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To the Graduate Council:

I am submitting herewith a thesis written by Chang Lim Yoou entitled "Some Factors Affecting Hydration and Texture of Four Varieties of Dried Beans, Phaseolus Vulgalis L." I recommend that it be accepted for nine quarter hours of credit in partial fullfillment of the requirements for the degree of Master of Science, with a major in Food Technology and Science.

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SOME FACTORS AFFECTING HYDRATION AND TEXTURE OF FOUR VARIETIES OF DRIED BEANS, PHASEOLUS VULGARIS L.

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Chang Lim Yoou

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ABSTRACT

Great Northern, Navy, Light Red Kidney, and Pinto varieties of beans were used to study the effect of moisture modification on hydration, texture, and "butterflying" of dried beans for processing. Pinto and Light Red Kidney varieties were used to study the effect of hydration in solutions of amylase, cellulase, and pectinase enzymes on water absorption and texture of dried beans.

Moisture absorption by dried beans during conditioning and soaking was directly related to intial moisture content. By exposure to saturated humidity for 48 hours, the impermeability of low moisture beans was reversed. Firmness of soaked beans was found to be variety dependent and inversely proportional to amount of water absorbed during soaking. After modification of moisture content of dried beans at 70° and 100° F, the rupturing of beans was reduced by 30 and 38 percent, respectively. Enzymes used did not accelerate water absorption rate nor alter texture of cotyledons of two varieties tested.

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CHAPTER I

INTRODUCTION

Beans have occupied an important place as a world food, dating back to the ancients. In the areas of Asia, Africa, and South America, animal protein is practically nonexistent in the diet of large segments of the population. In these areas, grain crops are the major contributor of protein to the diet. In certain eco-social groups in the U.S., dried beans constitute the major source of protein in the diet due to difference in price between animal and plant protein.

Because of their lack of cystine, beans are considered inadequate when used alone to supply protein; however, they do serve to supplement other more expensive nitrogenous foods and to add pleasing variety to the diet. Aside from their protein content, beans contain a high percentage of carbohydrate, and they are relatively rich in calcium, phosphorous and iron, magnesium, and other elements as well as vitamins A and B.

Generally it has been observed that the cooking of dry beans has presented difficulty because of the variation in their capacity to become soft. This variation was observed by the Greeks as far back as 300 B.C. (35)*.

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*The numbers in parentheses represent similarly numbered references in the Bibliography.

The practice of soaking beans in water serves several purposes, among which are (1) to facilitate cleaning of the beans, (2) to increase product yield, and (3) to ensure product tenderness and uniform expansion in the can during the thermal process. Industry soaking practices vary considerably due to such process variables as time, temperature and water hardness. Generally speaking, however, dry beans must be soaked for several hours prior to processing. Overnight soaking is not unusual.

This relatively long soaking time is undesirable to the canner for several reasons. First of all, bacteriological spoilage or other deterioration, such as nutrient leakage to soaking water can occur. A breakdown in the canning line may, therefore, result in substantial loss of product. Secondly, present soaking practices involve extensive equipment and valuable floor space. A short, continuous process would help resolve these problems, as well as reduce labor and increase plant flexibility.

In spite of available information on water absorption and other factors that contribute to toughness, practical guidelines to serve commercial processors seem to be lacking. The purpose of this study was to investigate: (1) effect of modifying the moisture content on hydration, texture and "butterflying", and (2) effect of holding in solutions of certain enzymes on hydration and texture of dried beans.

CHAPTER II

LITERATURE REVIEW

Variations in the permeability of seed coats of many different kinds of plants have been recognized for centuries. Theophrastus (40) in the third century B.C. referred to the differences in beans as "cookable" or "uncookable" and he also recognized that certain conditions of climate may cause this variation.

Snyder (35) reported encountering some beans that would not imbibe water even though the seed coat was scarified or removed. Gloyer (12) suggested that this condition may be caused by enzymic changes during the storage of seeds in damp atmospheres at high temperature. This kind of hardness in beans is much less commonly encountered than is the kind of hardness described by Gloyer that is due to hardshell, or impermeable seed coat. This latter condition is fairly common in most legumes, and has been thoroughly studied in connection with seed germination work. The information that has been accumulated by seedmen should be of value to food processors.

The problems of hardshell in beans has been studied by a number of investigators (23, 12, 13). Various treatments, such as treatment of seeds by concentrated sulfuric acid to increase the percentage of germination and scarification of the seed coat to increase the rate of water imbibition, have been recommended (12, 28). Snyder (35) reported that with beans cooked relatively well, the cooking time was reduced 40

percent by scarification but the appearance was less desirable. The scarification treatment has not been used extensively by bean processors, however, as it would be difficult, if not impossible, to prevent breaks in the seed coats of the treated beans.

It has frequently been observed that dry beans which have been stored for some time may take longer to cook than freshly harvested beans. Bigelow and Fitzgerald (2) reported that canners sometimes find that the heat process required to sterilize canned beans is insufficient to make them tender. Dawson and Lamb (7) found that pea beans stored for one year at 75° F required longer to cook than those stored at 40° F.

Morris and Wood (27), who used a standard cooking time for each variety, reported that beans with a moisture content above 13 percent deteriorated significantly in texture as well as flavor after six months at 77° F. Beans stored at less than 10 percent moisture content maintained their cooking quality for two years almost as well as control samples stored at -10° F.

Several authors report the use of some kind of heat treatment prior to soaking as a very effective, practical, and convenient means of preparing hardshell beans that are to be processed for food. Among the heat treatments suggested are steaming (12), a 1-minute dip in boiling water, and 1-minute dip in water at 170° F or 2 or 3 minutes at 150° F (28), and soaking at 50° C (122° F) (35). The application of heat during soaking appeared to have possibilities for home use.

Morris et al. (28) reported that a secondary effect of an initial 1-minute boil before soaking is the reduction of microorganisms. Signs

of fermentation and off-flavors have been reported in beans soaked overnight at room temeprature, particularly in hot weather. Some directions for preparing dry beans suggest draining the beans after soaking and adding fresh water for cooking as a means of reducing off-flavors in the cooked product.

By plant breeding and selection, strains have been developed that certain practically no hardshell beans under favorable conditions (12). Unfavorable environmental factors following planting, such as cold rainy weather, are recognized as factors that cause a progeny to certain a higher percentage of hardshell beans than would result if normal conditions prevailed during the germination period (12).

The nonhardshell beans that imbibe water readily frequently rot in cool, wet soil conditions, whereas the hardshell beans endure the unfavorable period and later germinate. This sort of chance selection may be responsible for some of the differences that occur in the hardshell character of beans from year to year, or between different plantings the same year.

The climatic conditions under which beans are grown probably affect the degree of hardshell present in a given lot of beans at harvest time. Beans grown and harvested in a hot, dry area are believed to be more subject to development of hardshell than are beans grown at lower temperatures and higher relative humidities.

Hyde (18) studied the function of the hilum in some Papilionanceae in relation to the permeability of the testa and he concluded that when relative humidity was low the fissure in the hilum opened permitting the

seed to dry out; when the relative humidity was high the fissure closed and prevented the absorption of moisture. This conclusion coincided with those given by Honma and Denna (16). They also found that the hilum operates as an hygroscopically activated valve and plays an important part in the impermeability phenomenon.

Smith and Nash (34) studied the water absorption of soy beans. They stated that water absorption is influenced by the initial moisture level in the beans; the lower the moisture the slower the rate of water absorption and the presence of hard shell beans also reduces the rate of water absorption.

Burr and Morris (3) presented a more systematic investigation of these factors. They reported that the beans under high temperature, high moisture content and long storage contributed to impaired cookability in pinto and sanilac beans. Crean and Haisman (4) stated that the incedence of seed peas which are extremely slow to take up water when soaked is shown to be directly related to the initial moisture content of peas. They reported that impermeability to water can be induced by drying the peas to less than 15 percent moisture. The change is reversible and impermeable peas kept under a high humidity regain their permeability as their moisture content rises.

Hard seed percentages are influenced by storage temperature and humidity. High humidity and high temperature decrease the portion of hard seed while low humidity and temperature increase the proportion of hard seed. Jones (20) working with Vicia villosa stated that, "the rate of change in permeability of hard seed for any humidity, as indicated by

their moisture percentage, is greatly accelerated by increased temperature." Although temperature does have a role in the expression of hard seed, relative humidity is the most important environmental factor under natural storage. Hyde (18) found that the percentage of hard seeds fluctuated in accordance with seasonal changes in relative humidity. Martin (24) reported that 80 to 100 percent of the hard seeds of clover stored in outside storage usually softened by the middle of April.

Nutile and Nutile (31) reported that the decrease in hard seed content is the direct result of the gradual increase in the relative humidity of the spring rainy season. As an example of the influence of relative humidity, the authors reported that Blue Lake variety (Phaseolus vulgaris L.), when stored in a relative humidity of 42.7 percent, had a moisture content of 10.3 percent and a hard seed content of 4 percent. The same variety stored at 18.8 percent relative humidity had a moisture content of 6.5 percent and a hard seed content of 33 percent after 60 days storage in the controlled relative humidity chamber.

