EFFECT OF STORAGE CONDITIONS ON THE QUALITY OF DRY AND PROCESSED NAVY BEANS

By

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ABSTRACT

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Storage factors affecting navy bean quality, including relative humidity and bean moisture, temperature, and time, were evaluated in a series of four studies.

Study 1 (packaging study) and Study 2 (chemical study) involved the storage of beans in Mylar® pouches. Studies were designed to independently evaluate quality change due to packaging environments (vacuum, air, CO_2) and chemical treatments (Grain Treet® and SO_2). Additional beans were dry stored for up to one year at various moisture contents prior to processing. An equilibrium moisture isotherm was obtained over static saturated salts at 70°F.

Results indicated increased bean discoloration and hard texture occurred with increased bean moisture, and increased storage temperature, time and relative humidity. Vacuum and CO_2 packaging did not provide significant maintenance in color stability and tenderness. Grain Treet® caused severe darkening of seedcoats and firmness of texture. Sulfur dioxide retained bean color and gave processed product with equivalent quality to air.

To my parents, brothers and sisters.

ACKNOWLEDGMENT

I wish to express my deepest gratitude to Dr. Mark A. Uebersax, my advisor, for his constant guidance, encouragement and valuable suggestions during the course of my work at Michigan State University. Appreciation is also extended to other members of the committee, Dr. Jerry N. Cash, Dr. Hugh E. Lockhart and Dr. Pericles Markakis for their comments and suggestions.

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INTRODUCTION

Legumes are generally recognized as good sources of vegetable protein. Dry edible beans have traditionally been widely consumed by native populations in the North and South American continents. Beans are popular in most American diets regardless of their high traditional meat consumption. In addition, considering the world nutritional problem, beans play a most important role as a source of protein for people in developing countries.

Dry edible beans rank as the third largest source of income among Michigan's agricultural crops, following corn and wheat (Robertson and Frazier, 1978). Navy beans which make up 85 to 90 percent of the production are the most common class. Recently, there has been an increasing demand for dry bean storage. Processors store beans prior to canning and growers store them after harvesting in September until the expected increased market demand, commonly occurring during the next spring. Moreover, Michigan navy beans are now being promoted for world-wide export. Michigan navy bean exports have increased from none during the years 1950-54 to an annual average of 1,200 to 1,400 thousand hundredweight during the years 1960-74. Since 1970, annual exports have varied from 19 to 30 percent of the U.S. crop (USDA, 1952-75). Thus, dry storage during handling and transportation accounts for a significant portion of the crops.

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Generally, quality degradation of beans occurs during storage. Such deterioration results from development of mold growth or texture changes. All of these deteriorations are attributed to storage conditions, such as moisture content of stored beans, storage temperature and time.

The purpose of this study was to evaluate the effects of various storage conditions on stored and processed bean quality. The investigation involved physical factors including bean moisture content, and temperature and time of storage; and the use of chemical treatments applied to beans before storage. The experiment was divided into four studies. Study 1 was designed to evaluate the effects of packaging environments. Beans with moisture content ranging from 14-22% were packaged in Mylar® pouches and stored under three different packaging environments. Study 2 was designed to evaluate the effects of chemical treatments. High moisture beans (18-22%) were treated with Grain Treet® and sulfur dioxide (SO_2), packaged in Mylar® pouches and stored. Study 3 consisted of the long-term storage of cans of beans having 8-18% moisture. Study 4 provided the equilibrium moisture content of beans at various relative humidities. After the designated storage time for the first three studies and the equilibrium moisture content for the last study were reached, beans were processed and evaluated for quality.

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REVIEW OF LITERATURE

Handling and Storage of Dry Beans

Nearly all of the United States navy or pea beans (Phaseolus vulgaris) are grown in Michigan. The statistical figures show that Michigan has accounted for 94 to 100% of the U.S. production of navy beans, with the peak production during 1960-64 of 6,710 thousand hundredweight representing 99.5% of the nationwide production (SRS, 1952-75).

Seventy-nine percent of Michigan navy beans were used in the domestic market during the period 1971-75. They were mostly in the form of canned products as pork and beans, beans and tomato sauce, and baked beans. A relatively small proportion was sold as dry beans. Twenty-one percent of Michigan navy beans were exported during the same period of time to the United Kingdom (the largest customer), the Netherlands, Australia, New Zealand, West Germany, Italy and Spain.

The five leading counties for Michigan navy bean production are Huron, Tuscola, Saginaw, Gratiot and Bay. Prevalent varieties grown are Sanilac, Gratiot, Seafarer, Kentwood, Fleetwood, Charity, Upland, Snow Flake and Show Bunting.

Navy bean seeds are chalky white, round to ovoid in shape, and weigh about 17 to 19 g per 100 seeds. Composition (Adams, 1972) shows that navy beans serve as good sources of protein, carbohydrate, and minerals, especially calcium and iron (Table 21).

Navy beans are harvested in September at a moisture content of 17-18% which provides beans enough moisture to avoid mechanical damage during harvest yet minimizes spoilage from mold. Higher moisture levels require mechanical drying prior to storage.

Nearly all dry beans are stored in weather tight silos. However, moisture migration in silos is a common problem (Troller and Christian, 1978). Being cooled from outside weather in fall or winter, the top and sides of the silos are lower in temperature than the middle. Water vapor from the warmer region then migrates to the cooler areas, giving the top and sides of the silos high moisture conditions favorable to mold growth. This moisture migration phenomenon is reversed during the summer. Mold may develop in the middle of the silos since water vapor migrates from the sides which are warmer. This problem can be terminated by installation of an aeration unit to uniformly circulate air throughout the beans within the silo.

Maddex (1978) suggested not using existing silos because aeration systems were difficult to install in them and filling equipment for loading beans into a silo usually caused bean damage. Recommended for bean storage were flat-bottomed, overhead wooden bins, round steel bins (recently the most popular form of storage), and concrete bins equipped with aeration systems.

Major factors to be considered in the storage condition of beans are moisture content, temperature, and time. Given favorable conditions, beans can be stored for a long time with good retention in quality. In contrast, beans stored under unfavorable conditions will lose quality dramatically. Generally, problems of prolonged bean storage are manifested as long cooking time due to hard texture, loss in nutritive value, off-flavor, off-color, and mold growth.

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Moisture Content Effect. During storage high moisture beans may develop off-flavors, undergo lipid oxidation, darken in color and become hard in texture.

Morris and Wood (1956) reported that beans with moisture content above 13% deteriorated significantly in both flavor and texture after 6 months at 77°F, and became unpalatable within 12 months. However, beans having moisture content below 10% maintained their quality for 2 years at 77°F. Additionally, rancid off-flavor and color changes were obvious in high moisture beans stored at high temperatures.

Morris (1963, 1964) studied the cooking quality of stored beans. The cooking time for low moisture beans was almost constant. High moisture samples required longer cooking time after 4 months of storage and the cooking time increased with increased moisture content.

Burr et al. (1968) reported an increase of cooking time with high moisture content beans. It was found that pintos with 16% moisture required 60 minutes to cook as compared to 20 minutes for pintos with 8.2% moisture. They also stated that soaking time was reduced when beans had high moisture.

Bedford (1972) reported that beans stored at high moisture (15-18%), showed a significant increase in their required cooking time while low moisture (8-9%) beans stored at 68-81°F for 4 years did not lose their cooking quality.

Temperature Effect. Quality degradation is faster at high temperature than at low temperature. Beans stored at high temperatures get darker in color and require longer cooking times. The deteriorative effect of high moisture on bean quality is increased by high temperature.

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Long cooking time of beans from high temperature storage was observed by Dawson et al. (1952), Morris (1963) and Burr et al. (1968). Morris (1964) stated that the reduction of 15°F in storage temperature had the same effect as the decrease of 0.6% moisture content to yield an equivalent short cooking time. Uebersax (1972) reported that deterioration rate both in discoloration and mold growth was minimized in beans stored at 55°F under relative humidities ranging from 75-100%. The influence of increased storage temperature became greater at higher relative humidity.

Storage Time Effect. Extended storage of beans results in hard texture, off-flavor, darkening and loss of nutritive value because of prolonged cooking.

Bigelow and Fitzgerald (1927) stated that canners sometimes found the heat process required to sterilize cans of stored beans was insufficient to make them tender. The increase in cooking time with increased storage time was also revealed by other researchers (Morris, 1963 and 1964; Burr et al., 1968; Bedford, 1972). Muneta (1964) reported that bean geographic origin had a considerable effect on cooking after extended storage. Molina (1975) reported a decrease in protein efficiency ratio (PER) for stored beans due to long cooking time.

Relative Humidity (RH) Effect. Snow et al. (1944) studied the mold development of locust beans held at various humidities. The plot between equilibrium relative humidity (%) and log time to molding (days) was utilized to predict storage life which appeared to be 1 month at 75% RH, 5 months at 70% RH and 2 years at RH not exceeding 65%.

Dexter et al. (1954) studied the storage of beans at various temperatures and RH controlled by sulfuric acid solution and reported

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the equilibrium moisture content and mold growth. The equilibrium moisture increased as RH increased. Molding was prominent at 75% RH and temperature between 70° and 100°F. Severe discoloration (darkening) and chemical deterioration were shown in samples held at high temperatures and RH. Sulfuric acid solutions did not maintain constant RH during the first few days of the experiment. Dexter (1968) reported using sawdust-salt mixture to control RH of bean storage.

Bedford (1972) reported that the mold growth of beans stored in a closed constant RH desiccator greatly increased at RH higher than 75%. Uebersax (1972) used saturated salt solutions to control RH for bean storage in static desiccators at 55°, 70°, 85°F temperatures. The quality of beans was maintained at 75% RH and all temperatures throughout 84 days of storage. Low temperature showed increased storage potential at all RH. As storage time, temperature and RH increased, bean deterioration, off-flavor, mold count and firmness also increased.

Molina et al. (1975) observed the hardness of black beans stored at 77°F and 70% RH for 9 months, and reported that heat treatment applied to beans prior to storage could reduce the hard-to-cook phenomenon.

Another factor which governs the keeping quality of beans in addition to storage conditions is the original quality of bean seeds themselves. Starting with good and perfect seeds under suitable conditions, stored beans will remain at high quality for a long time. Unfortunately, some beans arrive for storage damaged. This decreases the quality and shelf life of stored beans and subsequently of the canned products as well.

Damage to beans begins in the field because of improper growing, harvesting, sorting, and storing. Factors involved include insects,

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disease, mechanical and bin-burn damage, foreign matter infestation, and mold development (Dajani, 1977). It has been found that beans initially damaged during harvest are likely to be more susceptible to damage from subsequent handling and processing (Hoki and Pickett, 1972).

The most common types of damage are cracked skin or checked seedcoats, and complete splitting of the beans. These defects are caused by improper seed handling during harvesting and drying. If these seeds are canned, they will result in a highly disintegrated and unattractive product because solids are released from split seeds causing clumping of beans and firm gelatinization of the sauce.

Prevention of splits and checked seed coats can be done by harvesting beans at 17-18% moisture and using a gentle threshing method (Steinbuch, 1978), handling as few times as possible, while avoiding handling beans at below freezing temperatures.

Another important problem is moldy beans. Mold usually develops with severe storage conditions, such as high moisture content of beans, high relative humidity and warm temperature of storage. Moreover, Saettler (1972) suggested that production diseases like bacterial blight and root rot may influence the mold level of dry beans after harvest.

Prevention of mold development is done by control of storage conditions, such as storing clean beans at less than 17-18% moisture and providing sufficient aeration. A promising method in mold inhibition is use of chemicals. Khan and Tao (1973) reported that a fungicide termed PCNB (Pentachloronitrobenzene) dissolved in dichloromethane gave bean seeds good resistance to storage fungi infection.

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A commercial mold inhibitor Grain Treet® which is a mixture of acetic, benzoic and propionic acids is under investigation for potential use with navy beans. Grain Treet® was introduced many years ago by Kemin, Inc., Des Moines, Iowa. It was tested to be effective in keeping animal feed high moisture grains stored under adverse conditions in excellent quality for over a year (Smith, 1977). Deyoe and Tu (1977) reported the successful application of Grain Treet® with high moisture soybeans and soy products.

At the time of transportation, beans may be prepackaged in bags or shipped in bulk. The packaging materials generally used are paper, polypropylene, or burlap bags. Johnson (1964) reported that multiwall paper bags provided comparable protection and better stackability than burlap bags. However, handling precautions to avoid torn bags had to be taken. Johnson also pointed out that bulk shipment vs. bag shipment has the advantage of reducing loading and handling time, while also making sampling easier and more representative.

During overseas transportation, beans are readily subject to quality degradation because of the extreme differences in climatic zones. For example, condensation of water occurred in a shipment of pea beans from Detroit to London (Thompson et al., 1962) and the resultant water dripped onto the bags and favored mold growth. Consequently, handling treatments such as aeration during transportation are recommended.

