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**QUALITY EVALUATION OF DRY EDIBLE BEANS AFTER SOAKING,
PROCESSING, AND EXTENDED CANNED STORAGE**

By

Janet G. Wilson

A THESIS

**Submitted to
Michigan State University
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ABSTRACT

QUALITY EVALUATION OF DRY EDIBLE BEANS AFTER SOAKING, PROCESSING, AND EXTENDED CANNED STORAGE

By

Janet G. Wilson

Dry beans (Phaseolus vulgaris L.) were evaluated for quality in a series of three studies following soaking, processing, and extended storage.

Processed bean texture was measured in Study 1 using objective and subjective methods. In Study 2 the amount and rate of water and calcium absorbed during soaking was investigated. Study 3 evaluated processed bean quality during extended storage.

Significant correlations were developed between objective and subjective measures with prediction equations for processed texture. Calcium absorption was greater from soak medium than from brine medium during processing. A heated soak treatment allowed increased calcium absorption, increased firmness and decreased drained weight in processed beans when compared to an unheated soak. During extended storage of processed beans, a decrease in drained weight and an increase in firmness occurs. A heated soak treatment produced more quality changes over time while the unheated soak produced little change.

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INTRODUCTION

Dry edible beans are a staple food as a primary protein source in many lesser developed countries and considered a speciality item in more industrialized nations. Both household users and commercial processors want a product that will produce consistent quality over time. Texture of the final product will be a key attribute in the evaluation of quality.

Processed quality of beans is influenced by many factors including growing environment, storage conditions, soak treatments, processing parameters and length of processed storage. Soak water temperature and soak water additives such as calcium ion have shown to produce significant effects on final processed texture.

The objective of this study is to help develop consistency in processing, through an understanding of the factors influencing product quality and to provide a method for measuring and interpreting quality.

Measuring texture by objective and subjective methods was the goal of Study 1. The test also included variances on soak method and soak water additives to produce an array of textures and study the changes occurring from them. A relationship between instrumental measures and sensory

attributes was defined for further use in evaluating how processing parameters effect product texture.

Study 2 was conducted to evaluate the effect of heat treatment and calcium concentration on water and calcium absorption during soaking. Water and calcium absorption in beans have direct influence on final texture and their rates and total amount absorbed can be significantly influenced during soaking. The emphasis here is placed on the effect of heat and calcium concentration in both individual and combined effects on water and calcium absorption.

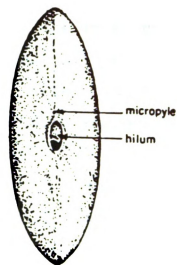
After processing, canned product will continue to undergo quality changes during extended storage as evaluated in Study 3. A bean-brine equilibration may occur over time especially in the presence of calcium or other ions. Calcium ions present in the brine attempt to achieve equilibrium with the bean causing a firming effect. Most research shows a decrease in drained weight over time which may be attributed to solids loss to the brine or a loss of water through calcium binding in the bean during equilibration.

LITERATURE REVIEW

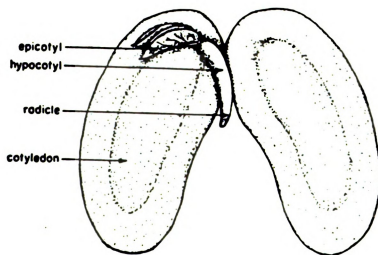
SEED COMPOSITION

The seeds of leguminous plants differ greatly in color, size, shape and seed coat thickness while they all possess similar seed structure comprising a seed coat and embryonic parts. The seed coat or testa is the outermost layer of the seed and serves as a protector of the embryonic structure. Two prominent external anatomical features include the hilum and micropyle and are thought by many to have a role in water absorption. These structures are shown in Figure 1. The hilum is a large oval scar where the seed and stalk were previously joined. The micropyle is a minute opening in the seed coat which served as a junction where the pollen tube entered the valve. The remaining portion of the seed is the embryonic stem tip, the hypocotyl or embryonic stem and the radicle or embryonic root. This portion is responsible for germination and is extremely vulnerable to damage during handling and storage.

Seed Coat. The seed coat has an important function in protecting the legume from damage due to water absorption and microbial contamination, especially during harvest and storage. An intact seed coat provides excellent protection from damage, while the presence of any splits or cracks will



A. External view



B. Internal view

Figure 1. Structure of typical legume seed: A) External view; B) Internal view. Source: Northern, 1958.

allow rapid entry of moisture and microorganisms developing a poor quality seed for later planting or food use. The seed coat consists of 7.7% of the total dry weight in the mature bean (Phaseolus vulgaris L.) reported by Powrie et al. (1960) with a protein content of 5% (d.b.). This protein content is consistent with earlier findings of 4.8% protein by Ott and Ball (1943).

The major components in the seed coat structure of legumes include the waxy cuticle layer, the palisade cell layer, the hourglass cells and the thick cell-walled parenchyma. These structures have been identified using scanning electron microscopy (SEM) in soybeans (Thorne, 1981), cowpeas (Sefa-Dedeh and Stanley, 1979a), faba beans (McEwen et al., 1974) white beans, pinto beans and adzuki beans (Sefa-Dedeh and Stanley, 1979c). The waxy cuticle layer is the outermost portion of the seed coat and its prime function is to prevent water penetration using its hydrophobic layers of waxy barriers. The cuticle does allow permeation of some polar and non-polar compounds but its main function is in the prevention of water penetration (Bukovac et al., 1981). The palisade layer has been reported by many researchers to appear with a linear lucida, or light line that gives the appearance of two layers of cells (Hamly, 1932; Corner, 1951). White and pinto beans have been found to have a light line (Sefa-Dedeh and Stanley 1979c) with the first cell layer being closest to the cuticle and highly organized while the second layer appears

amorphous. Other researchers believe the light line is only an optical effect (Corner, 1951), or simple refraction (Chowdhury and Buth, 1970). Some have found the light line to be completely absent suggesting it may only be present in the seed coat of selected legumes. The cell layers immediately beneath the palisade layer are termed hour glass cells (Corner, 1951). Sefa-Dedeh and Stanley (1979c) described this layer as the amorphous second layer in the palisade layer. The parenchyma layer cells have thick walls and stand out readily after hydration as they appear spongy and show noticeable swelling.

The role of the seed coat appears to have some effect on water absorption however the exact mechanism is not known. Research on soybeans has shown the water absorption rate to be dependent upon calcium content, seed coat surface, micropyle structure, and initial moisture content (Saio, 1976; Hsu, 1983). In studying the structural components, Sefa-Dedeh and Stanley (1979b) found seed coat thickness, seed volume, and hilum size along with protein content to all be factors in water uptake. This work demonstrated that thinner seed coats absorb water more rapidly during initial soaking (0-6 hrs).

Cotyledon. The cotyledon comprises the greatest portion of the bean in terms of weight and volume and contributes a valuable component to the texture and nutritive value of the bean as a food stuff. The cotyledon portion which is responsible for the embryonic leaf tissue

in germination makes up 90.5% of the total bean on a dry weight basis (Powrie et al., 1960). They also reported that dry cotyledons contain 39.3% starch, 27.5% protein, 1.65% lipids and 3.5% ash.

Processed texture and nutrient availability of beans are influenced by the dimensions and arrangement of the cotyledon cells. The outermost cells are identified as an epidermal layer with an inner and outer portion. The inner cells appear elongated and the outer cell layer as cubical. The epidermal layer is presumed to contain no starch as all cells appear granular which is characteristic of protein. The next apparent layer is the hypodermis which has larger elliptically shaped cells that also appear granular, characteristic of protein makeup.

The remaining and largest portion of the cotyledon contains parenchyma cells bound by a distinct cell wall and middle lamella with a few vascular bundles. The parenchyma cells have thick walls that give rigidity to the cotyledon. Within each parenchyma cell, starch granules are imbedded in a protein matrix. The secondary walls, found only in mature parenchyma cells are very thick and contain pits which facilitate the diffusion of water during soaking. Figure 2 shows a diagram of a plant cell wall. The intercellular space between primary walls of two cells is termed the middle lamella. The middle lamella is composed mainly of pectic substances and acts to hold cells together while giving strength to the total tissue. Pectic substances

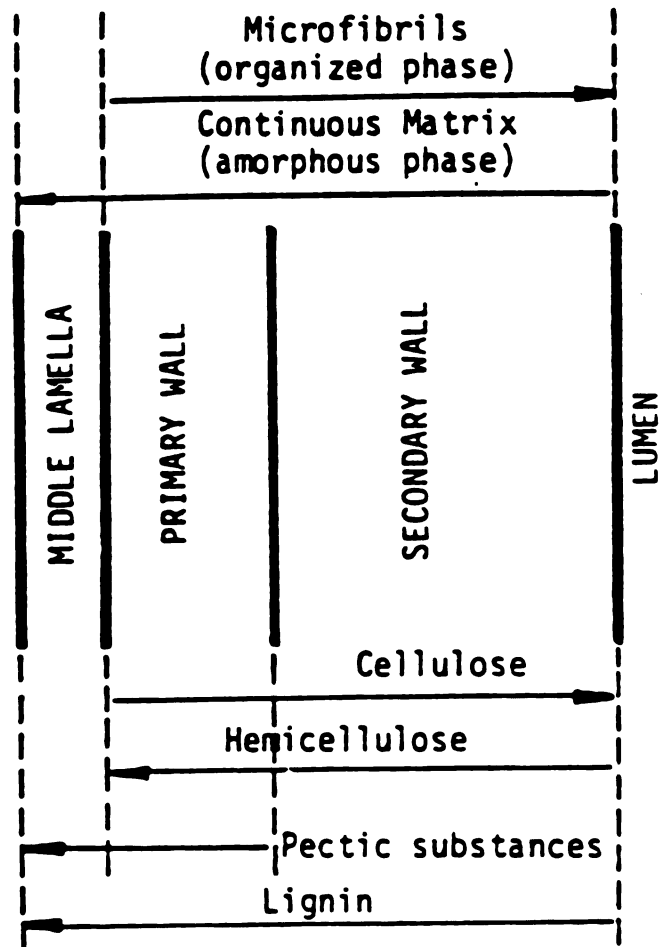


Figure 2. Diagram of a plant cell wall. Source: Bourne, 1983.

allow cross linking with divalent cations and significantly affect the texture of the plant tissue (Van Buren, 1979).

Mattson (1946) and Muller (1967) report that softening occurs in the cell wall during cooking from a reaction of phytate with insoluble Ca/Mg pectate to form soluble Na/K pectate.

Protein Content. Legumes are excellent sources of plant protein and range from 20 to 40 percent on a dry weight basis. Researchers of dry beans (Phaseolus vulgaris L.) have reported the protein content to fall in the range of 18.8% to 29.3% (Meiners, et al., 1976a; Varriano-Marston and DeOmana, 1979; Hosfield and Uebersax, 1980). Legume proteins make an important contribution to the diet especially in lesser developed countries. Legumes are found to have a deficiency in protein quality limited by methionine but supply an excess of lysine which is typically a limiting amino acid in cereal grains. Eating legumes and cereals together such as beans and tortillias, results in amino acid completion and increased protein quality for the diet. Total utilization of the legume protein is relatively low. Protein digestibility may be impaired possibly by the presence of tannins (Bressani et al., 1982; Aw and Swanson, 1985) or numerous antinutritional compounds which must be removed or destroyed by heating.

Lipid Content. Legumes vary greatly in their lipid content with the total quantity extractable in organic solvents ranging from 1 to 50 percent. Pulses, possessing

predominate carbohydrate reserves, have lower levels of lipid while oilseed legumes possess high lipid reserves. The major fraction of lipid found in legumes is of concern during storage as lipid oxidation can produce off flavors and odors.

Carbohydrate Content. Legumes contain 24% (winged beans) to 68% (cowpeas) total carbohydrate on a dry basis of which starch is the major fraction accounting for 24 to 56% (Reddy et al., 1984). Total soluble sugars comprised of mono- and oligosaccharides are only a small portion of the total carbohydrate content in legumes. Within the total sugars, the oligosaccharides of the raffinose family are most prevalent ranging from 31 to 76% (Rockland et al., 1979; Reddy and Salunkhe, 1980; Fleming, 1981; Sathe and Salunkhe, 1981). The oligosaccharides found include raffinose, stachyose, verbascose, and ajugose with stachyose being predominate in most varieties of Phaseolus vulgaris L. It is reported that legumes are a good source of crude fiber ranging from 1.2 to 13.5% (Reddy et al., 1984). Cellulose is the major fraction followed by hemicellulose, lignin, pectic and cutin substances.

The starch found in legumes has oblong granules which vary in size by species. Research has shown that the legume starch granule is resistant to swelling and rupture and generally contains 20 to 30% amylose content (Naivikul and D'Appolonia, 1979). Starch granules can greatly influence the cooking characteristics of legumes. Gelatinization

temperatures ranging from 60°C to over 75°C are relatively high compared to cereals and may contribute to processing variability (Hahn et al., 1977).

Ash and Minerals Content. Total ash content of legumes on a dry weight basis is in the range of 2.9 to 4.9% (Watt and Merrill, 1963; Fordham et al., 1975; Meiners et al., 1976; Tobin and Carpenter, 1978; Koehler and Burke, 1981). Ash content is found to decrease after cooking due to leaching with reported losses ranging from 10 to 70% (Watt and Merrill, 1963; Meiners et al., 1976). This wide range of losses could be due to different soaking and cooking methods. Raw beans also demonstrate differences in percent ash with factors such as variety, growing location, and soil composition contributing to the variance.

A review of current literature for Phaseolus vulgaris L. in the raw mature state, indicated that the following ranges for mineral content have been reported in parts per million concentration: Ca, 595-2600; Cu, 5-14; Fe, 13-135; Mg, 1230-2300; Mn 6-232; Na, 17-210; P, 2800-5700; Zn, 17-65; K, 8208-19400, (Watt and Merrill, 1963; Walker and Hymowitz, 1972; Fordham et al., 1975; Meiners et al., 1976b; Augustin et al., 1981; Koehler and Burke, 1981). Variability may be attributed to bean varieties, growing location, soil composition, and method of measurement.

Mineral retention during cooking has been studied. Meiners et al. (1976b) cooked ten legume varieties until tender and measured the contents of nine minerals in the raw

and cooked state. Minerals in the cooked legumes were one third to one half the values in the raw legumes. High levels of magnesium, phosphorus, and potassium were found in the cook water. Augustin et al. (1981) found retention of minerals during cooking was 80 to 90% with exception of 38.5% sodium retention and total calcium retention. Koehler and Burke (1981) in a similar study found close agreement with Augustin et al. (1981).

BEAN SOAKING AND BLANCHING

Research shows that soaking dry beans before cooking can provide many beneficial attributes to the final cooked product. Soaking serves to remove foreign material, facilitate cleaning of beans, aid in can filling through uniform expansion, ensure product tenderness and improve color (Cain, 1950; Crafts, 1944; Hoff and Nelson, 1966). Several methods of soaking have been proposed to accelerate water uptake during soaking thus decreasing the cook time required to tenderize the bean. Various soak methods or pretreatments include: 1) heat treatments (Gloyer, 1921; Dawson et al., 1952; Morris, et al., 1950; Snyder, 1936); 2) soak water additives (Greenwood, 1935; Morris et al., 1950; Reeve, 1947; Elbert, 1961; Rockland, 1963; Snyder, 1936); 3) vacuumization or sonification (Hoff and Nelson, 1967); 4) scarification of seed coat (Morris et al., 1950), and 5) dipping in concentrated sulfuric acid (Gloyer, 1921).

The results of these soak treatments provide a wide range of variability in quality attributes of cooked beans.

Regardless of treatment, research has demonstrated that there are many physiochemical factors that contribute to the water absorption rate during soaking. Some factors include seed coat thickness, availability of possible paths (the hilum, micropyle, and raphe) of water entry (Kyle and Randall, 1963; Saio, 1976; Sefa-Dedeh and Stanley, 1979c; Korban et al., 1981) pectic substances, storage temperature and humidity, age of bean, initial moisture content, protein content, seed density and bean size.

Heat Treatment in Soaking. Dry beans have traditionally been soaked overnight (12-14 hours) at ambient temperature prior to commercial processing. To increase the efficiency of water uptake and possibly improve quality aspects of the finished product, a heated blanch has been found by many researchers to be effective. Shorter soak times of dry beans for processing show beneficial effects on drained weight and riboflavin retention producing equal or improved quality than that attained in overnight soaking (Nordstrom and Sistrunk, 1977).

Junek et al. (1980) found different soak temperatures to have no effect on drained weight of navy beans but kidney and pinto beans had greatest drained weight when soaked at 25°C and 35°C compared to 15°C. Kidney and pinto beans showed increased splitting and decreased firmness when soaked at 35°C. Navy beans split more at 15°C but were softest when soaked at 35°C. Soaking at higher temperatures improved color of kidney and pinto beans with negligible

effects on the color of navy beans. Kon (1979) found that increasing the temperature of soak water yielded elevated rates of water uptake and shorter soak times to attain maximum imbibition. Hoff and Nelson (1966) while using soak temperatures from 50 to 90°C established the range for maximum uptake from 60 to 80°C. They attribute the rate of water uptake to the trapped or adsorbed gases in interstitial tissues being released from the bean surfaces by steam pressure, vacuum and sonic energy. Other researchers believe that heat is needed to precipitate the Ca^{++} and Mg^{++} ions to prevent tough pectin metal complexes from forming (Mattson, 1946). Another opinion lies with heat causing an inactivation of phytase and pectin esterase (Morris and Seifert, 1961). If these enzymes are allowed to act they could cause a shift in divalent ions and cause tough pectin-metal complexes. VanBuren (1980) measured the amount of calcium binding sites in snap beans inherently and after a 71 and 93°C blanch. The 71°C blanch had more binding sites and created a firmer texture in the presence of calcium added soak medium. More recent work shows that heating effects vegetable texture by causing cell separation and softening from the thermal degradation of intercellular and cohesive materials (Bourne 1976; Loh et al., 1982). During heating the native protopectin forms pectin and will depolymerize rapidly while heated.

Steam blanching of dry beans produces a higher drained weight and firmer texture than that attained when water

blanching is employed. This depends upon the cultivars used (Sevilla and Luh, 1974; Davis, 1976; Nordstrom and Sistrunk, 1977; Nordstrom and Sistrunk 1979; Drake and Kinman, 1984). Steam blanched beans had more nutrient retention and less leaching of soluble solids than did water blanched beans (Nordstrom and Sistrunk 1979; Sevilla and Luh, 1974). Blanch method as observed by Nordstrom and Sistrunk (1979) did not effect percent splits but bean type and storage time had a significant effect. Davis et al. (1980) determined that steam blanching produced an equivalent product to water blanching with no significant differences in quality. Beans blanched in steam, when evaluated by judges, were rated higher in color, liquor viscosity, bean wholeness and general appearance. The steam blanch may aid in setting color and produce gelatinization of starch with minimum leaching (Nordstrom and Sistrunk, 1979). Although there are many benefits of presoaking, Quast and DaSilva (1977b) found that hydration prior to cooking did not produce significantly different values for cook time. Hsu (1983) in developing a model for maximum water uptake found temperature, solute concentration, and initial moisture content were most important while protein content, density, and bean size had little effect on rate of water uptake.

Soak Water Additives. The topic of soak water additives and their effect on the rate of water uptake has been a primary area of emphasis by many researchers. Additives of interest include: sodium chloride, sodium

tripolyphosphate, sodium bicarbonate (Greenwood et al., 1935), sodium carbonate (Rockland and Metzler, 1967; Varriano-Martson and DeOmana, 1979), hexametaphosphate, malic acid and citric acid (Luh et al., 1975, Junek et al., 1980), ethylene diamine tetra acetic acid (EDTA) (Daoud et al., 1977; Kilgore and Sistrunk, 1981; Lu, et al., 1984), calcium chloride (Luh et al., 1975; Van Buren et al., 1984).

EDTA. Hoff and Nelson (1966) observed no effect of EDTA on water uptake. These results concur with data of Junek et al., (1980) where they found no difference in firmness of beans soaked in EDTA. However, EDTA has been found to prevent discoloration in foods due to its' ability to chelate metal ions and thus reduce their reactivity. Luh et al. (1975) reported EDTA effective in improving color of processed beans which may be attributed to the binding of iron or copper ions with EDTA Na₂. Soaking in EDTA produced no firming effects and rendered only a slight improvement in color for Lu et al. (1984). In nutritional studies on the effects of additives, EDTA was established not to have a detrimental effect on vitamin B₆ as did NaHSO₃ (Daoud, et al., 1977). Further nutritional studies suggested that EDTA has no effect on the B-vitamins, pantothenate, niacin and folacin (Kilgore and Sistrunk, 1981). As expected, EDTA alone had no effect on shear value and produced improved color values. However, when EDTA was used in combination with bicarbonate buffer, Kilgore and Sistrunk (1981) reported no improvement in color and a firming effect. EDTA

when used with phosphate or citrate had a softening effect.

Polyphosphates. In the investigation of water uptake, a correlation has been observed between tough beans and slow water uptake (Morris, 1963). Metal ions and pectins have obvious influences over bean tenderness as does protein and free fatty acids. Research on frozen fish has shown that small amounts of free fatty acids reduce the water holding capacity of proteins. Polyphosphates are used in the meat industry to increase water holding capacity and they also sequester divalent metal ions so they are especially beneficial in bean soaking. Addition of salts to the soak water will allow the proteins to become more soluble and facilitate water uptake and softening (Hoff and Nelson, 1965). When Hoff and Nelson (1965) did preliminary testing with the addition of polyphosphate and sodium chloride they found an increased amount of water uptake with the polyphosphate and a slightly depressed amount with the sodium chloride. They however, still found greater water uptake with the addition of polyphosphate or sodium chloride than with the conventional soak. Soaking with increased levels of polyphosphate (.5%), the seed coats were so tender they could not be handled without destruction. The optimum finished bean volume and tenderness was obtained by a combination of the additives (Hoff and Nelson, 1965).

Sodium Salts. The addition of sodium salts to soak water has been found beneficial in increasing water uptake by many researchers. It is suggested that the sodium salts

enhance solubilization of pectic substances due to an ion exchange where the sodium ions replace the toughening divalent ions. In 1936, Snyder reported that the addition of sodium bicarbonate to soften seed coats and cotyledons of beans, had no adverse effect to appearance or flavor. Other research (Dawson et al., 1952) supports the addition of sodium bicarbonate to enhance water uptake. These researchers reported a 42% increase in water uptake when cooked with added sodium bicarbonate. Lu et al. (1984), using a sodium bicarbonate solution to soak faba beans, reported increased drained weight and increased softness while color was darker. This treatment had no effect on B-vitamin retention. A variety of salt solutions have been investigated in an effort to produce a quick-cooking dry bean (Rockland and Metzler, 1967). These salt solutions included sodium chloride, sodium tripolyphosphate, sodium bicarbonate and sodium carbonate. Using the salt solutions for soaking medium and specific soak methods, these researchers produced a product that cooked in 15 minutes. Tripolyphosphate was found most effective in reducing cook time of cotyledons. Varriano-Marston and DeOmana (1979) reported the use of four sodium salt solutions on black beans. They found the amount of sodium ion (Na^{++}) present during soaking did not effect the water absorption but altered the mineral content and the amount of pectic substances solubilized during soaking and cooking. Further investigation using X-ray microanalysis suggested that ion

exchange and chelation were responsible for softening effects. Silva et al. (1981a) reported using the four sodium salt solution was most effective in promoting softening during cooking when compared to no soaking or distilled water soak. Sodium bisulfite was found to have a detrimental effect on vitamin B₆ retention although this treatment produced an improvement in color (Daoud et al., 1977).

pH. Addition of acid to soaking medium has been investigated by many researchers. Snyder (1936) used hydrochloric and acetic acids in various concentrations for soaking and found decreased water absorption and very tough seed coats. In her study, oxalic acid was found to soften the seed coat but this product was not feasible for consumption. Soaking in the presence of citric acid yielded improved color in canned beans and also resulted in a decreased drained weight with increasing acidity (Luh, et al., 1975). It is suggested that the citrate ion complexes with iron and copper making them unavailable to react with phenolic compounds thus controlling off color development. An increase in bean firmness was noted by Nordstrom and Sistrunk (1977) for beans processed in a tomato sauce of pH 5.0 to 5.2. Junek et al. (1980) also found an increase in firmness and improved color in navy beans when soaked in an acidic solution of citric or malic acid. Varriano-Marston and DeOmana (1979) reported a decrease in pH of soak water during the soak period resulting from a loss of hydrogen ion

in the cellular component of the beans. The changes of pH in soak water medium influences the amount of water absorption. Nutritional analysis showed soaking black eyed peas at pH ranging from 4.5 to 8.5 had no effect on vitamin retention (Kilgore and Sistrunk, 1981). They also noted that tenderness increased with increasing pH.

Minerals. Snyder (1936) reported that the addition of sulphates and chlorides of calcium and magnesium at 100 ppm, resulted in depressed water absorption and hardened seedcoats. A positive correlation was found between increasing concentrations and bean firmness. The addition of calcium ions to canned foods has been well substantiated and is commercial practice for producing a firmer product (Davis and Cockrell, 1976; Luh et al., 1975). Splitting of glycosidic bonds by B-elimination causes an increased solubility of pectic material or softening. This reaction is catalyzed by hydroxyl ions and other ions such as Ca^{++} , Mg^{++} , K^+ , citrate, malate, and phytate. Calcium can have two opposite effects on texture. First, a firming effect is caused when it links polyuronide chains to pectic substances by crosslinking the matrix. Second, it can also enhance tissue softening by the B-elimination reaction as described here. However, the net result of calcium addition is usually a firming effect (VanBuren, 1979). Quenzer et al. (1978) substantiates earlier work by demonstrating that calcium concentration was positively correlated with shear and negatively correlated with imbibition. Uebersax and

Bedford (1980) presented supporting data showing that with increasing calcium concentrations, beans were firmer and when calcium was added in the presence of heat the firming effect was even greater. As previously stated, VanBuren (1980) found an increase in the number of calcium binding sites after treating with a blanch of 71 and 93°C. Addition of CaCl_2 to soak and brine waters has contributed to a significant reduction in seed coat splitting of kidney beans (VanBuren et al., 1986). Levels of 150 to 350 ppm CaCl_2 resulted in lower weight gain during soaking, reduced drained weight, firmer processed beans and less seed coat splitting.

COOKING AND PROCESSING

Many factors are involved in the cookability and resulting cooking quality of dry edible beans. Although processed beans must be cooked long enough to obtain commercial sterility, achieving product tenderness is often a problem. Many studies have looked at cookability of beans and have found some of the influential parameters to include: 1) growing conditions, variety, initial moisture content and seed size; 2) storage conditions including temperature, relative humidity and time; 3) soaking, blanching and cooking conditions.

Growing and Genetic Effects. Snyder (1936) in studying great northern and pea beans, found growing location did not contribute to significant differences in cooking quality. Hosfield et al. (1984) did find significant differences in

drained weight, texture, and color in black turtle soup beans grown in three different seasons. Bean varieties were found to differ in genetic potential when grown in different environments (Muneta, 1964). They noted cook times differed considerably within a single variety from different locations in one season, and in different years. Size of bean has been examined to determine its effects on cookability. Larger seed could cook more slowly due to its mass, however, Snyder (1936) and Morris (1963) found seed size negligible in cook time.

Storage Effects. During storage of dry beans, temperature, relative humidity, initial moisture and time are critical factors in preserving good cooking quality. Snyder (1936) reports optimum storage conditions to include a tightly closed container held at 45°F. Morris and Wood (1956) found beans above 13% moisture had poor texture and flavor after canning when stored for six months at 77°F. Beans stored at 10% moisture or less had good cooking quality for two years. Morris (1963) also observed little change in cookability of pinto, navy and large lima beans stored with low moisture contents. In a study of cooking quality, beans with low original moisture contents (9.1-12.2%) had higher hydration ratios (Nordstrom and Sistrunk, 1979). Beans with 16% initial moisture and steam blanched were firmer in texture which also correlates with beans that had higher drained weights were less firm. Burr et al. (1968) observed as storage temperature and initial moisture

content increased, the rate of hydration decreased. Later research by Antunes and Sgarbieri (1979) supported this and concluded that cook time increases with increasing storage temperature and relative humidity. Burr et al. (1968) presented a dramatic increase in cook time of pinto and navy beans stored in adverse conditions. Pintos showed a fourteen fold increase in cook time from 24 minutes when fresh to 340 minutes after 7 months of storage at 90°F and 14% moisture. The navy beans at 14.2% moisture required 27 minutes to cook when fresh but after 11 months of storage at 90°F took 450 minutes. When beans were stored at 90°F with low moisture contents or stored at lower temperatures, there was a less dramatic change in cookability. Moscoso et al. (1984) reported that softening rate of kidney bean decreased with increasing time of storage.

Researchers agree that legumes stored at high temperatures and high humidities accelerate the increased cook time or hard to cook phenomena. These environmental conditions are similar to those found in the tropics where legumes are a major source of protein. Storage under these conditions can lead to mold growth, development of off flavors, lipid oxidation, darkened color and development of hardshell (Morris 1963; Muneta, 1964; Burr et al., 1968; Molina et al., 1976). The cause of hardshell development is not well understood but the phenomenon occurring is defined when a seed fails to imbibe water within a reasonable time when it is moistened (Bourne, 1967). Beans stored at low

temperature (4°C) or at low moisture content (8-10%) in a low relative humidity environment have less occurrence of hardshell condition (Burr et al., 1968; Kon, 1968; Morris and Wood, 1956; Muneta, 1964; Molina et al., 1976; Antunes and Sgarbieri, 1979). Bourne (1967) observed that hardshell beans tended to be smaller in size than non-hard shell beans. It is suggested by some that a heat treatment before storage gave favorable results on water absorption thus minimizing the hardshell development (Morris et al., 1950; Molina et al., 1975; Molina et al., 1976). Research conducted by Burr et al., (1968), Rockland (1963) and VonMollendroff and Preistley (1979) has shown that the hardshell condition is accelerated when beans are stored with moisture content above 13%.

Soaking, Blanching, and Cooking Effects. Studies to examine cooking rates have placed much emphasis on soaking and blanching treatments. Snyder (1936) stated that beans cook more rapidly if first subjected to soaking. Her recommendation is to soak at 120°F where beans doubled in weight in five to six hours. Juneck et al. (1980) reported an increase in soak temperature from 15°C to 35°C caused lower shear press values than water blanched beans (Nordstrom and Sistrunk, 1979). In a similar study by Davis (1976) and Nordstrom and Sistrunk (1977), pintos that were not blanched or steam blanched had higher drained weights and firmer texture than those water blanched. This suggests that there is less solids leaching with the no blanch or

steam blanch treatments. Quast and daSilva (1977b) presented findings that hydration during soaking in black beans does not significantly decrease cook times. Soaking of peas before cooking yielded higher drained weights but had no effect on the drained weight of black beans.

In another study, Quast and daSilva (1977a) noted raising the cook temperature 10°C caused a 3.36 fold decrease in cooking time for black beans. Davis (1976) reported that cook temperature had no effect on drained weight ratios or percent splits but had a pronounced effect on firmness. Light red kidney and pinto beans processed at 240°F for 45 minutes had significantly lower shear values than samples processed at 250°F for 20 minutes, regardless of blanch treatment. The opposite effect occurred for navy beans in this study. He concluded that process time had greatest effect on firmness in light red kidney and pinto beans and process temperature had the greatest effect on navy beans. Silva et al. (1981b) examined activation energies of bean softening in cooking ($90\text{--}135^{\circ}\text{C}$) after soaking in different solutions. The Z values for no soak, water soak, and salt combination soak were calculated at 17, 22, and 36°C respectively. Quast and daSilva (1977a) stated that cooking beans for nine minutes at 127°C gave the same result as cooking for 260 minutes at 98°C .

