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Physicochemical and Sensory Properties of a Chip-type Snack Food Based on Defatted Peanut and Soy Flour

(Under the direction of YAO-WEN HUANG)

Raw peanuts contain 45% oil, and mechanical extraction leaves 12-14% fat in the press cake. Peanut press cake is rich in protein and relatively low in fat; however, almost all of it is currently used as animal feed or fertilizer since the peanuts used in the oil extraction process are not edible grade. The goal of this research was to develop a chip-type snack food based on partially defatted flour processed from edible grade peanuts.

In a preliminary experiment, chips were produced from a mixture of peanut flour and either soy or corn flour. A consumer test showed that the panelists did not consider the chips completely acceptable. However, peanut-corn chips had a higher rating than peanut-soy chips for overall liking (4.9 versus 4.4, on a 9-point hedonic scale) and acceptability (46.7% considered the peanut-corn acceptable, compared with 40.7% for peanut-soy chips).

A second generation of peanut chips was produced by mixing 3 parts of peanut flour with 1 part of soy flour or wheat flour, cornstarch, peanut butter and sugar. A trained panel characterized the sensory attributes of the peanut chips in an analytical sensory test. Only a few significant differences in sensory quality were found between the peanut-soy chips and the peanut-wheat chips. However, the hardness appeared to be the biggest concern about the new product, with shear stress values close to 1000 N/g.

In a third experiment a new series of peanut chips was produced, containing peanut flour and soy in the ratio of 3:1, in addition to variable amounts of sugar, starch and peanut butter. A factorial design was used, with sugar, starch and peanut butter at three different levels. Twenty-seven formulations were produced in replicate. Kramer shear force, instrumental color and consumer acceptability were analyzed. The Kramer shear value was 441 N/g chip in formulations with high percentages of sugar, starch and peanut butter. Response surface methodology (RSM) was applied to investigate the optimum levels of each ingredient in the chips. Contour plots were built for each physical and sensory characteristic. They showed that chips made with the highest level of sugar, starch and peanut butter were about half as hard as chips made with the lowest level of each ingredient.

INDEX WORDS: Peanut flour, Soy flour, Dough sheeting, Impingement oven, Kramer shear, Optimization, Acceptability, Consumer testing, Snack chips.

PHYSICOCHEMICAL AND SENSORY PROPERTIES OF A CHIP-TYPE SNACK FOOD BASED ON DEFATTED PEANUT AND SOY FLOUR

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INTRODUCTION

Snacks are food consumed between meals. In today's hectic lifestyle, meals are often taken on the run, between classes, in the car and on the work desk. Snack foods are becoming part of everybody's life, and often consumed in place of regular meals. Furthermore, with more and more people attending every level of school, the general population is becoming more educated, and thus pays more attention to what they are eating. The USDA has succeeded in making everybody at least vaguely aware of the food pyramid. The result is that the choice of snack foods is becoming more sophisticated, and traditional potato chips or corn chips are not enough anymore. Consumers look for more protein, more vitamins, more fiber and less (saturated) fat.

Most snack foods produced today consist of starch from cereals, tubers or roots. However, in different countries, popular snacks are already enriched with protein from animal or vegetable origin (Suknark, 1998). In Southeast Asia it is possible to buy snack products made with tapioca and minced fish. However, vegetable proteins are less expensive and can be produced everywhere on earth provided there is some availability of water. Peanut (Woodroof, 1983) and soybean (Liu, 1997) are excellent sources of proteins that can be used to fortify starch-based snacks.

This dissertation describes the study and the production of a new snack food based on defatted peanut meal enriched with soybean, corn or wheat flour.

The first section covers the literature review, which describes the nutritional characteristics of peanuts and other nuts and the health benefits derived from eating unsaturated fatty acids. It also describes the challenge of producing a soft and tasty snack using peanut meal, because of the hard texture normally resulting from baking high-protein dough. In fact, proteins tend to form a harder network than starch. Therefore, peanut meal needs to be mixed with other ingredients that break the protein network and help in softening the texture of the chips. Soybean flour has the potential to be an important component of the chip, because of its content in protein and isoflavones. Response surface methodology (RSM) and consumer tests are also briefly discussed in Section 1.

Section II describes a first generation of experimental peanut chips obtained by mixing three parts of peanut meal and one part of either soy or corn flour, plus a minimum amount of sugar, salt and baking powder. The peanut meal was obtained by grinding the press cake produced as a co-product of industrial peanut oil extraction, using edible grade peanuts. The peanut press cake was provided by a Georgia company and was pellet-shaped. A consumer sensory test determined the acceptability of the chips.

Section III describes a new experiment in which different peanut chips were produced. The objective of this experiment was to improve not only the texture and acceptability of the peanut chips, but also our knowledge of the effect of increasing or decreasing the amount of different flour components, that is, peanut, soy or wheat flour. To this purpose, we hired and trained a sensory panel. The ensuing quantitative sensory test was expected to result in the measurement of the sensory qualities of chips produced using different levels of peanut, soy or wheat flour (Stone and Sidel, 1993). As in Section II, peanut chips were produced using flour derived from grinding pellet-shaped peanut press cake. The chips were fortified with soy flour or wheat flour. Corn was abandoned because of its longer baking time and its bland flavor. Soy and wheat were selected because of their respective advantages over corn, soy being rich in protein and isoflavones, wheat being tasty and easy to bake. To overcome the beany taste associated with soybean flour, peanut butter was added. Cornstarch was also added in order to improve the texture of chips that consumer panelists in the first experiment had rated too hard (4.4 to 4.5 on a 9-point hedonic scale). Sensory attributes of the chips were identified and quantitatively rated. Ratings were correlated with the results of the instrumental analysis. Results showed that hard texture and low peanut flavor were problems still present in the new peanut chips. The conclusion was that fortifying peanut chips with soy or wheat did not produce all the anticipated improvements in terms of texture and flavor.

Section IV shows the results of a new study in which components of the chips that had not been tested in Section III were analyzed. The new experiment was prompted by the results of literature research. Matz (1989) had stated that sugar, cornstarch and shortening had a softening effect on baked products. Peanut butter as shortening was chosen in the hope it could improve the flavor while at the same time softening the texture. Section IV describes a full factorial design in which chips, beside containing peanut meal and soy flour in the ratio of

3:1, contained sugar, starch and peanut butter at three different levels, for a total of 27 formulations. Three extra formulations were added as a “dummy control”, containing wheat flour instead of soy flour. The objective was to study how the physical and sensory characteristics of the chips were affected by varying the levels of the ingredients assumed to be responsible for chip texture: sugar, starch and peanut butter. Response surface methodology (RSM) was applied and contour plots were generated. Results showed that peanut chips were softer and more acceptable to consumers when the percentage of sugar, starch and peanut butter was increased. Optimal conditions for a soft texture are met when 10-15% starch, at least 20% peanut butter and at least 12% sugar are used. The results of the study show that the commercial production of a new, healthy chip-type snack food is feasible. This would have a positive economic impact on the peanut growers of Georgia, and would offer consumers a convenient and healthy new product. Section V contains the summary and conclusions of the three studies reported in sections II through IV.

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SECTION I

LITERATURE REVIEW

Snacks are foods eaten between meals; they tend to be high in calories and fat (Ranhotra and Vetter, 1991), but low in protein, vitamins and other nutrients. They can be either salty or sweet, like crackers, cookies, popcorn, potato chips, doughnuts and chocolate. Snack foods are very popular in the United States. The rate of snack food sales has been growing steadily in the last 10 years (Anonymous, 2001) with increases between 6.2% and 8.5% in the last 4 years on record. Among the snack foods, peanuts have particularly suffered from a negative trend, affected by popular perception about healthy foods. In 1996, peanut sales were at the lowest value in many years, due to a lack of new products, a decrease in marketing and promotional efforts and consumer concern over food allergy and fat content (Wilkes, 2001). Research efforts have changed that. Epidemiological and animal studies have shown that nuts (peanuts, walnuts, pistachios, etc.) offer several health benefits. Kris-Etherton *et al.* (1999) found that high-monounsaturated fatty acids lower both plasma cholesterol and triacylglycerol concentration. Furthermore, diets high in peanuts can reduce LDL susceptibility to oxidation and consequently reduce the chances of arteriosclerosis (Sabate, 1999). Other researchers (Awad *et al.*, 2000) discovered that peanuts contain β-sitosterol, a phytosterol that inhibits cancer growth (Kris-Etherton *et al.,* 1999). After the publication of the results of such research efforts and more intense advertisement, nut sales were up 50% in 2000 compared to 1996 (Anonymous, 2001). That is good news for the United States and in particular for the state of Georgia, a big producer of peanuts. For the year 2001, the estimated harvest of peanuts in the U.S. will be 4,239 million pounds (farmer stock equivalent) (Anonymous, 2002), the largest since 1994/1995 and almost a billion pounds up from the previous year. The yield will be a record 3000 pounds/acre, thanks to good weather and technological improvements in determining the best time for harvesting (Anonymous, 2002). The internal market will absorb 2,250 million pounds (53%) for food use; the rest will be exported (750 million pounds) or crushed (725 million pounds) for oil.

Chip-type snack foods are very popular all over the world because of their desirable sensory attributes and convenience. Hundreds of new products are introduced into the market every year (Anonymous, 1998). Starting in the nineties, under the pressure of a public concerned about too many calories in the American diet, companies began to produce low- and no-fat foods (Anonymous, 1998). However, today's consumers are more educated about nutritional values and have realized that certain kinds of fat are healthier (and more tasteful) than no fat. Companies are offering more healthy snack foods, with calcium, vitamins, fiber, proteins and some fat, possibly unsaturated (Malovany, 2001). More and more healthy snack foods will become available in the next years, because the interest of consumers is strong. Two basic technologies are used today for the production of snacks: extrusion and sheeting (Shukla, 2000).

Extrusion cooking is a high-temperature, short time process that combines the operations of feed transport, mixing, working, and forming in an efficient way to transform raw ingredients into intermediate and finished products (Harper, 1989). The raw material is fed into the hopper, and from there it is transported down the barrel, where it is transformed into a fluid paste by pressure, temperature and mechanical shear. Cooking takes place in the barrel. After being cooked, the food material is shaped at the die, at the end of the barrel (Baird and Reed, 1989). Two types of extruders are used, the single-screw and the twin-screw. The first is simpler, designed to convey feed down the barrel and create pressure at the die (Frame, 1994). The second can be of different types, depending on the relative direction of screw rotation, counter- and co- rotating, and degree of intermeshing (Harper, 1989). The twin-screw extruder is more expensive than the single-screw extruder, but it provides better conveying and mixing capability. Its co-rotating twin screws can intermesh and move feed material with both drag flow and positive displacement flow (Frame, 1994). The variables of the extrusion process are temperature, screw speed, screw configuration and feed rate (Suknark, 1998). Barrel temperature is an important factor in the quality of extrudates. At temperatures above 100 °C, water contained in the feed evaporates rapidly when passing through the die and results in direct-expanded products (Kinsella, 1978; Moore, 1994). In the so-called "half products", the dough is cooked in the barrel, but puffing is prevented by keeping the temperature at the die below 100 °C. The temperature in the barrel should be between 120 and 150 °C (Kinsella, 1978). In this temperature range the food has high viscosity, does not create excessive pressure at the die (Colonna *et al*., 1989), and reaches a high degree of expansion in the final product (Frame, 1994). Screw speed affects the residence time and the shear stress of the extruded materials (Colonna *et al*., 1989). High screw speed increases shear rate and product temperature, increasing the chances of damage to the food molecules (Harper, 1986). High shear rate at the die also reduces the starch molecular size, resulting in small-pore extrudates with low mechanical strength (Harper, 1986). Screw configuration is another way to affect the shear stress on the dough. Screw elements are added on the transport barrel, such as mixing paddles, reverse screws, cut flights and orifice plugs (Gogoi *et al*., 1996) to add mechanical energy to the transported food, and accelerate chemical processes such as starch gelatinization (Yam *et al*., 1994). Feed rate can affect the pressure at the die and the speed of mechanical transformation of food (Colonna *et al*., 1989). Twin-screw extrusion is more versatile than single-screw, allowing a more efficient mixing of the ingredients. Twin-screw extrusion was used by Suknark *et al*. (1999) to produce tapioca-fish and tapioca-peanut snacks and to determine the optimal extrusion conditions. Increasing temperature and screw speed resulted in increased expansion and decreased bulk density and shear strength. Both half products were best when the barrel temperature was between 95 °C and 100 °C and the speed ranged between 230 and 400 rpm.

Extrusion is a very efficient technology. However, it has also a harsh effect on some nutrients, such as vitamins. Some experiments showed how vitamins are affected by extrusion. Retinyl palmitate was reduced to 48% of its starting value in fish half-products and to 27% in peanut half-products (Suknark *et al*. 2001). Also tocopherols are damaged. However, after being fried, products may contain more vitamin E than the starting material because tocopherols are absorbed from the oil during deep fat frying (Suknark *et al*., 2001). Folic acid and vitamins B1 and B2 are severely damaged by extrusion (Cheftel, 1986). Carotenoids are resistant, but the porosity of the expanded snacks makes them susceptible to oxidation of carotenoids during later storage. Twenty to forty percent losses of vitamin C are constantly observed during extrusion, probably as a result of enhanced oxidation at high temperature (Cheftel, 1986).

Protein digestibility is generally increased by extrusion, particularly at higher temperature. However, enzyme activity is destroyed. Lipoxygenase is almost completely inactivated, with different efficiency for the three enzymatic species (L2>L1>L3) (Guzman *et a*l., 1989; Zhu *et al*., 1996). Isoflavones, a family of potent natural inhibitors of cancer cell proliferation, are not significantly affected (Mahungu *et al*., 1999). However, more recent studies determined that extrusion reduced the isoflavone content by 24%, not enough to cause reduction in its health benefit (Singletary *et al*., 2000).

Sheeting

Sheeting technology is simpler than extrusion and is easily available. Sheeting is the process of compacting and gauging the mass of dough into a sheet of even thickness and at the full width of the band. The dough sheet must have no significant holes, and the edges should be smooth, not ragged (Faridi, 1990). Sheeting is the direct industrial derivation of the age-old process of rolling dough in the home kitchen with a rolling pin on a flat table. The sheeting of dough is used in the baking industry for the production of cookies, pizza, bread and pastry doughs, as well as Mexican specialties such as tacos and tortillas

(Levine and Drew, 1990). It used to be the only method available for making pasta, but extrusion is more often used today. The snack industry makes wide use of sheeting for the production of fabricated snacks such as potato ‘crisps’ (such as Pringles®) and corn chips.

Few studies exist on the technical and quantitative aspects of sheeting. One from Kilborn and Tipples (1974) shows that the process of sheeting has the effect of “developing” the dough, resulting in bread loaves with higher volume. Photomicrographs of hard wheat dough revealed that proteins tend to form a network under the stress produced by sheeting. Excessive sheeting, however, tends to break down such network. Kilborn and Tipples (1974) observed that only 25% of the energy operating the rolls finds its way into the dough. The rest is lost as attrition and resistance, both from the dough and the mechanical components of the motor. The passage from the pilot laboratory to industrial production is usually accomplished by increasing the diameter of the rolls and their speed. However, higher roll diameter and higher speed result in higher energy input into the dough, which may affect the quality of the product. As a result, the scaling-up process from pilot plant to mass production in the industry can present problems difficult to solve. From Levine and Drew (1990), Levine and Levine (1997) and Levine (1998) studies on the sheeting process, some conclusions were that 1) the reduction ratio of dough into sheet should be small, otherwise the work required for sheeting would be too high and the quality of the product would suffer. It is better to use several reducing steps, possibly involving multiple rollers instead of a single one; 2) when several reducing steps need to be applied, it is better to use the more energetic steps in the beginning, and the less energetic at the end, when the dough is thinner; 3) high speed sheeting, as well as high ratio of roller diameter vs. gap, are hard on the quality of the product. The maximum pressure exerted by the rolls increases with the square root of the roll diameter; 4) there is a substantial spring back of the dough sheet after passing through the rollers, and the spring back increases as the ratio between roller diameter and gap increases; 5) when assembling a pair of rollers on a sheeter, care must be applied to center the shaft with respect to the roller, or the sheeted dough will be uneven.

Peanuts

Peanut (*Arachis hypogaea),* also known as groundnut, is a good source of food for the human diet (Woodroof, 1983). Peanut has a relatively high protein content (28%) (Woodroof, 1983), a pleasant flavor and a light tan color that facilitates its incorporation into a wide range of food products (Prinyawiwatkul *et al*., 1995). Like most legumes, peanuts are relatively low in sulphur-containing essential amino acids and tryptophan. The amount of another essential amino acid, lysine, is also low, but greater than in cereal grains (Duranti and Gius, 1997). However, other authors (Miller *et al*., 1978) studied the nutritional quality of meal made from different cultivars of peanut as measured by rat bioassay. They determined that the nutritional quality of peanut is low because the concentration of some essential amino acids is lower than required for growth of young animals. The protein efficiency ratio (PER) of peanut is 50 - 75% compared to casein, considered the reference standard (100%). The requirement in lysine was appraised at 1.0% of the total amino acids, against the determined average value of 0.5% in the studied cultivars. Threonine requirement was determined at 0.56%, while the authors detected 0.40%. The total requirement of methionine and cystine together was determined to be 0.67%, against the observed concentration of 0.14 for methionine and 0.16 for cystine in the studied cultivars. Such findings were confirmed by Khalil and Chughtai (1983). These authors studied the nutritional quality of peanut in 5 cultivars grown in Pakistan. They determined that lysine was the first limiting amino acid in 3 cultivars, followed by threonine, methionine and cystine. These amino acids suffer the biggest loss in the roasting process. Other essential amino acids such as leucine, phenylalanine and tyrosine were adequate.

In the United States, most of the peanut crop is marketed for direct consumption as roasted kernels or used to make peanut butter or cookies. In many countries of the world, peanuts are grown mainly for crushing (Woodroof, 1983). There are different methods for crushing. In developing countries such as Nigeria, oil is traditionally extracted from peanuts by primitive methods such as aqueous extraction or by hand pressing, so that little oil is obtained, and of poor quality. Bigger processors work by hydraulic or screw pressing, the latter method being more efficient. Two authors (Adeeko and Ajibola, 1990) described a study on the best conditions for peanut oil extraction. Increasing pressure yields more oil until a limit of 20 MPa. At higher pressure the oil production levels off or decreases. Moisture content also is a critical factor, with 6% moisture being the optimal amount. Above 6% the oil yield decreases in efficiency.

Heating helps by decreasing the oil viscosity, and in such way increasing the oil production. The heating time has been studied, and an upper limit of 25 min has been found to be the most efficient. India, the country with the largest production of peanuts, has a large industry of peanut oil extraction and relies mainly on expeller pressing methods. As in Nigeria, efficiency in oil extraction relies on the traditional system of leaving the skin on the kernels, and adding 1-2% of the hulls, so to facilitate extraction. The oil extraction leaves a press cake that is high in protein (40%) and low in fat (14%), is high in phenolic pigments and fibers, and is used as animal feed or fertilizer (Chavan *et al.,* 1991), if processed from non-food grade peanuts. Part the press cake is even exported.

Chavan's study described how the press cake, usually unfit for human consumption, can be obtained so to be food-grade. Peanuts were first deskinned, by means of pre-chilling the kernels at 4° C or alternatively by pre-heating them for 20 min at 80° C. The cake obtained from oil extraction was milled in a laboratory grinder to produce partially defatted peanut meal. Peanut meal was added to wheat flour in the proportion of 10, 20 or 30%, and used to produce bread, buns, cupcakes or doughnuts. A partially trained sensory panel judged the baked products containing 10% defatted peanut meal to be undistinguishable from the original products, but to become less and less acceptable when the peanut component was increased to 20 and 30%. Of particular importance was the fact that inclusion of defatted peanut meal resulted in denser, less expanded volume breads. There were two possible reasons for that, one being that peanut meal had higher water holding capacity, and the other that gluten, which is responsible for forming air cells in the dough during bread baking, was less effective because of being diluted by peanut meal. Other undesirable effects of enriching the wheat flour with 20 or 30% peanut meal were that the crumb was coarse and yellowish, and products had an unpleasant peanut aroma and taste and an unappealing brown color. The same author reported that defatted peanuts extracted with solvent (n-hexane) were considered more suitable for human consumption. Also the press cake could be made food-grade if the skin and hulls were removed from the peanuts prior to extraction and sanitary conditions observed in the processing plant.

Peanut, also known as groundnut, is one of the world's principal oilseed crops (Freeman *et*. *al*., 1999). The price of groundnut oil and meal has oscillated in the years between 1979 and 1996. The peak was reached in 1981, rising above $1000 per ton; the lowest level was reached in 1987 at $504 per ton. The two main reasons for such variability were the drought in Senegal and Sudan, among the largest exporters of peanut oil, and the shift of Argentina from groundnut production to soybean, considered a more lucrative crop. Factors of price variability are the thin market of groundnuts (the major producers such as India and China use most of their product for the internal market) and its substitutability. Substitutability means that peanut oil can be easily substituted by other oils, above all soybean, sunflower, cottonseed and rapeseed, even if peanut oil drew constantly higher prices in the years 1979-1996, being considered higher in quality. High substitutability, however, assures that international prices of all vegetable oil are closely correlated. Also oilseed meals are substitutable as animal feed, soybean meal being considered superior for protein content, digestibility and palatability for livestock. The international prices of peanut meal oscillated between $ 240 (1980) and $ 98 (1985) per ton. The historical trend indicates a long-term decline in price of groundnut meal, reflecting increasing competition from alternative protein sources (both oilseeds and cereals). For example, the share in import of the European Community has declined from 22% in 1979-81 to 5% in 1994-96, due to a reduction in livestock production after the bovine spongiformis encephalopathy (BSE) crisis, and the rising utilization of alternative, less expensive meals for animal feed. However, the medium term prediction of peanut utilization is that consumption of peanut oil and peanut meal will continue to grow, even if at a slower pace than in the 1970's and 80's, conditioned by population growth and, above all, by global improvement of per-capita income.

Considering that peanut meal can be of food-grade, finding an application for it, for example as a snack food, would be beneficial for consumers and for the economy of many countries. This would be true in particular for the United States, one of the largest peanut producing countries in the world, after India and China, and the top exporter (Anonymous, 2002). The world economy today cannot afford to waste anything. Waste represents not only lower profits but also the even bigger problem of disposal. Space is growing scarce in this overpopulated planet. Another example is represented by peanut hulls, which are filling the yards of peanut processing plants. Efforts to eliminate any peanut industry waste should be welcomed. For example, Johnson *et al*. (2002)

successfully used peanut hull pellets to absorb copper ions from wastewater, and Omar *et al*. (2002) developed a way to use acid-treated hulls from peanut (and other oilseeds) for bleaching vegetable oils.

Our work aimed at utilizing protein-rich peanut meal to produce nutritious snack foods for humans. A chip-type snack food, to be successful on the market, needs to be tasty, flavorful and crisp. A crisp, easily breakable texture is not always easy to accomplish in a new chip-type snack food. It requires a balance of ingredients and cooking procedures. Baked sweet snacks (cookies) technology indicates that the continuous structure of the cookie generally arises from components of the flour (Matz, 1989). The basic framework is constituted by either protein or starch, or both, and is tenderized by such components as sugar, egg yolk, ammonia, sodium bicarbonate (or baking powder), and shortening (Matz, 1993). A wide variety of flours are being used for sweet biscuits, ranging from a soft (low-protein) cookie flour to a rather strong (high-protein) sponge flour. Increasing protein content of the flour increases water absorption and makes the dough “bucky” and difficult to roll out. Diluting the high-protein flour with starch improves rollability (Miller and Trimbo, 1970). A high-protein flour leads to hardness of texture and coarseness of internal grains and surface appearance (Matz, 1993). Tenderness was found to be inversely related to the protein content of the flour, and the effect of the protein was accentuated when the water content of the dough was increased (Miller and Trimbo, 1970). Furthermore, crusts become softer with increased shortening content and decreasing water level. Piecrusts made with soft shortening were more tender than crusts made with hard shortenings. Dextrose can often be substituted for up to 20% of the sucrose. If it is used with care, invert syrup may make some cookies, particularly wafers, softer, lighter and spongier, with a more open texture (Matz, 1993). Lecithin in the amount of 0.4% will improve machinability.

Matz (1989) summarized his findings about the baking technology with a list of tougheners (binding materials) and softeners for cookies. Tougheners are: (1) Flour; (2) Water-because it hydrates the gluten; (3) Milk solids-not very effective as binders in the amounts normally found in cookie doughs; (4) Egg whites; (5) Egg yolks-which act as tougheners because of their protein content and as tenderizers because they contain fat and emulsifiers; (6) Cocoa or chocolate products; (7) Leavening acids; (8) Salt; (9) Oat flour; (10) Soy flour. Tenderizing materials include: (1) Sugar, probably the most important tenderizer in cookies; (2) Shortenings; (3) Emulsifiers; (4) Leavenings-because a more porous, "lighter" structure seems softer; (5) Egg yolks-see comment in tougheners' discussion; (6) Corn starch or wheat starch; (7) Corn flour; and (8) Ground raisins or ground dates. Generally, non-reactive (inert) substances act as tenderizers. Stewart (1984) described a method to produce crackers without yeast, but using sodium bicarbonate and ammonium bicarbonate. Proteases were added (0.03%) to make the dough less stiff and easier to handle.

