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DEVELOPMENT OF AN EXTRUDED PUFFED NAVY BEAN SNACK

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John H. Benzinger

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Mary E. Zabik
Major professor

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DEVELOPMENT OF AN EXTRUDED PUFFED NAVY BEAN SNACK

by

John H. Benzinger

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ABSTRACT

DEVELOPMENT OF AN EXTRUDED PUFFED NAVY BEAN SNACK

BY

John H. Benzinger

Puffs were produced by extrusion of navy bean starch containing bean hulls at 0 to 20% substitution levels, in order to examine the potential use of such fractions in a high fiber snack food. Substitution with hulls up to 20% results in no loss of expansion, but increased density and some color and texture differences.

Samples with 10% hulls received higher textural sensory scores than the control starch puffs. When flavored, the product garnered favorable response from consumers as well as trained taste panelists.

Storage stability was reduced when puffs were held at relative humidity levels greater than 33%, as the product became darker, tougher, and higher in moisture after 24 days. Under conditions similar to commercial operations all samples retained acceptabile quality through 60 days.

Enzyme Neutral Detergent Fiber Analysis of starch/hull mixtures revealed an increase in fiber with greater hull content. Extrusion processing resulted in a decrease in detectable fiber values.

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INTRODUCTION

Extrusion is a process commonly used to produce a wide range of food products, from snacks and ready-to-eat cereals to pasta and texturized vegetable proteins. While most past and present extruded snack foods have been based on wheat or corn starch and/or flour, research is now progressing on the possibility of utilizing other materials.

One alternative base for extruded products is the navy bean (*Phaseolus vulgaris*). Since it is a legume, the navy bean holds particular interest for researchers as its protein complements that of cereal grains. Past studies have met with some success in the partial substitution of bean flour for wheat in various baked goods (D'Appolonia, 1977; De Fouw et al, 1982a; De Fouw et al, 1982b).

Increased awareness of the importance of dietary fiber in preventing gastrointestinal disorders (Leveille, 1975) has spurred interest in fiber-rich food products. Navy bean hulls contain considerable amounts of non-digestible carbohydrates, specifically determined to be as much as 45% dietary fiber (De Fouw et al, 1982a), and thus present themselves as possible fiber sources to be incorporated into processed foods.

The purpose of this study was to determine the feasibility of producing an extruded snack food based on navy bean fractions--

both starch and hull--and to investigate the storage stability of such a product. Determinations were also made of the dietary fiber contents of extruded puffs containing 5 levels of bean hull, ranging from 0 to 20%.

LITERATURE REVIEW

Extrusion is a versatile process which can be used to produce a wide variety of foods, including puffed snacks. Extrusion involves mixing, cooking, and texturization, while extruder variables such as temperature, pressure, and moisture affect both nutritional and sensory character and quality of the final product.

While most puffed snack foods are made from cereal grains, navy beans present an alternative base upon which to develop new products. Navy bean hulls, a rich source of dietary fiber, are of particular interest given the attention currently focused on fiber and its role in gastrointestinal health.

Extrusion Process and Materials

Extrusion may be defined as the "shaping of products to desired configuration, size, and consistency by forcing material through a die usually under extremely high pressure (Hall et al, 1971). Extrusion is used to produce puffed and/or shaped snack foods, breakfast cereals, and texturized protein foods (Smith, 1975; Nielsen, 1976; Williams et al, 1977; Smith, 1979), as well as to pre-cook various flours, such as corn (Nunez and Maga, 1979; Smith et al, 1979), wheat (Paton and Spratt, 1978), cowpea (Elias et al, 1976), and soy (Mustakas et al, 1964). Pasta from both wheat and non-wheat sources (Tsao et al, 1976; Moy et al, 1980) is also produced via extrusion.

Extruder Design

The basic design for an extruder (Figure 1) includes a barrel containing the screw with a feed hopper and exit die at opposite ends. In addition the barrel may contain a steam/cold water jacket for the purpose of temperature control.

The extruder may be divided into 3 functional parts. The first, the feed section, is responsible for accepting material, mixing it into a continuous mass, and moving it down the screw. Deep flights (the spaces bewteen the screw and inside wall of the barrel) facilitate this operation (Harper, 1979; Hauck, 1981).

The compression or transition section exhibits decreasing flight heights, which serve to restrict the area through which material must pass. The resulting compression causes an increase in temperature and pressure through greater shear rate and mechanical energy input (see Figure 2). In this section, as in the previous one, communition and mixing of the material predominate (Aguilera et al, 1976).

The metering section is characterized by very shallow flights, resulting in even greater shear rate, mechanical energy, and internal mixing. Maximum temperature is reached in the last turns of the screw (Aguilera et al, 1976; Harper, 1979; Hauck, 1981). The release of pressure upon exit of material causes water to evaporate, resulting in the expansion of the internal structure and a "puffed" final product.

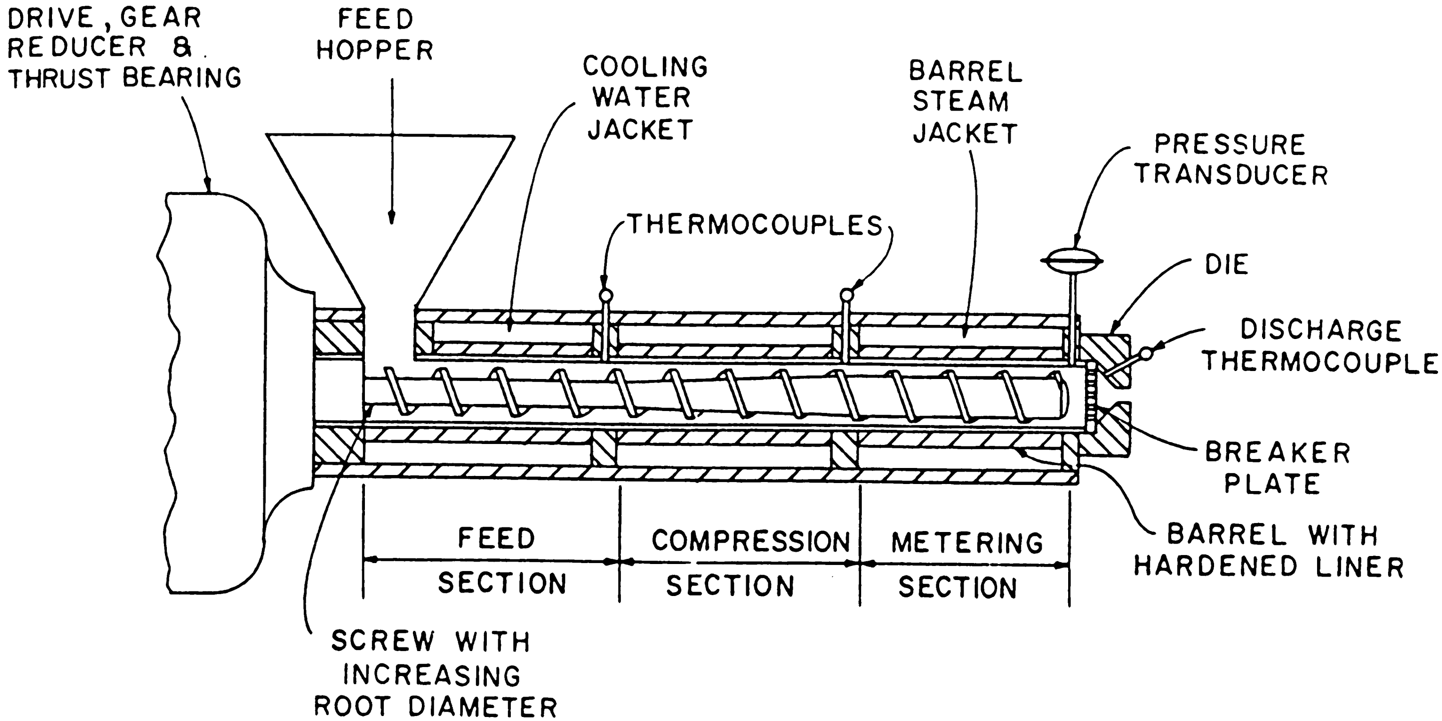

Figure 1. Cross-section of a typical food extruder

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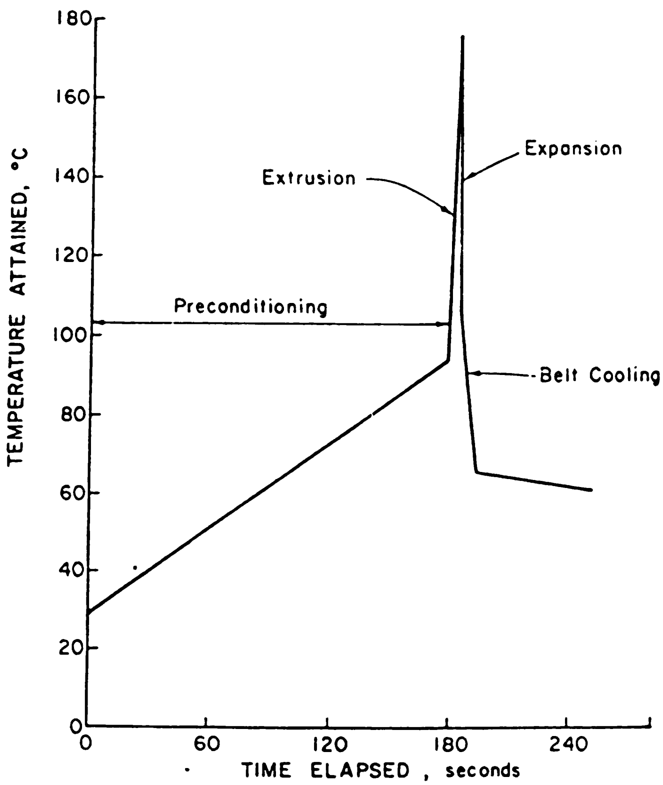

Figure 2. Typical temperature profile in a cooking extruder

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Types of Extruders

Extruders may be classified according to their common uses: pasta, high-pressure forming, low- or high-shear cooking, and collet (Harper, 1979). Other systems for categorizing extruders are by processing moisture: high (30-40%), intermediate (20-30%), and low (10-20%) (Tribelhorn and Harper, 1980), by the manner in which pressure is developed (Rossen and Miller, 1973), or according to thermodynamic characteristics (Tribelhorn and Harper, 1980).