An investigation of accelerated water uptake by Hoff and Nelson (1965) examined the effects of releasing gases by 1) steam pressure, 2) vacuum treatment or 3) sonication

before cooking. It was observed that during soaking the seed coat appears wrinkled and they suggest that gases fill the interstitial pores, preventing water uptake. Steam pressure showed no effect after two minutes exposure. Vacuum treatment for short periods did cause increased water absorption but sonication was suggested to be the most efficient means. The quick cooking method for lima beans developed by Rockland and Metzler (1967) included loosening seed coats by vacuum treatment, soaking in a four salt solution for 6 hours, rinsing and drying. Using this method, cook times ranged from 25 to 35 minutes.

SCANNING ELECTRON MICROSCOPY

Microstructure does influence water absorption characteristics and texture of soaked and cooked legumes. During cooking, legumes undergo a breakdown of the middle lamella and starch gelatinization. Sefa-Dedeh et al. (1978) demonstrated with raw cowpeas that the middle lamella is stronger than the cell walls. When sliced with a razor blade in the raw state, the tissue breaks across the cell walls. As the middle lamella becomes softer with cooking it ruptures when stress is applied, leaving the cells intact. Swanson et al. (1985) stated the structure of the cotyledon changes markedly after one hour of imbibition. During hydration the protein matrix loses its granular appearance and becomes homogeneous. Starch granules and protein bodies begin to swell and the middle lamella expands by water absorption. After soaking for 24 hours, fracturing occurs

exclusively around cells leaving only the exterior cell wall and middle lamella visible.

Swanson et al. (1985) observed the seed coat surface of an unsoaked Sanilac beans is relatively smooth with occasional crevices and numerous pieces of amorphous material. The seed coat of an unsoaked Nep-2 bean appeared randomly rough with small clumps sticking out from the surface. After soaking it appeared covered with large flakes and particles of wax like material. They stated, water absorption may result in compression of cells in a smooth seed coat to cause apparent roughness.

Sefa-Dedeh et al. (1978) studied the effect of heating temperature and time on the texture of cowpeas. They presented a linear decrease in maximum force required (softening) with increasing temperature (25 to 100°C). However, SEM did not show much microstructural change at these temperatures, suggesting other factors may contribute to softening.

EFFECTS OF CANNED STORAGE ON QUALITY OF PROCESSED BEANS

Quality characteristics have been observed to change over time in processed beans with the most noticeable being texture, drained weight, and percent splits. Luh et al., (1975) reported the texture of beans stored for six months was firmer than those stored for two months. It is suggested that calcium ions diffuse from the brine into the beans after canning causing a firming effect. Davis and Cockrell (1976) noted that shear press values increased

significantly from 1 day after processing to 1 month storage, regardless of the level of calcium added. However, they also noted that adding increasing levels of calcium significantly increased shear press values. Nordstrom and Sistrunk (1977) evaluated canned samples at three and six months and found a decrease in firmness at six months along with an increase in percent splits and a decrease in riboflavin. In a later study by the same researchers (1979), eight bean types were found to increase in shear press values from 0 to 6 months storage with each decreasing at 9 months. Percent splits increased over time with the greatest increases in navy, pinto, and Dwarf Horticulture #4. Vitamin E was found to decrease over time in the canned product. Soak time appears to play an important role in the quality changes during storage. In a one month study by Davis et al. (1980) pinto, small lima, and large lima beans were evaluated. Pinto showed no significant difference in drained weight or texture between one day and one month storage. Percent splits showed a significant decrease after one month storage perhaps because the splits closed to a point where they weren't detectable. Both small and large lima beans showed no significant difference in drained weight over time but they both were significantly different in texture after one month storage. Junek et al. (1980) reported drained weight of navy beans decreased slightly between 3 and 18 months of storage. Splits in pinto, kidney, and navy beans decreased with time. Shear press

values decreased with time but were not significant changes. The kidney and pinto beans were lighter in color and more red after 18 months. Panelist preferred kidney bean color at 18 months and pinto and navy at 3 months.

TEXTURE MEASUREMENT

Mechanical. Many instruments have been invented for measuring food texture and rheological properties. Of these instruments many have limited applications and have been replaced by fewer basic test instruments with multiple texture interpretations. By 1940 most principles of measuring food texture were established and provided a good base for developing texture measuring equipment. Use of electromechanical sensors and electronic recording systems further advanced the precision of the instruments. This lead to greater understanding of the complexity involved in the texture of food systems. Current criteria for all texture measuring instruments include a consistent means of deformation and a precise measurement of force, deformation, and time. Initial classification of texture measuring instruments can be divided into three classes depending on the type of motion used: (1) linear, (2) rotary, and (3) combined linear and rotary. Within each of these classes a further division of types include: (1) fundamental, (2) empirical, and (3) imitative. Fundamental methods are used to evaluate a specimen in a specific way with well defined parameters of force, deformation, and time. The results are used to directly relate the nature of the specimen to

rheological theories. Using empirical methods, the food is subjected to a combination of stresses and the sample reaction is recorded as one value. Empirical methods are the most common used and include instruments like the Warner-Bratzler meat shear (Warner, 1928) and the Kramer Shear Press (Kramer et al., 1951). These instruments measure the force required to achieve a certain change in food whereas, fundamental methods measure a single mechanical property. This total force can be a combination or sequence of stresses to include compression, tension, shear flow, or extrusion. Strict control of test parameters is required and results can only be considered comparative within a specific set of conditions. Imitative instruments are designed to simulate conditions that food might undergo such as chewing, biting or kneading. The forces involved here are very complex and theoretical analysis is most difficult.

In measuring texture of legumes, empirical methods seem most feasible and shearing devices within that class are the most popular. The Instron testing machine (Instron, Ltd.), a fundamental method, is employed for some theoretical analyses but is not feasible in many testing situations.

Fresh peas are the most thoroughly studied legume in terms of texture. Financial return on the product is determined by optimizing a harvest date that gives increased yield and acceptable tenderness. The F.M.C. Pea Tenderometer introduced in 1937 was used as a means to

determine pea tenderness at harvest, for grading and for price paid to grower. This was the first widely adapted texture measuring instrument that used a multiblade shearing principle. The tenderometer consists of a grid of blades rotated at constant speed through a second grid. As the peas are cut by the blades, the maximum force is indicated by a pointer moving over a graduated scale (Voisey and deMan, 1976). Although this is a simple machine and easy to operate, it has been suggested that it be retired because of its lack of precision (Voisey, 1974). Muneta (1964) in determining cook time of dry beans found the tenderometer readings to vary greatly among replicates. Many researchers have continued to work on the improvement of the tenderometer but have not had real success. The most beneficial results have come from adapting existing texture measuring instruments specifically for peas. The Ottawa texture measuring system has a special version called the Ottawa Pea Tenderometer (Voisey and Nonnecke, 1972) and the Kramer Shear Press is used with a model T-1300 Tenderometer system device by Food Technology Corporation.

The Ottawa texture measuring system introduced in 1971 (Voisey, 1971b) was designed to achieve results such as other shear instruments but at a reduced cost. It works by a simple screw operated press that accommodates different test cells. The purpose is to provide equipment that could be used in both research and quality control applications. Voisey (1973) used the Ottawa texture measuring system with

a wire extrusion cell to test baked bean texture.

One of the most popular and versatile texture measuring instruments is the Kramer Shear Press, developed at the University of Maryland (Kramer et al., 1951; Decker et al., 1957). This instrument has undergone many physical changes along with its name changing over the years. The basic machine is known as the "Texture Press". The system is driven hydraulically and the force is measured by a force transducer ranging from a 0 to 3000 lb capacity. The force is recorded on a strip chart recorder termed "texturecorder". The standard cell is a box with a multiple blade unit. However various test cells can also be employed to increase the versatility of the instrument. The advantage of the force transducer is its ability to stay calibrated during wet and rugged conditions. The texture press is probably the most widely used texture instrument in legume research. Early work demonstrated it could be used to estimate the quality of processed lima beans (Salunkhe and Pollard, 1955). Continuous improvements and adaptations of the instrument allowed its use for analytical testing in the research setting (Binder and Rockland, 1964).

The Instron testing machine was introduced in 1949 (Hindman and Burr, 1949) as a general purpose testing machine for textiles, paper, plastic and rubber. Bourne et al. (1966) introduced its use for food and scientists rapidly adopted it as a measuring device. The machine basically consists of two parts: 1) a drive mechanism that

moves a crosshead vertically by means of twin lead screws at selected speeds; and 2) the load sensing and recording system (Bourne et al., 1966). The Instron is only suitable for laboratory work because of its sophisticated controls. It is most useful in testing basic material properties such as tension, compression, and bending. Many new applications are being tested by adapting test cells from other equipment for use with it.

Voisey and Larmond (1971) tested baked beans with the Kramer shear-compression cell, a back extrusion cell, the F.M.C. Pea tenderometer, a plate extrusion cell and wire extrusion cell on the Instron universal testing machine. The results were highly correlated with sensory scores for hardness and cohesiveness. They concluded that the selection of an objective test be made on practical considerations and equipment at hand. Further work by Anzaldua-Morales and Brennan (1982) using the Instron for measuring puncture, shear, back extrusion and compression on baked beans also found correlations with sensory measures. Back extrusion correlated with sensory firmness and chewiness and the testing was faster and more reproducible compared to the other methods. Back extrusion is used by some bean researchers to measure cooked bean firmness (VanBuren et al., 1986).

Use of the Instron universal testing machine has the advantage of testing individual bean samples compared to multiple bean samples in the Kramer shear press. Bourne

(1972) adapted the puncture test to the Instron for simple, rapid and routine measurements of cooked dry beans. Silva et al. (1982a,b) have used the puncture test extensively and have found good correlations with sensory tests of cooked bean texture. They reported an Instron puncture force of 150g (0.14 cm probe, 5cm/min) accurately defined the "eating-soft" limit of texture acceptability. A considerable drawback to this method is the numerous amount of measurements that need to be taken, with some researchers taking 500 bean punches for one mean (Moscoso et al., 1984). The Instron is the only texture measuring system today that can measure raw or cooked beans. A wedge type blade mounted on the Instron was developed by Sefa-Dedeh et al. (1978) to cut through the hard dry bean.

An instrument designed especially to measure the texture or cookability of legumes was developed by Sante Mattson (Mattson, 1946; Mattson et al., 1950). This experimental legume cooker was first developed for peas but works equally well for beans. The objective of this instrument was to gather cook data for individual beans rather than a multiple bean sample. The apparatus is composed of a number of plungers, all of equal weight, that each rests upon a single bean. The cooking apparatus loaded with bean samples is lowered into a heated water bath and time for the plunger to penetrate each bean is recorded. Cook time is usually determined as the time for fifty percent of the plungers to penetrate. This cooking

apparatus has been used by many bean researchers and has been modified by some (Morris and Seifert, 1961; Morris, 1963; Burr et al., 1968; Burr, 1976; Jackson and Varriano-Marston, 1981).

Researchers at General Foods Corporation evaluated instruments that would interpret physical measurements of their subjective texture profile. This research resulted in development of the "Texturometer" (Friedman et al., 1963). This is an imitative instrument that simulates chewing and measures the changes on a strain-gauge sensing plate. They found good correlation between the instrumental values and subjective evaluations by a trained texture profile panel (Szczesniak et al., 1963).

Interpreting Force-Deformation Curves. To understand texture measurements with empirical instruments, consideration must go into the interpretation of total force or the force curve over time. Early instruments recorded one value of total force required which indicates little about the texture attributes involved. An instrument that could record force throughout the test would provide more information about the texture of the product. The General Foods Texturometer provided a major advance in texture research through its use of a force-time recorder. With the Texture Profile Analysis (TPA), Szczesniak et al. (1963) correlated eight textural parameters to the force-time curve.

The versatility of the Kramer shear press with such a wide variety of foods along with the complex forces applied, can lead to misinterpretation of force curves. Voisey (1977) suggested, direct observation of the testing with plastic inserts to determine the mode of action during the test. Szczesniak et al. (1970) concluded that few foods would undergo a single predominate force but rather that most foods are subjected to a combination of compression, extrusion, and shear. Voisey (1977) observed canned peas in the Kramer shear press and notes that the sample is compacted to 55% of its original volume before rupturing begins. The individual peas are forced into gaps between the blades which causes their skins to split and the cotyledons to be forced apart. When the peas were compacted to 5% there was a sudden increase in force as the blades approached the cell bottom and a disproportionate amount of skins were ruptured. He concluded that the peak force was influenced by skin toughness and not shear strength of the peas. This is in agreement with Binder and Rockland (1964) for samples of lima beans with and without seed coats and with seed coats alone. Lima beans without seed coats showed no shear peak however the intact beans clearly produced definable shear peaks. Hosfield and Uebersax (1980) report similar curve findings with samples of commercial dry bean cultivars.

Sensory. Many instruments have been developed to measure food texture but the results have little meaning

unless they can be correlated with consumer response. According to Abbott (1973), the food industry needs reliable sensory panels for three reasons: 1) to assess the relative importance of texture to the acceptability of a food item; 2) to determine the textural characteristics which are important to food; and 3) to evaluate the appropriateness of a particular objective test for a textural characteristic. Thus, subjective testing is required to evaluate and understand objective tests.

In sensory evaluation there are three fundamental types of panels used for flavor, color and/or texture testing. Preference/acceptance tests evaluate consumer opinions or likes and dislikes. Preference determines the preferred sample while acceptance asks "would you use this product?" Discriminatory tests evaluate only for differences that may occur between products. Descriptive tests evaluate differences and ask for a magnitude of difference between products.

Descriptive testing is the most commonly used method, especially when a definition and measurement of specific product characteristics are desired. The Flavor Profile method, developed by the Arthur D. Little company (Caul, 1957) was the first scientific method introduced to characterize flavors and scale their intensities. This procedure gained much attention and popularity. Other descriptive methods were developed using a similar approach. In the early 1960's, Dr. Alina Szczesniak (1963) lead

researchers at General Foods Corporation to develop a system for classifying textural characteristics. They also developed the Texture Profile Analysis (TPA) that used the Arthur D. Little Flavor Profile method as a model (Brandt et al., 1963). Texture Profile Analysis is the basis for sensory texture evaluation today. A Quantitative Descriptive Analysis (QDA) system introduced in 1974 by Stone et al. (1974) was designed as a modified profile procedure. This system uses extensive panel training, statistical analysis, and graphical presentation of the data. The QDA method was first reported as a successful tool in evaluating beer by sensory profiling by McCredy, et al. (1974).

In the study of legumes, many researchers have used sensory panels in a variety of methods and in varying degrees of complexity. The simplest determination is in the evaluation of cook time. The final cook time can be determined by squeezing the bean between your thumb and forefinger (Jones and Boulter, 1983) or by mastication (Binder and Rockland, 1964; Kumar, et al., 1978). Magnitude scaling tests are used on color, flavor, and overall acceptability along with texture (Morris and Wood, 1956; Silva et al., 1981a).

More sophisticated means of utilizing sensory data is in the correlation of panelist data with objective measurements. Voisey and Larmond (1971) determined correlations for many objective methods in attempting to

select the best method to evaluate baked bean texture. The sensory testing was conducted on hardness, guminess, adhesiveness, and acceptability as described by Szczesniak (1963) and Szczesniak et al. (1963). Hardness and guminess correlated at the 5% or 1% significance level for all the objective tests. Adhesiveness was not significantly correlated. They concluded that the objective method be determined on practical and economical considerations because of the high correlations with the tests they used. In predicting an acceptable texture of processed beans, Silva et al. (1981a) found highest correlations between puncture force from the Instron with sensory texture of black beans. A mathematical model was developed to predict sensory responses from instrumental data as follows: $\text{Sensory texture} = 2.54 \ln(\text{Force}) - 7.82$, ($r^2=0.91$). They predicted from the Instron puncture data that 150g of force is "eating soft", while 175g is undercooked and 125g is overcooked. Bourne (1972) reports that puncture tests by the Instron yield higher correlation coefficients with sensory scores than shear tests because of the number of measurements made on individual beans. An additional study on processed bean texture used firmness, chewiness, smoothness and a general hedonic rating for sensory scales (Anzaldua-Morales and Brennan, 1982). Correlations with objective measures were found. Compression tests correlated significantly with sensory firmness. Significant correlations in the back extrusion test, were maximum force

and energy for extrusion, with sensory firmness and chewiness respectively. Shehata et al. (1983) reported significant correlations between sensory softness score and penetrometer reading ($r = 0.83$, $P < 0.01$) and between softness score and Kramer maximum shear force ($r = -0.77$, $P < 0.01$).

Dos Santos Garruti and Bourne (1985) used Texture Profile Analysis (TPA) with a trained sensory panel and correlated results with the Instron for compression and puncture tests. Red kidney beans were stored at constant moisture and high and low temperatures for six months. Samples stored at higher temperatures were instrumentally measured and ranked higher for hardness, fracturability, guminess, chewiness, springiness, and cohesiveness. The same beans evaluated by the sensory panel, rated higher for hardness, fracturability, lumpiness, chewiness and skin toughness. They rated lower than the control for starchiness, guminess, pastiness and moisture absorption.

MATERIALS AND METHODS

DRY BEAN HANDLING PRIOR TO PROCESSING

Harvest and Storage. Figure 3 provides an outline of the dry bean handling procedure (Wilson et al., 1986). Samples of C-20 navy beans and Montcalm dark red kidney beans were harvested, thrashed, cleaned and brought to the MSU Legume Quality Laboratory from Michigan Foundation Seed Association, 2905 Jolly Road, Mason, MI and Wm. Mueller and Sons, Inc., Arthur Elevator, Reese, MI. Bean samples were stored in a temperature controlled room (25°C) until further processing.

Dry Bean Color. Objective surface color of beans was obtained with a Hunter Lab Model D25 Color and Color Difference Meter (Hunter Associates, Fairfax, VA). The color meter measures reflectance on three coordinates labeled L, a_L , and b_L . L measures darkness (0) to lightness (100), a_L from green (-) to red (+), and b_L from blue (-) to yellow (+). The instrument was standardized by a white tile with the coordinates $L = +94.5$, $a_L = -0.6$, $b_L = +0.4$. The sample was placed in an optically pure glass dish and covered to prevent interfering light. Coordinate values were recorded for each replicate of dry bean samples.

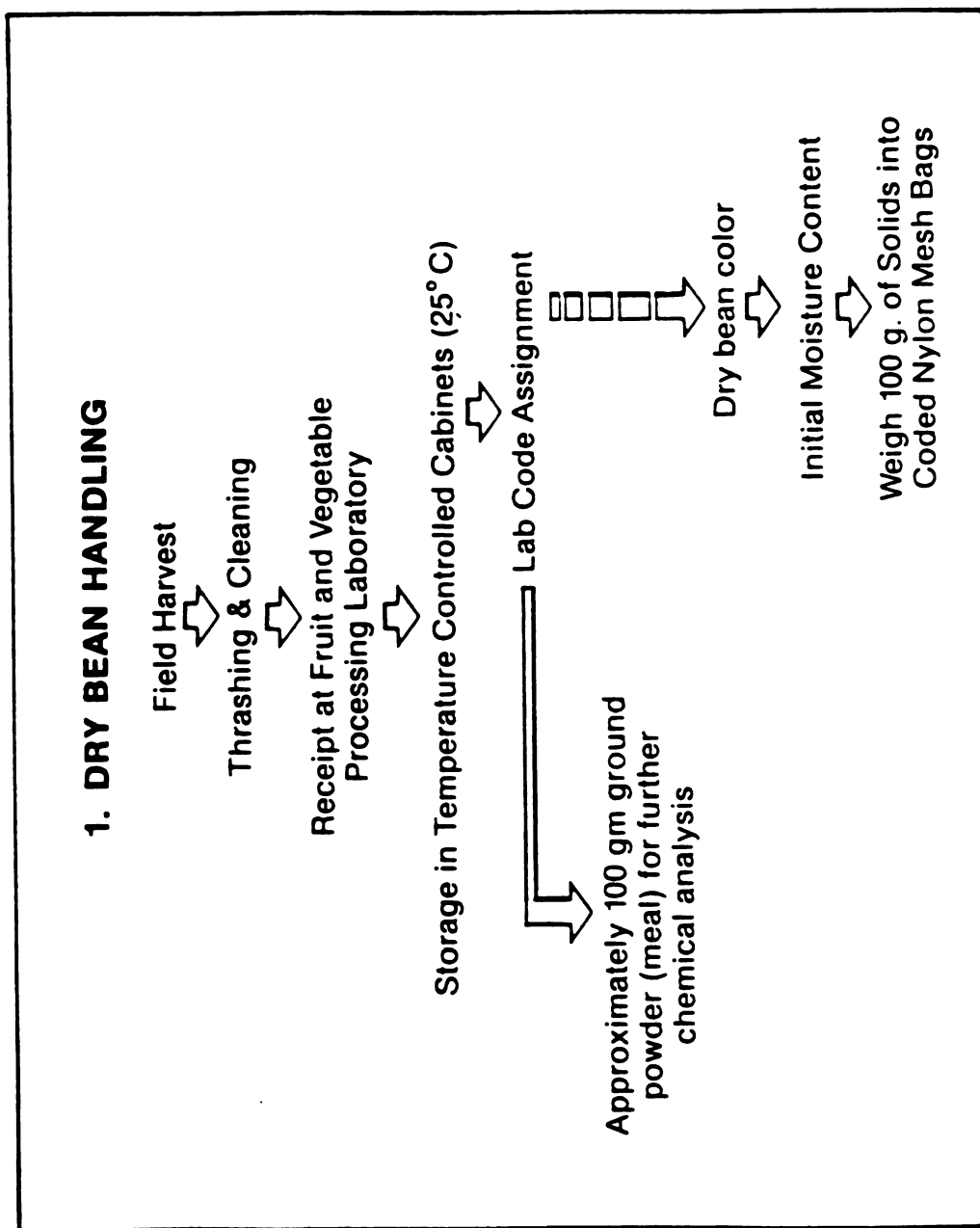


Figure 3. Dry bean handling, prior to processing. Source: Wilson et al., 1986.

Initial Bean Moisture and 100 g Solids. The initial moisture contents of all bean samples were measured with a Motomco Moisture Meter AACC method 44-11 (1982), (model 919, Motomco Inc., Clark, N.J.) and by the standard AACC method for vacuum oven (AACC 44-40, 1982).

The fresh weight equivalent of 100g total solids was calculated with the initial moisture content (Equation 1), weighed, and placed into individual nylon mesh bags.

Fresh weight equivalent of total solids required (g) =

$$\frac{\text{Total solids required (g)}}{\text{Solids at given moisture (g)}}$$

Equation 1. Calculation of fresh weight equivalent for total solids required.

BEAN SOAKING AND CANNING

Bean samples in Study 1 and 3 were subjected to a soak treatment, filling, brining and canning procedure as demonstrated in Figure 4 (Wilson et al., 1986; Hosfield and Uebersax, 1980).

Soaking for Canning. Following initial moisture determination the individual samples were weighed for 100 gram solids and placed in nylon mesh bags for soaking. The soak treatments for canned beans (Study 1 and 3) consisted of 1) overnight soak (12 hours at 20 °C) and 2) 30:30 soak (30 minutes at 20°C followed by 30 minutes at 87.8°C). The soak water was prepared from distilled water and analytical reagent grade CaCl_2 to contain various levels of Ca^{++} from 0

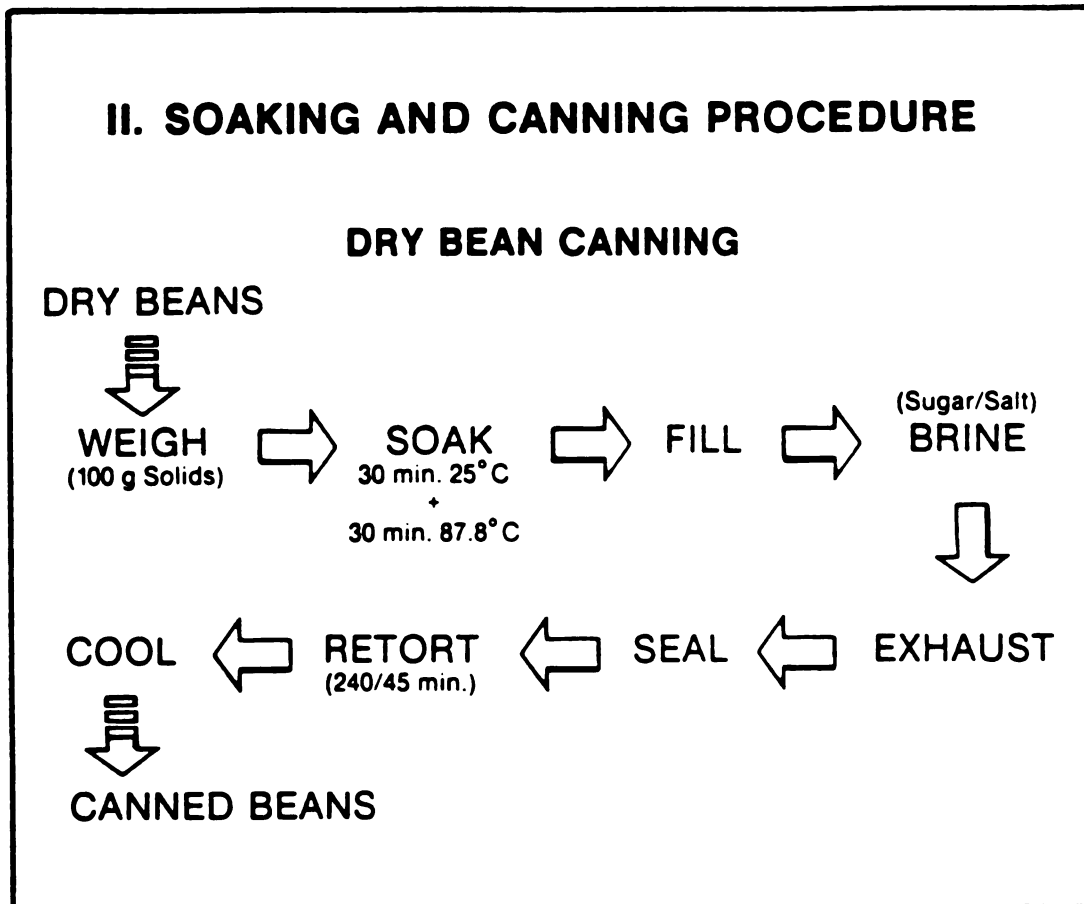


Figure 4. Bean soaking and canning procedure. Source: Wilson et al., 1986.

to 150 ppm (Equation 2). Following a heated soak, beans were immersed in cold water for one minute to terminate the hot soak and reduce vapor losses. Beans from both soaks were drained on perforated screen before can filling.

Molecular wt. $\text{CaCl}_2 = 111.08\text{g}$ Ca^{++} in $\text{CaCl}_2 = 36.08\%$
 e.g. for water with 100 ppm Ca^{++} ; need 0.1g Ca^{++} /Kg water
 $(0.1 \times 100)/36.08 = 0.28\text{g } \text{CaCl}_2/\text{Kg water}$

Equation 2. Calculation of CaCl_2 needed for water at a specified ppm Ca^{++} level.

Soaking. Test tube soaking of dry beans for rate of water uptake measurement was conducted in Study 2. Samples of eight beans of similar size were weighed and placed into labeled test tubes for soaking. Soaking was conducted at four temperatures including 60, 70, 80, and 90°C. At each temperature, bean samples were given one of four heated soak waters containing distilled water and 0, 50, 100, or 150 ppm calcium ion from calcium chloride.

The water bath used for soaking also contained the stoppered flasks of each soak medium to maintain consistent temperatures. The soak mediums were quickly dispensed to each respective test tube. The tubes were covered and immediately placed in the water bath. Samples were removed at ten minute intervals, drained, lightly dried with tissue and immediately weighed. Percent weight gain (Equation 3) was calculated at each time interval up to 60 minutes.

$$\text{Percent weight gain} = \frac{\text{Soaked wt.} - \text{Initial wt.}}{\text{Initial weight}} * 100$$

Equation 3. Calculation of percent weight gain.

Can Filling, Brining and Exhausting. Soaked beans for canning were rapidly transferred from individual bags to coded 303 x 406 cans. The filled cans were covered and immediately weighed for calculation of soaked bean moisture (Equation 4) and hydration ratio (Equation 5). Filled cans were transferred to a heated (98 - 100°C) exhaust box conveyor and hand filled with hot brine (90°C). The brine solutions contained 1.52% sucrose and 1.22% sodium chloride with a level of calcium from 0 to 150 ppm. The cans were conveyed through the exhaust box with a residence time of four minutes.

Soaked Bean Moisture % =

$$\frac{\text{Soaked bean weight g} - \text{Initial bean solids g}}{\text{Soaked bean weight g}} * 100$$

Equation 4. Calculation of percent soaked bean moisture.

$$\text{Hydration Ratio} = \frac{\text{Soaked bean weight g}}{\text{Initial bean weight g}}$$

Equation 5. Calculation of hydration ratio.

Sealing, Thermal Process, and Storage. From the exhaust box, the cans were loaded on a Canco vacuum closing machine (Model 6, American Can Co.) where the headspace was

adjusted and a lid added to produce a double seamed hermetic seal. The sealed cans were inverted and loaded into a retort basket. The full basket was transferred to the retort for thermal processing and to achieve commercial sterility. The retort used was a FMC vertical still retort (Food Machinery Corp., Hooperston, IL) equipped with an automatic temperature controller. Beans were vented for 2 minutes, processed at 115.6°C for 45 minutes, and cooled for 15 minutes in 20°C circulating water.

The processed cans were dried and placed in trays for temperature controlled storage. Processed bean samples were stored for a minimum of two weeks prior to quality evaluation for Study 1. This holding period is necessary for proper bean-brine equilibration. Processed cans for Study 3 were held in 50, 70 and 90°F storage and evaluated eleven times from Day 0 to Day 306.

CANNED PRODUCT EVALUATION

The outline for the quality evaluation of processed beans as followed for Studies 1 and 3 is found in Figure 5 (Wilson et al., 1986; Hosfield and Uebersax, 1980).

Total Weight, Vacuum and Headspace. All cans were weighed to determine net weight of processed beans and brine. Vacuum was measured with a standard vacuum gauge and recorded in inches of mercury. Removal of can lid allowed measurement of headspace to the nearest 16th of an inch.

Washed Drained Weight and Visual Examination. Drained weights were determined following the USDA method (1976).

III. CANNED PRODUCT EVALUATION

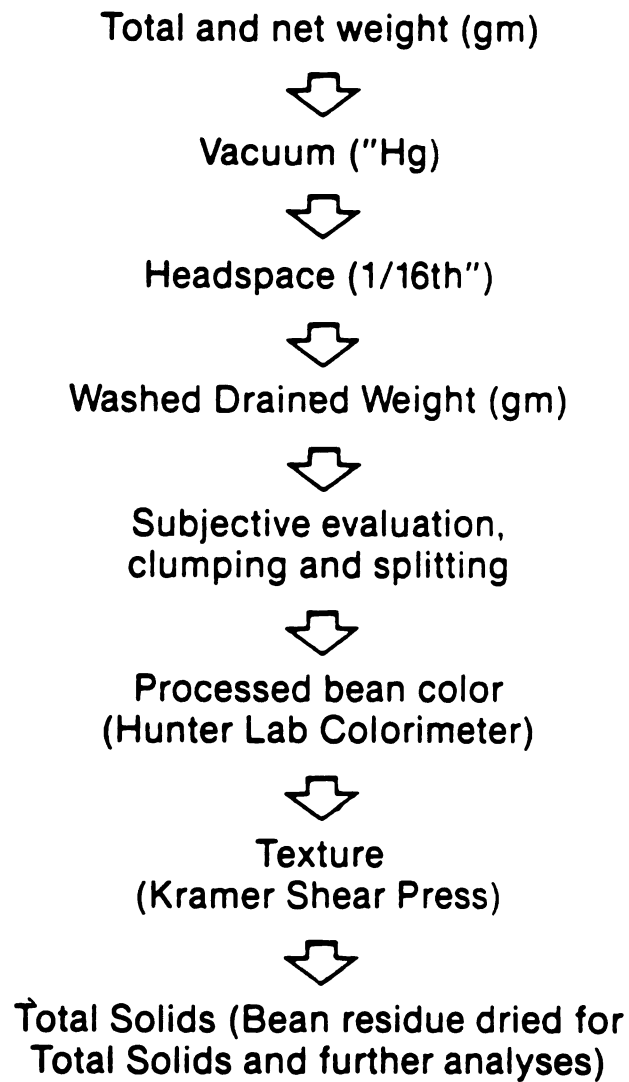


Figure 5. Canned product evaluation. Source: Wilson et al., 1986.