In a short review, Harrington (15) recorded that imbibition could always be induced in beans if the seed coat were scratched. He also showed that the number of hard seed was directly related to the moisture content and could be increased or decreased by varying the humidity.

Snyder (35) indicated that the pectic constituents which appear to be in the form of pectic acid or pectates are important factors in affecting the permeability of the seed coat and its capacity to soften

readily. She reported that sodium bicarbonate, a solvent of pectic acid, soften the seed coat and hydrochloric acid, calcium and magnesium salts harden the seed coats. It appeared that the pectic materials bound the cellulose so densely that water was prevented from passing through the seed coats.

Mattson (26) found that the most important factor in the cookability of peas was the high content of phytin, which is a calcium and magnesium precipitant. He states that the precipitating power of phytin is greatly increased at boiling temperatures. At the pH of peas (pH 6.0), phytin can function as a magnesium precipitant only at boiling temperature.

Greenwood (14) and Snyder (35) found the use of baking soda in either the soaking or cooking water to be an effective means of softening the seed coats of Pinto, Great Northern, or Navy beans. Reeve (32), in a study of possible tenderization treatments for peas by sodium hexametaphosphate, sulfites of both potassium and socium, oxalic acid, ammonium oxalate, and hydrochloric acid, found that the tenderization effects involved changes that reduce the toughening effects of calcium and magnesium on the seed coats.

Masters (25) found that among the methods which greatly reduced the cooking time and decreased the solids in the soaking water were soaking overnight or for four hours in tap water containing sodium bicarbonate, draining, and adding fresh water for cooking. When a concentration of 0.01 percent sodium bicarbonate was used in the cooking water, the cooking time was reduced and the loss of solids only slightly greater than

when the beans were cooked in tap water or distilled water. When 2 percent sodium bicarbonate was used in soaking, the cooking time was the same as for 1 percent, but the loss of solids was greater.

Legumes are often associated with low digestability and growth inhibition, which may be associated with the presence of enzyme inhibitors other than the well know trypsin inhibitor (19). Seidl et al. (33) reported the presence of an unspecific proteinase inhibitor in black bean globulin which prevented hydrolysis of the beans by pepsin, trypsin, chymotrypsin, papain, ficin, hurain and subtilism, after removal of the trypsin inhibitor. Gallagher (10) reported that legumes were able to inhibit ficin, trypsin and ht proteolytic enzymes, with the exception of lentiles which showed inhibition only toward trypsin.

Tamoda (38) reported that enzymic treatment enhances the extractability of protein in coconut meal and similar substances. Murray and Baker (29) recommended that the proteins be allowed to stand for 2 hours at 25° C in 10 times their weight of water before they were subjected to enzymic hydrolysis. Fukushima (9) reported that water dispersibility of soybean protein as a criterion to determine the degree of denaturation, which in turn, can be found by the extent of the enzyme's attack.

It is well known that denaturation of protein is a prerequisite for the enzyme attack. Fukushima (9) used the amount of protein attacked by enzymes as a means of determining the degree of heat denaturation, using soybean protein as the substrate. Tamura et al. (39) and Hoshina et al. (17) studied the effect of heating the substrate on enzyme attack and reported that heating enhances enzyme activity.

Sreekantiah *et al.* (36) reported that 20 minute cooking was sufficient for maximum enzyme attack when sesame meal and bengal gram flour was dispersed in lactate buffer of pH 2.5.

CHAPTER III

MATERIALS AND METHODS

I. RAW MATERIALS

The beans used in this study were obtained from Bush Brother's Canning Plant, Dandridge, Tennessee. Varieties studied were Great Northern, Navy, Light Red Kidney, and Pinto beans. Six lots of each variety, representing different areas of production, were used for Experiment One. Two varieties, Pinto and Light Red Kidney, were used for Experiment Two. Moisture content and percent of beans with split or broken seed coats were determined immediately upon receipt at the laboratory. The beans were placed in cardboard boxes and stored under laboratory conditions from the time they were received until they were used for further laboratory experiments.

The date received, moisture content, and damaged seed coats of each lot are given in Table I. A slight difference in moisture content was found to exist between the supplier's specifications and the determined values in most lots. This difference is possibly due to storage conditions and time lapse between determinations. The reason for presenting these data here is to indicate the nature of the materials used in this study.

Variations were found between lots within varieties and between varieties. Moisture content between lots ranged from 9.08 to 14.69 percent in Pinto, 9.73 to 16.43 percent in Light Red Kidney, 8.62 to 13.02

TABLE I

ORIGIN, DATE RECEIVED, MOISTURE CONTENT AND PERCENTAGE CRACKED SEED COATS OF FOUR VARIETIES OF DRIED BEANS

Variety	Lot No.	Date Received	Origin	Moisture Content (Percent)		Cracked Seed Coats
				Supplier's Values	Determined	
Great Northern	71	Jan. 7, 1972	Gering, Nebraska	11.76	10.01	20.83
	8	Jan. 25, 1972	Minatore, Nebraska	11.58	13.02	33,83
	43	Feb. 3, 1972	Kimberley, Idaho	10.90	11.77	10.50
	3	Feb. 23, 1972	Jerome, Idaho	10.44	8.62	36.00
	15	Feb. 26, 1972	Kimberley, Idaho	10.78	9.31	11.33
	99	Feb. 18, 1972	Minatore, Nebraska	10.60	9.10	24.83
	Average			11.01	10.31	22.89
Navy	106	Nov. 23, 1971	Turner, Michigan	16.05	14.71	1.50
	47	Feb. 5, 1972	Saginaw, Michigan	16.74	15.32	9.17
	77	Jan. 15, 1972	Gagetown, Michigan	17.69	13.77	5.17
	69	Jan. 6, 1972	Sunfield, Michigan	14.91	14.20	9.17
	94	Feb. 11, 1972	Bad Axe, Michigan	15.74	13.61	4.50
	54	Feb. 8, 1972	Carson City, Michigan	16.34	13.77	5.50
	Average			16.25	14.23	5.84
Light Red Kidney	127	Jan. 21, 1972	Brockport, New York	19.05	15.85	8.00
	79	Jan. 15, 1972	Morovia, New York	17.71	16.46	7.17
	26	Jan. 31, 1972	Pittsford, New York	18.98	15.45	14.67
	96	Feb. 11, 1972	Pittsford, New York	16.30	10.58	20.83
	105	Feb. 16, 1972	Morovia, New York	18.35	10.83	12.67
	118	Jan. 24, 1972	Morovia, New York	16.50	9.73	8.83
	Average			17.82	13.15	12.03

TABLE I (continued)

Variety	Lot No.	Date Received	Origin	Moisture Content (Percent)		Cracked Seed Oats
				Supplier's Values	Determined	
Pinto	85	Jan. 13, 1972	Cavalier, North Dakota	13.85	13.67	13.33
	21	Dec. 3, 1971	Hatton, North Dakota	16.91	14.69	5.17
	101	Feb. 15, 1972	Billings, Montana	9.69	9.40	7.67
	67	Feb. 9, 1972	Saginaw, Michigan	13.68	12.37	14.00
	113	Feb. 22, 1972	Cavalier, North Dakota	12.83	9.08	13.33
	103	Jan. 12, 1972	Hatton, North Dakota	16.20	10.90	3.67
	Average			13.86	11.69	9.53

percent in Great Northern and 13.61 to 15.32 percent in Navy. Average percent moisture of the four varieties was 10.31, 11.69, 13.15 and 14.23 for Great Northern, Pinto, Light Red Kidney and Navy beans, respectively. Percent damaged seed coats, like moisture content, varied both between lots within varieties and between varieties. Great Northern variety contained the largest percentage of broken seed coats with 22.89 followed in order by Light Red Kidney with 12.03, Pinto with 9.53, and Navy with 5.84.

All beans with cracked seed coats were removed from the samples used for each treatment. This was deemed necessary in order to remove all possibilities of any effects on water absorption and texture of the beans.

II. EXPERIMENTAL METHODS

Experiment One

Conditioning. Conditioning of dried bean samples was performed in environmental chambers under saturated humidity conditions and at temperatures of 70° and 100° F. The chambers consisted of large diameter five gallon aluminum chambers with tight fitting covers. One gallon of tap water was placed in the chamber. A strip of cheese cloth, with one end attached to lid of chamber and the other end submerged in the water, served as a wick to assist in maintaining a saturated condition inside the chamber. Samples of beans were placed in cheese cloth bags and suspended above the water level for conditioning purposes.

Preliminary studies had indicated that hydration was both time and temperature dependent. Consequently, 70° and 100° F for 48 hours were chosen as variables for this study. The chambers were charged with water, sealed, and stored at prescribed temperature for 24 hours for equilibration.

Fifty gram samples of dried beans were weighed into cheese cloth bags and exposed to high humidity conditions inside the sealed chambers. After 48 hours, the beans were removed from the chamber and moisture determined gravimetrically. Weight gained was expressed in percent as water uptake during conditioning.