Autogenous extruders rely on heat generated from the dissipation of mechanical energy, while isothermal machines are heated by outside sources such as steam jackets. Polytropic extruders combine the features of the first two types, being the most common cooking extruders (Tribelhorn and Harper, 1980).

Extruder Bases

In the past, corn and wheat seemed to be the major bases for extruded products (Smith, 1974b; Harper, 1979). Recent studies on the feasibility of using less traditional material for extrusion have met with encouraging results.

Brown rice grits with either defatted peanut flour or glandless cottonseed flour have been extruded to yield acceptable cold cereal foods (Spadaro et al, 1971). A blend of corn and soybean at a 70:30 ratio has been used to produce flakes (Bressani et al, 1978), while a whole corn/dehulled soybean extrudate of the same composition has proven acceptable as gruel (Maga and Lorenz, 1978).

Klein (1982) has developed an extruded snack based on a potato/wheat blend. A high-fiber crispbread-type product containing 30%

wheat bran, 60% wheat starch, and 10% gluten has also been cooked by extrusion (Anderson et al, 1981). In addition, puffed barley-based "nacho cheese" flavored snacks have received favorable consumer response (Andres, 1979).

Mottern et al (1969) have developed a cheese-flavored snack food based on both extruded whole grain white rice and extruded brown rice. Chocolate-flavored products made from whole ground corn meal and ground deoiled peanut meal in a 1:3 ratio have proven satisfactory (Williams et al, 1977). There is also some interest in the extruder's potential for processing cereal/legume and similarly blended materials for high protein food (Joao et al, 1980).

Texturization of Extruded Material

Cumming et al (1973) described four stages in the texturization of material during extrusion processing: (1) unprocessed, (2) extruded: a porous, continuous strand with little fiberization, (3) puffed: a less porous, more fiberized, steam-expanded piece, and (4) texturized: discontinuous strands having significant fiberization.

Texturization results from the combined effects of shear, heat, and pressure (Aguilera et al, 1976). Part (1976) has suggested that extrusion puffing is a two-step process: cooking and puffing. The latter occurs near the die, and such conditions as die temperature and pressure, dough properties, water content, and degree of cooking determine the extent of puffing.

Effect of Extruder Parameters

Extruder parameters affecting the nature of the extrudate include barrel temperature and residence time, the latter being a function of die nozzle size, screw speed, and feed rate. The effect of these two main variables on product temperature seems to be the major determinant of product character (Anderson et al, 1969; Molina et al, 1978; van Zuilichem, 1979). Park (1976) has further suggested that higher extrusion temperatures promote more rapid vapor nucleation.

Moisture content and particle size of the material before extrusion may also determine extrudate characteristics (Anderson et al, 1969; Bressani et al, 1978). Fine particles result in greater expansion than coarse ones. Heat treatment of 60-65°C for 10 minutes or addition of water to levels up to 21.4% prior to extrusion increases product specific volume, with the combination of the two affecting even greater expansion (Bressani et al, 1978).

Specific volume, a measure of expansion, is directly related to temperature, and thus inversely related to die nozzle size, feed rate, and shear rate (Molina et al, 1978). A similar relationship exists between those parameters and degree of starch gelatinization (Chiang, 1975; Chiang and Johnson, 1977). Lawton et al (1972) have demonstrated that maximum gelatinization occurs at high moisture and low temperature or low moisture and high temperature, as barrel temperature and moisture content exert the greatest effect on starch gelatinization.

Higher barrel temperature and moisture content may also increase degree of starch gelatinization, as indicated by the water solubility and water absorption indices of corn grits, but gel strength begins to weaken by 350°F (Anderson et al, 1969). Williams et al (1977) found maximum gelatinization of corn at 275°F and 27% moisture, at which point some dextrinization had begun. Moisture level significantly affects gelatinization at an extrusion temperature of 95-110°C, but not in the range of 65-80°C (Chiang, 1975; Chiang and Johnson, 1977).

Like starch gelatinization, extrudate expansion is affected by the interaction of extrusion temperature and moisture level. While Bressani et al (1978) have reported greater product expansion with higher pre-extrusion water content for a 70:30 corn/soybean mixture at 143°C, Mercier and Feillet (1975) have found loss of expansion with corn grits over similar moisture ranges (10.5-28.5%) but higher extruder temperature (225°C).

Faubion (1980) has reported results similar to those of Mercier and Feillet using wheat starch and flour, and Park (1976) has noted the same with corn starch. The latter found that temperature, pressure, and water solubles and moisture content of the material were primarily responsible for variations in specific volume. Screw speed also seems to be directly related to product expansion (Anderson et al, 1981), and Mercier and Feillet (1975) would add amylose content of the feed material to this list of expansion determinants (an inverse relationship).

Extrusion of wheat starch yields greater expansion than wheat flour. Scanning electron microscopy has revealed extruded starch to have large cells with smooth continuous walls, while flour has smaller, rough-walled cells (Faubion, 1980).

Expansion is also dependent on starch source and its interaction with extrusion temperature. At 135°C waxy corn and common wheat starch expand significantly more than corn and rice. However, at 225°C wheat and rice yield greater expansion than corn and waxy corn (Mericer and Feillet, 1975). Maximum expansion for these four starches occurs at 170-200°C (Mercier and Feillet, 1975; Chiang and Johnson, 1977). According to Peri et al (1983) and Faubion (1980) the level and source of protein in the feed material may also affect expansion.

Destrinization, the cleavage of starch molecules, is promoted by high temperature, shear rate (Harper, 1979), and pressure (Chiang and Johnson, 1977), as well as low moisture content (Gomez and Aguilera, 1983). Williams et al (1977) have found that at 135°C and 27% moisture all starch granules in the starchy portions of corn gelatinize and some dextrinization begins. Gomez and Aguilera (1983) point to dextrinization as the major mechanism of starch degradation during low moisture, high shear extrusion.

Sensory and Nutritional Quality of Extruded Products

The changes that occur in a material during the extrusion process affect both sensory and nutritional quality. Starch gelatinization and dextrinization plus protein denaturation are the major reactions. Less noticeable changes include the inactivation of enzymes such as alpha amylose (linko et al, 1980), the limited transformation of unsaturated fatty acids from cis to trans form (Maga, 1978), and the loss of various vitamins and lysine.

Joao et al (1980) have postulated that changes occuring in the carbohydrate fraction of the extrudate allow better protein utilization. Protein solubility increases when extrusion takes place in the presence of lactose or sucrose (Racicot et al, 1981). Also significant is the destruction of the trypsin inhibitor (Mustakas et al, 1964; Molina et al, 1978), especially noteworthy when extruding legume-based material (Elkowicz and Sosulski, 1980).

The loss of vitamins during extrusion is not severe. Most nutrients seem to be relatively stable through the process.

Only slight loss of thiamin has been reported (Mustakas et al, 1964, Beetner et al, 1974), with up to 95% retention of added thiamin in a corn/soy blend extruded at 154°C barrel temperature, and up to 85% when extruded at 171°C (Harper et al, 1977 in Harper, 1979). The same study found similar results for riboflavin, extrusion at 154°C barrel temperature causing 30% loss with none occurring at 171°C.

Beetner et al (1974) reported an average thiamin retention of 54% and riboflavin retention of 92% under the following conditions: 149-193°C temperature, 13-16% moisture, and 70-125 RPM screw speed. Thiamin retention may be directly related to die size and inversely related to temperature and screw speed. The last parameter, when slow, seems to have an adverse effect on riboflavin (Beetner et al, 1976).

When B-carotene (provitamin A) is added to material prior to extrusion, only 25% is retained; however, when incorporated in the form of vitamin A alcohol, acetate, or palmitate, approximately 90, 90, and 50-90% respectively, is retained. Higher screw speeds increase vitamin A retention (Lee et al, 1978). Harper (1979) has suggested that vitamin A loss, in contrast to thiamin and riboflavin, is not a function of shear rate, but one of residence time.

Few studies have been published concerning the retention of other vitamins during extrusion. Niacin is apparently very stable through the extrusion process (Mustakas et al, 1964; de Muelenaere and Buzzard, 1969). Ascorbic acid, or vitamin C, retention is surprisingly high at 70% (de Muelenaere and Buzzard, 1969; Harper et al, 1977 in Harper, 1979).