The contents of each can was poured onto a U.S. standard No. 8 screen (0.094 inch opening). The entire screen was immersed into 21°C water and agitated to rinse the beans and evenly distribute the sample. The screen was drained at a 15° angle for two minutes and the sample weighed on a tared scale. A drained weight ratio was calculated from Equation 6.

$$\text{Drained Weight Ratio} = \frac{\text{Washed bean drained weight (g)}}{\text{Soaked bean fill weight (g)}}$$

Equation 6. Calculation of drained weight ratio.

During the drained weight procedure, the beans were subjectively judged for clumping in the can and splitting of the seed coats. The beans were judged on hedonic scales of 1 to 5, with 1 = none and 5 = excessive.

Objective Color and Texture Evaluation. Processed bean color was measured with the Hunter Lab Color and Color Difference Meter in the same method as for the dry sample.

Instrumental analysis for texture was performed using a TR5 texture recorder (Food Technology Corp., Reston, VA) equipped with a No. C-15 standard multiple blade shear compression cell. Force deformation curves were plotted using a strip chart recorder. A sample size of 100 g of processed beans were distributed evenly in the cell and sheared. A typical Kramer force curve is found in Figure 6. Results for texture are reported in Kg of force/100 g sample as shown in Equation 7. The compression and shear

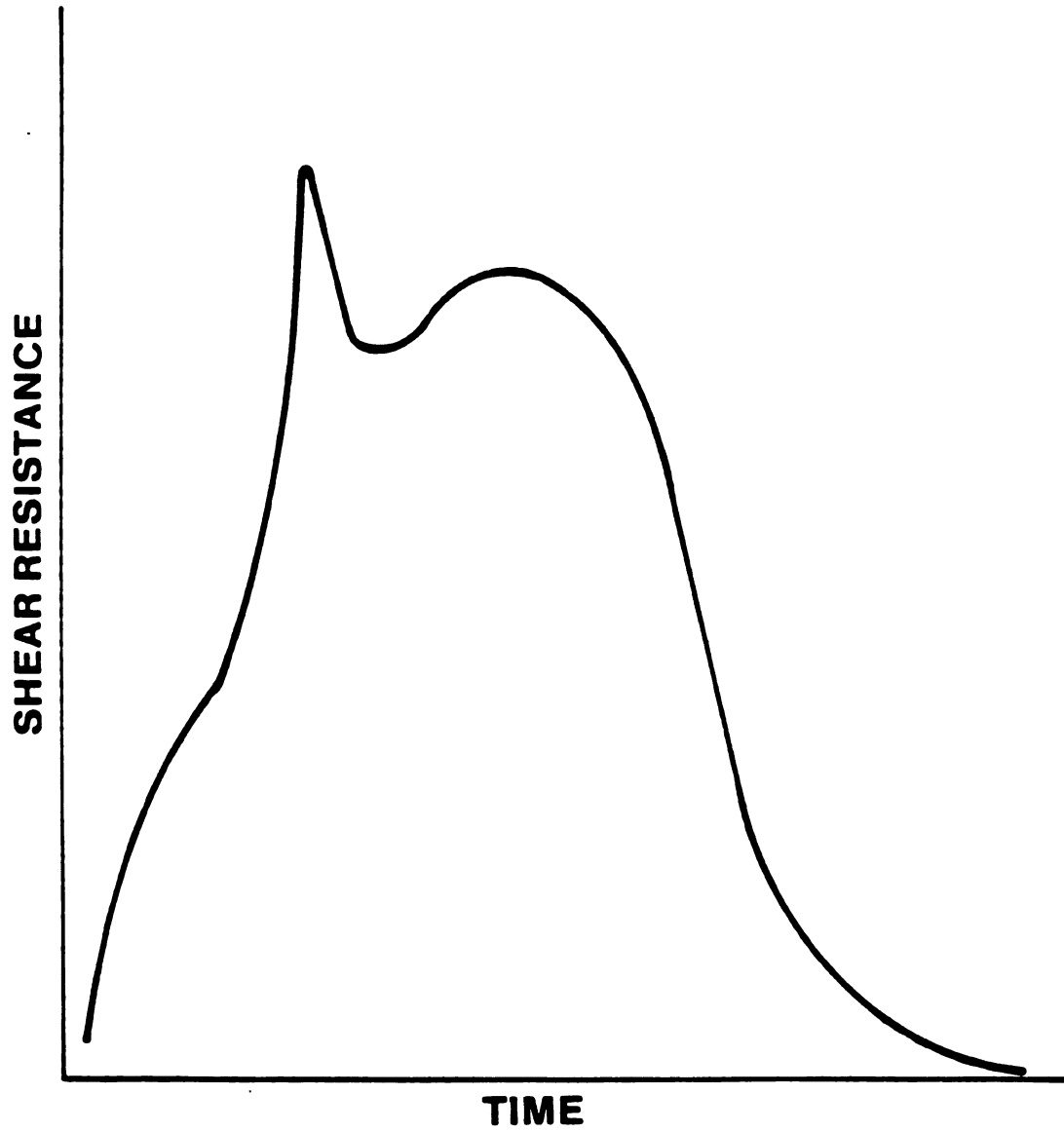


Figure 6. Typical Kramer force curve for processed beans.

components were measured for each sample. The relationship between the components is presented as a Ratio of Shear/Compression.

Kg Force/Sample size g =

$$\frac{((\text{Transducer Force lbs} \times \text{Range})/100)(1\text{Kg}/2.204 \text{ lbs})}{\text{Sample size g}} \times \text{Force Reading}$$

Equation 7. Calculation of force required per sample size.

Total Solids. Bean residue was used to calculate processed bean moisture and total solids. One hundred grams of residue was dried at 82°C to a constant weight in a Proctor-Schwartz cross current convection drier. Calculations of percent processed bean moisture and percent total solids are presented in Equation 8.

% Processed bean moisture =

$$\frac{\text{Processed Bean Residue} - \text{Dried Residue}}{\text{Processed Bean Residue}} \times 100$$

% Total solids =

$$100 - \% \text{ Processed bean moisture}$$

Equation 8. Calculation of processed bean moisture and total solids.

Moisture, Ash, and Calcium Determination. Samples were obtained after soaking and processing for determination of moisture, ash, and calcium content. Five grams of the soaked beans or ten grams of the processed beans were

evaluated for Study 1. In Study 3, all beans were separated following soaking, into cotyledon and seed coat parts. The beans were weighed into acid soaked and dried 50 ml porcelain crucibles. Samples were dried at 80°C for 24 hours in an air-oven dryer (Precision Scientific Co., Chicago, IL) for moisture determination. Samples were then ashed at 525°C for 30 hours in a Barber-Coleman muffle furnace (Model No. 293C, Thermolyne Corp., Dubuque, IA). Percent ash was calculated as in Equation 9.

$$\% \text{ Ash} = \frac{\text{Residue weight (g)}}{\text{Total dry sample weight (g)}} \times 100$$

Equation 9. Calculation of percent ash on a dry basis.

The ashed samples were dissolved in the crucibles with 2 ml of concentrated Baker Instra-analyzed nitric acid for one hour. The contents of the crucible was emptied to a 200 ml volumetric flask and filled to volume with distilled water. A 10 ml sample was prepared for Ca^{++} analysis using a Perkin-Elmer Atomic Absorption Spectrophotometer. To prevent Ca ionization, each sample received 1 ml of a 5% Lanthanum Chloride solution. Calculation of calcium ion in parts per million is illustrated in Equation 10.

$$\text{ppm Ca}^{++} = \frac{\text{Atomic Absorption Value (mg/l)} \times \text{Sample Volume (ml)}}{\text{Dry Sample Weight (g)}}$$

Equation 10. Calculation of ppm calcium from atomic absorption reading

Scanning Electron Microscopy (SEM). Navy bean samples soaked at 60°C and 90°C with 0 and 150 ppm calcium in the soak medium were used for SEM. Micrographs were taken of the seed coat and cotyledon cross sections to observe any structural changes related to soak temperature or calcium concentration in soak medium.

The cotyledons and seed coats from each treatment were cross sectioned with a razor blade and dried at room temperature for 48 hours. The dried samples were fixed on stubs with Avery-O-Glue and Tube Coat, then coated with gold using a Mini-coater Maclin. Micrographs were taken using a JEOL JSM-35CF Scanning Electron Microscope.

SENSORY EVALUATION OF PROCESSED BEANS

Quantitative Descriptive Analysis (QDA) was developed in Study 1, with trained panelists to identify and quantify, in order of occurrence, the sensory properties of the product. This analysis involved extensive methods of subject selection and product evaluation techniques for texture analysis. The basic outline of the technique as described by Stone et al., (1974) includes developing a uniform product language (terminology and descriptors), a standardized evaluation procedure, conducting panelist training, statistical evaluation of panelist data, and the graphical interpretation of results. The panelists met in group discussions to develop product language and rank product attributes in the order perceived. Following these discussions, a scorecard was developed using a ten

centimeter unstructured line with key anchor words or phrases at each end describing the product attributes. To evaluate a series of samples the panelists were instructed to mark the line where it best described the perceived attribute. The panelists were seated in segregated booths with individual lighting before actual testing began.

Three scorecards and reference sheets were developed for the texture evaluation of cooked bean products. Textural characteristics of processed bean samples were evaluated using a) visual (Figure 7); b) masticatory (Figure 8); and c) tactile (Figure 9) techniques. Visual evaluation required inspection of an emptied can of beans for a) color, b) glossiness (sheen), c) integrity, d) clumping or matting and e) brine clarity. Masticatory evaluation on a heated sample required scoring cotyledon consistency for a) smoothness, b) moisture, c) firmness, d) seed coat toughness and e) combined resistance of cotyledon and seed coat. Finally, 10 to 12 rinsed and drained beans were evaluated by manually compressing the bean between the index finger and thumb for a) resistance to rupture, b) smoothness, c) moisture, and d) uniform paste. Figure 10 is an example of the graphical presentation used for QDA results in this study.

COOKED BEAN TEXTURE EVALUATION VISUAL Using the reference sheet for texture evaluation, follow the techniques and defined terminology to rate each sample. Indicate your rating on this ballot by placing a slash anywhere along each 10 cm line. The fixed marks are located at 1, 5, and 9 cm on each line. 1. Bean Color Light _____ Dark _____ 2. Bean Glossiness (Sheen) Glossy _____ Dull _____ 3. Bean Integrity Intact _____ Broken _____ (Whole) (Smashed) 4. Clumping or Matting Free Flow _____ Solid Pack _____ 5. Brine Clarity Clear _____ Cloudy _____	REFERENCE SHEET OF TECHNIQUES & TERMINOLOGY FOR COOKED BEAN TEXTURE EVALUATION VISUAL One can of beans for each sample will be displayed in a standard white container for your visual examination. In this evaluation look at the bean color intensity, the surface appearance and integrity of the bean and the brine clarity. 1. Bean Color: the degree of lightness or darkness as related to the type of bean being evaluated. Examples of expected color for a particular bean variety will be demonstrated. 2. Bean Glossiness: the degree to which the bean surface is shiny and lustrous; not dull or cloudy. 3. Bean Integrity: the percent of beans found whole; with the center line representing 50 percent whole. 4. Clumping or matting: Solid pack is defined as the condition when an opened can of beans will not flow out when the can is inverted. A severe packing of beans in the bottom portion of a can is defined as matting. The presence of dense aggregated clumps of beans are characteristic of matting from an emptied can. Free flow occurs when the whole can readily empties upon inversion. 5. Brine/Sauce Clarity: The degree of solids in suspension in the liquid portion.
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Figure 7. Visual scorecard and reference sheet for texture evaluation of cooked beans using Quantitative Descriptive Analysis.

COOKED BEAN TEXTURE EVALUATION MASTICATORY		REFERENCE SHEET OF TECHNIQUES & TERMINOLOGY FOR COOKED BEAN TEXTURE EVALUATION MASTICATORY	
Name _____			
Date _____			
Sample _____			
QUANTITATIVE DESCRIPTIVE ANALYSIS Using the reference sheet for texture evaluation, follow the techniques and defined terminology to rate each sample. Indicate your rating on this ballot by placing a slash anywhere along each 10 cm line. The fixed marks are located at 1, 5, and 9 cm on each line.		Pick up ten to fifteen beans on a spoon and press them between your tongue and palate to evaluate for:	
1 Cotyledon Consistency a Smoothness Gritty _____ Pasty _____ b Moisture Dry _____ Wet _____ (Mealy) (Gummy) c Firmness Firm _____ Soft _____		1. Cotyledon Consistency a. Smoothness: evaluate for a smooth uniform paste when the cotyledon is compressed against your palate. If it contains small granular particles, or is abrasive, it is defined as gritty. b. Moisture: the degree of moisture released during compression of the cotyledon against your palate. c. Firmness: the degree of resistance exhibited by the beans to pressure applied with your tongue.	
2 Seed Coat Toughness Firm _____ Soft _____ (Brittle) (Pliable)		Place a spoonful of beans in your mouth between your molar teeth, bite down, chew and evaluate for:	
3 Cotyledon and Seed Coat Resistance to Mastication Firm _____ Mushy _____		2. Seed Coat Toughness: the ease of mastication of the seed coat; does it readily fragment and dissolve, or split into large pieces and resist breakdown? 3. Combined Cotyledon and Seed Coat Resistance to Mastication: the degree of resistance during the first bite and chewing; do the beans resist breakdown or are they mushy from the start?	

Figure 8. Masticatory scorecard and reference sheet for texture evaluation of cooked beans using Quantitative Descriptive Analysis.

COOKED BEAN TEXTURE EVALUATION TACTILE Name _____ Date _____ Sample _____ QUANTITATIVE DESCRIPTIVE ANALYSIS Using the reference sheet for texture evaluation, follow the techniques and defined terminology to rate each sample. Indicate your rating on this ballot by placing a slash anywhere along each 10 cm line. The fixed marks are located at 1, 5, and 9 cm on each line. 1 Resistance to Rupture High _____ Low _____ 2 Spreadability Gritty _____ Pasty _____ Dry _____ Wet _____ (Mealy) _____ (Gummy) _____ 3 Visual Hardcore _____ Uniform _____ (Granular) _____ Paste _____	REFERENCE SHEET OF TECHNIQUES & TERMINOLOGY FOR COOKED BEAN TEXTURE EVALUATION TACTILE This test is performed with two or three individual drained beans. Place one bean between your thumb and forefinger. Apply pressure and twist fingers approximately 1/2" to the right, (as if snapping your fingers). As you compress and rub the bean between your fingers, a paste will form. Use this procedure to evaluate the following: 1. Resistance to Rupture: the amount of force required to rupture coyledon between fingers. 2. Spreadability: by forming a paste between your fingers, do you feel a wet, uniform, smooth paste or a coarse, granular, dry one? 3. Visual: can you visually detect small particles or a hard core present in the smashed bean? if not, is the paste uniform?
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Figure 9. Tactile scorecard and reference sheet for texture evaluation of cooked beans using Quantitative Descriptive Analysis.

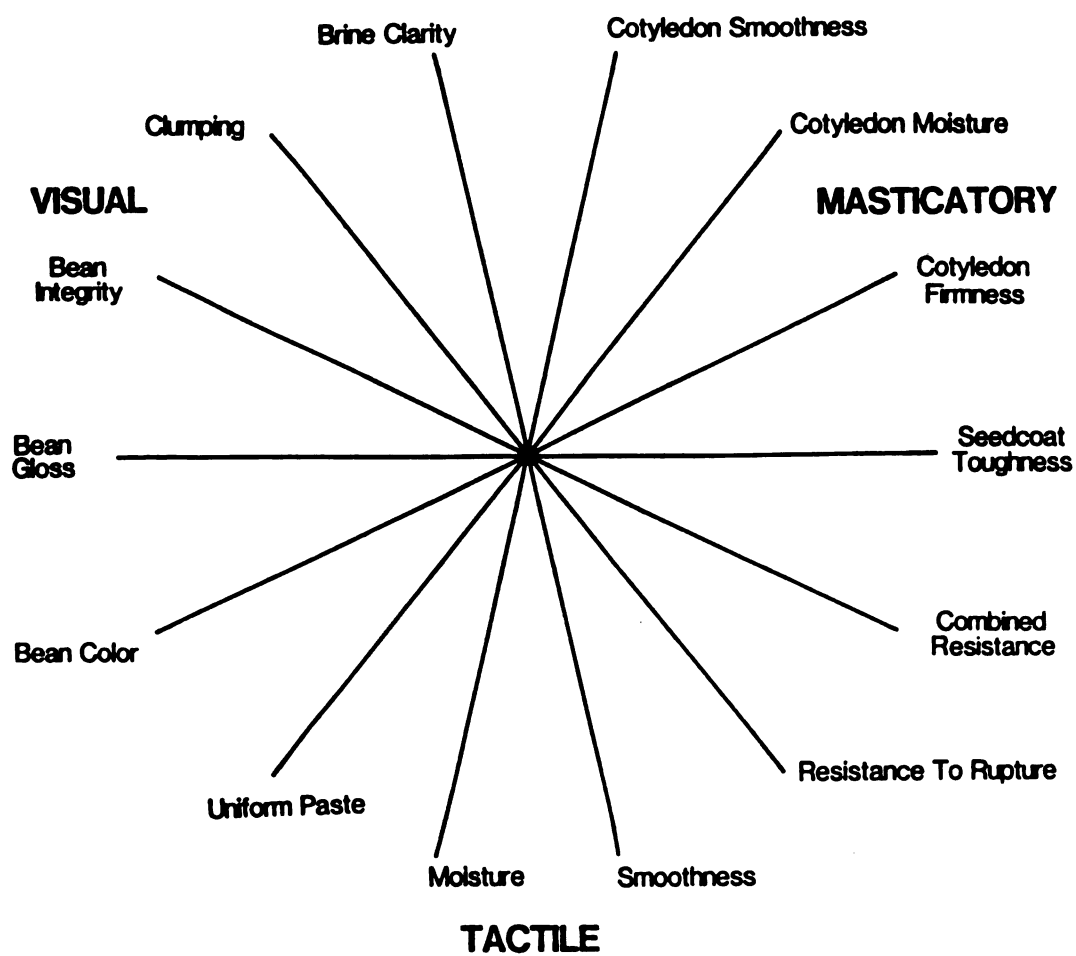


Figure 10. Graphical representation of Quantitative Descriptive Analysis results.

EXPERIMENTAL

Study 1: Correlation of objective and subjective measurements for defining texture of processed beans.

ABSTRACT

A three level factorial experiment was conducted to evaluate processed bean texture by objective and subjective methods. Evaluation of soak method (1. Overnight soak; 12 hrs. at 20°C and 2. 30:30 Soak; 30 min. at 20°C followed by 30 min. at 87.8°C) and calcium concentration (0, 50, 100, and 150 ppm) in soak water and brine medium, on final processed texture was conducted. Soak method, soak medium and brine medium all produced significant effects on processed bean texture. 30:30 soaked beans had increased calcium absorption, decreased drained weight, and greater measured firmness than the overnight soaked beans for all soak and brine medium treatments. Quantitative Descriptive Analysis (QDA) was effective in defining sensory attributes of processed bean texture. Drained weight, Kramer compression force, Kramer shear force, and measured calcium had the highest correlations with the subjective measures. These parameters produced multiple linear regression equations with good prediction accuracy for cotyledon firmness, seedcoat toughness, and combined resistance from

the sensory tests of QDA.

INTRODUCTION

Texture has long been recognized as a key measure of quality in consumption of foods including processed beans. Soaking and processing methods can greatly effect the final culinary quality of thermally processed beans. Further, soak water additives such as calcium ion have shown significant alterations in final cooked bean texture. Producing optimum texture has become a primary objective of dry bean processors. To achieve this goal, texture must be defined.

Consumer sensory panels can provide the best evaluation of the texture for a product but can also contribute panelist variability, sample fatigue, and scheduling conflicts. Texture measuring devices can measure properties quickly, at low cost per sample, and with repeatable results. The challenge is to understand how the physical measurements describe the sensory panelist's perceptions of texture.

The objective of this study was to soak and thermally process dry navy beans by two soak methods and in four levels of calcium ion to produce an array of textural characteristics for subjective and objective quality evaluation. The results will demonstrate the effects of overnight soak versus 30:30 soak on processed bean quality. Calcium concentration in the soak and brine will be evaluated for effect on bean texture and variances in uptake

due to soak treatment. Sensory evaluation by Quantitative Descriptive Analysis (QDA) will define consumer perceived texture. A relationship between instrumental measures and sensory textural attributes will be defined to facilitate interpretation of texture for further studies on cooking quality of dry beans.

MATERIAL AND METHODS

Dry Bean Handling Prior to Processing

Samples of C-20 navy beans were received at the MSU Legume Quality Laboratory and were handled as described by Wilson et al., (1986). Objective surface color of beans was obtained with a Hunter Lab Model D25 Color and Color Difference Meter (Hunter Associates, Fairfax, VA). The initial moisture contents of all bean samples were measured with a Motomco Moisture Meter, AACC Method 44-11 (1982), (model 919, Motomco Inc., Clark, N.J.) and by the standard AACC method for vacuum oven (AACC 44-40, 1982). The fresh weight equivalent of 100g total solids was calculated with the initial moisture content (Equation 1), weighed, and placed into individual nylon mesh bags.

Bean Soaking and Canning

Bean samples in individual bags were subjected to a standard soak treatment, filling, brining and canning procedure as performed by (Wilson et al. (1986) and Hosfield and Uebersax (1980).

Soaking. The soak treatments consisted of 1) overnight soak (12 hours at 20 °C) and 2) 30:30 soak (30 minutes at

20°C followed by 30 minutes at 87.8°C). The soak water was prepared from distilled water and analytical reagent grade CaCl_2 to contain various levels of Ca^{++} from 0 to 150 ppm (Equation 2).

The soaked beans were weighed immediately after soaking for calculation of moisture (Equation 4) and hydration ratio (Equation 5). Soaked beans ready for canning were filled with a salt and sugar brine made from 0 to 150 ppm Ca^{++} water. Sealed cans were placed in a vertical still retort and processed for 45 minutes at 115.6°C and cooled for 15 minutes at 20°C. The processed cans were dried and placed in trays for temperature controlled storage. Processed bean samples were stored for a minimum of two weeks prior to quality evaluation. This holding period is necessary for proper bean-brine equilibration.

Canned Product Evaluation

Quality evaluation of processed beans was performed following the procedure of Wilson et al. (1986) and Hosfield and Uebersax (1980). Drained weights were determined following the USDA method (1976). A drained weight ratio was calculated from Equation 6. The beans were subjectively judged for clumping in the can and splitting of the seed coats on a hedonic scales of 1 to 5, with 1 = none and 5 = excessive. Processed bean color was measured objectively with the Hunter Lab Color and Color Difference Meter (Hunter Associates, Fairfax, VA).

Instrumental analysis for texture was performed using a TR5 texture recorder (Food Technology Corp., Reston, VA) equipped with a No C-15 standard multiple blade shear compression cell. A sample size of 100 g of processed beans were distributed evenly in the cell and sheared. Results for texture are reported in Kg of force/100g sample as shown in Equation 7. The compression and shear components were measured for each sample. The relationship between the components is presented as a Ratio of Shear/Compression.

Bean residue was used to calculate processed bean moisture and total solids. One hundred grams of residue was dried at 82°C to a constant weight in a Proctor-Schwartz cross current convection drier. Calculations of percent processed bean moisture and percent total solids are presented in Equation 8.

Samples were obtained after soaking and processing for determination of moisture, ash, and calcium content. Samples were dried at 80°C for 24 hours in an air-oven dryer (Precision Scientific Co., Chicago, IL) for moisture determination. Samples were then ashed at 525°C for 30 hours in a Barber-Coleman muffle furnace (Model No. 293C, Thermolyne Corp., Dubuque, IA). Percent ash was calculated as in Equation 9. The ashed sample was prepared for mineral analysis of Ca^{++} using a Perkin-Elmer Atomic Absorption Spectrophotometer. Calculation of calcium ion in parts per million is illustrated in Equation 10.

Sensory Evaluation of Processed Beans

Quantitative Descriptive Analysis (QDA) was developed with trained panelists to identify and quantify, in order of occurrence, the sensory properties of the product. The basic outline of the technique as described by Stone et al., (1974) includes developing a uniform product language (terminology and descriptors), a standardized evaluation procedure, conducting panelist training, statistical evaluation of panelist data, and the graphical interpretation of results. Three scorecards and reference sheets were developed for the texture evaluation of cooked bean products. Textural characteristics of processed bean samples were evaluated using a) visual, b) masticatory, and c) tactile techniques.

RESULTS AND DISCUSSION

Objective Data

The mean values for dry and processed bean color are presented in Table 1. Processed navy beans became more dark (decrease L), more red (increase a_L), and more yellow (increase b_L) from initial dry bean values. The mean squares for processed color are in Table 2. Soak method produced the most significant changes in color values. Overnight soak had greater overall differences from the dry bean values in a_L (more red) and b_L (more yellow) than the 30:30 soak. Soak and brine medium had little effect on color change due to processing with a slight variance occurring in the 30:30 soak method with the b_L value

Table 1. Surface color analysis¹ of dry² and processed beans: Soaked and brined in four levels of calcium ion.

Soak Medium Brine Medium	Hunter Lab Coordinates		
	L	a _L	b _L
OVERNIGHT SOAK ³			
0 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	50.8a	7.6a	15.9b
50	51.1a	7.3a	16.0ab
100	51.8a	7.6a	16.5a
150	51.8a	7.5a	16.4ab
50 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	51.5a	7.4a	16.2ab
50	51.3a	7.5a	16.1ab
100	51.2a	7.5a	16.3ab
150	51.5a	7.6a	16.4ab
100 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	51.4a	7.3a	16.2ab
50	50.8a	7.6a	16.0ab
100	50.8a	8.0a	16.1ab
150	51.1a	7.7a	16.4ab
150 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	51.2a	7.5a	16.4ab
50	51.3a	7.3a	16.3ab
100	51.4a	7.4a	16.4ab
150	50.7a	7.6a	16.3ab

Table 1. (cont'd.)

Soak Medium Brine Medium	Hunter Lab Coordinates		
	L	a _L	b _L
30:30 SOAK ³			
0 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	51.5ab	4.7a	14.5fg
50	51.6ab	4.6a	14.4g
100	51.7ab	4.6a	14.7efg
150	51.4ab	4.7a	14.5fg
50 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	51.5ab	4.6a	14.8defg
50	51.1ab	4.8a	14.9cdefg
100	51.9ab	4.5a	15.0bcdefg
150	51.7ab	4.8a	15.5abc
100 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	52.2ab	4.6a	15.3abcde
50	51.9ab	5.0a	15.4abcd
100	51.0b	4.9a	15.1abcdef
150	52.2ab	4.6a	15.4abcd
150 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	52.2ab	4.8a	15.3abcde
50	52.4ab	4.6a	15.6ab
100	51.9ab	4.8a	15.5ab
150	52.5a	4.6a	15.7a

¹Mean values (like letters within each column for each soak method indicate no significant differences at $P \leq 0.05$ by Tukey mean separation; $n = 3$).

²Hunter Lab Coordinates for dry beans: $L = 60.0$; $a_L = 2.2$; $b_L = 12.0$.

³OVERNIGHT SOAK = 20°C soak for 12 hours. 30:30 SOAK = 20°C soak for 30 minutes followed with 87.8°C soak for 30 minutes

Table 2. Analysis of variance for surface color analysis of processed beans.

Source of Variation	df	Hunter Lab Coordinates		
		L	a _L	b _L
MEAN SQUARES				
Main Effects	7	1.289***	27.302***	5.214***
Soak method	1	7.370***	190.688***	31.625***
Soak medium	3	0.413	0.095	1.346***
Brine medium	3	0.138	0.046	0.278***
Two Way	15	0.578**	0.088	0.269***
Soak method x soak medium	3	1.271***	0.017	0.937***
Soak method x brine medium	3	0.152	0.066	0.053
Soak medium x brine medium	9	0.490*	0.118*	0.118**
Three Way				
Soak method x soak medium x brine medium	9	0.396	0.040	0.075*
Explained	31	0.686***	6.219***	1.329***
Residual	64	0.205	0.050	0.037
% CV		0.88	3.65	1.23

(yellow).

The mean moisture measurements for dry, soaked, and processed beans are in Table 3. The greatest amount of water absorption occurred during soaking in both soak methods. The overnight soak method had a higher moisture percentage at the end of soaking for all treatments. However after processing, both soak methods are similar in percent moisture with significant main effects shown for soak and brine mediums. These results are summarized by the mean squares in Table 4. The hydration ratio was significantly affected by soak method and soak medium while the drained weight ratio was also affected by brine medium.

Quality characteristics for dry, soaked, and processed beans are presented in Table 5 with the analysis of variance for these parameters in Table 6. Soaked bean weight decreased for both soak methods with increasing calcium in the soak medium. Soak method had a significant effect on soaked bean weight with lower values for the 30:30 soaked beans. Drained weights for both soak methods were decreasing with increasing calcium and had overall lower weights for the 30:30 soak compared to the overnight soak. The dried bean weight was not significantly different between the 30:30 and overnight soaks. Some effect of calcium in the soak and brine is noted for the 30:30 soak with increasing solids retained with increasing calcium levels.

Table 3. Moisture measurements¹ of dry², soaked and processed beans: Soaked and brined in four levels of calcium.

Soak Medium Brine Medium	Bean Moisture (%)		Mass Ratio Indexes ³	
	Soaked	Processed	Hydration	Drained Weight
OVERNIGHT SOAK ⁴				
0 ppm Ca ⁺⁺				
0 ppm Ca ⁺⁺	58.8abc	70.5abc	1.94abc	1.35a
50	59.2a	70.7abc	1.96a	1.29ab
100	58.9ab	69.9bc	1.95ab	1.24b
150	58.5bcde	70.1abc	1.93bcde	1.23b
50 ppm Ca ⁺⁺				
0 ppm Ca ⁺⁺	58.3cde	70.5abc	1.92cde	1.28ab
50	58.2de	70.2abc	1.91de	1.26b
100	58.3cde	68.8d	1.92cde	1.23b
150	58.5bcde	69.7cd	1.93bcde	1.23b
100 ppm Ca ⁺⁺				
0 ppm Ca ⁺⁺	58.5bcde	71.0a	1.93cde	1.27b
50	58.5bcde	71.1a	1.93bcde	1.29ab
100	58.5bcde	70.6abc	1.93bcde	1.25b
150	58.2de	70.4abc	1.92de	1.27b
150 ppm Ca ⁺⁺				
0 ppm Ca ⁺⁺	58.7abcd	70.9ab	1.94abcd	1.27b
50	58.0e	71.1a	1.91e	1.29ab
100	58.0e	70.6abc	1.91e	1.26b
150	58.0e	70.3abc	1.91e	1.26b

Table 3. (cont'd.)