Processing and Evaluation of Canned Beans

Beans may be processed in water or brine, tomato sauce and/or molasses. Beans to be processed should: 1) contain a moisture level

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of 12-16%; 2) be of uniform size; 3) be fully mature; and 4) be free from foreign materials and seed coat defects. Using high moisture beans (>18%) results in mold growth in dry beans, rancidity, high free fatty acid content and unacceptable products. Low moisture beans (9-11%) cause seed brittleness and seed coat checks which make poor canned products.

Processing of beans was reviewed by Adams and Bedford (1975), Bedford (1972), and Steinbuch (1978). It includes the following steps: soaking, blanching, filling, exhausting, processing, and equalization.

Soaking. The purpose of soaking is to ensure uniform expansion in cans during the thermal process, to ensure product tenderness, to increase product yield, and to facilitate bean cleaning.

Beans are soaked at 59-68°F for 8-16 hours or at 180-212°F for 20-40 minutes to reach 53-57% moisture content. The high temperature-short time soaking is preferred since it reduces labor cost, extensive equipment, floor space and potential bacteriological problems which might occur during a long soaking period.

Soak water is relatively soft with optimum quantity of calcium in the range of 25-50 ppm. Split and mushy beans occur in very soft soak water; whereas beans develop tough skins and firm texture while soaked in hard water. Soak water is also checked for metal (Fe, Cu) content to prevent bean discoloration and for microbial load to prevent potential spoilage.

Water uptake during soaking is influenced by initial bean moisture, age and composition, and storage condition. However, it can be accelerated by application of heat and vacuum during soaking; use of such additives in soak water as polyphosphate, ethylene diamine-tetracetic

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acid (EDTA) and alkali carbonate; or through use of gamma irradiation prior to soaking.

Blanching. The purpose of blanching is to continue bean swelling, to obtain the ultimate moisture content of 50-55%, to extensively clean, to expel air from bean tissue, and to lower bacterial counts.

The process used is water blanching at 194-203°F for 3-8 minutes in a standard rotary water blancher. Over blanching can cause skin splitting. After blanching, beans might be washed again with cold water spray in a continuous rod washer while broken beans and loose skins are automatically removed between the rods.

Filling. Cans are filled to not less than 90% of total capacity. Cans packed with too many beans will look too solid with crushed beans, and the desired tenderness and flavor of the final product cannot be achieved. Although too few beans in a can give a sloppy pack, it is more desirable than an overpack. The usual soaked bean fill is 9.5-11.5 ounces for No. 2 (307x409) cans and 7-8 ounces for No. 303 (303x406) cans.

Sauces added to beans can be tomato sauce, brine, or diluted molasses which are heated to boiling in order to prevent entrainment of air among beans.

Exhausting. The purpose of exhausting is to expel air from cans, to provide uniform closure temperature, and to reduce processing time.

Processing. The purpose of processing is to sterilize products, and to obtain the desired smooth texture.

In order to obtain desired tenderness, it has been found necessary for navy beans to be processed 10-30% longer than the processing

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time required for sterilization. Processing can be done in various ways depending on the desired final color and texture, the nature of soaking and blanching, and the type of sauce. The following processes are used for No. 2 1/2 cans or smaller of beans packed in brine or in low levels of tomato pulp without added starch:

a) 230°F / 125 minutes

b) 240°F / 45 minutes

c) 250°F / 20 minutes

d) 260°F / 12 minutes

e) 270°F / 9 minutes

It is recommended to use a lower temperature such as 230-240°F for processing with tomato sauce to minimize the darkening of the sauce. Agitation during cooling is beneficial since it decreases the level of gelling produced by released pectin and starch from beans.

Equalization. Beans will continue to absorb water for several days after processing, therefore, an equalization period of at least 2 weeks should be allowed before any evaluation.

Examination of processed beans is a part of normal quality control to comply with government regulations and to maintain high quality for consumers. The judgements from food scientists and from consumers use somewhat different criteria because the consumers have specific expectations and preferences in mind while informally judging products (Leveille et al., 1978).

Several researchers have reviewed the examination procedures and quality attributes of canned navy beans (Adams and Bedford, 1975; Bedford, 1972). There are as follow:

1. Wholeness is defined as the tendency of legume seeds to remain whole throughout the processing operations, not to break apart, burst or disintegrate. The measurement in the laboratory is done by visual inspection. Consumers react most readily to the wholeness of beans by downgrading or rejecting disintegrated beans.

2. Consistency is described as the smoothness and clarity of the sauce or brine, and the ease of bean separation from sauce. The inspection is done visually. While not necessarily recognizing the causes, consumers can easily notice the undesirable or grainy fluid of canned beans. The consistency is related to the amount of beans in the can. When excess beans are put into a can, they may cause seed matting and grainy sauce. On the other hand, too few beans result in complete separation of beans and sauce and clear sauce.

3. Absence of defects is expressed as the degree of freedom from extraneous materials, loose skins, and mashed beans. It is detected with visual examination. This property is related to processing. Using excessively dry beans results in cracked and split products. Inadequate inspection and sorting of raw materials introduce more defects. Over blanching causes loose skins; over filling causes mashed beans.

4. Flavor, i.e. off-flavors caused by mold, containers, and chemicals are detected by sensory evaluation. Consumers tend to express opinions about the flavor of the sauce rather than of the beans. However, they are able to recognize moldy odor and foreign flavors imparted by packaging materials or chemicals.

5. Color of beans packed in brine retain a normal white color, while beans packed in sweetened or tomato sauce become brownish. Off-color is looked for during the inspection. Color evaluation is done

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either by visual inspection or instrumental measurement. Uebersax (1972) used a Hunterlab Color Meter to determine the color of dry and processed beans. Consumers are more likely to react to and reject uncharacteristic colors than to notice and object to slight variations of a standard color.

6. Texture is defined as the tenderness of beans which should not be too firm or too soft and is evaluated either by sensory evaluation or instrumental determination. The Lee Kramer Shear Press was utilized by Binder and Rockland (1964) to measure the texture of cooked lima beans, and by Uebersax (1972) for canned navy beans. Other instruments include the Ottawa Texture Measuring System (O.T.M.S.) (Voisey and Larmond, 1971), the Instron Universal Testing Machine (Bourne, 1972), and the Allo Kramer Shear Press (Davis, 1976).

Consumers can generally recognize differences in bean texture. Genetic differences in flavor and texture, however, can only be detected by skilled professional tasters. Many factors resulting from storage and processing influence the texture of beans. These may include storage time and conditions, soak time and temperature, and hardness of water used in soaking, blanching, and sauce preparation.

In addition to the aforementioned specific bean quality attributes (wholeness, consistency, absence of defects, flavor, color and texture), other evaluations for normal canned products are also conducted. These measurements include vacuum, headspace and drained weight.

Water Activity (a_w) in Foods

The quantity of water present in foods is generally expressed in terms of percent water or moisture content. However, this term is

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inadequate to describe the property and availability of existing water for chemical and microbial reactions. The term "water content" can also cause confusion because the value varies according to food form; for example, the moisture content of whole peanuts, kernels and shells in equilibrium with relative humidity of 75% was 10.5, 9.4 and 15%, respectively (Karon and Hillery, 1949). Thus other terms such as water activity (a_w) or equilibrium relative humidity (ERH) are used extensively.

Definition

$$a_w = \frac{p}{p_o}$$

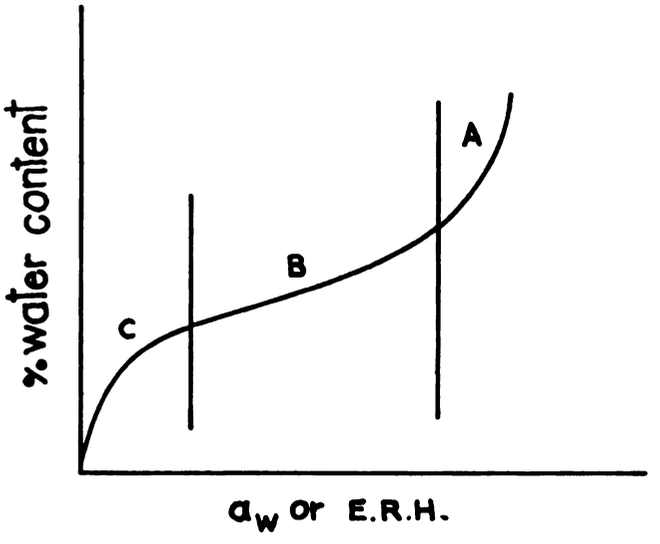
$$ERH = a_w \times 100$$

where p = vapor pressure of solution

p_o = vapor pressure of solvent

Water activity (a_w) of pure water is equal to 1.00. Glycerol, sucrose, and sodium chloride have a_w values of 0.9816, 0.9806 and 0.967, respectively. When moisture content in equilibrium with various relative humidities is plotted with a_w or relative humidity (RH), a water sorption isotherm is obtained.

The hydration process of a dry material is explained theoretically with the water sorption isotherm. It begins with the formation of a monolayer at very low RH (region C), followed by multilayer adsorption (region B), the uptake into pores and capillary spaces, dissolution of solutes and finally mechanical entrapment of water (region A) at the high level of RH (Troller and Christian, 1978).



General Water Sorption Isotherm

Brunauer-Emmett-Teller (BET) isotherm of Brunauer et al. (1938) was the first to estimate the size of the monolayer of absorbed water. The monolayer is important since it is considered to be the most stable water content of most foods and is related to the rate of many reactions, such as lipid oxidation and nonenzymatic browning in foods.

The water sorption isotherm is applicable to the prediction of storage life and development of suitable storage conditions for dry materials, so that their moisture contents at the storage temperature and RH do not exceed the critical values.

To obtain the water sorption isotherm, samples are equilibrated at various relative humidities until there is no change in moisture content. The final or equilibrium moisture content at each RH is plotted against RH. Relative humidity during equilibration is usually maintained by using saturated inorganic salt solutions. The relative humidity values exerted by saturated salt solutions were reviewed by Washburn (1926), Stokes and Robinson (1949), Wexler and Hasegawa (1954), Rockland

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(1960), and Weast (1972-1973). The reported values vary, however, the values reviewed by Stokes and Robinson (1949) are thought to be the best, currently available. A solution of sulfuric acid could also be used in place of the saturated salt solution, but preparation and handling of strong acidic solutions are more difficult and concentrations may change due to adsorption or desorption of water.

The amount of water present in food is involved in many biological and chemical reactions leading to the quality changes in food. Increase in moisture may accelerate or decelerate the reaction rate. The optimum condition is defined for many reactions in terms of a_w.

1. Lipid oxidation. The rate is high when a_w is below the monolayer level of moisture, and decreases as the a_w increases to the range of 0.3-0.5, then increases again. Labuza et al. (1970) reported that the oxygen uptake by a cellulose-containing model system supplemented with 30% glycerol was greater at RH less than 0.1% than at 75, 52 or 20%.

2. Enzymatic reaction. At a_w less than the monolayer, minimal or no enzymatic reaction occurs because little free water is available for the movement of substrate and products. On the contrary, as a_w increases above the monolayer, free water dissolves more substrate and the enzymatic reaction is accelerated. Although each enzyme possesses different optimum a_w, generally, enzymatic activity increases with a_w.

3. Microbial growth. Bacteria require higher a_w to grow than yeasts and molds. Most bacteria have maximum growth rates at a_w in the range of 0.997-0.980. The multiplication of yeasts occurs at a_w greater than 0.90, whereas molds still grow when the a_w level is much below 0.90 a_w. Halophilic bacteria, osmophilic yeasts and xerophilic molds continue their growth at low a_w, e.g. below 0.85 a_w.

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4. Textural change. Increase in RH results in an increase of hardness and chewiness of foods until the RH of 40-50% is reached (Heldman et al., 1972).

5. Color change. Most pigments from plants and animals are stabilized with increasing a_w except for chlorophyll, for which degradation to pheophytin increases at a_w greater than 0.32.

6. Nutritional change. Ascorbic acid is relatively stable at low a_w levels. The destruction of this vitamin is increased at high a_w (Labuza, 1973).

7. Nonenzymatic browning reaction. The complex reactions between reducing sugars and the amino groups of amino acids or proteins produce highly colored compounds. The nature of these reactions was reviewed in 1953 by Hodge. Lea and Hannan (1949) studied the browning reaction of a casein-glucose solution model system and reported that the loss of amino nitrogen (increase in browning) was increased with a_w because of greater mobility of protein molecules at high a_w. The loss was decreased after 0.70 a_w because the dilution effect reduces substrate available for reaction.

Browning in foods has been evaluated by numerous investigators. It was reported that the browning reaction generally increased to a maximum as a_w increased to the value of 0.60-0.80 and then decreased as a_w increased. The a_w for maximum browning reaction varies with food types. Present data suggest that maximum browning reaction rate in fruit and vegetable products occurs in the 0.65-0.75 a_w range, whereas for meat and muscle products it is in a wider range of 0.30-0.60 a_w.

In addition to a_w, other factors such as temperature, pH and sugar type, influence the rate of browing reaction.