Several studies have focused on lysine retention of extruded material by determining lysine loss curves (Thompson et al, 1976; Wolf et al, 1978). Tsao (1976) has noted up to 96% retention of available lysine, postulating that lysine degradation may result from the disruption of starch molecules and resultant release of glucose. Lysine loss seems to be dependent primarily upon water content and temperature (but not on screw speed), prompting Noguchi et al (1982) to recommend increasing moisture as the best way to minimize lysine loss.

Functionality of Navy Bean Starch

Since starch is the principal structural component of an extruded puffed product, some consideration must be given to the functional properties of navy bean starch. Compared to other legumes, navy bean starch possesses a pasting temperature which is higher and closer to that of wheat. On the other hand, navy bean starch also exhibits greater viscosity than wheat, reflecting less rupturing of granules, as demonstrated by the absence of a peak at 95°C in amylograms (Naivikul and D'Appolonia, 1979) . Starch granules from navy beans appear irregular and elliptical (Naivikul and D'Appolonia, 1979), while those from wheat are spherical and of assorted sizes (Kulp, 1973).

Navy bean starch possesses a lower amylose content than wheat, the former being 22.1% (Naivikul and D'Appolonia, 1979), while the latter ranges from 23.4 to 27.5% (Medcalf and Gilles, 1965). Higher amylose content is associated with less expansion during extrusion (Mercier and Feillet, 1975). In addition, the molecular weights of legume amyloses are lower than those of cereal (Biliaderis et al, 1981).

Navy bean starch, like that of other legumes, contains amylopectin of slightly longer chain length (22) than wheat (17-20) or waxy corn (19) (Biliaderis et al, 1981). The same investigators noted a negative correlation between degree of amylopectin branching and gelatinization temperature among legume starches.

The Incorporation of Navy Bean Fractions in Food

The use of whole navy bean flour in various baked goods, such as cookies and cakes, has been the subject of several recent studies. D'Appolonia (1977) has substituted various legume flours, including navy bean, for wheat in bread and found legume incorporation from 5 to 20% to have a detrimental effect on loaf volume. Yet roasting of navy beans prior to grinding minimized this effect and resulted in greater volume and better overall bread-making quality (D'Appolonia, 1978).

Aguilera et al (1984) have begun investigating the characteristics of extruded high-protein navy bean fractions, blending them with corn and substituting them for soy up to 30% in a texturized protein product. The extrudate has shown good expansion, a white color, and little beany flavor.

The Incorporation of Navy Bean Hulls

The possibility of using navy bean hull (high fiber) flour as a means of increasing the dietary fiber content of baker goods has been investigated in several recent studies. Pretreatment of the hulls by roasting at 240°C has been found to improve the color of baked goods, although roasting at a more moderate temperature of 160°C results in inferior color. Higher roasting temperatures may improve overall product quality (De Fouw et al, 1982a; De Fouw et al 1982b).

The incorporation of hulls in spice-flavored layer cakes up to the 15% level causes no decrease in acceptability (De Fouw et al, 1982b). Similarly positive results have been obtained in sugar-snap cookies using 10-30% hulls (De Fouw et al, 1982a). At the 20% level in cookies navy bean hull flour compared well with various brans--wheat, corn, and oat--as well as soy hulls (Jeltema et al, 1983). Consumer testing of peanut butter cookies has revealed no significant difference in acceptability between control samples and those containing 20% hulls (Aguilera et al, 1981).

Nutritional Significance of Fiber

The inclusion of high-fiber foods into the American diet has taken on more importance in recent years with the documentation of fiber's role in gastrointestinal health. Fiber also serves to dilute the caloric density of the diet.

Many gastrointestinal disorders are believed to result from chronic constipation caused by ingestion of a low fiber diet. Diverticular disease may develop when pressure from prolonged feces retention causes bulges and later pocket formation in the colon. Colonic cancer may also be promoted by constipation, as the colon is increasingly exposed to carcinogens (Burkett, 1974), and bacteria are allowed more time to convert bile acids to carcinogens (Burkett et al, 1972).

Fiber helps prevent constipation by holding water in feces through the gastrointestinal tract. By doing this, fiber decreases fecal transit time and increases stool weight, thus promoting bowel motivity and preventing constipation.

Incorporation of Fiber Sources in Food

Many studies have focused on the incorporation of high-fiber substances into baked goods. Wheat bran has been successfully substituted for flour at 30% in layer cakes (Springsteen et al, 1977; Shafer and Zabik, 1978), at 20% in sugar-snap cookies (Vratanina and Zabik, 1978), and at 50% in oatmeal cookies (Vratanina and Zabik, 1980).

Combinations of wheat bran and middlings (16% and 12%, respectively) also show promise in white (Brockmole and Zabik, 1976) and flavored cakes (Rajchel et al, 1975). Corn bran may be successfully incorporated into cakes at up to 30% substitution levels (Shafer and Zabik, 1978). Brewer's spent grains, while producing bread inferior to that containing equal levels of white wheat bran, may be incorporated into dough at the 5% level (Pomeranz et al, 1976).

Microcrystalline cellulose has proven acceptable as a substitute for flour in lean ratio cakes at the 40% level and in biscuits at the 20% level (Brys and Zabik, 1976). Zabik et al (1977) have successfully incorporated up to 30% microcrystalline cellulose and various coated and uncoated celluloses into white layer cake. The following levels have also been acceptable: 10% in sugar-snap cookies (Gorczyca and Zabik, 1979), 30% in vanilla and lemon cookies, 19% in chocolate cookies, and 25% in brownies (Pratt et al, 1971).

Working with cereal and legume brans, Jeltema and Zabik (1979) have determined that certain dietary fiber components in a given fiber source can be used to predict such characteristics in cakes as volume, tenderness, and grain. Hemicelluloses, both water-soluble and -insoluble, are particularly important determinants of cake quality. Likewise, variations in cookie quality are associated with water-insoluble hemicellulose content (Jeltema et al, 1983). Compared to such substances as wheat and corn bran, navy bean hulls are higher in water-soluble pentose (1.13%) and pectin (8.96%), but lower in cellulose (%.81%), water-insoluble hemicellulose (18.00%), and lignin (1.03%) (Jeltima et al, 1983).

EXPERIEMENTAL PROCEDURE

The purpose of this research was to determine the feasibility of producing an extruded puffed snack food from high-starch navy bean fractions and containing various levels of navy bean hulls. The storage stability of this product was studied in short term as affected by relative humidity and over a longer period under conditions comparable to commercial storage. Dietary fiber content of the starch/hull blends before and after extrusion was also determined.

Preparation of Extruded Snack

Ingredients

Common lots of salt, vegetable oil, macaroni and cheese mix, and onion powder were purchased from local retail food stores. The navy bean hulls and high-starch flour were obtained from Texas A & M University (Aguilera et al, 1982).

At the latter facility whole navy beans were roasted in a particle-to-particle heat exchanger prior to milling. The roasted beans were first dehulled by cracking in a disc atrition mill. After asperation had separated the hulls from the cotyledons, the latter were pin milled and air classified. The resulting fine fraction was used as high-protein flour and the coarse fraction was again pin milled and air classified to yield a second coarse fraction suitable for use as high-starch flour. Proximate analyses of both starch and hull fractions appear in Table 1.

Extrusion of Product

Starch and hull material were extruded using a Creusot Leirie French twin-screw extruder at the pilot plant facilities of Gerber Foods, Inc., in Fremont, Michigan. Unground navy bean hulls were substituted for bean starch at 0, 5, 10, 15, and 20% levels by weight. Conditions under which each blend was extruded are shown in Table 2.

After extrusion the puffs were oven-dried and stored in Polyethylene bags for transport. They were redried 24 hours later at Michigan State University in a Proctor convection flow oven for approximately 20 minutes at 175°F.

Initial color, tenderness, moisture, and density were determined within 24 hours of final product drying. Density was calculated by weighing a scoop filled to constant volume. The ratio of puff diameter (as determined by caliper readings) to die diameter (4 mm) was expressed as the expansion coefficient.

Flavoring of Product

Flavoring of the dried extruded puffs entailed spraying with vegetable oil through a high pressure atomizer, commonly used for Chromatography, until the puffs were evenly coated with vegetable oil to 10% of initial weight.

The oiled puffs were then poured into plastic bags to which were added the powdered flavor mix of either onion or cheese. The

Table 1. Proximate analyses of navy bean high-starch and hull flours[1]

Flour	Moisture[a] (%)	Ash[b] (%)	Protein[b] (%)	Fat[c] (%)	Dietary Fiber[b] (%)
High-Starch	8.35	2.69	16.12	1.02	2.30
Hull	9.03	6.32	18.44	1.01	35.43

[1]Lee et al (1983)

[a]% fresh weight basis

[b]% dry weight basis

[c]% solids basis

Table 2. Extruder parameters during the processing of five navy bean starch/hull blends

Hulls (%)	Screw Speed (RPM)	Barrel Temperature (°C)	Product Temperature (°F)	Pressure (PSIG)	Feed Setting
0	150	160	368	1100	4
5	150	160	345	900	4
10	150	150	363	1200	4
15	150	160	367	1000	4
20	150	160	362	1000	4

onion mix contained onion powder at 7.5% of puff weight, plus salt at 2.5%. The cheese mix included cheddar cheese powder at 15% of puff weight and salt at 2.5%. The puffs and flavor mix were shaken in the bag with a vertical motion for approximately 15 minutes.