Soak Medium Brine Medium	Bean Moisture (%)		Mass Ratio Indexes ³	
	Soaked	Processed	Hydration	Drained Weight
30:30 SOAK ⁴				
0 ppm Ca ⁺⁺				
0 ppm Ca ⁺⁺	57.1abc	71.4ab	1.87bc	1.30b
50	56.9bc	72.1a	1.86bc	1.35a
100	57.6ab	71.4ab	1.89ab	1.28b
150	58.1a	71.1abc	1.91a	1.22cde
50 ppm Ca ⁺⁺				
0 ppm Ca ⁺⁺	57.2abc	71.1abc	1.87abc	1.26bc
50	57.0bc	70.6bcd	1.86bc	1.25bcd
100	57.0bc	70.1cde	1.86bc	1.22cde
150	57.0bc	70.0de	1.86bc	1.21cde
100 ppm Ca ⁺⁺				
0 ppm Ca ⁺⁺	56.9bc	70.3cde	1.86bc	1.23cde
50	56.6cd	70.1cde	1.85cd	1.21de
100	56.3cd	69.5e	1.83cd	1.20de
150	56.7bcd	69.2e	1.85bcd	1.19e
150 ppm Ca ⁺⁺				
0 ppm Ca ⁺⁺	55.8d	69.7de	1.81d	1.22cde
50	56.3cd	69.2e	1.83cd	1.21cde
100	56.6cd	69.5e	1.85cd	1.21de
150	56.5cd	69.4e	1.84cd	1.19e

¹Mean values (like letters within each column for each soak method indicate no significant differences at $P \leq 0.05$ by Tukey mean separation; $n = 3$).

²Initial bean moisture = 19.9%.

³Hydration Ratio = soaked beans (g)/initial dry weight (g);
Drained Weight Ratio = processed beans (g)/soaked beans (g).

⁴OVERNIGHT SOAK = 20°C soak for 12 hours. 30:30 SOAK = 20°C soak for 30 minutes followed with 87.8°C soak for 30 minutes

Table 4. Analysis of variance for moisture measurements of soaked and processed beans.

Source of Variation	df	Bean Moisture (%)		Mass Ratio Indexes	
		Soaked	Processed	Hydration	Drained Wt.
MEAN SQUARES					
Main Effects	7	9.999***	2.820***	0.020***	0.015***
Soak method	1	59.518***	0.211	0.118***	0.028***
Soak medium	3	3.440***	3.400***	0.007***	0.011***
Brine medium	3	0.052	3.110***	0.000	0.014***
Two way	15	0.246***	2.008***	0.000***	0.003***
Soak method x soak medium	3	0.504***	8.782***	0.001***	0.008***
Soak method x brine medium	3	0.391**	0.227	0.001**	0.001
Soak medium x brine medium	9	0.112	0.343**	0.000	0.002***
Three way					
Soak method x soak medium x brine medium	9	0.491***	0.186	0.001***	0.001*
Explained	31	2.520***	1.662***	0.005***	0.005***
Residual	64	0.074	0.130	0.000	0.000
% CV		0.47	0.51	0.0	0.0

Table 5. Quality characteristics¹ of dry², soaked, and processed beans: Soaked and processed in four levels of calcium ion.

Soak Medium Brine Medium	Bean Weight (g)		Visual ³	
	Soaked	Drained	Dried	Clumps Splits
OVERNIGHT SOAK ⁴				
0 ppm Ca ⁺⁺				
0 ppm Ca ⁺⁺				
50	242.7abc	327.2a	29.5bcd	4.0a 2.0a
100	244.8a	316.7ab	29.3bcd	3.7ab 2.0a
150	243.5ab	301.9cd	30.1bc	4.0a 2.0a
	241.1bcde	296.3d	29.9bcd	2.0bcd 2.0a
50 ppm Ca ⁺⁺				
0 ppm Ca ⁺⁺				
50	239.6cde	307.7bcd	29.5bcd	3.7ab 2.0a
100	238.9de	301.0cd	29.8bcd	3.3abc 2.0a
150	239.5cde	293.7d	31.2a	2.3abcd 2.0a
	241.0bcde	295.6d	30.3ab	1.3d 2.0a
100 ppm Ca ⁺⁺				
0 ppm Ca ⁺⁺				
50	241.0bcde	306.6bcd	29.0d	3.3abc 2.0a
100	241.2bcde	311.3bc	28.9d	1.7cd 2.0a
150	241.2bcde	300.5cd	29.4bcd	2.3abc 2.0a
	239.1de	304.3bcd	29.6bcd	1.0d 1.0b
150 ppm Ca ⁺⁺				
0 ppm Ca ⁺⁺				
50	242.1abcd	308.2bcd	29.1cd	2.3abcd 2.0a
100	237.8e	307.2bcd	28.9d	1.0d 1.3b
150	237.9e	299.2cd	29.4bcd	2.0bcd 2.0a
	237.8e	299.3cd	29.7bcd	1.0d 1.0b

Table 5. (cont'd.)

Soak Medium Brine Medium	Bean Weight (g)			Visual ³	
	Soaked	Drained	Dried	Clumps	Splits
30:30 SOAK ⁴					
0 ppm Ca ⁺⁺					
0 ppm Ca ⁺⁺	233.1bc	302.2b	28.6de	4.0a	2.3a
50	231.8bc	313.0a	27.9e	2.7b	2.0ab
100	236.1ab	302.9ab	28.6de	2.0b	2.0ab
150	238.5a	290.1cd	28.9cde	1.0c	1.3c
50 ppm Ca ⁺⁺					
0 ppm Ca ⁺⁺	233.7abc	294.3bc	28.9cde	1.0c	2.0ab
50	232.7bc	290.7cd	29.4bcd	1.0c	2.0ab
100	232.7bc	282.9def	29.9abc	1.0c	2.0ab
150	232.4bc	280.def	30.0ab	1.0c	2.0ab
100 ppm Ca ⁺⁺					
0 ppm Ca ⁺⁺	232.2bc	285.0cde	29.7abc	1.0c	2.0ab
50	230.6cd	278.0ef	29.9abc	1.0c	2.0ab
100	228.9cd	274.9ef	30.5a	1.0c	2.0ab
150	231.0bcd	275.1ef	30.8a	1.0c	1.7abc
150 ppm Ca ⁺⁺					
0 ppm Ca ⁺⁺	226.4d	275.4ef	30.3ab	1.0c	2.0ab
50	228.8cd	277.3ef	30.8a	1.0c	2.0ab
100	230.6cd	278.2ef	30.5a	1.0c	2.0ab
150	229.6cd	272.6f	30.6a	1.0c	1.0a

Table 5. (cont'd.)

¹ Mean values (like letters within each column for each soak method indicate no significant differences at $P \leq 0.05$ by Tukey mean separation; $n = 3$).
² Initial bean weight for 100g solids = 124.8g.
³ Subjective visual examination for canned bean characteristics, 5 point scale (1 = none, 5 = excessive).
⁴ OVERNIGHT SOAK = 20°C soak for 12 hours. 30:30 SOAK = 20°C soak for 30 minutes followed with 87.8°C soak for 30 minutes.

Table 6. Analysis of variance for quality characteristics of soaked and processed beans.

Source of Variation	df	Bean Weight (g)			Visual	
		Soaked	Drained	Dried	Clumps	Splits
MEAN SQUARES						
Main Effects	7	309.123***	2133.490***	2.820***	12.560***	0.879***
Soak method	1	1841.002***	8618.460***	0.211	28.167***	0.094
Soak medium	3	106.156***	1335.371***	3.400***	12.292***	0.538***
Brine medium	3	1.464	769.954***	3.110***	7.625***	1.483***
Two way	15	7.241***	190.175***	2.008***	1.158***	0.183***
Soak meth. x soak medium	3	13.826***	600.207***	8.782***	1.194***	0.094
Soak meth. x brine medium	3	12.224**	83.888**	0.227	1.861***	0.038
Soak med. x brine medium	9	3.385	88.927	0.343	0.912***	0.260***
Three way						
Soak method x soak medium x brine medium	9	15.211***	64.916***	0.186	1.000***	0.186***
Explained		77.722***	592.623***	1.662***	3.687***	0.341***
Residual	31	2.247	17.678	0.130	0.198	0.042
%CV	64	0.63	1.42	1.22	23.4	11.0

Visual examination of clumping resulted in no clumping for the 30:30 soak when beans were soaked in the presence of calcium. The overnight soak produced clumping with most calcium treatments however the clumping decreased with increasing calcium levels. Splitting of bean seed coats was not different due to soak method. A slight decrease in splitting was noted at the highest level of calcium tested.

Texture analysis of processed beans is presented in Table 7 with analysis of variance in Table 8. Shear and compression force increased with an increasing level of calcium ion in the soak water and/or brine solution. Significant differences in texture occurred from the calcium ion treatments with the greatest effect occurring with the 30:30 treatment. From the Kramer force readings, shear, compression, and the ratio of shear:compression all were significantly affected by the soak method, soak medium and brine medium. A further analysis of bean texture as it relates to soak method, drained weight, and the calcium treatment is presented in Figure 11. Drained weight is inverse to bean firmness for both soak methods. Increased amount of calcium ion present produces an increased firmness and decreased drained weight for both soak methods. The overnight soak shows a dramatic decrease in drained weight in the presence of any calcium but with very little weight change from 50 to 150 ppm calcium present. The heated (30:30) soak shows a greater response to calcium than the overnight soak in terms of bean firmness and drained weight.

Table 7. Texture analysis¹ of processed beans: Soaked and brined in four levels of calcium ion.

Soak Medium Brine Medium	Kramer Force Readings ² (Kg/100g)		
	Shear Force	Compression Force	Ratio of Shear:Compression
OVERNIGHT SOAK ³			
0 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	32.0ij	44.9hi	0.71g
50	31.3j	43.3i	0.72g
100	37.7efghij	47.6fghi	0.79efg
150	47.6cde	53.5cdef	0.89bcdef
50 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	33.8hij	46.5ghi	0.73g
50	36.1ghij	51.7cdefg	0.70g
100	44.2defgh	56.9abcd	0.78fg
150	56.7abc	56.9abcd	1.00ab
100 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	36.3fghij	46.5ghi	0.78efg
50	42.0defghi	49.2efghi	0.85def
100	48.8bcd	54.4bcde	0.90bcde
150	58.5ab	60.6ab	0.97abcd
150 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	46.7cdef	53.3cdef	0.87cdef
50	45.5defg	50.6defgh	0.89bcde
100	56.3abc	57.6abc	0.98abc
150	63.7a	61.7a	1.03a

Table 7. (cont'd.)

Soak Medium Brine Medium	Kramer Force Readings ² (Kg/100g)		
	Shear Force	Compression Force	Ratio of Shear:Compression
30:30 SOAK ³			
0 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	24.3l	41.1h	0.59h
50	27.2kl	42.4h	0.64gh
100	33.6jk	47.0gh	0.71fg
150	46.7hi	54.2fg	0.86de
50 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	41.5ij	52.8fg	0.79ef
50	51.3h	56.7f	0.90cd
100	65.1g	65.8e	0.99abc
150	72.8efg	72.1de	1.01ab
100 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	68.5fg	72.8de	0.94bcd
50	75.3ef	75.5d	1.00ab
100	77.8de	73.3d	1.06a
150	90.5abc	86.2bc	1.05a
150 ppm Ca ⁺⁺			
0 ppm Ca ⁺⁺	86.6cd	83.5c	1.04a
50	87.8bc	84.8bc	1.03a
100	97.3a	92.1ab	1.06a
150	96.2ab	93.7a	1.03ab

¹Mean values (like letters within each column for each soak method indicate no significant differences at $P \leq 0.05$ by Tukey mean separation; $n = 3$).

² $[(\text{Transducer Force} * \text{Range}) / 100] (\text{Force Reading}) / (\text{Sample size}) = \text{Force/Sample}$.

³OVERNIGHT SOAK = 20°C soak for 12 hours. 30:30 SOAK = 20°C soak for 30 minutes followed with 87.8°C soak for 30 minutes

Table 8. Analysis of variance for processed bean texture.

Source of Variation	df	Kramer Force Readings ² (Kg/100g)		
		Shear Force	Compression Force	Ratio of Shear:Compression
MEAN SQUARES				
Main effects	7	4942.022***	2415.692***	1.406***
Soak method	1	9930.273***	6267.107***	0.118***
Soak medium	3	6235.078**	2820.674***	0.870***
Brine medium	3	1986.215***	726.906***	0.417***
Two way	15	474.510***	293.462***	0.278***
Soak method x soak medium	3	2209.907***	1388.768***	0.177***
Soak method x brine medium	3	18.625	15.059	0.028***
Soak medium x brine medium	9	48.005***	21.160***	0.073***
Three way				
Soak method x soak medium x brine medium	9	24.112*	15.757**	0.057***
Explained	31	1352.542***	692.051***	1.741***
Residual	64	10.686	5.565	0.076
%CV		6.0	3.9	0.0

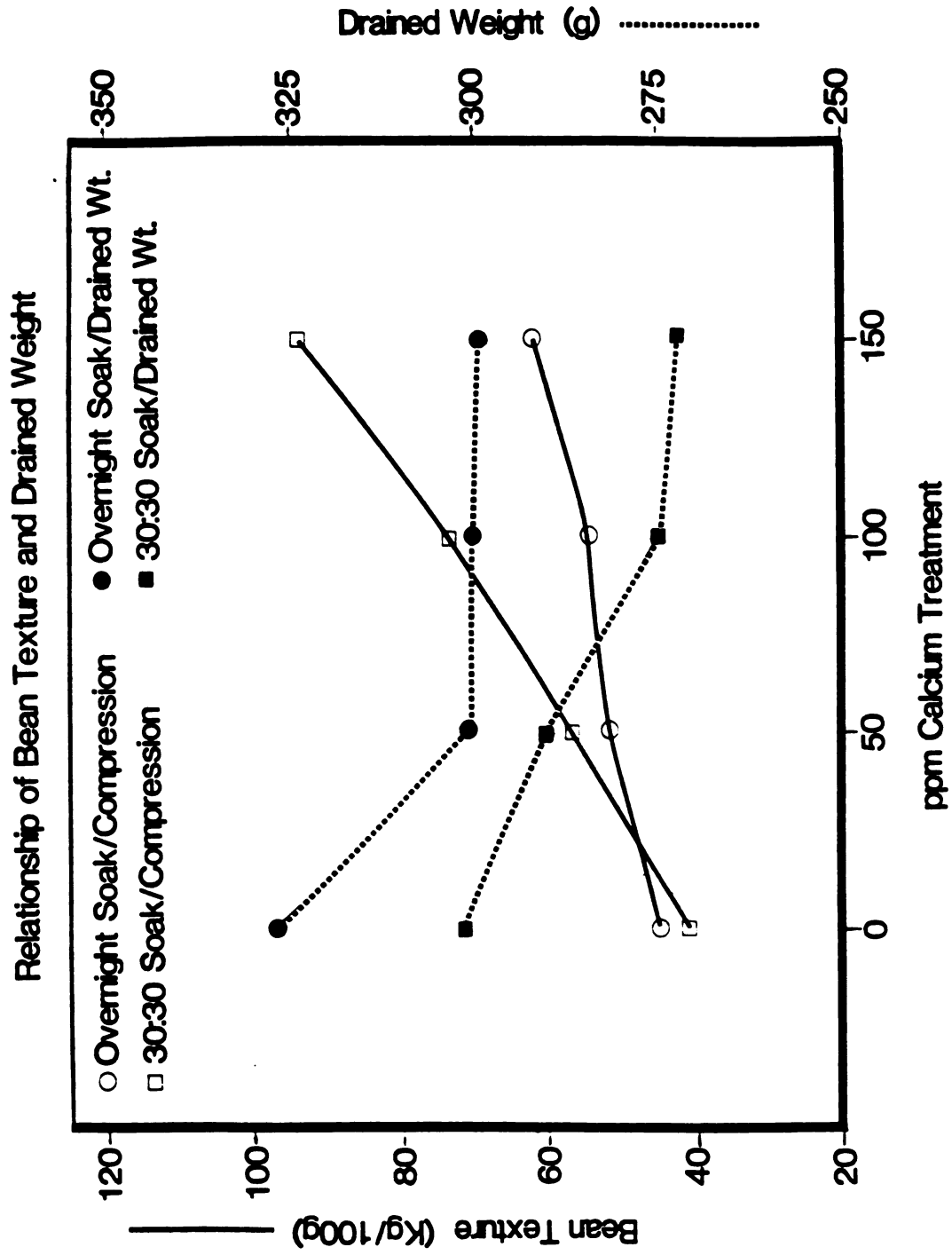


Figure 11. Relationship of bean texture and drained weight.

The heated soak produces a more linear response to the amount of calcium present producing significantly less yield and increased firmness at most treatment levels compared to the overnight soak.

Presence of calcium ion produced significant differences in texture as measured by the Kramer shear press in Figure 12. Shown here are typical Kramer force curves for beans with the same level calcium ion in their soak and brine medium and for each soak method. Increasing calcium treatments produced firmer beans for both soak methods with the 30:30 soak beans being firmer than the overnight soaked beans. Soak method also influenced the processed texture at all calcium levels. Close examination of the curves show a change in curve type from the 0 to 150 ppm levels. Previous work by Hosfield and Uebersax (1980) characterized the curves into two types. Type A with a large shear component that is involved with the extrusion of the beans through the bottom of the shear cell. Type B curves are due mainly to compression. Binder and Rockland (1964) demonstrated with lima beans that the seedcoats were responsible for the shear component. At the 0 ppm level the curves are very similar in shape and value for the two soak treatments. With increasing calcium ion treatments the curves converge to type A and are greater in value. In 1936, Snyder demonstrated that calcium ion toughens the seedcoat, possibly explaining the emergence of a shear component with increasing calcium treatments. Shear:compression values

Processed Navy Bean Texture

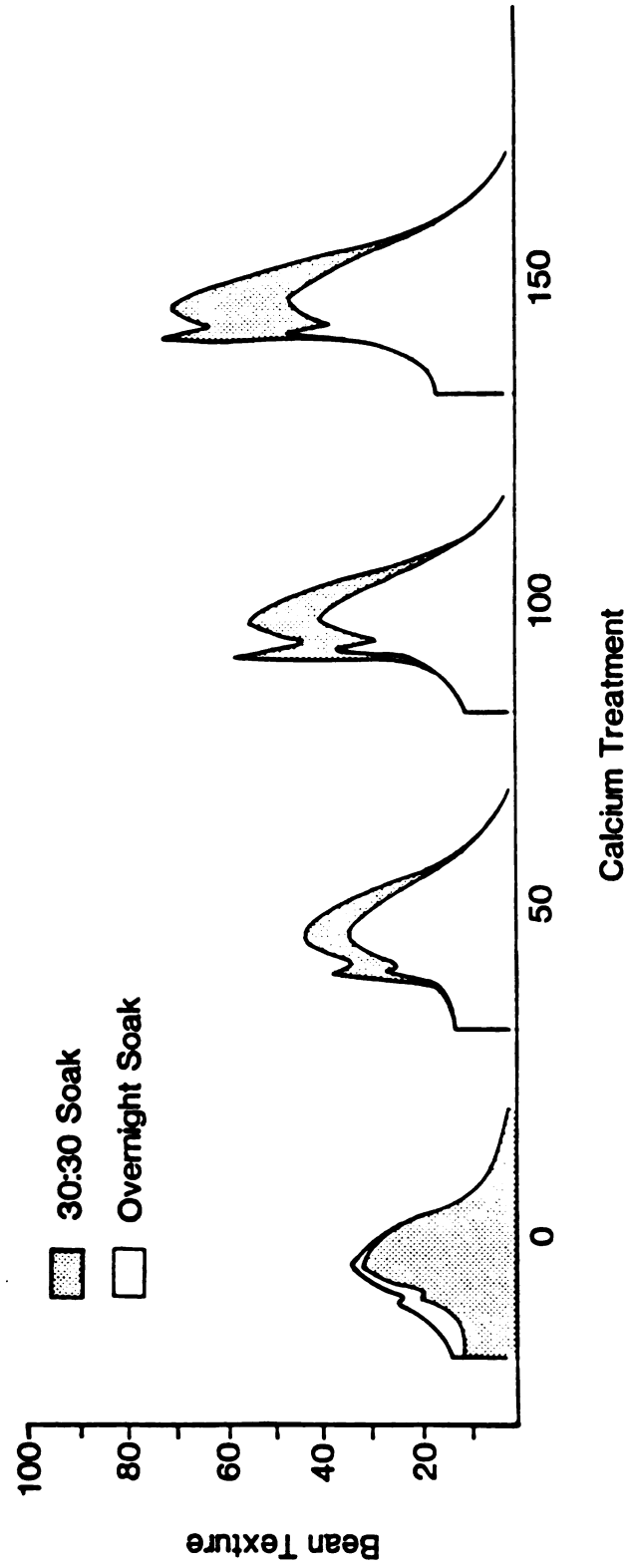


Figure 12. Typical Kramer force curves of overnight and 30:30 soaks with calcium treatments from 0 to 150 ppm.

presented in Table 7 represent the convergence of type B curves to type A. If the value is greater than 1.0, the shear component is larger than the compression value.

Mineral analysis of dry and processed beans is shown in Table 9. A general trend for both soak methods is an increasing amount of calcium ion is measured in beans with increasing levels of calcium in the soak and/or brine mediums. Overall the 30:30 soak absorbed higher amounts of calcium than the overnight soak. These results are in agreement with previous work by VanBuren (1980) and Uebersax and Bedford (1980) where an increased amount of calcium is bound in the presence of heat, creating a firmer texture. VanBuren (1980) measured the amount of calcium binding sites in snap beans and found an increased amount of sites available following a heated blanch. Measured values of calcium are significantly affected by the soak method, soak medium, and brine medium as shown in the mean squares of Table 10 for mineral analysis. Mean ash values were mostly affected by different soak methods and showed no significant differences within soak methods. The overnight soak had higher percent ash values than the 30:30 soak. All ash values were lower than the initial ash of the dry bean indicating a loss during processing with a slightly greater loss for the 30:30 soak than the overnight soak.

Calcium absorption in the overnight soaked beans was split into soak and brine effects and shown in Figures 13 and 14. Little distinction appears between the amount of

Table 9. Mineral analysis¹ of dry² and processed beans:
Soaked and brined in four levels of calcium ion.

Soak Medium Brine medium	Ca ⁺⁺ ppm	% Ash (db)
<u>OVERNIGHT SOAK</u> ³		
0 ppm Ca ⁺⁺		
0 ppm Ca ⁺⁺	1845de	4.070a
50	1775e	3.950a
100	1774e	3.900a
150	2062bcde	4.235a
50 ppm Ca ⁺⁺		
0 ppm Ca ⁺⁺	1872cde	3.905a
50	2002bcde	3.900a
100	2273abcde	4.020a
150	2273abcde	4.130a
100 ppm Ca ⁺⁺		
0 ppm Ca ⁺⁺	2006bcde	3.960a
50	2038bcde	4.055a
100	2401abcd	4.190a
150	2422abc	4.165a
150 ppm Ca ⁺⁺		
0 ppm Ca ⁺⁺	2090bcde	3.960a
50	2191abcde	3.915a
100	2526ab	3.965a
150	2711a	3.885a

Table 9. (cont'd).

Soak Medium Brine medium	Ca ⁺⁺ ppm	% Ash (db)
<u>30:30 SOAK</u> ³		
0 ppm Ca ⁺⁺		
0 ppm Ca ⁺⁺	2067e	3.765a
50	2219de	3.715a
100	2281de	3.705a
150	2315de	3.810a
50 ppm Ca ⁺⁺		
0 ppm Ca ⁺⁺	2558cde	3.750a
50	2646bcde	3.720a
100	2984abc	3.770a
150	2839abcd	3.805a
100 ppm Ca ⁺⁺		
0 ppm Ca ⁺⁺	2835abcd	3.710a
50	3018abc	3.685a
100	3016abc	3.720a
150	3310a	3.790a
150 ppm Ca ⁺⁺		
0 ppm Ca ⁺⁺	3214ab	3.870a
50	3184abc	3.765a
100	3401a	3.745a
150	3246ab	3.835a

¹Mean Values (like letters within each column for each soak method indicate no significant differences at $P \leq 0.05$ by Tukey mean separation; $n = 2$).

²Dry bean calcium = 2018 ppm; Ash db = 4.337%

³Overnight Soak = 20°C soak for 12 hours. 30:30 Soak = 20°C soak for 30 minutes followed with 87.8°C soak for 30 minutes

Table 10. Analysis of variance for mineral analysis of processed beans.

Source of Variation	df	Ca ⁺⁺ ppm	% Ash (db)
<u>MEAN SQUARES</u>			
Main Effects	7	19.9x10 ⁵ ***	0.166***
Soak method	1	73.8x10 ⁵ ***	1.023***
Soak medium	3	17.7x10 ⁵ ***	0.006
Brine medium	3	40.7x10 ⁴ ***	0.040*
Two way	15	63.4x10 ³ **	0.018
Soak method x soak medium	3	22.4x10 ⁴ ***	0.041*
Soak method x brine medium	3	30.5x10 ³	0.008
Soak medium x brine medium	9	20.8x10 ³	0.014
Three way			
Soak method x soak medium x brine medium	9	27.0x10 ³	0.007
Explained	31	48.8x10 ⁴ ***	0.048***
Residual	64	23.2x10 ³	0.013
%CV		6.14	2.93

OVERNIGHT SOAK

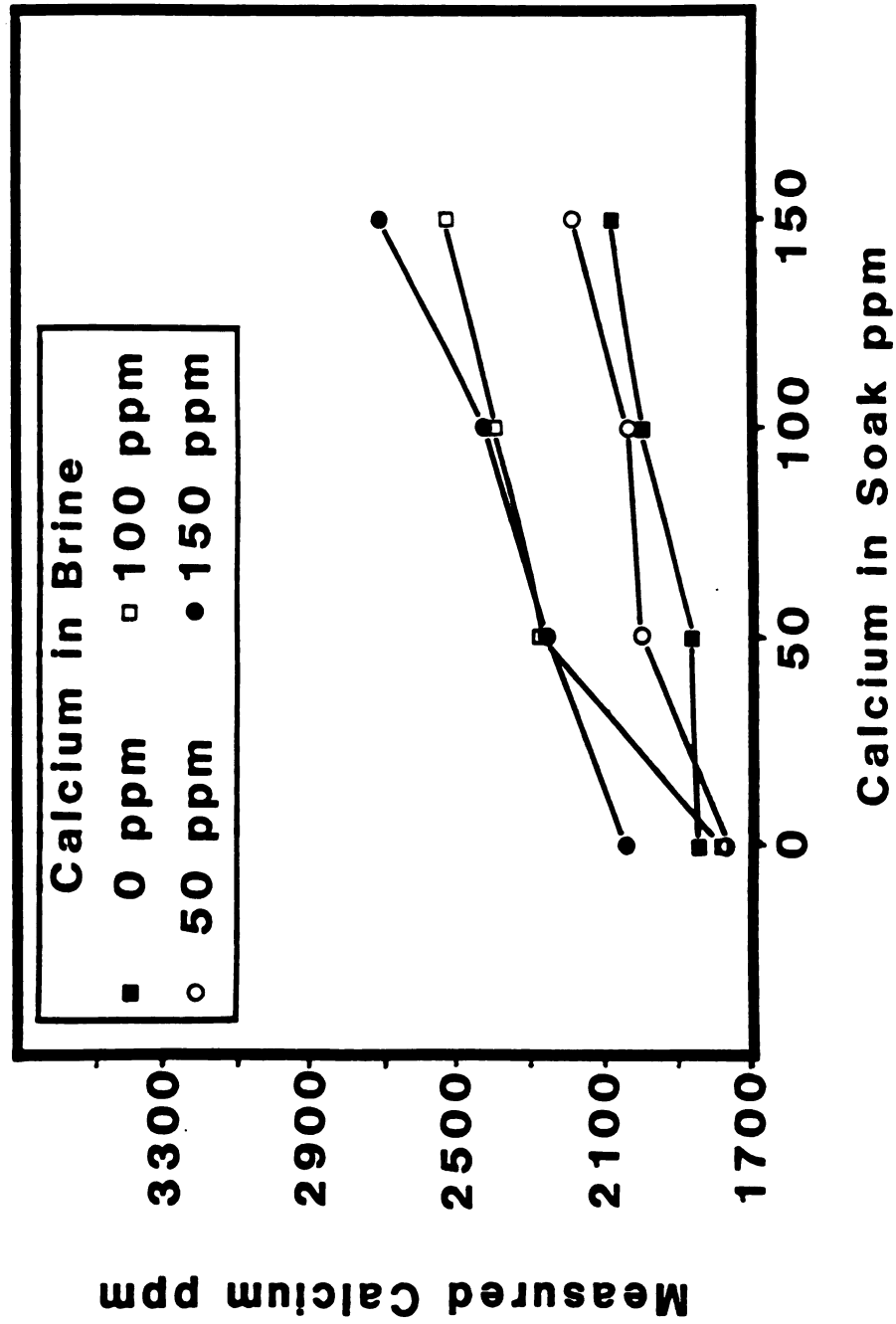


Figure 13. Effect of calcium in soak water on total measured bean calcium for overnight soaked beans.

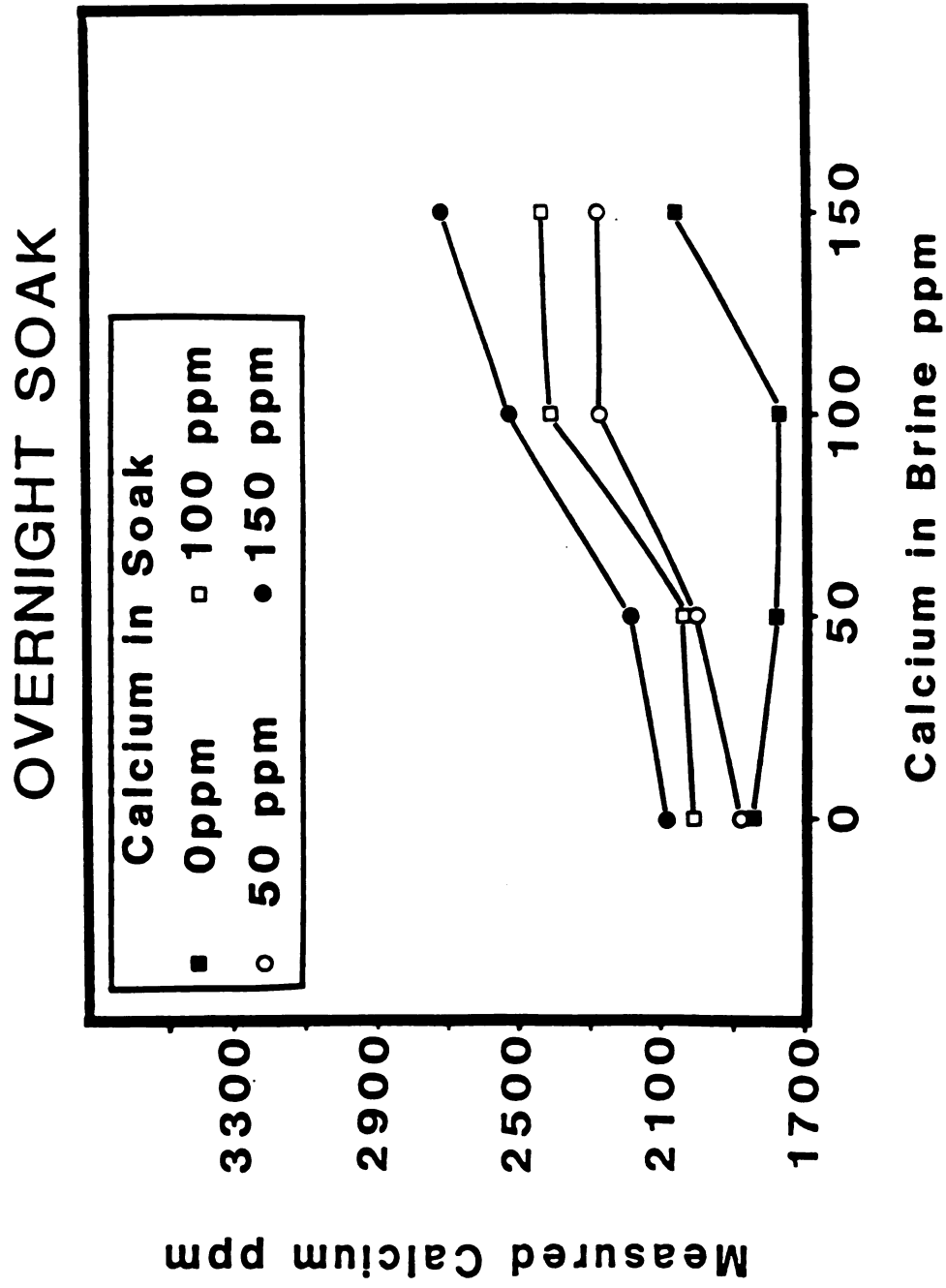


Figure 14. Effect of calcium in brine medium on total measured bean calcium for overnight soaked beans.

calcium absorption from the soak or brine mediums from the overnight soak. However, the greater the amount of calcium that was present resulted in a higher measured calcium for both soak and brine medium.

