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Characteristics of a snack food with added soy protein

Peter Mancuso

To the Graduate Council:

I am submitting herewith a thesis written by Peter Mancuso entitled "Characteristics of a snack food with added soy protein." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Science and Technology.

Sharon L. Melton, Major Professor

We have read this thesis and recommend its acceptance:

J. R. Mount, J. T. Smith

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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To the Graduate Council:

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Sharon L. Melton, Major Professor

We have read this thesis
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Date 12/10/87

CHARACTERISTICS OF A SNACK FOOD WITH ADDED SOY PROTEIN

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Peter Mancuso

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ABSTRACT

Variations of a potato-based snack food formulated with 0%, 10%, 20%, and 30% defatted soy flour and 10%, 20%, 30%, and 40% corn meal were deep-fat fried in partially hydrogenated soybean oil and were evaluated for physical, chemical, and sensory characteristics and protein quality.

There were no significant differences in texture among the different formulations. The Hunter color values "L," "a," and "b" were significantly affected by corn meal level, soy flour level, and their interaction. Only the "L" value was affected by day ($P < .05$).

The chemical analysis showed that the percentage of protein was affected significantly by soy flour level and corn and soy interactions. The percentage of fat was significantly affected by corn meal and soy flour and their interactions. The percentage moisture was affected significantly by corn meal and corn meal and soy flour interactions. Day significantly affected all three chemical components.

The analysis of variance for the sensory analysis showed that color, flavor, and overall acceptability were significantly affected by soy flour level. The chip containing 40% corn meal and 20% soy flour was chosen for further analysis and had a proximate composition of 13.33% protein, 20.33% fat, 2.75% crude fiber, 5.2% moisture, and 2.94% ash.

The protein efficiency ratio values were from the casein control (2.18) and the potato-based snack food (2.07) were not statistically different.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION	1
II. REVIEW OF THE LITERATURE	3
History	3
Chemical Composition and Nutritive Value	4
Use of Corn Meal in Snack Foods	7
Use of Soy Flour in Food Products	12
III. MATERIALS AND METHODS	16
Source of Ingredients	16
Experimental Design	16
Production of Chips	20
Evaluation of Physical Characteristics of Chips	20
Chemical Evaluation of Chips	21
Sensory Analysis	21
Protein Evaluation	22
Statistical Analysis	22
IV. RESULTS AND DISCUSSION	25
Physical Characteristics	25
Chemical Evaluation	33
Sensory Evaluation	41
Protein Evaluation	44
Conclusions	46
REFERENCES	48
APPENDICES	53
A. PROCEDURE FOR MODIFIED CRUDE FIBER	54
B. EQUATIONS FOR COLOR MEASUREMENTS AND CHEMICAL COMPONENTS	55
C. MODIFIED PROTEIN EFFICIENCY RATIO	56
VITA	57

LIST OF TABLES

TABLE		PAGE
1.	Vitamin content of soybean food products	5
2.	Mineral content of soybean food products	6
3.	Essential amino acid content of soybeans compared to the FAO requirements for adults.	8
4.	Essential amino acid content of some soybean products. . . .	9
5.	Nutritive value of food proteins based on biological evaluation	10
6.	Amino acid content of corn meal and soybeans	11
7.	Effect of soybean flour as a protein supplement to cereal grains on protein efficiency ratio	13
8.	Combinations of defatted soy flour and corn meal levels substituted for dry matter in a potato-based snack food. . .	17
9.	Ingredients for potato-based snack food.	18
10.	Order in which formulations were made for each replication.	19
11.	Analysis of variance for texture, color, and chemical composition of chips	23
12.	Sum of squares for the analysis of variance of the texture experimental chips	26
13.	Mean values for the force required to fracture potato-based chips of different formulation	27
14.	Sums of squares for the analysis of variance for measurements of color of the chips	28
15.	Analysis of variance for chemical components in potato-based chips.	34
16.	Percentages of protein, fat, and moisture in potato-based chip averaged across all corn meal levels for each soy flour level.	36

TABLE PAGE

17. Percentage of protein, fat, and moisture in the potato-based chips average across all soy flour levels for each corn meal level. 38

18. Analysis of variance of sensory attributes of chips containing 40% corn meal and different soy flour levels. . . 42

19. Mean sensory scores for chips containing 40% corn meal and different soy flour levels 43

20. Diet composition for protein efficiency ratio bioassay . . . 47

LIST OF FIGURES

FIGURE PAGE

1. Hunter color value, "L," of potato-based chips as a function of corn meal level and defatted soy flour level 29

2. Hunter color value, "a," of potato-based chips as a function of corn meal level and defatted soy flour level 30

3. Hunter color value, "b" of potato-based chips as a function of corn meal level and defatted soy flour level 31

4. Percentage protein in potato-based chips as a function of corn meal level and defatted soy flour level 35

5. Percentage fat in potato-based chips as a function of corn meal level and defatted soy flour level 39

6. Percentage moisture in potato-based chips as a function of corn meal level and defatted soy flour level 40

CHAPTER I

INTRODUCTION

Snack food sales totaled $23.1 billion in the United States in 1985, a 9.77% increase over the 1984 sales level (Anon., 1986). Sales for fabricated chips increased from $128 to $203 million during this period (Anon., 1986).

Since 1940, defatted soy meal has been primarily used in animal foods as a protein supplement. The conversion of this meal to edible soy protein for man adds to its value, but it still is the most economical, abundant source of protein for man (Langsdorf, 1981). Soy protein products have been studied in many types of foods (Pereira and de Campos, 1981) and are currently used in the commercial preparation of doughnuts and baked products in the United States for their functional properties rather than as a source of additional protein (Dubois and Hoover, 1981). Supplementation of any new or existing food with these soy protein products could increase their use and result in an increased market value for the soybean.

Although some patents were found in which soy protein products were used to produce high protein snacks (Duffy, 1981), no reports were found in the literature where soy protein products had been used to fortify a potato-based snack food. However, in some of the fabricated potato chips, corn meal was partially substituted for potato flakes to improve texture and to lower ingredient cost. Further substitution of the potatoes in these snack foods with defatted soy flour would increase their protein level and quality. In addition, this substitution could reduce ingredient costs to the snack food processor. The wholesale cost of a pound of dehydrated potatoes is 40 to 50 cents compared with 20 to 22 cents per pound for defatted soy flour (Cunningham, 1986). However, research is needed to determine the effects of substitution of soy flour for potatoes on the physical, chemical, and sensory characteristics; the acceptability; and the nutritive value of a potato-based snack food. Those were the objectives of the present experiment.

CHAPTER II

REVIEW OF THE LITERATURE

I. History

Although the soybean [Glycine max. (L.)] is grown in many parts of the world, its origin is Eastern Asia (Hermann, 1962). A member of the family Leguminsae, the soybean has a high protein content (30%-46%) (Liener, 1978) and is an important staple in Asian diets. It can be prepared by many methods, providing a variety of foods with different flavors and textures. Cultivation of the soybean was recorded as early as 2200 B.C. in China (Smith and Circle, 1978). The utilization of soybeans was widespread in Asia for thousands of years; however, it was not introduced in the United States until 1854 (Smith and Circle, 1978). At the time of its introduction, there was very little interest in producing such a crop since there was no commercial utilization of soybeans.

