-1, Henningsen Foods, Inc., Omaha, NE)	35.97g
Baking powder, double acting (Calumet, Kraft Foods, Inc., White Plains, NY)	18.00g
Salt (Morton, Morton International, Inc., Chicago, IL)	4.50g
Cornstarch (Agro, CPC International Inc., Englewood Cliffs, NJ)	2.93g
Soy lecithin powder (Centrolex® F 6450, Central Soya Company, Inc., Fort Wayne, IN)	0.98g
Non-fat dry milk (Extra grade high heat, Mid-America Farms, Springfield, MO)	44.21g
Soy flour (full-fat - Natural Products, Inc., Grinnell, IA; defatted - Cargill, Cedar Rapids, IA)	(specified level)
Water	619.50ml
Additional water[b]	

[a] Batch size for preparing about 25 doughnuts.
[b] Extra 10 ml of water was added into the dough containing 0%, 5%, 8% and 10% soy flour additions.

Flour was sifted and mixed with other dry ingredients. The sucrose-oil mixture was combined with the flour mixes and water was added. The dough was hand mixed with a spatula until all ingredients were combined. With the mixer at speed 1, dough was mixed for 2 minutes then allowed to rest for ten minutes before putting it into the hopper of a commercial automated Donut Robot Mark II Fryer (Belshaw Brothers, Seattle, Washington). The size of doughnuts was set at 2.5. Doughnuts were fried at 375°F for 150 seconds and turned halfway during frying. Doughnuts were cooled (air dried) on racks for 45-60 minutes, and then stored in closed containers.

Frying Fat Quality

Partially hydrogenated soybean oil (Iowa Donut Supply, Urbandale, IA) was used for frying. Doughnuts were fried in oil with free fatty acid (FFA) levels between 0.30% to 0.75% (Ca 5a-40, AOCS, 1987). The oil was replaced when the FFA levels exceeded 0.75%.

Physical Analyses

Color

The crust and crumb colors of doughnuts were measured using a 6100 Hunterlab Labscan Spectro Colorimeter (Hunterlab, VA). The instrument was standardized with a black and a white (X = 78.67, Y = 83.31, Z = 86.40) tile, under white cool fluorescent light, with a 10° observation angle. Doughnuts were placed on the reflectance port under a 1-cm (~0.375 inch) aperture to measure the L, a and b values. The crust color was determined on the second frying side of doughnut. A total of nine and six measurements were made for the crust and crumb, respectively, for each type at each replication.

Weight, width and height

For each replication, three doughnuts were randomly chosen and weighed. Samples were cut in half where the width and the height were measured on one cross-section of the doughnut.

Texture profile analysis (TPA)

The crusts of doughnuts were removed and samples were cut into 2-cm cubes for texture analysis. The Instron Universal Testing Machine (Model 4500 Series, Instron Corp., Canton, MA) was used to determine the hardness, cohesiveness, springiness, gumminess and chewiness of doughnuts. A 3.5-cm diameter aluminum compression anvil was used to compress doughnuts to 50% of the height at 100 mm/min crosshead speed. The load cell size was 50 kg. Six cubes from three doughnuts of each type were used for TPA analysis for each replication.

Proximate Analyses

Moisture

Doughnuts were hand crumbed and freeze dried (Model Unitrap II, Virtis Co., Gardiner, NY) for 48 hours for moisture determination. The moisture of dough was determined as well.

Fat

Dried doughnuts or dough were ground with dry ice (about 2 : 1 portions) in a coffee grinder (Model IDS50, Mr. Coffee, Inc., OH). Approximately 2 g of dried sample were wrapped in a 15-cm Whatman® no. 1 filter paper, inserted into a thimble and extracted using a Goldfisch extractor (AACC 30-25, 1984) for 4 hours. The percent fat absorption (%Fabs) was calculated by subtracting the percent fat in dough from the percent fat in doughnuts.

Protein

The percent protein was measured by the Kjeldahl method (AOAC method 955.04, 1995) where the total nitrogen was multiplied by 6.25. Kjeltabs Tct (K_2SO_4 = 94.34%, $CuSO_4 \bullet 5H_2O$ = 2.83%, TiO_2 = 2.83%) (Fisher Scientific, PA) was used as the catalyst for environmental reason. Both the dried doughnuts and dough were analyzed for protein contents.

Experiments

Soy flours were used in several ways (Table 23). For the first and second experiments, all samples were prepared on the same day for evaluation at each replication. However, due to large sample size in the third experiment, doughnuts were prepared as follows:

Day 1	control, 5% addition
Day 2	control, 5% addition
Day 3	8% addition
Day 4	8% addition
Day 5	10% addition
Day 6	10% addition

Table 23. Use of soy flours in doughnut manufacture.

Study	Treatment (weight basis)	Replications
1.	30% substitution for NFDM	3
2.	30% substitution for NFDM plus 30% substitution for dried egg solids	3
3.	5%, 8%, and 10% soy additions (flour weight basis)	2

Sensory Evaluation

Trained panel

Panelists were trained in two 1-hour sessions for darkness, tenderness, soy flavor, gumminess, moistness and oiliness of doughnuts (Appendix 3). Samples were evaluated by panelists on the same day of processing. Doughnuts were cut into half and presented simultaneously in individual sensory booths under white fluorescent light, and were served at room temperature. All samples were coded with 3 random digit numbers.

Consumer test

A one-day consumer test was conducted at Iowa State University using a paired preference test and hedonic rating (Appendix 1) between two doughnuts, the 30% D20- and F30- soy flour substituted (for NFDM) samples. Data were collected from 133 individuals of which 59 were males and 74 were females. The distributions of age and frequency of eating were summarized in Figure 12 and 13 (Appendix 2).

Statistical Analysis

Trained panel

All data were analyzed based on a randomized complete block design. The General Linear Model procedure (Statistical Analysis System, release 6.06, 1997) was used to test the effect of soy flour (first and second experiments) and the effects of soy flour and addition level in the third experiment. The t test for least significant difference was calculated at $\propto$ = 0.05. For the third experiment, soy flour or addition level was tested against the control using the Dunnett's T test for significant difference at $\propto$ = 0.05, between the control and the samples (Statistical Analysis System, release 6.06, 1997).

Consumer test

The paired preference test was calculated based on the minimum numbers of agreeing judgments (X) necessary to establish significance at α = 0.05, where $X = (z \sqrt{n} + n + 1)/2$ (Roessler et al., 1978).

RESULTS AND DISCUSSION

Substitution for NFDM (30%)

Physical analyses

Color

The crust of doughnuts containing soy flours were significantly "lighter" (higher L values) than that of the control which had no soy flour (Table 24). Non-fat dry milk contributes to the browning reaction in doughnuts as it contains significant amount of lysine and lactose (reducing sugar) which undergo the Maillard reaction. Substitution with soy flour, which contained non-reducing sugars (sucrose, raffinose and stachyose), decreased the degree of browning reaction, hence the lighter the color. This correlated with the "darkness" perceived by panelists (r = -0.86).

Table 24. The Hunter L, a and b values of doughnut[z].