Objective Measurements

Quality characteristics of texture and color were determined by objective measurement. Chemical analyses were employed to measure moisture and fiber content of the product.

Color

Surface color was determined with a Hunter Color Difference Meter (model D 25), using the following scales: L - 0 = black, 100 = white; a_L - + = red, - = green; b_L - + = yellow, - = blue. Optical glass containers were filled with 50 g samples after standardization of the instrument with a yellow tile (L = 83.0, a_L = -3.5, b_L = 26.5).

Texture

The Allo-Kramer Shear Press (model SP 12) equipped with a TR-3 recorder and a standard shear-compression blade was used to measure crispness during a 30 second downstroke. A 3,000-lb. transducer and range setting of 10 were used, with some samples during the relative humidity study requiring a range of 33. Crispness was calculated by the following formula and expressed as pound force per gram of sample.

$$\text{CRISPNESS} = \frac{\text{Transducer x Range x Reading}}{\text{Sample Wt. x 100 x 100}}$$

Moisture

Moisture determination was carried out on both the puffs and corresponding unextruded starch/hull blends. Samples of 2.000 $\pm$ 0.0001 g were dried for 15 hours at 100°C under a vacuum of 28 in. of Hg in a Hotpack vacuum oven, model 633 (AOAD, 1980).

After cooling in a dessicator, the samples were reweighed. The following formula was used to calculate percentage moisture.

$$\frac{\text{Original Wt. - Dried Wt.}}{\text{Original Wt.}} \times 100 = \%\ \text{MOISTURE}$$

Dietary Fiber

The following method was adopted from Robertson and Van Soest (1981). Neutral Detergent Solution was prepared from the following compounds =

Deionized water	3.00 l
Soldim Lauryl sulfate	90.00 g
Disodium (ethylene diaminetetraacetate) EDTA, Dihydrate crystal, reagent grade	58.83 g
Sodium borate decahydrate ($Na_2 B_4 O_7 \cdot 10 H_2O$), reagent grade	20.43 g
Disodium hydrogen phosphate ($NA_2 HPO_4$) anhydrous, reagent grade	13.68 g
2 - ethoxyethanol (ethylene glycol mono-ethyl ether), purified grade	30.00 ml

Sodium lauryl sulfate and 2-ethoxyethanol were combined in a 4000 ml beaker with 1500 ml deionized water and the solution mixed continuously with a magnetic stirrer until clear. In a 500 ml beaker the EDTA and sodium borate decahydrate were dissolved in 300 ml deionized water using heat. In a third (250 ml) beaker the disodium hydrogen phosphate was dissolved in 100 ml deionized water with the aid of stirring and heat. The last two solutions were added to the sodium lauryl sulfate solution, the final volume being adjusted to 3 l with more deionized water. The pH of the final neutral detergent solution was maintained at 7.0 $\pm$ 0.1 by addition of either hydrochloric acid or sodium hydroxide.

In order to extract fiber from the samples, puffs were ground to a coarse powder in a Sears Insta-Blend blender set on "crumb," and 0.80 $\pm$ 0.01 g weighed into Goldfisch beakers. To this 0.4 g NA_2 SO_3 and 1.6 ml decahydronapthalene were added (plus anti-foam spray), along with 90 ml Neutral Detergent Solution. The contents were then refluxed for 60 minutes using a Goldfisch extraction apparatus. The solution was filtered with vacuum through a Gooch Crucible containing glass wool. The crucible was rinsed with boiling water, as was the extract until foam was no longer pulled from the crucible.

After wrapping the bottom of the crucible with parafilm, 10 ml of 5% α- amylase (Type IV from porcine pancreas) and 40 ml deionized water (70°C) were added to the crucible and the extract held at 55°C for one hour. The extract was again washed with boiling water, and the incubation process repeated using α - amyloglucosidase (E. C. No. 3.2.1.3 from Rhiszophus genus mold).

After rinsing with water, the extract was rinsed with 80 ml acetone. The extract was finally dried in a vacuum over at 100°C for 16 hours, cooled in a dessicator, and weighed. The sample was then ashed in a muffle oven at 525°C for 16 hours and lastly weighed. The percentage Enzyme Neutral Detergent Fiber (ENDF) of the sample was calculated as:

$$\% \text{ ENDF} = \frac{\text{Sample Wt. After Drying - Sample Wt. After Ashing}}{\text{Original Sample Wt. (Dry Wt.)}} \times 100$$

Subjective Evaluation

Eight-member sensory panels were used in two distinct tests. An initial test was made to determine on a 5-point scale the textural character of puffs containing 0, 5, 10, 15 and 20% hulls. Onion-flavored puffs with hull levels of 0, 10 and 20% were then evaluated for general acceptability after 0, 30, and 60 days of storage, utilizing a 5-point hedonic scale.

The first series was preceded by panelist training sessions during which members were asked to rate commercially available puffed cheese snacks for texture. The snacks had been held for 8 hours in relative humidities which were lowered for each of 4 successive sessions. In this way panelists who could not discern textural differences could be eliminated from the testing.

In addition, a total of 228 consumers were asked to rate the taste of onion, cheese, and unflavored puffs made from navy, pinto, and black bean high-starch flours, utilizing a 7-point hedonic scale. This consumer testing was conducted at Focus: Hope, a food bank located in Detroit.

All other taste panels took place at Michigan State University in a room equipped with lighted booths, allowing for isolated evaluation of samples by individual panelists in simulated daylight. Copies of the score cards appear in the appendix.

Short-Term Relative Humidity Effects

Saturated solutions of lithium chloride, magnesium nitrate, sodium chloride, and potassium nitrate were prepared in dessicators to produce closed environments of 11, 33, 52, and 75% relative humidity, respectively (Rockland, 1960). Unflavored puff samples (about 50 g) were placed in wire containers in the dessicators. Samples were removed every third day over a 24-day period for moisture determination. Color and texture measurements were taken at 12-day intervals.

Long-Term Storage

In order to determine the stability of flavored puffs in conditions approximating commercial storage, samples were heat sealed in metallized polypropylene wrap and held in a storage room at approximately 24°C (75°F) and 40-50% relative humidity. After 30 and 60 days some pouches were opened and puffs subjected to sensory evaluation (general acceptability) and objective measurements (color and texture).

Data Analyses

All objective and sensory data were statistically analyzed to determine standard deviations of each variable mean, as well as to locate significant differences among variables. The latter was accomplished for initial product data using the Student-Newman-Keuls (Multiple Range) Test (Newman, 1939 and Keuls, 1952 in Zar, 1974). Storage data were analyzed in two-and three-way factorial arrangements with the least significant difference test.

RESULTS AND DISCUSSION

This study was carried out to determine the feasibility of producing an extruded puffed snack from navy bean starch and hull fractions. Objective measurements (shear, values, Hunter values, density, and moisture content) and sensory evaluation (texture and general acceptability) were used to characterize puffs containing up to 20% hulls. The storage stability of the products was also investigated over short (24 days) and long (60 days) storage times. The fiber content of the puffs before and after extrusion was also determined to reveal any changes occurring during production, as well as to ascertain the final product's fiber contribution to the daily diet.

Description of Freshly Extruded Navy Bean Puffs

The objective characteristics of navy bean starch puffs containing 0, 5, 10, 15, and 20% hulls are shown in Table 3. The analyses of variance for these data are given in Table 4.

All extruded samples expanded well, owing to the composition of navy bean starch, which contains approximately 22.1% amylose and 77.9% amylopectin (as calculated from data in Naivikul and D'Appolonia, 1979). Starches high in amylopectin produce lighter, more expanded extrudates, while high-amylose starches yield harder, more dense products (Feldberg in Harper, 1981).

The navy bean puffs compare well to similar products made from cereal starches, which typically contain 70% amylopectin and 30% amylose (Osman in Harper, 1981). The amylose content of navy bean starch falls within the range set by Murray et al (in Harper, 1981)

Table 3. Density, expansion coefficient, moisture content, and Hunter values of extruded navy bean starch puffs containing 5 levels of hull[1]

Hulls (%)	Density (g/100 ml)	Expansion Coefficient[2]	Moisture (%)	Hunter Values L	a_l	b_L
0	6.00^{a}	3.04^{a}	3.37^{a}	57.0^{a}	3.4^{a}	20.3^{a}
5	5.47^{b}	3.48^{b}	2.96^{a}	55.3^{b}	4.2^{b}	19.8^{bc}
10	6.48^{c}	3.63^{b}	3.15^{a}	57.0^{a}	2.6^{c}	20.1^{ab}
15	7.86^{d}	3.06^{q}	2.90^{a}	56.7^{a}	3.1^{d}	19.8^{bc}
20	7.11^{e}	3.50^{b}	4.68^{b}	58.5^{c}	1.7^{e}	19.5^{c}
Standard error	0.05	0.20	0.20	0.20	0.1	0.1

[1]based on 4 replications

[2]expansion coefficient = $\frac{\text{product diameter}}{\text{die diameter (4)}}$

[a-e]values in columns having the same superscript are not significantly different at $p < 0.01$ by SNK mean separation

Table 4. Analyses of variance for density, expansion coefficient, moisture content, and Hunter values of extruded navy bean starch puffs

Degrees of Freedom	Mean Squares					
	Density	Expansion Coefficient	Moisture	Hunter Values		
				L	a_L	b_L
Total 19	----	----	----			
Group 4	3.511**	2.436**	2.155**	1.706**	3.302**	0.959**
Error 15	0.007	0.159	0.166	0.123	0.016	0.038

** significant at $p < 0.01$

of 20 to 50% for acceptable puffed snacks.