The reaction between amino groups of protein and reducing sugars causes major loss to proteins during drying and storage of foods. The specific loss of the ε-amino groups of lysine usually occurs by a condensation with reducing sugars or other carbonyl compounds. In addition, pigments produced from nonenzymatic browning reaction could polymerize or complexe with the protein (Labuza, 1972). Such changes in protein and carbohydrate in bean cotyledons from nonenzymatic browing reaction are likely to be responsible for variation in bean hydration, processed bean drained weight and shear resistance.

Mylar® - A Packaging Material

Mylar® is the trade name of E. I. du Pont de Nemours & Co., Inc. for polyester film. Mylar® is usually produced from a condensation reaction between ethylene glycol and terephthalic acid which gives it its name "polyethlene terephthalate." It was developed in 1940 by J. R. Whinfield and J. T. Dickson.

Mylar® is a transparent film possessing exceptional tensile strength over 20,000 psi and elongation above 50% giving good impact strength. It is resistant to greases, oils, and most chemicals except strong acids, strong alkalines, phenols, cresols and benzyl alcohol. Moisture permeability of Mylar® is fairly high. The water vapor transmission rate of oriented polyester film is 1.7 g/24 hr/100 sq in/mil at 95°F, 90% RH; compared to 1.3 g/24 hr/100 sq in/mil for low density polyethylene and 19 g/24 hr/100 sq in/mil for nylon (Hanlon, 1971). Mylar® is a good barier to gases and odors. It has lower gas permeability than many other films. Its permeability to CO_2 is greater than to O_2 and N_2, with the rate of 16 cc/24 hr/100 sq in/mil at 77°F, 50% RH for

CO_2, compared to the values of 4 and 1 for O_2 and N_2 permeability, respectively. Mylar® has poor sealability. Self sealing with heat and pressure is possible but difficult. Usually it is utilized in the form of coated or laminated film. Coatings can be done with either vinylidene chloride or polyethylene. These coatings provide the sealability and improve moisture barrier properties.

The drawback of Mylar® is the high cost, it being three times as much as some other transparent films. However, because of its high strength, Mylar® can be utilized with less thickness than other films, thus helping to reduce the cost.

Application of Mylar® in food packaging is in the field of frozen foods, heat-and-serve foods and gas packaging of meats and cheeses.

MATERIALS AND METHODS

Raw Materials

Dry navy beans were supplied by B & W Co-Op, Inc., Breckenbridge, Michigan in a 100 lb multiwall paper bag. The moisture of beans was in the range of 10.6-11.7%.

Dry Bean Preparation and Storage

The storage experiment consisted of four studies. Each study was factorial for treatment, moisture content, temperature and time as follows:

Study 1 - Packaging environment

treatment: vacuum, air, carbon dioxide (CO_2)

moisture: 14-22%

temperature: 70°F and 90°F

time: 1, 2, and 3 months

Study 2 - Chemical treatment

treatment: control (air), Grain Treet® (0.75%), sulfur dioxide (SO_2) (100 ppm)

moisture: 18-22%

temperature: 70°F and 90°F

time: 1, 2, and 3 months

Study 3 - Long-term storage in cans

moisture: 8-18%

temperature: 50°F, 70°F and 90°F

time: 1, 12 and 24 (not shown) months

Study 4 - Equilibrium moisture

moisture: 9.2%

temperature: 70°F

RH: 48-97%

Beans were initially sorted by hand to remove cracked or imperfect seeds and foreign materials (soil and stones).

For the packaging and chemical treatments (Studies 1 and 2) beans were adjusted to moisture content ranging from 14 to 22%. The adjustments were done in a closed cabinet, using a small humidifier as a moisture supplier to layers of beans spread on perforated trays. The rate of moisture gain was approximately 0.75% per hour, checked periodically with the Motomco model 919 Moisture Meter.

Duplicate samples of 250 g beans were stored in 18.8x15.8 cm polyethylene laminated Mylar® bags, commonly used for frozen food. The thickness of the film was 3 mil (0.003 inch). The film had the water vapor transmission rate (WVTR) measured according to the ASTM standard E96 of 0.55 g/m^2-24hr at 72°F, 50% RH, and of 3.77 g/m^2-24hr at 100°F, 82% RH.

For the packaging study (Study 1), beans were packaged under one of three gases: vacuum, air or CO_2. The Kenfield Vacuum Sealer model C-14, (International Kenfield Distributing Co., Broadview, Illinois) capable of vacuum drawing and backflushing, was used to seal the bags.

Chemical treatments (Study 2) were performed before packaging beans under air. Chemicals were applied on a weight basis to a thin layer of beans with a chromatographic sprayer. Grain Treet® solution obtained from Kemin Industries, Inc., Des Moines, Iowa, was sprayed to a level of 0.75% (w/w). SO_2 (100 ppm, bean weight basis) was obtained by spraying a 5% (w/w) $NaHSO_3$ solution which provided 55% available SO_2.

Adjustment of bean moisture for the long-term storage study (Study 3), was done in a forced air chamber. Beans were held in this chamber and supplied with moist air. Beans were removed from the chamber when the proper moisture content was reached. Beans were then packaged in 303x406 cans. The cans were held in a walk-in refrigerator (50°F), at room temperature (70°F), and in a controlled temperature chamber (90°F), for the specified storage time.

For the equilibrium moisture study (Study 4), eight pairs of desiccators were filled with various saturated salt solutions which maintained different levels of RH as follows: KNO_2 (48% RH), $Mg(NO_3)_2$ (53% RH), $NaNO_2$ (64% RH), NaCl (75% RH), $(NH_4)_2SO_4$ (80% RH), KCl (86% RH), KNO_3 (92% RH), and K_2SO_4 (97% RH). Each desiccator was equipped with a small motor and fan to facilitate the atmospheric movement within the desiccator and in turn to accelerate equilibration rates. The fans were operated periodically during the equilibration period.

Samples of 150 g beans were placed in small cylindrical baskets made of wire mesh. Eight baskets were placed in each desiccator. Beans were allowed to equilibrate with the controlled RH. Moisture content determination (oven drying method) and color evaluation (Hunterlab) were performed periodically until the moisture content remained stationary. This final or equilibrium moisture content was recorded.

Equilibrated beans were canned in four replicates and evaluated with the same procedure used for the storage studies.

Bean Processing

At the end of each storage period moisture content of the beans was determined with the Motomco Moisture Meter. One hundred grams of bean solids were weighed and put into individual nylon mesh bags for soaking. Beans from Study 1 and 2 were processed in duplicate, while beans from Study 3 were processed in four replications.

Soaking was done in two steps. Cold soaking at 75°F for 30 minutes was followed by hot soaking at 190°F for 30 minutes. Soak water contained 50 ppm calcium. Hot soaked beans were cooled by dipping in cold tap water and then drained. Weight gain during soaking was recorded.

Beans were filled into 303x406 cans. Boiling brine added was formulated with 5 oz. of sugar and 4 oz. of salt in 20 lb of water containing 50 ppm calcium. Cans were exhausted and sealed.

A still retort was employed to process beans at 240°F for 45 minutes, followed by cooling to 100°F with cold running water for 15 minutes. Canned products were equilibrated at room temperature for two weeks prior to evaluation.

Canned Bean Evaluation

The following scheme was used to evaluate canned products:

1. Physical properties

Total and net weight, vacuum, headspace and drained weight were determined.

Drained weight. Canned beans were emptied onto a number 8 mesh screen (0.094 inch openings) and washed by a slow swirling motion for 1 minute in 70°F tap water to remove adhering brine. The screen was drained at a 15° angle for 2 minutes. Bean weight was recorded as washed drained weight.

2. Visual examination

During the 2 minute drain on the screen, bean samples were visually judged by hedonic scales in comparison with a commercial sample (Figure 29).

3. Color and texture measurement

Color. The Hunterlab Model D25 D2L Digital Color and Color Difference Meter (Hunter Associates, Fairfax, Virginia) was used for objective color measurement of beans. Two hundred g of dry or 100 g of washed processed beans were evenly distributed in an optically pure glass sample dish, which was placed over the optical port, and covered with a black can to shield interfering light. The instrument was standardized using a standard white tile no. C2-6004 having L = +95.25, a_L = -0.6 and b_L = +0.4 coordinates.

Two and four separate samples were taken from dry and processed beans, respectively. To normalize surface irregularities, two readings were taken for eacm sample; the second reading was recorded after turning the sample dish 90° from its original position.

Texture. After color determination, each sample (100 g) of processed beans underwent texture analysis. Firmness was measured with the Lee-Kramer Recording Shear Press, Model TR-1 (Food Technology Corporation, Reston, Virginia). The 3,000 lb test ring no. 10107 and standard shear compression cell and blade no. C 338 were employed. The

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rate of shear-compression blade travel was standardized to 0.52 cm/sec. The instrument was usually set at range 10 (300 lb of force full scale), except for very firm beans which required a range 20 (600 lb force full scale). The resistance to shear was shown as a peak curve. The result was expressed as peak pound force per 100 g of sample.

Additionally, final moisture content of sheared beans was determined by oven drying.

4. Sensory evaluation

Unopened cans of beans were heated in boiling water for 10 minutes. Cans were opened and held warm in hot water baths until serving time. Each sample was assigned a three digit random number. Samples were served in one ounce plastic portion cups, 8-9 samples divided into 2-3 sets per panel. They were evaluated under neutral white light in individually segregated panel booths. Panelists were selected randomly from students, faculty and staff of Michigan State University, primarily from the Department of Food Science and Human Nutrition. The panelists were asked to taste and evaluate each sample according to a 7 point hedonic scale (Figure 30).

Analytical Methods

1. Moisture content

Moisture meter. Two hundred and fifty g of stored dry beans were used in the Motomco Moisture Meter model 919 (Motomco Inc., Clark, New Jersey). The temperature and meter reading were recorded and converted to % moisture content with the calibration chart no. B-5 for navy beans. The result from the moisture meter was initially shown to agree with that from oven drying at 208°F for 6 hours.

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Air oven method. Moisture content of 100 g sheared beans was determined with the oven methods (AOAC, 1970). Beans were dried at 176°F to a constant weight. Moisture content (% w/w) was calculated from the weight change which was assumed to be due to water loss alone.

2. Water vapor transmission rate (WVTR)

The film of plastic bags used for dry bean storage was tested for WVTR according to the method of the American Society of Testing Materials (ASTM) no. E96 (1972). The film was cut into a 9-cm circle with a sample cutter blade. The cut samples were placed over standard aluminum dishes containing dry desiccant and the edges were sealed with wax. The dishes were weighed and held both at room condition (72°F, 50% RH) and in a walk-in controlled humidity cabinet (100°F, 82% RH). The weight change during storage was recorded and calculated for WVTR (g/m^2-24hr) for both conditions.

Statistical Analysis

The "Jeremy D. Finn's Multivariance-Univariate and Multivariate Analysis of Variance, Covariance, and Regression" modified and adapted by Scheifley and Schmidt (1973) for use on the CDC 6500 computer operated by Michigan State University Computer Laboratory was used to assist statistical analyses.

The multivariate analysis of variance, observed means and standard deviation, least square estimates and correlation matrix were determined from the Finn program. Mean squares from the analysis of variance were reported with significant level of 5% (*), 1% (**), and 0.1% (***).

Tukey's HSD (honestly significant difference) was calculated at 95% confidence limit for each main effect. Means which were not significantly different were indicated with like letters. Scheffe's method according to the "Comparisons among Treatment Means in an Analysis of Variance," ARS/H/6 of USDA was used to determine the response to treatment trends (Chew, 1977).

The significance of correlation matrix was examined with the "Statistical Tables" (Rohlf and Sokal, 1969).

Coefficient of variability (% CV) defined as the sample standard deviation expressed as a percentage of the sample mean was also calculated (Steel and Torrie, 1960).

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RESULTS AND DISCUSSION

Packaging Environment Study

Mean values of dry and processed bean characters following storage under various physical conditions are summarized in Table 1. The analysis of variance, Tukey's HSD and coefficient of variability of data are presented in Table 2.

The initial bean moisture content ranged between 14-22% and averaged 12% moisture after the storage period. The Mylar® film water vapor transmission rate (WVTR) was 0.55 g/m^2-24 hr at 72°F, 50% RH, and was 3.77 g/m^2-24 hr at 100°F, 82% RH. This relatively low WVTR should have minimized dry bean moisture loss during storage. However, moisture losses occurred at greater rates than accountable to film permeation rate. Imperfections of the bags, such as pinholes and leakage in sealed areas may be responsible for the accelerated bean moisture loss reported in the study.