Sample	Crust			Crumb		
	L	a	b	L	a	b
C	57.23[b]	7.32[a]	19.98[a]	76.82[ab]	-0.51[ab]	12.44[a]
FLS19	60.19[a]	6.75[b]	20.36[a]	76.87[ab]	-0.46[a]	12.74[a]
F30	59.95[a]	6.53[bc]	20.29[a]	75.80[b]	-0.50[ab]	12.63[a]
F44	59.19[a]	6.42[bc]	19.75[a]	76.63[ab]	-0.63[b]	12.76[a]
D20	59.36[a]	6.71[b]	20.37[a]	77.32[a]	-0.51[ab]	12.75[a]
D70	60.42[a]	6.11[c]	20.32[a]	77.25[ab]	-0.52[ab]	12.37[a]

[z] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).
C = control (no soy); FLS19 = full-fat low stachyose with 19 PDI;
F30 = full-fat 30 PDI; F44 = full-fat 44 PDI; D20 = defatted 20 PDI; and
D70 = defatted 70 PDI.

Weight, width and height

Doughnuts substituted with the D70-soy flour was significantly less heavy than the other treatments (Table 25). Lost of moisture resulting from the unfolding of proteins during frying could be the reason for this loss. The differences in width and height were negligible as they were less than 0.2cm.

Table 25. The weight, width and height of doughnut[z].

Sample	Weight (g)	Width (cm)	Height (cm)
C	60.82[a]	2.77[ab]	3.05[ab]
FLS19	61.58[a]	2.83[ab]	3.10[a]
F30	60.94[a]	2.73[b]	3.05[ab]
F44	62.41[a]	2.74[b]	3.08[ab]
D20	61.46[a]	2.81[ab]	3.01[ab]
D70	58.11[b]	2.85[a]	2.96[b]

[z] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$). C = control (no soy); FLS19 = full-fat low stachyose with 19 PDI; F30 = full-fat 30 PDI; F44 = full-fat 44 PDI; D20 = defatted 20 PDI; and D70 = defatted 70 PDI.

Texture profile analysis

The full-fat 30PDI and low stachyose soy flours produced doughnuts that were softer than those made with the defatted soy flours (Table 26). Doughnuts containing defatted soy flours were significantly more cohesive, more springy, gummier and chewier than doughnuts containing full-fat soy flours. In general, substitution by full-fat soy flours produced doughnuts with similar texture characteristics to the control.

Table 26. The texture profile analysis of doughnuts with 30% soy flour substitution for NFDM[z].

Sample	Hardness(N)	Cohesiveness	Springiness(mm)	Gumminess(N)	Chewiness(Nmm)
C	10.64^{ab}	0.36^{bc}	5.60^{c}	3.71^{b}	21.12^{c}
FLS19	10.34^{bc}	0.35^{c}	5.39^{c}	3.52^{bc}	19.06^{c}
F30	9.77^{c}	0.35^{c}	5.54^{c}	3.34^{c}	18.57^{c}
F44	11.17^{ab}	0.34^{c}	5.57^{c}	3.77^{b}	21.05^{c}
D20	11.31^{a}	0.37^{b}	6.38^{b}	4.08^{a}	26.32^{b}
D70	11.32^{a}	0.38^{a}	7.12^{a}	4.28^{a}	31.09^{a}

[z] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).

C = control (no soy); FLS19 = full-fat low stachyose with 19 PDI; F30 = full-fat 30 PDI; F44 = full-fat 44 PDI; D20 = defatted 20 PDI; and D70 = defatted 70 PDI.

Proximate analyses

Thirty percent soy flour substitution for NFDM affected very slightly the composition of the dough and doughnut. The percent fat absorption among samples was not significantly different. This was anticipated as there was less than 2% soy flour (on a flour basis) in the substituted samples. As mentioned by Martin and Davis (1986), "the major effect of soy flour on fat absorption by cake doughnut was a function of the quantity of protein added to the batter". Therefore, little protein difference among the dough (Table 27) was not sufficient to cause any difference in the fat absorption of the doughnut.

Sensory evaluation

Trained panelists rated the control sample as the darkest sample (Table 28). Doughnuts containing the full-fat 30PDI soy flour were significantly more

Table 27. The proximate analysis (wet basis) of dough and doughnut[z].

Sample	Dough			Doughnut			
	%M	%F	%P	%M	%F	%P	%Fabs
C	36.78^{a}	4.65^{c}	6.61^{c}	26.11^{ab}	18.46^{a}	6.24^{a}	13.81^{a} ±1.34
FLS19	36.89^{a}	4.81^{ab}	6.70^{bc}	26.01^{ab}	19.55^{a}	6.27^{a}	14.74^{a} ±1.10
F30	36.93^{a}	4.88^{a}	6.67^{bc}	26.03^{ab}	19.07^{a}	6.27^{a}	14.19^{a} ±0.71
F44	36.79^{a}	4.87^{a}	6.71^{bc}	26.39^{a}	18.77^{a}	6.34^{a}	13.90^{a} ±0.78
D20	36.49^{a}	4.76^{b}	6.83^{a}	25.44^{ab}	19.57^{a}	6.41^{a}	14.81^{a} ±0.45
D70	36.52^{a}	4.81^{ab}	6.76^{ab}	24.75^{b}	19.92^{a}	6.45^{a}	15.11^{a} ±0.78

[z] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).
%M = percent moisture; %F = percent fat; %P = percent protein; %Fabs = percent fat absorption; C = control (no soy); FLS19 = full-fat low stachyose with 19 PDI; F30 = full-fat 30 PDI; F44 = full-fat 44 PDI; D20 = defatted 20 PDI; and D70 = defatted 70 PDI.

Table 28. Sensory evaluation of doughnuts with 30% soy substitution for NFDM[z].

Sample	Darkness	Tenderness	Soy Flavor	Gumminess	Moistness	Oiliness	Preference
C	9.9[a]	8.6[ab]	0.7[a]	7.9[a]	6.5[ab]	5.7[a]	8.3[a]
FLS19	7.5[bc]	8.8[a]	1.0[a]	7.6[a]	6.0[ab]	5.3[a]	7.1[ab]
F30	7.1[bc]	9.2[a]	0.7[a]	7.4[a]	6.8[a]	5.0[a]	8.2[ab]
F44	6.7[c]	8.5[ab]	0.8[a]	7.6[a]	6.4[ab]	5.0[a]	7.8[ab]
D20	7.6[b]	7.7[b]	0.9[a]	7.1[a]	5.7[b]	5.0[a]	7.0[b]

[z] Means of three replications. Panelists no. = 13. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).
0 = light, not tender, no soy flavor, not gummy, very dry, not oily and least preferred;
15 = dark, very tender, intense soy flavor, very gummy, very moist, very oily and most preferred.
C = control (no soy); FLS19 = full-fat low stachyose with 19 PDI; F30 = full-fat 30 PDI; F44 = full-fat 44 PDI; and D20 = defatted 20 PDI.

tender and more moist than the doughnuts containing the defatted 20 PDI soy flour. This agreed with the Instron measurement as the F30 sample was less hard than the D20 sample. The sensory tenderness was negatively correlated to the Instron hardness (r = -0.90). Panelists scored no differences in soy flavor, gumminess and oiliness in all samples. The presence of soy flavor was insignificant. If the soy flavor score was set at 0 for the control, the intensity would be less than 0.3 cm in the other treatments. The control was significantly preferred by the panelists over the D20 sample. However, there was no preference among the control, FLS19, F30 and F44 samples. The D70 doughnuts were not included in the sensory panel.