Soaking. Soaking of the conditioned beans was accomplished by placing 100 gram aliquoits of beans in 400 ml of distilled water at ambient temperature. After soaking for two hours, the beans were removed from the soaking water and moisture determined gravimetrically.

Determination of initial moisture. Moisture content of beans before conditioning was determined by the Vacuum Oven Method (1). Twenty grams of sample were weighed into drying dishes and dried in a vacuum oven at 75° C and 20 inches of mercury for 16 hours, and then were cooled for 30 minutes before weighing. The percent moisture was calculated by dividing the weight lost by the original weight and multiplying by 100.

Moisture determination after conditioning and soaking. Water absorption by the beans after conditioning and soaking was determined gravimetrically. After removal from the soaking bath, the beans were

lightly rolled between two sheets of water absorbing tissue to remove all surface water. Weight gained was expressed in percent as water uptake during soaking.

Shear resistance. The Allo-Kramer Shear Press model SP-12 with a single blade cell was used to determine shear resistance of beans after soaking. Sample size consisted of six beans aligned with base orifice in such manner as to cause blade to shear transversely across the mid-section of the beans. A 1000 pound test ring with a 23 feet per second thrust was employed, and the maximum force (dial readings) required to shear the sample was recorded. The dial readings were converted to the equivalent pounds force by a standard curve.

Split count. Physical defects of the dried bean seed coats were determined by careful examination of each bean in a 50-gram sample. All beans with visible cracks or breaks of the seed coat were separated and weighed to determine percentage of damaged beans in each lot and variety.

Experiment Two

Hydration in enzyme solutions. The objective of Experiment Two was to evaluate the effects of various enzyme systems on hydration rate and texture of dried beans during soaking. Pinto and Light Red Kidney varieties of beans were selected for this experiment. Enzyme systems used were amylase, cellulase, and pectinase. Based on results of preliminary studies, a soaking time of two hours at 140° F and enzyme concentration of 0.5 percent were chosen as treatment conditions for this experiment. The moisture content of the beans was not adjusted.

The enzyme solutions were prepared by dissolving calculated weight of dry enzyme in distilled water at 140° F. After enzyme was completely dissolved, sample of beans was added and the solutions maintained for two hours at 140° F by use of a water bath. Water absorbed during soaking was determined by weighing the beans before and after soaking, as described in Experiment One.

The experiment consisted of a 2 x 3 x 4 factorial design replicated three times. The four treatments were: (1) control (soaking beans in distilled water), (2) soaking of nontreated beans, (3) blanching beans for three minutes at 212° F prior to soaking, and (4) blanching for three minutes plus freezing the beans prior to soaking.

Twenty gram aliquots of each of the varieties in treatments 2, 3, and 4 were submerged in solutions of each of the three enzyme solutions for a two hour duration. They were then removed from their respective solutions and briefly rolled between two sheets of absorbent tissue to remove excess surface water. Water absorption was determined by weight and shear value was determined as described in Experiment One. Control samples of each variety were handled in a similar manner except they were soaked in distilled water.

Description of enzymes studied. Fungal Amylase (Rohm and Haas Company) is effective in converting starch to dextrins, maltose, and glucose. This enzyme is characterized by both its high saccharifying and high liquefying power. Good results can be obtained at pH values of 4.7 to 5.2 when the conversion is carried out at 55° to 60° C. The activity of the enzyme is destroyed at temperatures of 80° to 85° C for 15 to 30 minutes.

Pectinol 5B (Rohm and Haas Company) is a food-grade preparation of primarily pectic enzymes. It hydrolyzes the α-1,4 glycosidic linkages in the galacturonic acid molecule. Secondary enzymes are also present, which are capable of hydrolyzing polysaccharides such as starch, xylan, insulin, and cellulose; disaccharides such as maltose and sucrose; and proteins. Diatomaceous earth and gelatin are contained as diluents. Optimum pH and temperature for activity are between 3.0 and 5.5, and 50° and 55° C, respectively. Enzyme reaction is inhibited by natural inhibitors such as heavy metals, strong acids, and strong alkalies.

Cellulase 36 (Rohm and Haas Company) is a standardized food-grade cellulolytic enzyme preparation of microbial origin. It contains a number of secondary enzyme systems and, as a result, exhibits catalytic activity on such substrates as pectin, proteins, pentosans, and hexosans. Optimum pH for activity is 4.0; optimum temperature is 50° C. It contains sodium chloride as a diluent. The principal enzyme system, cellulase, catalyzed the hydrolysis of cellulose, or cellulose derivatives, to lower molecular weight saccharides and ultimately to glucose.

III. STATISTICAL ANALYSIS

The Statistical Analysis System computer program at The University of Tennessee Computer Center was used for the calculation of analysis of variance. The following effects were tested by means of the analysis of variance in Experiment One:

1. Effect of variety and conditioning temperature on moisture absorption from the humidity chamber.

2. Effect of variety and conditioning temperature on water absorption during soaking.
3. Effect of variety and conditioning temperature on firmness of beans after soaking.
4. Effect of variety and conditioning temperature on splitting of beans after soaking.
5. Effect of each lot within each variety and conditioning temperature on moisture absorption from the humidity chamber, water absorption during soaking, firmness after soaking and splitting after soaking.

In Experiment Two, the lack of differences were so obvious that analysis seemed unnecessary.

Duncan's Multiple Range Test, available in the University of Tennessee Computing Center was used to perform the differences between means of above measurements.

CHAPTER IV

EXPERIMENTAL RESULTS

I. EXPERIMENT ONE

Moisture Absorption in Conditioning Chamber

Percent moisture of dried beans before and after 48 hour exposure to conditions of saturated humidity and temperature of 70° and 100° F is shown in Table II. The varieties differed in amount of moisture absorption in the conditioning chamber. Light Red Kidney and Navy varieties absorbed the most water. Light Red Kidney absorbed 6.46 percent and Navy absorbed 6.38 percent as compared to 5.04 percent by Pinto and 4.96 percent by Great Northern at 70° F. At 100° F, all varieties absorbed approximately the same amount of water. Although Navy and Light Red Kidney absorbed more water at 100° F than at 70° F (2.79 and 2.43 percent, respectively). Pinto and Great Northern exhibited the greatest difference in absorption between 100° F and 70° F with 4.21 and 4.08 percent, respectively.

The data in Table II reveals a direct relationship between initial moisture content and moisture absorbed in the conditioning chamber with a correlation coefficient of 0.9171. The lower the initial moisture content, the lower the total moisture absorbed during the conditioning period. The average moisture content of all beans increased 5.71 percent at 70° F and 9.08 percent at 100° F from an average of 14.48 percent initial moisture content, thus, the average

TABLE II

PERCENT MOISTURE CONTENT OF DRIED BEANS BEFORE AND AFTER 48 HOURS EXPOSURE TO CONDITIONS OF SATURATED HUMIDITY AND TEMPERATURE OF 70° and 100° F†

Variety	Percent				
	Initial Moisture (A)	Weight Gained at 70° F (B)	Weight Gained at 100° F (C)	Moisture After Conditioned at 70° F (A)+(B)	Moisture After Conditioned at 100° F (A)+(C)
Great Northern	11.01	4.96	9.04	15.97	20.05
Navy	16.25	6.38	9.17	22.73	25.42
Light Red Kidney	17.82	6.46	8.89	24.28	26.71
Pinto	13.86	5.04	9.25	18.90	23.11
Average	14.48	5.71	9.08	20.47	23.82

†Mean of 18 observations.

moisture content of the beans was adjusted to 20.47 percent at 70° F and 23.82 percent at 100° F. The two varieties with the highest initial moisture content (Light Red Kidney and Navy) absorbed an average of 6.42 percent moisture at 70° and 9.03 percent at 100° F for a total adjusted moisture content of 23.50 and 26.06 percent at 70° and 100° F, respectively. Great Northern and Pinto (lowest initial moisture content) absorbed an average of 5.00 and 9.14 percent for an average total adjusted moisture content of 17.43 and 21.58 percent moisture at 70° and 100° F, respectively.

Tables III through XII follow.

The summary of the analysis of variance and Duncan's multiple range test for effects among varieties and temperatures on moisture absorption by dried beans during 48 hour exposure in the high humidity chamber is presented in Tables VII and VIII, pages 27 and 28. The varieties were significant at the 0.05 level while temperatures and interactions between varieties and temperatures were significant at the 0.01 level. Duncan's multiple range test indicates significant differences between Great Northern and Navy, between Light Red Kidney and Great Northern, and between Pinto and Navy at the 0.01 level. No significant differences were found between Great Northern and Pinto, between Pinto and Light Red Kidney, and between Light Red Kidney and Navy.