In the beginning of the twentieth century, commercial interests in soybean utilization finally developed. Soybeans were expelled to produce an inexpensive oil which was used in soaps, paints, and varnishes (Smith and Circle, 1978). The defatted meal remaining was used to feed livestock. In 1926, a crude form of soybean flour was developed and marketed as "health flour". However, there was very little interest in the utilization of soy flour. The food shortage brought on by the second world war generated interest in the use of soy flour as a protein supplement to bakery products (Smith and Circle, 1978). Efforts to produce a satisfactory loaf of bread failed since the soy flour, which was crudely produced, was used improperly (Smith and Circle, 1978), and the functional properties of soy flour were not understood. After an understanding of the functional properties of soy flour were established, soy flour was successfully used in bread and confectionery products in the United States (Smith and Circle, 1978) as well as the United Kingdom (Wood, 1967).

II. Chemical Composition and Nutritive Value

The average proximate composition of defatted soy flour consists of 11% moisture, 44.7% protein, 1.1% fat, 5.5% ash, 37.7% carbohydrate, and 2.3% crude fiber (Burton, 1976). Soy flour is not a good source of essential vitamins; however, when used as a protein supplement, it can contribute a significant portion of vitamins as well as protein to a deficient diet (Liener, 1978). The vitamin content of various soybean protein foods is listed in Table 1.

Soybean products, shown in Table 2, contain significant amounts of essential minerals. However, the bioavailability of most minerals from soybean products is very low (Daniels and Nichols, 1917; Harmon et al., 1969). The presence of phytic acid which binds phosphorus and calcium (Nelson, 1968) and the ability of soy to proteins interfere with the uptake of zinc, manganese, copper, and molybdenum (Davis et al., 1962; Reid et al., 1956) prevent any significant contribution of essential minerals from soy products.

Table 1. Vitamin content of soybean food products.

Soybean Product	8-Carotene (µg/g)	Thiamine (µg/g)	Riboflavin (µg/g)	Niacin (µg/g)	Pantothenic Acid (µg/g)	Pyridoxine (µg/g)	Biotin (µg/g)	Folicin (µg/g)	Ascorbic Acid (µg/g)
Immature bean	4.5	6.4	3.5		12.0	3.5	0.5	1.3	0.2
Mature bean	0.22	14.2	2.3	23.0	12.0	6.4	0.6	2.3	0.2
Sprouts		16.9	5.9	39.0	26.6	15.9	1.4	3.7	0.4
Meal		28.0	3.0	29.0	14.6	8.8	0.2	4.4	
Flour		13.0	4.2	24.7	48.8			0.8	
Curd		3.9	3.7	5.5					
Milk	7.5	0.8	1.1	2.5					
Miso		1.3	1.4						21.6

(Smith and Circle, 1978)

Table 2. Mineral content of soybean food products.

Soybean Product	Calcium (mg/kg)	Phosphorus (mg/kg)	Magnesium (mg/kg)	Zinc (mg/kg)	Iron (mg/kg)	Manganese (mg/kg)	Copper (mg/kg)
Immature bean	1000	2600			21.3		
Mature bean	3100	6200	0.23	37	120	32	12
Sprouts	4000				100		
Meal	2700	6000	0.27	66	140	26	19
Flour	5300	6000			135		
Curd	8000	9000			105		
Milk	7600	1500			68		
Milk, powdered	8500	11000			100		
Miso	1100				35		
Natto	1800	4200			62		

(Smith and Circle, 1978)

Soybean protein, due to its well balanced amino acid content, has been instrumental in supplementing foods deficient in protein quality. With the exception of the sulfur-containing amino acids, soybean protein supplies adequate amounts of the essential amino acids recommended by the Food and Agricultural Organization of the United Nations (FAO/WHO, 1973). Table 3 is a comparison of the amino acid content of soybeans and the FAO/WHO requirement of amino acids for adults. The essential amino acid content of some soybean products is shown in Table 4. Soy protein also compares favorably with other plant protein sources in biological evaluations of protein quality as shown in Table 5.

III. Use of Corn Meal in Snack Foods

The corn meal that is typically used in the snack food industry is referred to as "cones." This granular type of corn meal can pass through a 40 to 70 USBS sieve and is the result of a dry milling process. In this process, degermed corn is ground, sifted, purified, aspirated, dried, and defatted (Matz, 1984). The utility of this product in the snack food industry is excellent since it contributes good texture and a desirable flavor (Matz, 1984). The amino acid content of corn meal and soybeans is shown in Table 6.

Corn meal contains about 86% (dry basis) starch which is located in starch granules. Gelatinization of the starch during snack food manufacture occurs according to the following sequence of events: diffusion of water in the swollen granule, hydration-aided melting and

Table 3. Essential amino acid content of soybeans compared to the FAO requirements for adults.

Amino Acid (mg/gm of protein)	Soybean	FAO, 1973
Isoleucine	50	40
Leucine	85	70
Lysine	70	55
Methionine + cysteine	28	35
Phenylanine + tyrosine	88	60
Threonine	42	40
Tryptophan	14	10
Valine	53	50

(FAO/WHO, 1973)

Table 4. Essential amino acid content of some soybean products.

Amino Acid	Defatted Soy Flour	Soy Isolate	Soy Concentrate
	(gm/16 gm of N)		
Isoleucine	4.6	4.6	4.9
Leucine	7.7	7.6	8.0
Lysine	6.2	5.5	6.6
Methionine	1.3	1.2	1.3
Cystine	1.2	0.8	1.6
Phenylalanine	5.3	5.5	5.3
Tyrosine	3.7	3.6	3.7
Threonine	4.2	3.5	4.3
Tryptophan	1.4	1.3	1.4
Valine	4.9	4.0	5.0

(Bressani and Elias, 1967; Huge, 1961; Meyer, 1967, 1969)

Table 5. Nutritive value of food proteins based on biological evaluation.

Source of Protein	PER[a]	BV[b]	NPU[c]	Limiting Amino Acid
Animal sources				
Whole egg	3.8	87-97	91-94	None
Cow's milk	2.5	85-90	86	S
Beef muscle	3.2	76	71-76	S
Salmon		72	71	Tryptophan
Plant sources				
Soybeans	0.7-1.8	58-69	48-61	S
Peanuts	1.7	56	43-54	S
Cottonseed	1.3-2.1	62	56-58	S
Rice	1.9	75	70	Lysine
Corn	1.2	60	49-55	Lysine
Wheat	1.0	52	52	Lysine

(Altschul, 1965; FAO, 1965)

Note: "S" denotes total sulfur-containing amino acids.

[a]PER (protein efficiency ratio) = weight gain of rat/% protein intake * 100.

[b]BV (biological value) = nitrogen intake - nitrogen excreted/ nitrogen intake * 100.

[c]NPU (net protein utilization) = (weight gain) + (weight loss of protein free group)/protein ingested.

Table 6. Amino acid content of corn meal and soybeans.

Amino Acid	Corn Meal	Soy Flour
	mg/100 gm of food	
Isoleucine	289	336
Leucine	810	482
Lysine	180	395
Phenylalanine	284	309
Tyrosine	382	199
Cystine	81	111
Methionine	116	84
Threonine	249	246
Tryptophan	38	86
Valine	319	328

(Bressani, 1981)

loss of anisotrophy and birefringence, and swelling of the starch granule (Shukla, 1981). During drying of a snack food the heat of the oil is transferred to the snack food, the water in the swollen granule escapes as steam and is replaced by the frying fat. The texture of the snack food becomes crisp and rigid (Melton, 1986).

IV. Use of Soy Flour in Food Products

Soy flour, which has a high lysine content, is a very useful nutritional supplement to cereal grains which are deficient in lysine. When soy flour is used in combination with cereal grains, the contribution of amino acids from both the soy flour and the cereal grains produce an excellent balance of amino acids, resulting in a high quality protein. Table 7 demonstrates this complementary effect between a mixture of soy flour and various cereal grains (Bressani, 1981). Successful attempts have been made to supplement staples containing cereal grains such as bread (Smith and Circle, 1978) and tortillas to produce high quality protein and acceptable sensory attributes (Bressani et al., 1977).