Studies with extruded products have also shown that high protein content is not compatible with a soft, crunchy chip (Faubion and Hoseney, 1982; Paton and Spratt, 1984). The degree of expansion of extruded products determines their bulk density and their texture characteristics of hardness, crunchiness or crispness. The more expanded an extruded product is, the softer its texture and the lower its shear strength. Expansion is inversely related to density and is the result of air cell formation in the dough, with the starch and proteins forming a network. However, starch and protein play a different role. Expansion may actually be reduced by the addition of proteins to a starchy system (Prinyawiwatkul *et al*., 1995), because proteins form a stronger and harder network than starch (Suknark, 1998). Gogoi *et al*. (1996) found that fish added to rice flour in increasing proportion resulted in lower expansion ratio and water solubility index, and increased bulk density and shear strength.

Fat also has an effect on texture of extruded snacks. Several studies found that both fat and protein content affect the texture of the chips. A low quantity of oil (3%) helps expansion (Mohamed, 1990), while high lipid content (>5%) prevents expansion (Cheftel, 1986). Suknark (1998) found that substituting starch with partially defatted peanut flour (PDPF) up to 15-30% was beneficial for expansion (some oil was still present in the PDPF), but higher substitution prevented expansion. In this case the depressing effect of the higher level of peanut flour on expansion was probably due not only to the presence of higher amounts of oil, but also to high content of protein. A mixture of oil or fat with other components including water is generally called an emulsion. Doughs are emulsions, and their behavior during the process of baking determines the lightness and marketability of the product (Rousseau, 1999). The role of fat crystals in emulsions has been discovered and studied in the last 20 years (Van

Boekel and Walstra, 1981). Their relevance in bread making has been stressed by Brooker (1996), who discovered that the fat crystals present in the shortening are responsible for producing quality high volume bread loaves. This effect is due to the stabilization of gas cells in bread dough by the fat crystals, which are adsorbed on the gas-water interface during proofing, and melt during baking. The newly melted fat provides materials for the expanding cell walls. When oil was used instead of fat, less expansion was observed.

In her dissertation on a snack food based on fish-starch or peanut-starch extrusion, Suknark (1998) hypothesized a different effect on texture derived from native and denatured proteins. Denatured proteins are insoluble. Therefore, they absorb less water than native proteins leaving the water available to starch for gelatinization. Thus, snack foods containing denatured proteins tend to be softer than snacks containing native proteins. However, denaturation could affect texture in other ways too. For example, denatured proteins could break and interact less with other proteins so that they would form a less continuous network (Han and Khan, 1990). Our previous study confirmed Suknark's hypothesis: chips made with partially defatted (12% fat, Golden Peanut Corp., Blakeley, GA) commercial peanut flour were softer than peanut chips prepared from cold pressed peanut flour recovered after oil extraction (Birdsong Peanut Corp.). Peanut flour was derived from cold temperature (50 ºC) oil processing and its proteins were not denatured. Conversely, chips made from commercial flour (PDPF, Golden Peanut Corp., Blakeley, GA) were derived from peanuts roasted at 175 ºC, which is above the minimum required for protein denaturation

(160 ºC). To improve the handling and nutritional properties of defatted peanut flour, it was decided to fortify it with soybean flour.

Soybean

Soybean (*Glycine max*) has a long history of cultivation and food application in the Far East (China). It was imported into the United States in 1764, but its use on a large scale started in 1922, with the opening of the first processing plant (Liu, 1997). Today the United States is the largest producer and exporter of soybean, with about half the world harvest. Soybean belongs to the family Leguminosae, subfamily Papilionoidae, genus *Glycine*. Many cultivars exist, with distinct characteristics of flowering, daylight and soil adaptation, so that soybeans can be cultivated all over the United States (Burton, 1997). Like many other legumes, soybean has the capability to take nitrogen from the air and convert it to metabolizable ammonium N, a process known as nitrogen fixation. This characteristic makes it a good rotational crop to alternate with high-nitrogen-consuming crops such as corn (Liu, 1997). Soybean is the legume with the highest protein content (40% dry weight); oil is 20% of the dry weight. Similar to other legume plants, soybean is deficient in the sulfur-containing amino acids, methionine and cysteine, and also in threonine. However, unlike other legumes and most cereals, soybean contains a sufficient amount of lysine. Considering the amount of oil percent in the individual seeds, soybean is the second oilseed after peanut (peanut = 48% dry weight (Liu, 1997). The oil concentration of all other legumes is between 1% and 3.6% (Salunkhe *et al*., 1983). Soybean oil consists mainly of palmitic (11%), oleic (23%), linoleic (52%) and linolenic (8%).

Linoleic and linolenic are considered essential fatty acids because the animal organism is not able to synthesize them. More specifically, the human body cannot introduce double bonds between the terminal methyl group and the first double bond situated in the carbon chain of the respective fatty acid (Liu, 1997). Linoleic and linolenic acids are required for synthesis of prostaglandins and the eicosahenoics and docosahenoics necessary for normal growth, health, skin smoothness and impermeability, reproduction, anti-inflammatory processes, etc. (Akoh and Min, 1998). Furthermore, linolenic acid belongs to the group of n-3 fatty acids, which are required for healthy liver function and brain phospholipids content (Akoh and Min, 1998). Recent dietary estimates for fatty acids intake are (Simopoulos, 1989):

saturated F. A. = 18 g/day;

linoleic acid (C18: 2 n-6) = 14g/day;

linolenic acid (C18: 3 n-3) = 3g/day.

Other important components found in soybean include phospholipids, vitamins, minerals and isoflavones. In recent years soybeans have been rapidly increasing in popularity among the western societies. The acknowledgment of the health benefit that comes from eating soy products regularly as part of a low-fat diet, and the abundance of this legume in the United States, have stimulated a strong research effort on ways to utilize soybeans in the human diet. Genta *et al*. (2002) reported a method to produce a candy using okara, a residue of soy processing, mixed with peanut, glucose, natural essences and hydrogenated oil.

Dhingra and Jood (2002) evaluated the nutritional and organoleptic characteristics of wheat bread fortified with soy flour. They found that addition of 20% soy flour was not detrimental to the consumer sensory rating of the product.

Isoflavones are a family of phytochemicals that were identified in 1941 (Walter, 1941). They are part of the larger family of flavonoids and can be isolated from soybeans and a few other legumes. Isoflavones are contained in only a few plants because of the limited distribution of the enzyme chalcone isomerase, which converts 2(R) naringinen, a flavone precursor, into 2-hydroxydaidzein (Coward *et al*., 1993). Isoflavones are found in soybeans or soy foods in the amount of 1.33 - 3.82 mg/g dry-weight, part as β-glycosides conjugates and part as aglicones (Coward *et al*., 1993; Wang and Murphy, 1994). Isoflavones have been the object of extensive research in the last ten years, after it was recognized that they could provide health benefits (Liu, 1997; Messina, 1999). In fact, extensive research has linked the isoflavones to reduction of osteoporosis and menopausal syndrome in aging humans, prevention of different cancers including breast and prostate cancer (Aronson et al., 1999), protection from cardiovascular diseases by lowering cholesterol levels and lipid oxidation in blood (Adlercreutz and Mazur, 1997; Kyle *et al*. 1997; Nagata *et al*., 1998; Guthrie *et al.,* 2000; Abraham *et al*., 2002; Ishimi *et al*., 2002). Many epidemiological studies have been initiated by the observation that Oriental women, whose daily diet includes relevant amounts of soy products (Nakamura *et al..* 2000; Kim and Kwon, 2001), have much lower incidence of breast cancers, osteoporosis, flashes and other menopausal symptoms than western females, whose diet hardly contains any soy products. The mechanism of action is not known. It is possible that many concomitant actions are responsible for the physiological effects. For example, isoflavones have a limited estrogenic action that might compete with mammalian estrogens for receptors (Zava and Duwe, 1995). Another mechanism involved could be the inhibition of protein tyrosine-kinase (Akiyama and Ogawara, 1991), which is part of a growth factor-stimulated signal transduction cascade in normal and transformed cells. Another possibility lies in its anti-oxidant potential, which can explain the effect of isoflavones in limiting the oxidation of LDL-cholesterol and the genesis of arteriosclerosis (Kanazawa *et al*., 1995).

Among the different isoflavones, daidzein and genistein are the most abundant in soybeans. A third isoflavone, glycitein, is exclusive of the soy hypocotyl (germ). The isoflavones are naturally present as beta-glucosides, usually with malonic acid esterified in position 6 of glucose, or as aglycones (no bound sugar). The malonyl-derivate is easily hydrolyzed to glucoside or aglycone by temperatures above 80 °C or acid reaction (Kudou *et al*., 1991; Sherkat *et al*., 2001). The level of conjugation of the isoflavones varies between fermented and non-fermented soy foods, as non-fermented foods contain mainly beta-glycosides and fermented foods have predominantly aglycones. These data are confirmed by Wang and Murphy (1994), who measured the isoflavone composition of the American and Japanese soybean grown in Iowa, and found that isoflavone content varies greatly with crop year, and also, in lesser measure, by location and variety. The same authors (Wang and Murphy, 1996) later studied how isoflavones withstand different processing conditions during the preparation of traditional soy products. They found that significant losses of isoflavones take place during soaking (12% loss) and heat processing in making tempeh (44%), during coagulation in tofu processing (44%) or alkaline extraction in protein isolate production (53%). Sometimes traditional soy foods can be prepared with different methods and each of them may have a different impact on isoflavones. Therefore, information on the whole process is required before the isoflavone content can be estimated.

Analysis of isoflavones can be done by gas chromatography (Fenner, 1996); however, HPLC is the technique of choice today. Methods for sample preparation vary, depending on the nature of the sample. Following the initial grinding, extraction has been performed with aqueous ethanol or methanol (80%) with or without the addition of HCl (AOAC, 2001). The sample has also been extracted directly in acetonitrile with 0.1% HCl (Wang and Murphy, 1994). Hydrochloric acid has been shown to hydrolyze the ether bond between isoflavone and glucose (Kudou *et al*., 1991; Gu and Gu, 2001), resulting in the isoflavones being detected mainly as aglycones. Extraction by refluxing at 80 °C has proved satisfactory for Franke *et al*. (1994). These researchers extracted isoflavones for 1, 2, 3 and 4 hr in the presence of different concentrations of HCl (0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 M). Their conclusion was that daidzein recovery was maximal after 1 hr reflux, and genistein after 3 hr, both in 2M HCl. These researchers also studied the phytoestrogen level in 40 food items, mainly legumes, and found isoflavones to be present in detectable amount in soybeans, black beans, clover sprouts and alfalfa sprouts. Most researchers have detected isoflavones by HPLC using gradient elution, but a method for isocratic elution was developed by Hutabarat *et al*. (1998). This method is simpler and faster, and results compare well with the gradient method. An optimization study of the extraction conditions by Chiang *et al*. (2001) concluded that optimal (R^2 = 0.967) extraction time, acid conditions and temperature for total isoflavones in soybean hypocotyls (germs) are: HCL = 3.42M; time = 205.5 min; T = 44.6 °C. More detailed information can be collected by HPLC- mass spectrometer (Gu and Gu, 2001) or by gas-chromatography (Fenner, 1996).

Peanut, being a legume like soybean, was expected to contain some level of isoflavones. Mazur and Adlercreutz (1999) reported groundnuts to contain daidzein and genistein in relatively high amount, but other researchers did not confirm their finding (Nakamura *et al*., 2000). Because of the increasing popularity of isoflavones as a health-promoting and disease-preventing compound, soy flour is an ideal candidate to fortify peanut pellet flour, to produce a tasty and healthy new snack food.

Oxidation

The shelf life of a food product is often limited by its fat content, because fat has a tendency to undergo oxidation. The mechanisms of oxidation can be enzymatic or spontaneous (autoxidation). Enzymatic oxidation is triggered by lipoxygenase on unsaturated fatty acids such as linoleic and linolenic. The enzyme triggers the reaction of molecular oxygen with the fatty acid, generating a hydroperoxide that later degrades into smaller molecules such as aldehydes, ketones, lactones, alcohols, etc. which impart off-flavors to the product. Autoxidation is triggered by metals, oxygen, light, high temperature, proceeds through the three steps of initiation, propagation and termination, and results in off-flavor and spoilage of a fat-containing food. Peanuts, containing 45-50% fat, mainly oleic and linoleic acids, but also linolenic and arachidonic (Andersen *et al*., 1998), are highly susceptible to oxidation. Soybeans contain 20% fat, which makes them also vulnerable to oxidative spoilage.

Researchers are very active in trying to understand the precise mechanism of oxidation in food products, so to prevent their degradation and enhance the shelf life. It is known, for example, that low moisture storage is critical for peanut crops. Peanuts, after harvesting, are carefully dried to 5-6% moisture before long term storage (Woodroof, 1983). Among researchers, Chiou *et al*. (1995) determined that the composition of fatty acids in peanuts and their tendency to oxidize varied in Taiwan with the crop location and season, even for the same cultivar. They found that the spring crop was more resistant to oxidation than the fall crop. Food oxidation can be retarded by the addition of synthetic or natural antioxidants. However, some research studies have shown that chemical antioxidants such as BHA and BHT are toxic to experimental animals (Witschi, 1986; Grice, 1988). Therefore, the use of natural antioxidants is now a trend in both research and industrial applications.

Tocopherol, phospholipids, ascorbyl palmitate, rosemary and catechin, either alone or in combination, have been shown to increase peanut oil stability (Chu and Hsu, 1999). One third of the peanut crop in Taiwan is processed for oil, but differently than in the U.S., peanuts are roasted before oil extraction by expel-pressing. In Chu's study, maximal protection from oxidation was shown by the association of 1500 ppm of catechin with 400 ppm of rosemary. Blending high oleic acid (HO) peanut with sesame and soy resulted in a spread product with increased resistance to oxidation (Sumainah *et al.,* 2000). Lee *et al*. (2000) extracted aroma compounds by steam distillation and solvent extraction (SDE) from soybeans, mung beans, kidney beans and azuki beans. Their results showed that even the volatile components of these, and other beans such as coffee (Singhara *et al*., 1998), have antioxidant activity.

The antioxidant effect of natural compounds is being studied by an ever-growing number of food scientists and chemists. A protein-rich fraction from oat was found to protect linoleic acid from oxidation in an aqueous suspension containing soybean lipoxygenase-1 and micellar linoleic acid (Lehtinen and Laakso, 2000). The protection was found to reach the maximum effect after 5 minutes and required contact between an oat fraction and linoleic acid. A group of researchers studied the inhibitory effect of natto, a product of soybean fermentation, on LDL oxidation in vitro (Iwai *et al*. 2002a) and in cholesterol-fed rats (Iwai *et al*., 2002b). Natto was divided into three water-soluble fractions, a high-molecular-weight viscous substance, a low-molecular-weight viscous substance and soybean water extract. The low-molecular-weight viscous substance was found to have the strongest free radical scavenging activity, as assessed by electron spin resonance. This fraction and the soybean water extract were fed to rats kept in a cholesterol-rich diet. Results showed that the two fractions had an inhibitory effect on the LDL oxidation *in vivo*, and could explain why Japanese people, who are habitual consumers of natto and other soybean-based foods, have low incidence of cardiovascular diseases.

The Maillard reaction has also been under study for its relevance in the oxidation process. Mastrocola and Munari (2000) determined that lipid oxidation is retarded by the accumulation of Maillard reaction products (MRPs) in a pre-heated mixture containing glucose, pre-gelatinized starch, lysine and soybean oil. They also showed that the MRPs continue to accumulate during storage even at room temperature, increasing their capability of retarding lipid oxidation. The Maillard reaction is also involved in the antioxidant activity of roasted and defatted peanut kernels (Hwang *et al*., 2001). The authors investigated the possibility of using roasted peanut pellets co-produced in the oil extraction procedure. Because the peanut kernels were roasted at 180 °C before solvent extraction, Maillard reaction products were left in the residue and showed to possess a measurable antioxidant activity. This works in several ways, by exerting reducing power, scavenging free radicals, chelating Fe(II) ions. Most important, the MRPs showed a measurable effect in inhibiting human LDL/cholesterol oxidation, which is considered a factor in atherosclerosis. This material, the authors explained, could be utilized, directly or with previous enzymatic digestion, as antioxidants, helping to solve the problem of how best to utilize peanut meal, currently used only as animal feed or fertilizer. The mechanism of action of the Maillard reaction products is under study. It has been reported that MRPs obtained by reacting xylose, glucose or fructose with lysine have shown some damaging effect on DNA in a culture of human lymphocytes. The phenomenon was probably the effect of free radicals formed at the time of MRPs formation (Yen *et al.,* 2002).

The problem of what to do with oilseed meal produced by oil extraction is not limited to peanuts. Matthaus (2002) described how the residues from 8 species of seeds (including rapeseed, mustard, crambe and sunflower), after their oil has been extracted, are used as animal feed or as fuel in power plants. However, such residues contain many antioxidants, which could be extracted and utilized. Several compounds with antioxidant activity (polyphenols, flavanoids and sinapines) were recognized and recovered from the defatted material. The optimal conditions of their extraction and their efficacy as reducing agents were studied.

Response Surface Methodology (RSM) is a collection of statistical and mathematical procedures aimed at determining how changes in one or more components in the formulation or in the processing conditions of a new product affect the quality of the product. It is a useful tool for analyzing and optimizing processes (experiments) in which several independent variables simultaneously influence a response (Floros and Chinnan, 1987). The ultimate goal of RSM is to optimize the critical response of a product (Walker, 2000). Most of the RSM applications come from areas such as chemical or engineering processing, industrial research and biological investigations (Floros and Chinnan, 1987). If an experiment has a large number of factors to be considered, one of the advantages of RSM is the reduced number of runs needed to provide sufficient information for statistically acceptable results. It is a faster and less expensive method of performing scientific research compared to the classical one-variable-at-a-time or full factorial design (Floros and Chinnan, 1988; Hinds *et al*., 1994). Another advantage of the RSM is that it can be applied to the generation of surface or contour plots, which allow visualizing how the response changes when the input variables increase or decrease. Response surfaces and contour plots are graphic expressions of prediction equations. They allow the researcher to predict the outcome of a process without the need to physically perform the process (Walker, 2000).

RSM starts by selecting the experimental design contemplating a reasonable number of variables (input variables) and their levels, and the responses (output variables). After performing the experiments, the data are collected and analyzed statistically. Parameter estimates are obtained and used as function coefficients. The function (model) is also called a prediction equation and is used to computer-generate contour plots. Once the plots are obtained, limits of acceptability are applied, so to identify optimum conditions. In the case of a snack food, the optimum conditions are assumed to be those producing the highest acceptability from the consumers. But constraints are also determined based upon cost of the ingredients and of manufacturing. The last step is the verification, which consists of running control (diagnostic) tests to assess the adequacy of the model (Dziezak, 1990).

Many papers have been published in recent years on optimization. Among them, one described the optimal amount of oat bran and water that can be added to a low fat chicken frankfurter without loss of quality (Chang and Carpenter, 1997). USDA regulations allow substituting water for fat, provided that the sum of fat and water does not exceed 40% by weight of the finished product. Contour plots showed optimum formulation at 2% oat bran and 20% added water. In RSM the variables are continuous. A variation in the application of RSM is called mixture design, useful when the factors to be studied are three, their individual values are between 0 and 1 and the sum is 1. The graphical representation is a simplex lattice design. Malundo *et al*. (1994) used the mixture design to determine the optimal amount of peanut extract mixed with cottonseed oil and water to produce a liquid coffee whitener. Another application of the same experimental design was described by Jaswir et al. (1999), who studied the life extension of palm oil used for deep-fat frying by natural antioxidants. Oleoresin rosemary and sage extracts, together with citric acid, were shown to be more affective than the synthetic BHA and BHT, in extending the life of frying oil. The optimal combination was found to be 0.059% rosemary extract, 0.063% sage extract and 0.028% citric acid.

Consumer sensory tests. During the long process of developing a new product, different sensory tests are planned, at different times, to optimize the product and maximize its chance of success in the market. Two kinds of sensory tests are known, analytical and affective (IFT, 1981). Analytical tests are used for laboratory evaluation of products in terms of differences or similarities and for identification and quantification of sensory characteristics. An analytical sensory test involves the detection, description and quantification of all sensory properties of a product (Walker, 2000). It usually requires a few (5-20) trained panelists to detect, evaluate and quantify the attributes of a prototype. Trained panelists often reveal important information that could not be described or identified by consumers in products that they consider acceptable or unacceptable.

Affective tests are used for evaluation of acceptance or preference of products by consumers (Hashim *et al.,* 1999). They are so called because the panelists are expected to express their feelings and personal opinion about the product (Resurreccion, 1998). During such tests, panelists can express simply their preference or perform a rating among different samples, depending on the type of product (Meilgaard *et al*., 1991). Participants are usually untrained and recruited among people who are consumers or potential consumers of the product. The minimum number of individuals that is required for consumer tests is much larger than that required in analytical tests, usually ranging between 50 and 100. Larger numbers of panelists would decrease the risk of errors, but the higher cost of more participants would not add enough statistical benefit to be worthwhile. The characteristics to be examined in a consumer test can be appearance, color, odor, taste, texture or overall acceptability of the food or beverage. The characteristics can be different from the ones listed above, or can be more detailed, depending on the product and the attributes that are considered most critical for its success in the market. However, the questions asked to the panelists cannot be too complex, because consumer panelists are not trained and could be easily confused (Resurreccion, 1998).

A very popular method of rating used in an affective test is the 9-point hedonic scale. It was developed by Jones *et al*. (1955) and Peryam and Pilgrim (1957). It is articulated so that each descriptor had 9 possible levels: “dislike extremely” (rating of 1), “dislike very much” (2), “dislike moderately” (3), “dislike slightly” (4), “neither like nor dislike” (5), “like slightly” (6), “like moderately” (7), “like very much” (8), “like extremely” (9). Other scale categories have been tried, including the 3-, 5- and 7- point hedonic scales (Stone and Sidel, 1993). They are used in cases when panelists have problems in understanding or expressing differences among, e.g., “like slightly” and “like moderately”, as in the case of children (Resurreccion, 1998). Even some adults have problems with a 9-point scale. For example, some tend to avoid the extreme points in rating food samples. Therefore, shorter scales are sometimes used, but they are of limited use, because they do not stress the amount of difference among samples. Furthermore, panelists who have the tendency to avoid the extremes of the scale end up cutting the extreme points of any scale, thus further reducing any 3-, 5- or 7- point hedonic scale (Stone and Sidel, 1993). Consumer affective tests have been the subject of the monograph “Consumer Sensory Evaluation” published in 1979 by the American Society for Testing and Materials (ASTM), Committee E-18.

The consumer (or acceptance) test is an important step in product development. It usually follows a descriptive test and precedes larger-scale market tests. Discriminative (or analytical) sensory tests are required to narrow the initial choice of samples to a smaller number. Then a consumer test determines the acceptability of a selected number of samples. Samples that are potentially most successful and generate information useful to optimize the product itself should be selected. Success with the panelists, however, does not guarantee success in the market. This will require a specific evaluation with a larger-scale consumer test, usually involving 100 or more people from different strategic locations (Resurreccion, 1998).

The objectives of an acceptance test are to 1) determine the level of acceptability of a product among potential consumers of that product, 2) determine the acceptability of different qualities of a product, like appearance, color, aroma, taste, hardness, overall liking and 3) quantify the consumers' response by correlating the results of the sensory test with the results of analytical sensory tests as well as physical tests. If consumer acceptance can be related to the attribute intensities, then a relationship between sensory characteristics and formulation process can be established (Walker, 2000). This relationship can be transformed into a predictive equation and displayed in response surfaces or contour plots.

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SECTION II

PHYSICAL CHARACTERISTICS AND CONSUMER ACCEPTABILITY OF LOW-FAT PEANUT CHIPS FORTIFIED WITH CORNMEAL OR SOY FLOUR[1]

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[1]Zenere, A., Huang, Y.-W., and McWatters, K. H. To be submitted to Peanut Science.

ABSTRACT

Peanut press cake, an edible grade co-product of the peanut oil industry in the form of pellets, was ground into meal. It was fortified with one third of either cornmeal or soy flour and mixed with salt, sugar, baking powder and water, to make dough. The dough was sheeted, cut into triangular shapes, and baked in an impingement oven at 205 ºC for approximately 2 min. Color was measured in CIE L*a*b* units. The peanut-corn and peanut-soy chips were similar in lightness (L* = 60.64 - 59.25) but the peanut-soy chips had lower values of a* (5.67), b* (18.98), hue (73.36) and chroma (19.81) compared to the peanut-corn chips (a*=6.80, b*=24.45, hue =74.46 and chroma = 25.38). Texture was determined using an Instron fitted with a Kramer cell. The peanut/soy chips showed lower shear stress compared with peanut/corn chips (53.5 vs. 69.98 N/cm^2). A sensory test with 75 participants was conducted to determine the acceptability of the product. Peanut-corn chips received higher hedonic ratings for appearance, color, aroma and overall liking than peanut-soy chips. Consumers found the peanut-corn chips to be more acceptable than peanut-soy chips (46.7% vs. 40.7%).

INTRODUCTION

Chips are a very popular food item today. They are convenient and rather inexpensive. People enjoy them between meals and at mealtime (Anonymous, 1998). In 1999, the sale of potato chips reached a record $4.6 billion and tortilla (corn) chips $3.7 billion (Anonymous, 2000). However, corn and potato chips are not the only snack foods to meet with success by consumers. New snack foods appear on the market every day with different formulations. Food companies strive to produce new items to take advantage of new production technologies, cultural trends, nutrition and health discoveries, and Dietary Guidelines from FDA (Fuller, 1994). On a global scale, another reason to develop new food items is the expanding world population. Feeding billions of people is an enormous challenge and will require a judicious use of resources. The focus will be on developing new ways to deliver the required amount of proteins, essential fatty acids, minerals and vitamins. The "mad cow disease" emergency in Europe reminded us that some well established sources in the food supply might be denied on short notice. Every alternative source of proteins must be explored and developed (Phillips and Falcone, 1988; Ward, 1995; Suknark *et al.*, 1998). Peanuts meet all of these requirements, particularly because of their high protein content. It is true that they also contain a significant quantity of fat (35.8-54.2%) (Woodroof, 1983), but the ratio of unsaturated vs. saturated fatty acids is high (Andersen *et al*., 1998). Furthermore, some unsaturated fatty acids are essential components of the human diet (Shukla, 1994). There are also ways to remove some or nearly all of the oil without damaging the other nutrients.