The incorporation of hulls caused no loss of expansion, as the bean starch was apparently able to accommodate increasing amounts of non-expandable hulls with concurrently decreasing amounts of starch. Other investigators have found no loss of volume with 30% wheat bran in layer cakes (Springsteen et al, 1977), 16% wheat bran and 12% middlings in layer cakes (Brockmole and Zabik, 1976), 20% microcrystalline cellulose in biscuits (Brys and Zabik, 1976), 15% navy bean hulls in layer cakes (De Fouw et al, 1982b), or 30% oat and corn bran or soy hulls in layer cakes (Shafer and Zabik, 1978).

Puffs containing hulls at 10% and above exhibited significantly greater density than those made from starch alone. This was expected, since the hulls themselves would not expand appreciably due to the presence of up to 40% ENDF and a slightly higher protein content.

Moisture content of the product was not dependent on level of hull incorporation. The differences among the five types may be due to the lack of strict controls on production, especially post-extrusion drying. All values in this study were lower than those obtained by Aguilera et al (1984), who reported 7.7% moisture for an extruded snack produced from 100% high starch fractions of navy beans. The latter study utilized a Wenger X-5 extruder with slower screw speed (755 RPM), lower barrel temperature (85-90°c), and greater die size (4.6 mm) than those employed in this project. The lower barrel temperature was probably the main reason for the higher moisture content of the extrudate.

Hunter L values revealed no noticeable trend, with samples containing 5% hulls appearing darker and those with 20% hulls appearing lighter than the control. Aguilera et al (1984) produced much lighter snacks having an L value of 76.8 (100% high starch fraction). Once again, the differences in extrusion conditions previously discussed were probably responsible. Lower barrel temperature would minimize heat-induced browning of the extrudate, resulting in a lighter product.

The incorporation of hulls at the 5% level caused an increase in Hunter a_L value over the control, indicating greater redness; however, greater hull substitution yielded lower a_L values, especially to 20% hulls, reflecting less redness. The usual L and a_L color values of puffs containing 5% hulls (as compared to the other hull levels) could possibly be due to lower barrel pressure or lower product temperature during extrusion (see Table 2).

Hunter b_L values were lower for hull-containing puffs than for the control, indicating less yellowness. Overall there seemed to be a paling effect with the incorporation of hulls, most evident at the 20% level, while at 5% hulls, a browner puff was produced. Hulls may contain less reducing sugars than starch; therefore, less Maillard browning would occur during the extrusion process. They are also lower in sucrose than the starch--2.30 vs. 2.60% (Uebersax and Zabik, 1982)--which may also result in a paler product. Puffs made from navy bean fractions may be expected to exhibit more browning during extrusion than puffs containing wheat, due to greater sucrose content, as the latter contains only 0.84% sucrose (Bechtel et al, 1964).

Sensory evaluation of the freshly extruded product for textural quality (Table 5) revealed hull incorporation at a 10% level to result in a crisper, more crunchy product. These findings did not coincide with shear values obtained with the Allo Kramer Shear Press, as the 0, 10, and 20% hull samples all required less shearing force than the 5 and 15% puffs. Perhaps the density of the puffs containing 10% hulls, which fell between those of the other puffs, served to optimize the sensation of crispness and crunchiness. The analysis of variance for textural data is given in Table 6.

In this study the 10% hull puffs were extruded at a lower barrel temperature (150°C) than the other samples (160°C). The statement by Smith (1974a) that maximum product crispness results from extrusion parameters of low moisture and high temperature is not born out by present findings. Perhaps the moisture content during extrusion, which was not recorded, played a more important role in final product texture. Navy bean hulls and starch possess relatively small amounts of fat, 1.01 and 1.02% respectively (Lee et al, 1983). Low fat content is also a characteristic which promotes extrudate crispness (Smith, 1974a).

Effect of Relative Humidity During Short-Term Storage

Moisture Content

Changes in moisture content of the puffs during storage at various levels of relative humidity are shown in Table 7 and Figures 3-6, analysis of variance appearing in Table 8. At 11% relative humidity, puffs lost moisture, while relative humidity of 33% and above caused sample to absorb moisture. Of course, as relative humidity increased, so did moisture absorption.

Table 5. Shear values and texture sensory scores of extruded navy bean starch puffs containing 5 levels of hull[1]

Hulls (%)	Shear (lb/g)	Texture Score[2]
0	5.7[a]	3.69[a]
5	7.8[b]	3.63[a]
10	5.4[a]	4.34[b]
15	7.8[b]	3.08[ab]
20	5.9[a]	4.13[ab]
Standard error	0.3	0.35

[1]based on 4 replications

[2]scale = 5 = very crunchy
1 = spongey

[ab]values in columns having the same superscript are not significantly different at $p < 0.01$ by SNK mean separation

Table 6. Analysis of variance for shear values and texture sensory scores of extruded navy bean puffs

	Degrees of Freedom		Mean Squares	
	Shear	Sensory Score	Shear	Sensory Score
Total	139	159	----	----
Group	34	4	10.165**	3.002**
Error	105	155	0.475	0.488

**significant at $p < 0.01$

Table 7. Changes in moisture content of extruded navy bean starch puffs at 12 and 24 days storage under 4 levels of relative humidity[1]

Relative Humidity	Hulls	Moisture Change[2] (%)	
		Day 12	Day 24
11	0	-2.9	-12.3
	5	-4.7	-15.4
	10	-9.2	-12.2
	15	-6.0	-10.1
	20	-13.0	-23.6
33	0	41.7	44.8
	5	28.2	30.7
	10	42.8	43.0
	15	49.2	48.3
	20	17.7	20.2
52	0	87.5	75.9
	5	70.7	67.9
	10	84.4	82.7
	15	104.5	96.8
	20	59.5	55.1
75	0	202.0	192.0
	5	186.8	173.1
	10	214.1	198.9
	15	224.7	218.3
	20	147.6	136.4
Standard Error		0.4	0.4

[1]based on 4 replications

[2]all values are significantly different at $p < 0.01$ by LSD mean separation

Table 8. Analyses of variance for changes in moisture content of extruded navy bean puffs during short-term storage

	Degrees of Freedom	Mean Square
Total	159	----
Relative Humidity	3	3.348**
Rime	1	183.916**
RH x T	3	164.644**
Hulls	4	2.961**
RH x H	12	47.332**
R x H	4	0.178**
RH x T x H	12	164.630**
Error	120	0.569

**significant at $p < 0.01$

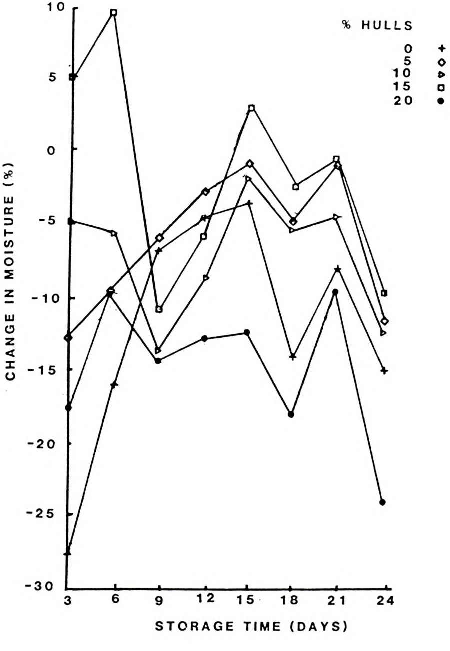

Figure 3. Change in moisture content of navy bean puffs stored at 11% relative humidity

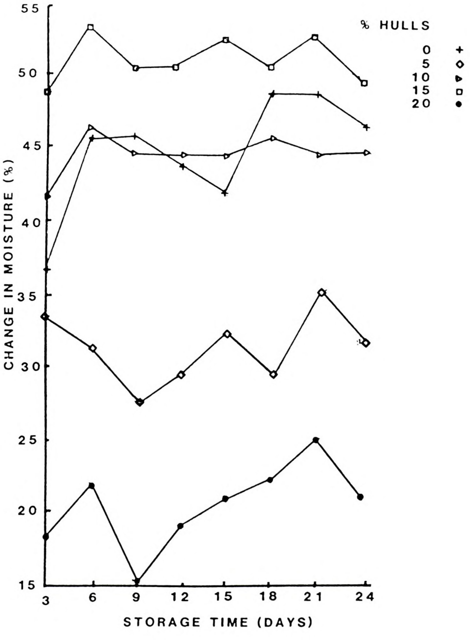

Figure 4. Change in moisture content of navy bean puffs stored at 33% relative humidity

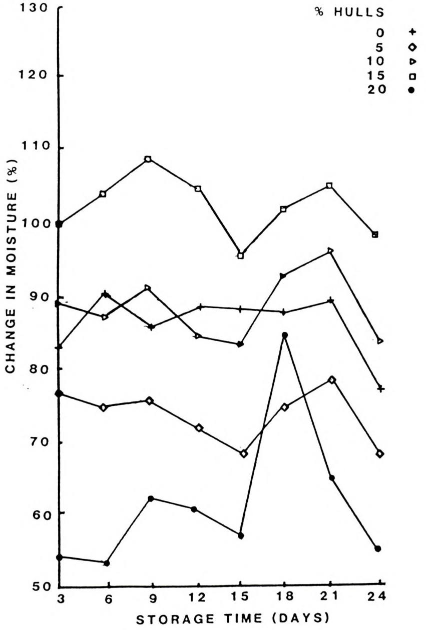

Figure 5. Change in moisture content of navy bean puffs stored at 52% relative humidity