Soy flour has been used as an extender in food products to replace other food proteins for economic purposes without sacrificing protein quality (Bressani, 1981). Soy flour has been used in canned chili, salisbury steak, tamales, stews, luncheon meats, and many other meat products as an extender (Smith and Circle, 1978) and to reduce the proportion of animal fat (Smith and Circle, 1978).

Table 7. Effect of soybean flour as a protein supplement to cereal grains on protein efficiency ratio (PER*).

Cereal Grain	Level of Soy Flour (%)	PER
Maize	---	1.00
Maize + soybean flour	8.0	2.25
Rice	---	1.87
Rice + soybean flour	8.0	2.88
Wheat flour	---	0.70
Wheat flour + soybean flour	10.0	2.01
Whole wheat flour	---	1.32
Whole wheat flour + soybean flour	8.0	1.91

(Bressani et al., 1974)

*PER = weight gain of rat/% protein intake * 100.

Functional properties of soy flour have been used in the baking and confectionery industries. Soy flour has been incorporated into bread dough to extend or replace nonfat milk solids (Guy et al., 1969; Larson et al., 1951), increase protein content (Belshaw, 1971), and control crumb moisture (Melton, 1986). In doughnuts, soy flour is added to decrease fat uptake during frying (Dubois and Hoover, 1981). It is also utilized in the confectionery industry to extend milk products in fudges and caramels and to produce good texture (Nowacki, 1975).

Snack foods composed of high starch cereal grains have been successfully supplemented with soy flour. The addition of up to 15% soy flour to a cereal-based snack food can substantially increase the nutritive value of a snack food (Smith and Circle, 1978). The amount of soy flour added is limited by the characteristic "beany flavor" introduced to the product with the addition of soy flour (Kinsella et al., 1985).

Although the utilization of soy isolates in snack foods has been practiced and studied extensively (Green et al., 1977; Nowacki, 1975), very little work has been done in the utilization of soy flour which is the most economical source of soy protein.

Soy flour has been added to snack foods to increase the protein content in three different studies. The first was the incorporation of soy flour into a rice-based snack in Thailand (Siegel and Lineback, 1976). In this study, four different snack foods were developed. One snack contained 32% full-fat soy flour; another 26% full-fat soy flour plus 5% fish protein concentrate; a third, 26% full-fat soy flour plus

5% ground whole sesame; and the fourth, 29% soy protein concentrate. The base ingredient for all of the snacks was rice flour. Doughs for the snacks were mixed and dried in a sheet prior to being cut and deep fat fried in hot vegetable oil. The snacks were then presented to elementary school children for acceptability testing along with control snacks (commercially produced cassava-rice flour chip products). The snacks with the added soy flour were accepted very well by the elementary students; each food containing soy was scored higher than the control on a 5-point hedonic scale where 1 = really bad to 5 = great. The snacks containing soy flour also absorbed less oil during frying compared with those snacks not containing soy protein. The soy flour addition decreased caloric content of the snack while increasing protein quality.

Another study involving the use of soy flour was conducted by Dr. J. L. Johnsun (Anon., 1978). This snack was formulated with 20% soy flour and 80% corn flour (called snoiks). The product was extruded in a screw jacketed extruder to form a cheese curl type product. The product was sprayed with vegetable oil and sprinkled with flavoring (cheese, butter, garlic, etc.).

Finally, a procedure for manufacturing an extruded potato-based snack food containing 30% textured vegetable protein was reported by Larson (1981). This product is described as a tasty protein-fortified snack food item resembling the appearance of "Tater Tots."

CHAPTER III

MATERIALS AND METHODS

I. Source of Ingredients

Potato granules, potato flakes, and corn meal were obtained from Tom's Snack Food, Inc. of Knoxville, Tennessee. Soy flour that had been sifted through a 200 size mesh screen and which had a protein dispersability index of 70 was obtained from Cargill, Inc. of Cedar Rapids, Iowa. Partially hydrogenated soybean oil with an iodine value of 110 was obtained from a fat/oil processor in Tennessee. The corn meal, potato granules, and potato flakes were stored at room temperature, and the soybean oil was stored under refrigeration until utilization.

II. Experimental Design

All possible combinations of 0%, 10%, 20%, and 30% defatted soy flour with 10%, 20%, 30%, and 40% corn meal, as shown in Table 8, were substituted for potato granules in the formulation of a potato-based snack food, shown in Table 9. The combination constituted a single replication, and two replications were performed. The order of production for each combination was randomized within each replication. Four combinations were made in a single day, and the effect of day was blocked as shown in Table 10 (Sanders, 1987).

Table 8. Combinations of defatted soy flour and corn meal levels substituted for dry matter in a potato-based snack food.

Level of Defatted Soy Flour Substituted (%)	Level of Corn Meal Substituted (%) 10	20	30	40
	- - - - - - Combination*			
0	11	12	13	14
10	21	22	23	24
20	31	32	33	34
30	41	42	43	44

*Represents different combinations of defatted soy flour levels and corn meal level; 11 = 0% defatted soy flour and 10% corn meal and 44 = 30% defatted soy flour and 40% corn meal.

Table 9. Ingredients for potato-based snack food.

Ingredient	Weight (gm)
Potato flakes	85
Potato granules	0-180[a]
Corn meal	30-120[b]
Defatted soy flour	0-90[b]
Salt	5
Distilled water	450-500[c]

[a]Amount changed depending on level of corn meal and defatted soy flour substitution.

[b]Substituted for potato granules.

[c]Amount depended upon defatted soy flour level; 500 gm was added with 0 gm soy flour and 450 gm was added with 90 gm of soy flour.

Table 10. Order in which formulations were made for each replication.

Day	Order	Level of Corn Meal (%)	Level of Soy Flour (%)
		-First Replication-	
1	1	20	0
	2	30	10
	3	10	30
	4	40	20
2	1	20	10
	2	30	20
	3	40	30
	4	10	0
3	1	40	10
	2	30	0
	3	10	20
	4	20	30
4	1	40	0
	2	20	20
	3	10	10
	4	30	30
		Second Replication-	
5	1	20	30
	2	30	10
	3	40	20
	4	10	0
6	1	20	0
	2	30	30
	3	40	10
	4	10	20
7	1	30	20
	2	40	0
	3	20	10
	4	10	30
8	1	30	30
	2	20	0
	3	10	10
	4	40	30

III. Production of Chips

For each combination of soy flour and corn meal given in Table 8, the snack food dough ingredients shown in Table 9 were mixed with 60°C distilled water at the number 5 speed setting on a 5-quart Kitchen Aid mixer for 20 minutes. Approximately 5 gram portions of dough per chip were then rolled out to the thickness of .80 mm with a rolling pin and stainless steel rolling guides. Using a boning knife, 6 holes per inch were punched into each chip to allow moisture to escape during frying. The chips were then placed on drying screens and dried for 30 minutes in a forced air dehydrator at 50°C. The chips were immediately fried in partially hydrogenated soybean oil at 170°C for 25 seconds. After draining for approximately 30 seconds, the chips were allowed to cool to room temperature and were stored at ambient temperature under nitrogen in air-tight containers until evaluation.

IV. Evaluation of Physical Characteristics of Chips

The texture of each chip from each formulation was determined as the force required to break a single chip by a Model 1132 Instron Universal Testing Machine (Anon., 1975). A blade 2.5 mm thick operating against a 3.2 mm open groove, 7 cm long, was used. The blade moved at a rate of 10 cm/min. For each formulation the force required to break each of 10 chips was measured; the highest and lowest force values were discarded, and an average force/chip was determined from the remaining 8 force values. A 5,000 gram load cell was used in the force measurement, and the force was determined as grams of force required to break each chip.