In light of today's trend towards consumption of low-fat (but good tasting) foods in the United States, we developed a new chip from defatted peanut pellets, an edible-grade co-product of the peanut oil industry. Previous experiments with peanut flour were described by McWatters and Heaton (1972), who produced peanut flour by grinding raw, full-fat peanuts. Chips were produced by mixing peanut flour and water, forming, cutting and deep fat frying the dough. The final chips varied in oil content depending on the flour particle size. Peanut flour separated with a 14- and 18-mesh sieve absorbed more oil than 30-mesh particle size flour. Nevertheless, all the chips produced contained too much oil to be marketable. Another experiment with defatted peanut flour was described by McWatters and Cherry (1980). They produced peanut chips with commercial peanut flour, partially defatted or full-fat, toasted or untoasted. The dough, formed by mixing peanut flour and water, was sticky and difficult to handle unless the peanuts had been toasted at 160 ºC. Chips produced with flour from peanuts toasted at a temperature of 171 or 177 ºC did not hold together when fried. Furthermore, those chips that maintained their shape during deep fat frying had final oil content between 47.8 and 62.4%, too high to be appealing to customers. Our objective was to produce a chip from defatted peanut pellets, an edible grade co-product of the peanut oil industry, fortified with soy flour or cornmeal, and to determine the physical characteristics and acceptability of the peanut-soy and peanut-corn chips.

MATERIALS AND METHODS

Peanut Pellet source. The defatted peanut press cake, in pellet shape, was kindly provided by Birdsong Peanut Corporation, Suffolk, VA. This material was received in August 1999, and stored at 4 ºC until used. It was derived from Virginia variety seeds, extra large and medium size, harvested in 1998. The oil had been extracted by hydraulic compression, and the temperature generated in the process did not exceed 50 ºC. Pellet color was mocha-brown, and they had very little residual peanut flavor. Product specifications provided by the company indicated a protein content of 40-44%, oil content 10-14%, moisture 8%, fiber 3.7% and ash 3.1%. Soy flour (Arrowhead Mills, Hereford, TX) was lightly roasted, full fat, and was purchased at a local store. Cornmeal (Arrowhead Mills, Hereford, TX) was also purchased at a local grocery store.

Dough Preparation. The pellets were passed through a grinder (Model 4E, The Stroub Co., Philadelphia, PA), and then sieved with a # 15 mesh U.S. Standard screen. Defatted peanut (150 g) flour was machine mixed on low speed (Kitchen Aid®, model KSM50PVH, Hobart Corp., Troy, OH) with 50 g of either soy flour or cornmeal, together with 4 g salt, 12 g sugar, 3 g baking powder and 80 g of water. The ingredients were mixed until the dough formed a solid mass around the beater (ca 2 min). The bowl and beater were then scraped and mixing continued (ca 1 min).

Sheeting and Baking. The dough was divided into roughly two parts of 150 g each. One part was enclosed in a plastic bag (Ziploc®) and left at room temperature. The other was placed between two layers of 60 µm plastic

(Cryovac, Duncan, SC). The dough was then passed through a sheeter (Model S-18-BNO 4458, Moline Machinery, Ltd., Duluth, MN) set at the lowest possible thickness (fourth lowest position) that allowed the dough to be removed from the plastic without breaking. The dough was then rapidly cut into 5.1-cm-side squares with a blade cutter. Each square was then cut diagonally with a pizza cutter to obtain two triangular chips. The chips were released onto a wire screen and placed on the belt of an impingement oven preheated at 205 ºC, set at a 2-min time. In the meantime, the other part of the dough was processed by the same procedure. The chips were cooled, put into plastic bags (Ziploc®) and stored in the refrigerator until used for physical and sensory evaluation.
Corn chips were not adequately crispy and dry after 2 minutes baking. A supplemental baking time of 30 seconds was found to be satisfactory, and 2.5 min baking time was applied for all corn chips.

Proximate Composition. Percent moisture (Table 2.1) was determined by drying the samples in a vacuum oven at 100 ^{o}C (AOAC, 1995, Method 4.1.06). Fat was determined by extraction with petroleum ether using a Soxhlet apparatus (AOAC Method 4.5.01). Protein content was determined by a private laboratory (Seaboard Farms, Athens, GA) on a nitrogen analyzer (Model FD-428, LECO, St. Joseph, MI).

Color Determination (Table 2.2). Instrumental measurement of chip color was obtained using a Minolta colorimeter (model CR 200, Osaka, Japan). L*, a*, b*, hue and chroma values (CIE system) for 10 chips were recorded (L* =

lightness, a^* = red to green, b^* = yellow to blue, hue = $\tan^{-1}(b^*/a^*)$ and chroma = $(a^{*2}+b^{*2})^{1/2}$.

Texture. Physical determination of texture was done using an Instron Universal Testing Machine (model 1122, Canton, MA) fitted with a Kramer cell. The load cell had a range of 500 Kg and the crosshead speed was 50 mm/min. The maximum force required to shear the sample was recorded as shear stress and expressed in N/cm^2. Ten chips per formulation were tested, one at a time. The average thickness of 1.6 mm was measured with a caliper, but the data was not used in the final calculations, as all the chips had approximately the same thickness. Chips were sheared one at a time because two chips were large enough to overlap and three chips were hard enough to overload and tip the Instron.

Sensory Evaluation. Sensory evaluation was conducted in the Department of Food Science and Technology of the University of Georgia, Athens. Seventy-five panelists (untrained consumers) were recruited from UGA students, staff and faculty. They signed a consent form approved by the University of Georgia Institutional Review Board, and were informed of the nature of the food. After completing a demographic questionnaire, the panelists were seated in individual booths in a climate-controlled laboratory equipped with fluorescent lighting. Two samples, in duplicate, were offered on a tray in four muffin paper cups, each marked by a random three-digit number. Two samples contained peanut-soy and two contained peanut-corn chips. The presentation order of the chips was randomized for each panelist. Water, unsalted crackers and an expectoration cup were provided. Together with the chips, the panelists received four ballots, one for each sample. Panelists rated each chip sample using a 9-point hedonic scale (1 = dislike extremely, 5=neither like nor dislike, 9 = like extremely) for appearance, color, aroma, flavor, texture and overall liking. Product acceptance (yes or no) was also asked for each sample.

Statistical analysis was performed using the General Linear Model (GLM) Procedure with the Statistical Analysis System (SAS Institute, Inc. 1996). Analysis of Variance and Duncan's Multiple Range Test were performed on the physical, instrumental (color and texture) and sensory data ($p<0.05$).

RESULTS AND DISCUSSION

The baking process required 0.5 min longer for peanut-corn chips than peanut-soy chips to obtain a level of lightness, crispness and moisture as close as possible to the peanut-soy chips. The chemical analysis of the baked chips showed a high protein and a very low oil content (Table 2.1). Color determination showed similar values for lightness (L*), but peanut-corn chips had higher values of a*, b*, hue angle and chroma than peanut-soy chips (Table 2.2). Texture was also different, with peanut-soy chips (53.51 N/cm^2) less hard than peanut-corn chips (69.98 N/cm^2). The demographic characteristics of the sensory panelists are shown in Table 2.3. The population was almost equally represented by males (52.2%) and females (47.8%). Nearly 70% were under the age of 35, and 58% were students. Forty-nine percent were white, 31.3% were Asian, and 10.4% were Hispanic. More than half had never been married, and

46.3% were married. Not surprisingly, a large percentage (70.1%) had completed graduate or professional school.

The panelists did not detect any difference between peanut-soy and peanut-corn chips in flavor and texture. Flavor received similar rating of 4.6 to 5 (“neither like nor dislike”) and so did texture, with scores of 4.4-4.5 (dislike slightly) (Table 2.4). Peanut-corn chips received higher ratings than peanut-soy chips for appearance, color and aroma, with ratings above 6 (“like slightly”) for the chip containing 25% corn. Overall liking showed also a higher rating for peanut-corn (4.9) than peanut-soy (4.4). The flavor was bland in both kinds, apparently because the previous defatting process had extracted much of the peanut flavor along with the oil. No external flavor, natural or artificial, was added. Responses by consumers were disparate. For example, in response to the question: “Overall, how do you like this sample?” the same kind of chip sometimes received a score of 1 (dislike extremely) and sometimes a score of 9 (like extremely). This shows the risk that may be encountered in this kind of sensory evaluation, where a quantitative assessment is required from people with no training. A final question was asked of the panelists: “is this product acceptable?” Of those responding, 46.7% answered positively for the peanut-corn chips, whereas 40.7% responded favorably for the peanut-soy chips (Table 2.5).

CONCLUSIONS

Chips were produced with defatted peanut flour, a food-grade co-product of the peanut oil industry, fortified with 25% soy flour or 25% cornmeal. The preparation was simple and easy, thanks largely to a powerful sheeter and an impingement oven. Baking the chips instead of frying them resulted in low fat content in the final product (7.5% in peanut-soy and 5.5% in peanut-corn chips), which would allow to label such snack food as a “low-fat” product. The difference in physical characteristics between the two chips was small, and also the consumer test did not show a strong difference between them. However, the ratings of texture by the consumers, and the optional comments the panelists wrote on the ballots, suggest that the chips were too hard, and needed to be softened. Nonetheless, the low fat content of the final product leaves open the possibility of adding peanut butter to the mix. It could increase the peanut flavor, tenderize the chips and still keep the fat level reasonably low. The addition of cornstarch or potato starch to the formulation could also enhance the level of softness or crispness in the peanut chip. Overall, the commercial production of a peanut chip that is low in fat and high in protein seems possible and practical. Fortification with soy flour could provide additional health benefit. Findings from this study are being used to guide further development of a nutritious, novel food from peanuts.

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Table 2.1. Moisture, fat and protein content of peanut chips[1]

Chips	% Moisture	% Fat	% Protein
Peanut 75% -corn 25%	3.8	5.5	38.2
Peanut 75% -soy 25%	4.3	7.5	42.8

[1] Duplicate observations. All data are on a wet basis.

Table 2.2. Mean instrumental color and texture values of peanut chips[1]

Chips	Color					Shear force
	L*[2]	a*	b*	Hue Angle	Chroma	(N/cm^2)
Peanut-corn	60.64a[3] (1.23)	6.80a (0.56)	24.45a (1.21)	74.46a (0.88)	25.38a (1.28)	69.98a (12.62)
Peanut-soy	59.25a (1.78)	5.67b (0.35)	18.98b (0.75)	73.36b (0.75)	19.81b (0.79)	53.51b (13.10)

[1] Numbers in parenthesis are standard deviations.
[2] L* = Lightness, a* = red to green, b* = yellow to blue, hue angle = $\tan^{-1}(b^*/a^*)$, chroma = $(a^{*2} + b^{*2})^{1/2}$.
[3] Means in a column not followed by a common letter are different ($p < 0.05$).

Table 2.3. Demographic characteristics of consumer panelists (n = 67)[1]

Variable	Percentage
Age (years)	
18 to 24	26.9
25 to 34	41.8
35 to 44	19.4
45 to 54	8.9
55 to 64	3.0
Gender	
Males	52.2
Females	47.8
Race	
White	49.3
Hispanic	10.4
Asian	31.3
Black	9.0
Marital Status	
Never married	52.2
Married	46.3
Divorced	1.5
Education	
High school	4.5
Vocational school	16.4
Completed college	9.0
Graduate or professional school	70.1
Employment status	
Full time employee	32.8
Part time employee	7.5
Unemployed	1.5
Student	58.2
Household income	
Less than $19,999	47.0
$20,000 to $39,999	28.8
$40,000 to $59,999	4.5
$60,000 and over	19.7

[1] Only 67 out of the 75 panelists returned the demographic questionnaire

Table 2.4. Mean hedonic ratings for sensory attributes and overall liking of peanut chips[1]

Chips	Appearance	Color	Aroma	Flavor	Texture	Overall liking
Peanut -Corn	6.4a	6.4a	6.1a	5.0a	4.5a	4.9a
Peanut -Soy	5.8b	5.7b	5.2b	4.6a	4.4a	4.4b

[1] Scale of 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely. Means in a column not followed by a common letter are different ($p < 0.05$).

Table 2.5. Percentage of panelists (n = 75) who considered the peanut chips acceptable[1]

Sample	Acceptable (%)	Not acceptable (%)	No response (%)
1) Peanut - corn	46.7	51.3	2.0
2) Peanut - soy	40.7	56.0	3.3

SECTION III

PHYSICAL AND SENSORY PROPERTIES OF PEANUT CHIPS FORTIFIED WITH SOY AND WHEAT FLOURS

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[1] Zenere, A., Huang, Y.-W., McWatters K. H. and Lyon, B. G. To be submitted to the Journal of Food Science.

ABSTRACT

Peanut flour (10% fat), made from cold pressed peanut pellets and fortified with 25% partially roasted soy flour or wheat flour, was made into baked chips. Chips made from 75% peanut flour and 25% soy flour had higher intensities of “burnt” and “cardboardy” flavors than those made with 100% peanut flour or with 75% peanut flour and 25% wheat flour. However, chips made from skinless cold pressed peanut pellets had lower intensities of peanut butter, grainy and burnt flavors as compared to skin-on peanut pellets. The shear stress for chips made with 100% defatted peanut flour was 106 Kg/g, while that for chips with commercial roasted peanut flour was 80 Kg/g. Adding soy or wheat flours resulted in softer chips.

INTRODUCTION

According to a recent report of the Snack Food Association (SFA), the sale of snack foods reached the level of $30 billion in 1999 (Anonymous, 2000). In 1997, a total of 1,400 new snack foods had been produced and the average consumer who bought snack foods had spent approximately $55 for those items (Anonymous, 1998). Snack nut consumption has decreased in the past few years because of concern about fat content and a lack of new products. However, the last report from the SFA (Anonymous, 2000) shows an increase in nut sales of 13.7% in 1999. This improvement was due to the positive publicity that nuts contain mono-unsaturated fatty acids, considered a healthy kind of fat. Peanuts have been used alone or mixed with fish or other flours such as tapioca and sorghum (Phillips and Falcone, 1988; Suknark et al.,1999) to produce extruded foods. Extrusion is convenient and is finding more and more applications, but it requires expensive equipment that not every processor can afford. Furthermore, it can have a harsh effect on the nutrients. A more traditional process, like sheeting, may sometimes be more convenient. At the present time, no low fat peanut-based chip is available in the market. The objective of this research was to develop a baked chip product based on defatted peanut flour.

MATERIALS AND METHODS

Peanut flour and other ingredients

Cold pressed peanut pellet, an edible grade by-product of the peanut oil industry (Birdsong Peanut Corp., Suffolk, VA) was used for the study. Shelled peanut kernels were pressed through an oil extractor at 50°C for 30 sec. The skin was left on the seeds during processing because it facilitated the movement of the crushed kernels through the oil extractor. Specifications provided by the peanut processor for the proximate composition of the peanut pellet were: protein, 40-44%; fat, 10-14%; moisture, 8%; fiber, 3.7% and ash, 3.1%. The peanut pellets, in the form of sticks, were ground with a split grinder (Model 4E, The Straub Co., Philadelphia, PA) on the day of each experiment. Commercial peanut flour (Golden Peanut Co., Alpharetta, GA) used as a control was lightly roasted and partially defatted (fat = 12.7%). The moisture and protein contents were 2.2% and 53.7%, respectively. Lightly roasted soybean flour (Arrowhead Mills, Hereford, TX) and unbleached wheat flour (Arrowhead Mills, Hereford, TX) were purchased at a local grocery store in Athens, GA. Creamy peanut butter (Kroger - Tara Foods, Albany, GA) and pre-gelatinized, modified cornstarch (BAKA-Snack, National Starch and Chemical Corp., Bridgewater, NJ) were also used. The formulations of tested chips are shown in Table 3.1.

Sample preparation

The dry ingredients were mixed first manually and then put into a Kitchen Aid® mixer (Model KSM 50PWH, St. Joseph, MI) for 1 min. After adding water (at 40°C), the ingredients were mixed until dough formed. The dough was placed between two thick sheets (60 µm) of plastic film (Cryovac, Duncan, SC), and passed through a sheeter (Model S-18-BNO 4458 Moline Machinery, Ltd., Duluth, MN) set to the fourth lowest position, so as to deliver a sheet of 1.6 mm thickness with a size of ca. 30 x 50 cm. The sheet was sprinkled on both sides with sugar. Approximately 12 g of sugar per batch was added. The sheet was cut into squares (5 cm x 5 cm) by using a multiple-blade pizza cutter. The chips were put on a metal tray and set on the belt of an impingement oven (Model 1450, Lincoln Foodservice Products, Fort Wayne, IN). They were first dried at 98°C for 20 min to reduce the moisture content to 8-10%, and then baked at 160°C for 2 min. Final moisture content of the chips was 2-3%. The chips were cooled, stored in Ziploc® bags and refrigerated until the next day when the sensory tests were conducted.

Sensory evaluation

A quantitative analytical sensory method was used (Meilgaard et al., 1991). The eight-member trained descriptive panel was comprised of males and females ranging in age between 23 and 63 who had previously been screened and selected. All but one panelist had more than two years' experience in descriptive panel work. Panelists met twice a week from 9:00 to 11:00 a.m. Initial training sessions were held to develop the list of descriptive attributes appropriate for a range of commercial chips and crackers. The list of descriptors and references was refined and finalized as appropriate for the test samples (Table 3.2). The descriptors chosen were: peanut butter flavor, grainy/nutty, scorched/burnt, cardboardy, sweet, salty, bitter/astringent, roughness, hardness, fracturability, moisture absorption, gritty/grainy particles, chewiness and toothpack. Attributes were scored on a scale of 1 to 15 with 1 being the low intensity of the attribute and 15 being high intensity. Tests were conducted in individual test booths equipped with low-pressure sodium vapor lighting to mask color differences. Water, expectorating cups, unsalted crackers and apple slices were served with test samples for mouth cleansing. After a warm-up sample, duplicate chips in coded plastic bags were presented in two sets of three samples with a 15-min break between sets. Order of samples within a set was randomized. The test was presented via computer using the Compusense Sensory Analysis system (Compusense® five, Release 4.0, Compusense, Inc., Guelph, ON, Canada). Panelists followed the computer screen instructions to evaluate the samples and record their responses on the 15-point unstructured line scales for each attribute.

Proximate composition

Moisture was determined using a HR73 Halogen Moisture Analyzer (Mettler-Toledo, Greifensee, Switzerland). Fat content was determined by extraction with petroleum ether (AOAC 4.5.01, 1995). Protein content was determined by a private laboratory (Seaboard Farms, Athens, GA) on a nitrogen analyzer (Model FD-428, LECO, St. Joseph, MI).

Color determination

Instrumental measurement of chip color was obtained using a Minolta colorimeter (model CR 200, Osaka, Japan). L*, a* and b* values for 10 replicates per sample were recorded (L* = lightness, a* = redness, and b* = yellowness).

Texture measurement

For the Kramer shear test, an Instron Universal Testing Machine (Model 1122, Instron Corp., Canton, MA) was fitted with a Kramer cell attachment. The cross bar with a 5000 N load cell moved at 50 mm/min speed. Data were recorded and analyzed by a series IX Automated Material Testing System software (Instron, Canton, MA). One chip (ca. 2.7 g) was laid on the center of the Kramer cell. The force required to crush it was recorded as shear stress and expressed as Kg/g. The total work required to break the chip ("energy to break point") was also recorded and expressed in Kg*mm. In the snapping test (Bruns and Bourne, 1975) the chip was positioned on top of two bars 2.5 cm apart and broken by a vertical bar connected to the Instron loading cell and moving at 50 mm/min. The results were expressed in Newtons.

Statistical analysis

Analysis of Variance was performed using the General Linear Model procedure (PROC GLM) with statistical software (SAS Institute Inc.

1996). Analysis of Variance and Duncan's multiple range tests determined whether the effect of treatment (formula) was significant at $P<0.05$. Correlation between sensory data and the physical data shear stress, "energy-to-break- point" and "snapping force" was determined using the Pearson correlation procedure (PROC CORR).

RESULTS AND DISCUSSION

Experiment 1.

Five experiments for five formulations, each with at least three replications, were conducted. Mean values obtained in Experiment 1 are shown in Table 3.3. This experiment was performed using cold-pressed defatted peanut pellets. Pellets were ground just before the experiment, to prevent oxidation and rancidity. Chips made from 100% peanut (Formula 1) were visually observed to have a dark brown color; this formula had the least redness and yellowness. Formula 5, which contained the lowest level of peanut pellet (50% peanut pellet, 25% soy and 25% wheat), had the highest energy-to-break-point (190 Kg*mm), indicating the highest amount of work required to break the chip.

Of all the sensory descriptors, only "burnt", "cardboard", "roughness" and "hardness" were different in the 5 formulations. Formula 2 (75% peanut, 25% soy) was the highest in burnt (3.5) and cardboard (4.3) flavors and hardness (8.3). Formula 1 (100% peanuts) had the lowest intensities of burnt (2.3) and cardboard (3.0).

Experiment 2.

To determine if the flavor and the textural attributes were influenced by the peanut composition or by the peanut defatting process, Experiment 2 was conducted using commercial-partially defatted-lightly roasted peanut flour (fat content = 12.7%, protein = 53%, moisture =2.2%). The formulations were the same as that in Experiment 1. The commercial flour was finely ground and lighter in color than the one obtained by grinding the pellets. Therefore, the appearance of the second set of chips was different. Chips made from the commercial flour had higher redness (a* ranged from 8.49 to 10.52) and yellowness (b* = 28.6 - 30.79) than those made with flour from pellets (a* = 7.26 - 9.19 and b* = 20.01 - 29.57) (Table 3.4). In addition, the shear stress was different (75.8 - 94.8 Kg/g) compared to 92.1 - 102.9 Kg/g for cold pressed, suggesting that the chips made from commercial flour were softer than chips from pellets. There were no perceived differences among the different formulations containing commercial peanut flour, except for “burnt” and “cardboard”, with the 25% soy chips always having greater intensities of these attributes than chips with 25% wheat or 100% peanut. Ratings for chips in the two experiments were very similar, thus it seemed relevant to test the two different chips, from pellets or from commercial flour, side by side, in a parallel experiment.

Experiment 3.

Table 3.6 shows the result of Experiment 3, in which three formulations with cold pressed peanut pellets (CP) are compared with identical formulations using lightly roasted commercial peanut flour (LR). Table 3.5 shows the relative percentages of the flour mixtures. As in the two previous experiments, sugar was sprinkled on the chip surface.

Experiment 4.

This experiment was identical to Experiment 3, the only difference being that sugar was not sprinkled on the chips (Table 3.7). The chips made from pellets were lighter in color than those made from commercial flour (60.5 and 56.0, respectively). Redness and yellowness were both higher in non-sugarcoated chips made from commercial flour (10.4 and 30.4, respectively) compared with chips from pellets (7.8 and 24.5). The same trend had been previously noted in chips with topical sugar. The shear stress for chips made from pellets was 17.9% to 45.6% higher than that for chips made from commercial flour, with the coat of sugar usually adding to the hardness. In either Experiment 3 or 4, chips made with 100% peanut had higher shear stress than the other formulas (with the exception of Formula 2 in non-sugarcoated peanut pellet chips). This indicated that texture of chips made from 100% peanut flour is harder than that of chips made from mixed flours. The snapping test was applied in Experiment 3, 4 and 5. Chips prepared with 100% commercial peanut flour (LR) tended to have lower snapping force values than the mixed-flour chips containing commercial flour. Moreover, chips prepared with commercial peanut flour had higher snapping force values than chips obtained from pellets.

The sensory analysis in Tables 3.6 and 3.7 shows low values for intensities of taste and flavor attributes, also noted in previous experiments. However, peanut butter flavor was generally higher in chips with topical sugar than in chips without topical sugar (3.6 and 3.1, respectively), suggesting the possibility that sugar may intensify peanut flavor.

Experiment 5.

Peanut skin can yield a final product with darker color than when the skin is not present. Furthermore, the skin is known to contain tannins (Woodroof, 1983), which cause bitter taste. To observe if the peanut skin had any effect on color and flavor of chips, a sample of pellets derived from peanuts that had been blanched (separated from their skin) before processing was obtained from the company. The results are shown in Table 3.8. The L* and b* values were higher when the skin had been removed than when present. However, most of the other physical characteristics were not affected by the skin. Chips made from pellets with skin had slightly higher intensities of some flavor attributes (peanut butter, grainy/nutty, burnt) and roughness than chips that had no skin. Toothpacking was less intense in chips that contained peanut skin than when skin was not present.

The physical attribute energy-to-break-point showed a trend: the chips made from 100% peanut pellets had often lower values than chips made with 75% or 50% peanut pellet flour (Tables 3.3 and 3.8). This trend was not apparent in chips made from commercial peanut flour (Table 3.4). This textural characteristic may be the result of interaction among different proteins. Peanut proteins derived from cold pressed pellets were not denatured during low-temperature processing (50°C), so they were more likely to interact with proteins contained in soy flour or wheat flour than the proteins present in defatted and roasted commercial peanut flour.

Correlation analysis

No statistical correlation was found between sensory and physical data. This was to be expected because the differences among formulations were small. No correlation above 0.5 was identified, with the exception of hardness and snapping force (0.57).