The analysis of variance for effects among lots within varieties and temperature on moisture absorption by dried beans in the high humidity chamber is presented in Table III, page 23. The differences among lots within varieties and among temperatures were significant at the 0.01

TABLE III

SUMMARY OF THE ANALYSIS OF VARIANCE FOR EFFECTS AMONG LOTS AND TEMPERATURES ON MOISTURE ABSORPTION BY DRIED BEANS DURING 48 HOUR EXPOSURE IN HIGH HUMIDITY CHAMBER

Variety	Source	D.F.	M.S.	F-Ratio
Great Northern	Lot	5	3.766076	8.34372**
	Temp.	1	149.858403	332.01035**
	Lot x Temp.	5	0.732929	1.62380
	Error	24	0.451367	
	Total	35	5.233892	
Navy	Lot	5	0.7333978	4.63109**
	Temp.	1	69.8338778	440.97097**
	Lot x Temp.	5	0.5620911	3.54936*
	Error	24	0.1583639	
	Total	35	2.2889159	
Light Red Kidney	Lot	5	23.5061	40.84485**
	Temp.	1	52.8529	91.83867**
	Lot x Temp.	5	0.3551133	0.61705
	Error	24	0.5754972	
	Total	35	5.3134543	
Pinto	Lot	5	1.222938	6.04293**
	Temp.	1	159.811736	789.68122**
	Lot x Temp.	5	0.898289	4.43874**
	Error	24	0.202375	
	Total	35	5.007854	

*Statistical significance at the 0.05 percent level of probability.

**Statistical significance at the 0.01 percent level of probability.

TABLE IV

SUMMARY OF THE ANALYSIS OF VARIANCE FOR EFFECTS AMONG LOTS AND TEMPERATURES ON WATER ABSORPTION DURING SOAKING OF HIGH MOISTURE BEANS

Variety	Source	D.F.	M.S.	F-Ratio
Great Northern	Lot	5	467.15266	166.76788**
	Temp.	2	6099.90082	2177.59123**
	Lot x Temp.	10	94.68712	33.80216**
	Error	36	2.80121	
	Total	53	294.02415	
Navy	Lot	5	36.92755	61.45639**
	Temp.	2	198.37252	330.13993**
	Lot x Temp.	10	0.76029	1.26532
	Error	36	0.60087	
	Total	53	11.52108	
Light Red Kidney	Lot	5	38.30278	16.62434**
	Temp.	2	3250.15508	1410.64625**
	Lot x Temp.	10	349.99564	151.90661**
	Error	36	2.30402	
	Total	53	193.86274	
Pinto	Lot	5	388.99041	99.94848**
	Temp.	2	6920.19686	1778.09820**
	Lot x Temp.	10	134.19824	34.48134**
	Error	36	3.89191	
	Total	53	325.80070	

**Statistical significance at the 0.01 percent level of probability.

TABLE V

SUMMARY OF THE ANALYSIS OF VARIANCE FOR EFFECTS AMONG LOTS AND TEMPERATURES ON SHEAR VALUE AFTER SOAKING OF HIGH MOISTURE BEANS

Variety	Source	D.F.	M.S.	F-Ratio
Great Northern	Lot	5	345.107407	8.89643**
	Temp.	2	711.726852	18.34742**
	Lot x Temp.	10	24.326852	0.62712
	Error	36	38.791667	
	Total	53	90.353948	
Navy	Lot	5	25.049074	1.44052
	Temp.	2	198.740741	11.42918**
	Lot x Temp.	10	1.951852	0.11225
	Error	36	17.388889	
	Total	53	22.042365	
Light Red Kidney	Lot	5	359.90463	8.06844**
	Temp.	2	3922.69907	87.94011**
	Lot x Temp.	10	205.07130	4.59734**
	Error	36	44.60648	
	Total	53	250.97109	
Pinto	Lot	5	2270.0630	18.55708**
	Temp.	2	15622.1435	127.70628**
	Lot x Temp.	10	1021.6602	8.35176**
	Error	36	122.3287	
	Total	53	1079.5290	

**Statistical significance at the 0.01 percent level of probability.

TABLE VI

SUMMARY OF THE ANALYSIS OF VARIANCE FOR EFFECTS AMONG LOTS AND TEMPERATURES ON SPLITTING AFTER SOAKING OF HIGH MOISTURE BEANS

Variety	Source	D.F.	M.S.	F-Ratio
Great Northern	Lot	5	349.167421	20.35627**
	Temp.	2	445.139467	25.95138**
	Lot x Temp.	10	28.250051	1.64696
	Error	36	17.152822	
	Total	53	66.719210	
Navy	Lot	5	17.3742044	12.84052**
	Temp.	2	6.4233722	4.74724*
	Lot x Temp.	10	1.8036833	1.33302
	Error	36	1.3530759	
	Total	53	3.1408553	
Light Red Kidney	Lot	5	288.523052	25.96648**
	Temp.	2	61.423272	5.52797**
	Lot x Temp.	10	8.901288	0.80110
	Error	36	11.111367	
	Total	53	38.763847	
Pinto	Lot	5	298.528727	71.84243**
	Temp.	2	128.452496	30.91274**
	Lot x Temp.	10	11.245079	2.70618*
	Error	36	4.155326	
	Total	53	37.954550	

*Statistical significance at the 0.05 percent level of probability.

**Statistical significance at the 0.01 percent level of probability.

TABLE VII

SUMMARY OF THE ANALYSIS OF VARIANCE FOR EFFECTS AMONG VARIETIES AND TEMPERATURES ON MOISTURE ABSORPTION IN CONDITIONING CHAMBER, WATER ABSORPTION DURING SOAKING, SHEAR VALUE, AND SPLITTING AFTER SOAKING OF BEANS

	Source	D.F.	M.S.	F-Ratio
A	Variety	3	5.33506	3.7753*
	Temperature	1	410.26502	290.3214**
	Var. x Temp.	3	7.36396	5.2110**
	Error	136	1.41314	
	Total	143	4.47936	
B	Variety	3	3399.9643	64.2287**
	Temperature	2	13174.0902	248.8716**
	Var. x Temp.	6	1098.1784	20.7457**
	Error	204	52.9353	
	Total	215	250.8649	
C	Variety	3	16288.9968	93.4388**
	Temperature	2	12992.1493	74.5271**
	Var. x Temp.	6	2487.7203	14.2704**
	Error	204	174.3279	
	Total	215	582.9791	
D	Variety	3	1523.75412	47.9273**
	Temperature	2	456.91081	14.3714**
	Var. x Temp.	6	61.50927	1.9347
	Error	204	31.79305	
	Total	215	57.39498	

A: Moisture absorption in high humidity chamber. B: Water absorption during soaking. C: Shear value after soaking. D: splitting after soaking.

*Statistical significance at the 0.05 level of probability.

**Statistical significance at the 0.01 level of probability.

TABLE VIII

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR EFFECTS OF VARIETIES ON MOISTURE ABSORPTION IN CONDITIONING CHAMBER, WATER ABSORPTION DURING SOAKING, SHEAR VALUE, AND SPLITTING AFTER SOAKING OF BEANS

Variety	Percent			
	Moisture Absorption in Chamber†	Water Absorption During Soaking††	Shear Value After Soaking††	Splitting After Soaking††
Great Northern	6.99 a	66.50 e	67.20 i	15.72 n
Navy	7.77 b	75.12 f	57.49 j	2.89 p
Light Red Kidney	7.65 cb	72.30 g	80.38 k	8.03 q
Pinto	7.14 ac	57.15 h	97.59 m	10.72 r

Means followed by the same letter within a column are not significantly different at the 0.01 level of probability.

†Mean of 36 observations.

††Mean of 54 observations.

TABLE IX

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR EFFECTS OF LOTS ON MOISTURE ABSORPTION IN CONDITIONING CHAMBER, WATER ABSORPTION DURING SOAKING, SHEAR VALUE, AND SPLITTING AFTER SOAKING OF HIGH MOISTURE BEANS

Variety	Lot No.	Moisture Absorption in Chamber (Percent)	Water Absorption During Soaking† (Percent)	Shear Value After Soaking†† (Pound Force)	Splitting After Soaking†† (Percent)
Great Northern	71	8.02 a	73.84 a	77.56 a	6.45 a
	8	6.89 b	74.34 a	66.33 b	17.33 b
	43	6.69 bc	63.59 b	62.17 b	12.24 c
	3	6.02 c	66.63 c	61.28 b	22.70 d
	15	6.47 bc	54.88 d	64.61 b	13.60 bc
	99	7.87 a	65.72 c	71.28 c	22.06 d
Navy	106	7.72 de	73.78 e	59.28 d	1.62 e
	47	7.28 d	73.70 e	56.44 d	3.39 f
	77	7.75 de	76.28 f	55.17 d	2.47 ef
	69	8.34 f	75.62 f	59.50 d	5.47 g
	94	7.63 de	72.99 e	57.50 d	2.42 ef
	54	7.93 ef	78.38 g	57.06 d	2.02 e
Light Red Kidney	127	6.16 g	72.14 h	77.11 eh	3.52 h
	79	5.97 g	73.74 i	72.94 h	9.89 i
	26	6.18 g	74.34 i	75.94 eh	7.32 ij
	96	8.60 h	71.80 h	84.33 fg	18.38 k
	105	8.14 h	68.57 j	90.22 f	3.02 h
	118	11.00 i	73.23 hi	81.72 eg	6.08 hj
Pinto	85	6.91 jm	66.29 k	84.11 i	11.47 m
	21	7.91 km	56.38 m	82.78 i	3.99 n
	101	7.09 m	53.93 n	110.61 j	8.59 p
	67	6.46 j	55.20 mn	109.33 j	17.98 q
	113	7.30 km	63.08 p	82.83 i	15.10 r
	103	7.81 k	48.06 q	115.89 j	3.98 n

Means followed by the same letter within a column are not significantly different at the 0.01 level of probability.