Chips from each combination and replication were crushed to a powder with a mortar and pestle. Using the Hunter Color Difference Meter (Model 025M-2), the color of each sample was measured in terms of the Hunter color values, "L," "a," and "b" values (Anon., 1979). The instrument was standardized using the white tile No. C2-21125 with L = 91.03; a = -1.3; and b = 1.6. The sample was placed in a glass cuvette prior to color measurement.

V. Chemical Evaluation of Chips

Protein, fat, and moisture content were determined for each combination in both replications. Crude fiber and ash contents were measured on the flour combinations chosen for sensory evaluation in addition to moisture, fat, and protein levels. Protein, ash, and moisture levels were analyzed according to AOAC (1984) methods. Protein content was determined by the Kjeldahl method (%N x 6.25). Moisture was determined in a vacuum oven at 100°C. Ash was measured as the inorganic residue after the organic matter had been oxidized in a Muffle furnace at 580°C. Crude fiber was measured according to a modified AOAC procedure (Appendix A). Fat was determined by a modified Babcock procedure.

VI. Sensory Analysis

Samples of the potato-based formulated chips produced commercially were obtained from several snack food companies, and the texture of each sample was measured as described for the experimental chips. Experimental chips from four combinations of soy flour and corn meal were selected for sensory evaluation because their texture was closest to the average texture of the commercial chips. Chips from each of the four combinations were prepared the day before evaluation and stored in a sealed polyethylene container at room temperature until evaluated.

Each sample for sensory evaluation was coded with a randomly chosen 3-digit number and served to a 48-member inexperienced sensory panel between 12:00 a.m. and 4:00 p.m. The order in which each of the four chip samples were served to each panelist was rotated to eliminate bias, and one sample at a time was evaluated. Panelists were asked to rinse their mouths with water between samples. Each sample was evaluated for color, texture, flavor, and overall acceptability on an 8-point hedonic scale where 8 = like extremely and 1 = dislike extremely.

VII. Protein Evaluation

The chip that received the highest overall acceptability rating and protein content was analyzed for protein efficiency ratio (PER) using a modified AOAC (1984) procedure (Appendix C).

VIII. Statistical Analysis

The texture, color, and chemical composition (protein, fat, and moisture levels) of the chips were analyzed according to the analysis of variance given in Table 11 by the general linear model (GLM) program in Statistical Analysis Systems (SAS, 1982). Significantly different means for defatted soy flour (S), corn meal level (C), and S*C

Table 11. Analysis of variance for texture, color, and chemical composition of chips.

Source	Degrees of Freedom
Soy flour level (S)	3
Corn meal level (C)	3
S*C	9
Day of preparation	7
Error	9
Total	31

interactions were separated into linear, quadratic, and cubic effects for both S and C and all possible combinations of these S and C effects. Equations showing these significant effects were obtained and then graphed in a 3-dimensional plot. Sensory scores were analyzed by analysis of variance as a function of soy level (0%, 10%, 20%, 30%) and panelists. Significantly different means among soy flour levels were separated by orthogonal polynomials. An equation showing significant effects was obtain and graphed. The means for the protein efficiency ratio bioassay were analyzed using the Fisher's least significant difference test (SAS, 1982).

CHAPTER IV

RESULTS AND DISCUSSION

I. Physical Characteristics

The texture of the chips produced in the present experiment was not significantly affected by level of corn meal or soy flour or their interactions as shown by the analysis of variance in Table 12. Further separation of the corn meal and defatted soy flour levels (CL and SL, respectively) into linear, quadratic, and cubic effects or their interaction, CL*SL, also showed no significant effects. The average force required to fracture commercially produced potato-based chips was 194.3 ± 98.1 gm (n = 30). The experimentally produced chips with a texture closest to that of the commercial chips were those that contained 40% corn meal and 0%, 10%, 20%, and 30% soy flour as shown in Table 13. Based on this observation, these chips were chosen for further evaluation by a sensory panel.

The analysis of variance for the Hunter color measurements ("L," "a," and "b") for the chips are shown in Table 14. " L," "a," and "b" were significantly affected by one or more of the following: corn level (CL), soy flour level (SL), and their interaction (CL*SL). Only the L value was affected by day ($P < .05$). Equations showing the significant effects are given in Appendix B. A 3-dimensional graph was constructed for each equation. The effects of CL, SL, and CL*SL on "L," "a," and "b" are shown in Figures 1 through 3, respectively.

Table 12. Sum of squares for the analysis of variance of the texture experimental chips.

Source	df	Sum of Squares
Corn meal level (CL)	3	33253.4
Soy flour level (SL)	3	13574.3
CL*SL	9	40393.0
Day	7	108582.3
Error	9	84279.6

Table 13. Mean values for the force (gm) (texture) required to fracture potato-based chips of different formulation.

Corn Meal (%)	Defatted Soy Flour (%) 0	10	20	30
	Force (gm)			
10	328	277	294	298
20	300	375	298	325
30	232	323	295	435
40	237	240	247	252

Table 14. Sums of squares for the analysis of variance for measurements of color of the chips.

Source	df	Sum of Squares "L"	"a"	"b"
Corn level (CL)	3	55.33	30.07	7.09
Linear (C)	1	3.84	0.40	1.06
Quadratic (C^2)	1	50.00*	29.64**	3.78
Cubic (C^3)	1	1.48	0.25	2.26
Soy Level (SL)	3	57.44	5.22	11.59
Linear (S)	1	52.44**	0.01	7.66
Quadratic (S^2)	1	0.84	4.06	3.78
Cubic (S^3)	1	4.16	1.06	0.16
CL*SL	9	71.77	37.90	28.80
C*S	1	14.20	12.30*	10.81*
$C*S^2$	1	0.04	0.76	1.06
$C*S^3$	1	4.03	0.43	1.90
C^2*S	1	0.01	0.02	6.81
C^2*S^2	1	1.05	1.20	0.78
C^2*S^3	1	18.22	2.07	2.76
C^3*S	1	16.58	7.30	4.65
C^3*S^2	1	16.13	13.81*	0.01
C^3*S^3	1	1.50	0.02	0.01
Day	7	162.02*	24.35	6.43
Error	9	50.22	15.12	16.02

*Significant at the $P < .05$ level.