Dry bean moisture increased from approximately 12% to 51% following soaking and attained a final bean moisture of 69% after processing. Soaked and processed bean moisture decreased as initial dry bean moisture during storage increased (Figure 1). These decreases were linearly significant (Table 3). These data indicated that the water uptake capacity during soaking and processing was reduced for high moisture stored beans and may be caused by changes of protein and other constituents within cotyledon matrix. Rockland (1963) reported

Table 1. Dry and processed navy bean characteristics dry stored at varying moisture content under selected packaging environments and at 70° and 90°F for up to 3 months prior to processing.[1]

Time month	Initial Bean Moisture (%) 14	16	18	20	22
Dry Bean Moisture (%)					
			70°F		
			Vacuum		
1	10.85± .07	10.30±1.27	12.15± .07	13.75± .49	15.40± .71
2	11.15± .07	11.35± .35	11.45± .07	12.55± .35	13.85± .21
3	11.35± .35	12.35± .21	12.95± .21	13.70± .42	15.80± .14
			Air		
1	10.60± .14	11.90± .00	12.40± .14	13.60± .57	15.10± .42
2	10.55± .14	11.90± .00	11.30± .00	12.55± .07	13.10± .28
3	10.80± .28	12.95±1.20	12.85± .35	13.70± .00	15.40±1.13
			CO_2		
1	10.45± .21	11.55± .35	12.40± .14	13.55± .35	15.65± .07
2	10.50± .14	11.15± .07	11.70± .28	12.65± .49	13.70± .14
3	10.75± .35	12.20± .14	12.20± .00	14.25± .07	15.35± .21
			90°F		
			Vacuum		
1	10.50± .00	11.40± .00	12.20± .42	12.45± .35	14.90± .85
2	10.65± .21	10.70± .00	11.70± .42	12.35± .64	13.45± .92
3	10.50± .14	11.60± .14	12.70± .00	12.90± .28	14.80± .00
			Air		
1	9.70± .71	11.30± .28	12.35± .07	13.50± .28	15.70± .57
2	9.95± .07	10.65± .35	10.85± .21	13.05± .78	12.90± .00
3	10.00± .00	11.05± .07	11.30± .57	12.60± .57	14.35± .49
			CO_2		
1	10.05± .21	11.35± .49	11.60± .28	12.90± .71	15.10± .14
2	9.60± .42	10.25± .07	10.95± .21	12.15± .07	13.60±1.13
3	10.15± .07	11.20± .28	11.40± .14	13.00± .42	13.40± .00

Table 1. (cont'd.)

Time month	Initial Bean Moisture (%) 14	16	18	20	22
Soaked Bean Moisture (%)					
			70°F		
			Vacuum		
1	53.05± .35	51.75± .35	51.60± .00	50.95± .49	50.70± .57
2	52.15± .07	51.95± .49	49.95± .21	49.15±1.20	47.85±2.05
3	53.00± .28	52.25± .07	51.85± .07	50.60± .14	50.30± .28
			Air		
1	53.00± .28	52.25± .07	51.85± .07	50.60± .14	50.30± .28
2	52.75± .35	52.05± .07	50.20±1.27	49.15± .92	48.80± .28
3	51.40± .14	51.85± .78	51.10± .57	49.50± .00	49.70± .42
			CO_2		
1	53.00± .42	52.35± .21	51.85± .21	51.00± .14	50.85± .49
2	53.30± .14	51.70± .85	51.15± .07	50.00± .71	48.70± .57
3	52.40± .00	52.40± .71	50.50± .14	50.60± .28	50.35± .64
			90°F		
			Vacuum		
1	52.85± .35	52.05± .21	51.30± .00	50.40± .00	49.95± .07
2	52.30± .99	52.15± .64	49.95± .21	48.55± .21	48.20±2.69
3	51.85± .07	51.15± .07	51.25± .07	50.00± .00	49.70± .70
			Air		
1	52.50± .57	52.10± .00	51.85± .07	50.50± .99	50.80± .28
2	52.60± .42	51.25± .07	50.55± .49	49.60± .00	48.15± .07
3	51.80± .00	51.35± .49	50.90± .28	49.75± .07	50.00± .28
			CO_2		
1	52.95± .07	52.40± .28	51.60± .42	50.75± .49	50.50± .28
2	52.40± .71	51.45± .07	51.30± .42	50.30± .14	49.25± .49
3	52.20± .42	52.05± .21	50.75± .35	50.40± .14	49.25± .78

Table 1. (cont'd.)

Time month	Initial Bean Moisture (%) 14	16	18	20	22
Processed Bean Moisture (%)					
			70°F		
			Vacuum		
1	70.04± .27	70.31±2.68	70.00± .08	71.13±1.52	69.75± .08
2	69.40± .23	69.69± .29	67.05±1.70	69.08± .25	68.71± .57
3	70.09± .03	70.50± .35	69.86± .06	69.42± .33	69.04± .04
			Air		
1	70.07± .33	70.34±2.84	70.87± .72	70.89±1.57	69.92± .54
2	70.07± .51	70.10± .25	69.53± .04	69.16± .01	69.29± .21
3	69.94± .40	70.46± .29	69.83± .06	68.58±1.59	68.98± .18
			CO_2		
1	69.40± .24	71.40±1.48	70.40± .19	70.66±1.20	69.99± .47
2	70.31± .04	66.18± .37	69.22± .50	69.10± .84	68.57± .33
3	70.00± .27	70.92±1.21	69.52± .07	69.56± .34	68.82± .27
			90°F		
			Vacuum		
1	70.35± .16	69.93±2.72	68.85± .98	69.70±1.14	68.46± .19
2	69.56± .18	69.06± .21	67.49± .13	67.50± .00	67.91± .21
3	70.06± .06	69.47± .40	67.96± .06	67.27± .52	67.00± .13
			Air		
1	69.87± .31	71.06±1.33	69.69± .54	68.33± .98	69.90±1.14
2	69.58± .33	68.51± .21	67.24± .96	67.58± .39	67.20± .08
3	69.93± .33	69.57± .18	68.13± .32	68.48±1.80	67.02± .24
			CO_2		
1	69.47±1.44	70.34±1.43	69.62± .04	69.93±1.45	68.69± .23
2	70.10± .61	67.46± .34	68.39± .23	67.68± .61	67.46± .50
3	69.82± .04	69.34± .74	68.00± .11	67.50± .57	66.98± .08

Table 1. (cont'd.)

Time month	Initial Bean Moisture (%) 14	16	18	20	22
Processed Bean Drained Weight (g)					
			70°F		
			Vacuum		
1	285.0± 6.0	275.0± 4.0	276.4± 2.0	276.5± 6.0	269.4± 4.0
2	297.7± .0	284.9± 2.0	277.8± .0	270.8± 2.1	263.7±16.1
3	296.3± 2.1	299.1± 2.1	283.5± .0	275.8± 1.1	269.4± 4.0
			Air		
1	286.4± 4.0	283.5± 4.0	280.7± .0	270.8± 2.1	273.6± 2.0
2	297.7± .0	289.2± .0	283.5± 4.0	275.0± .0	266.5± 4.0
3	296.3± 2.1	297.3± 4.5	287.8± 6.0	261.0± .2	270.8± 2.1
			CO_2		
1	284.9± 2.0	269.4±16.1	284.9± 2.0	273.6± 2.0	270.8± 2.1
2	303.4± .0	290.6± 6.0	280.7± 8.0	275.0± .0	269.4± 4.0
3	293.5± 6.0	294.5± 4.6	283.5± 4.0	276.2± 1.6	276.4± 2.0
			90°F		
			Vacuum		
1	289.2± 8.0	285.0± 6.0	273.6± 2.0	260.8± .0	262.3± 6.0
2	302.0± 2.1	279.3± 2.1	269.4± .1	273.6±10.0	255.2± 8.0
3	303.4± 4.0	285.5± 1.1	273.6± 2.0	260.1± 1.0	270.8±14.1
			Air		
1	290.6±10.0	270.8±22.0	279.3± 6.0	260.8± .0	262.3± 6.0
2	299.1± 2.0	279.3± 2.1	269.4± 4.0	269.4± 4.0	253.8± 2.1
3	294.9± 4.0	284.3± 2.8	276.5± 6.0	263.9± .2	258.0± 4.0
			CO_2		
1	287.8± 6.0	268.0±18.0	272.2± 8.0	270.8± 2.1	272.2± 4.0
2	299.1±10.0	287.8± 2.1	279.3± 2.1	266.5± 8.1	259.4± 2.0
3	303.4± 4.0	285.5± 1.1	273.6± 2.0	260.1± 1.0	270.8±14.1

Table 1. (cont'd.)

Time month	Initial Bean Moisture (%) 14	16	18	20	22
Shear Resistance (g/100 g bean)					
			70°F		
			Vacuum		
1	120.8±15.9	129.5± 2.6	112.8±12.2	90.6± 5.1	146.1± 5.1
2	129.7± 2.3	114.7±24.3	141.6±14.9	140.9±30.8	151.4±33.7
3	95.9± 1.1	66.3± .0	105.6± 3.0	160.2± .0	158.7± 6.4
			Air		
1	114.9± 6.9	120.4± 5.7	132.9±25.0	115.9±17.2	115.2±12.3
2	120.7±14.6	88.2± .0	129.0±31.4	143.6±25.2	137.4± .4
3	77.7±21.6	63.9± .0	102.6±15.7	262.2± .0	158.9± 8.3
			CO_2		
1	119.7±14.9	104.9± 6.2	145.4±15.7	132.6±22.1	143.3±17.0
2	97.0± 7.4	111.3±17.8	109.1± 7.9	133.7±14.2	140.0±12.9
3	67.2± 8.5	89.4± .0	128.7± 8.9	167.3± .0	169.0±20.1
			90°F		
			Vacuum		
1	122.1± 7.2	125.9± 7.9	202.5± 2.1	220.9± 4.4	182.5±19.4
2	130.1±27.4	136.4± 7.4	211.1± 7.4	247.1±13.8	237.8±44.8
3	91.5±23.8	101.7± .0	197.9±10.0	292.2± .0	286.8± 8.4
			Air		
1	122.3± 1.5	135.8± 6.2	175.6± 7.9	168.1±35.5	198.0±33.9
2	120.1± 6.6	152.7± 2.5	184.1±24.4	211.2±48.8	243.5± 7.0
3	78.2± 1.5	93.6± .0	202.5±16.6	264.6± .0	281.6± 2.8
			CO_2		
1	136.0± 8.6	142.8±20.4	164.5±73.2	195.6±14.4	173.4±14.4
2	116.4±18.7	145.4±13.4	175.1± 1.9	214.1±40.5	242.3±39.2
3	69.9±13.2	138.9± .0	227.0±14.2	251.1± .0	277.1± .6

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Table 1. (cont'd.)

Time month	Initial Bean Moisture (%) 14	16	18	20	22
Hunter L Value of Dry Beans					
			70°F		
			Vacuum		
1	61.1 ± .3	60.8 ± .6	60.8 ± .1	60.7 ± .0	60.5 ± .1
2	61.2 ± .1	61.0 ± .0	61.0 ± .1	61.0 ± .6	60.3 ± .2
3	61.0 ± .2	60.6 ± .2	60.6 ± .1	60.1 ± .1	59.8 ± .0
			Air		
1	61.2 ± .4	60.9 ± .1	60.7 ± .1	60.8 ± .0	59.9 ± .1
2	61.3 ± .3	60.9 ± .1	60.8 ± .2	60.8 ± .0	60.2 ± .1
3	61.0 ± .0	60.6 ± .1	60.6 ± .0	60.1 ± .0	59.6 ± .1
			CO2		
1	61.3 ± .1	60.8 ± .1	61.3 ± .1	60.7 ± .3	60.5 ± .0
2	61.2 ± .3	60.9 ± .3	61.4 ± .4	61.2 ± .1	60.8 ± .1
3	61.1 ± .3	60.8 ± .3	60.8 ± .1	60.3 ± .2	59.9 ± .4
			90°F		
			Vacuum		
1	61.1 ± .1	60.6 ± .0	60.7 ± .0	60.2 ± .1	59.3 ± .1
2	60.9 ± .3	60.3 ± .2	60.2 ± .1	59.7 ± .4	58.8 ± .1
3	60.5 ± .1	60.3 ± .1	59.6 ± .1	58.8 ± .2	57.4 ± .1
			Air		
1	60.9 ± .1	60.8 ± .1	60.8 ± .1	60.4 ± .0	59.6 ± .4
2	60.7 ± .3	60.5 ± .3	60.7 ± .1	59.9 ± .0	58.4 ± .1
3	60.5 ± .1	60.4 ± .5	59.5 ± .4	58.7 ± .2	56.9 ± .1
			CO2		
1	61.2 ± .0	61.0 ± .1	61.0 ± .0	60.3 ± .4	59.8 ± .1
2	60.9 ± .1	60.4 ± .1	60.8 ± .1	60.0 ± .1	58.9 ± .1
3	60.9 ± .1	60.3 ± .1	59.6 ± .1	59.1 ± .4	57.2 ± .1

Table 1. (cont'd.)