†Mean of six observations.

††Mean of nine observations.

TABLE X

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR EFFECTS OF CONDITIONING TEMPERATURE ON WATER ABSORPTION DURING SOAKING, SHEAR VALUE, AND SPLITTING AFTER SOAKING OF HIGH MOISTURE BEANS†

Treatment	Water Absorption During Soaking (Percent)	Shear After Soaking (Pound Force)	Split After Soaking (Percent)
Control	53.25 a	90.93 d	12.04 g
70° F	70.03 b	70.42 e	8.39 h
100° F	80.02 c	65.64 f	7.20 i

Means followed by the same letter within a column are not significantly different at the 0.01 level of probability.

†Mean of 72 observations.

TABLE XI

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR EFFECTS OF CONDITIONING TEMPERATURE ON WATER ABSORPTION DURING SOAKING, SHEAR VALUE, AND SPLITTING AFTER SOAKING OF EACH VARIETY OF HIGH MOISTURE BEANS†

Variety	Treatment	Water Absorption During Soaking (Percent)	Shear After Soaking (Pound Force)	Splits After Soaking (Percent)
Great Northern	Control	47.48 a	74.22 a	21.34 a
	70° F	67.80 b	65.30 b	13.98 b
	100° F	84.23 c	62.08 b	11.87 b
Navy	Control	71.58 d	61.08 c	3.54 c
	70° F	75.64 e	56.86 d	2.81 cd
	100° F	78.15 f	54.53 d	2.35 d
Light Red Kidney	Control	56.87 g	97.31 e	10.07 e
	70° F	78.60 h	73.67 f	7.55 f
	100° F	81.44 i	70.17 f	6.48 f
Pinto	Control	37.10 j	131.11 g	13.20 g
	70° F	58.09 k	85.86 h	9.23 h
	100° F	76.28 m	75.81 i	8.12 h

Means followed by the same letter within a column are not significantly different at the 0.01 level of probability.

†Mean of 18 observations.

TABLE XII

MOISTURE ABSORPTION IN CONDITIONING CHAMBER AND WATER ABSORPTION DURING SOAKING OF BEANS AT VARIOUS TEMPERATURES AND TIMES†

Variety	Lot	Percent Moisture Absorption in Conditioning Chamber					Percent Water Absorption After Conditioning and Soaking				
		Conditioning Temperature					Conditioning Temperature				
		70° F	100° F		130° F		70° F	100° F		130° F	
		Conditioning Time					Conditioning Time				
		48 hr.	48 hr.	24 hr.	48 hr.	72 hr.	48 hr.	48 hr.	24 hr.	48 hr.	72 hr.
Great Northern	99	6.04	9.70	7.58	11.60	15.53	65.83	83.72	84.67	89.04	90.25
Pinto	85	4.43	9.38	7.22	9.45	13.57	64.91	76.50	74.33	75.56	76.12
	103	5.56	10.06	7.60	10.21	12.93	49.28	74.80	72.25	76.46	82.59
Navy	47	6.36	8.20	9.58	18.24	-	74.13	76.18	87.58	87.59	-
	94	6.51	8.74	10.72	17.49	-	73.59	75.83	86.91	87.02	-
Light Red Kidney	96	7.59	9.61	8.21	10.67	14.57	82.81	86.77	85.46	86.90	88.01

†Mean of two observations.

level for each variety. Interactions between lots within varieties and temperatures in Great Northern and Light Red Kidney was not significant, but was significant in Navy at the 0.05 level and in Pinto at the 0.01 level. Table IX, page 29, presents Duncan's multiple range test for effects of lots on moisture absorption in the conditioning chamber. Significant differences were found between lots within each variety. The variations were about the same within each variety and could be related to similar variations found in initial moisture of the different lots.

Water Absorption During Soaking

Results of the analysis of variance and Duncan's multiple range test to determine the effects among varieties and temperatures on water absorption during soaking of high moisture beans are shown in Tables VII and VIII, pages 27 and 28. There was a significant difference among varieties, and conditioning temperatures and interactions between varieties and temperatures at the 0.01 level. When all temperature treatments were combined for each variety and their means tested against water absorbed by Duncan's multiple range test, significant differences were found among all varieties. Navy beans absorbed the largest volume of water with a 75.12 percent weight increase, followed in order by Light Red Kidney, Great Northern, and Pinto with 72.03, 66.50 and 57.15 percent weight increase, respectively. Water absorption during soaking, like moisture absorption in the conditioning chamber, correlated with initial moisture content of the beans. The correlation coefficient was 0.7897 between the initial moisture and total moisture absorbed.

The analysis of variance for effects among lots and temperatures on water absorption during soaking of high moisture beans is given in Table IV, page 24. There was a significant difference among lots within varieties and among temperatures at the 0.01 level for each variety. The interactions among lots and temperatures were significant at the 0.01 level for all varieties except Navy.

Table IX, page 29, presents Duncan's multiple range test for effects of lots within varieties on water absorption during soaking. These data show quite a difference among lots in Great Northern and Pinto beans, but much less in Navy and Light Red Kidney.

As shown in Table X, page 30, when varieties were summed according to soaking temperatures, beans that increased by 5.71 percent at 70° F (Table II, page 21) absorbed 16.78 percent more water than the control. At 100° F, when the moisture content was increased to 9.08 percent, the beans absorbed 26.76 percent more water than the control during soaking. By increasing the conditioning temperature by 30° F, the amount of water absorbed during soaking increased by approximately 60 percent. Thus, the conditioning temperature treatment was found to be the most significant factor influencing water absorption of the beans.

Table XI, page 31, shows that the conditioning temperature of 100° F gave 106 percent increase in water absorption during soaking by Pinto, 78 percent by Great Northern, 43 percent by Light Red Kidney, and 9 percent by Navy in comparison with their respective controls. The Navy beans were not greatly influenced by the conditioning temperature. The beans which increased in moisture content by approximately 5 percent

at 70° F during conditioning, absorbed approximately 20 percent more water than their respective controls. When the moisture content was increased by approximately 9 percent by conditioning at 100° F, the beans absorbed approximately 36 percent more water than the beans not conditioned. Navy beans increased by 6 and 9 percent moisture during conditioning at 70° and 100° F, but absorbed only 4 and 6 percent more water during soaking than the respective controls.

Firmness After Soaking

The summary of the analysis of variance and Duncan's multiple range test for effects among varieties and temperatures on shear value after soaking of high moisture beans is shown in Tables VII and VIII, pages 27 and 28. The differences among varieties, temperatures, and interactions between varieties and temperatures were significant at the 0.01 level. Shear value of Pinto beans (97.59) was almost twice the shear value of Navy (57.49) and Great Northern (67.20). Shear value of Light Red Kidney was intermediate at 80.38 pounds force. An inverse relationship was found between water absorption and shear value after soaking of high moisture beans with a correlation coefficient of -0.8085.

The analysis of variance for effects among lots and temperatures on shear value after soaking of high moisture beans is presented in Table V, page 25. Lots within varieties, among temperatures and interactions between lots and temperatures were all found to be significant at the 0.01 level with the exception that no significance occurred among the lots of Navy beans and interactions of lots and temperatures in Navy and Great Northern beans. Pinto beans, in which the difference in water absorption during soaking between lots was greater, gave the greatest difference in shear value between lots than all other varieties.

The results of Duncan's multiple range test for effects of lots on shear value after soaking of high moisture beans are shown in Table IX, page 29. The mean shear values of all lots in Navy beans were not significantly different at the 0.01 level, but significant differences were found among lots within all other varieties.

Average mean shear value of high moisture beans was found to be temperature dependent as shown in Duncan's multiple range test for effects of conditioning temperature on shear value after soaking (Table X, page 30). By conditioning at 70° F, the average firmness of all beans was reduced by approximately 20 pounds. When the temperature was increased to 100° F in the conditioning chamber, firmness was reduced by approximately 5 pounds below the beans at 70° F and 25 pounds below the controls. Among varieties, Pinto beans (Table XI, page 31) was affected the most by conditioning at 70° F which decreased by 45 pounds as compared to 23, 9, and 4 pounds reduction for Light Red Kidney, Great Northern, and Navy beans, respectively.

Firmness was further reduced in beans conditioned at 100° F chamber temperature in the same order as at 70° F. The firmness of Pinto beans was reduced by 55 pounds, Light Red Kidney by 27 pounds, Great Northern by 12 pounds and Navy by 6 pounds by conditioning at 100° F (Table XI, page 31).