**Significant at the $P < .01$ level.

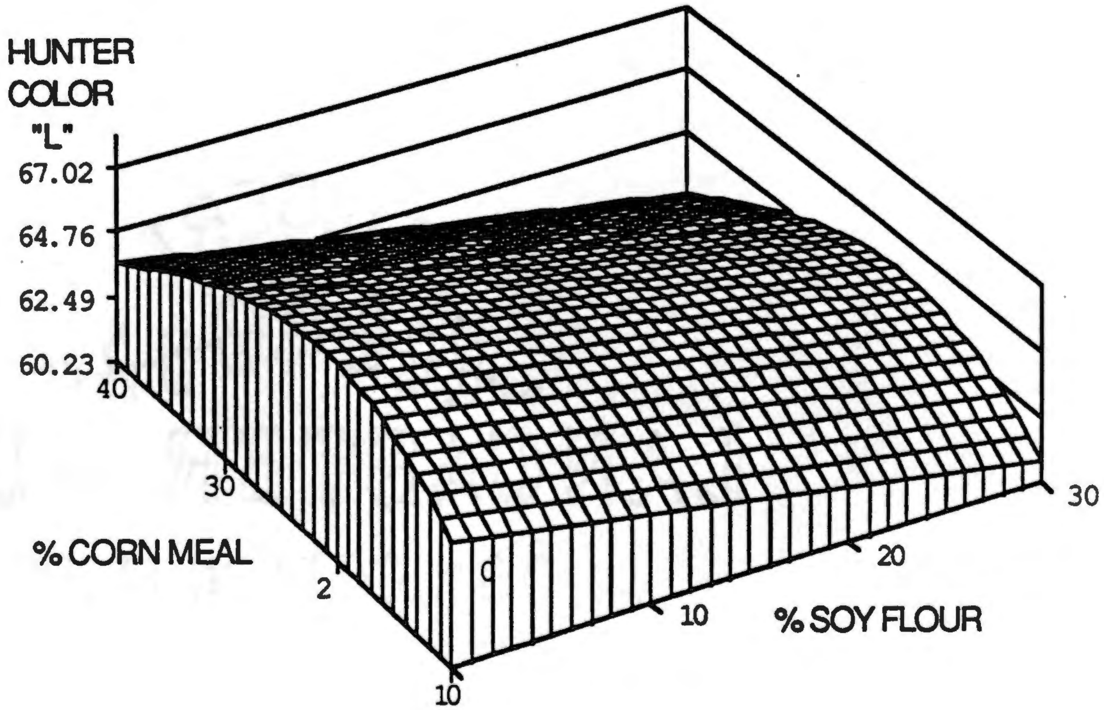

Figure 1. Hunter color value, "L," of potato-based chips as a function of corn meal level and defatted soy flour level.

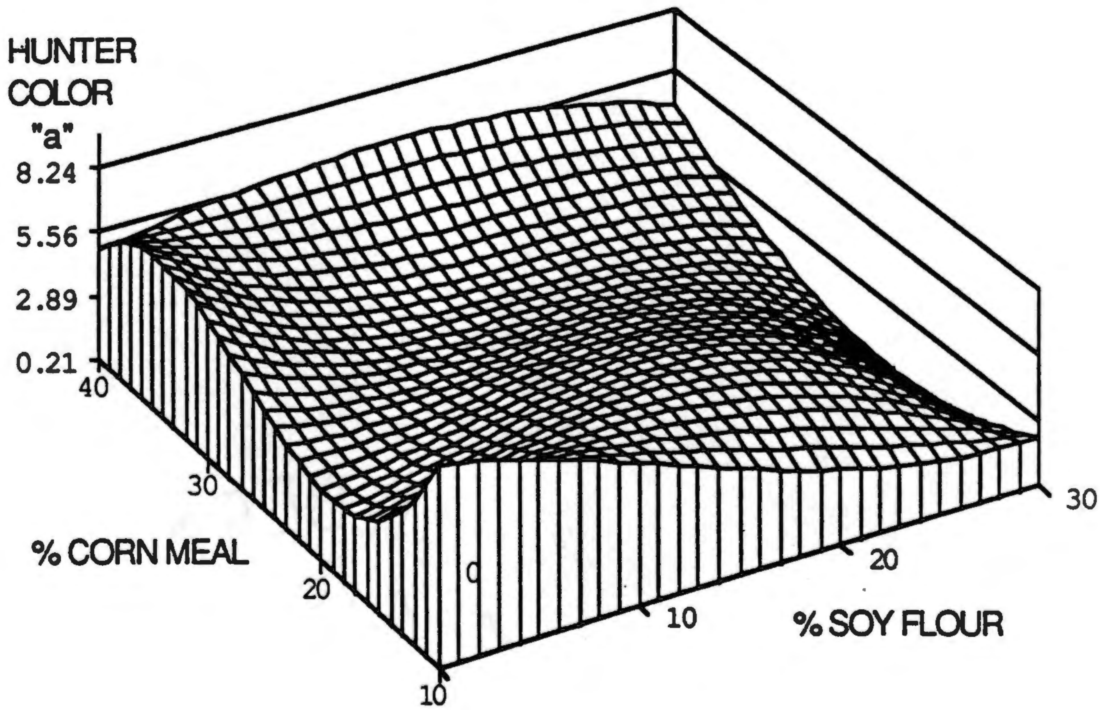

Figure 2. Hunter color value, "a," of potato-based chips as a function of corn meal level and defatted soy flour level.

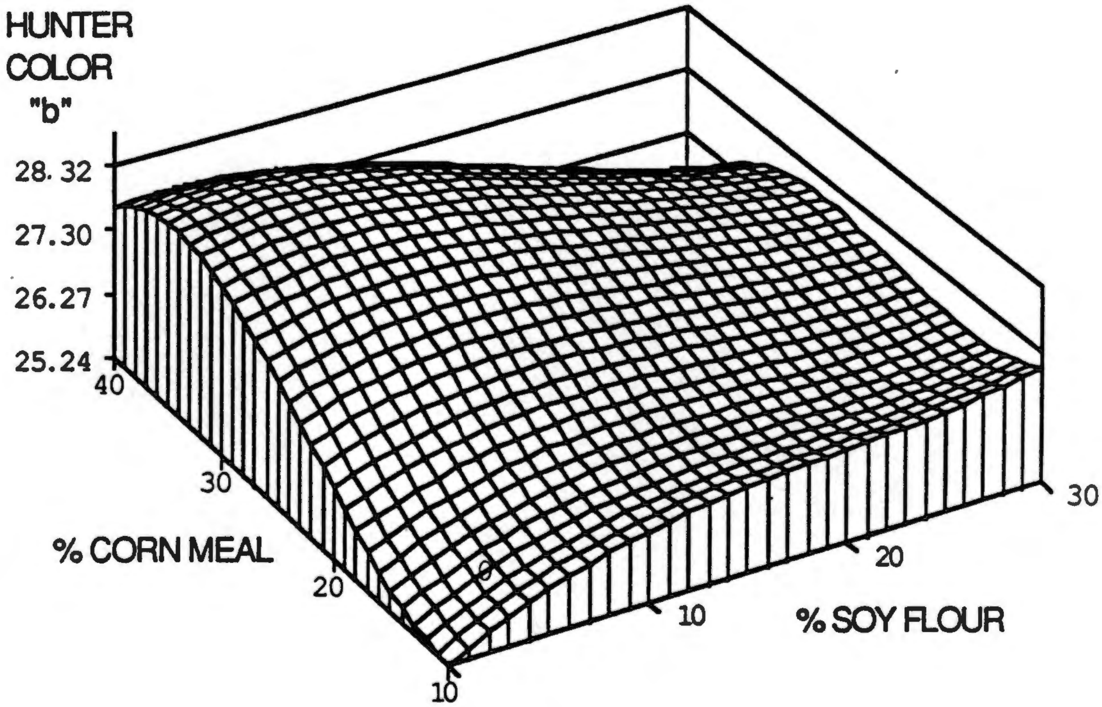

Figure 3. Hunter color value, "b," of potato-based chips as a function of corn meal level and defatted soy flour level.

In Figure 1, the effects of corn meal and soy flour levels on the Hunter color parameter "L" are shown. "L" decreased linearly with increasing soy flour level at all levels of corn meal. The addition of 10% to 25% corn meal for potatoes increased the "L" value, but further addition (25% to 40%) decreased the "L" value.

Chips with the highest "L" value contained about 25% corn and no soy flour, while chips with the lowest "L" value contained 40% corn meal and 30% soy flour. Increasing darkness in the chips with increasing levels of soy flour may have been due to the higher protein level or to the increasing levels of the basic amino acids (lysine, arginine, and histidine). Either would have increased formation of melanoidin pigments which are very dark in color (Whistler and Daniel, 1985) by reaction with reducing sugars present in potatoes or corn meal.