Comparison with commercial products

The texture of a snack food is critical for customer acceptance. In order to evaluate the progress done in this area, and the work that still needs to be done, four comparable products already in the market (Air Crisps Wheat Thins® and Wheatsworth® from Nabisco, Wheatables® and Toasteds® from Keebler) were analyzed with the Instron and Kramer cell. The four products are all described as crackers. Commercial chips (like potato chips or corn chips) were wavy and irregular in shape and could not be as easily tested for shear or snapping-force as our peanut chips. The results are shown in Table 3.9. The shear stress of three of the four products ranged between 10.1 and 15.9 Kg/g. Only the Wheatables® were as high as 31.2 Kg/g. Defatted peanut chips show a much harder texture than the commercial cracker-like products. However, when the flour from pellets was replaced with commercial flour, the average shear stress decreased from 106.1 to 86.7 Kg/g (Table 3.6). Chips made with a mixture of soy and peanut flours decreased further in hardness (70.5 Kg/g in sugarcoated and 66.0 Kg/g in non-sugarcoated chips) (Table 3.6 and Table 3.7). There is space for further improvement. For example, the peanut percentage in the flour mix could be decreased and different starch formulations could be investigated (for example, potato starch). Also changing the chip geometry should help. For example, smaller chips made with 75% commercial peanut flour and 25% wheat, sugarcoated, drew praises and interest at the public show "Peanut and Jelly Day" at the State Capitol, Atlanta on March 1, 2000. Another way to improve the geometry could be by puncturing or pricking the dough as is done with most commercial crackers.

CONCLUSIONS

A snack chip prepared from defatted peanut flour, a by-product of peanut oil extraction, could be a successful new product, with its high content of protein and other nutrients and low fat content. Furthermore, the chip could have a very low cost, because the principal ingredient is an edible grade by-product of peanut oil extraction. Mixing commercial peanut flour with flour from pellets could add the advantage of softer texture to that of the low cost of defatted pellet flour. Problems with a hard texture persist, but it has been shown that it is possible to add softness to the product, for example, by adding different flours. More improvement could be achieved with different flour formulations and a different geometry of the chips. Descriptive sensory analysis did not detect a strong difference in flavor and texture between chips prepared with 100% peanut flour or a mix of 75% peanut and 25% soy or wheat flour. If improvement can be made in baked peanut chip quality, potential exists for providing peanuts in a novel, ready-to-eat form.

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Table 3.1. Ingredients[1] used for peanut chip formulations (g)

Formula	Peanut	Soy	Wheat	Starch	Peanut butter	Sugar	Salt	Baking powder	Water
1	140	0	0	20	40	12	4	3	80
2	105	35	0	20	40	12	4	3	80
3	105	0	35	20	40	12	4	3	80
4	105	17.5	17.5	20	40	12	4	3	80
5	70	35	35	20	40	12	4	3	80

[1] The total amount of flour mixture was 140 g plus 20 g starch and 40 g peanut butter, for a total of 200 g (100%). Sugar, salt, baking powder and water are constant.

Table 3.2. Sensory attributes and references used in the descriptive analysis of peanut chips

Attribute	Definition	References
Flavor, Aromatics		
I-1. Peanut Butter	Aromatic taste sensation associated with peanut butter	soda note in Nabisco saltine cracker = 2 cinnamon note in Wrigley's Big Red gum = 12
I-2. Grain/Nutty	aromatic taste sensation associated with non-specific grains/nuts.	
I-3. Burnt/Scorched	aromatic taste sensation associated with burnt/scorched	
I-4. Cardboardy	aromatic taste sensation associated with cardboard	
Flavor, Basic Tastes		
II-5. Sweet	Taste stimulated by sucrose and other sugars	2% sucrose solution = 2 16% sucrose solution =15
II-6. Salty	Taste stimulated by NaCl and other salts	0.2% NaCl solution = 2.5 0.7% NaCl solution = 15
Flavor, after feel, (evaluate after swallow)		
III-7. Bitter/Astringent/Dry	Combined effect of bitter taste and drying of mouth tissues.	Welch's grape juice = 6.5 (astringency)
Texture, Phase I. Feel the surface of *product* with the lips		
I-1. Roughness	The amount of particles in the surface.	Jello gelatin = 0 Finn Crisp Rye Wafer = 15
Texture, Phase II. Evaluate during first 3 chews		
II-2. Hardness	Force to bite through the sample with the molar teeth.	Land o` Lakes American cheese = 4.5 Lifesavers = 14.5
II-3. Fracturability	Force with which the sample breaks.	Nabisco graham cracker=4.2 Sophie Mae peanut brittle=13
Texture, Phase III. Evaluate during chewdown		
III-4. Moisture absorption	Amount of saliva absorbed by the sample.	Shoestring licorice = 0
III-5. Gritty/Grainy particles	Amount of gritty/grainy particles in the wad.	Jello gelatin = 0 Jim Dandy quick grits = 13
III-6. Chewiness	Amount of work to chew the sample.	Cobblestone Mill rye bread=1.7
Texture, Phase IV. Evaluate after swallow		
IV-7. Toothpack	Degree to which the product sticks on the surface of the teeth.	Uncooked carrot = 1 Jujubes = 15

All lines anchored with Low = 0 and High = 15

Table 3.3. Instrumental and sensory analysis of chips prepared from ground cold-pressed peanut pellets after oil extraction. Formula 1 = 100% peanut, formula 2 = 75% peanut, 25% soy flour, formula 3 = 75% peanut, 25% wheat, formula 4 = 75% peanut, 12.5% soy, 12.5% wheat, formula 5 = 50% peanut, 25% soy, 25% wheat.

	Instrumental				
Attribute	**Formula 1**	**Formula 2**	**Formula 3**	**Formula 4**	**Formula 5**
L* Value	59.93**b**[1]	59.96**b**	58.81**b**	59.18**b**	62.58**a**
a*	7.26**c**	8.91**ab**	9.11**ab**	9.19**ab**	7.96**bc**
b*	20.01**c**	27.84**b**	27.16**b**	27.85**b**	29.57**a**
Shear (Kg/g)	99.6**ab**	101.4**ab**	100.6**ab**	102.9**a**	92.1**b**
Energy to break point [2] (Kg*mm)	130.0**c**	152.0**bc**	161.0**b**	172.0**ab**	190.0**a**
	Sensory[3]				
Attribute	**Formula 1**	**Formula 2**	**Formula 3**	**Formula 4**	**Formula 5**
Peanut butter	4.1**a**	4.1**a**	4.1**a**	3.7**a**	3.4**a**
Grainy/nutty	4.9**a**	4.5**a**	4.6**a**	4.9**a**	4.5**a**
Burnt	2.3**c**	3.5**a**	2.6**bc**	3.1**ab**	3.0**abc**
Cardboardy	3.0**b**	4.3**a**	3.2**b**	3.8**a**	4.2**a**
Sweet	3.8**a**	3.4**a**	3.8**a**	3.4**a**	3.3**a**
Salty	3.3**a**	3.3**a**	3.4**a**	3.4**a**	3.4**a**
Bitter/astringent	3.6**a**	4.4**a**	4.1**a**	4.2**a**	4.5**a**
Roughness - Evaluate with lips	7.2**a**	7.4**a**	7.1**ab**	7.0**ab**	6.6**b**
Hardness - first 3 chews	7.7**b**	8.3**a**	8.0**ab**	7.9**ab**	8.0**ab**
Fracturability - first 3 chews	6.9**a**	7.2**a**	7.2**a**	7.0**a**	7.3**a**
Moisture Absorption evaluate during chewdown	7.3**a**	7.7**a**	7.5**a**	7.6**a**	7.6**a**
Gritty/grainy particles	5.8**a**	6.1**a**	6.0**a**	6.0**a**	6.0**a**
Chewiness -evaluate during chewdown	5.1**a**	5.5**a**	5.3**a**	5.4**a**	5.2**a**
Toothpack – evaluate after swallow	6.7**a**	6.5**a**	6.3**a**	6.7**a**	6.2**a**

[1] Values in a row with the same letter are not significantly different.

[2] Total work done until the chip breaks in the Kramer cell. It is equal to the area under the force-deformation curve.

[3] Each value is the result of 25 observations.

Table 3.4. Instrumental and sensory analysis of peanut chips prepared from commercial roasted peanut flour

	Instrumental				
Attribute	**Formula 1**	**Formula 2**	**Formula 3**	**Formula 4**	**Formula 5**
L* Value	54.90**b**[1]	55.75**b**	56.54**b**	55.67**b**	59.27**a**
a*	10.52**a**	10.32**a**	10.13**a**	10.09**a**	8.49**b**
b*	28.67**c**	30.28**ab**	29.76**b**	29.86**b**	30.79**a**
Shear (Kg/g)	94.8**a**	77.1**b**	75.8**b**	76.3**b**	80.2**ab**
Energy to break point [2] (Kg*mm)	162.0**a**	167.0**a**	164.0**a**	169.0**a**	172.0**a**

	Sensory[3]				
Attribute	**Formula 1**	**Formula 2**	**Formula 3**	**Formula 4**	**Formula 5**
Peanut butter	3.9**a**	3.7**a**	3.9**a**	3.6**a**	3.4**a**
Grainy/nutty	4.6**a**	4.8**a**	4.6**a**	4.7**a**	4.7**a**
Burnt	2.8**bc**	3.6**a**	2.3**c**	3.2**ab**	3.3**ab**
Cardboardy	3.4**ab**	4.1**a**	3.0**b**	3.9**a**	3.8**a**
Sweet	3.2**a**	2.8**a**	3.3**a**	3.2**a**	3.1**a**
Salty	2.8**a**	3.0**a**	2.9**a**	3.1**a**	2.8**a**
Bitter/astringent	3.8**a**	4.3**a**	3.6**a**	4.1**a**	4.1**a**
Rough - Evaluate with lips	6.4**a**	6.9**a**	6.6**a**	7.4**a**	6.9**a**
Hardness - first 3 chews	7.6**a**	7.9**a**	7.3**a**	7.6**a**	7.5**a**
Fracturability - first 3 chews	6.8**a**	7.1**a**	6.6**a**	6.9**a**	6.9**a**
Moisture Absorption evaluate during chewdown	7.7**a**	7.7**a**	7.7**a**	7.9**a**	7.8**a**
Gritty/grainy particles	5.6**a**	5.6**a**	5.5**a**	6.0**a**	5.8**a**
Chewiness - evaluate during chewdown	5.4**a**	5.4**a**	5.2**a**	5.3**a**	5.3**a**
Toothpack – evaluate after swallowing	6.6**a**	6.3**a**	6.4**a**	6.8**a**	6.1**a**

[1] Values in a row with the same letter are not significantly different.

[2] Total work done until the chip breaks in the Kramer cell. It is equal to the area under the force-deformation curve.

[3] Each value is the result of 20 observations.

Table 3.5. Flour mix formulations used in Experiments 3, 4 and 5.

Formula	Peanut pellet flour (%)	Light roasted flour (%)	Soy flour (%)	Wheat flour (%)
CP1	100	0	0	0
CP2	75	0	25	0
CP3	75	0	0	25
LR1	0	100	0	0
LR2	0	75	25	0
LR3	0	75	0	25

Table 3.6. Comparison of sensory and physical analysis of sugar-coated (6% dry weight) chips made from cold pressed (CP) peanut pellets and roasted flour (LR)

			Instrumental			
Attribute	**CP1**	**CP2**	**CP3**	**LR1**	**LR2**	**LR3**
L* Value	60.08**a**[1]	60.69**a**	60.81**a**	55.27**c**	55.77**c**	57.05**b**
a*	7.32**d**	8.38**c**	8.08**c**	10.60**ab**	10.80**a**	10.04**b**
b*	19.51**f**	27.11**d**	26.25**e**	29.18**c**	30.63**a**	29.93**b**
Shear (Kg/g)	106.1**a**	93.2**bc**	95.9**b**	86.7**c**	70.5**d**	71.3**d**
Energy to break point[2] (Kg*mm)	138.8**b**	147.9**b**	176.7**a**	149.2**b**	137.8**b**	152.9**b**
Snapping force (N)	4.2**bc**	3.7**c**	4.6**bc**	4.9**bc**	5.6**b**	7.4**a**
			Sensory[3]			
Attribute	**CP1**	**CP2**	**CP3**	**LR1**	**LR2**	**LR3**
Peanut butter	4.1**a**	3.7**ab**	3.6**b**	3.5**b**	3.3**b**	3.5**b**
Grainy/nutty	4.4**a**	4.4**a**	4.4**a**	4.3**a**	4.1**a**	4.2**a**
Burnt	2.9**c**	3.5**ab**	2.9**c**	3.2**bc**	3.9**a**	3.5**abc**
Cardboardy	3.4**c**	4.1**ab**	3.5**c**	3.8**bc**	4.5**a**	3.8**bc**
Sweet	3.2**a**	2.9**ab**	3.1**ab**	3.1**ab**	2.7**b**	2.9**ab**
Salty	2.8**a**	3.1**a**	2.9**a**	2.9**a**	2.9**a**	2.8**a**
Bitter/astringent	3.9**b**	4.2**ab**	3.8**b**	3.8**b**	4.5**a**	4.0**ab**
Roughness - Evaluate with lips	6.2**b**	7.0**a**	6.7**ab**	6.3**b**	6.6**ab**	6.6**ab**
Hardness - first 3 chews	7.8**a**	7.6**a**	8.1**a**	7.5**a**	7.9**a**	7.7**a**
Fracturability - first 3 chews	6.8**a**	6.7**a**	6.8**a**	6.8**a**	6.8**a**	7.0**a**
Moisture Absorption evaluate during chewdown	7.5**ab**	7.4**bc**	7.3**c**	7.4**bc**	7.5**a**	7.4**abc**
Gritty/grainy particles	6.0**a**	6.2**a**	6.2**a**	5.9**a**	5.9**a**	6.0**a**
Chewiness -evaluate during chewdown	5.6**a**	5.5**a**	5.8**a**	5.5**a**	5.6**a**	5.6**a**
Toothpack - evaluate after swallow	6.5**a**	6.4**a**	6.4a	6.6a	6.2a	6.5**a**

[1] Values in a row with the same letter are not significantly different.

[2] Total work done until the chip breaks in the Kramer cell. It is equal to the area under the force-deformation curve

[3] Each value is the result of 34 observations

Table 3.7. Comparison of sensory and physical analysis of non sugar-coated chips made from cold pressed (CP) peanut pellets and lightly roasted flour (LR)

Instrumental

Attribute	CP1	CP2	CP3	LR1	LR2	LR3
L* Value	60.98**b**[1]	62.38**a**	61.48**ab**	56.22**cd**	55.55**d**	57.45**c**
a*	7.36**c**	7.99**c**	8.07**c**	10.80**a**	10.48**ab**	9.89**b**
b*	19.94**c**	27.34**b**	26.27**b**	30.13**a**	30.46**a**	30.59**a**
Shear (Kg/g)	96.1**a**	96.1**a**	89.5**ab**	81.5**b**	66.0**c**	64.4**c**
Energy to break point[2] (Kg*mm)	120.5**a**	142.8**a**	133.8**a**	120.9**a**	114.6**a**	122.9**a**
Snapping force (N)	2.8**c**	2.7**c**	3.0**c**	4.5**b**	5.0**ab**	5.7**a**

Sensory[3]

Attribute	CP1	CP2	CP3	LR1	LR2	LR3
Peanut butter	3.6**a**	2.9**b**	2.9**b**	3.2**ab**	2.8**b**	2.9**b**
Grainy/nutty	4.2**ab**	4.3**a**	4.2**ab**	3.8**bc**	3.9**abc**	3.7**c**
Burnt	2.6**b**	3.1**ab**	2.9**ab**	2.9**ab**	3.4**a**	3.2**a**
Cardboardy	3.5**b**	4.2**a**	3.7**ab**	3.8**ab**	4.2**a**	3.8**ab**
Sweet	2.7**a**	2.5**a**	2.6**a**	2.6**a**	2.5**a**	2.4**a**
Salty	2.6**ab**	2.4**ab**	2.7**a**	2.5**ab**	2.6**ab**	2.3**b**
Bitter/astringent	3.6**b**	4.0**a**	3.7**ab**	3.7**ab**	4.0**ab**	3.7**ab**
Roughness - Evaluate with lips	3.9**a**	3.8**ab**	3.9**a**	3.3**bc**	3.5**abc**	3.1**c**
Hardness - first 3 chews	6.7**b**	6.9**ab**	7.1**ab**	7.0**ab**	7.2**a**	6.9**ab**
Fracturability - first 3 chews	6.3**a**	6.4**a**	6.6**a**	6.4**a**	6.5**a**	6.2**a**
Moisture Absorption-evaluate during chewdown	7.0**b**	7.1**ab**	7.1**ab**	7.4**a**	7.1**ab**	7.1**ab**
Gritty/grainy particles	5.6**abc**	5.8**a**	5.7**ab**	5.3**c**	5.6**abc**	5.4**bc**
Chewiness - evaluate during chewdown	5.2**a**	5.4**a**	5.3**a**	5.2**a**	5.1**ab**	4.9**b**
Toothpack – evaluate after swallow	6.3**ab**	6.0**b**	6.2**ab**	6.5**a**	6.0**b**	5.9**b**

[1] Values in a row with the same letter are not significantly different.

[2] Total work done until the chip breaks in the Kramer cell. It is equal to the area under the force-deformation curve

[3] Each value is the result of 26 observations.

Table 3.8. Instrumental and sensory analysis of peanut chips prepared with cold pressed flour processed from blanched (no SKIN) or unblanched (with SKIN) peanuts.

	Instrumental					
Attribute	CP1-NO SKIN	CP2-NO SKIN	CP3-NO SKIN	CP1+SKIN	CP2+SKIN	CP3+SKIN
L* Value	70.91**a**[1]	69.54 **b**	68.24 **c**	61.36 **de**	62.27 **d**	60.33 **e**
a*	6.68 **b**	7.34 **b**	8.75 **a**	6.80 **b**	7.19 **b**	7.97 **ab**
b*	27.32 **c**	31.45 **b**	33.23 **a**	19.84 **e**	26.38**cd**	25.96 **d**
Shear (Kg/g)	104.7 **a**	100.6 **a**	96.5 **a**	102.7 **a**	102.3 **a**	94.2 **a**
Energy to break point[2] (Kg*mm)	130.8 **b**	155.9 **a**	141.8 **ab**	125.2 **b**	156.8 **a**	155.3 **a**
Snapping force (N)	2.5 **b**	3.3 **ab**	4.3 **a**	3.9 **ab**	3.7 **ab**	3.9 **ab**

	Sensory[3]	
Attribute	**CP-NO SKIN**	**CP + SKIN**
Peanut butter	2.8 **b**	3.2 **a**
Grainy/nutty	3.8 **b**	4.0 **a**
Burnt	2.4 **b**	2.6 **a**
Cardboardy	3.4 **a**	3.4 **a**
Sweet	2.7 **a**	2.7 **a**
Salty	2.6 **a**	2.6 **a**
Bitter/astringent	3.6 **a**	3.7 **a**
Roughness - Evaluate with lips	4.0 **b**	4.3 **a**
Hardness - first 3 chews	6.4 **a**	6.5 **a**
Fracturability - first 3 chews	6.0 **a**	5.9 **a**
Moisture Absorption evaluate during chewdown	6.8 **a**	6.8 **a**
Gritty/grainy particles	5.6 **a**	5.6 **a**
Chewiness – evaluate during chewdown	5.2 **a**	5.2 **a**
Toothpack – evaluate after swallowing	6.1 **a**	5.8 **b**

[1] Values in a row with the same letter are not significantly different.

[2] Total work done until the chip breaks in the Kramer cell. It is equal to the area under the force-deformation curve.

[3] Each value is the result of 90 observations.

Table 3.9. Shear stress of commercial crackers, as determined with an Instron equipped with Kramer cell

	Wheat Thins®	Wheatables®	Toasteds®	Wheatsworth®	Peanut chips
Shear stress (Kg/g)	14.0	31.2	15.9	10.1	96.1[1]

[1] 75% peanut pellet, 25% soy, non-sugarcoated.

Table 3.10. Protein and fat content of the peanut chips made with pellet flour

	Protein	Fat
Formula 1[1]	37.1	10.1
Formula 2	34.2	11.5
Formula 3	30.5	9.0
Formula 4	32.0	10.9
Formula 5	31.2	12.0

[1] Formula 1=100% peanut pellet flour; 2=75% peanut pellet flour, 25% soy flour; Formula 3=75% peanut pellet, 25% wheat; Formula 4=75% peanut pellet, 25% soy and 25% wheat; formula 5 = 50% peanut pellet flour, 12.5% soy flour and 12.5% wheat flour.

SECTION IV

CONSUMER ACCEPTABILITY OF A PEANUT-SOY CHIP-TYPE SNACK OPTIMIZED BY RESPONSE SURFACE METHODOLOGY

A. Zenere, Y. W. Huang, and G.O. Ware. To be submitted to the Journal of Food Science or Food Research International.

ABSTRACT

A series of peanut chip formulations were made with cold pressed peanut flour and soy flour. The chips also contained sugar, cornstarch and peanut butter at one of 3 different levels, in a 3 X 3 X 3 full factorial design. The chips were tested for shear force, snapping force and CIE L* a* b* color. Hardness was found by Instron / Kramer cell to be as low as 442.4 N/g for chips containing 18% sugar, 15% starch and 20% peanut butter. A consumer test was designed using chips of the 27 formulations, in addition to three peanut-wheat formulations included as dummy controls, in a balanced incomplete block design. The results showed that the sensory characteristics were dependent on the levels of sugar, starch and peanut butter. The acceptability of peanut-soy chip was >90% for chips made with 18% sugar and 30% peanut butter. Starch was not a significant factor for taste, sensory hardness and acceptability, but it was for the physical and some sensory properties. Response Surface Methodology (RSM) was used to generate contour plots, showing that the physical properties and sensory texture, appearance, aroma, taste and overall liking of the new product were optimal when sugar, starch and peanut butter were high. Optimal areas were identified.

INTRODUCTION

In the United States, most of the peanut crop is marketed either for direct consumption as roasted kernels, peanut butter and cookies or for oil extraction. Extraction, when done by pressing raw peanuts, leaves a cake that is high in protein (40%) and low in fat (14%). If processed from non food-grade peanuts, the cake is used as animal feed or fertilizer (Woodroof, 1983; Hwang *et al.*, 2001; Matthaus, 2002). Chip-type snack foods have been popular in the market and are produced by either extrusion or sheeting (Shukla, 2000). In a previous study prototype chips were produced using defatted peanut press cake fortified with either soy or wheat flour (the cake was in the shape of pellets). Consumers rated the texture of the chips 4.4 (peanut-soy) and 4.5 (peanut corn) on a 9-point hedonic scale. Less than 50% of the consumers rated the chips as acceptable, implying that the quality of the chips was not fully satisfactory. A successive study by the same authors resulted in a series of chips containing, in addition to cold pressed peanut meal, soy or wheat flour, 9.1% peanut butter, 10.95% sucrose and 4.5% cornstarch (percentages do not include water). A trained descriptive panel rated these chips as little different from each other in terms of texture and flavor. They rated the organoleptic properties with values that were mostly between 2.6 and 4.3, and hardness as high as 7-8 on a 15-cm line scale. However, instrumental (shear stress) tests done with an Instron and Kramer cell yielded results varying among the various formulations. In particular, chips containing no soy or wheat were as hard as or harder than chips containing 25% soy or wheat flour. In the same study it was observed that chips produced with commercial (roasted) defatted peanut flour were softer than chips produced with cold pressed peanut meal, especially when fortified with soy or wheat. Nonetheless, a comparison between cold pressed peanut meal chips (with soy) and four commercial crackers showed that the shear force of the softest peanut chips was threefold higher than the hardest of the commercial crackers, and five times higher than their average. The wheat-based crackers were not fully comparable with peanut chips, due to the different content in protein and starch. However, they were chosen as controls because they were the most similar samples commercially available.

Previous studies have shown that high-protein components yield a harder and crunchier extruded chip than low-protein components (Faubion and Hoseney, 1982; Paton and Spratt, 1984). Suknark (1998) observed that increased proteins in formulation form a strong, hard network. Conversely, expansion of an extruded product may actually be increased by the addition of starch (Prinyawiwatkul *et al.*, 1995). Also addition of 3% oil helps expansion (Mohamed, 1990), although an oil level at 5% or more may prevent expansion (Cheftel, 1986). Suknark (1998) found that substituting starch with partially defatted peanut flour (PDPF) up to 15-30% was beneficial for expansion, but higher substitution prevented expansion due to the higher content of oil and protein. Soybeans contain phospholipids, vitamins, minerals and isoflavones. The level of isoflavones in soybean and soyfood ranges from 1.33 to 3.88 mg/g dry weight (Coward *et al.*, 1993; Wang and Murphy, 1994). Therefore, fortifying cold pressed peanut flour with soy flour would yield a healthy product. Our previous study determined that addition of soy or wheat flour can result in crispier and at least as tasty chips. However, it was not clear how much of the change was due to soy or wheat flour and how much was due to other ingredients such as sugar, starch and peanut butter. These ingredients had been added because sugar and cornstarch were known to have a tenderizing effect (Matz, 1989). Peanut butter was expected to have a shortening effect (it contains 55% fat) and to carry the additional benefit of its rich peanut flavor. In the present investigation it was decided to focus on soy flour as main secondary ingredient (besides cold pressed peanut flour), because of the nutritional advantage provided by its high content in protein and isoflavones. The objective was to study the influence exerted by the ingredients sugar, starch and peanut butter on texture and sensory characteristics of the chips and to identify the most acceptable formulation by an optimization process.