Figure 15 demonstrates the measured calcium from the overnight soak of soaked and processed beans. The calcium treatments represented here have the same ppm calcium in their soak water and brine solution. During soaking at ambient temperatures for twelve hours the amount of calcium absorbed is very similar to the level after processing except at the highest concentration Ca^{++} . During processing the 150 ppm Ca^{++} treatment beans showed a slight increase in Ca^{++} absorption over the soaked amount. Thus during a long soak, the beans absorb a maximum level of calcium from the water source. Soaking is also the time when beans absorb the greatest water and as expected a greater calcium absorption along with the water transport into the bean.

The measured bean calcium values from the soak and brine mediums in the 30:30 soak are shown in Figures 16 and 17. In the 30:30 soak, an increase in soak or brine calcium creates a direct increase in measured calcium. From the Figures it shows that calcium is absorbed more from the soak medium than the brine medium. In Figure 16, all lines depicting calcium in the brine are very similar in slope and close in value, representing little change due to brine. The lines of Figure 17 showing calcium in the soak differ greatly in value with increasing calcium giving increasing

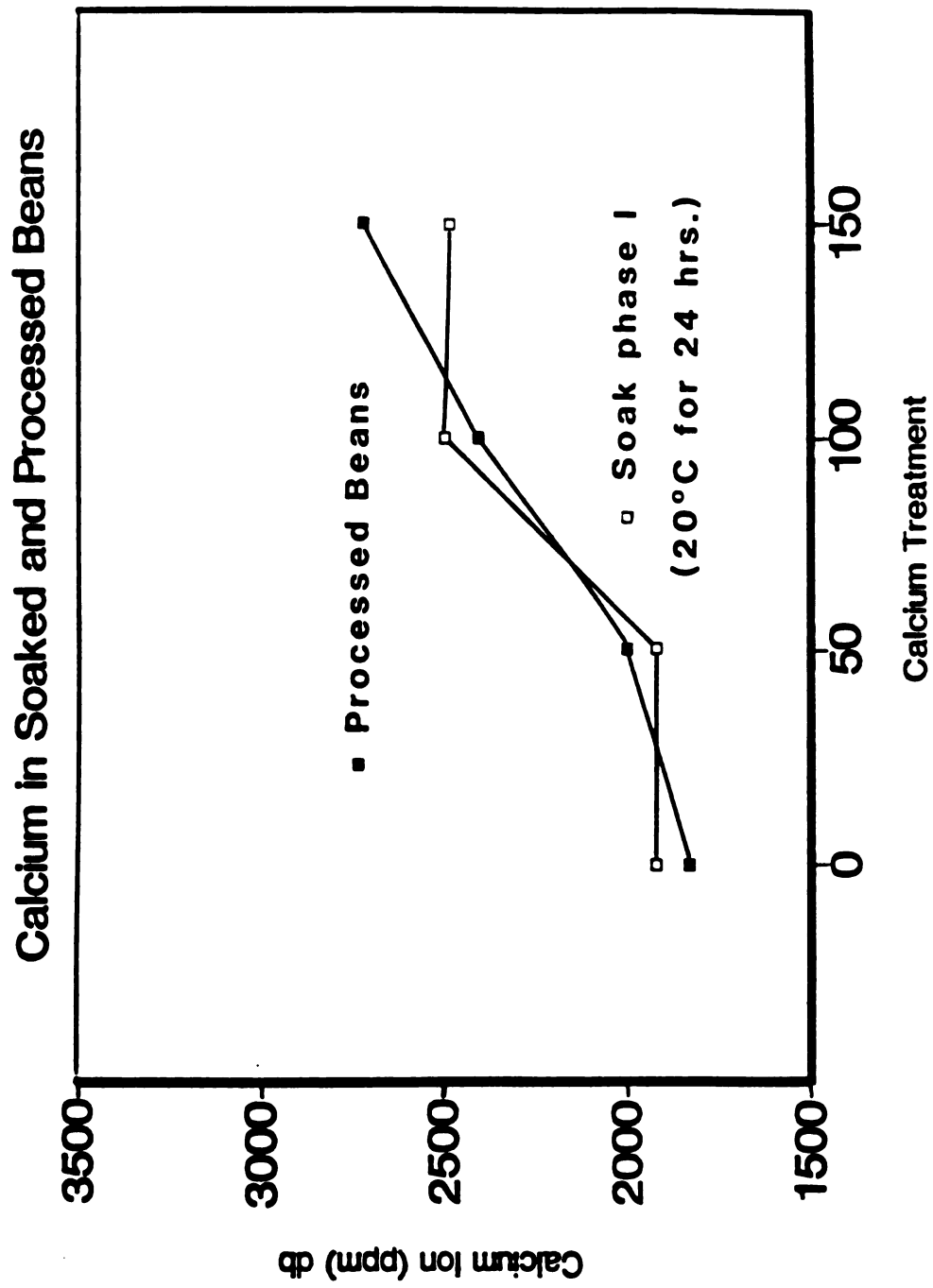


Figure 15. Measured calcium in overnight soaked and processed beans in calcium from 0 to 150 ppm.

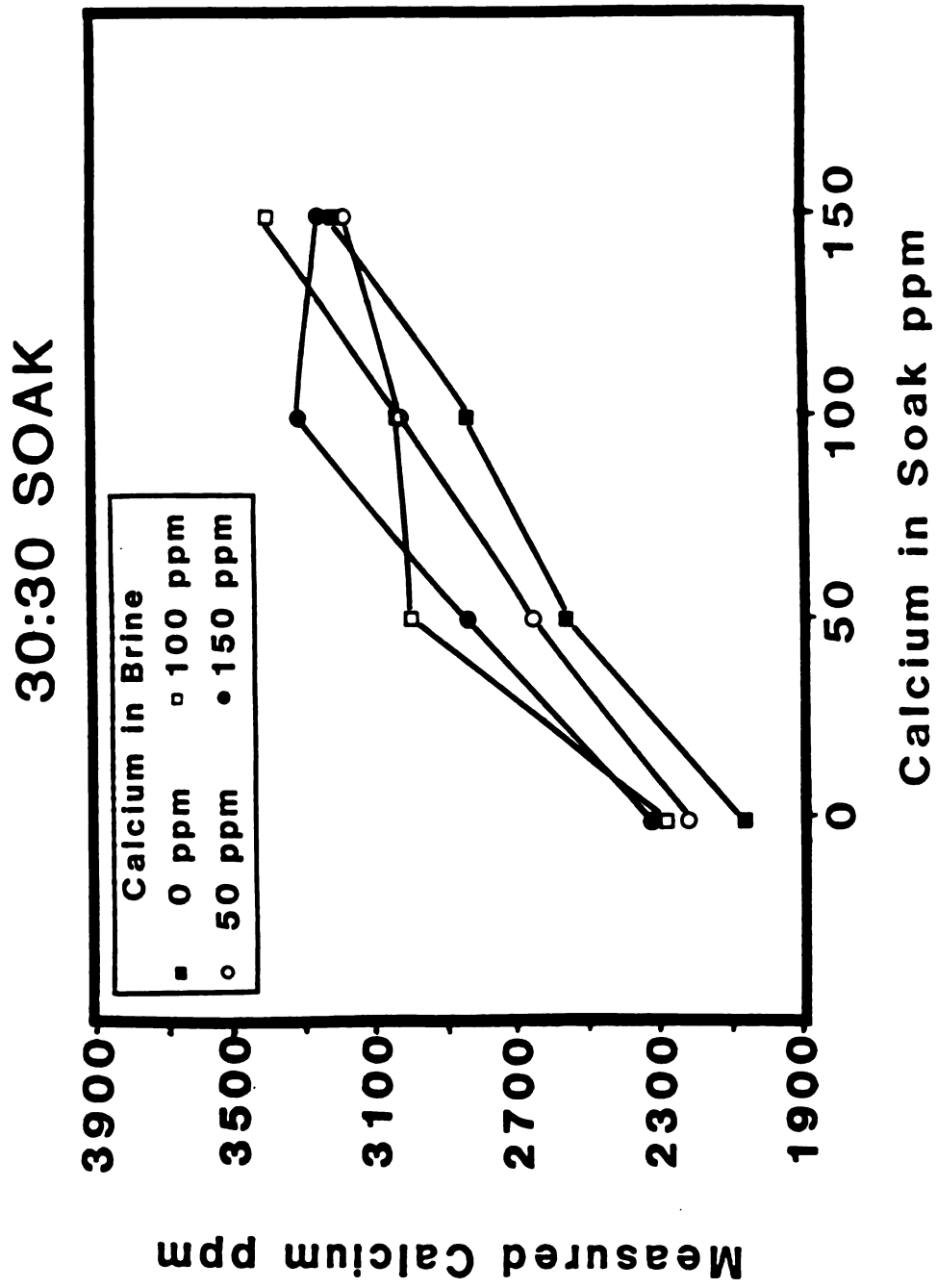


Figure 16. Effect of calcium in soak water on total measured bean calcium for 30:30 soaked beans.

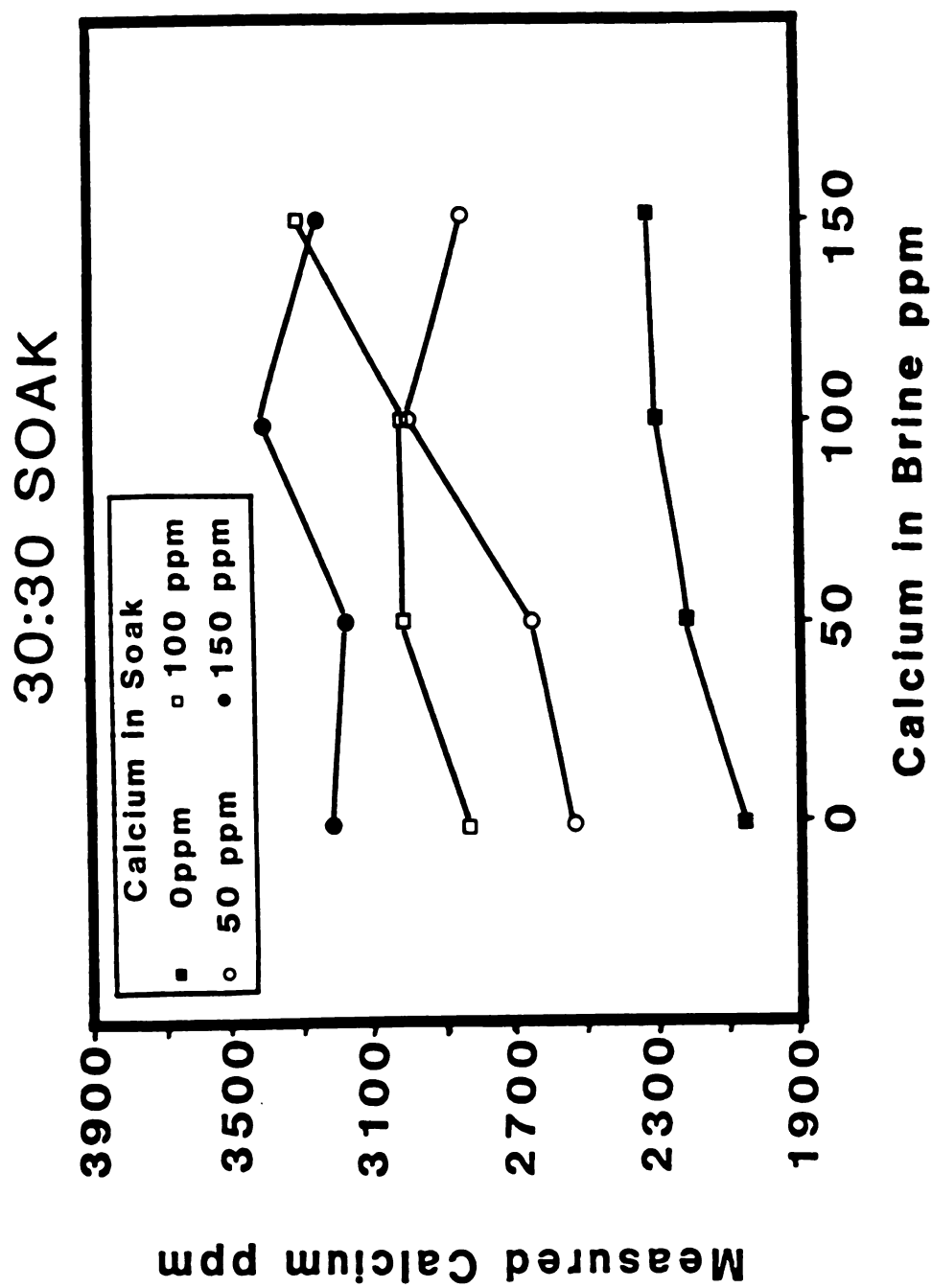


Figure 17. Effect of calcium in brine medium on total measured bean calcium for 30:30 soaked beans.

total measured calcium. All slopes are approaching zero stating the small effect of brine calcium on total measured calcium.

Figure 18 represents the amount of calcium present in the bean during soaking and after processing. Soak phase 1 is at ambient temperature for 30 minutes and shows very little Ca^{++} absorption at all levels. Soak phase 2 immediately follows in 87.8°C water for 30 minutes. A dramatic increase in measured calcium is found by the acceleration of absorption due to heat. Processing provides a further absorption of calcium with the greatest increase at the 50 ppm level, a smaller increase at 100 ppm and a tapering off at the 150 ppm level. The steady decrease in absorption suggests a limit to the amount of calcium that can be bound.

Of the quality measures presented here, many are correlated with each other for defining total product quality. Texture is a major factor in product quality of processed beans and in this study many measures were conducted to better define processed texture. Pearson correlation coefficients of all physical measurements were calculated and the significant correlations are presented in Table 11. Kramer shear force, Kramer compression force, and measured calcium are significantly correlated with soak weight, drained weight and total solids. In addition, drained weight is significantly correlated with soak weight. For physical measurement of processed bean texture, drained

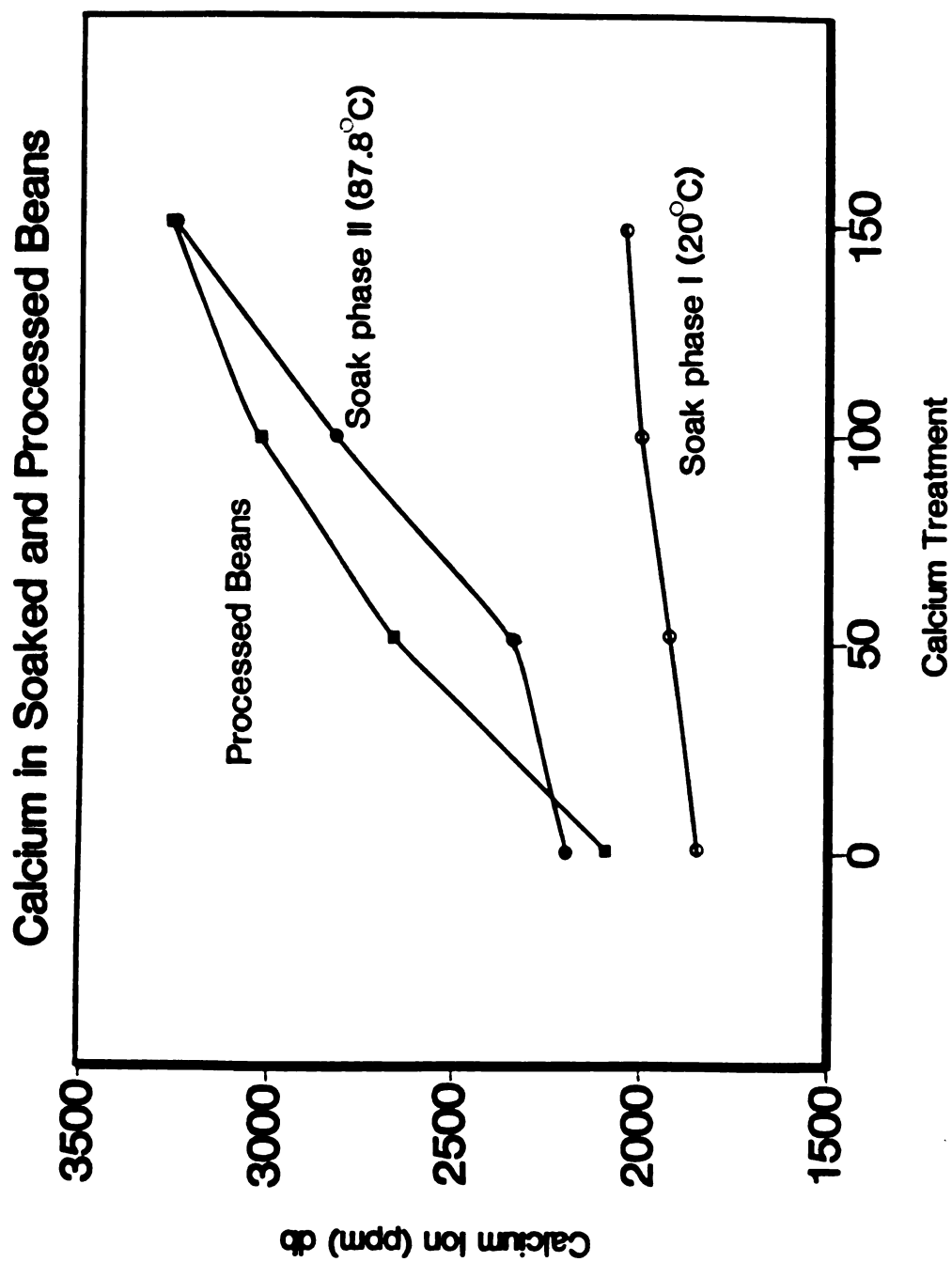


Figure 18. Measured calcium in 30:30 soaked and processed beans in calcium from 0 to 150 ppm.

Table 11. Pearson correlation coefficients of physical texture measurements.

Physical Texture Measurement	Correlation coefficient ^a (r)					
	1	2	3	4	5	6
1) Soak Weight	-----					
2) Drained Weight	<u>.7882</u>	-----				
3) Total Solids	-.4077	-.5319	-----			
4) Compression Force	<u>-.6003</u>	<u>-.8016</u>	<u>.7830</u>	-----		
5) Shear Force	<u>-.5850</u>	<u>-.7893</u>	<u>.7648</u>	<u>.9768</u>	-----	
6) Measured Calcium	<u>-.6956</u>	<u>-.8427</u>	<u>.6300</u>	<u>.8930</u>	<u>.9302</u>	-----

^aCorrelation coefficients significant at $p \leq 0.001$ are underlined.

weight, compression force, shear force, and measured calcium behave similarly while other measures vary independently.

Subjective Data

Subjective tests including rank analysis and Quantitative Descriptive Analysis (QDA) were completed on eight of the original thirty two treatments in this study. These treatments represent samples from both soak mediums with the same ppm Ca^{++} in their soak medium and brine solution (i.e. ppm Ca^{++} soak medium:ppm Ca^{++} brine solution, 0:0, 50:50, 100:100, 150:150). Mean rank scores by the panelists are presented in Table 12. Ranking was performed separately on the four treatments from each soak. Panelists were asked to rank in order of texture firmness with softest = 1 and firmest = 4. Kramer rank sums show significance at all levels.

Table 12. Mean rank scores¹ of processed beans soaked and brined in four levels of calcium ion.

<u>Soak Method</u>	<u>Soak and Brine Medium (ppm Ca^{++})</u>			
	0	50	100	150
Overnight	1.2**	2.0**	2.9**	3.9**
30:30	1.0**	2.2*	2.9*	3.9**

¹ Ranked from softest to firmest with softest = 1 and firmest = 4.

Panelist means from QDA are presented with corresponding analysis of variance in Tables 13 through 18.

The results are divided in three sensory testing methods including masticatory, tactile, and visual. In general terms, characteristic descriptions of a firm bean are on the low end of the scale and a soft bean on the high end. Panelist means for the masticatory test are presented in Table 13 with Tukey mean separations by soak. Panelists detected some significant differences between calcium treatments in the overnight soak for all five parameters. For the 30:30 soak, panelists detected no significant differences among calcium treatments for cotyledon smoothness but significant differences for the remaining four parameters. Analysis of variance (Table 14) showed significance for all main effects except for the panelist in the combined resistance attribute.

Mean panelist results for the tactile test are in Table 15. Panelists detected slight textural differences from calcium treatments in both soaks with some significant differences in all parameters except uniform paste for the overnight soak. Mean squares (Table 16) for the tactile test show all main effects were significant except for soak method in cotyledon and seed coat smoothness and uniform paste.

Visual test results are presented in Table 17 with no significant differences detected by the panelists in the overnight soak samples. Slight differences were detected from calcium treatments in the 30:30 soak. Analysis of variance in Table 18 shows significant main effects for all

Table 13. Panelist means¹ of Quantitative Descriptive Analysis masticatory test: Processed beans were soaked and brined in four levels of calcium ion.

ppm Ca ⁺⁺	<u>Cotyledon</u>			<u>Seed Coat</u>	<u>Combined</u>
	Smoothness	Moisture	Firmness	Toughness	Resistance
OVERNIGHT SOAK ²					
0	7.7a	6.9a	7.6a	8.2a	7.9a
50	6.4ab	6.3ab	6.8a	7.2ab	7.1ab
100	6.3ab	6.1ab	6.3ab	6.2bc	6.4bc
150	5.5b	4.7b	4.9b	5.0c	5.2c
30:30 SOAK ²					
0	6.9a	6.7a	7.5a	8.0a	7.5a
50	5.5a	5.2ab	4.7b	5.1b	5.0b
100	5.3a	4.4b	3.4bc	3.3c	4.0bc
150	5.2a	3.8b	2.8c	3.1c	3.2c

¹Mean values (like letters within each column for each soak method indicate no significant differences at $P \leq 0.05$ by Tukey mean separation; $n = 10$).

²OVERNIGHT SOAK = 20°C soak for 12 hours. 30:30 SOAK = 20°C soak for 30 minutes followed with 87.8°C soak for 30 minutes

Table 14. Analysis of variance for Quantitative Descriptive Analysis Masticatory test.

Source of Variation	df	Cotyledon			Seed Coat Toughness	Combined Resistance
		Smoothness	Moisture	Firmness		
MEAN SQUARES						
Main Effects	13	17.059***	22.636***	38.606***	46.913***	31.203***
Soak Treatment	1	22.801*	36.290**	129.780***	129.240***	120.930***
Calcium Treatment	3	27.869***	45.212***	99.167***	128.327***	86.119***
Panelists	9	12.817***	13.593***	8.289**	10.627***	2.928
Two way	39	3.406	3.726	3.018	4.187*	2.365
Soak x calcium	3	1.179	3.711	13.402**	11.873**	8.287*
Soak x panelist	9	2.398	2.257	1.785	2.471	1.916
Calcium x panelist	27	3.989	4.217	2.275	3.905	1.856
Three way	27	4.357	3.214	2.580	2.960	3.610
Soak x calcium x panelist						
Explained	79	5.977*	6.663*	8.724***	10.799***	7.536***
Residual	80	3.753	3.997	2.875	2.600	2.347
%CV		31.9	36.3	31.0	28.1	26.6

Table 15. Panelist means¹ of Quantitative Descriptive Analysis tactile test: Processed beans were soaked in four levels of calcium ion.

ppm Ca ⁺⁺	Cotyledon and Seed Coat			Uniform Paste
	Resistance to Rupture	Smoothness	Moisture	
OVERNIGHT SOAK ²				
0	6.7a	7.1a	7.1a	6.9a
50	6.1ab	7.0a	6.1ab	6.9a
100	6.3ab	7.1a	5.6ab	7.0a
150	5.1b	5.5b	4.8b	6.2a
30:30 SOAK				
0	6.6a	7.1a	6.4a	7.3a
50	5.4ab	6.9a	5.4ab	7.2a
100	4.5bc	5.8ab	4.3b	6.4ab
150	3.8c	5.3b	4.0b	5.6b

¹Mean values (like letters within each column for each soak method indicate no significant differences at $P \leq 0.05$ by Tukey mean separation; $n = 10$).

²OVERNIGHT SOAK = 20°C soak for 12 hours. 30:30 SOAK = 20°C soak for 30 minutes followed with 87.8°C soak for 30 minutes

Table 16. Analysis of variance for Quantitative Descriptive Analysis Tactile test.

Source of Variation	df	Cotyledon and Seed Coat			
		Resistance to Rupture	Smoothness	Moisture	Uniform Paste
MEAN SQUARES					
Main Effects	13	16.836***	9.640***	25.330***	8.920***
Soak Method	1	36.195***	7.268	27.889***	0.420
Calcium Treatment	3	34.840***	23.317***	41.852***	12.808**
Panelists	9	8.684***	5.344**	19.538***	8.568***
Two way	39	3.130	3.964**	3.981*	4.093*
Soak x calcium	3	5.127	3.664	0.865	3.009
Soak x panelist	9	4.600	2.730	4.130	3.060
Calcium x panelist	27	2.418	4.408**	4.278*	4.558*
Three way	27	2.624	1.647	3.786	2.026
Soak x calcium x panelist					
Explained	79	5.212***	4.106***	7.428***	4.181**
Residual	80	2.390	1.939	2.353	2.458
%CV		27.8	21.6	28.1	23.5

Table 17. Panelist means¹ of Quantitative Descriptive Analysis visual test: Processed beans were soaked and brined in four levels of calcium ion.

ppm Ca ⁺⁺	<u>Whole Bean</u>				<u>Brine</u>
	Color	Gloss	Integrity	Clumping	Clarity
OVERNIGHT SOAK ²					
0	5.7a	4.5a	3.5a	6.3a	5.4a
50	4.9a	4.8a	3.4a	5.0a	4.6a
100	4.7a	5.3a	3.6a	5.6a	4.5a
150	4.1a	4.9a	3.2a	3.2a	4.3a
30:30 SOAK					
0	4.7a	4.6a	4.4a	5.6a	2.8a
50	4.7a	3.4ab	2.8b	3.7b	2.9a
100	3.1b	2.4b	2.5b	2.5bc	2.2ab
150	1.9b	2.5b	2.5b	1.7c	1.5b

¹Mean values (like letters within each column for each soak method indicate no significant differences at $P \leq 0.05$ by Tukey mean separation; $n = 10$).

²OVERNIGHT SOAK = 20°C soak for 12 hours. 30:30 SOAK = 20°C soak for 30 minutes followed with 87.8°C soak for 30 minutes

Table 18. Analysis of variance for Quantitative Descriptive Analysis visual test.

Source of Variation	df	Whole Bean				Brine
		Color	Gloss	Integrity	Clumping	Clarity
MEAN SQUARES						
Main Effects	13	23.925***	16.444***	24.914***	38.630***	26.170***
Soak method	1	64.136***	109.230***	5.148	107.256***	222.312***
Calcium treatment	3	37.150***	6.034	9.418**	78.940***	10.795*
Panelists	9	15.048***	9.604	32.276***	17.568***	9.501*
Two way	39	3.539	6.210	2.725	2.320	2.490
Soak x calcium	3	6.458	16.451*	8.228**	10.206	2.561
Soak x panelist	9	7.203*	7.857	5.951**	2.642	2.225
Calcium x panelist	27	1.994	4.523	1.038	1.336	2.225
Three way	27	2.617	2.291	1.895	2.350	2.228
Soak x calcium x panelist						
Explained	79	6.579***	6.555	6.093***	8.305***	6.297*
Residual	80	3.137	4.961	2.003	4.084	3.855
%CV		42.0	55.3	43.8	48.1	55.6

but whole bean gloss and integrity. The significant main effect for gloss is soak method and for integrity is calcium treatment along with panelist interaction.

Graphical representations of the QDA panelists results for the overnight and 30:30 soak are found in Figures 19 and 20 respectively. Comparing the two, panelists found more significant differences in the 30:30 soak than the overnight. This result also corresponds to the larger range of measured calcium found in the 30:30 soaked beans when we correlate measured calcium with objective and subjective measures of texture. Figure 21 demonstrates the perceived differences by the panelists for the two soak methods and each calcium treatment of 0, 50, 100, and 150 ppm.

Pearson correlation coefficients are presented in Table 19 for the fourteen texture attributes evaluated by the QDA panelists. Most of the sensory attributes are related to texture and they are highly correlated as would be expected. Results of the masticatory and tactile tests have the highest correlations. The visual test shows a very high correlation of clumping with the other attributes. Clumping is easily defined and detected by the panelists. The other visual attributes were either not strongly related to texture changes or more difficult for panelists to detect.

In future use of QDA for bean texture, one might consider eliminating some characteristics that are highly correlated. The Pearson correlation coefficients help point out which texture attributes are expressing the same

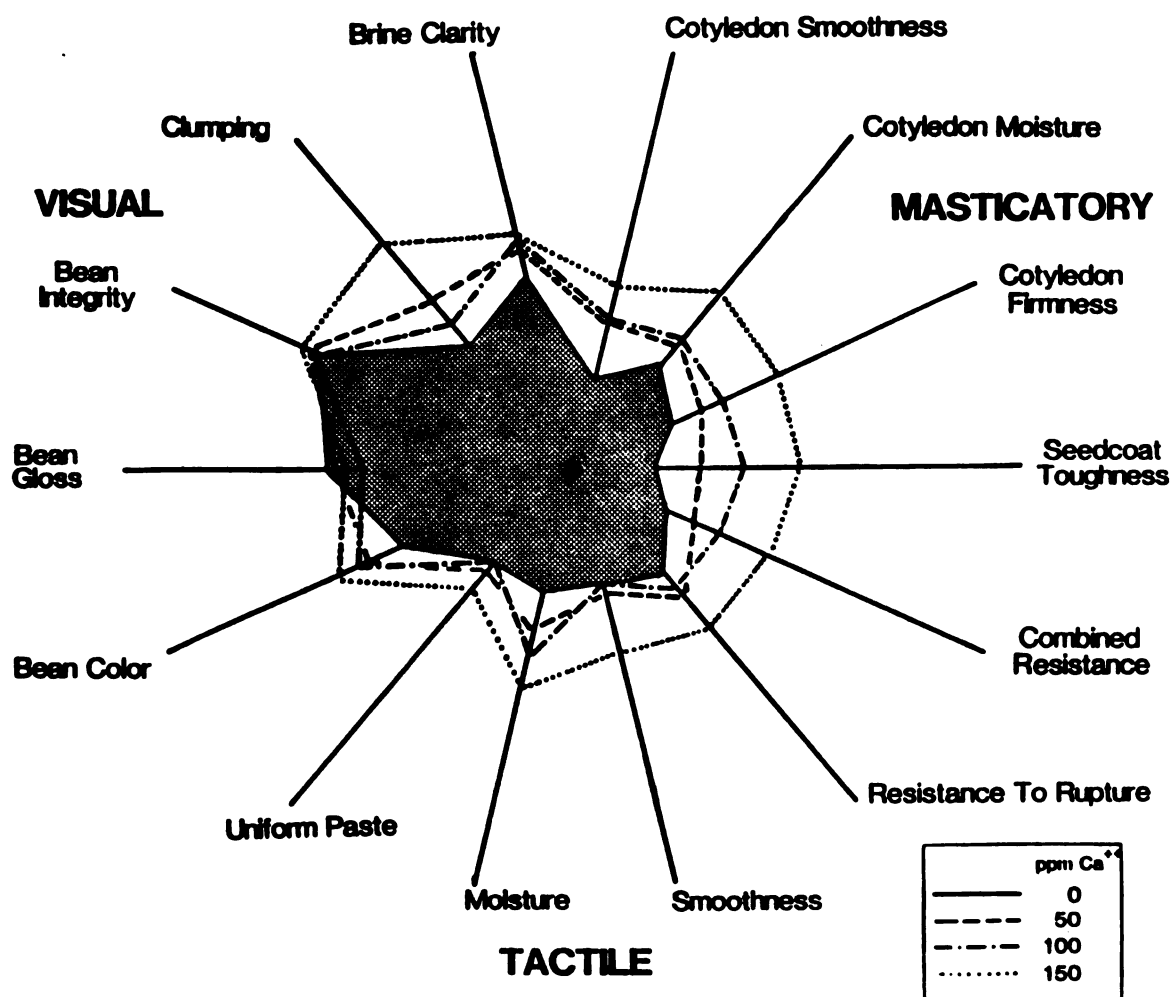


Figure 19. QDA representation of panelist means for the overnight soak over four calcium treatments.