Figure 2 shows the surface response graph for the Hunter color value "a" of the chips. No negative "a" values were found. In general, chips containing 10% corn meal and no soy flour had the highest "a" value and chips containing 20% to 30% corn meal and 30% soy flour had the lowest "a" values. In addition, chips containing 40% corn meal and approximately 15% soy flour also had high "a" values in comparison with that of other chips except for the chip containing 10% corn meal and no soy flour.

Although no significant effects of corn meal level or soy level were found on the Hunter color "b" value, the significant CL*SL interaction (Table 14) resulted in a rather complicated graph as shown in Figure 3. Chips containing 10% corn meal and 0% soy flour and those containing 40% corn meal and 30% soy flour had minimum "b" values. Chips containing 30% to 40% corn meal and no soy flour had the highest "b" values of all chips. No negative "b" values were found.

Positive "b" values measure yellowness in color and therefore an increase in the "b" value is to be expected with increasing levels of yellow corn meal. However, the decreases in the "b" value with increasing levels of corn meal from 30% to 40% in chips containing 30% soy flour cannot be explained at this time.

II. Chemical Evaluation

The analysis of variance for the effects of corn meal level (CL), soy flour level (SL), their interaction (CL*SL), and day on the levels of chemical components (protein, fat, and moisture) in the chips are given in Table 15. The percentage of protein was affected significantly by SL and CL*SL. The percentage of fat was affected by CL, SL, and their interaction ($P < .05$). The percentage moisture was affected significantly by CL and the CL*SL interaction. Equations showing these significant effects are shown in Appendix B. Day significantly affected levels of all three chemical components.

The most dramatic change in percentage protein in the chip was its increase with increasing levels of soy flour as shown in Figure 4 and Table 16. This increase in protein can easily be explained by the substitution of soy flour which contained 50.3% protein for potatoes (6.49% protein) in the chip.

Table 15. Analysis of variance for chemical components in potato-based chips.

Source	df	% Protein	% Fat	% Moisture
Corn level (CL)	3	1.17	42.09	3.29
Linear (C)	1	0.26	13.5	2.98
Quadratic (C^2)	1	0.36	1.76	0.18
Cubic (C^3)	1	0.55	26.81*	0.13
Soy Level (SL)	3	376.90*	140.64*	0.48
Linear (S)	1	373.66**	134.10*	0.44
Quadratic (S^2)	1	0.00	4.13	0.02
Cubic (S^3)	1	3.25	2.37	0.02
CL*SL	9	46.31	48.51	13.16
C*S	1	0.27	10.70	0.00
$C*S^2$	1	23.30*	0.12	7.77**
$C*S^3$	1	1.08	0.07	2.28
C^2*S	1	7.32	30.19*	0.01
C^2*S^2	1	2.00	1.32	0.26
C^2*S^3	1	10.13*	0.01	0.05
C^3*S	1	0.78	0.94	2.17
C^3*S^2	1	0.15	2.89	0.61
C^3*S^3	1	1.11	2.56	0.01
Day	7	38.64	34.38	5.54
Error	9	18.36	47.97	6.84

*Significant at the $P < .05$ level.

**Significant at the $P < .01$ level.

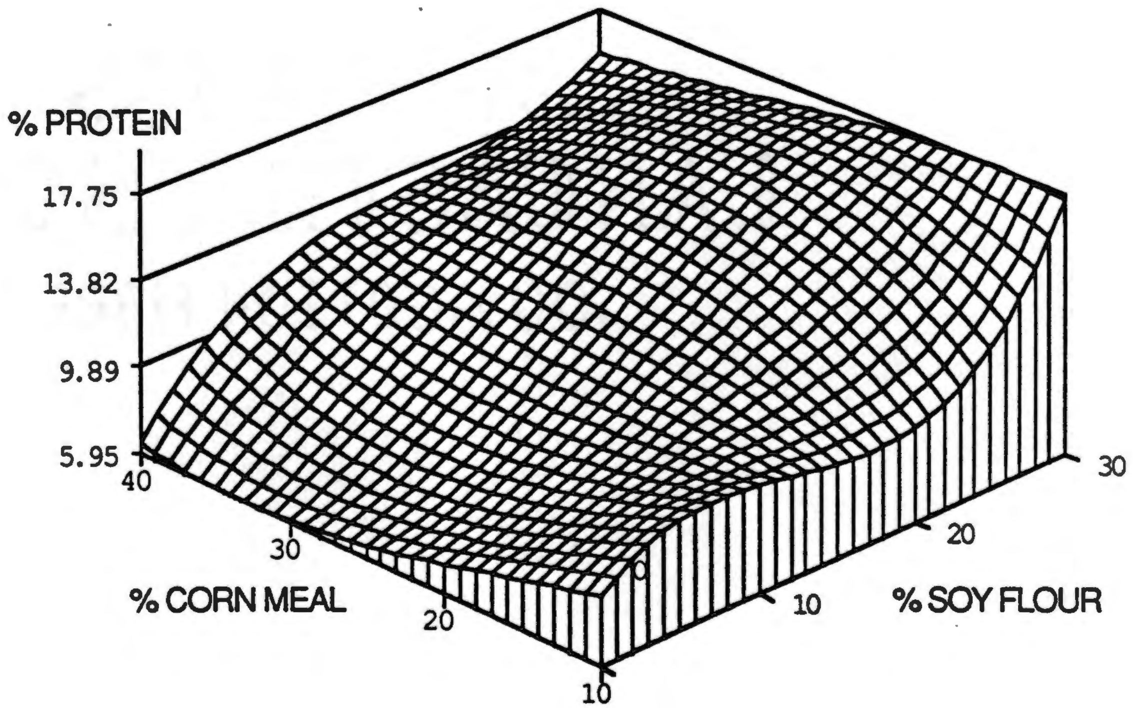

Figure 4. Percentage protein in potato-based chips as a function of corn meal level and defatted soy flour level.

Table 16. Percentages of protein, fat, and moisture in potato-based chip averaged across all corn meal levels for each soy flour level.

Soy*	%Protein	%Fat	%Moisture
0	7.22	23.12	5.62
10	10.83	21.06	5.63
20	13.03	18.50	5.80
30	16.68	17.88	5.91

*Mean values of 4 observations.

The percentage of protein in the chip was not significantly affected by the level of corn meal (Table 15). The corn meal Figure 4 substituted for the potatoes in the chip had approximately the same amount of protein at the potato (6.12% in the corn versus 6.12% in the potatoes). However, significant CL*SL effects on the percentage protein in the chip caused the irregular shaped response curve shown in Figure 4.

In general, increasing the level of corn meal in the chip increased the fat content (Table 17 and Figure 5) and decreased the moisture content (Figure 6) when no soy flour was present. In chips containing any level of corn meal, the percentage fat decreased with increasing soy level (Table 16 and Figure 5).

The ability of soy flour to exclude fat from fried foods has been reported in doughnuts (Dubois and Hoover, 1981) and soy-rice chips (Siegel and Lineback, 1976). The reason given for this property of soy flour was that it bound water; however, that mechanism for excluding fat is not readily apparent in the chip since the soy flour level did not significantly affect the moisture content of the chip (Table 15).

The effect of interactions of corn meal with soy flour on the response surface graph is easily seen in the moisture content of the chip (Figure 6). At 10% to 20% corn meal, the percentage moisture first decreased before increasing with increasing soy levels from 0% to 30%. AT 20% to 40% corn meal, the moisture level increased with increasing soy level from 0% to approximately 18% before decreasing with continued soy flour increase (Figure 6).

Table 17. Percentage of protein, fat, and moisture in the potato-based chips averaged across all soy flour levels for each corn meal level.