MATERIALS AND METHODS

Formulation. Defatted peanut cake (protein 40-44%, fat 10-14%, moisture 8%, fiber 3.7% and ash 3.1%) in the form of pellets was kindly provided by Birdsong Peanut Corp., Suffolk, VA, stored at -30° C and ground in our laboratory on the day it was used. Soy flour (Arrowhead Mills, Hereford, TX) was purchased at a local grocery store. Peanut-soy chips were prepared using different levels of sugar, starch and peanut butter, in a 3 X 3 X 3 full factorial design, while keeping peanut flour to soy flour ratio as 3:1. A total of 27 formulations were produced. The three factors were 1) sugar, at the levels of 6%, 12% and 18%; 2) starch, at the levels of 5%, 10% and 15%; 3) peanut butter, at the levels of 10%, 20% and 30%. The experiment was replicated twice, for a total of 54 samples.

Sample preparation. In all 27 treatments the ratio of peanut flour to soy flour was kept at 3:1, the same as in our previous studies (Table 4.1). The variables were sucrose, modified cornstarch (Baka-Plus, National Starch and Chemicals, Bridgewater, NJ) and creamy peanut butter (Tara Foods®, Albany, GA). The chips were prepared as described elsewhere. Pellet-shaped peanut press cake was ground in a split grinder (Model 4E, The Straub Co., Philadelphia, PA). The required amounts of flour were blended with soy flour, sugar, starch, peanut butter, salt, baking powder and approximately 30% warm water in a Kitchen Aid® mixer (Model KSM 50PWH, St. Joseph, MI) for 3 min at speed 2. The dough was sheeted using an industrial sheeter (Model S-18-BNO 4458, Moline Machinery, Ltd., Duluth, MN), cut into ca. 3.8-cm-side squares, and then baked in an impingement oven (Model 1450, Lincoln Foodservice Products, Fort Wayne, IN). Baking was performed in two steps: 1) 20 min at 98° C, so to bring moisture content down to 9-10%; 2) 2 min at 160° C, to finally bake the product. Drying the chips for 20 min before baking them prevented most of the bubbling that would have otherwise covered the chips surface and produced an unpleasant visual effect. The chips, cooled to room temperature, were bagged (Ziploc® bags), flushed with nitrogen and stored at -30° C. For the consumer test, three extra formulations were prepared using wheat flour instead of soy flour. The three peanut-wheat samples are referred to as “dummy controls”. The purpose of adding a few peanut-wheat samples was to use them in the consumer test together with the peanut/soy chips. In fact, during a previous analytical sensory test, a trained sensory panel had found only small, if any, differences between peanut/soy and peanut/wheat chips. It was important to see if a panel of untrained consumers was able to discriminate between the two chips.

Since all 30 formulations could not be produced in the same day, a maximum of nine formulations, consisting of a one-third fractional factorial, was prepared each day. Three separate one-third fractional factorials were generated covering all 27 treatments. The three treatments with wheat (Formulas 28, 29 and 30) were prepared last. Chips for the physical tests were made in the larger size of 5.1-cm-side squares, to fit the Kramer cell used in the shear test. The average weight was 2.7 g. Chips prepared for the sensory test were smaller squares of 3.8-cm side and weighed ca. 1.7 g. For either large or small chips the thickness was 1.6 mm. The reason for chips of different size was that smaller chips were perceived as being softer, but the larger size chips fit the Kramer cell better.

Proximate composition

Percent moisture. About 2 grams of ground product in duplicate were dried at 100 °C overnight in a vacuum oven (AACC, 1986).

Fat. Extraction was carried out in a Soxhlet apparatus. About 2 grams of sample were loaded into pre-dried and weighed 185 mm-diameter Whatman® No.1 filter paper, folded and stapled at one end. Then the samples were dried at 100 °C overnight in a vacuum oven. The samples were cooled in a dessicator, weighed and inserted in the Soxhlet units, four samples per unit. Reflux with petroleum ether was carried out for 6 hrs. The extracted samples were dried in a vacuum oven at 100 °C, cooled in a dessicator and weighed (Nielsen, 1998).

Protein. An automated Kjeldahl system (Fisher Scientific, Pittsburg, PA), was used. One g of sample, in triplicate, was added to each 250-ml glass tube, followed by adding 7 g of K_2SO_4, 0.8 g of $CuSO_45H_2O$ and 15 ml H_2SO_4. Digestion of the samples was carried out in a TCDB 20 digestion block at 420 °C for 30-90 min. Distillation was accomplished in a Kjeltec® 2200 Auto Distillation Unit. Titration of the receiving solution was done using 0.1889 N HCl.

Ash. Approximately 3 grams of each ground sample were placed in a ceramic crucible with lid and heated overnight in an oven at 600 °C. After the samples were cooled in the oven, they were placed into a dessicator and weighed.

Color. The color of chips was determined using a Minolta Chroma meter (model CR 200, Osaka, Japan) with CIE L* a* b* values, where L* denotes lightness, a* red to green, b* yellow to blue, hue = $\tan^{-1}$ (b*/a*) and chroma = $(a^{*2}+b^{*2})^{1/2}$. Ten chips per treatment per replication were tested, for a total of 20 chips per formulation.

Texture. An Instron Universal Testing Machine (Model 1122, Instron Corp., Canton, MA) fitted with a Kramer cell was used to evaluate chip texture. The cross bar with a 500 Kg load cell had a speed of 50 mm/min. One 5.1 -cm square chip was positioned in the cell, and the force required to shear was recorded. The texture was analyzed also by a snapping test, following the method described by Bruns and Bourne (1975), with modifications. Two wood blocks, each 50 mm long, had been glued to a wood board at a distance of 15 mm from each other. One chip at a time was set bridging over them, and was broken (snapped) by a single blade connected to an Instron. The cross bar had a load cell of 50 Newtons and a speed of 50 mm/min. The system was operated by Merlin computer software (Instron Corp., Canton, MA). The blade was made with a 3-mm-thick Plexiglas plate tapered on one side to a moderately sharp edge. A computer monitor showed how the force increased to a maximum and finally dropped at the chip failure. The peak force was recorded in Newtons (N). Six chips per formulation per 2 replications were tested, for a total of 12 chips per formulation.

Sensory evaluation. Ninety untrained panelists, recruited among students, faculty and staff of the University of Georgia, Athens, GA, participated in the consumer sensory test twice, for a total of 180 panelists (Resurreccion, 1998). Each consumer tasted 5 random samples, in a balanced incomplete block design, so that each formulation was judged by a total of 30 panelists. The samples were presented on a tray in random order (presentation in monadic order was not practical due to the large number of participants). Before each test, a randomized list of 90 groups of 5 samples was generated utilizing a SAS software (SAS/QC, 1995), distributed in such a way that all treatments were presented the same number of times (15 per rep). The panelists evaluated each sample on a 9-point hedonic scale, where 1 was defined as “dislike extremely”, 5 as “neither like nor dislike” and 9 as “like extremely” (Figure 4.1) (IFT Sensory Evaluation Division, 1981; Ward, 1995; Hashim et al., 1999). Panelists rated the following descriptors: appearance, color, aroma, taste, hardness, overall liking, and acceptability. The scale was reduced for one descriptor, hardness, so to have only 5 points, 1 being “very hard”, 2 “hard”, 3 “adequate”, 4 “soft” and 5 “very soft”, to simplify and clarify the textural analysis for the participants. During four days, most panelists participated in the sensory test twice, with an interval of two days between sessions.

Statistical Analysis. Data were recorded on a Microsoft® Excel 97 program. The physical property data of Replicate 1 were tabulated and analyzed independently from those of Replicate 2. This allowed us to obtain prediction equations from the first replicate, and verify them using the data from the second replicate. Eventually both replicates were combined and analyzed together. PROC GLM (analysis of variance), PROC CORR (correlation), PROC REG and PROC PLOT (regression analysis and contour plots) were the procedures in the SAS® Release 6.12 (SAS Institute Inc., Cary, NC) used in the analysis. Analysis of variance and regression analysis were conducted to determine the significance level of each component in the model. A mathematical relationship (model) between independent variables and dependent variables (or responses) was expected to approximate the form of a second-degree polynomial equation (Floros and Chinnan, 1987; Floros and Chinnan, 1988):

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + x_1^2 + x_2^2 + x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3$$

in which Y was the response; β_0, β_1, β_2 and β_3 were coefficients and x_1, x_2, x_3 were the coded independent variables sugar, starch and peanut butter, respectively. A full model for each physical and sensory characteristic was developed including all linear and quadratic terms representing the independent variables, plus all the pairwise cross products between the linear terms. Reduced models were constructed for all response variables by regression procedure (PROC REG) and backward elimination. If the reduced model was not significantly different from the full model, it was used to predict the response variable (Walker, 2000). The prediction models were used to build contour plots, which represented all the combinations of the independent variables that were found to have a significant effect on the attribute of the product. A computer program (Statistica®, version 5.0, 1995) was used to transform the model for each physical or sensory characteristic into contour plots. Plotting was done using two variables at a time and keeping the third variable fixed at one level. The fixed variable was usually the least significant for that response. When only two variables were significant for an attribute, a single plot was drawn for that attribute, with the two significant factors used on the X and Y-axes.

RESULTS AND DISCUSSION

Chemical composition

Percent moisture, fat, protein and ash content of selected chips and of the primary ingredients are presented in Table 4.2. The fat content ranged from 10.1 to 16.0%, protein ranged from 16.3 to 21.3%, ash ranged from 3.8 to 4.3% and moisture ranged from 2.2 to 3.0%. The fat content was lower than expected calculating the fat content of the ingredients. One reason was that the plastic sheets had high affinity for fat and removed part of the oil from the chips, to the point that fat had to be wiped from the plastic sheets between batches, to avoid transferring fat from batch to batch. Substituting part of the cold pressed peanut flour with soy flour and peanut butter improved the texture and flavor of the chips, but resulted also in increased fat content, compared with previous experiments. Higher fat content is not ideal, but it is a trade off compared with a peanut chip with lower fat but harder texture and less acceptable to consumers.

Physical properties

Texture. Shear force varied between 950.4 N/g (Formula 1) and 442.4 N/g (Formula 26) (Table 4.3). The highest shear force values were prevalent among the treatments with low sugar, starch and peanut butter, while low values of shear force were found among formulations with high sugar, starch and peanut butter such as Formulas 18, 26, and 27. The results show that sugar, starch and peanut butter were all highly significant ($p = 0.001$) in making the chips softer.

The snapping test resulted in values ranging between 13.3 (Formula 16) and 7.0 Newtons (N) (Formula 14) and decreased with increasing amounts of sugar and peanut butter. The trend was similar to shear force, but shear values decreased progressively with increasing sugar and starch, while snapping force showed a minimum value at 10% starch and then increased with 15% starch. However, the significance of the data on snapping force is limited by the higher standard deviation in snapping force data compared with the shearing test data. For example, a chip exposed to the pressure from the blade during the snapping test sometimes broke almost immediately upon application of force (probably due to the presence of invisible fractures in the chip), and other times resisted a pressure of 12-14 N before undergoing fracture. As a control, two commercial crackers, Wheatable® low fat and Toasted Wheat® were tested in both a shear test and a snapping test (Table 4.4). They also showed a higher standard deviation for snapping forces than shear forces. Previous literature on the snapping test (also called three-point-bending test) from Bruns and Bourne (1975) and many others (Katz and Labuza, 1981; Ward, 1995; Piazza and Masi, 1997), show that they conducted the test by calculating the slope of the force-deformation curve, probably avoiding high standard deviations. Those researchers did not report tables with standard deviations, so it is difficult to compare our data with theirs. However, even with such drawbacks, our values of (peak) snapping force provided useful information.

Color. The average values for L*, a* and b* were 63.9, 8.1 and 28.7, respectively (Table 4.5). L* values were slightly higher in chips with lower peanut butter, and higher starch. Hue angle ranged between 70.94 (Formula 3) and 76.72 (Formula 25), with values decreasing with increasing peanut butter. The diminishing hue angles were due to increasing values of a* more than to changing values of b*. On the L*a*b* color chart, 70.94 corresponds to a brown hue while 76.72 falls in a more yellow area. Chroma ranged between 31.95 (Formula 3) and 27.10 (Formula 25). Chroma, which measures the color intensity (saturation), depended on both a* and b*. Its values increased with diminishing sugar and increasing peanut butter.

The regression analysis of the data after the first replicate of the instrumental analysis showed a good fit, with R^2 for shear stress equal to 0.91, and L* a* and b* with an R^2 of 0.73, 0.78 and 0.78, respectively (Table 4.6).

However, the regression analysis after the second replicate showed a lower coefficient of determination. L* value, for example, had a total $R^2 = 0.33$ indicating that this characteristic has a high variability and may be difficult to control (Table 4.7). Yellowness (b* values) had a coefficient of determination even lower (R^2=0.276). Redness (a* values) had a high R^2 (=0.66) after the second replicate, indicating a higher predictability than L* and b*. This could be important for quality control, because the a* value could be used to check the baking stage in an automated peanut chip production. Hue values were statistically analyzed only after the second replicate but showed a high value of $R^2 = 0.72$. In the hue model sugar, starch and peanut butter were all significant. Chroma depended only on sugar and peanut butter, but its R^2 was low (=0.31).

Yellowness (b*) was only dependent on sugar ($p<0.001$) and peanut butter ($p<0.05$). Redness (a* value) increased with decreasing starch and increasing peanut butter. Yellowness (b* value) increased with increasing peanut butter and decreasing sugar.

Consumer acceptance

On average, the panelists rated the appearance of the chips 6.68 on a 9-point hedonic scale (Table 4.8) which is between 6 =like slightly and 7 =like moderately. However, most scores ranged between 6.36 and 7.1 (the only exception being Formula 25, rated 5.67) showing little discrimination among formulations. The same lack of discrimination was found in color and aroma. Ratings of color ranged between 6.10 and 7.20, while ratings for aroma were between 5.57 and 6.96. Both showed an increase in consumer rating with increasing amounts of sugar, starch and peanut butter. However, the R^2 was low ($R^2<0.5$) for all three responses appearance, color and aroma (Table 4.9). Few independent variables were significant with a $p< 0.05$, which is probably the effect of how little agreement there is among consumers on evaluation of appearance, color and aroma. For the attribute taste, panelists showed a greater discrimination, with a minimum rating of 4.27 for Formula 4 (6% sugar, 10% starch and 10% peanut butter), and a maximum rating of 7.24 for Formula 24 (18% sugar, 10% starch and 30% peanut butter). Taste showed a low dependence on sugar ($p = 0.509$) and peanut butter ($p = 0.99$), but a high dependence ($p<0.05$) on the interaction of sugar-peanut butter. The descriptors overall liking and acceptability showed the same trend, with formula 24 receiving the highest rating (7.35 and 100%, respectively) and formula 1 receiving the lowest. Acceptability increased with increasing sugar and peanut butter ($p<0.001$) but did not show any dependence on starch. An acceptability of 100% is the ideal target of any new product manufacturer. However, because such level of acceptability is hardly realistic, it was decided to consider an acceptability of 80% as a more practical goal. Seven formulations were above the 80% threshold (9 if we count the samples containing wheat). Three of the samples, all containing 30% peanut butter, were above 90% acceptability. This compared well with the acceptance of extruded tapioca-peanut snacks described in Suknark's work (1998). Her product, an extruded and fried peanut-based cracker, was rated as acceptable by more than 80% of both American and Asian consumers. However, her alternative product, a tapioca-fish cracker, was rated as acceptable by only 60-70% of the American consumers (while more than 80% of the Asian consumers rated the fish cracker as acceptable). This difference in the rating of fish snacks shows how ethnic background is an important factor in predicting the success of a new food product, independently from its nutritional quality. It also shows that peanut snacks are rated highly in both American and Asian cultures.

Sensory hardness showed the same trend as acceptability: Formula 4 (6% sugar, 10% starch and 10% peanut butter) was rated "hard" (1.90 on a 5-point hedonic scale) and Formula 24 (18% sugar, 10% starch and 30% peanut butter) was rated "adequate" (2.96). In general, about the other formulations, the lower was the level of sugar and peanut butter, the lower was the rating. There were some notable exceptions, however. Formulas 2, 3 and 9 had a high rating for hardness even though if they were low in sugar. Formula 12 (medium sugar and low starch) was high not only in hardness, but also in acceptability (82.86%) and taste (6.33). These formulations are interesting because they could be produced commercially at lower cost than chips with high sugar and starch, with almost the same likelihood of being accepted by consumers. For hardness a target of at least 2.5 in the consumer rating was considered acceptable in such a high protein peanut-based chip. Sensory hardness was dependent only on sugar ($p<0.01$) and peanut butter ($p<0.01$), but not on starch. This differs from the data of physical hardness, which was dependent on starch. Such discrepancy may have derived from the smaller amplitude of the 5-point scale compared with the 9-point hedonic scale, which left the panelists with less ground for discrimination.

However, starch had a smaller significance also in the instrumental analysis of texture compared with sugar and peanut butter.

Statistical analysis

As explained before, the physical data were analyzed after the first replication. Because the coefficients of determination were high, ranging between an R^2 = 0.67 (for snapping force) and an R^2 = 0.91 (for shear force), prediction equations were derived for each physical property. The purpose was to verify the models using the data from the second replicate. The predicted values were plotted against the observed values from the second replicate, letting the observed values be on the X-axis and the predicted values be on the Y-axis (Figures 4.2A and 4.2B and Figure 4.3A, 4.3B and 4.3C). It can be seen that the data points are more evenly spread out along the slope line in the graphs of shear stress and a* values than in the plots for snapping force, L* and b*.

When the data from the two replicates were later combined, only shear force, a* and hue values maintained a coefficient of determination greater than 0.5. Specifically, shear force decreased from R^2 = 0.91 to R^2 = 0.80. The a* value decreased from an initial R^2 = 0.79 to R^2 = 0.66, indicating a higher variability in the redness of the chips, even if not as high as lightness and yellowness.

For the sensory data taste, hardness, overall liking and acceptability were the only ones to have an R^2 > 0.5 after the second replicate. Hardness and acceptability appeared to depend only on sugar and peanut butter (Table 4.9) while taste and overall liking depended on their interaction too. Among the more significant descriptors, only aroma and overall liking depended on starch. The prediction equations for the physical and sensory data are reported in Table 4.10 and Table 4.11, respectively. The intercepts and the slopes of each model are listed. For the characteristic shear force, for example, the negative slopes of the factor sugar, starch and peanut butter showed that increasing the amount of each of them resulted in a decrease in hardness. Table 4.12 lists the observed ratings of all 27 peanut/soy chips formulations. Beside each column of observed values is a column of predicted values, each calculated by using the prediction equation for each sensory characteristic. Predicted and observed values are close in most cases, with deviations of 20% or more from each other only in 6 cases (Formulas 1, 8, 10, 16, 20 and 25).

Response Surface Methodology. Contour plots of shear force were generated with peanut butter on the Y-axes and sugar on the X-axes. The third variable, starch, was considered fixed, and a plot for each level of starch was drawn (Figure 4.4a-b-c). The three plots were similar, but the values on the plots were different. Each plot showed that increasing sugar and peanut butter resulted in softer chips. Comparing the three plots showed that also increasing starch yielded softer chips. The parabolic plots of snapping force showed a minimum value at 10% starch (Figure 4.5a-b-c) showing that chips were crispier (more easily fracturable) at 10% starch level than 5% or 15%. The reason for this is not known. It could be that such amount of cornstarch breaks the bond among other components, particularly proteins, while adding more starch could create new interactions with other starch molecules that more than compensate for the diminished amount of proteins. Contour plots for L* (Figure 4.6) show that lightness decreased with increasing content of sucrose and peanut butter, but increased with starch. Redness (a*) (Figure 4.7) increased with peanut butter, but was inversely related to sugar. The effect of starch on a* was weak at low levels, but increased exponentially at levels above 10%. Yellowness (b* values) increased with decreasing sugar and increasing peanut butter (Figure 4.8). Starch had no effect on this physical property. Hue angle (Figure 4.9) increased with increasing sugar, but was inversely related to starch and peanut butter. The contour plot for hue angle shows that starch can have a negative effect on chips color, because more starch results in lighter and paler looking yellow chips. Chroma (Figure 4.10) was independent from starch and was directly related to peanut butter and inversely to sugar. Peanut butter seems to be the most significant factor in the hardness and color of the chips. The difference is strong between chips made with 10% peanut butter and 30% peanut butter. Chips containing 10% peanut butter were lighter and more yellow in color, harder to break in the mouth, less “peanutty” and all in all with less pleasant visual effect than chips with 30% peanut butter (personal evaluation of the author).

Contour plots for each sensory descriptor were also generated. Appearance, color and aroma plots all had similar shapes, due to their dependence on peanut butter squared values. Only one contour plot (aroma) is presented (Figure 4.11), as it was the most significant (R^2 = 0.49). Taste (Figure 4.12) was independent from starch and was affected by sugar, peanut butter and the interaction of sugar with peanut butter. Sensory ratings for taste increased with increasing sugar and peanut butter. An optimal area was outlined, with acceptable values of taste above a rating of 6.5. Sensory hardness was determined to be independent from starch, and showed an optimal area on the right top region of the graph (high sugar, high peanut butter). A rating of hardness above 2.5 was considered acceptable (Figure 4.13). Starch, however, not only had an effect on overall liking (Figure 4.14), but at 10% level resulted in the highest ratings by consumers. This preference can be inferred from the contour plots, where the 10% starch plot has a slightly larger optimal area (area of acceptance is that with rating of at least 6.5). This observation reminds us of the plots for snapping force, where 10% starch appeared to be associated with lower force required to fracture the chips. It is possible that concentrations of starch below or above 10% produce a less crisp product (see snapping test) that consumers are able to detect. The contour plot for acceptability (Figure 4.15) showed that this variable was independent from starch.

Of the formulations containing wheat flour instead of soy flour, Formula 29 and Formula 30 were well accepted by consumers. Formula 29 was rated 86.7% for acceptability, 6.86 for overall liking, 2.33 for hardness and 7.10 for taste; Formula 30 was rated 86.7% for acceptability, 7.00 for overall liking, 2.70 for hardness and 6.95 for taste. This showed that wheat flour could represent a good alternative to soy flour for peanut chip fortification. In particular, Formula 29 received a higher rating for taste than Formula 30, even if its peanut butter content was 10% lower. Cost considerations might dictate the choice between soybean flour and wheat flour as fortificants, balanced against the nutritional benefit of soybean flour and its isoflavone content.

The optimal area was identified with the region of the contour plot with acceptance ratings above 80%. It can be seen, for example, that chips containing 16% sugar and 20% peanut butter occupy such area. Increasing sugar and peanut butter above 18% and 30%, respectively, could improve sensory qualities and consumer acceptability, but it would increase the amount of calories; this would deviate from the healthy snack desired. Nonetheless, consumer acceptability close or equal to 100% for some formulations indicated that an optimal area was reached when 18% sugar and 20-30% peanut butter were used.

Verification. A final test was conducted to verify that the contour plots were reliable. Two sets of chips were produced using the same ingredients of Formula 12 and Formula 25. The ingredients and the preparation conditions were the same used for the 27 formulations, with the exception of the soybean flour (the original one could not be found. The new soybean flour was labeled “organic” and was produced by the same company as the old flour (Arrowhead Mill, Hereford, TX). The verification samples were tested only for some of the physical properties (snapping test was not done). It would not be possible to test the sensory properties in a consumer test. Ten chips were tested for shear force, L* value, a*, b*, hue angle and chroma (Table 4.13). Under each result the comparative original value is reported, and the percentage variation is indicated between parenthesis. The test showed that the shear force of the test chips was lower than that of the original chips. Color, as tested with the Minolta chroma meter, did fall most of the times in the range of the original values +/- 5% (Hinds *et al*., 1994). Even if redness (a*) had a deviation of 18%, such deviations were not apparent in hue angle and chroma values. L* values of the test sample was found 6% lower (i.e. darker chips) than original samples from the same formulation. However, a much larger difference was found in the shear force of the two verification samples, which was 20% lower than the original Formula 12 and Formula 25. The difference could be explained with some quality difference in the soybean flour used for the original samples and the verification samples (a lapse of 16-18 months intervened between the original test and the verification test. It is possible that soybean flour could have been produced from different varieties or cultivars). However, the verification test of the chips for color could be considered satisfactory, and the deviations from the expected values were small.

Machinability. Experiments were conducted to see if it was possible to sheet the peanut-soy dough without the plastic sheets. Two hundred grams of flour mix were prepared, using the same conditions and amount of components used previously for Formula 24. However, 90 ml of water was added instead of the usual 55 ml. The formed dough, as expected, became very wet and stuck to the bowl. It was removed from the container by hand, set on a teflon surface and dusted with soy flour just enough not to be sticky. Soy flour was used because it was fine and more suitable than the coarse peanut meal. By carefully adding more soy flour when required, it was possible to flatten the dough with a rolling pin enough for the dough to pass through the sheeter. A few passes were required to reach the final thickness. The dough sheet was manually removed from the sheeter and laid on a table to be cut into chips. These were baked in the impingement oven as usual. The chips were cooled and placed in plastic bags, to be refrigerated. The chips appeared to be the same as usual (personal observation of the author), the only small difference being that a more irregular surface was noticed, with the presence of small bubbles. The soy flour used for dusting the dough did not add unpleasant flavors (personal observation of the author). Another difference was that the chips were slightly thinner than those made with plastic sheets. In fact, without the plastic sheets the sheeter was set to a lower thickness in order to compensate for the missing plastic sheets. The whole process without plastic sheets was simple and with some mechanical equipment, it could be much faster than with plastic sheets. This finding was important because it showed that producing peanut chips with low manual operation is possible. The dusting and sheeting of the dough is a process that could be done by machines, such as is already done in high-volume commercial bakeries today.