Results from the consumer test indicated no preference between the D20 and F30 substituted doughnuts for texture, flavor, less greasiness and overall preference (Table 29). This agreed with the responses of the trained panel. The preference was not affected by the gender, age and eating frequency. The hedonic ratings were similar for both samples as well (Table 29, Figure 10).

Substitution for NFDM (30%) and Dried Whole Eggs (30%)

Physical analyses

Color

By substituting for 30% of the NFDM and egg with soy flours, the crust of doughnuts became "lighter" (except the FLS19 sample) than the control sample (Table 30). Again, replacement by soy flour decreased the browning reaction of

Table 29. The consumer paired preference and hedonic test results.

		D20	F30	Significance
paired preference[a] (n = 133)	texture	71	62	NS
	flavor	61	72	NS
	less greasiness	67	66	NS
	overall	64	69	NS
gender	male (n=59)	25	34	NS
	female (n=74)	39	35	NS
age	<10 (n=11)	4	7	NS
	10-19 (n=27)	17	10	NS
	20-29 (n=28)	14	14	NS
	30-39 (n=16)	6	10	NS
	40-49 (n=34)	17	17	NS
	50-59 (n=10)	2	8	NS
	60-69 (n=6)	4	2	NS
	70+ (n=1)	0	1	S
eating frequency	>=2times/week (n=15)	9	6	NS
	once/week (n=21)	8	13	NS
	every other week (n=31)	15	16	NS
	once/month (n=34)	15	19	NS
	once/3 months (n=14)	9	5	NS
	once/6 months (n=11)	6	5	NS
	do not eat (n=7)	2	5	NS
hedonic rating	like extremely	27	29	
	like moderately	51	56	
	like slightly	35	30	
	neutral	9	12	
	dislike slightly	8	5	
	dislike moderately	3	0	
	dislike extremely	0	1	

[a] at $\alpha = 0.05$, $X = (z\sqrt{n} + n + 1)/2$ (Roessler et al., 1978).
D20 = defatted 20 PDI and F30 = full-fat 30 PDI.

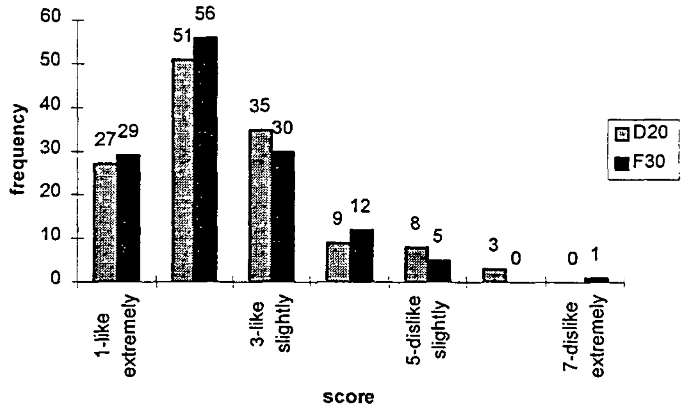

Figure 10. The distribution of hedonic ratings.

NFDM. The Hunter "darkness" (smaller L values) were positively correlated to the sensory "darkness" (r = 0.80). Although there were differences among all the samples in the L, a and b values for the crusts and crumbs, they were similar visually.

Weight, width and height

The control and the FLS19 samples were significantly heavier than doughnuts with defatted soy flour replacement (Table 31). This might due to more moisture and fat absorption in the control and FLS19 samples, respectively. The D20 and D70 samples were "shorter" in height than the control, while the full-fat soy flour samples were not different from the control. Nevertheless, the differences were very small (< 0.2 cm).

Table 30. The Hunter L, a and b values of doughnut[z].

Sample	Crust			Crumb		
	L	a	b	L	a	b
C	54.58[c]	8.12[a]	19.51[c]	76.60[a]	-0.52[bc]	12.00[b]
FLS19	56.50[bc]	7.42[ab]	19.75[bc]	75.76[ab]	-0.31[a]	12.19[ab]
F30	57.07[b]	6.99[b]	19.92[abc]	73.97[b]	-0.47[b]	12.22[ab]
F44	59.28[a]	6.14[cd]	20.15[ab]	77.00[a]	-0.60[c]	12.33[a]
D20	58.14[ab]	6.70[bc]	20.34[a]	75.26[ab]	-0.36[a]	12.14[ab]
D70	59.57[a]	5.70[d]	19.95[abc]	76.95[a]	-0.49[b]	11.99[b]

[z] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).
C = control (no soy); FLS19 = full-fat low stachyose with 19 PDI;
F30 = full-fat 30 PDI; F44 = full-fat 44 PDI; D20 = defatted 20 PDI; and
D70 = defatted 70 PDI.

Table 31. The weight, width and height of doughnut[z].

Sample	Weight (g)	Width (cm)	Height (cm)
C	61.83[a]	2.70[ab]	3.13[a]
FLS19	61.31[a]	2.74[ab]	3.05[ab]
F30	59.19[b]	2.68[b]	3.03[ab]
F44	60.07[ab]	2.79[a]	3.02[ab]
D20	59.07[b]	2.77[a]	2.94[b]
D70	58.11[b]	2.75[ab]	2.94[b]

[z] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).
C = control (no soy); FLS19 = full-fat low stachyose with 19 PDI; F30 = full-fat 30 PDI; F44 = full-fat 44 PDI;
D20 = defatted 20 PDI; and D70 = defatted 70 PDI.

Texture profile analysis

Doughnuts containing defatted soy flour were harder, gummier and chewier than doughnuts substituted by the full-fat 30PDI soy flour, which were less cohesive, less springy, less gummy and less chewy than the control (Table

32).

Proximate analyses

Interestingly, doughnuts with 30% FLS19 and F30 soy flour substitutions for NFDM and egg had greater fat absorption than the control (Table 33). Soy flours with lower PDI most likely had lost their functional properties due to protein denaturation during the manufacturing process. Higher moisture retention in the control could have reduced the fat absorption as well. Partial soy flour replacement for NFDM and egg did not lower the fat absorption since very little soy protein was added to the dough.

Sensory evaluation

There was no difference in gumminess, moistness and oiliness among all the samples (Table 34). Doughnuts containing full-fat low stachyose soy flour had more soy flavor than the control. In addition, "off-flavor", "rancid flavor" and "nuttiness" were also noted by the panelists. The same sample was less preferred than the F30, F44 and D20 samples. The tenderness of doughnuts was negatively correlated to the Instron hardness (r = -0.85).

Soy Flour Additions

Physical analyses

Color

The crusts of doughnuts with 10% soy flour addition were significantly darker (smaller L value) and more red (greater a value) than that of doughnuts

Table 32. The texture profile analysis of doughnuts with 30% soy substitutions for NFDM and egg[z].

Sample	Hardness(N)	Cohesiveness	Springiness(mm)	Gumminess(N)	Chewiness(Nmm)
C	10.34[b]	0.31[a]	5.12[a]	3.16[b]	16.18[ab]
FLS19	11.45[a]	0.29[b]	5.12[a]	3.25[ab]	16.65[ab]
F30	10.18[b]	0.29[b]	4.67[c]	2.91[c]	13.65[c]
F44	10.89[ab]	0.29[b]	4.89[abc]	3.10[bc]	15.23[bc]
D20	11.37[a]	0.28[b]	4.81[bc]	3.23[b]	15.65[b]
D70	11.48[a]	0.30[a]	5.04[ab]	3.46[a]	17.44[a]

[z] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).
C = control (no soy); FLS19 = full-fat low stachyose with 19 PDI; F30 = full-fat 30 PDI; F44 = full-fat 44 PDI; D20 = defatted 20 PDI; and D70 = defatted 70 PDI.