Corn*	% Protein	%Fat	% Moisture
10	11.90	18.63	6.10
20	12.96	21.31	5.87
30	11.83	19.44	5.76
40	11.7	21.19	5.22

*Mean values of 4 observations.

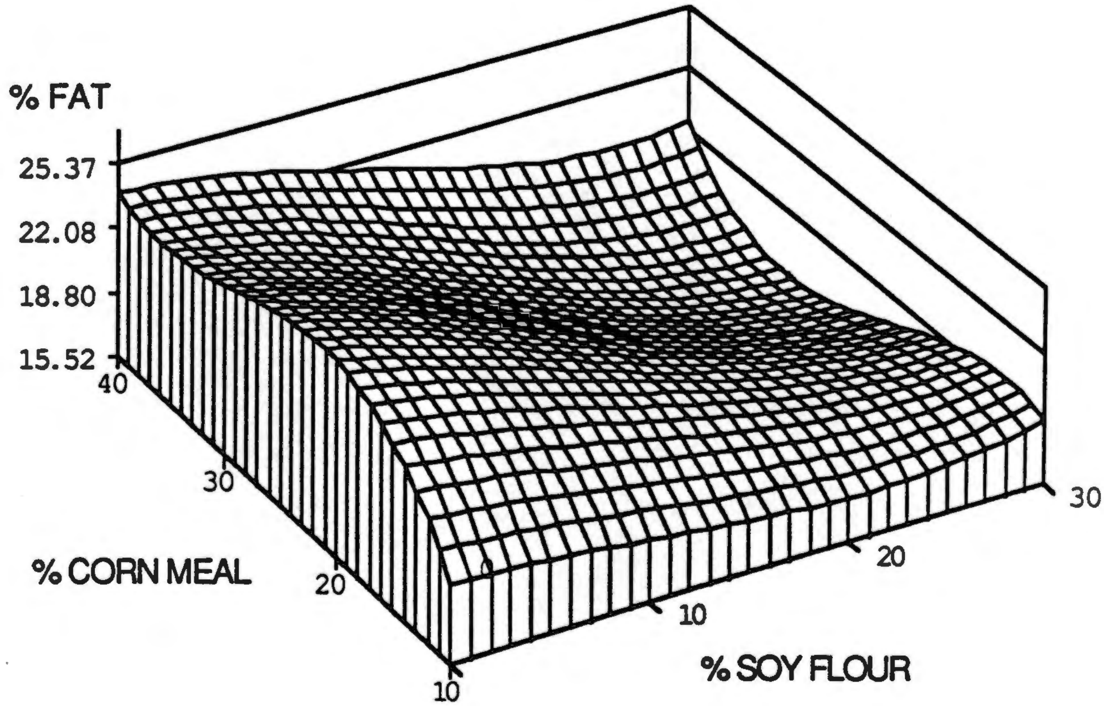

Figure 5. Percentage fat in potato-based chips as a function of corn meal level and defatted soy flour level.

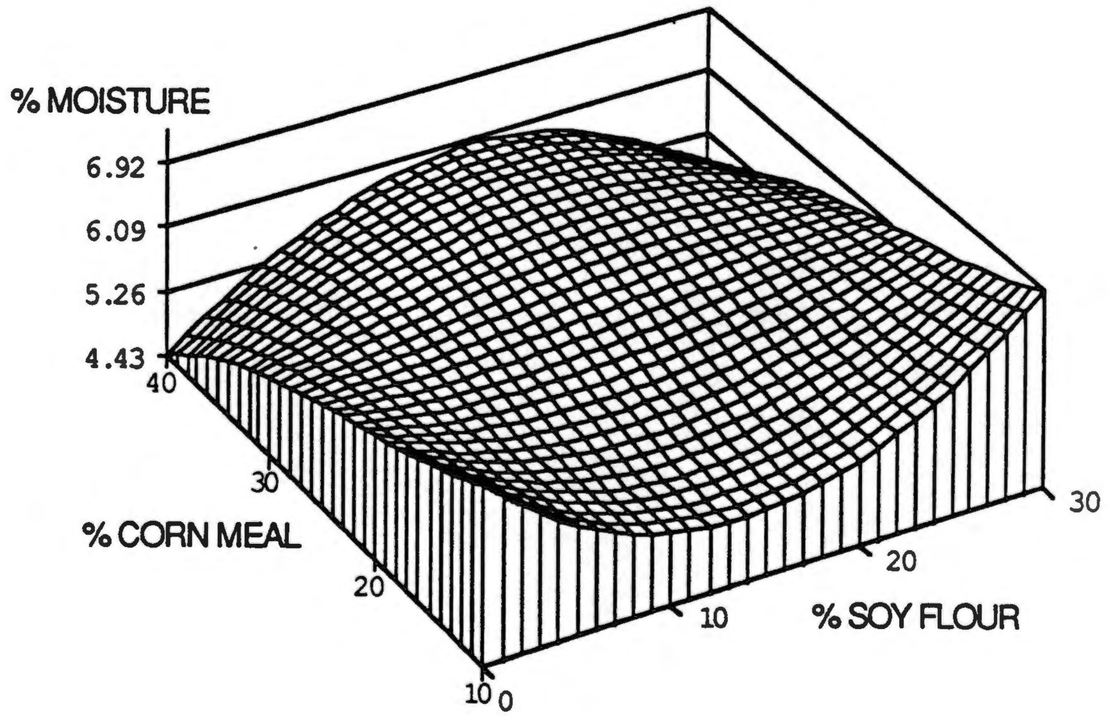

Figure 6. Percentage moisture in potato-based chips as a function of corn meal level and defatted soy flour level.

III. Sensory Evaluation

The analysis of variance and mean values for the sensory evaluation of color, flavor, texture, and overall acceptability of the chips containing 40% corn and different soy flour levels are shown in Tables 18 and 19 respectively. Color and flavor were significantly influenced by soy flour level although texture and overall acceptability were not. However, when orthogonal polynomials were used to partition the sums of squares, overall acceptability was found to have been significantly affected by soy flour level (Table 18). This linear effect in which overall acceptability score was found to decrease as soy flour level increased. The flavor score also decreased linearly with increasing soy flour level as shown in Table 18. The effect of soy flour level on color was cubic as shown in Table 18. Addition of soy flour from 0% to 23% in general reduced the color score from 6.4 to 5.0 while addition of 23 to 30% soy flour increased the color score from 5.1 to 5.6.

The reduction of the flavor score resulting from the addition of the soy flour may be due to a "beany" flavor which is characteristic of soy flour (Kinsella, 1985) even though no "beany" flavor was mentioned by the panelists on the score sheets. The flavor scores may have had a direct effect on the overall acceptability scores of the chips since both decreased linearly with the addition of soy flour.

The decrease in the color score from the 0% to 20% soy flour level may have been due to the increasing darkness in color of the chips,

Table 18. Analysis of variance of sensory attributes of chips containing 40% corn meal and different soy flour levels.

Source	df	Sum of Squares			
		Color	Flavor	Texture	Overall
Soy flour					
Level	3	47.96**	18.56**	7.26	10.26
Linear	1	27.34**	10.62*	0.38	10.21*
Quadratic	1	11.02*	3.25	2.75	0.05
Cubic	1	9.60*	4.68	4.13	0.00
Panelist	47	121.75*	134.45	198.99	149.83
Error	142	209.54	199.19	324.48	199.98

*Significant at the P < .01 level.

Table 19. Mean sensory scores* for chips containing 40% corn meal and different soy flour levels.