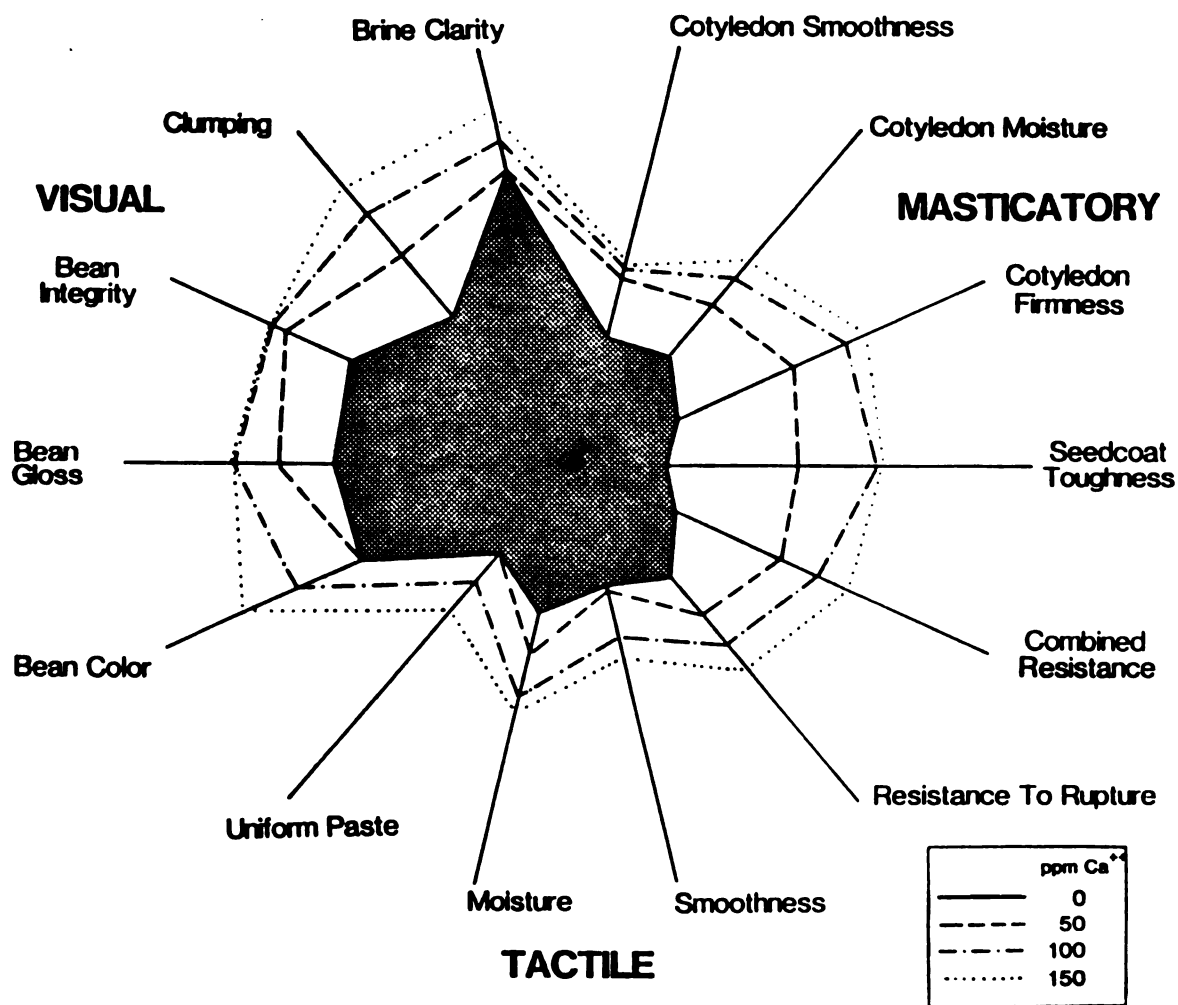


Figure 20. QDA representation of panelist means for the 30:30 soak over four calcium treatments.

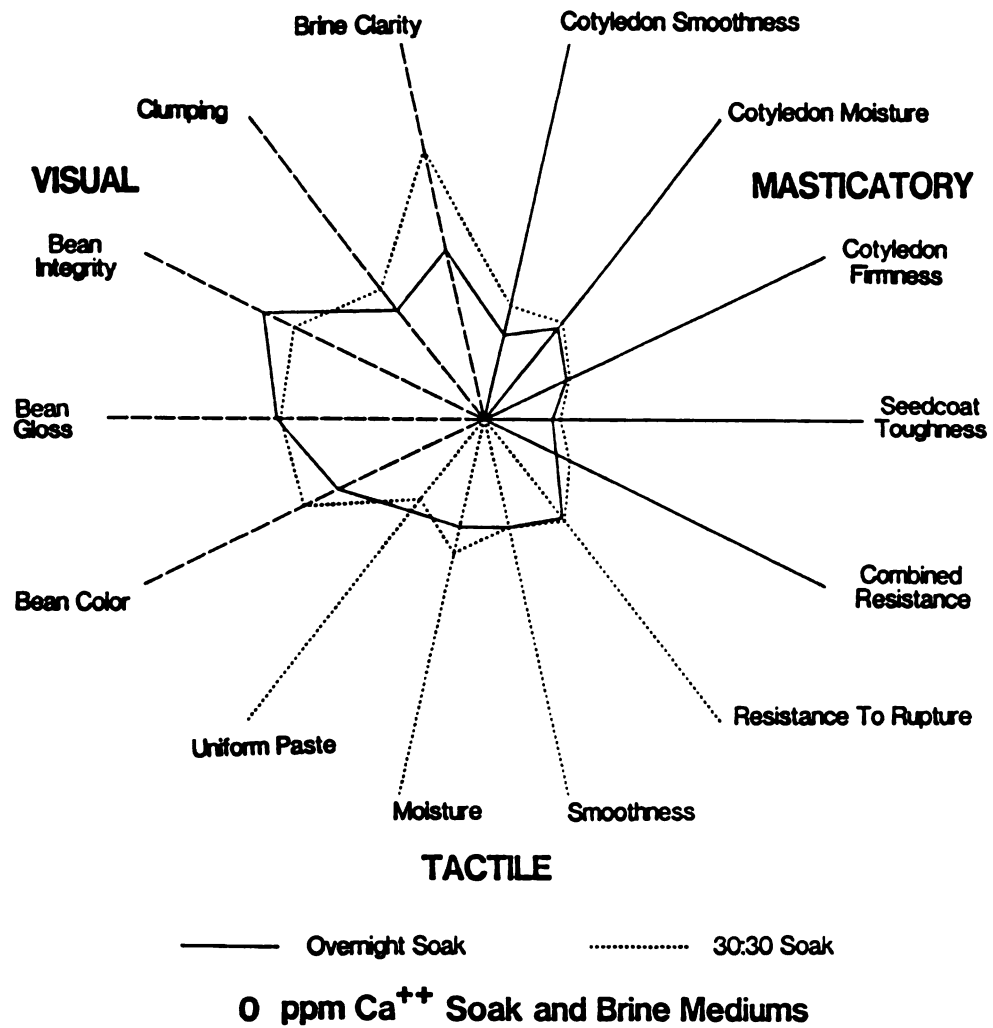


Figure 21a. QDA representation of panelist means for two soak methods and 0 ppm calcium treatment.

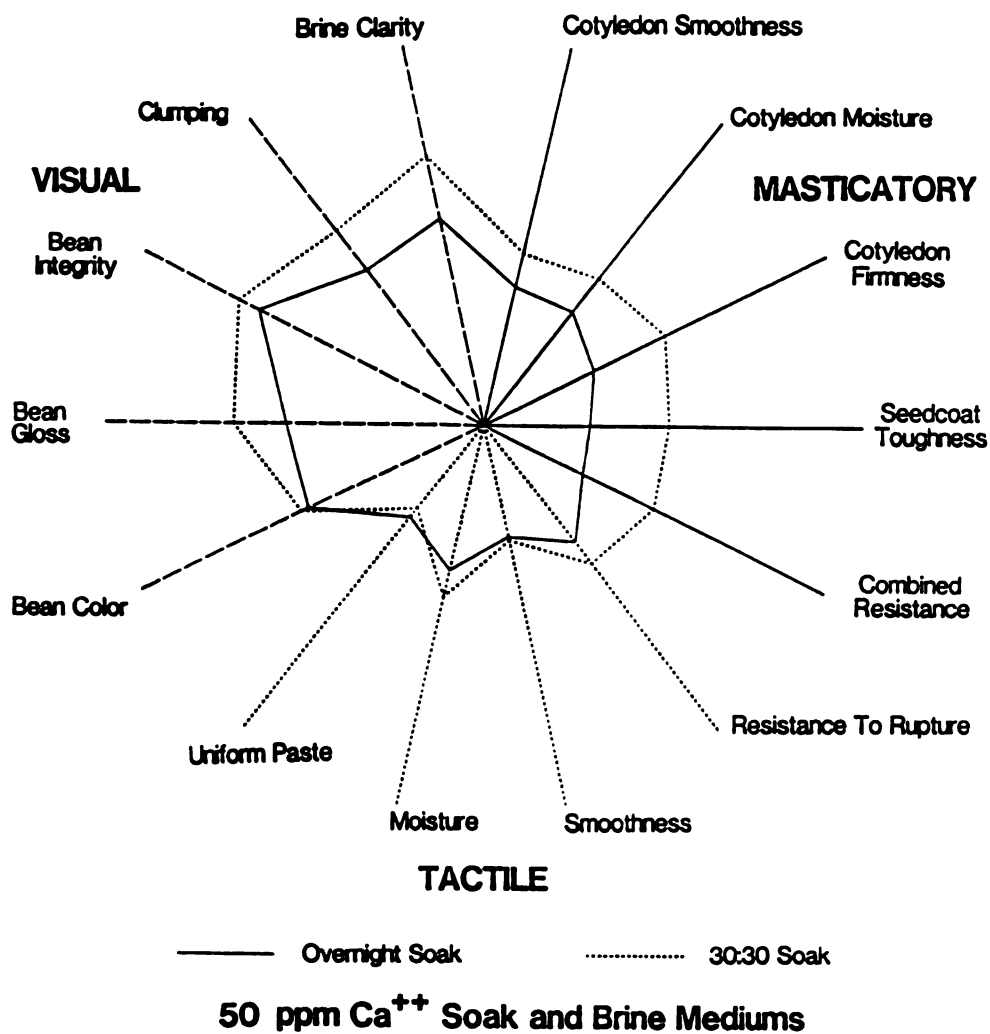


Figure 21b. QDA representation of panelist means for two soak methods and 50 ppm calcium treatment.

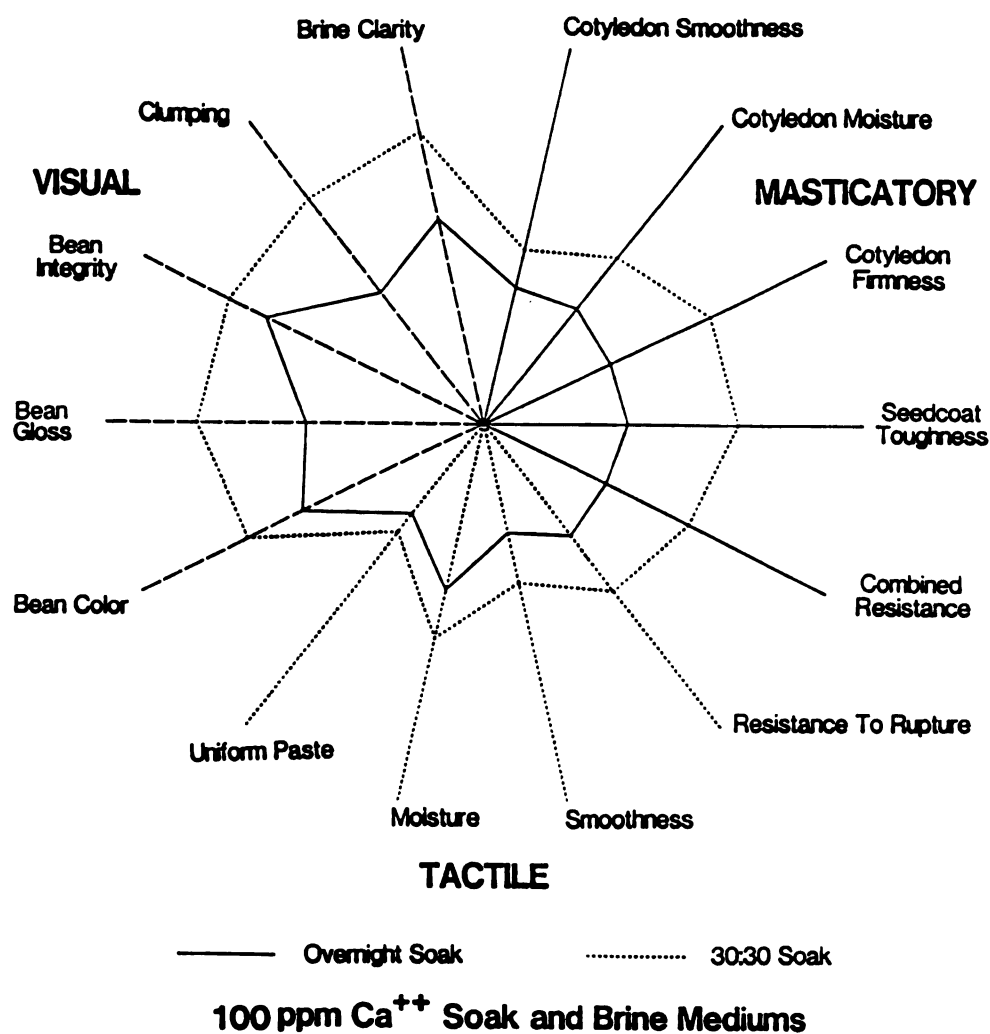


Figure 21c. QDA representation of panelist means for two soak methods and 100 ppm calcium treatment.

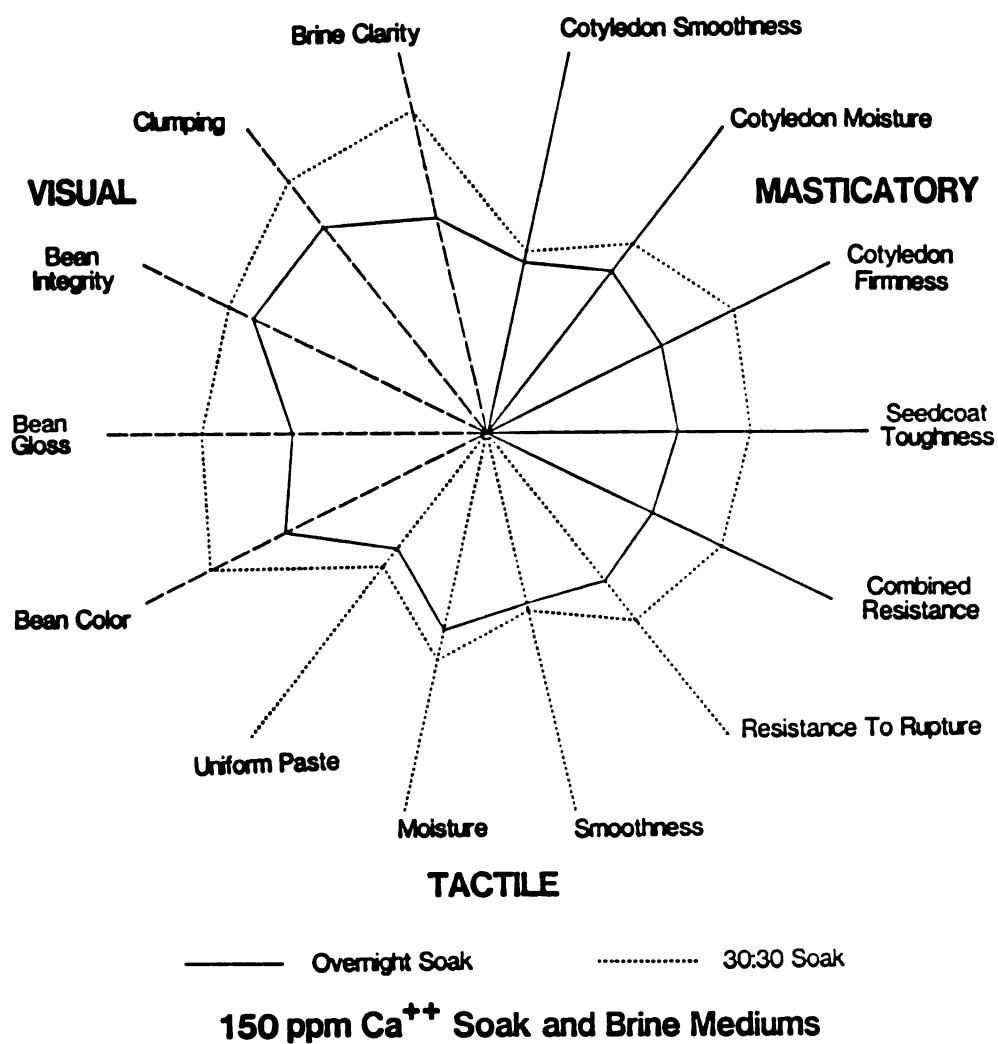


Figure 21d. QDA representation of panelist means for two soak methods and 150 ppm calcium treatment.

Table 19. Pearson correlation coefficients¹ for texture attributes evaluated by QDA.

	Masticatory				
	1	2	3	4	5
1)Cotyledon Smoothness	-----				
2)Cotyledon Moisture	.9447	-----			
3)Cotyledon Firmness	.8610	.9499	-----		
4)Seedcoat Toughness	.8688	.9448	.9932	-----	
5)Combined Resistance	.8605	.9459	.9973	.9913	-----
6)Resistance to Rupture	.9096	.9834	.9590	.9455	.9511
7)Spreadability	.8484	.9368	.8296	.8240	.8184
8)Moisture	.9591	.9773	.9240	.9326	.9203
9)Uniform Paste	.7930	.8673	.7164	.7094	.7035
10)Color	.8442	.9246	.8934	.8815	.8934
11)Gloss	.7664	.8280	.8150	.7819	.8013
12)Integrity	.8688	.8806	.7870	.7752	.7656
13)Clumping	.8941	.9652	.9680	.9511	.9611
14)Brine Clarity	.7411	.7605	.7744	.7447	.7871

Table 19. (cont'd.)

	Tactile			
	6	7	8	9
1)Cotyledon Smoothness				
2)Cotyledon Moisture				
3)Cotyledon Firmness				
4)Seedcoat Toughness				
5)Combined Resistance				
6)Resistance to Rupture	-----			
7)Spreadability	.9302	-----		
8)Moisture	.9646	.9138	-----	
9)Uniform Paste	.8643	.9356	.8497	-----
10)Color	.9467	.8908	.9327	.8523
11)Gloss	.8514	.7470	.7810	.7327
12)Integrity	.8632	.8132	.8425	.8576
13)Clumping	.9780	.8957	.9410	.7725
14)Brine Clarity	.7762	.6461	.7543	.5698

Table 19. (cont'd.)

	Visual				
	10	11	12	13	14
1)Cotyledon Smoothness					
2)Cotyledon Moisture					
3)Cotyledon Firmness					
4)Seedcoat Toughness					
5)Combined Resistance					
6)Resistance to Rupture					
7)Spreadability					
8)Moisture					
9)Uniform Paste					
10)Color	-----				
11)Gloss	.8402	-----			
12)Integrity	.7575	.8602	-----		
13)Clumping	.9196	.8211	.7957	-----	
14)Brine Clarity	.8548	.8646	.6107	.7946	-----

¹Correlation coefficients >0.5698 are significant at $p \leq 0.001$.

information for the food product. However, intercorrelation may be high with one type of food and not with another. The results presented here exclusively represent the texture of processed navy beans.

Objective and Subjective Correlations

Simple correlations of objective and subjective measures for texture were calculated. The objective measures that correlate best with the sensory attributes tested are drained weight, compression force, shear force, and measured calcium and are presented in Table 20. All correlations were very significant with most at $p \leq 0.001$. A general trend from this data shows a high correlation of all four instrumental measures with cotyledon firmness, seedcoat toughness and combined resistance, all from the masticatory test.

To better understand the relationship between the sensory and instrumental measures, linear regression analyses were calculated. The parameters of Equation 11 are K_0 (the intercept) and K_1 (the coefficient) which provides a prediction of a sensory attribute by an instrumental measure. This shows that for a unit increase in an instrumental measure, we expect a K_1 unit increase in perceived texture. The strength of the relationship and the proportion of variation in the sensory attribute as explained by the instrumental measure is the r^2 value. The r^2 indicates the proportion of explained variation between the dependent and independent variables.

Table 20. Pearson correlation coefficients for objective and subjective measures of texture.

Sensory Attribute	Correlation coefficient (r) ¹			
	Drained Weight	Compression Force	Shear Force	Measured Calcium
Cotyledon Smoothness	.6636	-.5373	-.5992	-.5366
Cotyledon Moisture	.7085	-.7225	-.7751	-.6757
Cotyledon Firmness	.8329	-.8589	-.8995	-.8375
Seedcoat Toughness	.8352	-.8463	-.9003	-.8452
Combined Resistance	.8378	-.8559	-.8967	-.8469
Resistance to Rupture	.7319	-.7859	-.8133	-.6932
Spreadability	.5385	-.6394	-.6932	-.5463
Moisture	.7259	-.7028	-.7542	-.6589
Uniform Paste	.3855	-.5362	-.5613	-.3501
Color	.7604	-.7738	-.7716	-.6536
Gloss	.6378	-.5799	-.5822	-.4875
Integrity	.4510	-.4811	-.5292	-.3710
Clumping	.7953	-.7994	-.8309	-.7556
Brine Clarity	.7838	-.5821	-.5613	-.5744

¹Correlation coefficients >0.5750 are significant at $p \leq 0.001$.

$$\text{Sensory Attribute} = K_0 + K_1(\text{Instrumental Measure})$$

Equation 11. Linear regression equation.

Simple linear regression shows the strongest relationships with instrumental measures are cotyledon firmness, seed coat toughness and combined resistance. Linear, logarithmic, exponential, and power equations were calculated with no one method producing stronger relationships with the sensory attributes.

The linear equation was most consistent and used for examination of multiple regression. The resulting equations for multiple regression are presented in Table 21. Multiple linear regression was calculated with stepwise regression. Drained weight, compression force, shear force, and measured calcium were the independent variables and the dependent variables were the fourteen sensory attributes. Each step of regression selects one independent variable that explains the greatest amount of variance unexplained by the variables already in the equation. Addition of variables to the prediction equation stops when inclusion criteria is not met. An indicator of prediction accuracy that gives an absolute amount of explained or unexplained variation in the equation is the standard error of estimation (SE). Table 21 shows the regression equations for the fourteen sensory attributes with physical and chemical measurements of texture. From the r^2 value, cotyledon firmness, seedcoat toughness, and combined resistance are best predicted from

Table 21. Stepwise multiple linear regression equations for objective and subjective measures of processed bean texture.

Cotyledon Smoothness

$$= -7.4732 + (\text{Drained Wt.} * 0.0458)$$

$$r^2=0.44 \quad \text{S.E.}=0.90$$

Cotyledon Moisture

$$= 7.9398 + (\text{Shear Force} * -0.0452)$$

$$r^2=0.60 \quad \text{S.E.}=0.88$$

Cotyledon Firmness

$$= 9.3413 + (\text{Shear Force} * -0.0720)$$

$$r^2=0.81 \quad \text{S.E.}=0.84$$

$$= -2.3721 + (\text{Shear Force} * -0.05141) + (\text{Drained Weight} * 0.0358)$$

$$r^2=0.85 \quad \text{S.E.}=0.76$$

Seedcoat Toughness

$$= 9.9329 + (\text{Shear Force} * -0.0779)$$

$$r^2=0.81 \quad \text{S.E.}=0.90$$

$$= -2.9106 + (\text{Shear Force} * -0.0554) + (\text{Drained Weight} * 0.0393)$$

$$r^2=0.85 \quad \text{S.E.}=0.81$$

$$= -8.9075 + (\text{Shear Force} * -0.1340) + (\text{Drained Weight} * 0.0489) + (\text{Compression Force} * 0.1238)$$

$$r^2=0.89 \quad \text{S.E.}=0.70$$

$$= -20.8196 + (\text{Shear Force} * -0.1952) + (\text{Drained Weight} * 0.0719) + (\text{Compression Force} * 0.1644) + (\text{Measured Calcium} * 0.0024)$$

$$r^2=0.93 \quad \text{S.E.}=0.61$$

Table 21. (cont'd.)

Combined Resistance

$$=9.3493 + (\text{Shear Force} * -0.0666)$$

$$r^2=0.8041 \quad \text{S.E.}=0.7860$$

$$=-2.1507 + (\text{Shear Force} * -0.0464) + (\text{Drained Weight} * 0.0352)$$

$$r^2=0.8490 \quad \text{S.E.}=0.7064$$

Resistance to Rupture

$$=7.8223 + (\text{Shear Force} * -0.0421)$$

$$r^2=0.6615 \quad \text{S.E.}=0.7203$$

Spreadability

$$=8.0273 + (\text{Shear Force} * -0.0292)$$

$$r^2=0.4806 \quad \text{S.E.}=0.7252$$

Moisture

$$=7.6787 + (\text{Shear Force} * -0.0413)$$

$$r^2=0.5688 \quad \text{S.E.}=0.8595$$

Uniform Paste

$$=7.8235 + (\text{Shear Force} * -0.0214)$$

$$r^2=0.3151 \quad \text{S.E.}=0.7527$$

$$=4.5133 + (\text{Shear Force} * -0.0665) + (\text{Measured Calcium} * 0.0023)$$

$$r^2=0.5346 \quad \text{S.E.}=0.6351$$

Color

$$=8.0742 + (\text{Compression Force} * -0.0646)$$

$$r^2=0.5988 \quad \text{S.E.}=0.8807$$

Table 21. (cont'd.)

Gloss

$$=-11.2069 + (\text{Drained Weight} * 0.0515)$$

$$r^2=0.4068 \quad \text{S.E.}=1.0824$$

Integrity

$$=4.4205 + (\text{Shear Force} * -0.0222)$$

$$r^2=0.2801 \quad \text{S.E.}=0.8520$$

Clumping

$$=7.5366 + (\text{Shear Force} * -0.0621)$$

$$r^2=0.6903 \quad \text{S.E.}=0.9944$$

Brine Clarity

$$=-17.1982 + (\text{Drained Weight} * 0.0699)$$

$$r^2=0.6144 \quad \text{S.E.}=0.9647$$

the independent measures including drained weight, shear force, compression force and measured calcium. Seed coat toughness is the only attribute to include all four independent measures in the prediction equation. By examining each step for seedcoat toughness, the variance is decreasing with each variable added by r^2 increasing and SE decreasing.

In evaluating processed beans for acceptable texture, Kramer force readings and drained weight are feasible to obtain even when testing numerous samples. Measured calcium is more time consuming and costly to obtain but as shown here a valuable measure for texture evaluation. From this study of texture perceptions, sensory attributes of the masticatory test including cotyledon firmness, seedcoat toughness, and combined resistance were effective in defining perceived texture and can be predicted with good accuracy from instrumental measures including drained weight, Kramer compression force, Kramer shear force, and measured calcium.

SUMMARY

Soak method, soak medium, and brine medium all produced significant effects on processed bean texture with increasing calcium levels producing firmer beans. Overnight soak produced softer beans than the 30:30 soak in all soak and brine medium treatments that included calcium. Calcium absorption occurred more from the soaking medium than the brine medium for both soak methods with 30:30 showing a more

dramatic effect. The effect of heat during soaking, as in the 30:30 soak produces a difference in the amount of calcium absorbed.. The 30:30 soak allowed greater calcium absorption with decreased drained weights and increased measured firmness. The overnight soak absorbed less calcium ion, had increased drained weights and decreased firmness.

Quantitative descriptive analysis was effective in defining the processed texture of beans with trained panelists by three methods including: Masticatory, Tactile and Visual Tests. The masticatory and tactile tests were most effective in evaluating texture of processed navy beans. Most of the sensory attributes were highly correlated indicating some redundancy in evaluation for this product.

Correlation coefficients of objective and subjective data show drained weight, Kramer compression force, Kramer shear force, and measured calcium are the best objective measures of subjective descriptors used in this study. These parameters produced multiple linear regression equations with good prediction accuracy for cotyledon firmness, seed coat toughness, and combined resistance from the masticatory test.

Study 2: The effect of heat treatment and calcium concentration on water and calcium absorption of dry beans during soaking.

ABSTRACT

Water and calcium absorption were measured during soaking over a range of temperatures (60, 70, 80, 90°C) and calcium ion concentrations (0, 50, 100, 150ppm). After 60 minutes of soaking, total water uptake was greatest at the lowest soak temperature (60°C) and decreasing with higher soak temperatures of 70 and 80°C at all calcium ion concentrations. Soaking at 90°C produced a total absorption greater than at 80°C but less than 60°C after 60 minutes. Within each soak temperature, higher calcium levels in the soak produced respectively lower total water absorptions. The effect of soak temperature on total calcium absorption is minimal from 60 to 80°C but at 90°C a significant increase occurs. The rates of water uptake are highest with the lowest soak temperature for all soak calcium concentrations tested.

INTRODUCTION

Soaking dry beans prior to cooking, aids in efficient processing and provides beneficial attributes to the final cooked product. Soak methods that can accelerate water uptake, decrease cook time, and increase processor's yield

are most desirable. Soak treatments can provide a wide range of quality attributes in cooked beans. The objective of this study is to isolate two soak variables and evaluate them for their optimum performance during soaking.

The variables chosen for study include a range of heated soak temperatures and a range of calcium ion concentrations in the soak water. Heated soaks have shown beneficial in decreasing soak times and increasing drained weights (Nordstrom and Sistrunk, 1977). The effect of calcium in processing has long been established to create a firming of texture in vegetables (Van Buren, 1979). Earlier work by Uebersax and Bedford (1980) demonstrated that adding calcium during soaking has a greater effect on firming than by adding calcium during the final processing. Based on this information, this study will specifically examine the calcium absorption during soaking alone. Also under consideration is where the calcium taken up during soaking is located in the bean. Researchers have found the seed coat to play a major role in water uptake and have shown the rate to be dependent upon calcium content, seed coat surface, micropyle structure, and initial moisture content (Saio, 1976; Hsu, 1983). Here we will examine the seed coat and cotyledon structures for total measured calcium found after 60 minutes of soaking.