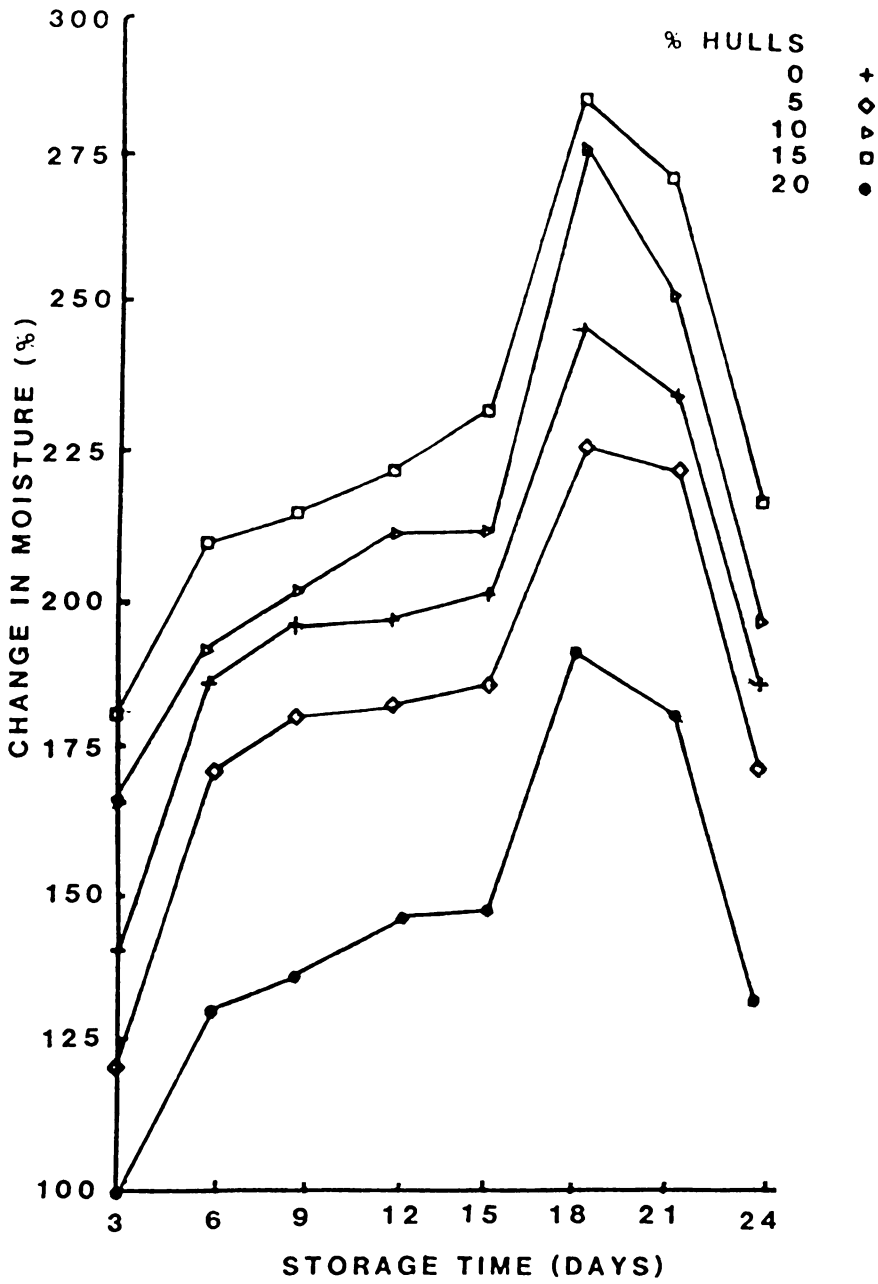

Figure 6. Change in moisture content of navy bean puffs stored at 75% relative humidity

Samples containing hulls at the 20% level had the least affinity for water, losing the most at 11% relative humidity and gaining the least at higher levels. Puffs with 15% hulls absorbed the most moisture at relative humidity levels at and above 33%. There was no clear relationship between changes in moisture content and level of hull incorporation.

Texture

Table 9 shows the effect of various levels of relative humidity on shear values of puffs after 12 and 24 days of storage. Table 10 presents the corresponding analysis of variance.

After 12 days samples held at 75% relative humidity had become tougher (rubbery to the hand). At 52% relative humidity the control showed slightly greater, but not significant, loss of crispness when compared to puffs containing hulls. The presence of hulls may have deterred textural deterioration to some extent, possibly through dilution of starch content. Starch retrogradation is believed to be a major reaction in the staling process.

After 24 days of storage all samples held at 52 and 75% relative humidities had become tougher. Storage at 11 and 33% relative humidities resulted in no significant textural change through 24 days. Apparently, at a point between 33 and 52% relative humidity, starch retrogradation was sufficiently promoted to alter product texture.

Color

As evident from Table 11, puffs showed darkening (lower Hunter L values) after 12 days; however, samples containing hulls retained

Table 9. Shear values of extruded navy bean starch puffs at 0, 12, and 24 days storage at 4 levels of relative humidity[1]

Relative Humidity	Hulls	Shear[2] (lb/g) Day 0	Day 12	Day 24
11	0	5.7	6.8	6.2
	5	7.8	7.7	7.5
	10	5.4	5.4	6.5
	15	7.8	7.2	7.5
	20	5.9	5.9	6.3
33	0	5.7	5.7	6.8
	5	7.8	8.0	7.8
	10	5.4	5.6	6.2
	15	7.8	8.3	8.4
	20	5.9	6.3	6.3
52	0	5.7	9.9	9.2
	5	7.8	7.8	11.9
	10	5.4	5.6	9.2
	15	7.8	8.3	11.1
	20	5.9	5.9	8.4
75	0	5.7	66.0	309
	5	7.8	67.5	486
	10	5.4	70.5	438
	15	7.8	76.5	445
	20	5.9	84.0	354
Standard Error		1.2	1.2	1.2

[1]based on 4 replications

[2]LSD's among storage time means = 5.3
hull level means = 6.8
relative humidity means = 6.1

Table 10. Analysis of variance for shear values of extruded navy bean starch puffs during short-term storage

	Degrees of Freedom	Mean Square
Total	239	----
Relative Humidity	3	336307.852**
Time	2	215851.077**
RH xT	6	209891.760**
Hulls	4	1269.053**
RH x H	12	1280.698**
T x H	8	1082.337**
RH x T x H	24	1040.960**
Error	180	6.092

**significant at $p < 0.01$

Table 11. Hunter L values of extruded navy bean starch puffs at 0, 12, and 24 days storage at 4 levels of relative humidity[1]

Relative Humidity (%)	Hulls (%)	Hunter L Value[2] Day 0	Day 12	Day 24
11	0	56.9	55.5	55.7
	5	56.2	56.3	55.5
	10	57.1	57.3	57.6
	15	56.9	56.4	56.2
	20	58.0	57.6	57.3
33	0	56.9	55.7	56.3
	5	56.2	54.5	56.2
	10	57.1	55.7	56.5
	15	56.9	55.7	57.5
	20	58.0	55.8	57.6
52	0	56.9	53.4	56.6
	5	56.2	54.3	56.5
	10	57.1	55.2	56.3
	15	56.9	54.4	57.4
	20	58.0	54.8	57.5
75	0	56.9	54.5	54.1
	5	56.2	52.3	54.1
	10	57.1	54.5	54.8
	15	56.9	53.5	52.5
	20	58.0	55.5	53.2
Standard Error		0.2	0.2	0.2

[1]based on 4 replications

[2]LSD's among storage time means = 0.1
hull levels means = 0.2
relative humidity means = 0.2

greater lightness when held at 11% relative humidity. Although by day 24 no pattern could be discerned, it could be concluded generally that storage resulted in lower Hunter L values.

Working with samples of high starch navy bean flour, Lee et al (1982) reported no change in Hunter L values after 8 weeks' storage at relative humidity levels of 48 to 75%. The same study revealed no darkening of hull flour under the same conditions.

The heat of extrusion processing may have rendered the starch and hull material more susceptible to Maillard browning or similar reactions. The fact that Hunter values can be affected by sample texture suggests a second explanation: textural changes in the puffs during storage resulted in lower Hunter L values. This relationship is especially evident at 75% relative humidity, where the greatest increases in shear value parallel the greatest reductions in L values.

Hunter a_L values (Table 12) changed drastically after 12 days, moving from positive to negative as color became less red and more green for all samples. Curiously, values increased by day 24, with greatest values occurring at the highest relative humidity (75%). The latter trend (from day 12 to 24) is supported by results obtained by Lee et al (1982), who noted a_L values becoming less negative with 8-week storage in relative humidities at and above 64%.