CONCLUSIONS

An experimental design with peanut-soy chips made with different levels of sugar, starch and peanut butter showed that all three components had a significant effect on the physical properties of the chips. The sugar effect is that by increasing its level the chips become less hard, more easily fracturable, darker (because of a caramelization effect or Maillard reaction), with a slightly higher hue and a lower chroma. Sugar at a level of 18% of the dry mix (not including the water) was most effective in reducing the hardness of the chip. Increasing starch provided more fracturability (until we reach a 10% level; at 15% starch chips become harder and less fracturable), lighter in color and with a higher hue (which means chips are more yellow and less brown), especially at higher levels of peanut butter. Peanut butter produced less hard, more easily fracturable and darker chips. Furthermore, peanut butter resulted in lower hue (more brown color, having an opposite effect than cornstarch), and higher chroma. A consumer sensory test with 90 panelists, in duplicate, showed that increasing the content of sugar, starch and peanut butter resulted in softer, tastier and more acceptable chips. The sensory effect of sugar and peanut butter is particularly significant for taste, texture, overall liking and acceptability, implying that an increase in the two components increased ratings on taste, overall liking and acceptability and texture. Starch appeared to be less significant that the other two ingredients, and was significant (at $\alpha<0.1$) only in overall liking. The optimal area on the contour plots was identified, and it contains formulations receiving a rating of at least 6.5 for taste and overall liking, 2.5 for hardness and 80% acceptability.

Future investigation

For commercial production of peanut-soy chips a more automatic process will be required, especially in the area of sheeting and cutting. During our study the sheeting of the dough has been carried out using two sheets of plastic. Without the plastic sheets, the dough showed a tendency to stick to the rollers, to become entangled, fold and break. A preliminary experiment for making the process more automatic and less labor intensive was successful (see the section on Machinability). More research focus on more automatic manufacturing is required in order to keep labor costs low and production volume high.

Further work can be applied in the area of texture, for example by studying the use of emulsifiers or proteases, which could break the bond among proteins and possibly help in softening the chips. In the area of flavor, improvements could derive from adding flavoring such as cocoa, which is already successfully used in peanut cookies. Improved taste and flavor could result from dusting the dough with commercial defatted roasted peanut flour, instead of soy flour. More research could be applied to the fat content. Sheeting the dough with plastic sheets had the unplanned effect of absorbing part of the fat from the peanut dough. Without the plastic sheets, as would be the case in a more automatic processing, the final product would probably a have higher fat content. An effort should be made to reduce fat content of the peanut chips below 10%, so to qualify them as a “low fat” product (for example, using low fat peanut butter).

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Table 4.1. Formulation of the 27 peanut-soy and 3 peanut-wheat treatments. Each formulation includes 1% salt and 1% baking powder

Formula #	Peanut flour (%)	Soy flour (%)	Wheat flour (%)	Sugar (%)	Starch (%)	P.Butter (%)
1	57.75	19.25	-	6	5	10
2	50.25	16.75	-	6	5	20
3	42.75	14.25	-	6	5	30
4	54.00	18.00	-	6	10	10
5	46.50	15.50	-	6	10	20
6	39.00	13.00	-	6	10	30
7	50.25	16.75	-	6	15	10
8	42.75	14.25	-	6	15	20
9	35.25	11.75	-	6	15	30
10	53.25	17.75	-	12	5	10
11	45.75	15.25	-	12	5	20
12	38.25	12.75	-	12	5	30
13	49.50	16.50	-	12	10	10
14	42.00	14.00	-	12	10	20
15	34.50	11.50	-	12	10	30
16	45.75	15.25	-	12	15	10
17	38.25	12.75	-	12	15	20
18	30.75	10.25	-	12	15	30
19	48.75	16.25	-	18	5	10
20	41.25	13.75	-	18	5	20
21	33.75	11.25	-	18	5	30
22	45.00	15.00	-	18	10	10
23	37.50	12.50	-	18	10	20
24	30.00	10.00	-	18	10	30
25	41.25	13.75	-	18	15	10
26	33.75	11.25	-	18	15	20
27	26.25	8.75	-	18	15	30
28	57.75	-	19.25	6	5	10
29	42.00	-	14.00	12	10	20
30	37.50	-	12.50	18	10	20

Table 4.2. Chemical composition (w b) of some selected[1] peanut chip samples. Each value is the average of 2 observations

Formula #	% Moisture	% Fat	% Protein	% Carbohydrate	% Ash
12	2.2	nd[2]	nd	nd	4.3
21	2.3	14.3	21.2	58.1	4.1
22	3.0	10.1	21.3	61.6	4.0
23	2.8	13.0	20.2	60.0	4.0
24	2.7	14.6	19.1	59.6	4.0
27	2.8	16.0	16.3	61.1	3.8
30	2.9	11.4	17.2	nd	nd

[1] For the composition of each sample see Table 1. All the selected formulas have acceptability above 80%.
[2] nd = not determined.

Table 4.3. Instrumental texture analysis of baked peanut chips. Shear values are the average of 20 chips per replication, while snapping force values are the average of 12 chips per replicate (numbers in parenthesis represent standard deviations)

Formula #	Shear force (N/g)	Snapping force (N)
1	950.40 (107.60)	11.54 (2.97)
2	865.73 (126.03)	11.13 (3.36)
3	787.72 (110.15)	7.72 (3.05)
4	810.95 (143.57)	10.96 (3.41)
5	802.52 (88.98)	10.89 (3.54)
6	659.14 (113.88)	8.97 (2.27)
7	734.60 (82.71)	11.73 (4.03)
8	606.32 (95.16)	11.46 (2.61)
9	547.33 (63.60)	8.30 (2.00)
10	858.28 (123.87)	13.09 (4.43)
11	828.68 (97.22)	10.48 (2.19)
12	746.27(116.33)	8.03 (3.08)
13	754.11 (83.20)	10.77 (4.15)
14	683.55 (86.14)	7.04 (2.55)
15	594.46 (51.16)	9.12 (2.32)
16	682.47 (77.62)	13.27 (4.15)
17	500.87 (45.37)	10.70 (2.95)
18	442.66 (46.65)	9.87 (2.93)
19	713.93 (29.11)	12.20 (4.14)
20	693.25 (74.28)	9.60 (2.48)
21	706.38 (81.93)	8.02 (1.96)
22	658.75 (88.69)	10.21 (2.03)
23	601.32 (55.57)	7.28 (2.20)
24	506.17 (55.76)	8.12 (2.06)
25	584.76 (70.76)	9.98 (3.24)
26	442.37 (48.41)	8.30 (1.82)
27	473.83 (55.27)	7.65 (2.99)

Table 4.4. Snapping force and shear force required for breaking two commercial crackers[1]

	Snapping force		Shear force	
	Weight (g)	Force (N)	Weight (g)	Force (Kg/g)
Wheatable®-low fat				
AVG	2.3	19.2	2.3	21.2
STDEV		3.9		1.4
CV		20.3		6.6
Toasted® wheat				
AVG	3.3	17.7	3.3	14.3
STDEV		5.7		1.2
CV		32.2		8.4

[1] n = 10

Table 4.5. Color values of chips with different formulations. Numbers in parenthesis are standard deviations. Each number is the average of 20 chips from each formula

Formula #	L*	a*	b*	Hue Angle	Chroma
1	64.84 (0.71)	7.93 (0.55)	28.64 (1.68)	74.50 (1.16)	29.72 (1.66)
2	62.45 (1.82)	8.64 (0.75)	28.68 (1.20)	73.26 (0.91)	29.96 (1.33)
3	60.14 (1.06)	10.43 (0.46)	30.19 (1.01)	70.94 (0.77)	31.95 (1.03)
4	65.58 (1.03)	7.72 (0.93)	29.25 (1.43)	75.26 (1.15)	30.25 (1.59)
5	63.13 (1.95)	9.01 (0.97)	30.27 (1.57)	73.46 (1.10)	31.58 (1.74)
6	61.63 (1.88)	9.50 (0.54)	30.20 (0.79)	72.45 (0.66)	31.49 (0.89)
7	65.61 (2.76)	7.28 (1.32)	29.87 (1.75)	76.39 (1.67)	30.76 (2.00)
8	64.30 (1.50)	8.57 (1.04)	30.47 (1.13)	74.33 (1.40)	31.66 (1.33)
9	62.91 (2.88)	8.32 (1.11)	28.94 (1.99)	74.03 (1.14)	30.12 (2.21)
10	66.02 (3.65)	6.39 (1.16)	26.80 (2.22)	76.70 (1.40)	27.56 (2.42)
11	62.90 (1.45)	8.82 (0.69)	29.32 (1.04)	73.28 (0.82)	30.63 (1.17)
12	61.46 (2.27)	9.79 (1.21)	29.12 (1.28)	71.48 (1.47)	30.74 (1.57)
13	64.09 (2.45)	8.38 (1.05)	29.65 (1.03)	74.24 (1.72)	30.82 (1.13)
14	63.98 (1.14)	8.90 (0.88)	29.43 (1.38)	73.21 (0.91)	30.74 (1.56)
15	62.79 (1.71)	9.00 (0.72)	28.68 (1.32)	72.60 (0.76)	30.06 (1.45)
16	66.70 (2.14)	7.15 (1.01)	27.75 (1.93)	75.62 (1.15)	28.67 (2.10)
17	66.48 (1.62)	7.20 (1.11)	28.18 (1.58)	75.73 (1.44)	29.10 (1.78)
18	64.57 (1.49)	7.79 (0.52)	28.75 (1.13)	74.85 (0.56)	29.79 (1.21)
19	66.76 (3.17)	6.77 (1.53)	28.32 (1.91)	76.69 (2.19)	29.14 (2.18)
20	64.48 (1.49)	8.00 (0.66)	27.90 (1.49)	74.01 (0.71)	29.02 (1.59)
21	63.10 (0.76)	9.03 (0.49)	28.70 (1.22)	72.52 (0.93)	30.09 (1.22)
22	67.29 (1.41)	6.89 (0.60)	27.13 (1.16)	75.76 (0.77)	27.99 (1.25)
23	64.97 (0.93)	7.77 (0.63)	27.82 (1.14)	74.40 (1.02)	28.88 (1.20)
24	62.33 (1.56)	9.08 (0.64)	29.21 (0.74)	72.74 (1.01)	30.60 (0.82)
25	67.65 (1.05)	6.24 (0.89)	26.37 (1.12)	76.72 (1.45)	27.10 (1.25)
26	65.40 (1.30)	7.15 (0.83)	28.08 (1.20)	75.76 (1.21)	28.98 (1.38)
27	64.72 (1.17)	7.86 (0.51)	28.01 (0.64)	74.33 (0.78)	29.09 (0.72)

Table 4.6. Model variables with associated significance levels (p-values[1]) calculated after the first replicate of the instrumental analysis. Independent variables and responses are on the left and on the top of the table, respectively. Numbers represent levels of significance. Dashed lines indicate variables deleted during model reduction

MODEL[2]	Shear	Snap	L*	a*	b*	Hue angle	Chroma
SUGAR	0.0001	0.0616	0.0004	0.6472	0.1787	0.0331	0.2419
STARCH	0.0050	0.0050	0.0024	0.1222	0.0076	0.0178	0.0223
PEANUT BUTTER	0.7111	0.0004	0.0001	0.0010	0.0696	0.0002	0.0105
[SUGAR]*[SUGAR]	----	0.0435	----	----	----	0.0311	----
[STARCH]*[STARCH]	----	0.0269	----	----	----	0.0354	----
[PEANUT BUTTER]*[PEANUT BUTTER]	----	----	----	----	----	----	----
[SUGAR]*[STARCH]	0.0757	----	----	0.0321	0.0002	0.0878	0.0005
[SUGAR]*[PEANUT BUTTER]	----	----	----	----	----	----	----
[STARCH]*[PEANUT BUTTER]	0.0875	0.0134	----	0.0693	----	0.0364	----
R^2 =	0.9140	0.6712	0.7360	0.7870	0.7855	0.8498	0.7875

[1] $\alpha < 0.1$
[2] $n = 90$

Table 4.7. Model variables with associated significance levels (p-values[1]) calculated after combining the data from the two replicates of the physical tests. Numbers represent levels of significance. Dashed lines indicate variables deleted during model reduction

MODEL[2]	Shear	Snap	L*	a*	b*	Hue angle	Chroma
SUGAR	0.0001	0.0266	0.2115	0.0003	0.0003	0.0054	0.0003
STARCH	0.0001	0.0473	0.0010	0.0127	----	0.0084	----
PEANUT BUTTER	0.0001	0.0001	0.0091	0.0001	0.0449	0.0001	0.0069
[SUGAR]*[SUGAR]	----	----	----	----	----	----	----
[STARCH]*[STARCH]	----	0.0467	----	0.0225	----	0.0143	----
[PEANUT BUTTER]*[PEANUT BUTTER]	----	----	----	----	----	----	----
[SUGAR]*[STARCH]	----	----	----	----	----	----	----
[SUGAR]*[PEANUT BUTTER]	----	----	0.0929	----	----	----	----
[STARCH]*[PEANUT BUTTER]	----	----	----	0.0103	----	0.0030	----
R^2	0.8049	0.4666	0.3351	0.6602	0.2760	0.7282	0.3148

[1] $\alpha < 0.1$
[2] n = 180

Table 4.8. Average rating for each descriptor in the consumer acceptance test. Numbers in parenthesis are standard deviations[1]

Formula #	Appearance	Color	Aroma	Taste	Hardness[2]	Liking	Acceptability
1	6.5 (1.65)	6.6 (1.61)	5.9 (1.37)	4.6 (1.66)	1.9 (0.81)	4.5 (1.43)	17.4 (0.38)
2	7.0 (1.25)	7.0 (1.34)	6.6 (1.30)	5.7 (1.53)	2.5 (0.57)	5.6 (1.74)	55.0 (0.51)
3	6.7 (1.18)	6.8 (1.30)	6.4 (1.45)	5.2 (1.67)	2.5 (0.56)	5.2 (1.67)	58.6 (0.50)
4	6.8 (1.30)	6.8 (1.19)	5.6 (1.59)	4.3 (1.68)	1.9 (0.71)	4.6 (1.56)	48.6 (0.49)
5	6.5 (1.54)	6.4 (1.61)	6.0 (1.68)	4.9 (1.72)	2.2 (0.77)	5.0 (1.63)	48.1 (0.51)
6	6.4 (1.22)	6.6 (1.38)	6.1 (1.49)	5.7 (1.60)	2.4 (0.62)	5.5 (1.59)	70.0 (0.47)
7	6.8 (1.30)	6.9 (1.40)	5.9 (1.30)	4.9 (1.98)	1.9 (0.64)	4.8 (1.81)	46.7 (0.51)
8	6.7 (1.34)	7.0 (1.41)	5.8 (1.41)	5.3 (1.89)	2.4 (0.67)	5.5 (1.72)	66.7 (0.48)
9	6.4 (1.12)	6.6 (1.10)	5.7 (1.03)	5.0 (1.30)	2.6 (0.50)	5.2 (1.36)	50.0 (0.51)
10	6.7 (1.09)	6.3 (1.57)	5.7 (1.35)	4.8 (1.40)	2.2 (0.79)	4.7 (1.46)	38.3 (0.49)
11	6.7 (1.21)	7.1 (1.04)	6.5 (1.22)	5.3 (1.53)	2.3 (0.64)	5.2 (1.55)	66.7 (0.48)
12	6.6 (1.33)	6.9 (1.43)	6.4 (1.45)	6.3 (1.45)	2.6 (0.56)	6.1 (1.78)	82.9 (0.39)
13	6.9 (1.24)	7.0 (1.14)	6.0 (1.45)	5.6 (1.78)	2.3 (0.66)	5.7 (1.56)	56.7 (0.50)
14	7.1 (1.17)	7.1 (1.08)	6.3 (1.28)	5.6 (1.78)	2.2 (0.66)	5.6 (1.68)	66.7 (0.48)
15	6.9 (1.22)	6.8 (1.39)	6.3 (1.25)	5.7 (1.59)	2.3 (0.65)	5.7 (1.50)	63.3 (0.48)
16	6.8 (1.17)	7.0 (1.20)	6.0 (1.30)	5.5 (1.81)	2.2 (0.68)	5.6 (1.61)	68.0 (0.48)
17	6.5 (1.40)	6.7 (1.34)	5.9 (1.77)	5.6 (1.73)	2.3 (0.67)	5.5 (1.76)	65.5 (0.48)
18	6.4 (1.28)	6.3 (1.37)	6.2 (1.36)	5.9 (1.60)	2.6 (0.67)	6.1 (1.49)	73.3 (0.45)
19	6.7 (1.31)	6.7 (1.18)	5.9 (1.44)	5.4 (1.62)	2.4 (0.86)	5.6 (1.56)	73.3 (0.45)
20	7.0 (1.23)	7.0 (1.26)	6.6 (1.36)	5.9 (1.77)	2.6 (0.56)	6.1 (1.60)	63.3 (0.49)
21	6.9 (1.19)	7.2 (1.15)	7.0 (1.07)	7.2 (1.32)	2.6 (0.63)	6.9 (1.43)	93.3 (0.25)
22	6.6 (1.30)	6.8 (1.07)	6.5 (1.33)	6.7 (1.45)	2.5 (0.61)	6.4 (1.76)	82.9 (0.36)
23	6.8 (1.09)	7.0 (0.85)	6.4 (1.36)	6.1 (1.59)	2.5 (0.68)	6.3 (1.96)	83.3 (0.36)
24	6.6 (1.20)	7.1 (1.03)	6.8 (1.27)	7.2 (0.97)	3.0 (0.49)	7.4 (0.95)	100.0 (0.00)
25	5.7 (1.40)	6.1 (1.03)	5.5 (0.97)	5.0 (1.86)	2.3 (0.60)	5.1 (1.78)	54.8 (0.51)
26	6.9 (1.20)	6.9 (1.40)	6.3 (1.34)	6.2 (1.30)	2.2 (0.64)	6.5 (1.03)	83.3 (0.38)
27	6.5 (1.25)	7.0 (1.11)	6.7 (1.46)	6.9 (1.31)	2.6 (0.67)	7.1 (1.26)	96.7 (0.18)
28	6.5 (1.20)	6.7 (1.42)	6.0 (1.25)	5.6 (1.57)	2.1 (0.80)	5.7 (1.40)	62.1 (0.49)
29	7.1 (1.21)	7.0 (1.29)	6.7 (1.20)	7.1 (1.18)	2.3 (0.66)	6.9 (1.56)	86.7 (0.35)
30	6.9 (1.31)	6.9 (1.14)	6.7 (1.51)	7.0 (1.65)	2.7 (0.79)	7.0 (1.74)	86.7 (0.35)

[1]The number of observations is 30 per each formulation.
[2]The hedonic scale for hardness was reduced to 5 points: 1 = very hard; 2 = hard; 3 = adequate; 4 = soft; 5 = very soft.

Table 4.9. Model variables with associated significance levels (p-values) used in the two combined replicates of the sensory test. Dashed lines indicate variables deleted during model reduction

MODEL[1]	Appearance	Color	Aroma	Taste	Hardness	Overall liking	Acceptability
Sugar	0.0901	0.0953	0.4966	0.5093	0.0001	0.5460	0.0001
Starch	0.0316	0.2206	0.0256	----	----	0.0788	----
Peanut butter	0.1282	0.1321	0.1053	0.9898	0.0001	0.7591	0.0001
[Sugar]*[Sugar]	----	----	----	----	----	----	----
[Starch]*[Starch]	----	----	----	----	----	0.1049	----
[Peanut butter]*[Peanut butter]	0.0225	0.0735	0.0555	----	----	----	----
[Sugar]*[Starch]	----	----	----	----	----	----	----
[Sugar]*[Peanut butter]	0.0678	0.0241	0.0272	0.0401	----	0.0138	----
[Starch]*[Peanut butter]	----	0.1025	----	----	----	----	----
R^2 =	0.2261	0.2357	0.4914	0.6134	0.5540	0.6805	0.6519

[1] n = 180

Table 4.10. Parameter estimates for variables used in prediction models for physical properties of peanut-soy chips. A dashed line means that the parameter estimate was not significant and was eliminated

	Parameter estimates						
Variables	Shear force	Snap force	L*	a*	b*	Hue Angle	Chroma
Intercept	123.3528	17.3728	66.1702	4.9106	29.5076	79.4630	30.3958
Sugar	-1.3086	-0.1014	-0.2194	-0.0799	-0.1375	0.0782	-0.1540
Starch	-2.4246	-0.7584	0.2739	0.4754	------	-0.6573	------
Peanut butter	-0.7259	-0.1540	-0.2823	0.1704	0.0435	-0.2678	0.0661
[Sugar]*[Sugar]	------	------	------	------	------	------	------
[Starch]*[Starch]	------	0.0376	------	-0.0202	------	0.0284	------
[Peanut butter]*[Peanut butter]	------	------	------	------	------	------	------
[Sugar]*[Starch]	------	------	------	------	------	------	------
[Sugar]*[Peanut butter]	------	------	0.0137	------	------	------	------
[Starch]*[Peanut butter]	------	------	------	-0.0081	------	0.0124	------
R^2	0.805	0.467	0.335	0.660	0.276	0.728	0.315
Prob	0.0001	0.0001	0.0004	0.0001	0.0003	0.0001	0.0001

Table 4.11. Parameter estimates for variables used in prediction models for consumer acceptance of peanut-soy chips[1]

	Parameter estimates						
Variables	Appearance	Color	Aroma	Taste	Hardness	Overall liking	Acceptability
Intercept	6.6717	6.2460	5.5214	4.4978	1.7473	3.7578	1.8399
Sugar	-0.0384	-0.0409	-0.0177	0.0252	0.0201	0.0203	-0.0246
Starch	-0.0223	0.0358	-0.0271	0.1899	------	------	------
Peanut butter	0.0578	0.0652	0.0719	0.0003	0.0196	-0.0062	-0.0106
[Sugar]*[Sugar]	------	------	------	------	------	------	------
[Starch]*[Starch]	------	------	------	------	------	-0.0086	------
[Peanut butter]*[Peanut butter]	-0.0021	0.0017	-0.0020	------	------	------	------
[Sugar]*[Starch]	------	------	------	------	------	------	------
[Sugar]*[Peanut butter]	0.0019	0.0026	0.0027	0.0037	0.0039	------	------
[Starch]*[Peanut butter]	------	-0.0022	------	------	------	------	------
R^2	0.226	0.256	0.491	0.613	0.555	0.680	0.652
Prob	0.026	0.041	0.0001	0.0001	0.0001	0.0001	0.0001

[1]180 panelists (90 x 2 replicates) participated to the consumer test.

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Table 4.12. Observed values from the consumer test and expected values as calculated from the prediction equations

Formula #	Taste		Hardness		Overall liking		Acceptability	
	O[1]	P	O	P	O	P	O	P
1	4.56	4.87	1.93	2.06	4.49	4.79	17.38	40.85
2	5.70	5.10	2.47	2.26	5.57	4.96	55.00	51.54
3	5.22	5.32	2.53	2.46	5.17	5.14	58.57	62.22
4	4.27	4.87	1.90	2.06	4.63	5.09	48.57	40.85
5	4.90	5.10	2.21	2.26	5.01	5.26	48.08	51.54
6	5.66	5.32	2.42	2.46	5.46	5.44	70.00	62.22
7	4.93	4.87	1.93	2.06	4.77	4.96	46.67	40.85
8	5.31	5.10	2.38	2.26	5.53	5.13	66.65	51.54
9	5.02	5.32	2.60	2.46	5.22	5.31	50.00	62.22
10	4.80	5.25	2.17	2.18	4.73	5.15	38.33	55.77
11	5.30	5.69	2.27	2.38	5.23	5.56	66.67	66.45
12	6.33	6.14	2.63	2.58	6.12	5.97	82.86	77.14
13	5.58	5.25	2.30	2.18	5.68	5.45	56.65	55.77
14	5.59	5.69	2.17	2.38	5.59	5.86	66.67	66.45
15	5.67	6.14	2.31	2.58	5.74	6.27	63.34	77.14
16	5.50	5.25	2.23	2.18	5.57	5.32	67.95	55.77
17	5.55	5.69	2.28	2.38	5.49	5.73	65.48	66.45
18	5.90	6.14	2.63	2.58	6.10	6.14	73.33	77.14
19	5.38	5.62	2.37	2.30	5.57	5.50	73.33	70.69
20	5.90	6.29	2.62	2.50	6.07	6.15	63.33	81.37
21	7.18	6.95	2.55	2.70	6.87	6.80	93.32	92.06
22	6.70	5.62	2.46	2.30	6.44	5.81	82.86	70.69
23	6.13	6.29	2.47	2.50	6.25	6.45	83.33	81.37
24	7.24	6.95	2.96	2.70	7.35	7.10	100.00	92.06
25	5.00	5.62	2.30	2.30	5.07	5.67	54.76	70.69
26	6.23	6.29	2.23	2.50	6.46	6.32	83.33	81.37
27	6.87	6.95	2.55	2.70	7.07	6.97	96.67	92.06

[1]O = Observed value; P = predicted value.

Table 4.13. Verification of the contour plots for shear stress, L*, a*, b*, hue angle and chroma. Two samples were prepared for the verification test following the recipes of Formula 12 (Sample 1) and Formula 25 (Sample 2). Percentage of variation from the data of the contour plots is indicated.

	Shear (N/g chip)	L*	a*	b*	Hue angle	Chroma
Sample 1	592.54	57.73	11.64	29.84	68.69	32.03
Original values	746.27	61.46	9.79	29.12	71.48	30.74
(variation)	(20.6%)	(6.1%)	(18.9%)	(2.5%)	(3.9%)	(4.2%)
Sample 2	465.85	65.64	5.82	25.62	77.20	26.27
Original values	584.80	67.65	6.24	26.37	76.72	27.10
(variation)	(20.3%)	(3.0%)	(6.7%)	(2.8%)	(0.6%)	(3.1%)

Figure 4.1. The questionnaire used for the consumer evaluation of the experimental peanut chips.