Table 33. The proximate analysis (wet basis) of dough and doughnut[z].

Sample	Dough			Doughnut			
	%M	%F	%P	%M	%F	%P	%Fabs
C	37.38^{a}	4.71^{ab}	6.56^{c}	27.43^{a}	18.23^{c}	6.30^{a}	$13.53^{c} \pm 0.93$
FLS19	37.46^{a}	4.87^{a}	6.61^{bc}	25.90^{c}	20.29^{a}	6.30^{a}	$15.42^{a} \pm 0.10$
F30	37.52^{a}	4.82^{a}	6.56^{c}	26.37^{bc}	19.58^{ab}	6.22^{a}	$14.75^{ab} \pm 0.69$
F44	37.21^{a}	4.85^{a}	6.62^{bc}	26.53^{b}	19.02^{bc}	6.32^{a}	$14.18^{bc} \pm 0.80$
D20	37.38^{a}	4.56^{bc}	6.70^{a}	26.38^{bc}	18.86^{bc}	6.36^{a}	$14.29^{bc} \pm 0.14$
D70	37.51^{a}	4.53^{c}	6.67^{ab}	26.86^{b}	18.71^{bc}	6.33^{a}	$14.18^{bc} \pm 1.14$

[z] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).
%M = percent moisture; %F = percent fat; %P = percent protein;
%Fabs = percent fat absorption; C = control (no soy); FLS19 = full-fat low stachyose with 19 PDI; F30 = full-fat 30 PDI; F44 = full-fat 44 PDI;
D20 = defatted 20 PDI; and D70 = defatted 70 PDI.

with 5% additions (Table 35). No significant difference was found in the b values. The b values of crumb was significantly highest in the 10% samples, followed by the 8% and then the 5% samples. The D70 soy flour made the most yellow crust with the least yellow crumb.

Weight, width and height

The weight of doughnuts decreased from 5% to 8% to 10% soy flour addition (Table 36). The decrease in moisture retention and fat absorption could be the cause (Table 38).

Doughnuts with defatted soy flour weighed less and were smaller in size compared to those with added full-fat soy flours. Although there were significant differences in weight, width and height, all samples looked very similar.

Table 34. Sensory evaluation of doughnuts with 30% soy substitutions for NFDM and egg[y].

Sample	Darkness	Tenderness	Soy Flavor	Gumminess	Moistness	Oiliness	Preference
C	9.4[a]	9.0[ab]	0.6[b]	7.9[a]	6.7[a]	5.2[a]	7.4[ab]
FLS19[z]	8.7[ab]	8.6[b]	1.2[a]	7.4[a]	6.9[a]	5.3[a]	6.8[b]
F30	8.0[b]	9.6[a]	0.8[ab]	7.9[a]	7.4[a]	5.3[a]	8.5[a]
F44	7.9[b]	8.7[ab]	0.7[b]	7.4[a]	6.8[a]	4.9[a]	8.3[a]
D20	8.7[ab]	8.7[ab]	1.0[ab]	7.4[a]	6.9[a]	4.8[a]	8.2[a]

[z] Means of three replications. Panelist no. = 11. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).
0 = light, not tender, no soy flavor, not gummy, very dry, not oily and least preferred;
15 = dark, very tender, intense soy flavor, very gummy, very moist, very oily and most preferred.

[z] Off-flavor, rancid flavor and nuttiness were also noted by panelists for the FLS sample.
C = control (no soy); FLS19 = full-fat low stachyose with 19 PDI; F30 = full-fat 30 PDI; F44 = full-fat 44 PDI; and D20 = defatted 20 PDI.

Table 35. The Hunter L, a and b values of doughnuts with 5%, 8% and 10% soy flour additions[y].

Treatment	Crust			Crumb		
	L	a	b	L	a[1]	b[1]
C	51.39	8.90	19.07	75.76	-0.67	12.21
5%	55.38^{az}	7.84^{bz}	20.05^{a}	76.14^{a}	-0.49^{b}	13.41^{cz}
8%	54.07^{ab}	8.06^{ab}	20.01^{a}	77.02^{a}	-0.44^{ab}	14.09^{bz}
10%	53.42^{b}	8.57^{a}	20.09^{a}	76.31^{a}	-0.43^{a}	14.33^{az}
C	51.39	8.90	19.07	75.76	-0.67	12.21
F30	54.42^{ab}	7.77^{a}	19.85^{b}	76.79^{ab}	-0.46^{bz}	14.21^{bz}
F44	53.49^{b}	8.36^{a}	19.83^{b}	76.94^{a}	-0.69^{c}	14.49^{az}
D20	53.19^{b}	8.37^{a}	19.75^{b}	75.54^{b}	-0.19^{az}	13.74^{cz}
D70	56.07^{az}	8.12^{a}	20.78^{az}	76.70^{ab}	-0.48^{bz}	13.35^{dz}

[y] Means of two replications. Means with the same letter(s) within a column for each treatment are not significantly different ($p < 0.05$).
[z] Significantly different from the control ($p < 0.05$).
[1] Significant interactions between soy addition and type of flour ($p < 0.05$).
C = control (no soy); F30 = full-fat 30 PDI; F44 = full-fat 44 PDI; D20 = defatted 20 PDI; and D70 = defatted 70 PDI.

Texture profile analysis

Overall, doughnuts with 10% soy flour additions tended to be more springy, gummier and chewier than the 5% and 8% samples (Table 37). Soy additions also made doughnuts more springy, gummier and chewier than the control (no soy). D70 doughnuts were significantly more cohesive, more springy, gummier and chewier than other samples.

Proximate analyses

The 10% addition doughnuts were significantly drier and had less fat absorption than the 5% addition doughnuts (Table 38). The protein contents of doughnuts increased significantly from 5 to 10% soy flour additions.

Table 36. The weight, width and height of doughnuts with 5%, 8% and 10% soy flour additions[y].

Treatment	Weight (g)	Width (cm)	Height (cm)
C	67.01	3.18	3.32
5%	59.40^{az}	2.88^{az}	2.91^{bz}
8%	56.01^{bz}	2.76^{bz}	3.01^{az}
10%	53.99^{cz}	2.73^{bz}	3.08^{a}
C	67.01	3.18	3.32
F30	59.21^{az}	2.84^{az}	3.12^{a}
F44	57.88^{bz}	2.87^{az}	3.05^{a}
D20	55.38^{cz}	2.76^{abz}	2.89^{bz}
D70	53.03^{dz}	2.68^{bz}	2.94^{bz}

[y] Means of two replications. No interaction between soy addition and type of flour. Means with the same letter(s) within a column for each treatment are not significantly different ($p < 0.05$).
[z] Significantly different from the control ($p < 0.05$).
C = control (no soy); F30 = full-fat 30 PDI; F44 = full-fat 44 PDI;
D20 = defatted 20 PDI; and D70 = defatted 70 PDI.

Table 37. The texture profile analysis of doughnuts with soy flour additions[y].