Time month	Initial Bean Moisture (%) 14	16	18	20	22
Hunter a_L Value of Dry Beans					
			70°F		
			Vacuum		
1	- .2 ± .1	.2 ± .1	.1 ± .0	.4 ± .1	.4 ± .0
2	.1 ± .1	1.1 ± .1	1.3 ± .1	1.4 ± .1	1.6 ± .1
3	.0 ± .0	.2 ± .0	1.2 ± .1	1.4 ± .0	1.5 ± .1
			Air		
1	- .1 ± .0	.1 ± .1	.1 ± .0	.3 ± .1	.6 ± .1
2	.1 ± .0	1.0 ± .0	1.2 ± .1	1.3 ± .0	1.6 ± .1
3	.1 ± .1	.2 ± .1	1.1 ± .0	1.5 ± .0	1.6 ± .1
			CO_2		
1	.3 ± .1	.3 ± .1	.4 ± .1	.5 ± .0	.6 ± .1
2	1.1 ± .1	1.3 ± .0	1.3 ± .0	1.4 ± .0	1.5 ± .0
3	.3 ± .1	.9 ± .6	1.3 ± .1	1.4 ± .1	1.5 ± .1
			90°F		
			Vacuum		
1	- .1 ± .0	.2 ± .0	.3 ± .1	.5 ± .1	.8 ± .0
2	.1 ± .1	1.2 ± .0	1.4 ± .1	1.7 ± .1	2.4 ± .1
3	.0 ± .0	.3 ± .0	1.3 ± .0	1.9 ± .1	2.7 ± .0
			Air		
1	- .2 ± .1	.1 ± .0	.1 ± .0	.4 ± .1	.7 ± .1
2	.4 ± .4	1.2 ± .1	1.3 ± .0	1.5 ± .1	2.3 ± .0
3	.0 ± .0	.3 ± .1	1.1 ± .1	1.6 ± .1	2.5 ± .0
			CO_2		
1	.3 ± .1	.3 ± .0	.4 ± .0	.5 ± .1	.7 ± .1
2	1.1 ± .0	1.4 ± .1	1.3 ± .0	1.6 ± .1	2.1 ± .2
3	.2 ± .1	1.2 ± .0	1.3 ± .1	1.7 ± .1	2.4 ± .1

Table 1. (cont'd.)

Time month	Initial Bean Moisture (%) 14	16	18	20	22
Hunter b_L Value of Dry Bean					
			70°F		
			Vacuum		
1	9.9 ± .1	10.2 ± .2	10.2 ± .1	10.4 ± .2	10.8 ± .1
2	10.0 ± .1	10.3 ± .1	10.5 ± .0	11.0 ± .0	11.6 ± .1
3	10.3 ± .1	10.5 ± .0	10.7 ± .0	11.2 ± .1	12.1 ± .2
			Air		
1	9.9 ± .2	10.1 ± .1	10.2 ± .0	10.5 ± .1	10.7 ± .1
2	10.1 ± .0	10.2 ± .1	10.5 ± .1	10.9 ± .1	11.4 ± .0
3	10.2 ± .0	10.4 ± .1	10.6 ± .0	11.3 ± .1	12.0 ± .1
			CO2		
1	9.9 ± .1	10.2 ± .1	10.3 ± .1	10.6 ± .0	10.6 ± .1
2	10.1 ± .0	10.3 ± .0	10.6 ± .1	10.8 ± .0	11.3 ± .1
3	10.3 ± .0	10.6 ± .1	10.7 ± .1	11.2 ± .1	11.7 ± .1
			90°F		
			Vacuum		
1	10.4 ± .1	10.6 ± .1	11.0 ± .2	11.4 ± .1	12.5 ± .1
2	10.8 ± .0	11.2 ± .1	11.7 ± .1	12.7 ± .0	14.3 ± .0
3	11.1 ± .1	11.5 ± .1	12.2 ± .1	13.5 ± .1	14.8 ± .1
			Air		
1	10.3 ± .1	10.6 ± .1	10.8 ± .0	11.4 ± .1	12.1 ± .1
2	10.8 ± .1	11.1 ± .1	11.7 ± .1	12.6 ± .1	14.0 ± .1
3	11.0 ± .1	11.5 ± .1	11.9 ± .1	13.0 ± .0	14.7 ± .1
			CO2		
1	10.4 ± .0	10.8 ± .1	11.0 ± .1	11.4 ± .0	11.9 ± .1
2	10.8 ± .1	11.3 ± .0	11.8 ± .2	12.6 ± .1	13.7 ± .1
3	11.0 ± .0	11.7 ± .0	12.2 ± .1	13.2 ± .1	14.5 ± .1

Table 1. (cont'd.)

Time month	Initial Bean Moisture (%) 14	16	18	20	22
Hunter L Value of Processed Beans					
			70°F		
			Vacuum		
1	48.7 ± .0	49.0 ± .8	49.0 ± .0	49.6 ± .0	49.4 ± .6
2	49.0 ± .4	49.1 ± .6	49.3 ± .1	48.9 ± .4	48.9 ± .4
3	49.1 ± .5	49.5 ± .4	49.5 ± .2	49.1 ± .3	49.1 ± .5
			Air		
1	48.8 ± .1	48.7 ± .2	48.8 ± .2	49.2 ± .0	49.1 ± .0
2	49.1 ± .1	48.9 ± .1	49.3 ± .6	49.1 ± .5	48.8 ± .2
3	49.2 ± .1	49.0 ± .8	49.1 ± .1	48.4 ± .0	49.3 ± .0
			CO2		
1	49.0 ± .0	49.0 ± .6	49.4 ± .4	49.7 ± .0	49.7 ± .3
2	49.1 ± .1	49.1 ± .1	49.2 ± .4	49.3 ± .1	48.8 ± .0
3	49.0 ± .0	49.2 ± .1	49.1 ± .1	49.2 ±1.2	49.9 ± .5
			90°F		
			Vacuum		
1	48.9 ± .1	49.4 ± .0	49.2 ± .6	49.2 ± .4	48.7 ± .0
2	48.9 ± .1	48.8 ± .2	48.8 ± .1	48.3 ± .1	46.9 ± .4
3	49.0 ± .1	48.8 ± .6	48.7 ± .2	47.8 ±1.0	45.3 ± .2
			Air		
1	48.9 ± .0	48.4 ± .5	48.4 ± .5	48.3 ± .0	48.9 ± .1
2	48.9 ± .5	48.8 ± .1	48.8 ± .2	48.5 ± .6	47.0 ± .1
3	48.6 ± .1	48.7 ± .4	48.8 ± .1	48.1 ± .4	45.7 ± .9
			CO2		
1	49.3 ± .4	48.8 ± .8	49.4 ± .0	49.3 ± .1	48.8 ± .3
2	48.5 ± .6	48.7 ± .4	48.5 ± .1	48.5 ± .1	47.8 ± .2
3	48.9 ± .6	48.6 ± .2	49.1 ± .1	47.7 ± .7	46.7 ± .1

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Table 1. (cont'd.)

Time month	14	16	18	20	22
Hunter a_L Value of Processed Beans					
			70°F		
			Vacuum		
1	3.6 ± .0	3.8 ± .4	3.7 ± .1	3.7 ± .0	3.5 ± .4
2	4.0 ± .2	3.6 ± .1	3.8 ± .1	3.6 ± .4	3.6 ± .7
3	3.5 ± .0	3.4 ± .4	3.6 ± .1	4.1 ± .1	4.3 ± .1
			Air		
1	3.8 ± .1	3.6 ± .0	3.6 ± .2	3.7 ± .0	3.7 ± .0
2	4.0 ± .1	3.5 ± .3	3.5 ± .1	3.6 ± .4	3.6 ± .1
3	3.4 ± .1	3.4 ± .3	3.7 ± .1	4.5 ± .1	4.0 ± .4
			CO_2		
1	3.8 ± .0	3.6 ± .6	3.4 ± .1	3.1 ± .0	3.3 ± .4
2	3.8 ± .2	3.7 ± .0	3.3 ± .2	3.8 ± .3	4.1 ± .1
3	3.3 ± .3	3.6 ± .3	3.6 ± .0	4.2 ± .2	3.8 ± .4
			90°F		
			Vacuum		
1	3.4 ± .3	3.1 ± .0	3.2 ± .0	3.4 ± .4	3.9 ± .0
2	3.9 ± .1	3.3 ± .4	3.7 ± .1	4.0 ± .0	4.9 ± .1
3	3.3 ± .1	3.6 ± .4	3.8 ± .1	4.7 ± .0	6.3 ± .1
			Air		
1	3.6 ± .0	3.5 ± .3	3.7 ± .3	3.8 ± .0	3.8 ± .1
2	3.9 ± .0	3.6 ± .2	3.5 ± .1	4.0 ± .1	4.9 ± .1
3	3.4 ± .4	3.3 ± .2	3.7 ± .0	4.2 ± .2	5.9 ± .3
			CO_2		
1	3.5 ± .0	3.6 ± .5	3.8 ± .0	3.7 ± .1	3.7 ± .1
2	4.0 ± .1	3.6 ± .3	3.7 ± .1	4.1 ± .0	4.7 ± .1
3	3.3 ± .3	3.8 ± .4	3.9 ± .2	4.6 ± .1	5.4 ± .0

Table 1. (cont'd.)

Time month	Initial Bean Moisture (%) 14	16	18	20	22
Hunter b_L Value of Processed Beans					
			70°F		
			Vacuum		
1	14.1 ± .0	14.2 ± .3	13.7 ± .1	15.7 ± .0	13.8 ± .1
2	14.4 ± .1	14.2 ± .1	14.3 ± .0	14.3 ± .1	14.3 ± .8
3	14.2 ± .0	14.2 ± .1	14.4 ± .0	14.9 ± .1	15.2 ± .3
			Air		
1	13.7 ± .1	14.2 ± .6	13.8 ± .2	15.5 ± .0	13.6 ± .0
2	14.4 ± .2	13.9 ± .2	14.2 ± .3	14.3 ± .3	14.4 ± .1
3	14.2 ± .4	14.2 ± .1	14.6 ± .0	15.4 ± .5	15.1 ± .4
			CO_2		
1	13.9 ± .0	14.3 ± .6	13.5 ± .0	15.2 ± .0	13.6 ± .1
2	13.8 ± .1	14.2 ± .1	13.7 ± .0	14.6 ± .4	14.8 ± .0
3	14.1 ± .3	14.1 ± .6	14.6 ± .1	14.8 ± .4	14.8 ± .5
			90°F		
			Vacuum		
1	13.6 ± .2	14.5 ± .0	13.9 ± .2	14.6 ± .6	14.5 ± .0
2	14.2 ± .1	14.3 ± .4	14.9 ± .1	15.3 ± .1	15.9 ± .1
3	14.2 ± .1	14.6 ± .3	14.9 ± .1	15.6 ± .6	16.5 ± .1
			Air		
1	13.8 ± .0	13.8 ± .3	14.2 ± .2	14.1 ± .0	14.9 ±1.1
2	14.2 ± .1	14.6 ± .1	14.6 ± .1	15.2 ± .1	16.0 ± .1
3	14.2 ± .2	14.2 ± .2	15.2 ± .1	15.0 ± .9	16.3 ± .0
			CO_2		
1	14.0 ± .1	14.2 ± .4	14.1 ± .0	14.8 ± .6	14.2 ± .1
2	14.4 ± .4	14.5 ± .4	14.6 ± .2	15.2 ± .0	15.8 ± .3
3	14.1 ± .4	14.6 ± .7	15.3 ± .3	15.6 ± .1	16.2 ± .1

[1]Mean values and standard deviation (n = 2 replicate samples).

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Table 2. Analysis of variance of dry and processed navy bean characteristics dry stored at varying moisture content under selected packaging environments and at 70° and 90°F for up to 3 months prior to processing.

Source of Variation	df	Dry and Processed Bean Characteristics: Dry Bean Moisture (%)	Soaked Bean Moisture (%)	Processed Bean Moisture (%)	Drained Weight (g)	Shear Resistance (g/100 g)
				Mean Squares		
Main Effects						
Moist(M)	4	90.36***	51.89***	11.42***	4676.73***	57578.9***
Treat(Tr)	2	.85**	3.05**	.65	43.13	375.3
Temp(Tp)	1	15.02***	.49	40.58***	1178.62***	136741.7***
Time(Tm)	2	13.81***	16.61***	29.24***	292.55**	310.6**
M x Tr	8	.44*	.17	.85	50.25	373.5
M x Tp	4	.03	.07	3.37***	171.61**	11444.1***
M x Tm	8	1.68***	2.09***	3.28***	315.96***	9699.8***
Tr x Tp	2	.45	.06	.15	9.94	513.5
Tr x Tm	4	.66**	.39	.22	49.79	594.9
Tp x Tm	2	2.46***	.06	1.19	84.17	2292.5**
M x Tr x Tp	8	.33	.16	.18	40.22	1522.4**
M x Tp x Tm	8	.31	.12	.28	16.19	988.9**
M x Tr x Tm	16	.25	.48	1.34**	34.90	746.4**
Tr x Tp x Tm	4	.18	.14	1.23	15.12	375.7
MxTrxTpxTm	16	.20	.22	.64	42.95	343.0
Residual	90	.17	.32	.70	32.98	337.3
				Tukey's HSD		
Moisture		1.16	1.57	2.33	16.03	51.26
Treatment		.99	1.35	1.99	13.72	43.87
Temperature		.83	1.12	1.66	11.43	36.56
Time		.99	1.35	1.99	13.72	43.87
% CV		3.39	1.11	1.20	2.06	12.07

Table 2. (cont'd.)