Panelist Code:________ Sample Code: _____________ Date: ___________________

Please evaluate this product and check the space that best reflects your feeling about the product for all 7 questions. You may write any other comments in the space provided below.

1. How would you rate the "**APPEARANCE**" of this product?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like Nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

2. How would rate the "**COLOR**" of this product?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like Nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

3. How would you rate the "**AROMA**" of this product?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like Nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

4. How would you rate the "**TASTE**" of this product?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like Nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

5. How would you rate the "**HARDNESS**" of this product?

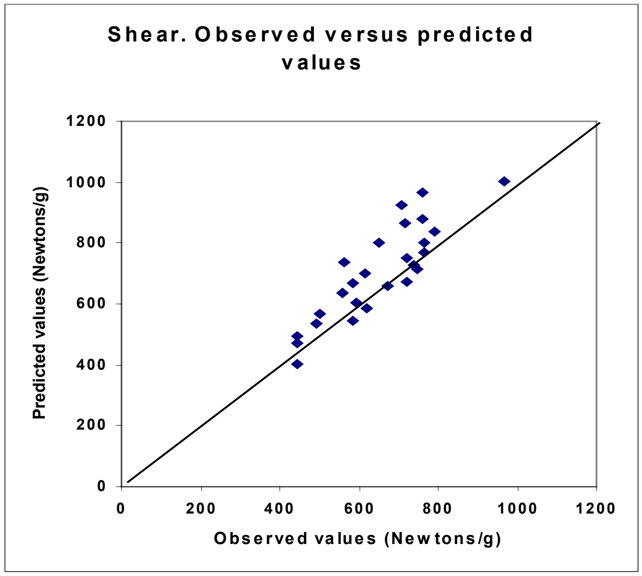
Very hard	Hard	Adequate	Soft	Very soft
[ ]	[ ]	[ ]	[ ]	[ ]

6. **OVERALL**, how do you **Like** this product?

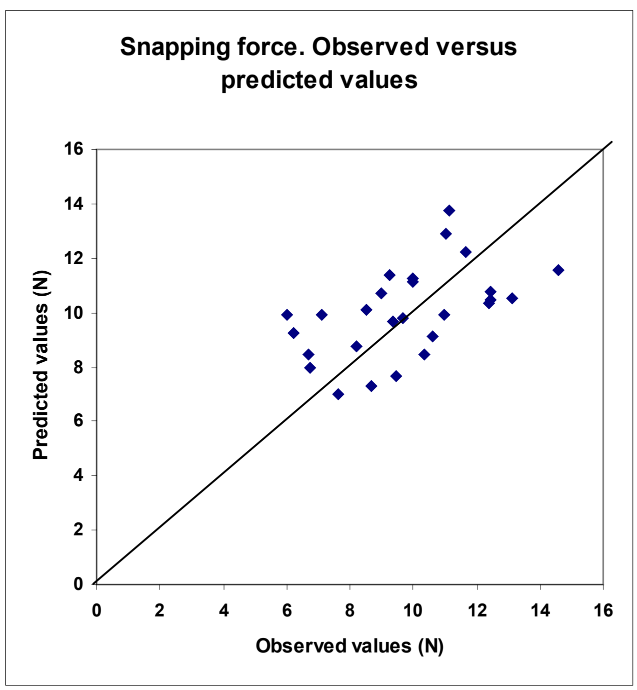
Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like Nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

7. Is this product **ACCEPTABLE**? Yes [ ] No [ ]

Figure 4.2. The predictive equations for the responses shear force (A) and snapping force (B). On the X-axis are the observed values, on the Y-axis are the predicted values. The straight lines (y = x) show where the points would fall if there was identity between observed and predicted values.

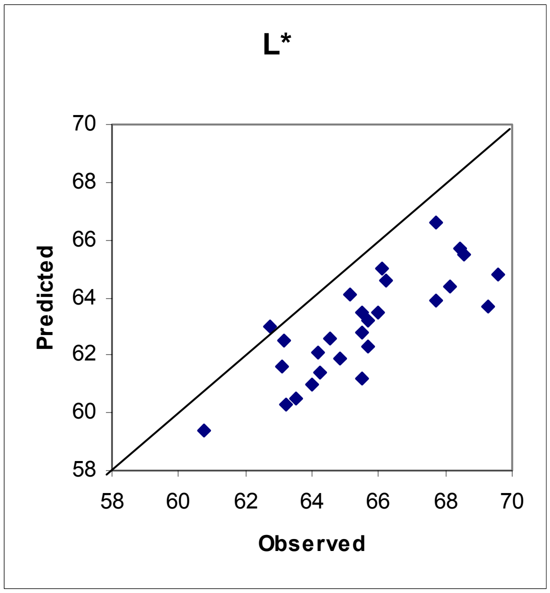

Shear. Observed versus predicted values
Predicted values (Newtons/g)
Observed values (Newtons/g)
0
200
400
600
800
1000
1200

A


Snapping force. Observed versus predicted values
Predicted values (N)
Observed values (N)
0
2
4
6
8
10
12
14
16

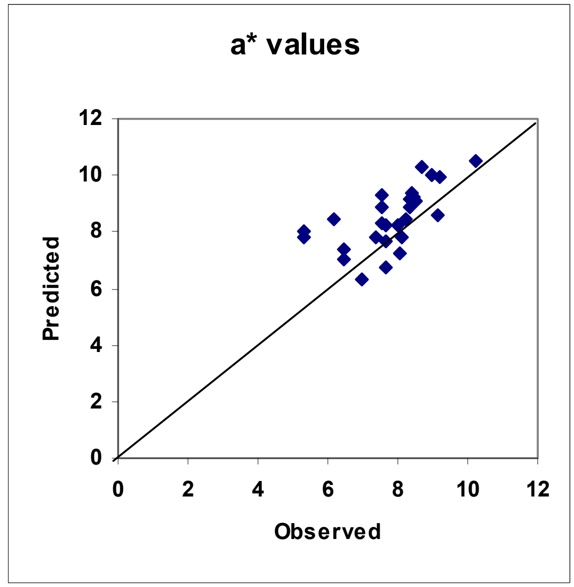
B

Figure 4.3. The predictive equation for the responses lightness = L* (A), redness = a* (B), and yellowness = b* (C). X-axis indicates the observed values, Y-axis indicates the predicted values.



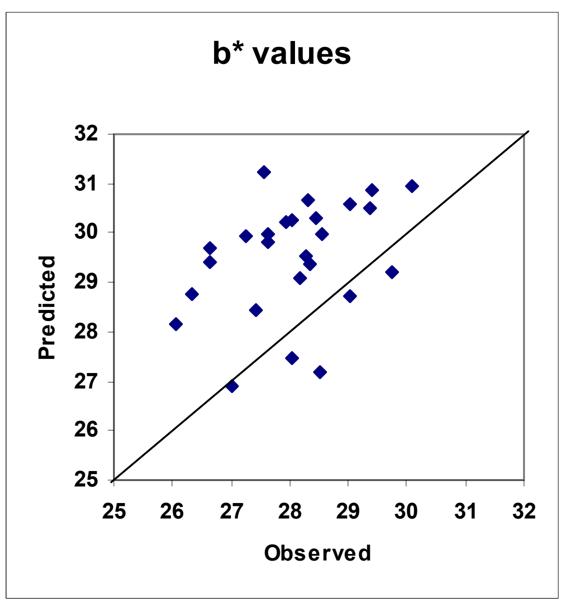
L*
70
68
66
64
62
60
58
58
60
62
64
66
68
70
Predicted
Observed

A



a* values
12
10
8
6
4
2
0
0
2
4
6
8
10
12
Predicted
Observed

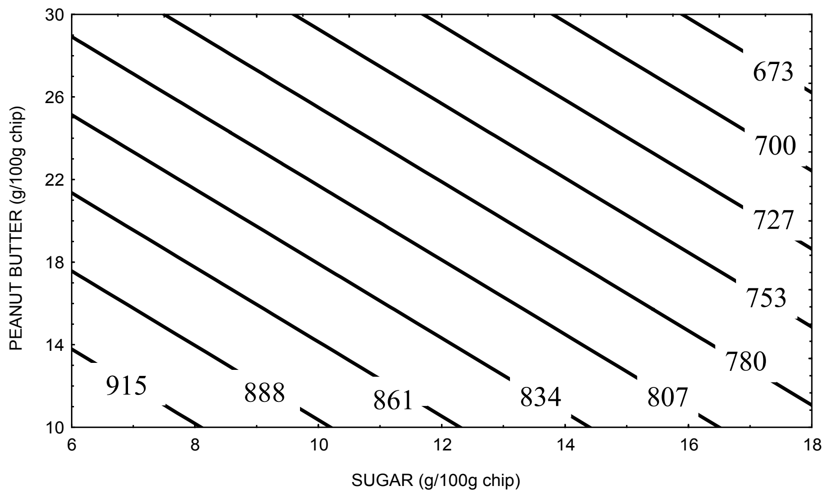
B



b* values
32
31
30
29
28
27
26
25
25
26
27
28
29
30
31
32
Predicted
Observed

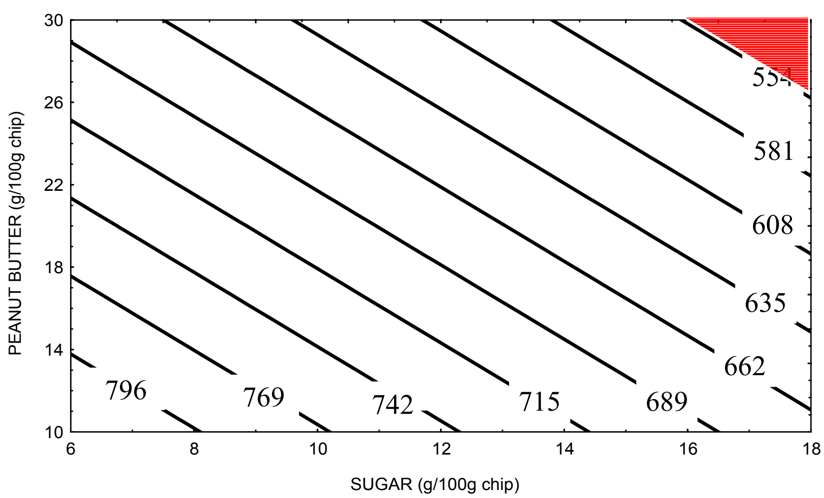
C

Figure 4.4. Contour plots of shear strength for peanut-soy chips at (a) 5% starch, (b) 10% starch and (c) 15% starch. Numbers on the axes represent percentages of sucrose (x) and peanut butter (y) (g/100g chip). Values on the plot represent forces per units of weight of the chips (N/g).



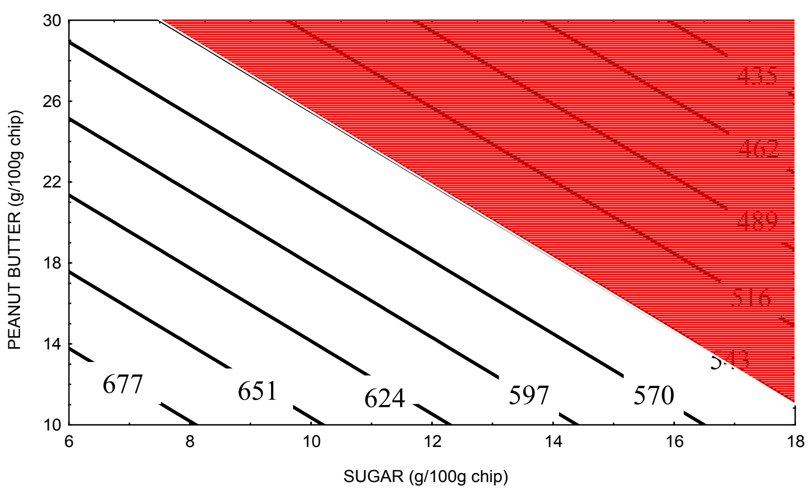
a

5% Starch



b

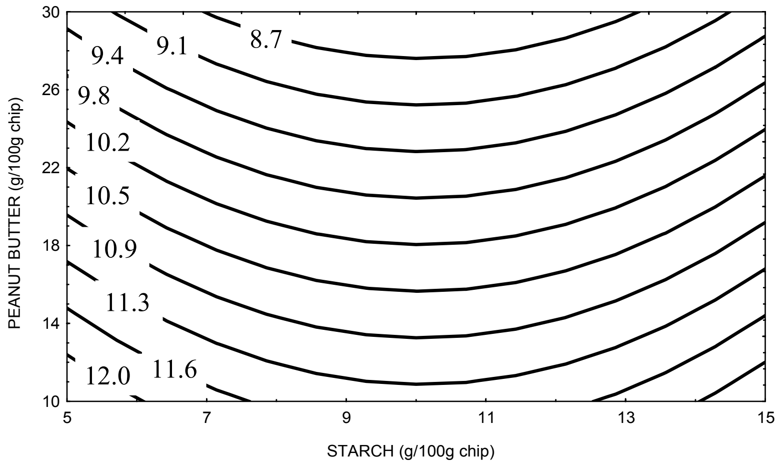
10% Starch



c

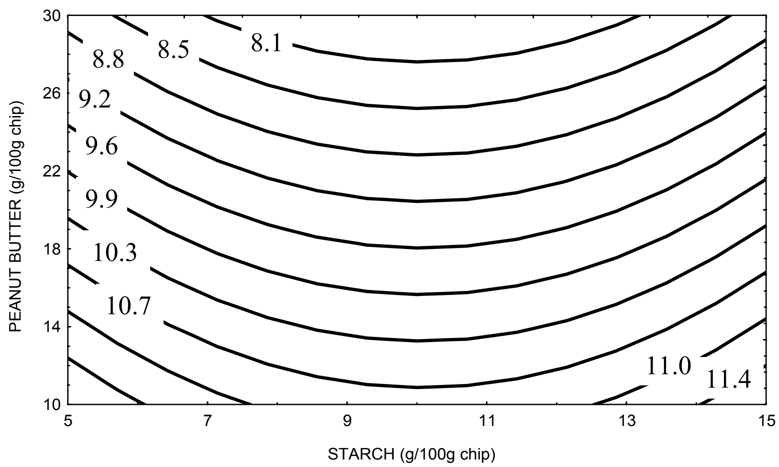
15% Starch

Figure 4.5. Contour plots of snapping force of peanut-soy chips at (a) 6% sugar, (b) 12% sugar and (c) 18% sugar. Numbers on the axes represent percentages of cornstarch (x) and peanut butter (y) (g/100g chip). Numbers on the plot represent forces expressed in Newtons (N).



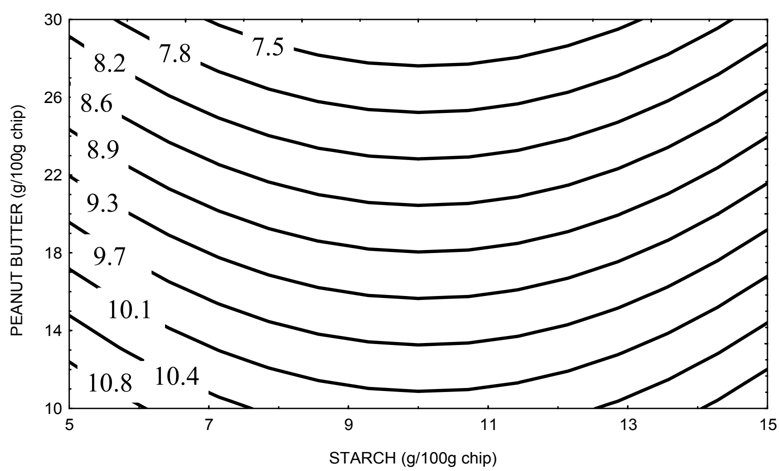
a

6% Sugar



b

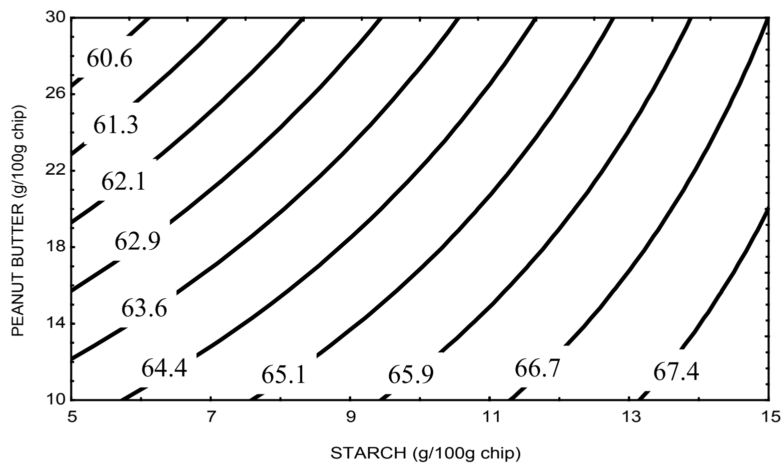
12% Sugar



c

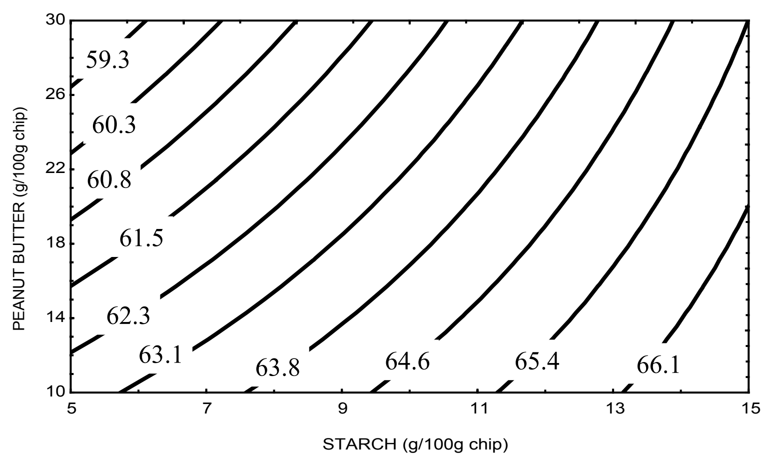
18% Sugar

Figure 4.6. Contour plot of L* (lightness) values at 6, 12 and 18% sugar. Values were determined by Minolta Chroma meter (black = 0, white = 100). Numbers on the axes represent percentages of cornstarch and peanut butter (g/100g chip).



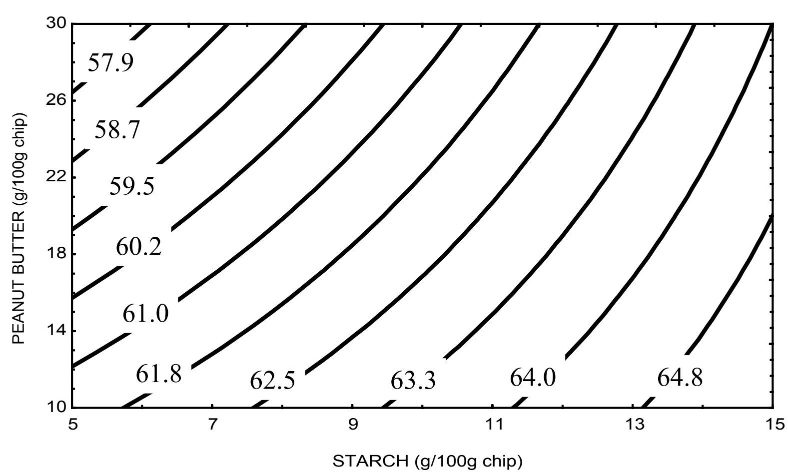
a

6% sugar



b

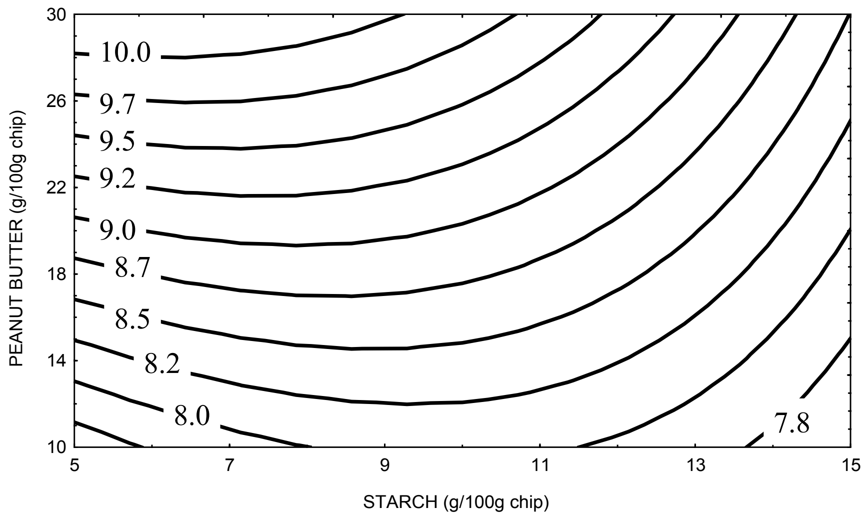
12% sugar



c

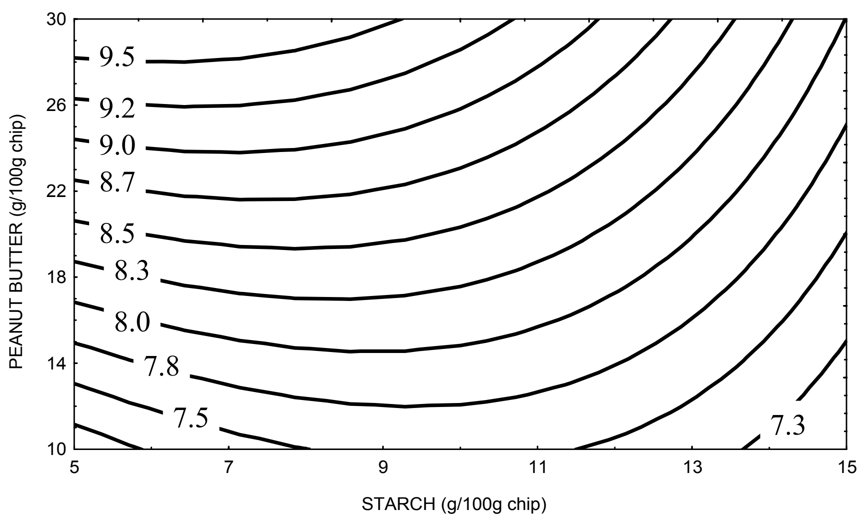
18% sugar

Figure 4.7. Contour plot of a* (redness) at different concentrations of sugar (in CIE L* a* b* system). Numbers on the axes represent percentages of cornstarch and peanut butter (g/100g chip).



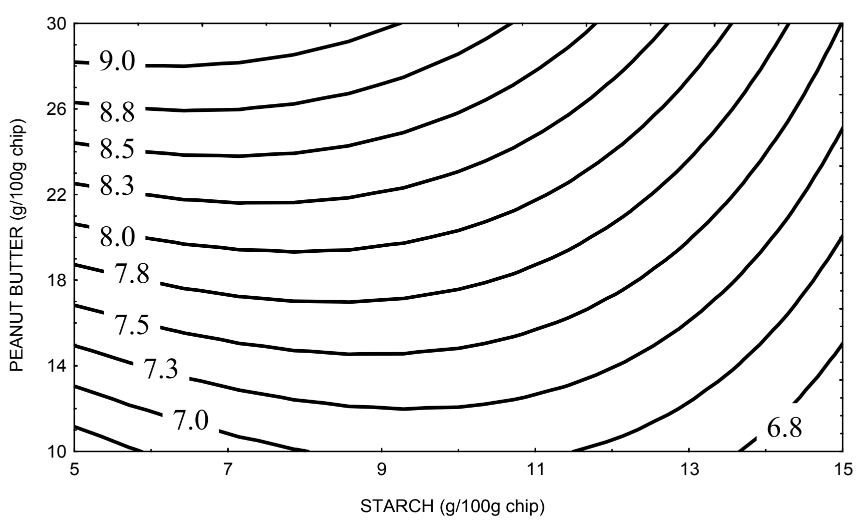
a

6% sugar



b

12% sugar



c

18% sugar

Figure 4.8. Contour plot of yellowness (b*) as determined with Minolta® Chroma-meter. Yellowness is independent from starch. Numbers on the axes represent percentages of sucrose and peanut butter (g/100g chip).