Treatment	Hardness (N)	Cohesiveness[1]	Springiness[1] (mm)	Gumminess[1] (N)	Chewiness[1] (Nmm)
C	10.11	0.30	4.76	3.04	14.57
5%	10.83^{b}	0.32^{a}	5.22^{cz}	3.45^{bz}	18.14^{bz}
8%	11.42^{az}	0.31^{b}	5.51^{bz}	3.48^{abz}	19.20^{bz}
10%	11.25^{abz}	0.33^{az}	6.13^{az}	3.66^{az}	22.53^{az}
C	10.11	0.30	4.76	3.04	14.57
F30	11.37^{abz}	0.30^{c}	5.41^{bz}	3.38^{b}	18.44^{bz}
F44	10.62^{c}	0.32^{b}	5.57^{bz}	3.36^{b}	18.73^{bz}
D20	11.02^{bc}	0.31^{c}	5.63^{bz}	3.37^{b}	19.01^{bz}
D70	11.72^{az}	0.35^{az}	5.92^{az}	4.03^{az}	23.97^{az}

[y] Means of two replications. Means with the same letter(s) within a column for each treatment are not significantly different ($p < 0.05$).
[z] Significantly different from the control ($p < 0.05$).
[1] Significant interactions between soy addition and type of flour ($p < 0.05$).
C = control (no soy); F30 = full-fat 30 PDI; F44 = full-fat 44 PDI;
D20 = defatted 20 PDI; and D70 = defatted 70 PDI.

Table 38. The proximate analysis (wet basis) of doughnuts with soy flour additions[w].

Treatment	%M[1]	%F[1]	%P[1]	%Fabs[1]
C	28.50	18.81	5.81	14.03
5%	28.30[a]	17.20[a]	6.83[cz]	12.17[a]
8%	27.98[ab]	17.14[a]	7.26[bz]	11.91[ab]
10%	27.62[b]	16.75[a]	7.59[az]	11.52[b]
C	28.50	18.81	5.81	14.03
F30	27.27[c]	18.98[a]	6.95[cz]	13.56[a]
F44	27.84[b]	17.69[b]	7.05[cz]	12.17[b]
D20	27.02[cz]	18.16[b]	7.30[bz]	13.30[a]
D70	29.73[a]	13.28[cz]	7.61[az]	8.45[cz]
commercial 1[x]	27.56	19.56	5.73	16.78
commercial 2[y]	20.13	20.14	6.28	NA

[w] Means of two replications. Means with the same letter(s) within a column for each treatment are not significantly different ($p < 0.05$).
[x] Doughnut made from commercial mix (Iowa Donut Supply, Urbandale, IA).
[y] Doughnut bought from grocery store (Cub Foods, Ames, IA). The %Fabs could not be determined.
[1] Significant interactions between soy addition and type of flour ($p < 0.05$).
[z] Significantly different from the control ($p < 0.05$).
%M = percent moisture; %F = percent fat; %P = percent protein; %Fabs = percent fat absorption; C = control (no soy); F30 = full-fat 30 PDI; F44 = full-fat 44 PDI; D20 = defatted 20 PDI; and D70 = defatted 70 PDI.

Less fat absorption at higher addition level was due to a greater amount of added protein and also the type of soy flour added. The D70 soy flour was most effective in reducing fat absorption during frying (about 40% reduction), followed by the F44 (13%), D20 (5%) and F30 (3%) soy flours. This was expected as the unfolding of proteins in high PDI soy flour in the doughnuts formed a protective coat that prevented excessive fat absorption. The proteins in low PDI soy flour had already been denatured during soy flour manufacturing thus had lost their functionality (Wolf and Cowan, 1975). In the full-fat soy flours, doughnuts made with a PDI of 44 absorbed significantly less fat than doughnuts made with a PDI of 30. Similarly, in the defatted soy flours, a PDI of 70 was more effective in reducing the fat uptake than the PDI of 20.

The fat absorption was negatively correlated with the protein content in doughnuts (r = -0.98). Martin and Davies (1986) concluded that at a PDI of 50 and above, the fat reduction was a function of the amount of protein added. Only at PDI 30 or lower, did the insoluble proteins lose their functionality.

When the percent fat absorption was calculated and plotted at each addition level for each type of soy flour (Table 39, Figure 11), the D70 sample was found to absorb the least amount of fat at all levels. Fifty percent fat reduction was achieved at 10% addition level with the use of D70 soy flour.

Table 39. The percent fat absorption of doughnuts at 5%, 8% and 10% soy flour additions.

	Addition level			
Soy flour	0% (control)	5%	8%	10%
F30	14.03	12.56	14.12	14.00
F44	14.03	12.56	12.11	11.85
D20	14.03	12.94	13.59	13.37
D70	14.03	10.62	7.85	6.87

F30 = full-fat 30 PDI; F44 = full-fat 44 PDI;
D20 = defatted 20 PDI; and D70 = defatted 70 PDI.

Although the D20 and F30 soy flours showed 9 - 10% fat reduction at 5% addition level, increasing fat absorptions were observed at 8 and 10% addition levels. A similar scenario was found by Murphy-Hanson (1992) at the 8% addition level using the spray dried soymilk powder (SDSM). Higher fat reduction was found when the SDSM was used. Since part of the carbohydrates have been removed during the soymilk making process, this would have increased the protein content in the powder. The F44 soy flour gave continuous fat reduction when the addition level increased. About 15% reduction was found at a 10% addition level.

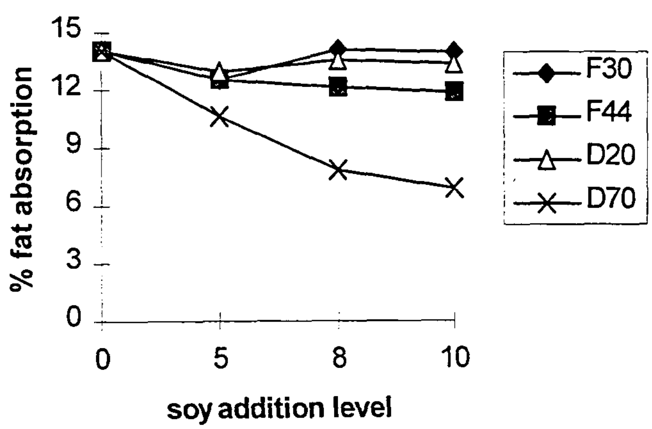

Figure 11. The fat absorption of doughnuts at 5%, 8% and 10% soy flour additions. F30 = full-fat 30 PDI; F44 = full-fat 44 PDI; D20 = defatted 20 PDI; and D70 = defatted 70 PDI.

Defatted soy flour seemed to be more effective in reducing fat absorption as the protein concentration in defatted soy flour was higher than in the regular full-fat soy flour (due to fat removal). This was also shown in the study of Murphy-Hanson (1992), who found greater fat reduction in doughnuts with defatted soy flour addition (NSI = 67.75) than that with spray dried soymilk powder addition (NSI = 23.24). The lower PDI of the spray dried soymilk was believed to be the main factor that reduced the functionality. Skimming of spray dried soymilk was suggested to further enhance the fat reduction capability.

Although the commercial doughnuts were not subjected to statistical analysis, the fat contents of both commercial samples were higher than the fat contents in doughnuts made in this study.

Sensory evaluation

Among the 5%, 8% and 10% additions, differences were found only in darkness, soy flavor and moistness (Table 40). Panelists rated the 8% and 10% additions as darker than the 5% addition and the control. The soy additions made doughnuts less tender than the control. Although there were significant differences in soy flavor at various levels, they were not different from the control which contained no soy at all. Hence, the soy flavor could be ignored.