Splitting After Soaking

Summary of the analysis of variance and Duncan's multiple range test for effects among varieties and temperatures on splitting after soaking of high moisture beans is shown in Tables VII and VIII, pages

27 and 28. There were significant differences among varieties and temperatures, but no significant interactions between varieties and temperatures at the 0.01 level. Duncan's multiple range test indicates a significant difference among all varieties on splitting. Great Northern indicated the highest incidence of splitting with 15.73 percent followed in order by Pinto with 10.73, Light Red Kidney with 8.03 and Navy with 2.90 percent splits, respectively.

Table VI, page 26, is presented to show the effects of lots within varieties and temperatures on splitting after soaking of high moisture beans. There were significant differences among lots within all varieties and all temperatures at the 0.01 level with the exception of temperatures in Navy beans which was significant at the 0.05 level. The interactions among lots and temperatures were not significantly different, except for Pinto beans which were significant at the 0.05 level. Table IX, page 29, shows mean values of splitting after soaking in each lot within each variety. Significant differences were found among all but one lot of Pinto beans and among some lots of all other varieties.

The data in Table X, page 30, includes the results of Duncan's multiple range test for effects of conditioning temperature on splitting after soaking of high moisture beans. Significant differences were found among all treatments. Conditioning at 70° F reduced splitting from 12.04 in the control to 8.39 percent in treated beans. Increasing the temperature to 100° F reduced the incidence of splitting to 7.20, or 14 percent more than conditioning at 70° F. The temperature, although significant among

all treatments, did not appear to exert as great an influence on splitting as did conditioning regardless of temperature. The data in Table XI, page 31, includes effects of temperature on splitting after soaking for each variety. The varieties which had the highest percentage of splitting after soaking, Pinto and Great Northern, were the same varieties with the highest initial percentage of splits (Table I, page 12). The percentage decrease in splitting after conditioning at 70° F and soaking was 35 for Great Northern, 30 for Pinto, 25 for Light Red Kidney and 21 percent for Navy beans. Conditioning at 100° F followed by soaking further reduced the incidence of splitting in all varieties. Splitting in Great Northern was reduced by 44 percent followed by Pinto, Light Red Kidney, and Navy with 38, 36, and 34 percentage reductions, respectively (Table XI, page 31).

Table XII, page 32, shows percent moisture absorption in conditioning chamber and water absorption during soaking of beans at various temperatures and times. When temperature was increased to 130° F, the beans absorbed almost the same amount of water in 24 hours as in 48 hours at 100° F. Soaking beans beyond 24 hours at 130° F did not result in increased water absorption. This indicates that total water absorbed in soaking of uncooked beans is directly related to conditioning temperature. As the conditioning temperature increased the soaking time required for the beans to reach approximately 50 percent moisture content decreased.

It can be assumed, based upon the relationship of temperature and total water absorption, that increasing the conditioning temperature beyond 130° F would result in further reduction in soaking time. It may be possible that further increases in conditioning temperature and

soaking at temperatures sufficient to hydrolyze protein and starch would not only result in further reduction in soaking time but may also significantly effect retort time.

II. EXPERIMENT TWO

Effect on Hydration and Texture of Soaking Beans in Enzyme Solutions

Results of the effect of amylase, cellulase, and pectinase enzymes on hydration and texture of Pinto and Light Red Kidney beans are presented in Tables XVII and XVIII in the Appendix.

Differences obtained between treatments were so small that statistical analysis seemed unnecessary. It was readily apparent that the beans retained much of their raw characteristics. Consequently, enzymatic activity was prohibited by the presence of native inhibitory substances and the uncooked nature of the beans in all treatments.

CHAPTER V

DISCUSSION

I. EXPERIMENT ONE

Quality of Raw Material

The objectives of soaking beans prior to processing is to clean the beans, increase yield, ensure uniform expansion in the can, and improve texture. Results reported in this study indicate that satisfactory attainment of these objectives is dependent upon exercising proper control over certain physical factors which contribute to final product quality.

The data presented in Table I, page 12, indicates the wide variability in quality of dried beans received by processing plants. Moisture content ranged from 8.62 to 13.02 in Great Northern, from 9.08 to 14.69 in Pinto, from 9.73 to 16.46 in Light Red Kidney, and from 13.61 to 15.32 in Navy. The percentage of damaged seed coats ranged from 7.17 to 20.83 with an average of 12.03 in Light Red Kidney, from 3.67 to 14.00 with an average of 9.53 in Pinto, from 10.50 to 36.00 with an average of 22.89 in Great Northern, and from 1.50 to 9.17 with an average of 5.84 in Navy. Such variations in these two factors give rise to the possibility that other factors influencing water imbibition and texture of beans may also have been adversely affected. Although observed but not tested, the incidence of small hard beans was greater

in the Great Northern and Pinto varieties than in Light Red Kidney and Navy. This factor varied with lots within varieties.

These data indicate that greater attention to growing conditions and maturity rates coupled with greater control exercised over methods of harvesting, drying and storing of dried beans would possibly result in an improved quality product being delivered to the processor. This in turn could result in improved quality at reduced cost of the final product.

Moisture Absorption in Conditioning Chamber

Previous work has shown that moisture absorption is an inherited characteristic of dried beans and that it is temperature dependent (37). The results of this study appear to bear out the role of heredity in moisture absorption. However, initial moisture content was shown to be a major contributing factor with a correlation coefficient of 0.9171. Irrespective of variety, beans of a specific moisture content absorbed approximately the same volume of water during conditioning at both 70° and 100° F (Tables XIII, XIV, XV, and XVI in the Appendix). For example, Great Northern beans with 10.01 initial moisture content increased to 16.03 and 20.03 percent during conditioning at 70° and 100° F respectively as compared with Light Red Kidney with initial moisture of 10.83 percent and an increase to 17.85 and 20.09 percent, and with Pinto with an initial moisture of 10.90 and an increase to 16.46 and 20.96 percent at 70° and 100° F, respectively. Similar comparisons can be made across varieties at other initial moisture contents.

The same relationship was indicated between initial moisture content and total percentage moisture increase after conditioning at 70° and 100° F, and soaking. The results are somewhat masked by the possible influence of hard beans and by beans with damaged seed coats. This is especially observable in the beans soaked without prior conditioning. For example, Navy beans which had the lowest percentage of beans with damaged seed coats and observable small units also had the most uniform initial moisture content among lots and the most consistent increase in moisture absorption upon soaking with no conditioning and also upon soaking following conditioning.

Other varieties, which had higher incidences of damaged seed coats and observable small beans, fluctuated widely among lots in their response to both conditioning and soaking treatments. After conditioning, however, the fluctuations were of less magnitude and beans of initial moisture content of approximately 13 percent, for example, increased by approximately 40 and 68 percent after conditioning at 70° and 100° F respectively regardless of varietal differences.

The data presented in this study indicate that if beans are to be processed as presently practiced the moisture content should not be permitted to fall below 12 percent while in storage. This is in apparent agreement with work performed by Nutile and Nutile (31) who reported that reducing moisture content to 9-10 percent resulted in an increase in hard seed content in Decatur variety and with Kyle (22) who reported that storage under low relative humidity conditions increased hard seed content and protected viability of bean seeds.

In mixed lots where the range of initial moisture content varies as in this study, conditioning the beans prior to soaking will compensate for the differences by uniformly adjusting the moisture content to a higher level and thereby reducing the total soaking time required to reach maximum moisture content in the beans.

Water Absorption During Soaking

Varieties, lots within varieties, and conditioning temperatures significantly influenced water absorption during soaking of dried beans. These differences indicate that water permeability is possibly associated to some degree with varietal hereditary characteristics but which can be greatly altered by environmental factors, particularly those affecting moisture content. As in the conditioning treatment, initial moisture content was found to be significantly related to total moisture absorption of the beans irrespective of variety. The correlation coefficient between initial moisture and total percentage increase in weight due to water absorption was 0.7897.

The possible influence of hard beans or beans with an initial moisture content below 12 percent was readily apparent (Tables XIII, XIV, XV, XVI in the Appendix). Untreated lots within varieties containing relatively large numbers of small units and with a moisture content below 12 percent increased an average of approximately 40 percent in weight as compared to an average of approximately 70 percent for lots with higher moisture contents. This is in agreement with observations by Sun (37). The full impact of this factor on total percentage increase in weight was possibly obscured by the influence of

units with cracked seed coats as can be seen by comparing uniformity of percentage weight increase in Navy with widely fluctuating increase in Great Northern beans. Kyle (22) reported that damaged seed coats such as cracks between strophiole and hilum, around periphery of micropyle, and cracks extending from strophiole to end of beans significantly affected water absorption.

Although an effort was made to remove all damaged beans prior to conditioning and soaking treatment, damage in areas mentioned above could have been too minute to be readily observable. This possible influence on water absorption is apparent among varieties and conditioning temperatures. Great Northern and Pinto varieties, with high initial damaged units, gained an average of 17.31 percent more water when conditioned at 100° F before soaking than when conditioned at 70° F. Navy and Light Red Kidney beans, with low initial damaged units, gained an average of 2.68 percent water upon soaking after conditioning at 100° F than at 70° F (Table XI, page 31). Thus, it would appear that the physical condition of the bean rather than temperature per se is the major factor in determining total moisture absorption.