The goal of this study is to evaluate the effect of heat treatment and calcium concentration, on water and calcium absorption during soaking. Evaluation of bean

microstructure during soaking at different temperatures and calcium concentrations will also be included. The results will show: first, the individual effects of heat and calcium on water absorption; second, the effects of heat and calcium concentration on calcium absorption; third, the interactions of heat treatment and calcium concentration on the absorption of water and calcium; and fourth, SEM micrographs depicting bean microstructure during soaking.

MATERIAL AND METHODS

Samples of C-20 variety navy beans were obtained for testing with an initial dry bean moisture of 12.4% (db) from the AACC method 44-40, 1982.

Soaking. Samples of eight beans of similar size were weighed and placed into labeled test tubes for soaking. Soaking was conducted at four temperatures including 60, 70, 80, and 90°C. At each temperature, bean samples were given one of four heated soak waters containing distilled water and 0, 50, 100, or 150 ppm calcium ion from calcium chloride.

The water bath used for soaking also contained the stoppered flasks of each soak medium to maintain consistent temperatures. The soak mediums were quickly dispensed to each respective test tube. The tubes were covered and immediately placed in the water bath. Samples were removed at ten minute intervals, drained, lightly dried with tissue and immediately weighed. Percent weight gain (Equation 3) was calculated at each time interval up to 60 minutes.

Samples soaked for 60 minutes from each temperature and soak medium were separated into seed coat and cotyledon parts using a razor blade. The bean parts were evaluated for moisture and ash using AACC methods. Total calcium was measured using a Perkin-Elmer 506 Atomic Absorption Spectrophotometer. Percentage ash was calculated as in Equation 9 and calculation of calcium ion in parts per million is illustrated in Equation 10.

Navy bean samples soaked at 60° and 90°C with 0 and 150 ppm calcium in the soak medium were used for Scanning Electron Microscopy. Micrographs were taken of the seed coat and cotyledon cross sections to observe any structural changes related to soak temperature or calcium concentration in soak medium.

RESULTS AND DISCUSSION

Water Absorption

Table 22 shows the water absorption over time for four soak temperatures (60,70,80,90°C) and four calcium ion concentrations in the soak water of 0,50,100,150 ppm. Water absorption follows the same pattern for each variable, however differences exist in the total amount of water uptake and the rate of uptake. Each test was ended after 60 minutes of soaking.

When evaluating soak temperature for water uptake at 60 minutes, a decrease in total water absorption occurs with increasing temperature from 60 to 80°C for all calcium levels. Thus at 60°C there is a greater amount of water

Table 22. Percent water absorbed in four soak temperatures and four soak calcium concentrations.

Soak Temperature Soak Calcium	Time (minutes)					
	10	20	30	40	50	60
60°C						
0 ppm	53.4	62.5	73.8	77.4	83.7	83.7
50	46.6	62.3	69.5	73.5	79.7	80.7
100	41.8	58.9	68.1	71.8	77.0	79.9
150	44.4	60.0	67.1	73.3	72.8	75.7
70°C						
0 ppm	53.5	66.2	72.9	76.7	77.4	76.7
50	55.7	61.6	71.0	74.0	76.8	75.6
100	53.1	59.9	67.3	72.0	72.9	74.4
150	49.4	57.6	65.5	69.3	70.3	72.5
80°C						
0 ppm	54.4	65.7	69.6	71.9	76.4	74.8
50	51.1	63.0	69.1	69.2	72.0	71.9
100	46.0	58.4	63.7	66.2	69.5	70.5
150	40.9	57.4	61.8	64.1	69.0	70.3
90°C						
0 ppm	55.4	68.6	75.9	79.1	81.8	84.2
50	55.4	63.4	66.2	73.3	76.8	77.1
100	49.5	63.5	66.2	68.6	71.9	72.5
150	45.5	59.2	61.4	67.8	69.6	72.1

absorbed than at 70°C and 80°C (60>70>80). At the 90°C soak temperature, water absorptions are elevated and do not follow the general decrease in absorption with an increase in temperature found at lower temperatures after 60 minutes. In the absence of calcium, the water absorption at 90°C equals that at 60°C. It appears from the data that at the 90°C soak, a combined effect of heat and calcium on water absorption occurs from 50 to 150 ppm. The values from the 90°C soak do not follow the same trends recorded from the 60 to 80°C soaks. Changes that occur in the bean microstructure at the 90°C soak may cause the decrease in the rate and eventually the amount of water absorbed. Earlier work has suggested that this is the temperature range of starch gelatinization for beans (Hahn et al., 1977), and may explain differences in water absorption at this temperature. Gelatinatization of starch allows increased water absorption, but in this case is restricted by some mechanism as the total amount at 90°C is not greater than at 60°C. Only with zero calcium present is the absorption slightly greater than the 60°C amount. This suggests that calcium binding is occurring with the heated soak and causing a reduced amount of water to be absorbed. By examining the measured calcium data, it is clear that a significant increase in calcium absorption occurs in the 90°C soak.

Effect of Soak Calcium Level on Water Absorption

The effect of soak calcium level on water absorption after 60 minutes of soaking, follows the same order for all four soak temperatures. Increasing levels of calcium concentration in soak water produced lower water absorptions for all temperatures studied. (water absorption 0>50>100>150 ppm Ca^{++}). This generally holds true during the entire duration of the test however, a few non significant inversions are found.

Effect of Soak Temperature on Calcium Absorption

Figure 22 demonstrates the effect of soak temperature on calcium absorption for the whole bean. Slight changes in total measured calcium occur in the 60 to 80°C soaks. The 90°C soak shows a dramatic increase in total measured calcium with increasing amounts in each respective soak calcium from 0 to 150 ppm.

Research has shown that the seed coat plays a major role in soak water uptake and is also a possible site for calcium absorption (Saio 1976; Sefa-Dedeh and Stanley 1979b; and Hsu 1983). Previous work has demonstrated that beans soaked and processed in high levels of calcium produce intact, tough seed coats (Van Buren et al., 1986). VanBuren (1968) stated that concentration of calcium strongly influenced the amount of calcium uptake in snap beans. After 60 minutes of soaking, the bean parts were separated and tested for total calcium to evaluate if calcium absorption was mostly in the seed coat or cotyledon during

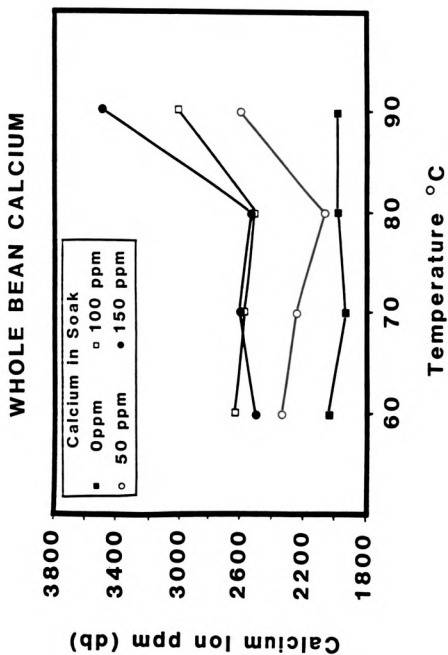


Figure 22. Calcium absorption in the whole bean following soaking at four temperatures and in four calcium ion concentrations.

soaking. Figure 23 shows the measured calcium values in the seed coat over soak temperatures. At all calcium soak levels, there is a depression in measured calcium from 60°C soak to 70°C. At the 60 and 70°C soaks, the 100 ppm calcium level has greater measured calcium in the seed coat than found for the 150 ppm soak. In the 80 and 90°C soaks, the measured calcium increases with increasing soak calcium. Figure 24 shows measured calcium in the cotyledon. Only the total amount of calcium absorbed changes for each soak concentration until the 90°C soak. At this temperature, a significant increase occurs in measured calcium in both the seed coat and cotyledon. This follows the findings of VanBuren (1968), who found that the higher the blanch temperature, the greater the rate of calcium uptake when at 71 to 100°C. Variances in measured calcium in the seed coat can be expected due to the amount of solute passing through during absorption. In contrast, the cotyledon appears to absorb water and calcium in a slower, more controlled manner and results such as found here would be expected.

Combined Effect of Soak Calcium and Temperature on Water Absorption

Soak water temperature and calcium concentration can each produce significant effects on final bean quality during soaking. A goal of this study is to understand the combined effects of calcium and temperature during soaking. At all soak temperatures, increasing levels of calcium decreases water absorption. When no calcium is present in

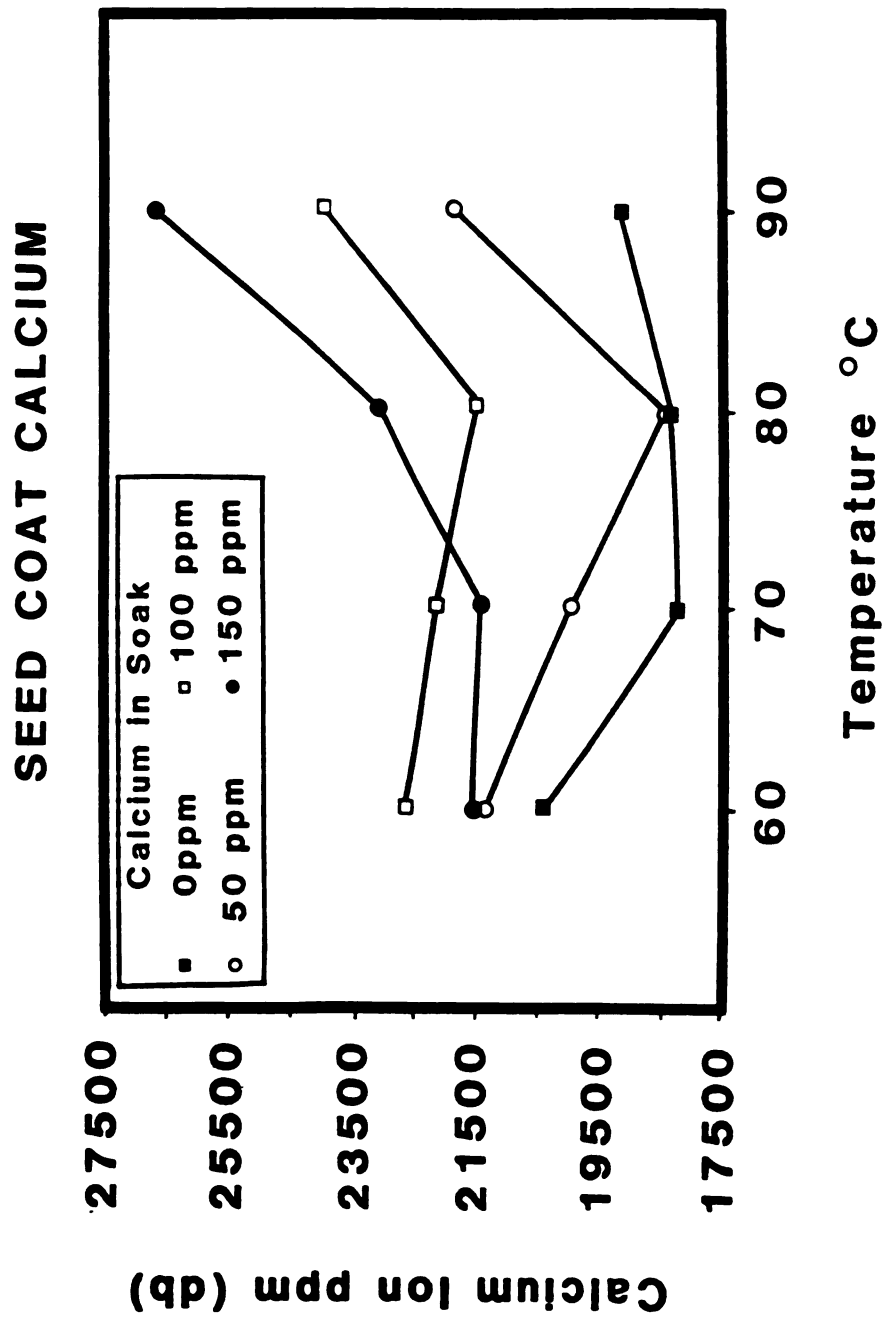


Figure 23. Calcium absorption in the seed coat of the bean following soaking at four temperatures and in four calcium ion concentrations.

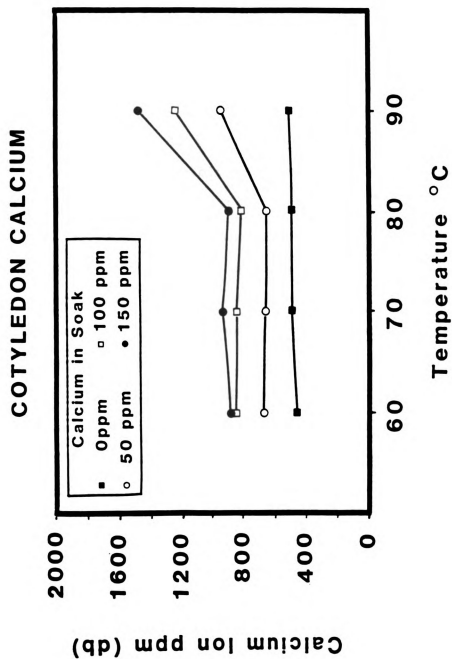


Figure 24. Calcium absorption in the cotyledon of the bean following soaking at four temperatures and in four calcium ion concentrations.

the soak water, the water uptake decreases with increasing soak temperature from 60° to 80°C. At 90°C, the water absorption is slightly greater than the amount at 60°C. This is possibly the result of reaching the gelatinization temperature of starch and requiring increased water uptake for the swelling of the starch granules. This may create a stronger gradient for water uptake in the bean. In the presence of calcium at 90°C there is increased water uptake at 60 minutes compared to amounts at lower temperatures but it is restricted, possibly by the calcium present as shown in Figure 25. In soak waters with calcium at the 60, 70, and 80°C soaks, increasing temperature decreases water uptake as with the 0 ppm soak water. At 90°C soak, the water absorption does not follow the pattern of increased soak temperature with decreased water absorption. However, it does follow that water uptake decreases with increased calcium concentration in the soak water. Over the same 60 minute soak period, the water absorption is highest at the 0 ppm level and decreases proportionately with increasing calcium concentrations.

Rate of Water Uptake

After 60 minutes of heated soak, the water uptake slows, after where there appears to be an exponential decline in rate with 150 ppm soak calcium showing the most dramatic effect. Table 23 presents the best fit regression lines for each of the soak treatments, fit to the equation: Water Uptake (y) = log(time) + b. Correlation coefficients

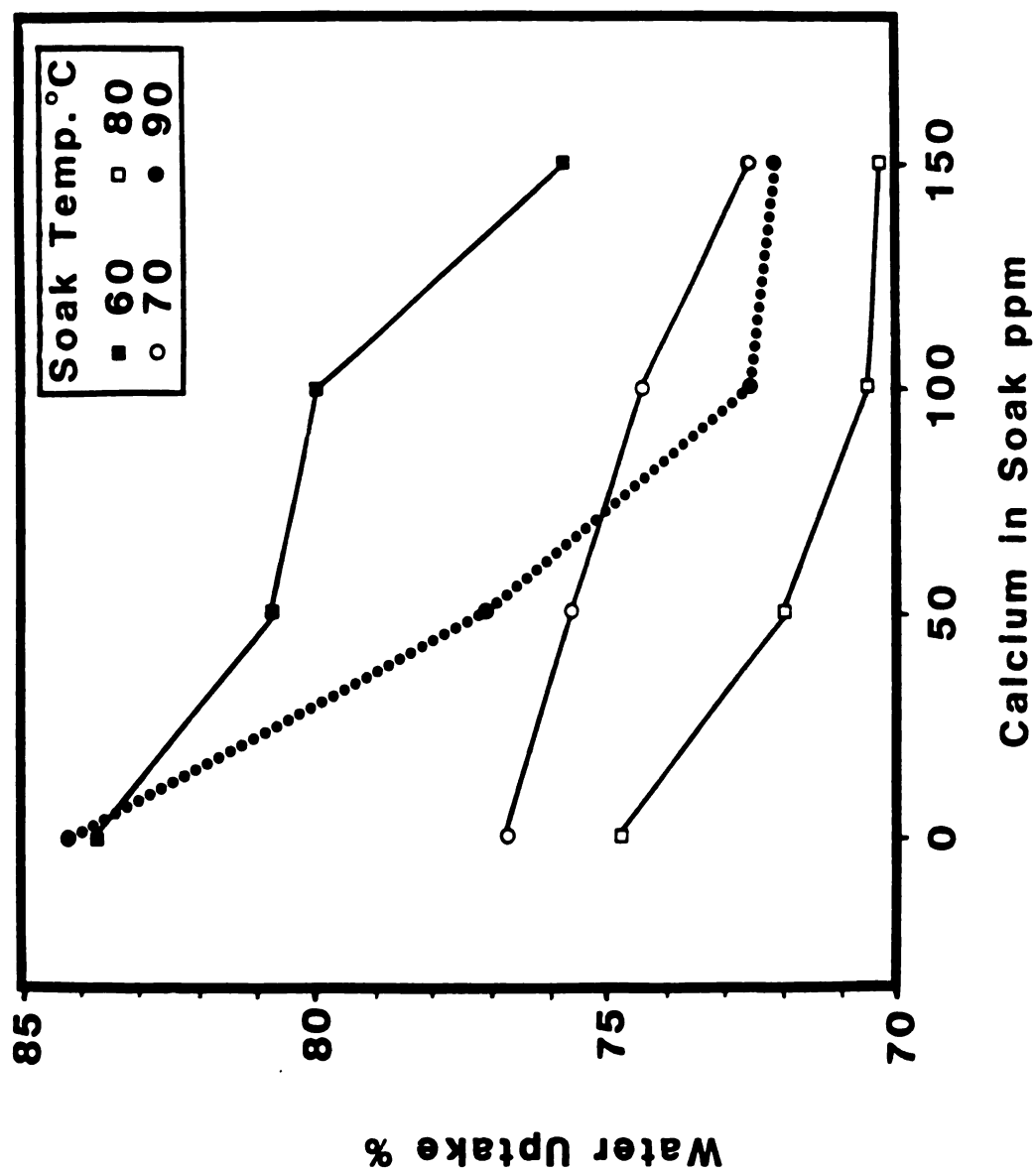


Figure 25. Percent water uptake after 60 minutes of soaking at four temperatures and four calcium ion concentrations.

Table 23. Simple regression lines for soak treatments.

Soak Temperature Soak Calcium	Intercept	Slope	r^2
60°C			
0 ppm	10.709	41.803	.989
50	3.296	44.314	.995
100	-5.572	48.639	.996
150	6.130	40.244	.984
70°C			
0 ppm	24.038	31.519	.968
50	26.411	28.921	.976
100	23.817	28.985	.990
150	18.222	31.176	.992
80°C			
0 ppm	28.437	27.331	.980
50	26.436	26.834	.965
100	16.052	31.389	.990
150	6.409	36.680	.982
90°C			
0 ppm	19.698	36.893	.994
50	25.296	29.416	.986
100	23.006	28.685	.975
150	13.265	33.404	.989

were found to be better than $r^2 = .96$ for each soak treatment. Rates of water uptake are computed as dy/dt .

Although this equation may not reflect the true "kinetic" relationship between the soak time and water absorption, the good fit found here suggests that it does provide a useful estimator for this process. The slope of the best fit line is therefore a relative indicator for rates of water absorption. The rate of water uptake is highest at 60°C for each soak calcium concentration used. At 70, 80, and 90°C soak temperatures, in the presence of calcium, the rate of water uptake increases with increasing calcium. A possible explanation is that the increased calcium in the soak could increase the rate of calcium uptake by the bean.

SEM Micrographs of Bean Microstructure

Scanning electron micrographs may provide a useful tool in understanding the water and calcium uptake during soaking. Those prepared from this study are presented in Plates 1 and 2. Samples represent the cotyledon and seed coat portions from the 60 and 90°C soaks at 0 and 150 ppm Ca^{++} concentration soaks.

Plate 1 represents the top and bottom of the seed coat soaked in the parameters previously described. In comparing the top seed coat surface by temperature, the 90°C soak and 0 ppm Ca^{++} appears more rough with small cell groupings protruding. Swanson et al. (1985) report the seed coat surface of an unsoaked bean is smooth with occasional

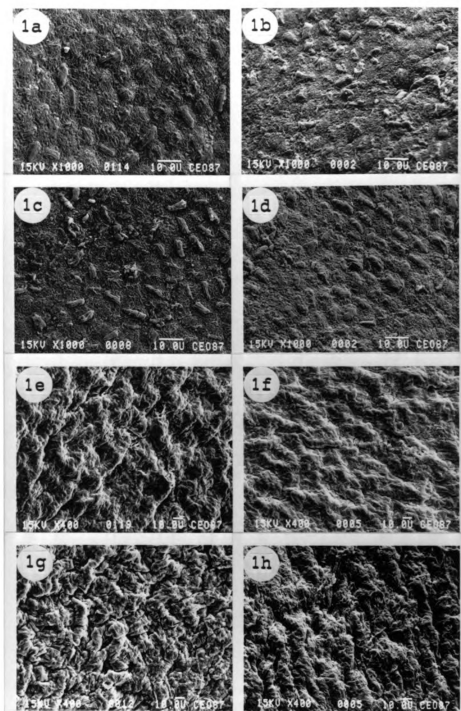


Plate 1. Navy beans: Top of seed coat (a-d) and bottom of seed coat (e-h) following soaking at two temperatures and in two calcium concentrations. A & E = 60°C/0 ppm, B & F = 60°C/150ppm, C & G = 90°C/0 ppm, D & H = 90°C/150 ppm.

crevices and numerous pieces of amorphous material. After soaking 24 hours the roughness or waviness is enhanced with swelling of individual cells into pod like groupings. After soaking, Nep-2 beans appeared covered with large flakes and particles of wax like material. Water absorption may result in a compression of cells in a smooth seed coat to cause apparent roughness (Swanson et al., 1985). The bottom side of the seed coat showed no apparent differences between soak temperature and calcium concentration.

The cotyledon portion of the bean undergoes noticeable structural changes during soaking. Many researchers have shown the basic structures to appear in raw beans as starch granules, protein bodies, cell walls, and middle lamella (Rockland and Jones, 1974; Sefa-Dedeh et al., 1978; Sefa-Dedeh and Stanley, 1979c). Cell walls are composed mainly of pectic substances and hemicellulose. The middle lamella, which cements the cells together, consists of pectic substances associated with divalent cations such as calcium or magnesium and proteinaceous material.

Sefa-Dedeh et al. (1978) reported that cowpeas soaked and heated to 50, 70 and 90°C showed little change in microstructure. Micrographs of these cowpeas show that when sliced with a razor, the fracture occurs at the cell wall exposing the interior cell because of the strong middle lamella. When cowpeas are heated and soaked to 100°C the fracture occurs at the middle lamella due to softening leaving most of the cells intact.

Plate 2 displays micrographs of the cotyledons that were in 60 and 90°C soak water with 0 and 150 ppm Ca^{++} for 60 minutes. There appears to be little microstructural change due to the amount of calcium present during this soak period between the temperatures studied. Significant microstructural changes do occur between soak temperatures. It appears that at the 60°C soak when sliced, it fractures across the cell wall and at the 90°C soak it fractures at the middle lamella leaving some cells intact. These findings agree with those previously reported by Rockland and Jones (1974) and Sefa-Dedeh et al., (1978).

From close examination of Plate 2 at 90°C, some differences may appear due to calcium level. At the 0 ppm Ca^{++} there are less intact cells compared to the 150 ppm soak. It is difficult to determine if the fracture occurs at the middle lamella or the cells walls. The cell walls appear very fragmented possibly due to high temperature soaking. Rockland and Jones (1974) reported that a short heat treatment loosened the middle lamella to allow separation of individual cells without rupture to the cell walls. Perhaps 60 minutes was too severe and damaged the cell wall structure while the 150 ppm soaked beans had the calcium to help protect its' integrity. It is well documented that divalent cations bridge to support the pectinaceous matrix between cells (Rockland and Jones, 1974).

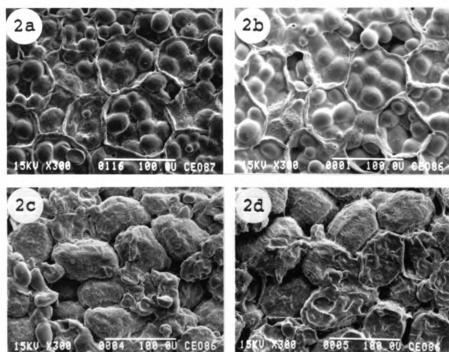


Plate 2. Navy beans: Cross section of cotyledon (a-d) following soaking at two temperatures and in two calcium concentrations. A = 60°C/0 ppm, B = 60°C/150 ppm, C = 90°C/0 ppm, D = 90°C/150 ppm.

There are no obvious differences between calcium concentrations at the 60°C soak after 60 minutes. This heating is gentle and causes less softening and cell rupture. Differences may occur when judging time to achieve desired softness. The calcium ions will prevent the intercellular breakdown which is related to bean softening by many researchers. Rockland and Jones (1974) and Sefadneh and Stanley (1979c) both report that textural characteristics of whole beans are also dependent upon mechanical stresses due to starch gelatinization and protein denaturation which may or may not facilitate cell separation but does contribute to the uniform smooth texture of softened beans.

SUMMARY

Heated soak treatments and calcium concentration in soak waters have shown to produce differences during bean soaking. Water uptake is decreased with increasing temperatures from 60 to 80°C. At 90°C the absorption level is increased compared to soaks from 60 to 80°C. Calcium concentration in soak water effects water uptake with higher calcium concentrations lowering the water uptake at all temperatures studied. Calcium uptake does not appear to be a function of temperature between 60 to 80°C but is at 90°C where a significant increase occurs. At 60, 70, and 80°C soak, water uptake decreases with increasing temperature at all soak calcium levels. At the 90°C soak, water uptake is greater for the 0 ppm soak level where it is slightly

greater than the 60°C soak. The water uptake for the 90°C soak decreases proportionately with increasing calcium levels. Changes that occur in the bean microstructure due to gelatinization may cause the decrease in rate and the amount of water absorbed at the 90°C soak.

Rate of water uptake is highest at 60°C for all calcium levels tested. The rate of water uptake increases with increasing calcium in the 70, 80, and 90°C soak while in the presence of calcium. The increasing calcium levels in the soak could create a stronger gradient for equilibrium into the bean.

SEM micrographs did show visible changes in bean microstructure due to soak temperature. Little change was observed due to soak calcium. Beans from the 60°C soak when sliced, fractured at the cell wall and those from the 90°C soak fractured at the middle lamella. This agrees with previous work on beans heated and soaked up to 100°C where the middle lamella is softened and leaves the cells intact.

Study 3: Post Processed quality evaluation of dark red kidney beans subjected to different soak treatments, storage temperatures and time intervals.

ABSTRACT

Dark red kidney beans were evaluated for canned product quality during 306 days of storage at 50, 70, and 90°F. Two soak methods were used in processing including 1) Overnight soak, 12 hours at 20°C and 2) 30:30 soak, 30 minutes at 20°C followed by 30 minutes at 87.8°C. The soak methods had significant effect on product quality over time. Both soak methods produced decreased drained weights over time with the 30:30 soak producing a greater decline in drained weight. The 30:30 soak had greater increases in firmness over time than the overnight soak. Drained weight and bean firmness are inversely related for both soak methods with the 30:30 soak creating the greater differential in firmness and drained weight.

INTRODUCTION

Final eating quality of processed beans is influenced by many factors including growing environment, storage conditions, soak treatments and processing parameters. Processed beans can be evaluated by measuring texture and drained weight. After processing, the canned product may continue to undergo quality changes during storage as

reported by many researchers (Luh et al., 1975; Davis and Cockrell, 1976; Nordstrom and Sistrunk, 1977; Nordstrom and Sistrunk, 1979; Davis et al., 1980; and Junek et al., 1980), A period of bean-brine equilibration may occur after processing especially in the presence of added calcium or other ions. Calcium ions present in the brine attempt to achieve equilibrium with the bean causing a firming effect over time (Davis and Cockrell, 1976). Most research shows a decrease in drained weight over time which may be attributed to solids loss to the brine from bean breakdown or a loss of water through calcium binding in the bean during equilibrium.

This study was designed to evaluate the effects of soak treatment, canned bean storage temperature and length of storage on the final eating quality attributes of processed kidney beans. Drained weight and bean texture are measured to evaluate processed bean quality.

MATERIAL AND METHODS

Dry bean samples of dark red kidneys (Montcalm variety) were obtained for testing with an initial moisture content of 13.7% (db) by the AACC method 44-40, 1982.

Bean Soaking and Canning

Beans were soaked and canned following the procedure of Hosfield and Uebersax, 1980. Following initial moisture determination, the individual samples were weighed for 100 gram solids and placed in nylon mesh bags for soaking. The soak treatments consisted of 1) Overnight soak, 12 hours at

20°C and 2) 30:30 soak, 30 minutes at 20°C followed by 30 minutes at 87.7°C. The soak water was prepared from distilled water and analytical reagent grade CaCl_2 to contain 50 ppm Ca^{++} .

The soaked beans were immediately weighed for calculation of moisture (Equation 4) and hydration ratio (Equation 5). Soaked beans ready for canning were filled with a salt and sugar brine made from 50 ppm Ca^{++} water. Sealed cans were placed in a vertical still retort and processed for 45 minutes at 115.6°C and cooled for 15 minutes at 20°C.

The processed cans were dried and placed in trays for temperature controlled storage at 50, 70 and 90°C. Samples were evaluated eleven times from Day 0 to Day 306.

Canned Product Evaluation

Drained weight and texture measurements were conducted on days 0, 1, 4, 7, 14, 21, 54, 89, 187 and 306 days of storage. Duplicate samples were taken from each storage temperature and two samples were taken from each soak treatment for evaluation. Drained weights were determined following the USDA method (1976). A drained weight ratio was calculated from Equation 5. Instrumental analysis for texture was performed using a TR5 texture recorder (Food Technology Corp., Reston, VA) equipped with a No. C-15 standard multiple blade shear compression cell. A sample size of 100 g of processed beans were distributed evenly in the cell and sheared. Results for texture are reported in

Kg of force/100 g sample as shown in Equation 7. The compression and shear components were measured for each sample.

RESULTS AND DISCUSSION

Table 24 shows the drained weight means for processed kidney beans soaked by two methods and stored under three temperatures. In both soak treatments the overall result for drained weight is decreasing over time. For both soak treatments there are no significant changes in drained weight due to the storage temperatures used. Soak treatment has greater effect on drained weight over time than storage temperature, as is demonstrated in Figures 26 to 28 for overnight soak and 29 to 31 for 30:30 soak. The 30:30 soak showed greater decreases than the overnight soak. The largest decline in drained weight over time occurred for the 30:30 soak between day 21 and day 28 for all storage temperatures. The overnight soaked beans showed a gradual decline in drained weight, but declines never equaled the losses encountered after 306 days in the 30:30 soak.

Texture is measured by compression and shear force values, which are presented in Tables 25 and 26, respectively. During the first 30 days of sampling, the beans are equilibrating with the brine and as a result, the textures are varied. After this period the beans continue to firm, possibly resulting from calcium ions forming cross bridges in the cotyledons. There appears to be no significant differences in compression force due to storage

Table 24. Washed drained weights¹ of processed kidney beans soaked by two methods and stored at three temperatures over time.