The 10%-soy doughnuts were significantly less moist than the 8%-soy doughnuts and the control. However, there was no difference between the 10% and 5% doughnuts in moistness.

Table 40. Sensory evaluation of doughnuts with 5%, 8% and 10% soy flour additions[y].

Treatment	Darkness	Tenderness	Soy Flavor	Gumminess	Moistness[1]	Oiliness	Preference[1]
C	8.14	10.51	1.86	7.86	7.49	6.09	7.55
5%	8.29[b]	8.73[az]	1.72[a]	8.12[a]	6.41[b]	6.40[a]	7.30[a]
8%	9.53[az]	8.55[az]	1.13[b]	7.57[a]	7.02[a]	6.77[a]	7.80[a]
10%	9.39[az]	8.92[az]	1.27[ab]	7.81[a]	6.40[bz]	6.89[a]	7.20[a]
C	8.14	10.51	1.86	7.86	7.49	6.09	7.55
F30	8.94[a]	9.39[a]	1.51[a]	7.66[a]	7.10[a]	6.75[a]	8.16[a]
F44	9.54[az]	8.99[abz]	1.37[a]	7.91[a]	6.55[ab]	7.13[a]	7.63[a]
D20	9.64[az]	8.63[bcz]	1.30[a]	7.91[a]	6.66[ab]	6.56[a]	7.36[ab]
D70	8.15[b]	7.95[cz]	1.32[a]	7.86[a]	6.08[bz]	6.34[a]	6.59[b]

[y] Means of two replications. Panelist no. = 8. Means with the same letter(s) within a column for each treatment are not significantly different ($p < 0.05$). No interactions among soy addition, type of flour and panelist.
0 = light, not tender, no soy flavor, not gummy, very dry, not oily and least preferred;
15 = dark, very tender, intense soy flavor, very gummy, very moist, very oily and most preferred.

[z] Significantly different from the control ($p < 0.05$).

[1] Significant interactions between soy addition and type of flour ($p < 0.05$).
C = control (no soy); F30 = full-fat 30 PDI; F44 = full-fat 44 PDI; D20 = defatted 20 PDI; and D70 = defatted 70 PDI.

The type of soy flour used affected the darkness, tenderness, moistness and preference of doughnuts. The F44 and D20 samples were significantly darker than the D70 sample and the control. The F44, D20 and D70 made doughnuts less tender than the control. A decrease in tenderness was more obvious in doughnuts with defatted soy flour additions, especially the D70 samples. Less fat absorption in these doughnuts could have decreased the tenderness. The D70 doughnuts were significantly less moist than the control and the F30 doughnuts. Again, less fat absorption might be the factor.

Although the D70 doughnuts had the least fat content, panelists preferred doughnuts made with full-fat soy flours. The tenderness and moistness contributed by the full-fat soy flours could be the reasons.

Cost analysis

The cost of soy flours are given as follow (based on 2,500 lbs quantities):

full-fat low stachyose (Natural Products, Inc.)	\$0.34/ lb
full-fat 30PDI (Natural Products, Inc.)	\$0.34/ lb
full-fat 44PDI (Natural Products, Inc.)	\$0.34/ lb
defatted 20PDI (Cargill, Inc.)	\$0.40/ lb
defatted 70PDI (Cargill, Inc.)	\$0.40/ lb

The price of soy flours are not affected by the PDI value. For quality purposes, one has to choose the proper soy flour with specific PDI and use it at the optimum level to achieve the desired quality of the bakery item. Soy flour is much cheaper (\$0.36/ lb on average) than NFDM (\$1.60/ lb) and dried whole egg solids (\$2.70/ lb), therefore if used for partial substitutions (30%) for NFDM and or egg, it will reduce the cost without significant changes in overall quality.

CONCLUSIONS

Thirty percent soy flour substitutions for NFDM, NFDM and egg combinations, did not change the overall quality of doughnuts as compared to the control.

Except for the full-fat low stachyose soy flour, other soy flours did not produce soy flavors or off-flavors in doughnuts (up to 10% soy flour addition). Although the defatted 70 PDI soy flour reduced the overall fat absorption by 40%, the doughnuts were less preferred by the panelists than doughnuts with full-fat soy flour added. Drier and less tender attributes occurred at higher addition levels which could be the reasons for lower preference. The full-fat 44 PDI soy flour reduced the fat absorption by 13% (overall), while preserving the sensory attributes of doughnuts in this study.

RECOMMENDATIONS

Substitutions for NFDM and or egg by soy flour reduced the cost of doughnut mixes. However, substitution at a level higher than 30% is not recommended due to "whitening" or loss of browning in the doughnuts, and change in texture and flavor qualities.

To balance between the fat absorption and eating quality of doughnuts, soy flour with PDI of 40 - 60 is recommended for 3 to 8% addition (flour weight basis). By adding soy flour into the mixes, the batch size increases with additional water, the nutritional quality improves, and the fat absorption decreases. These changes are beneficial to the doughnut manufacturers as well as to the consumers.

GENERAL CONCLUSIONS

Soy flours yielded 10 -30% more soymilk and produced 50% less waste (okara) than soy chips, soy flakes, and soybeans, using the Takai Automated Soymilk and Tofu System (steam injection cooking). Use of soy flour reduced the soymilk processing time while produced good quality soymilk. Soymilk made from soy flours, chips and flakes had significantly less fat than soymilk made from the whole beans. The lowest fat content was found in the LPLS-soy flour soymilk.

Despite better yield, soy flour made unacceptable tofu due to poor texture quality. No significant difference in "beaniness" was found among all the soymilk samples, while the LPLS-tofu was rated as less beany than the flake tofu.

When roasted full-fat soy flours of 30 and 44 PDI (protein dispersibility index) and defatted soy flours of 20 and 70 PDI were used for 30% NFDM and or egg substitutions in doughnuts, the color, texture, moisture, fat and protein contents, fat absorption, and the sensory attributes of the doughnuts were very similar among all the samples including the control (no soy).

Except for the full-fat low stachyose soy flour, other soy flours did not produce soy flavors or off-flavors in doughnuts (up to 10% soy flour addition). Although the defatted 70 PDI soy flour reduced the overall fat absorption by 40%, the doughnuts were less preferred by the panelists than doughnuts with full-fat soy flour added. The full-fat 44 PDI soy flour reduced the fat absorption by

13% (overall), while preserving the sensory attributes of doughnuts in this study.

APPENDIX 1. SENSORY SCORECARDS

Soymilk Sensory Scorecard

RESPONDANT CODE ___________________
DATE ________________

SENSORY CHARACTERISTICS OF SOYMILK

Place a mark perpendicular to the horizontal line corresponding to the intensity of the attributes. Label the mark with the 3-digit sample code.

YELLOWNESS - Intensity of yellowness

____

none intense

BROWNNESS - Intensity of brownness

____

none intense

NUTTINESS/ CEREAL/ PASTA FLAVOR - Flavor that is characteristic of nut, cereal or pasta

____

none intense

BEANINESS - Flavor that is characteristic of soy beans

____

none intense

ASTRINGENCY - Mouth-drying sensation

____

none intense

Do you find any off-flavor or any undesirable flavor other than the above attributes? If yes, please specify the attribute.