A similar trend was exhibited by Hunter b_L values (Table 13). Decreases in values, reflecting reduced yellowness, occurred by day 12 with some recovery noticeable in the next 12 days. Lee et al (1982) reported increases in b_L values after 8 weeks at 75% relative

Table 12. Hunter a_L values of extruded navy bean starch puffs at 0, 12, and 24 days storage at 4 levels of relative humidity[1]

Relative Humidity (%)	Hulls (%)	Hunter a_L Value[2] Day 0	Day 12	Day 24
11	0	2.7	-0.3	0.3
	5	3.5	-0.8	-0.4
	10	2.2	-1.5	-0.1
	15	2.7	-0.6	-0.7
	20	1.0	-2.2	-0.7
33	0	2.7	-1.6	-0.2
	5	3.5	-1.7	-0.5
	10	2.2	-2.7	-0.7
	15	2.7	-1.7	-0.7
	20	1.0	-2.9	-0.9
52	0	2.7	-1.8	0.3
	5	3.5	-1.1	0.4
	10	2.2	-2.5	-0.2
	15	2.7	-1.4	-0.4
	20	1.0	-2.7	-0.8
75	0	2.7	-1.6	0.6
	5	3.5	-1.0	1.1
	10	2.2	-1.7	0.5
	15	2.7	-0.9	0.9
	20	1.0	-2.6	-0.1
Standard Error		0.3	0.3	0.3

[1]based on 4 replications

[2]LSD's among storage time means = 0.3
hull level means = 0.4
relative humidity means = 0.4

Table 13. Hunter b_L values of extruded navy bean starch puffs at 0, 12, and 24 days storage at 4 levels of relative humidity[1]

Relative Humidity (%)	Hulls (%)	Hunter b_L Value[2]		
		Day 0	Day 12	Day 24
11	0	20.2	18.7	19.5
	5	19.9	18.4	19.3
	10	19.8	19.1	19.3
	15	19.7	18.6	19.2
	20	18.7	17.6	18.3
33	0	20.2	17.3	18.8
	5	19.9	17.3	18.7
	10	19.8	17.4	18.6
	15	19.7	17.5	18.5
	20	18.9	17.2	17.8
52	0	20.2	17.6	18.3
	5	19.9	17.5	18.3
	10	19.8	17.4	18.4
	15	19.7	17.3	18.3
	20	18.0	17.5	17.8
75	0	20.2	16.3	17.4
	5	19.9	16.4	17.6
	10	19.8	17.1	17.5
	15	19.7	17.1	17.7
	20	18.9	16.6	17.6
Standard Error		0.2	0.2	0.2

[1]based on 4 replications

[2]LSD's among storage time means = 0.1
hull level means = 0.1
relative humidity means = 0.1

Table 14. Analyses of variance for Hunter values of extruded navy bean starch puffs during short-term storage

	Degrees of Freedom	Mean Square		
		L	a	b
Total	239	----	----	----
Relative Humidity	3	35.737**	3.855**	12.482**
Time	2	71.481**	334.477**	97.237**
RH x T	6	17.420**	2.612**	3.351**
Hulls	4	13.899**	17.437**	4.080**
RH x H	12	1.358**	0.176	0.324**
T x H	8	0.849**	2.154**	0.733**
RH x T x H	24	1.427**	5.165**	0.165**
Error	180	0.109	0.325	0.077

**significant at $p < 0.01$

humidity for starch fractions and at 64 and 75% relative humidity for hulls. Analyses of variance for L, a_L and b_L values are shown in Table 14.

Combining the 3 Hunter values, the puffs apparently became more gray during storage at all levels of relative humidity. A color change was not unexpected, although browning of the product would be more understandable, given the relatively high total sugar content of navy bean flour--5.61%, compared to wheat's 1.6% (Naivikul and D'Appolonia, 1978).

Non-enzymatic browning, also known as Maillard browning, occurs when reducing sugars react with amino acids to form melanoidins. The reaction is promoted under conditions of high relative humidity. Of all puffs remaining after 24 days of this study, Hunter L and a_L values were lowest and b_L values greatest for samples held at 75% relative humidity. Such values reflect browner color, although the degree of change is slight.

Effect of Long-Term Storage

Color

When puffs were coated with oil, onion powder, and salt and stored in commercial-like conditions for 60 days, both the control and samples containing 10% hulls had become darker (lower L values), while puffs made with 20% hulls retained original color (Table 15, with analysis of variance in Table 18). Again, the possibly lower reducing sugar content of the hulls could have retarded Maillard browning.

Table 15. Hunter L values of onion-flavored navy bean starch puffs at 0, 30, and 60 days storage under commercial-like storage[1]

Hulls (%)	Hunter L Value		
	Day 0	Day 30	Day 60
0	55.8[ac]	55.6[c]	54.4[f]
10	56.2[ad]	56.4[d]	54.9[g]
20	57.3[b]	58.5[e]	57.7[b]
Standard Error	0.1	0.1	0.1

[1]based on 4 replications

[a-g]values having the same superscript are not significantly different at $p < 0.01$ by LSD mean separation

Table 16. Hunter a_L values of onion-flavored navy bean starch puffs at 0, 30, and 60 days storage under commercial-like storage[1]

Hulls (%)	Hunter a_L Value		
	Day 0	Day 30	Day 60
0	-1.2[a]	-1.4[ab]	-1.3[a]
10	-1.5[ab]	-1.7[b]	-1.7[b]
20	-2.2[d]	-2.1[d]	-2.2[d]
Standard Error	0.1	0.1	0.1

[1]based on 4 replications

[a-d]values having the same superscript are not significantly different at $p < 0.01$ by LSD mean separation

As shown in Table 16, Hunter a_L values remained unchanged through the storage period. Puffs containing 20% hulls retained a greener color during storage.

Initially samples having 10 and 20% hull incorporation exhibited greater b_L values (Table 17), indicating greater yellowness, than the control. These values remained stable during storage, excepting the unaccountable wild fluctuation at day 30 for the 20% hull sample. Analyses of variance for all Hunter values are given in Table 18.

Texture

Changes in the flavored products' crispness were minimal during 60-day storage, as presented in Table 19. The analysis of variance for shear values appears in Table 21. Initial values among the 3 hull levels did not differ, and no differences developed by day 60. Apparently all starch and hull combinations were texturally stable under moderate storage conditions for at least 2 months.

Navy bean starch could conceivably possess extrusion qualities similar to those of modified starches. The incorporation of slightly modified pregelatinized waxy starch into extruded products is known to extend crispness (Feldberg in Harper,1981).

General Acceptability

Table 20 presents the sensory scores given to the puffs by 8 taste panel members, and the analysis of variance for these scores is shown in Table 21. Samples containing hulls (10 and 20%) were initially judged more acceptable than the control (no hulls), yet

Table 17. Hunter b_L values of onion-flavored navy bean starch puffs at 0, 30, and 60 days storage under commercial-like storage[1]

Hulls (%)	Hunter b_L Value		
	Day 0	Day 30	Day 60
0	12.8^{c}	12.8^{c}	13.2^{b}
10	13.5^{ab}	13.4^{ab}	13.2^{b}
20	13.7^{a}	12.2^{d}	13.5^{ab}
Standard Error	0.1	0.1	0.1

[1]based on 4 replications

[a-b]values having the same superscript are not significantly different at $p < 0.01$ by LSK mean separation

Table 18. Analyses of variance for Hunter values of navy bean starch puffs during commercial-like storage

	Degrees of Freedom	Mean Square		
		L	a_L	b_L
Total	35	----	----	----
Hulls	2	22.222**	2.303**	0.610**
Time	2	4.218**	0.039	1.053**
H x T	4	1.220**	0.034	0.954**
Error	27	0.047	0.034	0.033

**significant at $p < 0.01$

Table 19. Shear values of onion-flavored navy bean starch puffs at 0, 30, and 60 days storage under commercial-like conditions[1]

Hulls (%)	Shear (lb/g)		
	Day 0	Day 30	Day 60
0	5.7^{ab}	6.2^{b}	6.5^{b}
10	5.1^{a}	5.6^{ab}	5.6^{ab}
20	5.6^{ab}	6.5^{b}	6.5^{b}
Standard Error	0.2	0.2	0.2

[1]based on 4 replications

[ab]mean values having the same superscript are not significantly different at $p < 0.01$ by LSD mean separation

Table 20. Sensory scores of onion-flavored navy bean starch puffs at 0, 30, and 60 days storage under commercial-like conditions[1]

Hulls (%)	Sensory Score[2]		
	Day 0	Day 30	Day 60
0	2.8^{a}	3.4^{abc}	3.1^{ac}
10	3.8^{bc}	3.6^{bc}	4.0^{b}
20	3.6^{bc}	3.2^{ac}	3.2^{ac}
Standard Error	0.4	0.4	0.4

[1]based on 4 replications using an 8-member panel

[2]scale: 5 = like extremely
1 = dislike extremely

[a-c]mean values having the same superscript are not significantly different at $p < 0.01$ by LSD mean separation

Table 21. Analyses of variance for shear values and sensory scores of navy bean puffs during commercial-like storage

	Degrees of Freedom		Mean Square	
	Shear	Sensory	Shear	Sensory
Total	35	287	-----	----
Hulls	2	2	2.112**	10.412**
Time	2	2	1.939**	0.016
H x T	4	4	0.077	2.438**
Error	27	279	0.148	0.701

**significant at $p < 0.01$.

this preference disappeared for 1-month-old puffs. No change in acceptability occurred within any individual hull level throughout the storage period, and by day 60 samples containing 10% hulls were rated superior to the others.