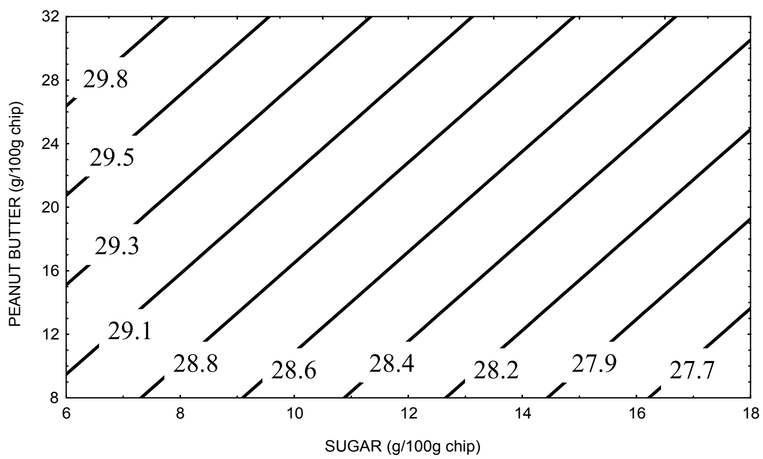
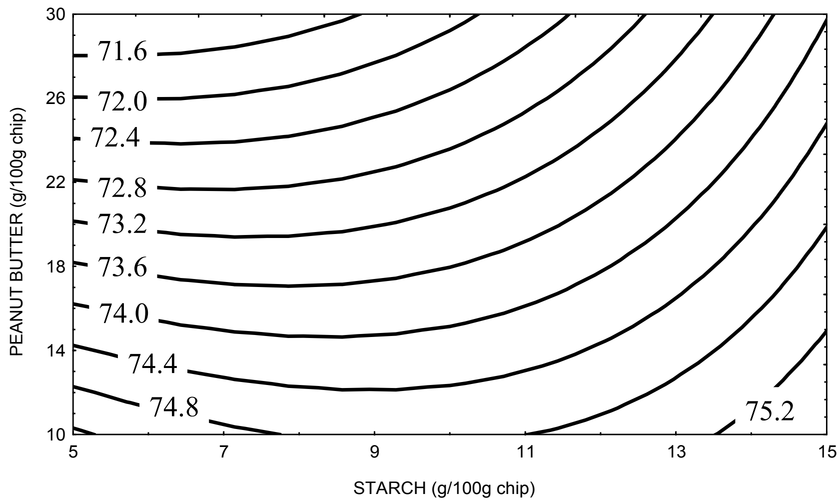
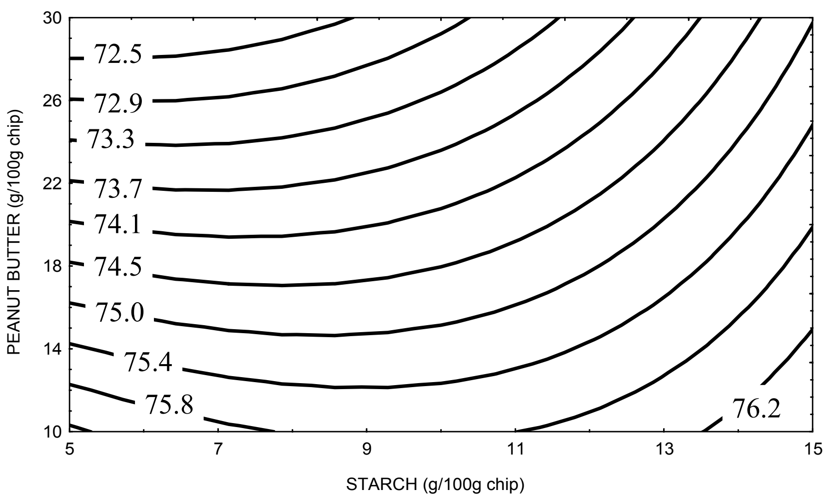

29.8
29.5
29.3
29.1
28.8
28.6
28.4
28.2
27.9
27.7
PEANUT BUTTER (g/100g chip)
SUGAR (g/100g chip)
32
28
24
20
16
12
8
6
8
10
12
14
16
18

Figure 4.9. Contour plot for hue angle values at 6, 12 and 18% sugar. Numbers on the axes represent percentages of cornstarch and peanut butter (g/100g chip).



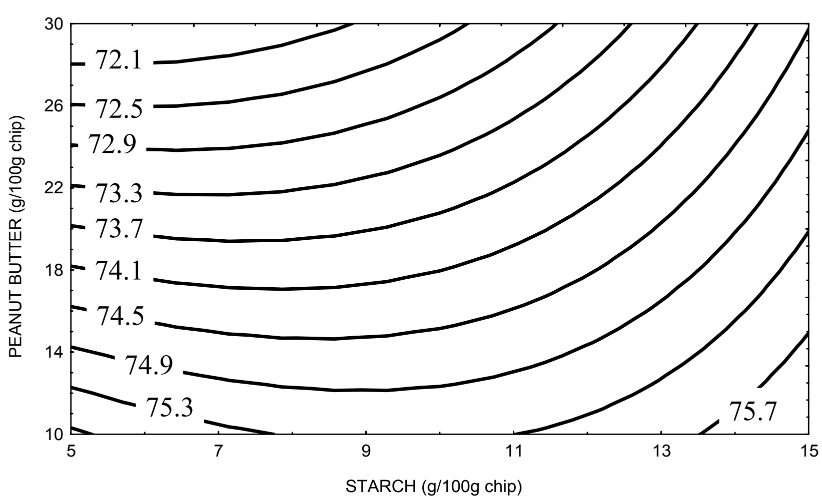
a

6% sugar



b

12% sugar



c

18% sugar

Figure 4.10. Chroma values. Only sugar and peanut butter were significant in this model. Therefore, starch was not included and only one plot was drawn. Numbers on the axes represent percentages of sucrose and peanut butter (g/100g chip).

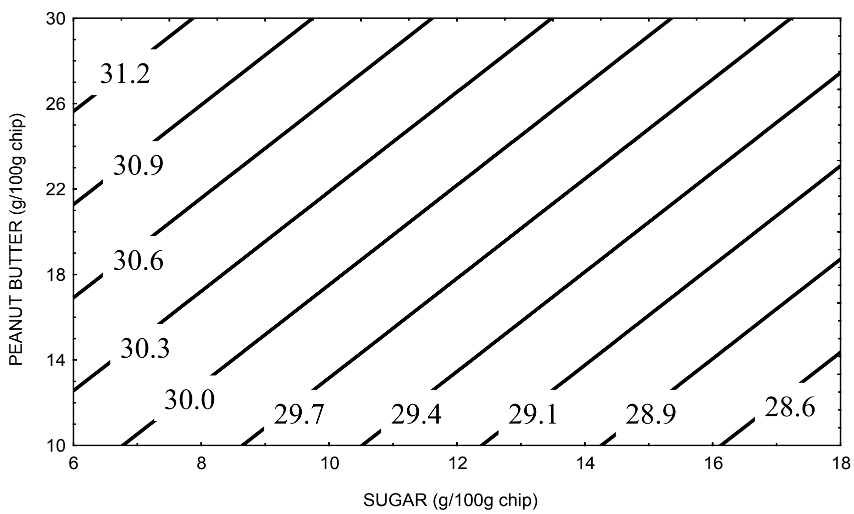
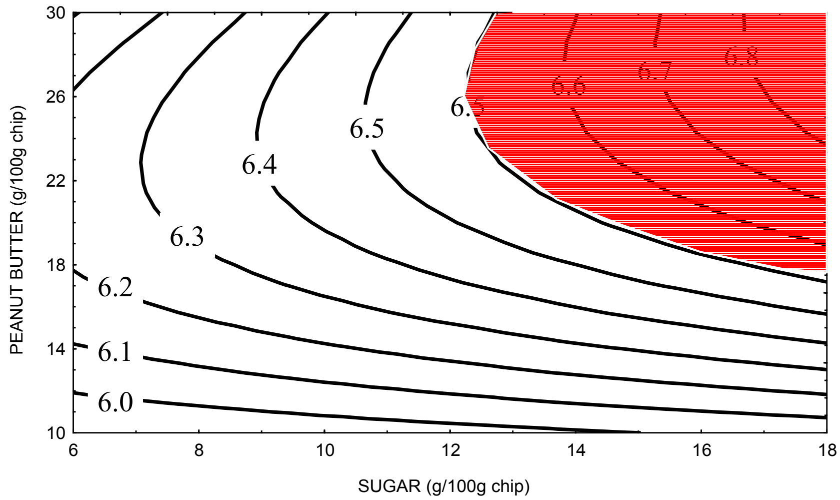
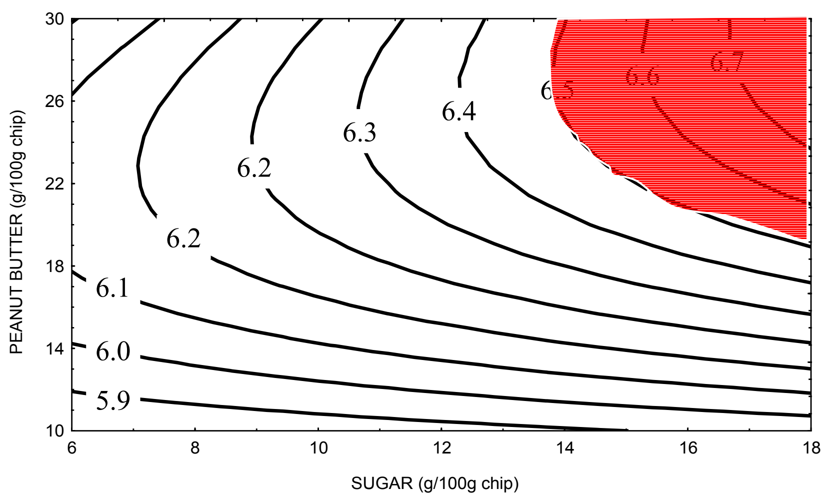

31.2
30.9
30.6
30.3
30.0
29.7
29.4
29.1
28.9
28.6
PEANUT BUTTER (g/100g chip)
SUGAR (g/100g chip)
30
26
22
18
14
10
6
8
10
12
14
16
18

Figure 4.11. Contour plot for aroma. Numbers represent values on a 9-point hedonic scale (1=dislike extremely; 5=neither like nor dislike; 9=like extremely). Numbers on the axes represent percentages of sucrose and peanut butter (g/100g chip). Each plot represents the effect of a different starch level.



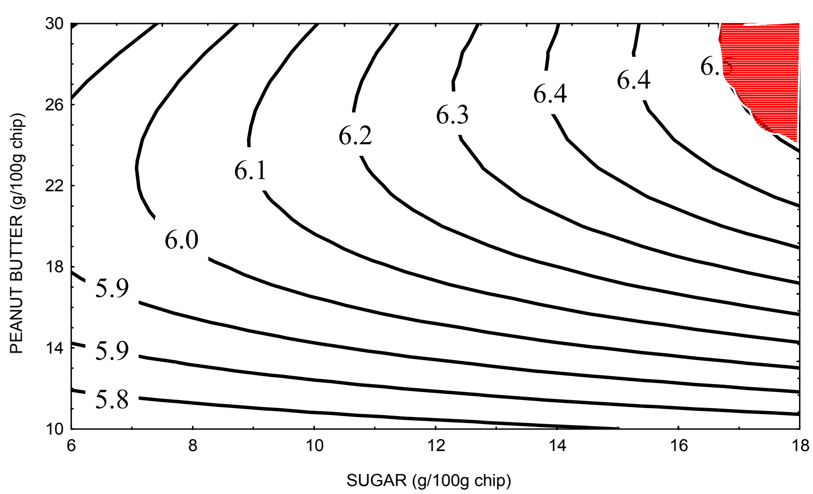
a

5% Starch



b

10% Starch



c

15% Starch

Figure 4.12. Contour plot of taste. Numbers on the lines represent values on a 9-point hedonic scale, with 1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely. Taste ratings depended on sugar and peanut butter, but were independent from starch.

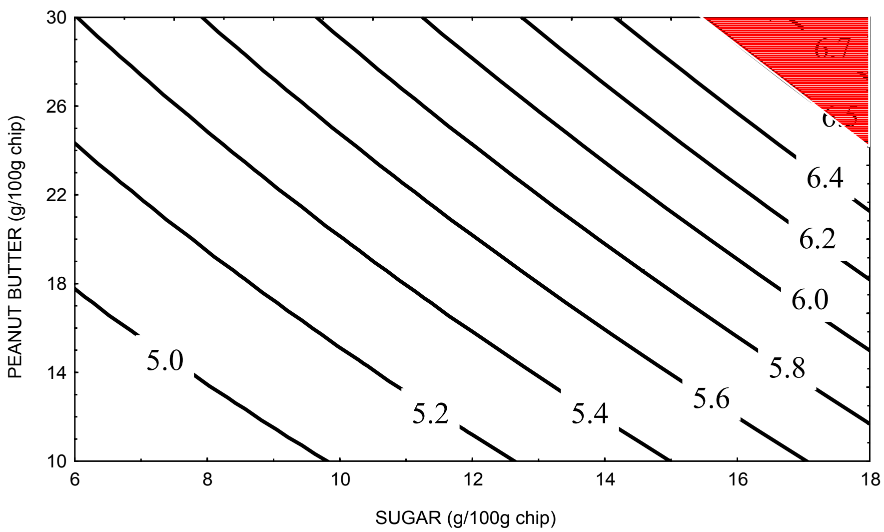

30
26
22
18
14
10
6
8
10
12
14
16
18
PEANUT BUTTER (g/100g chip)
SUGAR (g/100g chip)
5.0
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.7

Figure 4.13. Contour plot of sensory hardness, determined on a 5-point hedonic scale (1= very hard; 3= adequate; 5= very soft). Numbers on the axes represent percentages of sucrose and peanut butter (g/100g chip).

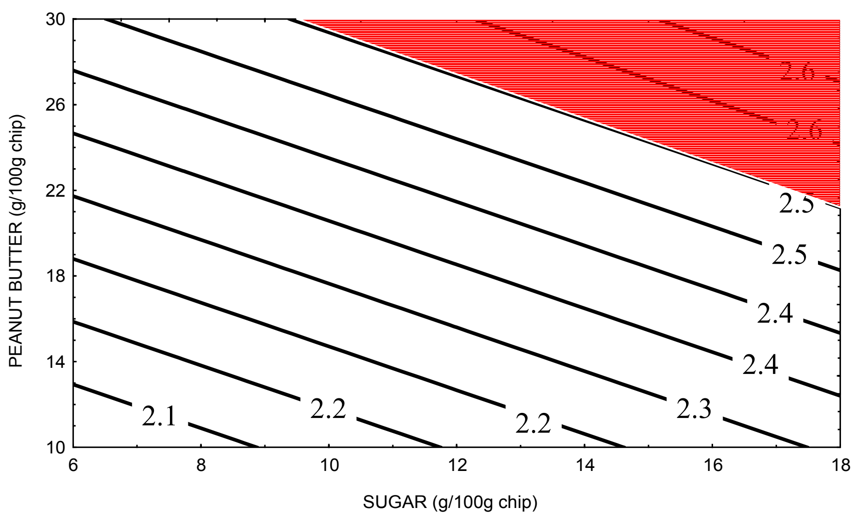
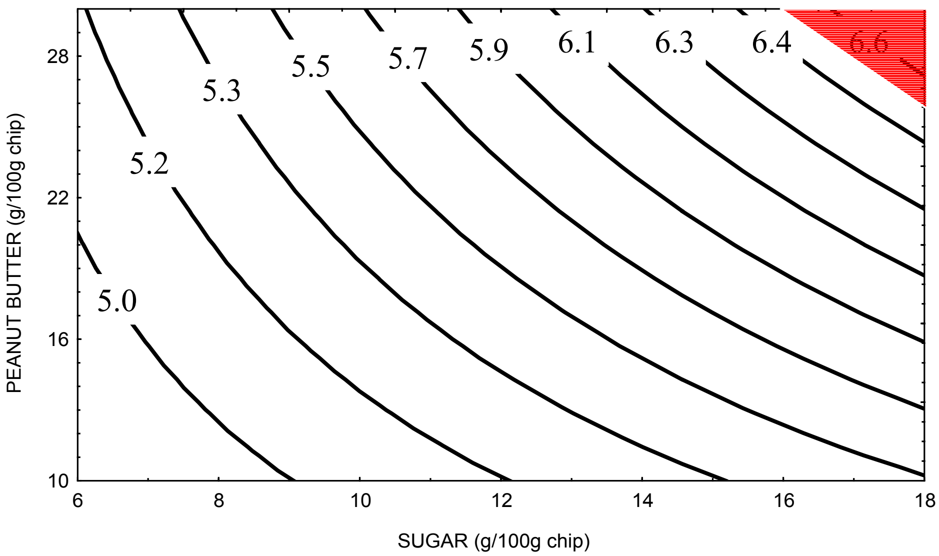
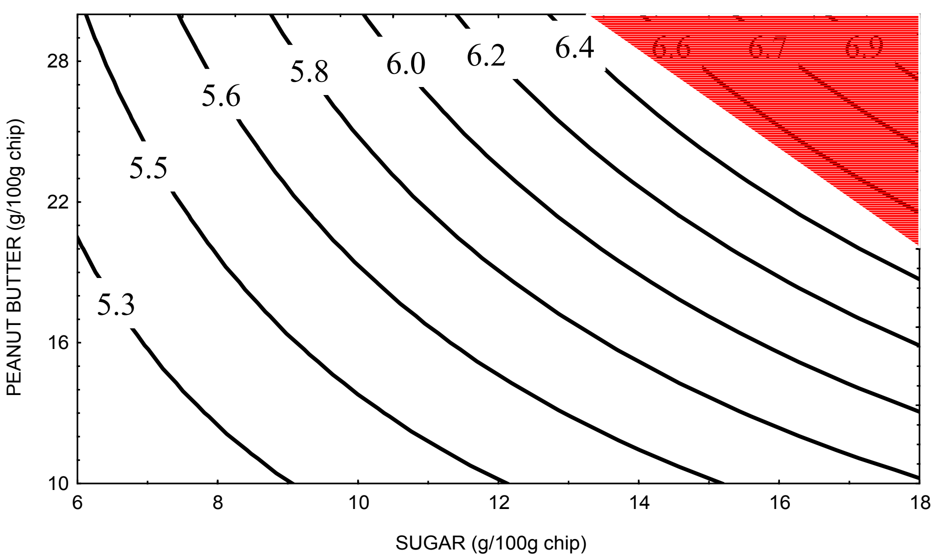

PEANUT BUTTER (g/100g chip)
SUGAR (g/100g chip)
30
26
22
18
14
10
6
8
10
12
14
16
18
2.1
2.2
2.2
2.3
2.4
2.4
2.5
2.5
2.6
2.6

Figure 4.14. Contour plot for overall liking determined on a 9-point hedonic scale. Numbers on the axes represent percentages of sucrose, cornstarch or peanut butter (g/100g chip).



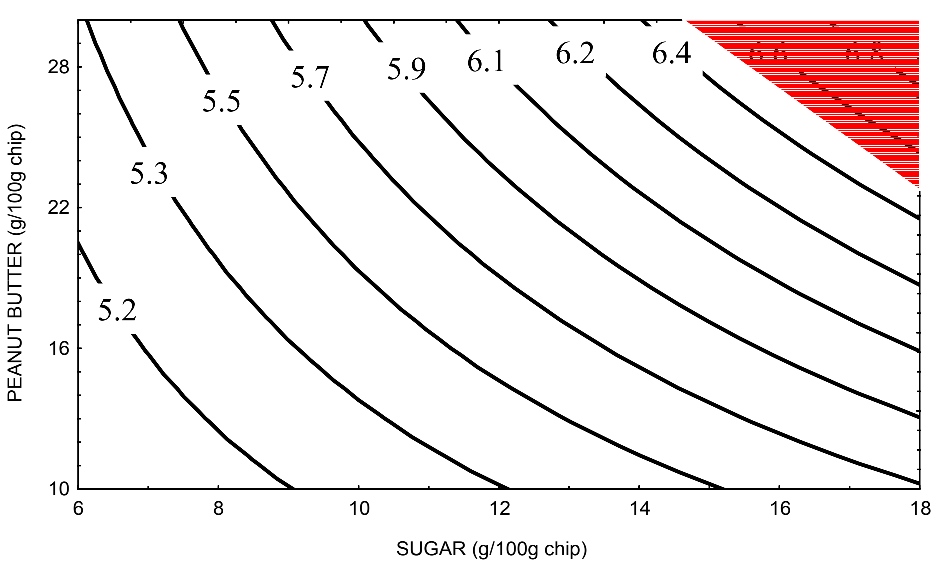
a

5% Starch



b

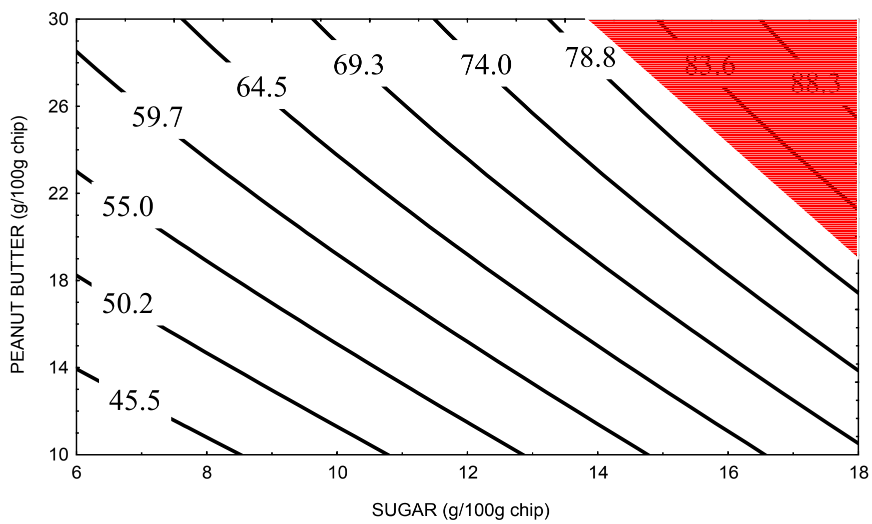
10% Starch



c

15% Starch

Figure 4.15. Contour plot of acceptability. The numbers on the plot represent percentages of panelists who considered the chips acceptable.


30
26
22
18
14
10
PEANUT BUTTER (g/100g chip)
6
8
10
12
14
16
18
SUGAR (g/100g chip)
45.5
50.2
55.0
59.7
64.5
69.3
74.0
78.8
83.6
88.3

SECTION V

SUMMARY AND CONCLUSIONS

The goal of this research was to create a new snack food based on peanut meal, a secondary product of the peanut oil industry. Chip-type snack foods are very popular with consumers from all over the world, but especially from the U.S. However, snacks have been formulated so far mostly with starch and have been cooked preferentially by deep fat frying. Such snacks have met with high acceptance from consumers because of their taste, but nonetheless they have been criticized by nutritionists for being high in calories and low in real nutrients. Things are changing now. Companies are focusing on producing foods with less fat and more protein, minerals, fiber and vitamins. Our goal was to produce a snack based on peanut press cake, the product left after the oil is extracted from the peanuts by compression. Previous experiments with peanut flour had resulted in chips with good taste and appearance, but too high in oil content to meet the interest of consumers.

In a preliminary experiment, we produced peanut chips fortified with corn or soy flour. This product was very low in fat (5-7%) but a consumer test determined that the chips were not completely acceptable (rating = 4.9 for peanut-corn and 4.5 for peanut-soy, on a 9-point hedonic scale). A second study involved the use of a trained panel. Twelve subjects were trained for a few weeks before the beginning of the study. During the test they were required to analyze a series of peanut chips fortified with either soy or wheat. The panel rated the peanut-soy and the peanut-wheat as very similar. Furthermore, they rated the texture of the chips as hard and the peanut flavor as low. However, this experiment showed that the soy flour commercially available did not have the strong raw beany flavor that we had experienced earlier, and peanut-soy chips were not rated differently from the peanut-wheat product. Therefore, it was concluded that soy was preferable to wheat as a fortifier in our chips, because of its content of proteins and isoflavones.

At this point of the study on peanut-soy chip development, the new product was still rough, far from being ready for the market, the main problem being that it was hard and had low flavor. Several publications reported how proteins and fat affect the hardness of starch-based snack foods, baked or fried, sheeted or extruded. We investigated such interaction among proteins, fat and carbohydrates (including sucrose) by producing 27 formulations of peanut chips prepared using 3 different levels of 3 ingredients (sucrose, starch and peanut butter). A statistical analysis with graphic representation of the data is called Response Surface Methodology (RSM). Such method allowed us to draw contour plots and predict the optimum conditions based on the physical and sensory properties of the chips. The contour plots showed that higher sugar, higher starch and higher peanut butter resulted in softer, more flavorful and more acceptable chips than lower levels of these ingredients.

One of the problems still present was the machinability of the chips. In fact, the peanut dough had proved to be too sticky to go through a sheeter without the protection of two plastic sheets. The two plastic sheets separated the dough from the metal roller and made the sheeting process easy and fast. However, this could not be a viable component of commercial production because removing the chip-shaped dough from the plastic was difficult and time consuming. A method was devised to eliminate the use of plastic sheets. A batch of very fluid dough was prepared using a higher quantity of water than usual. After mixing, the dough was removed from the mixing bowl, laid on a table and dusted abundantly with soy flour. The dough could be patted to a round ball. With frequent dusting the dough flattened with a rolling pin, such that it was possible to pass it through a sheeter two or three times, until it reached the thickness required for chips. The dough sheet was then removed to a table, cut into squares, and laid on the oven belt. The chips, baked in the same time and temperature as usual, appeared and tasted as good as the plastic-sheeted chips. This proved that a more automated production of peanut chips is possible, and the peanut-soy flour dough is as workable as the wheat flour dough used to produce commercial bread.

In summary, press cake from cold pressed peanuts was used successfully to produce a chip-type snack. The peanut flour was mixed easily with other flours and resulted in a dough easy to handle and to sheet. The addition of peanut butter, sugar and starch added softness and flavor to the final product, and a RSM was very helpful in determining the optimum amount of the three ingredients to use in order to obtain chips acceptable to consumers. The technique could be easily expanded to identify the optimum of any other ingredients in the mixture.

Further research

1- Further experiments will be required to improve the mechanization of the peanut chip making process, especially in the sheeting and cutting stage.

2- In order to produce and market the peanut chips as “low fat”, efforts should be made to lower the fat content of the chips below 10%.

3- The texture could be improved further, softening the chips by addition of ingredients that break the bond between proteins, for example with emulsifiers or proteases.

4- The flavor could be enriched, adding roasted peanut flavor or different flavors such as cocoa, already used in confections together with peanut.