COMMENTS:

Tofu Sensory Scorecard

RESPONDANT CODE ____________________ DATE ________________

SENSORY CHARACTERISTICS OF TOFU

Place a mark perpendicular to the horizontal line corresponding to the intensity of the attributes. Label the mark with the 3-digit sample code.

YELLOWNESS - Intensity of yellowness

____

none intense

BROWNNESS - Intensity of brownness

____

none intense

SURFACE SMOOTHNESS - Absence of rough particles and cracks on the surface of tofu cube (surface texture)

____

very rough very smooth
(0 = crouton) (15 = silken tofu)

FIRMNESS - Amount of force required to bite through the sample between incisors at first bite

____

soft firm
(1= jello) (5 = cream cheese) (15 = cheddar cheese)

BEANINESS - Flavor that is characteristic of raw soy beans

____

none intense

Please specify any other flavor (if present) you find from any of these tofu samples:

Doughnut Sensory Scorecard

RESPONDANT CODE ________________ DATE __________

SENSORY EVALUATION OF CAKE DOUGHNUTS

Place a mark perpendicular to the horizontal line corresponding to the intensity of the attributes. Label the mark with the 3-digit sample code.

DARKNESS - intensity of darkness

____

light dark

TENDERNESS - degree of tenderness/ softness

____

not tender very tender

SOY FLAVOR - intensity of soy flavor **if present**

____

none intense

GUMMINESS - stickiness within sample

____

not gummy very gummy

MOISTNESS - amount of wetness present (water and oil)

____

very dry very moist

OILINESS/ GREASINESS - amount of oil residues left on fingers

____

not oily very oily

PREFERENCE

____

least preferred most preferred

Cake Doughnut Consumer Evaluation Scorecard

CAKE DOUGHNUT CONSUMER EVALUATION

1. What is your age?

______ under 10 ______ 10-19 ______ 20-29 ______ 30-39
______ 40-49 ______ 50-59 ______ 60-69 ______ 70+

2. Are you ______ male or _______ female?

3. How often do you eat doughnut?

______ Two or more times per week ______ Once per month
______ Once per week ______ Once every three months
______ Every other week ______ Once every six months
______ I do not eat donut

4. Please evaluate the two doughnut samples:

(please check)	**631**	**482**
	______ Like Extremely	______ Like Extremely
	______ Like Moderately	______ Like Moderately
	______ Like Slightly	______ Like Slightly
	______ Neutral	______ Neutral
	______ Dislike Slightly	______ Dislike Slightly
	______ Dislike Moderately	______ Dislike Moderately
	______ Dislike Extremely	______ Dislike Extremely

5. Which doughnut do you prefer...

for texture? ______ 631 ______ 482

for flavor? ______ 631 ______ 482

for less greasiness? ______ 631 ______ 482

6. Overall, which one do you prefer? ______ 631 ______ 482

THANK YOU!

Donut Triangle Test

PRODUCT: Cake donuts
NAME OR INITIAL ______________________ DATE ___________

Two of these three samples are identical, the third is different. Evaluate and taste the samples in the order indicated and identify (mark) the odd or different sample.

Code	Check the odd or different sample
______	______
______	______
______	______

What makes the odd one different? Based on (please check all that apply):

Color	______	specify ____________________________________
Appearance (e.g. shape, size, cracks etc.)	______	specify ____________________________________
Texture	______	specify ____________________________________
Flavor	______	specify ____________________________________

APPENDIX 2. ADDITIONAL TABLES AND FIGURES

Table 41. The Hunter L, a and b values of raw soy ingredients used in soymilk processing[z].

sample	L	a	b
LPLS	90.48[a]	-0.70[d]	19.02[d]
	±0.57	*±0.10*	*±0.18*
LP	90.76[a]	-0.58[d]	20.47[c]
	±0.27	*±0.04*	*±0.63*
SF	89.91[a]	-0.22[c]	16.59[e]
	±0.03	*±0.05*	*±1.10*
CH	65.57[c]	3.95[a]	22.58[b]
	±0.55	*±0.22*	*±0.50*
F	79.89[b]	1.06[b]	24.02[a]
	±0.72	*±0.11*	*±0.38*

[z] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$). LPLS = low lipoxygenase and low stachyose soy flour; LP = low lipoxygenase soy flour; SF = regular soy flour; CH = soy chips; F = soy flakes.

Table 42. The Hunter L, a and b values of raw soy ingredients used in tofu processing[z].

sample	L	a	b
LPLS	90.30[a]	-0.76[c]	18.47[b]
	±0.10	*±-0.05*	*±0.29*
SF	89.14[a]	-0.44[c]	16.86[b]
	±0.61	*±-0.12*	*±2.07*
G	76.59[c]	2.04[a]	23.22[a]
	±2.56	*± 0.35*	*±0.30*
F	82.79[b]	0.59[b]	21.33[a]
	±0.86	*± 0.22*	*±0.77*

[z] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$). LPLS = low lipoxygenase and low stachyose soy flour; SF = regular soy flour; G = soy grits; F = soy flakes.

Table 43. The proximate analysis of raw soy ingredients used in soymilk processing[x].

sample	%M	%S	%Fdb	%Fwb	%Pdb	%Pwb	%C+Adb[y]
LPLS	7.86[b]	92.14[b]	21.30[b]	19.63[b]	44.95[a]	41.35[a]	33.76[c]
	±0.84	*±0.84*	*±1.03*	*±0.96*	*±0.81*	*±0.46*	*±1.31*
LP	7.43[bc]	92.57[ab]	22.87[a]	21.17[a]	43.17[b]	39.96[b]	33.97[c]
	±0.76	*±0.76*	*±0.96*	*±0.94*	*±0.46*	*±0.50*	*±0.94*
SF	7.88[b]	92.12[b]	21.11[b]	19.45[b]	40.45[cd]	37.26[d]	38.44[b]
	±0.13	*±0.13*	*±2.09*	*±1.91*	*±1.77*	*±1.61*	*±3.56*
CH[z]	11.05[a]	88.95[c]	17.85[c]	15.87[c]	40.08[d]	35.66[e]	42.07[a]
	±0.72	*±0.72*	*±1.72*	*±1.52*	*±1.27*	*±1.29*	*±1.25*
BN	8.06[b]	91.94[b]	21.21[b]	19.50[b]	39.53[d]	36.35[de]	39.26[b]
	±1.20	*±1.20*	*±0.94*	*±0.79*	*±0.85*	*±1.19*	*±1.01*
F	7.04[c]	92.96[a]	20.82[b]	19.35[b]	41.43[c]	38.51[c]	37.75[b]
	±0.68	*±0.68*	*±1.94*	*±1.80*	*±1.22*	*±1.06*	*±2.27*

[x] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).
[y] %C+Adb = 100%-%Fdb-%Pdb.
[z] Lower fat content due to incomplete extraction from coarse chips, which gave higher carbohydrates content (calculated by difference). %M = percent moisture; %S = percent solids; %Fdb = percent fat in dry basis; %Fwb = percent fat in wet basis; %Pdb = percent protein in dry basis; %Pwb = percent protein in wet basis; %C+Adb = percent carbohydrates and ash in dry basis; LPLS = low lipoxygenase and low stachyose soy flour; LP = low lipoxygenase soy flour; SF = regular soy flour; CH = soy chips; BN = soybeans; and F = soy flakes.