Source of Variation	df	Dry and Processed Bean Characteristics					
		Dry Bean Color[1]			Processed Bean Color[1]		
		L	a_L	b_L	L	a_L	b_L
		Mean Squares					
Main Effects							
Moist(M)	4	15.25***	9.05***	24.35***	3.17***	3.61***	6.58***
Treat(Tr)	2	.79***	.74***	.15***	1.05***	.01	.06
Temp(Tp)	1	26.60***	1.84***	73.47***	21.15***	2.69***	6.92
Time(Tm)	2	10.01***	16.01***	16.21***	3.15***	2.43***	6.14***
M x Tr	8	.09*	.27***	.13***	.28	.08	.07
M x Tp	4	3.09***	.56***	3.89***	4.72***	2.07***	2.20***
M x Tm	8	.84***	1.05***	1.01***	1.46***	1.44***	1.40***
Tr x Tp	2	.05	.05**	.04**	.00	.08	.14
Tr x Tm	4	.02	.01	.01	.33	.13*	.01
Tp x Tm	2	2.88***	.20***	2.56***	3.17***	.80***	1.69***
M x Tr x Tp	8	.04	.01	.02*	.08	.09	.15
M x Tp x Tm	8	.36**	.10***	.14***	1.03***	.29***	.36***
M x Tr x Tm	16	.04	.11***	.01	.15	.07	.09
Tr x Tp x Tm	4	.03	.02	.00	.13	.13*	.08
MxTrxTpxTm	16	.05	.01	.01	.12	.06	.11
Residual	90	.04	.01	.01	.15	.05	.09
		Tukey's HSD					
Moisture		.59	.27	.26	1.08	.63	.85
Treatment		.50	.23	.23	.92	.54	.73
Temperature		.42	.19	.19	.77	.45	.61
Time		.50	.23	.23	.92	.54	.73
% CV		.3	11.30	.84	.79	6.00	2.11

[1]Hunter value L, a_L, and b_L.

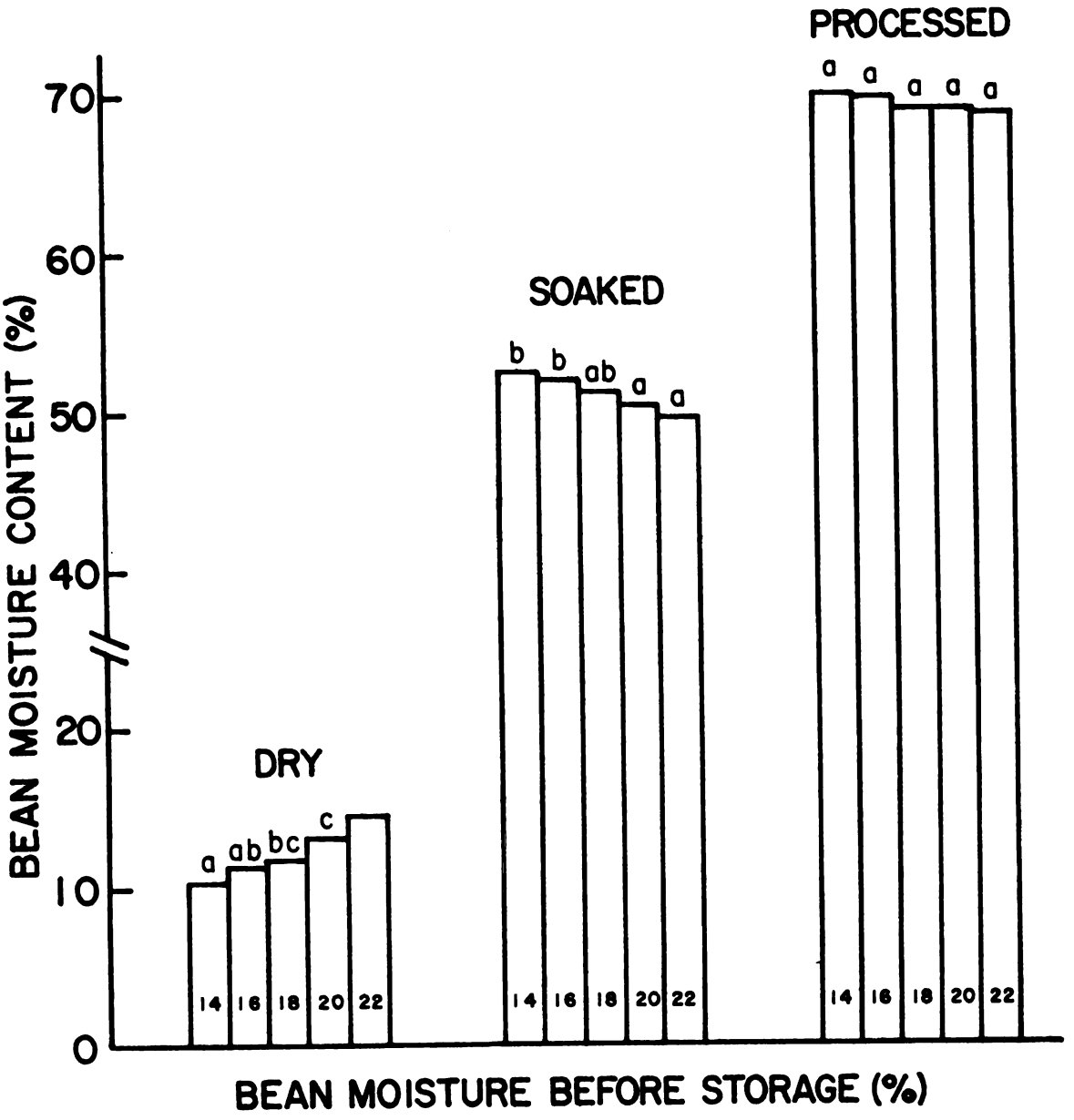

Figure 1. Mean moisture contents (over packaging environment, storage temperature and time) for beans dry stored at varying initial moisture content (14-22%) under selected packaging environments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

Table 3. Response of dry bean moisture content and storage time intervals for beans stored at varying moisture under selected packaging environments and at 70° and 90°F for up to 3 months prior to processing.[1]

Source of Variation	df	Range of Contrast: Dry Bean Moisture (%)	Soaked Bean Moisture (%)	Processed Bean Moisture (%)	Drained Weight (g)	Shear Resistance (g/100 g)
Moisture	4					
Linear	1	2.9 to 3.4*	-2.7 to -2.1*	-1.5 to - .6*	-25.6 to -19.5*	67.2 to 86.5*
Quadratic	1	.2 to .7*	- .3 to .3	- .4 to .5	- .2 to 5.9	-16.0 to 3.4
Cubic	1	.0 to .4	- .1 to .5	- .4 to .5	- 3.5 to 2.6	-30.5 to -11.2*
Quartic	1	- .4 to .1	- .2 to .4	- .7 to .2	- 1.5 to 4.6	- 5.9 to 13.4
Time	2					
Linear	1	- .1 to .2	- .7 to - .3*	- .9 to - .3*	1.2 to 4.9*	3.9 to 15.7*
Quadratic	1	.5 to .8*	.4 to .7*	.4 to 1.0*	- 2.4 to 1.3	- 9.6 to 2.2

[1]Scheffe's Contrast $(\hat{\Psi}) \pm \sqrt{(t-1)(F_{.05;t-1,\nu})}$ standard error$_{(\hat{\Psi})}$

*Significant at 5% level.

Table 3. (cont'd.)

Source of Variation	df	Range of Contrast					
		Dry Bean Color			Processed Bean Color		
		Hunter L	Hunter a_L	Hunter b_L	Hunter L	Hunter a_L	Hunter b_L
Moisture	2						
Linear	1	-1.3 to -1.1*	.9 to 1.1*	1.5 to 1.6*	-.6 to -.2*	.4 to .6*	.6 to .9*
Quadratic	1	- .5 to - .3*	-.1 to .0	.3 to .4*	-.5 to -.1*	.2 to .4*	-.1 to .2
Cubic	1	- .3 to - .1*	.0 to .1*	.0 to .1*	-.3 to .1	-.2 to .1	-.3 to -.1*
Quartic	1	.0 to .2	.0 to .1	- .1 to .0	-.2 to .3	-.1 to .1	-.4 to -.1*
Time	2						
Linear	1	- .6 to - .4*	.5 to .6*	.7 to .8*	-.4 to -.2*	.2 to .4*	.4 to .6*
Quadratic	1	- .3 to - .1*	-.5 to - .4*	- .2 to - .1*	.0 to .2	-.1 to .0	-.1 to .1

[1]Scheffe's Contrast $(\hat{\Psi}) \pm \sqrt{(t-1)(F_{.05;t-1,\nu})}$ standard error$_{(\hat{\Psi})}$

*Significant at 5% level.

protein changes in dry lima beans during maturation and storage at 90°F and at high moisture levels.

No significant differences were shown among packaging environments for dry, soaked and processed bean moisture (Figure 2). Slight decreases in soaked and processed bean moisture were shown for dry beans stored under vacuum. Vacuum stored beans possessed idented seedcoats due to atmospheric pressure on pouches. This may have physically altered the micro structure and thus inhibited imbibition and swelling of cotyledons.

The dry, soaked and processed bean moisture for dry beans stored at 90°F were each lower than those stored at 70°F (Figure 3). Moisture loss in the dry state was significantly greater at 90°F. No significant differences among storage time were shown for all bean moistures (Figure 4).

The hydration ratio after soaking (not shown) which equals the weight of soaked beans divided by the weight of dry beans ranged between 1.7-1.9. Nordstrom and Sistrunk (1977) reported hydration ratios in the range of 1.8-2.0 for other types of dry beans.

Water absorbed during soaking and processing contributes a direct effect on drained weight assuming that intact beans undergo little loss of solids during thermal processing. Therefore, drained weight (Figure 5) followed the same significant linear decreasing relationship as soaked and processed bean moisture.

No significant differences in drained weight were shown for packaging environment, storage temperature and storage time.

Shear resistance of processed beans was approximately 152 g/100g with 278 g drained weight. The processed beans had relatively

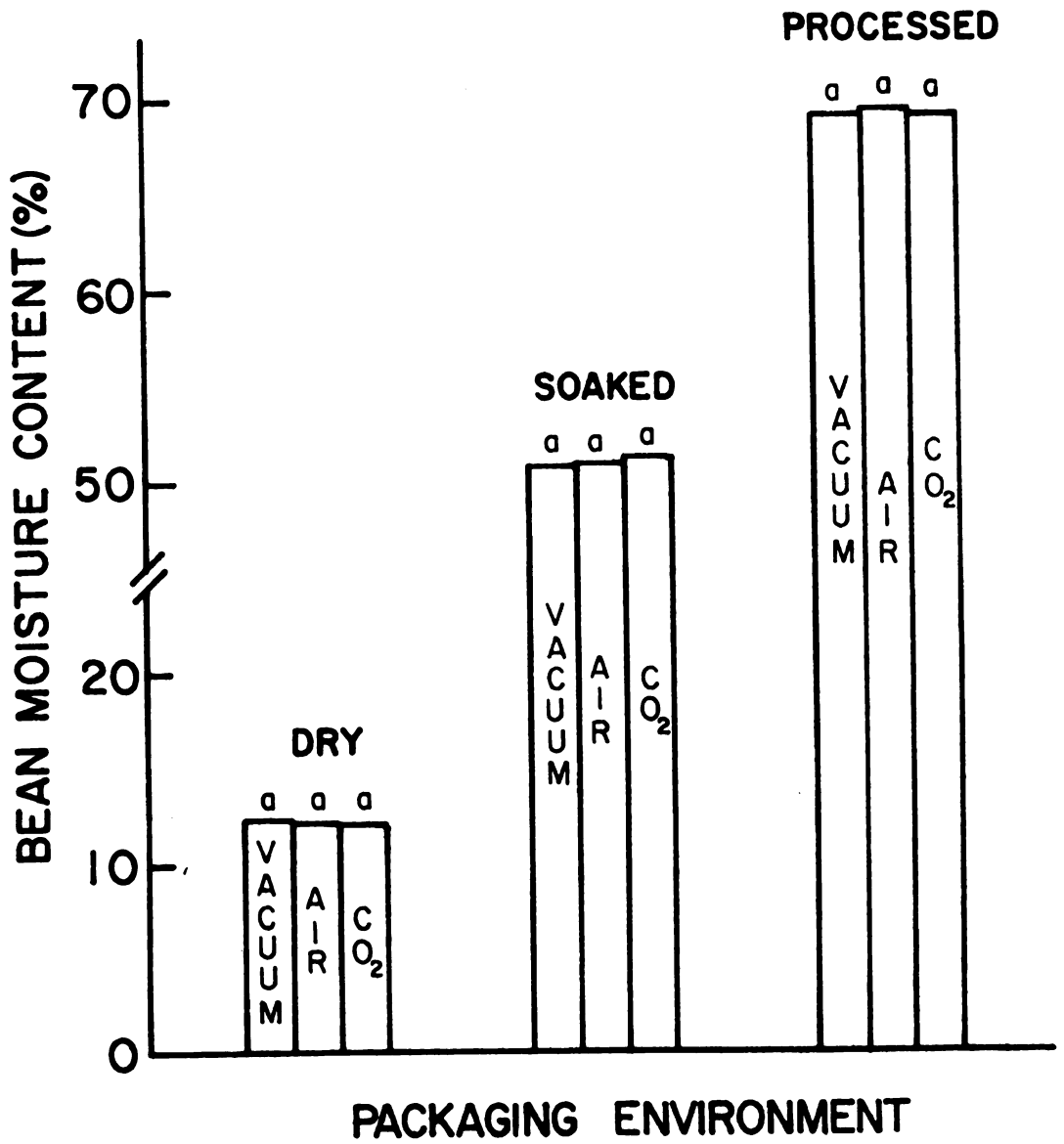

Figure 2. Mean moisture contents (over bean moisture, storage temperature and time) for beans dry stored at varying initial moisture content (14-22%) under selected packaging environments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