Days of Storage	Storage Temperature °F		
	50	70	90
<u>OVERNIGHT SOAK²</u>			
0	295.8ab	295.7a	295.9abc
1	304.0a	297.9a	299.4abc
4	304.0a	296.2a	297.3abc
7	301.8a	303.2a	306.2a
14	302.0a	303.3a	301.0abc
21	304.9a	299.9a	305.4ab
28	300.0ab	300.0a	301.1abc
54	304.0a	298.6a	298.7abc
89	304.4a	299.6a	299.0abc
187	287.8b	292.7a	288.7c
306	293.1ab	293.1a	291.1bc

Table 24. (cont'd.)

Days of Storage	Storage Temperature °F		
	50	70	90
	<u>30:30 SOAK</u>		
0	292.5abc	292.4ab	292.6ab
1	293.8ab	293.3ab	293.3ab
4	293.4abc	289.7ab	290.3abc
7	302.6a	299.5a	299.5a
14	296.1a	294.4ab	293.1ab
21	297.5a	295.2a	294.3a
28	281.2cd	283.8bc	279.0bcd
54	279.7d	276.0cd	275.0d
89	281.6bcd	283.1bc	284.9abcd
187	274.5d	274.4cd	276.5cd
306	276.5d	271.7d	274.2d

¹Mean values (like letters within each column for each soak method indicate no significant differences at $P \leq 0.05$ by Tukey mean separation; $n = 2$).

²Overnight Soak = 20°C soak for 12 hours. 30:30 Soak = 20°C soak for 30 minutes followed with 87.8°C soak for 30 minutes.

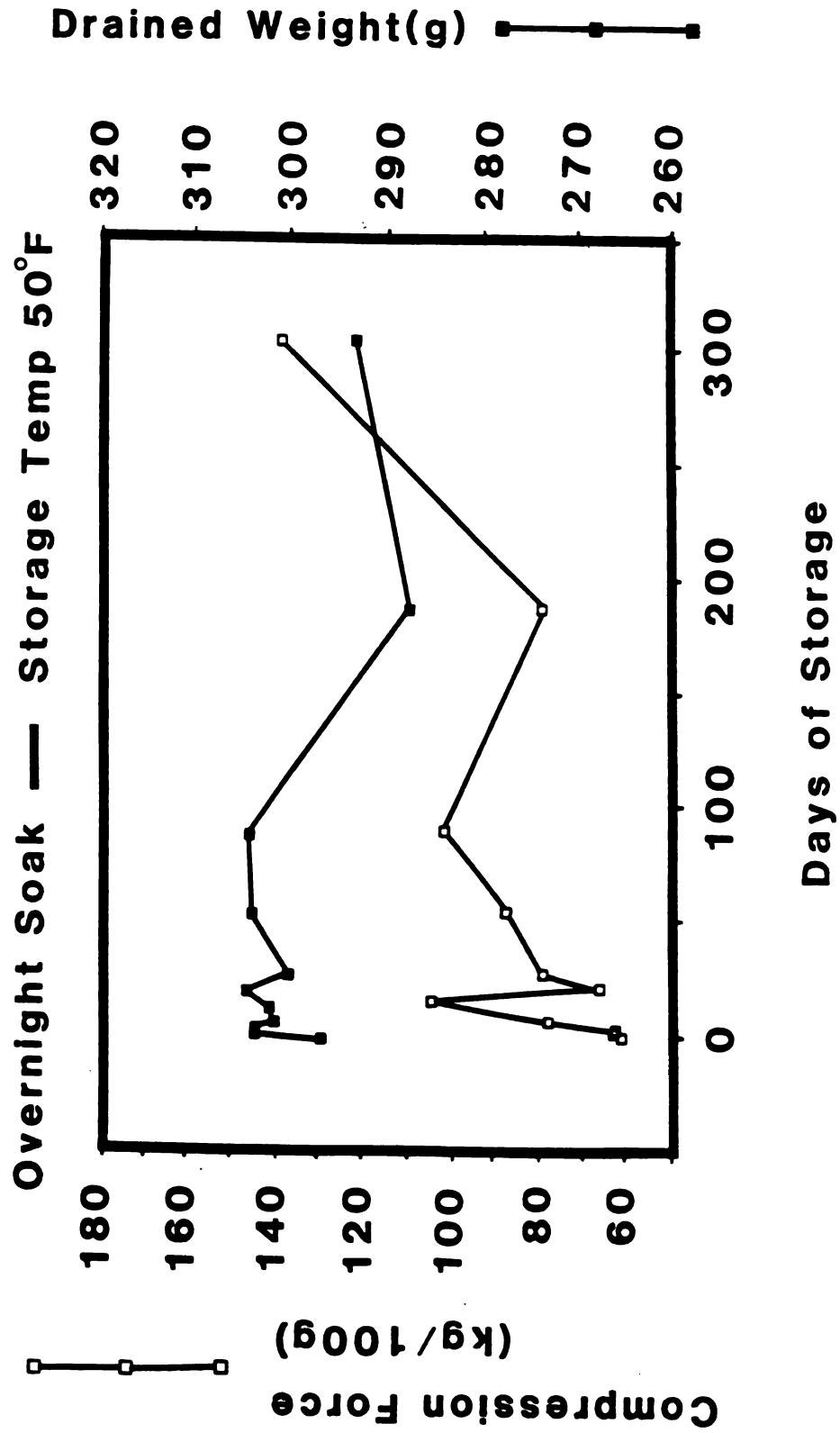


Figure 26. Relationship of bean firmness and drained weight for overnight soaked beans during extended storage at 50°F.

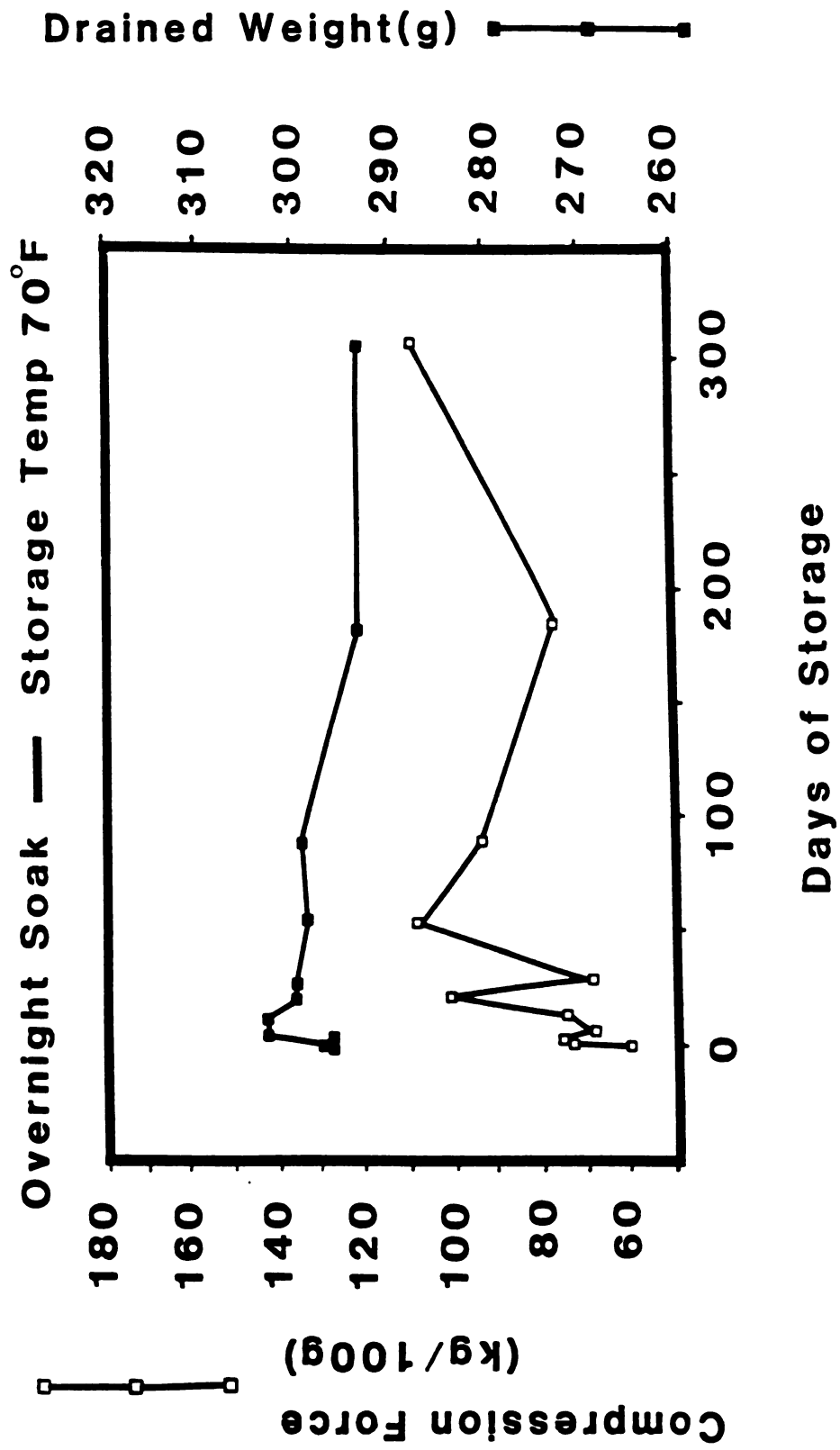


Figure 27. Relationship of bean firmness and drained weight for overnight soaked beans during extended storage at 70°F.

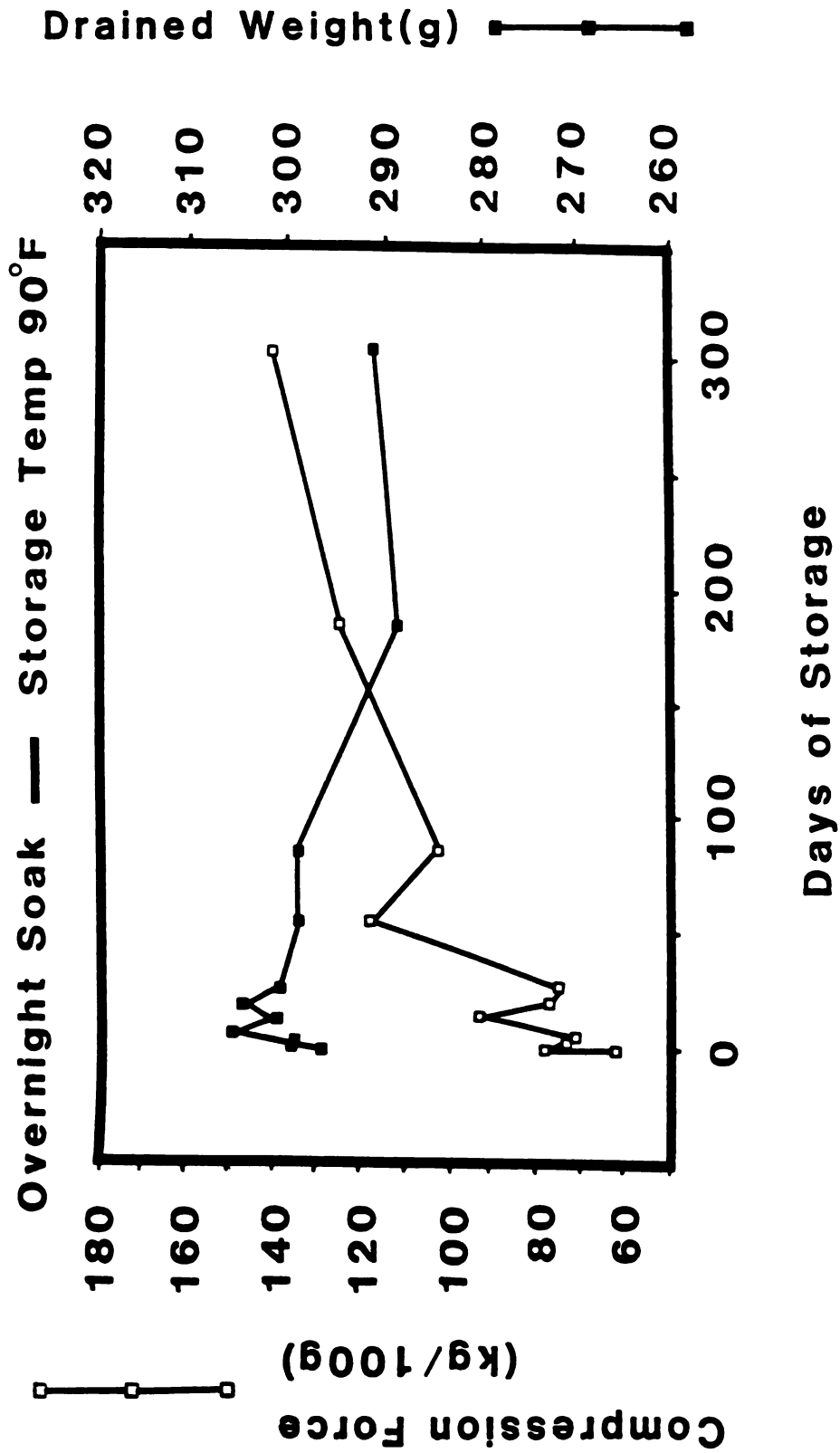


Figure 28. Relationship of bean firmness and drained weight for overnight soaked beans during extended storage at 90°F.

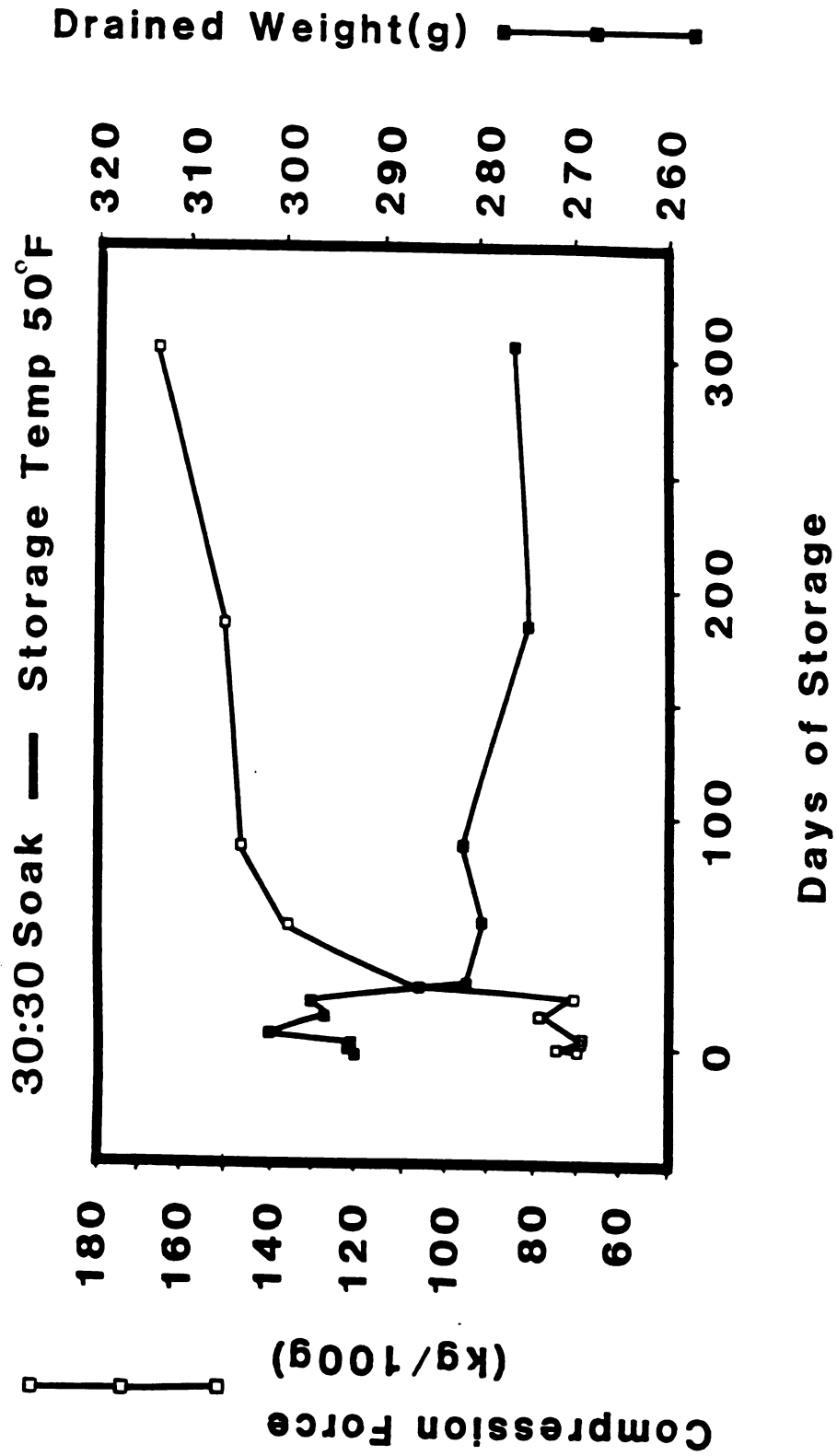


Figure 29. Relationship of bean firmness and drained weight for 30:30 soaked beans during extended storage at 50°F.

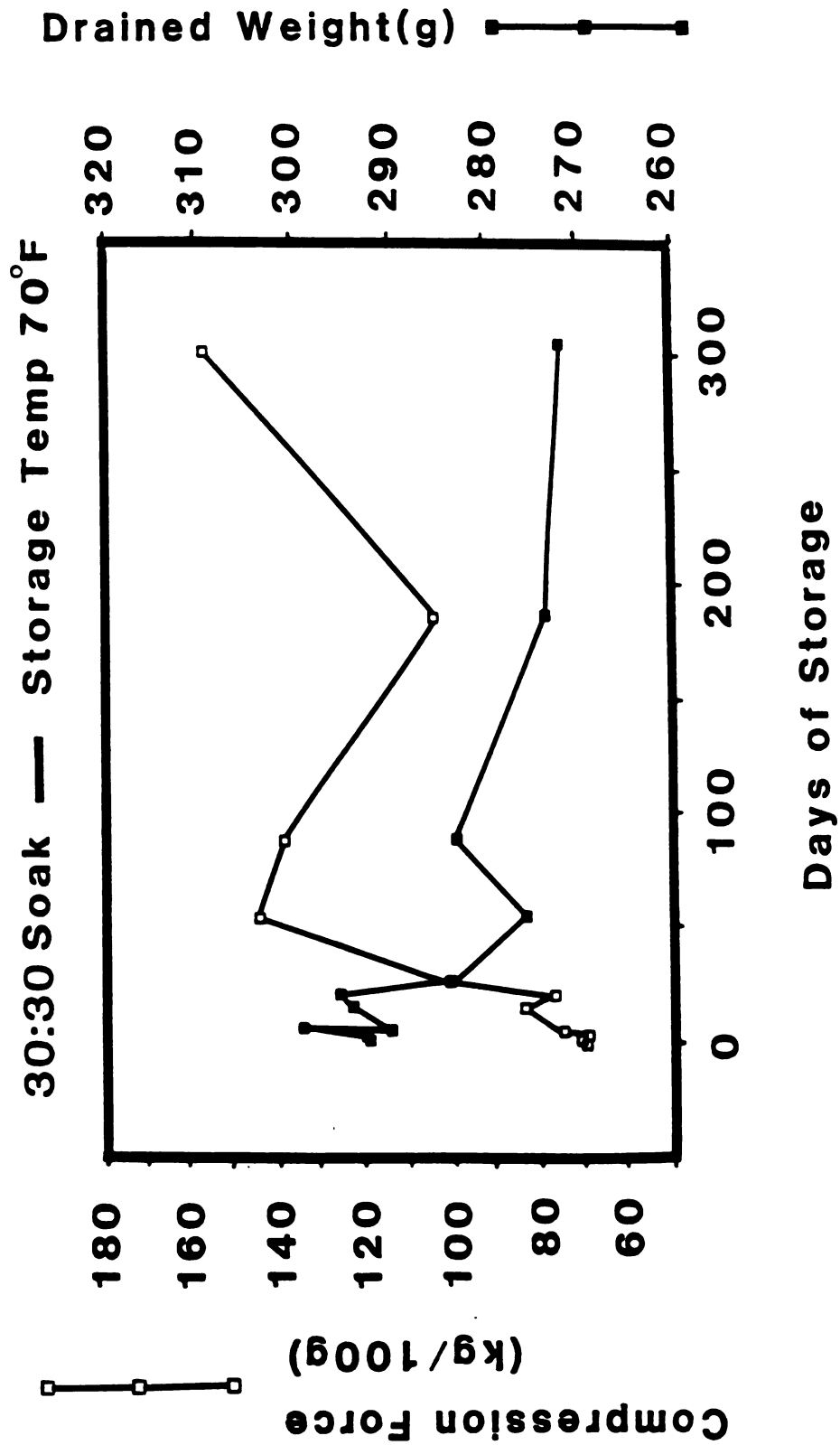


Figure 30. Relationship of bean firmness and drained weight for 30:30 soaked beans during extended storage at 70°F.

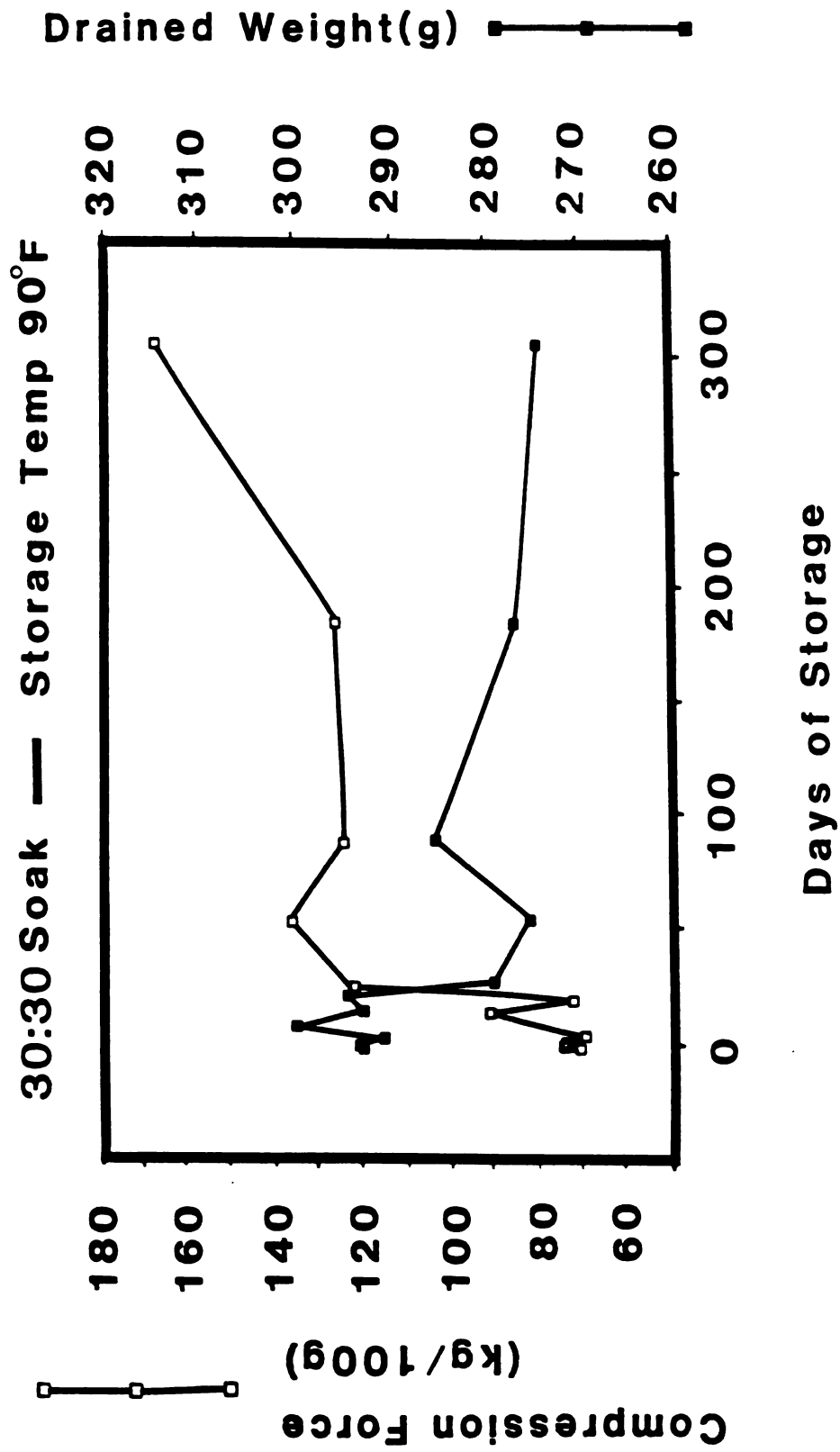


Figure 31. Relationship of bean firmness and drained weight for 30:30 soaked beans during extended storage at 90°F.

Table 25. Kramer compression force (Kg/100g)¹ of processed kidney beans soaked by two methods and stored at three temperatures over time.

Days of Storage	Storage Temperature °F		
	50	70	90
<u>OVERNIGHT SOAK²</u>			
0	59.5e	58.9c	60.2f
1	62.9de	73.5abc	79.4def
4	62.1de	76.7abc	73.1ef
7	77.7cde	67.2bc	70.3ef
14	104.3b	75.5abc	93.0cde
21	65.7de	101.2abc	77.6def
28	79.9bcde	69.4abc	74.5def
54	86.8bcd	109.5ab	118.7abc
89	102.2bc	94.6abc	101.4bcd
187	79.8bcde	76.2abc	125.2ab
306	137.3a	110.1a	140.2a

Table 25. (cont'd.)

Days of Storage	Storage Temperature °F		
	50	70	90
	<u>30:30 SOAK</u>		
0	70.8c	70.1c	71.4b
1	75.7bc	72.1c	75.4b
4	68.7c	69.1c	74.8b
7	68.6c	75.2c	69.1b
14	78.9bc	83.7c	90.5ab
21	71.3c	76.7c	72.5b
28	105.8abc	100.9c	122.1ab
54	136.1ab	144.3a	136.1ab
89	147.0a	139.1ab	125.4ab
187	150.7a	104.4bc	125.9ab
306	165.7a	156.6a	168.0a

¹Mean values (like letters within each column for each soak method indicate no significant differences at $P \leq 0.05$ by Tukey mean separation; $n = 2$).

²Overnight Soak = 20°C soak for 12 hours. 30:30 Soak = 20°C soak for 30 minutes followed with 87.8°C soak for 30 minutes.

Table 26. Kramer shear force (Kg/100g)¹ of processed kidney beans soaked by two methods and stored at three temperatures over time.

Days of Storage	Storage Temperature °F		
	50	70	90
<u>OVERNIGHT SOAK²</u>			
0	77.2d	76.6a	77.8c
1	77.4d	89.8a	97.6bc
4	73.4d	89.4a	81.1c
7	91.4bcd	77.2a	78.8c
14	106.3b	83.4a	100.3abc
21	72.8d	100.9a	78.9c
28	84.0bcd	72.1a	74.5c
54	92.2bcd	108.4a	114.7ab
89	103.5bc	96.8a	98.8bc
187	79.7cd	73.4a	111.9ab
306	131.7a	116.3a	126.6a

Table 26. (cont'd.)

Days of Storage	Storage Temperature °F		
	50	70	90
	<u>30:30 SOAK</u>		
0	84.8cd	84.2bcd	85.1bc
1	83.7cd	82.7bcd	87.7bc
4	76.0d	75.4cd	77.9bc
7	75.2d	76.2cd	72.4bc
14	80.0cd	81.5bcd	87.0bc
21	75.6d	72.3d	71.8c
28	81.9cd	82.8bcd	88.3bc
54	94.0bcd	100.4ab	95.6bc
89	107.8ab	97.2bc	100.1ab
187	100.0abc	84.0bcd	81.9bc
306	118.6a	122.6a	125.4a

¹Mean values (like letters within each column for each soak method indicate no significant differences at $P \leq 0.05$ by Tukey mean separation; $n = 2$).

²Overnight Soak = 20°C soak for 12 hours. 30:30 Soak = 20°C soak for 30 minutes followed with 87.8°C soak for 30 minutes.

temperature up to 187 days. At 187 days, significant differences appear due to storage temperatures but seemingly is erroneous as the means again are not significant at 306 days.

After the equilibrium period, the 90°C storage beans show a steady increase in compression force with time for the overnight soak. The 50 and 70°C storage temperatures show a significant increase in compression from day 21 to day 54 for the overnight soak. As with the 30:30 soak there appears to be significant differences due to storage temperature at day 187. There is no apparent explanation for this variation, and therefore it may represent sampling error. At day 306 for the overnight soaked beans compression force is increasing at all storage temperatures. The 30:30 soak increases in compression force over time with a significant increase from day 21 to day 54 for all storage temperatures. Overall, the 30:30 soak was found to cause a greater compression force value than the overnight soak.

Similar to the findings of Study 1, drained weight is inverse to bean texture for both soak methods as shown in Figures 26 to 28 and 29 to 31. Over time the drained weight is decreasing and firmness measured by Kramer compression force is increasing. The overnight soak has a gradual decline in drained weight and increase in firmness. A sudden change occurs for the 30:30 soak in drained weight and firmness between 2 and 3 weeks of storage. This change shows the dramatic inverse relationship of the two

measurements. Following this inversion, the slope slightly changes over time with the drained weight decreasing and the firmness increasing.

The shear force values for both soak methods follow similar curves and means (Table 26). There is an overall increase in shear force over time for both soak methods and all storage temperatures. Shear force has been reported to correlate with seedcoat toughness. Therefore we would expect more differences in compression over time with equilibration of calcium in the cotyledon.

SUMMARY

The effect of soak method and storage temperature on final processed bean quality was evaluated. Soak method produced more significant differences in the quality attributes measured than storage temperature. Storage temperature of the processed beans showed no definite relationship to quality changes over time.

The overnight and 30:30 soak produced decreased drained weights over time. The 30:30 soak had greater losses in drained weight than the overnight soak. The 30:30 soak also had greater increases in firmness than the overnight soak over time. A possible explanation lies with the increased availability of calcium binding sites in the heated soak beans (30:30 soak) thus allowing more calcium binding and possibly forcing water molecules out.

SUMMARY

Soak method, soak medium and brine medium all produced significant effects on processed bean texture. Soak method produced significant differences in quality changes over extended storage but storage temperature showed no definite relationship to quality changes over time. Overnight soak produced softer beans than the 30:30 soak in all soak and brine treatments. Calcium absorption occurred more from the soak medium than the brine for both soak methods.

The 30:30 soak allowed greater calcium absorption with decreased drained weights and increased measured firmness in both Studies 1 and 3. The overnight soak absorbed less calcium, had increased drained weights and decreased firmness. For overnight and 30:30 soaked beans, an inverse relationship is demonstrated between drained weight and bean texture. The overnight and 30:30 soaks both produced decreased drained weights over time.

Quantitative Descriptive Analysis was effective in defining processed bean texture with the masticatory and tactile tests being the most effective.

Correlation coefficients of objective and subjective data show drained weight, Kramer compression force, Kramer shear force, and measured calcium are the best objective

measures of subjective descriptors used in this study. These parameters produced multiple linear regression equations with good prediction accuracy for cotyledon firmness, seed coat toughness, and combined resistance from the masticatory test.

Heated soak treatments and calcium concentration in soak waters have shown to produce differences during bean soaking. Water uptake is decreased with increasing temperatures from 60 to 80°C. At 90°C the absorption level is increased compared to soaks from 60 to 80°C.

Calcium concentration in soak water effects water uptake with higher calcium concentrations lowering the water uptake at all temperatures studied. Calcium uptake does not appear to be a function of temperature between 60 to 80°C but is at 90°C where a significant increase occurs.

At 60, 70, and 80°C soak, water uptake decreases with increasing temperature at all soak calcium levels. At 90°C soak the water uptake is greater for the 0 ppm soak level, where it is slightly greater than the 60°C soak. The water uptake for the 90°C soak decreases proportionately with increasing calcium levels. The rates of water uptake are highest with the lowest soak temperature for all soak calcium concentrations tested.

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