Table 44. The proximate analysis of raw soy ingredients used in tofu processing[y].

sample	%M	%S	%Fdb	%Fwb	%Pdb	%Pwb	%C+Adb[z]
LPLS	8.44^{b}	91.56^{b}	21.98^{ab}	20.13^{b}	44.63^{a}	40.86^{a}	33.39^{c}
	±0.94	*±0.94*	*±0.03*	*±0.23*	*±0.36*	*±0.50*	*±0.37*
SF	8.95^{b}	91.05^{b}	21.79^{b}	19.84^{b}	41.59^{b}	37.87^{b}	36.62^{b}
	±0.16	*±0.16*	*±0.51*	*±0.44*	*±2.62*	*±2.34*	*±3.08*
G	10.75^{a}	89.25^{c}	19.91^{c}	17.77^{d}	40.85^{bc}	36.46^{bc}	39.24^{a}
	±0.49	*±0.49*	*±0.56*	*±0.43*	*±0.51*	*±0.57*	*±0.71*
BN	9.16^{b}	90.84^{b}	20.37^{c}	18.50^{c}	39.37^{c}	35.76^{c}	40.26^{a}
	±0.27	*±0.27*	*±0.36*	*±0.38*	*±0.55*	*±0.60*	*±0.83*
F	7.42^{c}	92.58^{a}	22.40^{a}	20.74^{a}	40.41^{bc}	37.42^{b}	37.19^{b}
	±1.33	*±1.33*	*±0.52*	*±0.69*	*±0.98*	*±1.10*	*±1.05*

[y] Means of three replications. Means with the same letter(s) within a column are not significantly different ($p < 0.05$).
[z] %C+Adb = 100%-%Fdb-%Pdb.

%M = percent moisture; %S = percent solids; %Fdb = percent fat in dry basis; %Fwb = percent fat in wet basis; %Pdb = percent protein in dry basis; %Pwb = percent protein in wet basis; %C+Adb = percent carbohydrates and ash in dry basis; LPLS = low lipoxygenase and low stachyose soy flour; SF = regular soy flour; G = soy grits; BN = soybeans; and F = soy flakes.

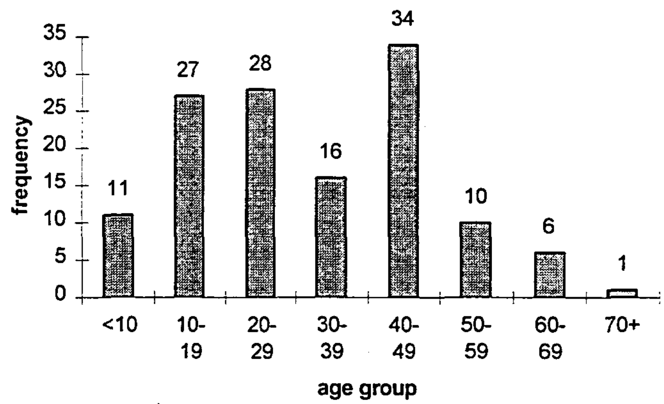

Figure 12. The distribution of age groups.

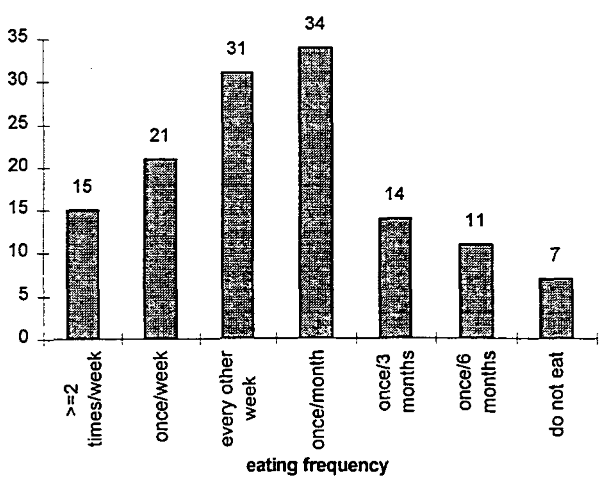

Figure 13. The distribution of eating frequency.

Table 45. The proximate analysis (wet basis) of dough with soy flour additions[y].

Treatment	%M	%F[1]	%P[1]
C	38.43	4.78	6.45
5%	37.91[az]	5.03[b]	7.17[cz]
8%	36.21[bz]	5.22[a]	7.69[bz]
10%	36.20[bz]	5.23[a]	7.98[az]
C	38.43	4.78	6.45
F30	36.82[ab]	5.43[az]	7.42[bz]
F44	36.82[ab]	5.52[az]	7.47[bz]
D20	36.89[a]	4.87[b]	7.77[az]
D70	36.58[bz]	4.84[b]	7.80[az]

[y] Means of two replications. Means with the same letter(s) within a column for each treatment are not significantly different ($p < 0.05$).
[z] Significantly different from the control ($p < 0.05$).
[1] Significant interactions between soy addition and type of flour ($p < 0.05$).
%M = percent moisture; %F = percent fat; %P = percent protein;
C = control (no soy); F30 = full-fat 30 PDI; F44 = full-fat 44 PDI;
D20 = defatted 20 PDI and D70 = defatted 70 PDI.

APPENDIX 3. PRELIMINARY DATA FOR DOUGHNUT STUDY

The cake doughnut formula was adopted from Murphy-Hanson et al. (1992) with some modification in the mixing procedure (p. 71). Roasted soy flours, (1) full-fat-30PDI (F30), (2) full-fat-44PDI (F44), (3) full-fat, low-stachyose-19PDI (FLS19), (4) defatted-20PDI (D20)and (5) defatted-70PDI (D70), were substituted for flour, non-fat dry milk (NFDM), dried egg solids, and combinations of these at different levels. Doughnuts were tested in several triangle tests (Appendix 5) for differences (if any).

Table 46. Summary for doughnut triangle tests

Sample	No. of correct answers	Significance at α =0.05
(Flour substitution)		
C[a] vs. 3% F30	11/17	Yes
C vs. 5% F30	10/17	Yes
C vs. 3% F44	8/16	No
C vs. 3% FLS19	10/17	Yes
3% F30 vs. 3% F44	4/15	No
3% F30 vs. 3% FLS19	6/16	No
C vs. 3% D20	3/14	No
C vs. 3% D70	6/13	No
3% D20 vs. 3% D70	4/15	No
3% F30 vs. 3% D20	5/16	No
3% F44 vs. 3% D70	7/16	No

[a] C = control (no soy); FLS19 = full-fat low stachyose with 19 PDI; F30 = full-fat 30 PDI; F44 = full-fat 44 PDI; D20 = defatted 20 PDI and D70 = defatted 70 PDI.

When soy doughnuts containing F30 and FLS soy flours were tested against the control (no soy), panelists detected the odd one based on color, texture and or flavor differences (except the control and 3% F44 combination). Panelists could not tell the difference between the control and the ones with defatted soy flours. However, when two types of soy doughnuts were compared, the differences were not significant for all combinations. Presence of soy flour in both samples reduced the differences between doughnuts.

For economical reason, soy flour was used to substitute 30%, 40%, 50% and 100% of the NFDM and egg individually. Replacement of NFDM at level higher than 30% produced “whiter” doughnuts and the “whitening” effect was extreme at 100% substitution. This was most likely due to the loss of browning reaction without the NFDM

When dried egg solids were substituted at level higher than 30%, doughnuts tended to have drier mouthfeel and less flavor.

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