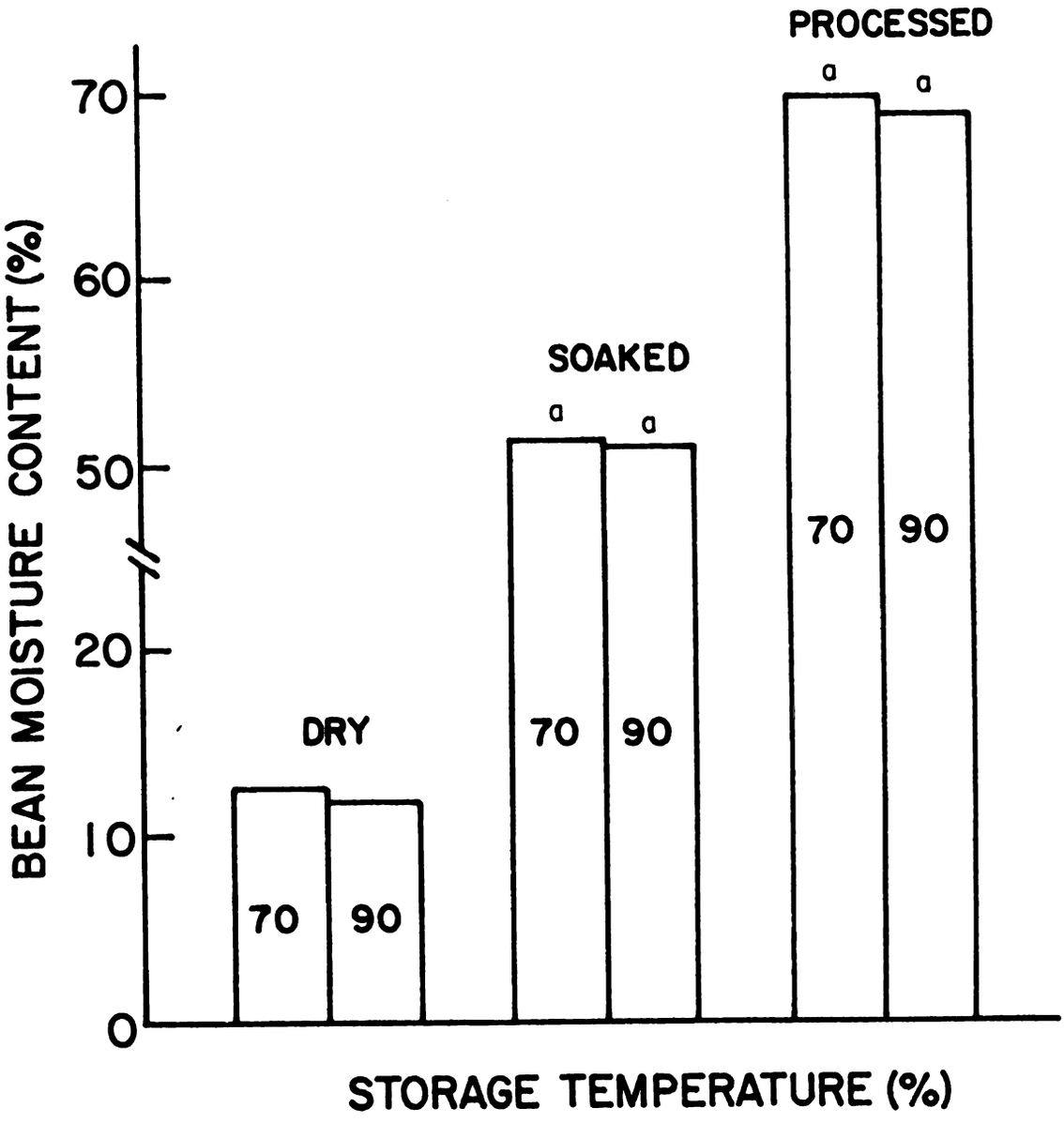

Figure 3. Mean moisture contents (over bean moisture, packaging environment and storage time) for beans dry stored at varying initial moisture content (14-22%) under selected packaging environments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

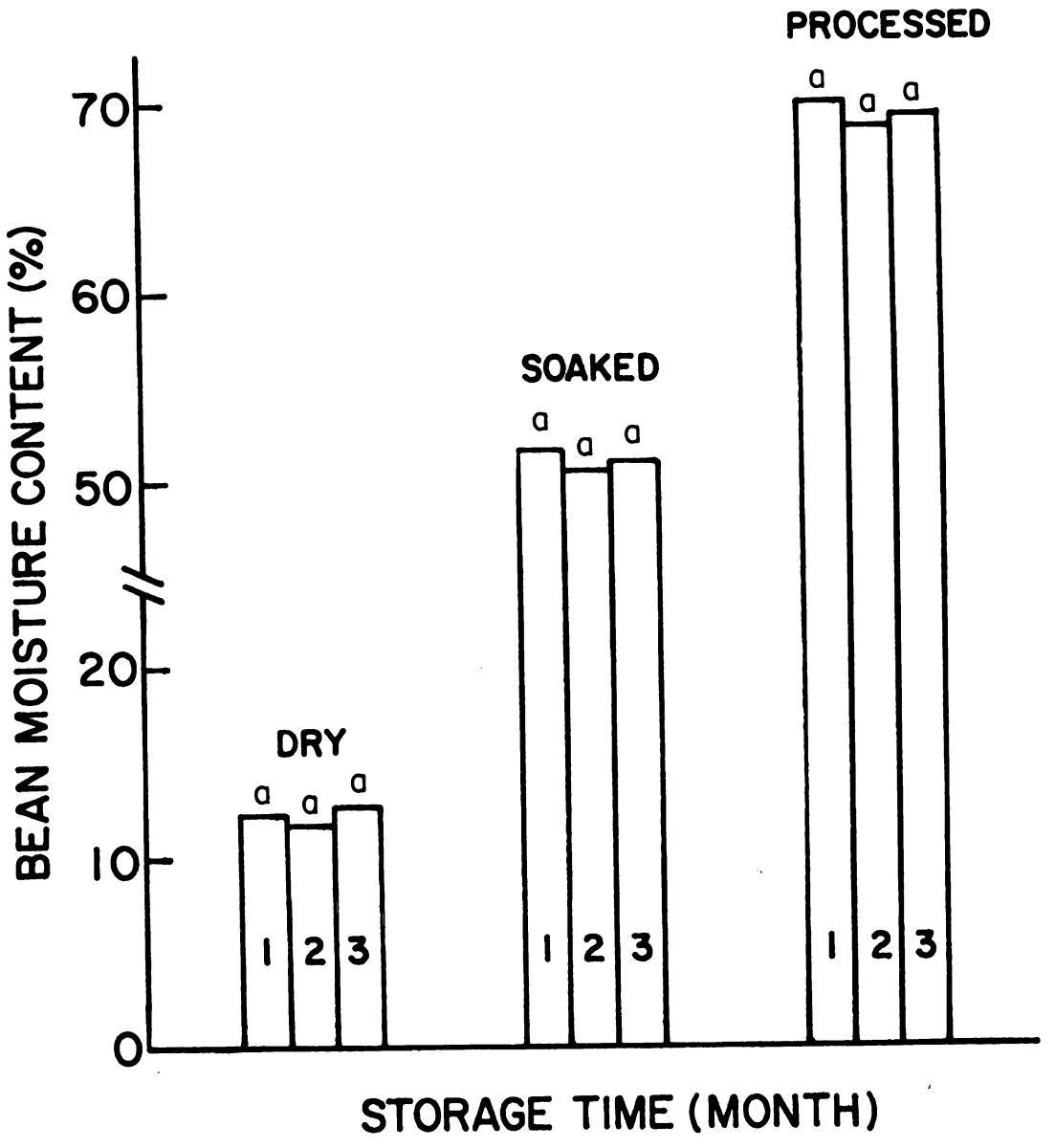

Figure 4. Mean moisture contents (over bean moisture, packaging environment and storage temperature) for beans dry stored at varying initial moisture content (14-22%) under selected packaging environments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

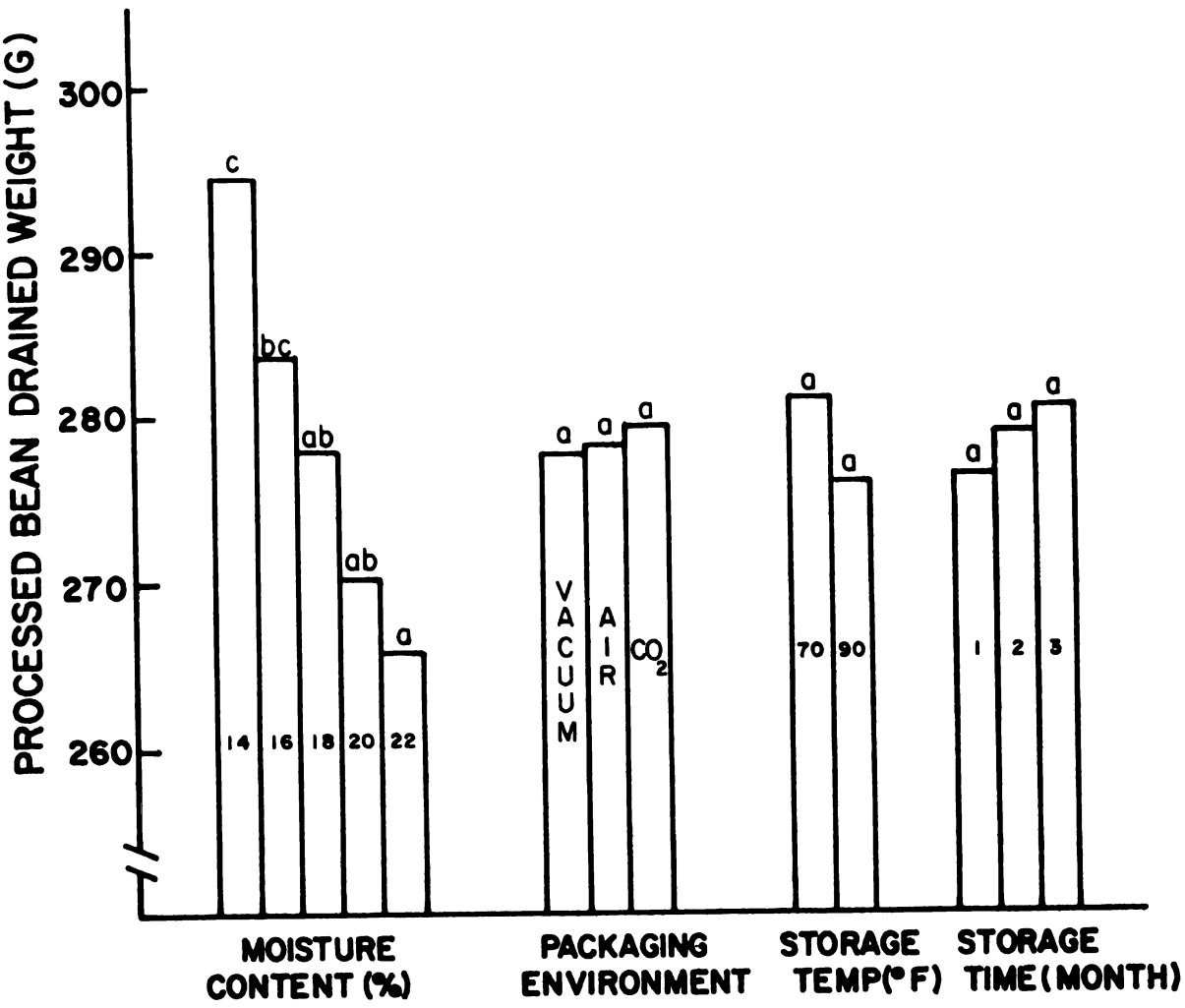

Figure 5. Overall main effect mean processed bean drained weight for beans dry stored at varying initial moisture content (14-22%) under selected packaging environments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

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firmer texture than commercial canned beans used as a standard in the quality evaluation of which shear resistance was 132 g/100g with 284 g drained weight.