	Soy Flour Level (%)			
	0	10	20	30
Color	6.5	6.0	5.1	5.6
Flavor	5.9	5.1	5.3	5.1
Texture	5.6	5.4	5.7	5.1
Overall	5.6	5.4	5.2	5.0

*8-point scale where 1 = dislike extremely and 8 = like extremely.

demonstrated by the decreasing "L" values from the color analysis in Figure 1 (p.). This darker color may have been objectionable to the panelists. The darkening of the chips with increasing soy flour may have been caused by the presence of higher protein levels and (or) increasing levels of basic amino acids in the soy flour which produced a darker color in the chip through participation in the Maillard browning reaction.

IV. Protein Evaluation

The chip containing 40% corn meal and 20% soy flour was chosen for further evaluation of protein since it had a trend toward a more desirable flavor and texture than did the chip containing 10% or 30% soy flour (Table 19) and also had a relatively high protein content. The proximate composition of this chip was as follows: 13.44% protein, 20.35% fat, 2.75% crude fiber, 5.2% moisture, and 2.94% ash.

This chip was used to formulate a diet for albino rats of the Sprague Dawley strain for a protein efficiency ratio (PER) bioassay. The formulations for the diets are shown in Table 20 where casein was used as the control protein. The mean values for the PER of the casein and chip diets were 2.18 and 2.07 respectively, and these two values were not significantly different. The accepted value for the PER of casein is 2.5 (FAO, 1970).

The age and range of weights of the rats used in this study were not within the limits set by the AOAC procedures for a protein efficiency ratio bioassay (age of rats was greater than 28 days and the range of individual weights was greater than 10 gm). The length of the feeding trial was also shorter than the AOAC standard procedure (25 days versus 28 days). Although the length of the feeding trial and the range of individuals weights probably did not significantly affect the PER values, the age of the rats (which is relative to their growth requirements) may have had a significant effect on the PER values. As the rats age, their growth is less rapid, their requirement for high quality proteins is not as critical, and this makes PER bioassay less effective in evaluating protein quality (Smith, 1987). If younger rats were used, the PER values may have been larger for casein and smaller for the potato-based chip.

V. Conclusions

There were no significant differences among the chips of different formulations in texture.

The significant effects of corn meal and soy flour level on "L," "a," and "b" values are shown in Table 14 (p. 28). "L," "a," and "b" were significantly affected by one or more of the following: corn meal level, soy flour level, and their interaction. Only the "L" value was affected by day ($P < .05$). These effects are shown in Figures 1, 2, and 3 (pp. 29-31) for the "L," "a," and "b" values respectively.

The analysis of variance for effects of corn and soy levels and day on the chemical components of the potato-based chips are shown in Table 15 (p. 34). The percentage of protein was affected significantly by soy flour level and corn and soy interactions. The percentage of fat was significantly affected by corn meal and soy level and their interactions. The percentage of moisture was affected significantly by corn meal and corn meal and soy flour interactions. Day significantly affected all three chemical components. Figures 4, 5, and 6 (pp. 35, 39, 40) demonstrate these effects.

The analysis of variance for the sensory evaluation of color, flavor, texture, and overall acceptability of chips containing 40% corn meal and different levels of soy flour are shown in Table 19. Color, flavor, and overall acceptability were significantly affected by soy flour level. The chip containing 40% corn meal and 20% soy flour was chosen for further protein evaluation and had a proximate composition of 13.33% protein, 20.33% fat, 2.75% crude fiber, 5.2% moisture, and 2.94% ash.

The protein efficiency ratio values from the casein control (2.18) and potato-based chip (2.07) diets were not significantly different (Table 20). These results may have been different if the age and range of individual weights of the rats were within the AOAC (1984) guidelines.

Table 20. Diet composition for protein efficiency ratio bioassay.

Ingredient	Percentage in Diet	
	Chip Diet	Casein Diet
Chip	74.0	----
Casein	----	10.0
Sucrose	12.0	30.0
Corn starch	----	30.0
Crisco	----	10.0
Wesson oil	----	5.0
Vitamin mixture	2.0	2.0
Salt mixture	3.0	3.0
Alpha cellulose	9.0	10.0

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REFERENCES

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APPENDICES

APPENDIX A

PROCEDURE FOR MODIFIED CRUDE FIBER

Weight the initial sample and place it in 100 ml of 0.255N H_2SO_4 in a beaker and place it on a hot plate and boil for 30 minutes. At the end of 30 minutes of boiling, without removing the flask, add 10 ml of 2.837N NaoH with an Oxford Macro-Set Pippet. Add an additional 10 ml, washing down the sides of the flask each time, which is a total of 20 ml of 2.8375N NaoH. Boil this liquid for 30 minutes. Remove and filter the sample. Wash the sample with hot tap water until it becomes clear. Add 50 ml of 1N HCL to neutralize the NaoH. Rinse the sample with hot tap water 3 times. Rise the sample with acetone 3 times. Put the filtered sample in the over at 100°C overnight. Cool the sample and weigh (1st wt). Place the sample in a cold Muffle Furnace and incinerate the sample at 600°C for 4 hours. Let the sample cool to room temperature and weight (2nd wt). Percent crude fiber is calculated by subtracting the 2nd wt from the 1st wt divided by the weight of the initial sample times 100.

Crude fiber = 1st wt - 2nd wt/wt of initial sample x 100

APPENDIX B

EQUATIONS FOR COLOR MEASUREMENTS AND CHEMICAL COMPONENTS

Color Measurements:

"L" = 56.44 + 1.1298*C - .03656*C*C + .0003208*C*C*C - .1145*S

"a" = 33.18 - 3.879*C + .1583*C*C - .001976*C*C*C - 3.32129*S +
.0218*S*S + .00201*S*S*S + .5376*C*S - .008230*C*S*S
- .000205*C*S*S*S - .02558*C*C*S + .000583*C*C*S*S +
.0000038*C*C*S*S*S + .0003574*C*C*C*S - .0000098*C*C*C*S*S

"b" = 27.04 - .4032*C + .0263*C*C - 0003958*C*C*C + .22458*S
- .00812*S*S + .0001402*S*S*S - .00465*C*S

Chemical Components:

Protein = 10.04 - .0286*C - .00932*C*C + .000195*C*C*C + 1.605*S
- .206*S*S + .00528*S*S*S - .126*C*S + .01796*C*S*S
- 000444*C*S*S*S + .00276*C*C*S - .0003524*C*C*S*S +
.0000084*C*C*S*S*S

Fat = - 1.89 + 3.1676*C - .1177*C*C + .001365*C*C*C + .3344*S
- .00625*S*S + .00025*S*S*S - .04344*C*S - .0003375*C*S*S +
.0000063*C*S*S*S + .0008688*C*C*S

Moisture = 8.03 - .1913*C + .00629*C*C - .000094*C*C*C - .3463*S +
.01296*S*S - .0000379*S*S*S + .01328*C*S - .000441*C*S*S

APPENDIX C

MODIFIED PROTEIN EFFICIENCY RATIO

This bioassay was performed according to AOAC procedure number 43.253. However, the age of the rats was unknown but they were probably older than 28 days since they were rather large. There was also a range in weight of greater than 10 grams.

VITA

Peter Mancuso was born in Somerville, New Jersey, on July 15, 1962. After graduating from Randolph High School in Randolph, New Jersey, he entered Purdue University in West Lafayette, Indiana, as an undergraduate. He received a Bachelor of Science in Agriculture with a major in Food Science in May 1985. In September 1985 he entered the Graduate School of The University of Tennessee, Knoxville and began working toward a Master of Science degree in Food Technology and Science.

He is a member of the Institute of Food Technologists, the Rowing Club of The University of Tennessee, and the United States Rowing Association.