Firmness of Beans After Soaking

Differences in firmness among varieties, lots within varieties, and conditioning temperatures were significantly different at the 0.01 level. Firmness was found to be variety dependent. Navy beans, for example, had the lowest shear value under all treatment conditions of all varieties. Pinto had the highest values, followed in order by Great Northern and Light Red Kidney. This indicates either a physical

or physiological differences among varieties. Evidence of physical differences such as small, immature or hard beans was noted in the reduction in pound force required to shear different varieties of non-conditioned beans and beans that had been conditioned at 100° F before soaking. Force required to shear Navy beans was reduced by 6.55 pounds, compared to a reduction of 12.14 pounds for Great Northern, 27.14 pounds for Light Red Kidney, and 55.30 pounds for Pinto (Table XI, page 31). Differences due to physiological factors was noted in the relationship of total water absorbed and force required to shear the soaked beans that had been conditioned at 100° F. All beans absorbed approximately the same amount of water after two hours of soaking but Navy required an average of 54.53 pounds force to shear, Great Northern required 62.08 pounds, Light Red Kidney required 70.17 pounds, and Pinto required 75.81 pounds.

Firmness of the beans within varieties was found to be related to total amount of water absorbed during soaking. A negative correlation coefficient of -0.8089 was found between firmness and water absorption, as water absorption increased, shear resistance decreased within all lots and all varieties. Sun (37) reported similar results.

Incidence of Splitting During Soaking

Splitting of beans during the soaking of dried beans is an interesting, but highly undesirable characteristic of certain varieties. Variations were found in percent damaged seed coats among varieties and among lots within varieties. The average damaged units found was 22.89 percent in Great Northern, 12.03 percent in Light Red Kidney, 9.53

percent in Pinto, and 5.84 percent in Navy (Table I, page 12). All obviously damaged units were removed from samples before treatments. Data presented in Tables XIII, XIV, XV, and XVI in the Appendix gives the percentage of split units observed after soaking beans for two hours. In beans not conditioned prior to soaking, Great Northern contained an average of 21.34 percent split units, Pinto contained 13.20 percent, Light Red Kidney contained 10.07 percent and Navy contained 3.54 percent. This indicates that either all damaged units were not removed, such as damage mentioned by Kyle (22) or that inherent structural differences in seed coats among varieties afforded varying degrees of resistance to rupture.

Where seed coats are intact, previous workers have established that the micropyle, hilum and raphe are the major passage ways of water into dried beans and that little or no water passes directly across the seed coat. This being the case, swelling of the cotyledons and the seed coat is initiated from inside a dry shell. If for any reason absorption of water and expansion of cotyledons is disproportionate to expansion of the seed coat, rupturing will occur. Such a condition could occur as the result of mechanical rupture of the seed coat thereby permitting entry of water at points other than through major passage ways. Certain chemical or physiological alterations within the cotyledons and/or seed coats resulting from mishandling of the product could cause expansion of cotyledons before seed coats absorbed enough water to become sufficiently pliable to accept the expansion even though water enters through normal passageways and thus cause rupturing.

Results obtained from soaking nontreated beans strongly suggest mechanical damage as the causative factor due to wide variations found in lots within varieties and between varieties. Results obtained from conditioning the beans at 70° and 100° F prior to soaking, however, strongly suggest chemical or physiological changes may be equally important in "butterflying" of beans during soaking.

Navy had the lowest incidence of splitting after soaking of nontreated beans followed in order by Light Red Kidney, Pinto, and Great Northern. A point of greater interest is the reduction in incidence of splitting obtained by conditioning the beans prior to soaking. Conditioning the beans at 70° F resulted in a reduction in splitting of 35 percent in Great Northern, 25 percent in Light Red Kidney, 30 percent in Pinto, and 21 percent in Navy. Conditioning the beans at 100° F reduced splitting by 44 percent in Great Northern, 36 percent in Light Red Kidney, 38 percent in Pinto, and 34 percent in Navy.

Results of this study indicate a possibility of structural and compositional differences in seed coats among varieties which provides a degree of resistance to mechanical damage peculiar to that variety. For example, seed coats of Great Northern beans was shown to be highly susceptible to mechanical damage whereas Navy beans exhibited a low level of susceptibility. Sun (37) reported differences in seed coat composition among varieties but did not relate them to "butterflying" during soaking. Although not a part of this study, the possibility of physiological changes resulting from mishandling techniques can not be ignored.

Results reported in this study suggest a reevaluation of the production and handling techniques of dried beans for processing based

upon inherent physiological differences peculiar to individual varieties. Processing and handling techniques such as: (1) size grading to remove small hard beans, strict adherence to maturation dates and selective harvesting methods for varieties of high susceptibility to damage, (2) controlled drying and storing conditions to uniformly dry and hold beans above minimum acceptable moisture level, and (3) conditioning beans by short duration exposure to high relative humidity immediately prior to soaking would ensure greater uniformity of water absorption and tenderness, reduce "butterflying", shorten soak time, and generally improve overall quality of final product.

II. EXPERIMENT TWO

Effect of Enzyme Solutions

Experiment two was designed to study the effects of enzymes on hydration and texture of dried beans during soaking. Beans were hydrated in solutions of amylase, cellulase and pectinase enzymes which preliminary studies had indicated were native to dried beans. It was hypothesized that one or more of the enzymes would react with components of the skin from the outside or that they would pass through hilum, micropyle or raphe and attack the skin from the inside. In either case, the skin would become more water permeable thus increasing hydration rate.

Results obtained indicate that none of the enzymes reacted with the bean skin to accelerate water passage (Table XVII in the Appendix) nor on the cotyledons to soften texture (Table XIII in the Appendix). Some effect on water absorbed and texture was observed due to heat treatment given samples 3 and 4.

Enzyme inactivity observed was possibly due to presence of native inhibitors in the two varieties of beans towards the enzymes studied. Jaffe and Hannig (19) reported that legumes are often associated with low digestibility and growth inhibition, which may be associated with the presence of enzyme inhibitors other than the well known trypsin inhibitor. Seidl et al. (33) noted the presence of an unspecific proteinase inhibitor in black bean globulin which was resistant to hydrolysis by pepsin, trypsin, chymotrypsin, papain, ficin, hurain and subtilism after removal of the trypsin inhibitor. Gallagher (10) reported that legumes were able to inhibit ficin and trypsin, with the exception of lentiles which showed inhibition only toward trypsin.

Uncooked seeds, pulses and beans are not attacked by enzymes (9). Heating of these products serves to deactivate or complex inhibitory substances and to denature proteins and gelatinize starch (39, 17, 9).

The heat treatment given to beans in this study apparently was not sufficient to destroy inhibitory substances nor to initiate any enzymatic activity. Heating the beans followed by freezing before hydration in enzyme solutions likewise failed to initiate any enzyme activity.

CHAPTER VI

SUMMARY

The effect of modifying the moisture content and the use of certain enzymes on the hydration, texture and "butterflying" of beans for processing was studied. Great Northern, Pinto, Light Red Kidney and Navy varieties of beans were used to study the effect of moisture modification. Pinto and Light Red Kidney varieties were used to study the effect of hydration in solutions of amylase, cellulase and pectinase enzymes. Moisture absorption, texture and "butterflying" data were collected and analyzed.

Data from this study indicates that physical and/or chemical properties of the beans as received by the processor exert a positive influence upon process operations and quality of final product.

Based upon the conditions employed, the following are the major conclusions of this investigation: The quality of processing stock received from processor varied significantly among lots within varieties and among varieties. Moisture content ranged from 8.62 to 16.46 percent. Damaged seed coat content ranged from 1.50 to 36.00 percent. Moisture absorption by dried beans was directly related to initial moisture content. The correlation coefficient of this relationship was found to be 0.9171 during conditioning and 0.7897 during soaking periods. Impermeability of low moisture beans in all lots of all varieties was reversed by exposure to saturated humidities. Rehumidification at both 70° and 100° F for 48 hours increased rate of water

imbibition in all lots of all varieties of beans. Firmness of soaked beans was found to be variety dependent and inversely proportional to amount of water absorbed by the beans ($r = 0.8089$).

"Butterflying" of beans during soaking was variety associated. Exposture of beans to high humidity conditions for 48 hours at 70° and 100° F reduced ruptured beans by 30 and 38 percent, respectively. Enzymes used did not accelerate water absorption rate nor alter texture of cotyledons of any of the varieties of beans tested, thus indicating that dried beans contain a complex system of inhibitor substances other than just protein inhibitors.