The flavored puffs obviously exhibited considerable stability over a 2-month period. No adverse flavor changes, such as rancidity, or textural changes, such as staling, could be detected by panel members.

Dietary Fiber Content of Extruded Navy Bean Puffs

The results in Table 22 (see Table 23 for analysis of variance) show the increase in ENDF (enzyme neutral detergent fiber) content with increased hull incorporation. This was expected as the hulls are rich in hemicellulose (about 40%) and other non-digestible carbohydrates.

Noteworthy are the lower percentages of ENDF found in extruded puffs when compared to corresponding mixes of unextruded starch and hull flour. Apparently the extrusion process caused some destruction of fiber, or possibly an alteration of the material which impaired analytical detection. Post-extrusion decreases in detected ENDF became greater as hull level and fiber content increased.

Navy bean puffs containing 20% hulls possess amounts of ENDF (by %) comparable to such commercially available products as Jiffy Bran Miffin Mix (9.67%) and Nature Valley Granola Bars with Coconut (8.09%) (Jwuang, 1978).

Table 22. ENDF content of 5 navy bean starch/hull blends before and after extrusion processing[1]

Hulls (%)	ENDF[2, 3] (%) Before Extrusion	After Extrusion
0	5.296	5.052
5	6.743	6.322
10	8.650	7.628
15	9.475	8.613
20	10.828	9.610
Standard Error	.016	.016

[1]based on 4 replications

[2]dry weight basis

[3]all values significantly different at $p < 0.01$ by LSD mean separation

Table 23. Analysis of variance for ENDF content for navy bean starch/hull blends

	Degrees of Freedom	Mean Square
Total	39	----
Heat	1	5.671**
Hulls	4	32.009**
H x H	4	0.334**
Error	30	0.001

**significant at $p < 0.01$

The high starch fraction itself contains some fiber, enough to yield ENDF values similar to those of fig bars (4.25%) and C. W. Post Family Style Cereal (4.56%). While the puffs produced in this study possess lower ENDF values than most bran cereals, they can be expected to contribute significant amounts of fiber to the daily diet.

Consumer Response to Various Bean Puffs

Table 24 presents the scores given to flavored and unflavored puffs made from navy bean starch. Consumers responded favorably to both cheese- and onion-flavored samples, and plain puffs were rated lower but "okay," suggesting that the extrudates, being themselves rather bland, could accommodate a wide range of flavors.

Consumer response to cheese-flavored navy bean puffs is compared to that for samples made from pinto and black bean starches in Table 25. No significant differences were found among bean types, all receiving positive responses. Table 25 shows the analysis of variance for all sensory data.

The slightly lower, but not significantly different, scores given to the black bean samples were most likely due to the dark color of the samples. It is unknown whether the fact that the consumer group was predominantly low income Black had a significant effect on acceptability ratings.

Table 24. Consumer sensory scores for unflavored and cheese- and onion-flavored navy bean starch puffs[1, 2]

Cheese	Onion	Plain
6.06 ± 0.80[a]	5.75 ± 1.23[a]	5.03 ± 1.47[b]

[1]based on responses of 63 consumers

[2]scale = 7 = tastes great
1 = tastes terrible

[ab]mean values having the same superscript are not significantly different at $p < 0.01$ by SNK mean separation

Table 25. Consumer sensory scores for cheese-flavored puffs made from high-starch fractions of navy, pinto, and black beans[1, 2, 3]

Navy	Pinto	Black
5.71 ± 1.24	5.82 ± 1.05	5.45 ± 1.36

[1]based on responses of 51 consumers

[2]scale = 7 = tastes great
1 = tastes terrible

[3]no significant difference among mean values at $p < 0.01$ by SNK mean separation

Table 26. Analyses of variance for consumer sensory scores of extruded bean starch puffs

	Degrees of Freedom		Mean Square	
	Cheese-Flavored	Navy Bean	Cheese-Flavored	Navy Bean
Total	152	188	----	----
Group	2	2	1.850	17.593**
Error	150	186	1.498	1.439

**significant at $p < 0.01$

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate the extrusion potential of various blends of navy bean starch and hulls and subsequently to examine the characterisitcs of the extrudates. The puffs were evaluated in objective terms of moisture, color, and texture, as well as subjective terms of texture and general acceptability. The last characteristic was measured after flavoring of the product with onion powder, salt, and vegetable oil.

The storage stability of the puffs was also determined under various levels of relative humidity (11, 33, 52, and 75%) through 24 days and under commercial-like conditions through 60 days. The dietary fiber contents (ENDF values) of unextruded and extruded starch/hull blends were also determined.

The incorporation of up to 20% hulls did not adversely affect expansion of the product, while hull levels of 10% and greater resulted in denser puffs. No correlation was found between hull and moisture contents. Samples containing 20% hulls were slightly paler than the control, and puffs made with 10% hulls received greater textural scores than the control.

Storage studies suggested the existence of a critical value between 33 and 52% relative humidity, above which textural deterioration occurred by 24 days. Incorporation of navy bean hulls may have deterred toughening of the starch-based puffs. A darkening, specifically a graying, of the puffs occurred during storage at all levels of relative humidity.

When heat sealed in metallized polypropylene pouches, puffs containing 20% hulls retained lighter color, while samples with lower hull levels became darker during storage. Shear values and acceptability scores remained unchanged through 60 days.

Consumer response to cheese- and onion-flavored navy bean starch puffs was favorable. Unflavored samples received good-to-neutral scores, indicating minimal beany flavor and thus considerable flavoring flexibility.

Dietary fiber (ENDF) content of the product increased with greater hull incorporation, a maximum of 9.61% contained in the 20% hull samples. Extrusion processing caused a decrease in detected ENDF values.

Based on the findings of this study, navy bean starch can be considered an excellent base for extrusion puffing, being able to accommodate at least 20% hull incorporation without loss of product quality. In fact, the presence of hulls may enhance product desirability, as reflected in greater initial texture (crunchiness) scores and greater general acceptability scores. Hulls may also serve to minimize color (darkening) and textural (toughening) changes during storage. Last, hulls provide considerable amounts of dietary fiber, a positive nutritional attribute in any potential snack food.

PROPOSALS FOR FUTURE STUDIES

1. An investigation of the effect of greater levels of hull incorporation (20%) on the quality characteristics of a puffed bean starch extrudate should be initiated to determine maximum acceptable fiber levels.

2. A study on the effect of incorporating high-protein fractions in bean starch/hull extrudates is recommended in order to optimize nutritional quality of the puffs.

3. Combinations of navy bean fractions and cereal grains should be extruded and tested in order to develop products having superior protein quality.

4. Further investigation of the effect of extrusion processing on fiber (ENDF) values is recommended in order to quantitate possible effects and determine the mechanics involved.

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APPENDIX

PUFFED SNACK TEXTURE EVALUATION

Please write the sample number and the texture description number (see scale below) in the spaces provided. Thank you.

Textural Scale:

5 - very crunchy, optimum crispness

4 - moderately crunchy, crisp

3 - slightly crunchy, no crispness

2 - little or no crunch, slightly soggy

1 - spongey, soggy, tough, call Goodyear

Sample No.	Texture No.

Figure 7. Score card used for texture rating of navy bean puffs

PUFF EVALUATION

Please rate the puffs before you by recording sample code and appropriate descriptive number. Thank you.

Scale: 5 = like extremely
4 = like moderately
3 = neither like nor dislike
2 = dislike moderately
1 = dislike extremely

Sample No.	Descriptive No.

Figure 8. Score card used for general acceptability rating of navy bean puffs

BEAN FLOUR PUFFS

SENSORY EVALUATION

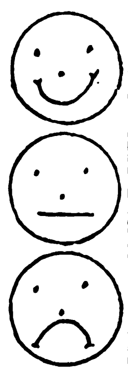
INSTRUCTIONS:

1. You will be given three (3) samples of puffs in a divided plate. Each sample is labeled with a symbol such as: ###, %%%, ***.
2. Taste each product individually and record your reaction to the product's taste on the ballot below.
3. Place an "X" next to your score for each product. Be sure to keep the coded sample in proper order.
4. Record any comments you have about the product's taste.

PLACE AN "X" IN THE BLANK WHICH BEST DESCRIBES YOUR REACTION TO THE PUFFS.

Sample Code
###

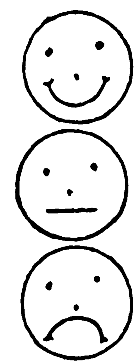
___ Tastes Great
___ Tastes Good
___ Tastes Okay
___ Tastes Neither Good Nor Bad
___ Tastes Poor
___ Tastes Bad
___ Tastes Terrible



Comments:

Sample Code
%%%

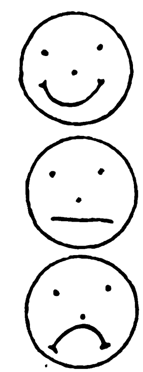
___ Tastes Great
___ Tastes Good
___ Tastes Okay
___ Tastes Neither Good Nor Bad
___ Tastes Poor
___ Tastes Bad
___ Tastes Terrible



Comments:

Sample Code
***

___ Tastes Great
___ Tastes Good
___ Tastes Okay
___ Tastes Neither Good Nor Bad
___ Tastes Poor
___ Tastes Bad
___ Tastes Terrible



Comments:

Figure 9. Score card used for consumer rating of pean puffs