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APPENDIX

TABLE XIII

INITIAL MOISTURE, WATER ABSORPTION, SHEAR VALUE, AND SPLIT UNITS AFTER SOAKING OF GREAT NORTHERN

Lot No.	Percent								Pound Force			Percent		
	A	B	C	D	E	F	G	H	I	J	K	M	N	O
71	10.01	6.02	10.02	16.03	20.03	48.36	82.86	90.31	83.50	75.33	73.83	10.21	5.03	4.12
8	13.02	4.18	9.62	17.20	22.64	65.22	71.78	86.03	69.67	66.33	63.00	28.55	12.50	10.93
43	11.77	4.67	8.71	16.44	20.48	40.33	64.15	86.28	68.33	61.17	57.00	16.78	10.22	9.70
3	8.62	4.09	7.95	12.71	21.19	48.60	68.05	83.23	66.33	60.83	56.67	26.68	21.83	19.58
15	9.31	4.74	8.22	14.05	17.53	34.74	54.11	75.79	76.67	60.83	56.33	15.61	15.20	9.97
99	9.10	6.04	9.70	15.14	18.80	47.60	65.83	83.72	80.83	67.33	65.67	30.21	19.09	16.89
Average	10.31	4.96	9.04	15.26	19.34	47.48	67.80	84.23	74.22	65.31	62.08	21.34	13.96	11.87

A: initial moisture; B: moisture uptake during conditioning at 70° F, and C: at 100° F; D: total moisture content after conditioning at 70° F(A+B), and E: at 100° F(A+C); F: water absorption during soaking without conditioning, G: after conditioning at 70° F, and H: at 100° F; I: shear value without conditioning, J: after conditioning at 70° F, and K: at 100°F; M: split units without conditoning, N: after conditioning at 70° F, and O: at 100° F.

TABLE XIV

INITIAL MOISTURE, WATER ABSORPTION, SHEAR VALUE, AND SPLIT UNITS AFTER SOAKING OF NAVY BEANS

Lot No.	Percent								Pound Force			Percent		
	A	B	C	D	E	F	G	H	I	J	K	M	N	O
106	14.71	6.17	9.27	20.88	23.98	70.19	74.13	77.01	61.67	59.00	57.17	1.73	1.64	1.50
47	15.32	6.36	8.20	21.68	23.52	70.79	74.13	76.18	60.00	55.67	53.67	3.45	3.53	3.19
77	13.77	6.03	9.47	19.80	23.24	72.11	76.77	79.95	58.50	55.00	52.00	3.26	2.32	1.83
69	14.20	6.85	9.83	21.05	24.03	71.64	76.18	79.03	63.50	59.50	55.50	7.78	4.89	3.74
94	13.61	6.51	8.74	20.12	22.35	69.37	73.79	75.83	62.00	56.33	54.17	2.78	2.19	2.26
54	13.77	6.37	9.48	20.14	23.25	65.35	78.85	80.92	60.83	55.67	54.67	2.23	2.27	1.57
Average	14.23	6.38	9.17	20.61	23.40	71.58	75.64	78.15	61.08	56.86	54.53	3.54	2.81	2.35

A: initial moisture; B: moisture uptake during conditioning at 70° F, and C: at 100° F; D: total moisture content after conditioning at 70° F(A+B), and E: at 100° F(A+C); F: water absorption during soaking without conditioning, G: after conditioning at 70° F, and H: at 100° F; I: shear value without conditioning, J: after conditioning at 70° F, and K: at 100° F; M: split units without conditioning, N: after conditioning at 70° F, and O: at 100° F.

TABLE XV

INITIAL MOISTURE, WATER ABSORPTION, SHEAR VALUE, AND SPLIT UNITS AFTER SOAKING OF LIGHT RED KIDNEY BEANS

Lot No.	Percent								Pound Force			Percent		
	A	B	C	D	E	F	G	H	I	J	K	M	N	O
127	15.85	4.99	7.32	20.83	24.17	65.78	74.41	76.23	86.33	74.00	71.00	4.27	3.72	2.56
79	16.46	5.01	6.93	21.47	23.39	69.29	74.91	77.01	78.67	71.17	69.00	11.34	9.55	8.78
26	15.45	4.63	7.73	20.08	23.18	72.61	74.88	75.52	87.00	71.67	69.17	7.86	7.52	6.58
96	10.58	7.59	9.61	18.17	21.19	45.81	82.81	86.77	119.17	76.83	67.00	22.49	17.88	14.76
105	10.83	7.02	9.26	17.85	20.09	40.51	80.04	85.16	128.33	77.00	75.33	3.66	2.77	2.64
118	9.72	9.53	12.47	19.26	22.20	47.23	84.53	87.94	104.33	71.33	69.50	10.82	3.87	3.54
Average	13.15	6.46	8.89	19.61	22.37	56.87	78.60	81.44	97.31	73.67	70.17	10.07	7.55	6.48

A: initial moisture; B: moisture uptake during conditioning at 70° F, and C: at 100° F; D: total moisture content after conditioning at 70° F(A+B), and E: at 100° F(A+C); F: water absorption during soaking without conditioning, G: after conditioning at 70° F, and H: at 100° F; I: shear value without conditioning, J: after conditioning at 70° F, and K: at 100° F; M: split units without conditioning, N: after conditioning at 70° F, and O: at 100° F.

TABLE XVI

INITIAL MOISTURE, WATER ABSORPTION, SHEAR VALUE, AND SPLIT UNITS AFTER SOAKING OF PINTO BEANS

Lot No.	Percent								Pound Force			Percent		
	A	B	C	D	E	F	G	H	I	J	K	M	N	O
85	13.67	4.43	9.38	18.10	23.05	57.45	64.91	76.50	106.33	73.00	73.00	16.58	9.27	8.58
21	14.69	4.89	9.69	19.58	24.38	40.96	57.27	70.90	92.67	83.33	76.33	5.57	3.58	2.83
101	9.40	4.88	9.29	14.28	18.69	30.61	52.45	78.75	146.33	103.50	82.00	11.53	7.93	6.30
57	12.37	4.59	8.33	16.96	20.70	33.25	57.33	75.00	146.83	102.83	78.33	22.18	15.98	15.78
113	9.08	5.86	8.74	14.94	14.82	40.23	67.30	81.72	113.83	67.50	69.17	19.94	13.87	11.47
103	10.90	5.56	10.06	16.46	20.96	20.09	49.28	74.80	184.67	87.00	76.00	3.42	4.74	3.79
Average	11.69	5.04	9.25	16.72	20.93	37.10	58.09	76.28	131.11	85.86	75.81	13.20	9.23	8.12

A: initial moisture; B: moisture uptake during conditioning at 70° F, and C: at 100° F; D: total moisture content after conditioning at 70° F(A+B), and E: at 100° F(A+C); F: water absorption during soaking without conditioning, G: after conditioning at 70° F, and H: at 100° F; I: shear value without conditioning, J: after conditioning at 70° F, and K: at 100° F; M: split units without conditioning, N: after conditioning at 70° F, and O: at 100° F.

TABLE XVII

WATER ABSORPTION BY PINTO AND LIGHT RED KIDNEY BEANS DURING SOAKING IN 0.5 PERCENT SOLUTIONS OF AMYLASE, CELLULASE AND PECTINASE†

Variety	Treatment	Percent		
		Nontreated Beans	3 Minutes Blanch Before Soaking	3 Minutes Blanch Plus Freeze Before Soaking
Pinto	Control	78.84	85.54	87.50
	Amylase	79.27	86.04	87.93
	Cellulase	78.06	85.13	86.88
	Pectinase	79.50	86.26	87.71
Light Red Kidney	Control	81.30	88.37	90.65
	Amylase	80.71	87.94	89.38
	Cellulase	82.58	88.40	90.14
	Pectinase	81.24	89.07	90.70

†Mean of three observations.

TABLE XVIII

SHEAR VALUE OF PINTO AND LIGHT RED KIDNEY BEANS AFTER SOAKING IN 0.5 PERCENT ENZYME SOLUTIONS OF AMYLASE, CELLULASE AND PECTINASE†

Variety	Treatment	Pound Force		
		Nontreated Beans	3 Minutes Blanch Before Soaking	3 Minutes Blanch Plus Freeze Before Soaking
Pinto	Control	81.50	69.23	65.71
	Amylase	84.28	68.70	63.80
	Cellulase	80.60	66.25	62.00
	Pectinase	81.33	71.52	65.10
Light Red Kidney	Control	77.78	70.13	64.00
	Amylase	79.04	73.45	66.64
	Cellulase	77.30	69.06	65.32
	Pectinase	76.52	72.10	66.60

†Mean of three observations.

VITA

The author was born on January 2, 1943, in Korea. In March 1972 he entered The Kyungpook National University and was graduated with a Bachelor of Science degree in Agricultural Chemistry in 1967. From March 1967 to October 1969 he worked with the National Inspection Institute of Agricultural Supplies, in the Chemistry Inspection Division. In March 1968, he attended the Korea University and was graduated with a Master of Science degree in Agricultural Chemistry in February 1970. Since Fall of 1970 he has been studying at the University of Tennessee, Knoxville, in the Department of Food Technology and Science, and working to complete the requirements for the degree of Master of Science.