There was a significant variation in Kramer shear resistance of processed beans among moisture levels and between storage temperatures. Dry beans stored under these conditions had significantly higher shear resistance than beans stored under low moisture and temperature conditions (Figure 6). These results agree with numerous previous studies which reported longer cooking time for beans stored at high moisture and temperature levels.

The hydration of beans during soaking and processing does not affect texture per se. The correlation coefficient of drained weight and shear in this experiment was not significant. Hosfield and Uebersax (1979) reported no association between soak water uptake properties and textural differences among tropical bean genotypes. Molina et al. (1975) and Burr et al. (1968) obtained the same result. However, water uptake may be associated with other factors affecting texture, including changes in protein and other constituents during storage which influenced the amount of absorbed water. Morris (1963) stated that changes in the cotyledons not the seedcoat were responsible for most of the changes in cookability of high moisture beans.

No significant differences for shear resistance of processed beans were shown among packaging environments.

Shear resistance of processed beans increased with storage time. The relationship between shear and time was linearly significant (Table 3). The results agree with the previous literature which indicated that stored beans required long cooking time to obtain the desired tenderness.

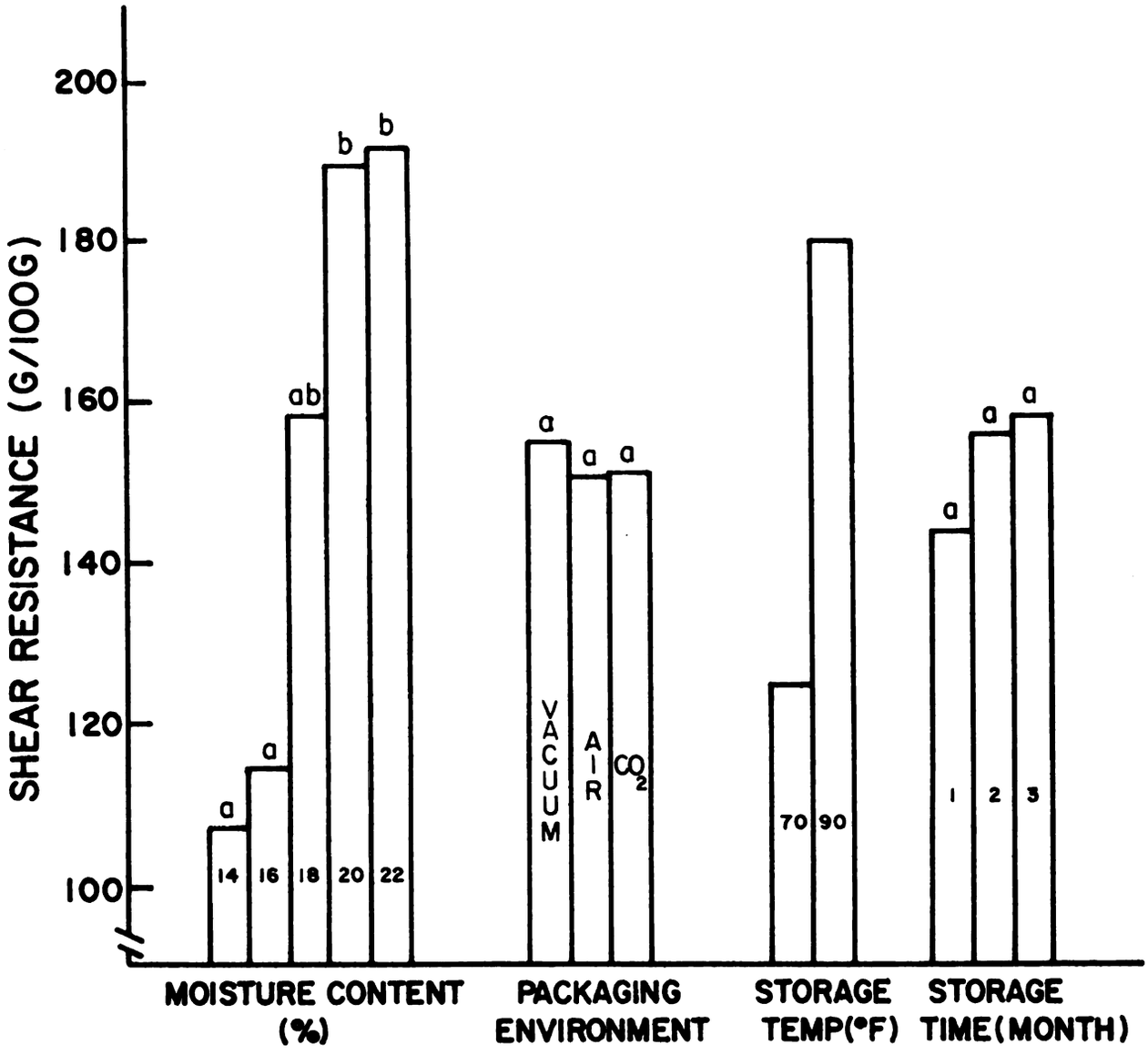

Figure 6. Overall main effect mean shear resistance for beans dry stored at varying initial moisture content (14-22%) under selected packaging environments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

Bean discoloration increased remarkedly during storage and processing. Beans prior to storage had Hunter values of L (lightness) 65.3, a_L (red) -0.3 and b_L (yellow) +12.2. After dry storage these values were 60.0, +1.0 and +11.0, respectively. They changed again after processing. Processed bean Hunter values were L = 48.0, a_L = +11.0 and b_L = +15.0. These changes indicate increase in browning during dry storage which is further increased during canning process. It was observed that discolored beans possessed firmer texture, decreased levels of splits with more whole beans than acceptable colored beans.

Color difference was noted among moisture levels. For dry bean color, Hunter L value decreased while a_L and b_L values increased significantly as been moisture content before storage increased (Figures 7 through 9). Processed beans also showed a slight reduction in L value, and increase in a_L and b_L values.

Dry beans stored at 90°F were darker in color than those stored at 70°F. Changes in Hunter L, a_L and b_L values shown at elevated temperature were similar to those observed for increased initial moisture content.

Brown color of beans increased with increase in storage time. Changes in Hunter L, a_L and b_L values were similar to those shown for moisture and temperature effects. Significant differences in Hunter L, a_L and b_L values were only shown in the dry beans and not for processed beans. There were no significant differences among packaging environments for Hunter L, a_L and b_L values.

Dry bean moisture was significantly correlated to soaked (r = 0.31**) and processed (r = -0.33**) bean moisture. Soaked bean moisture


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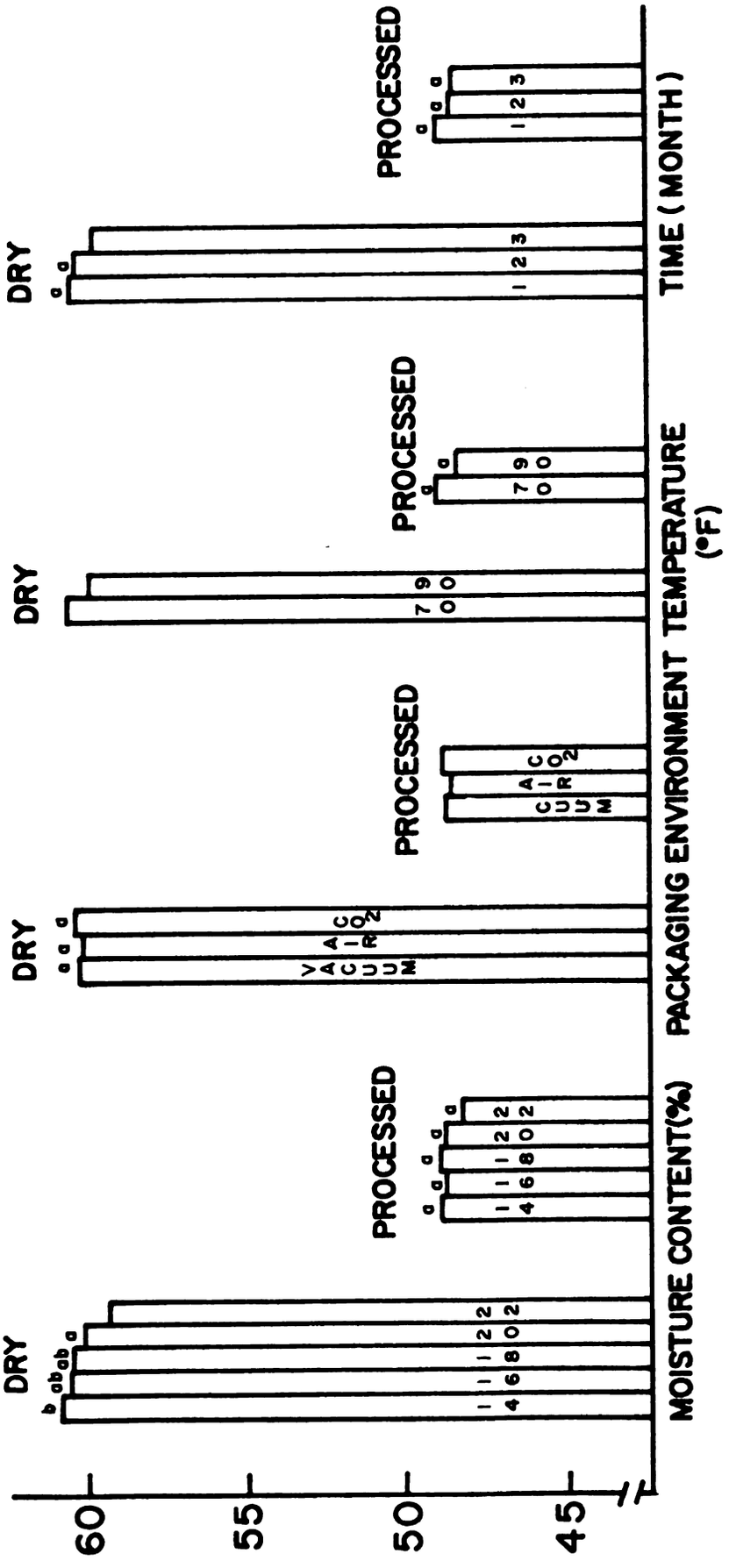

Figure 7. Overall main effect mean Hunter L value for dry and processed beans dry stored at varying initial moisture content (14-22%) under selected packaging environments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

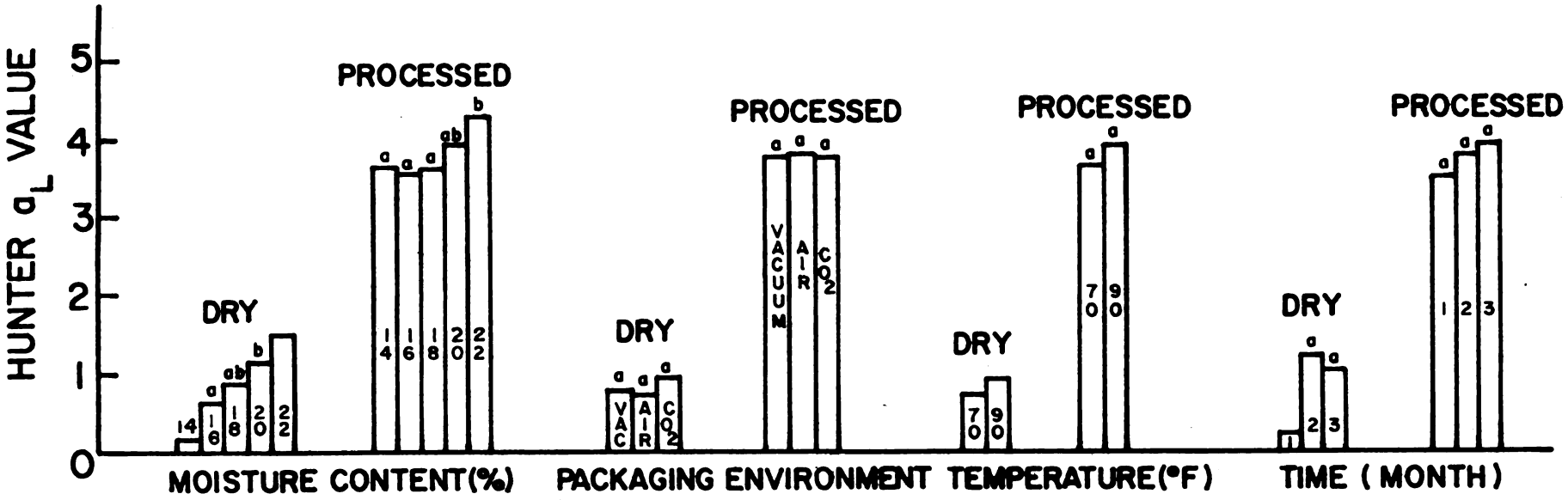

Figure 8. Overall main effect mean Hunter a_L value for dry and processed beans stored at varying initial moisture content (14-22%) under selected packaging environments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

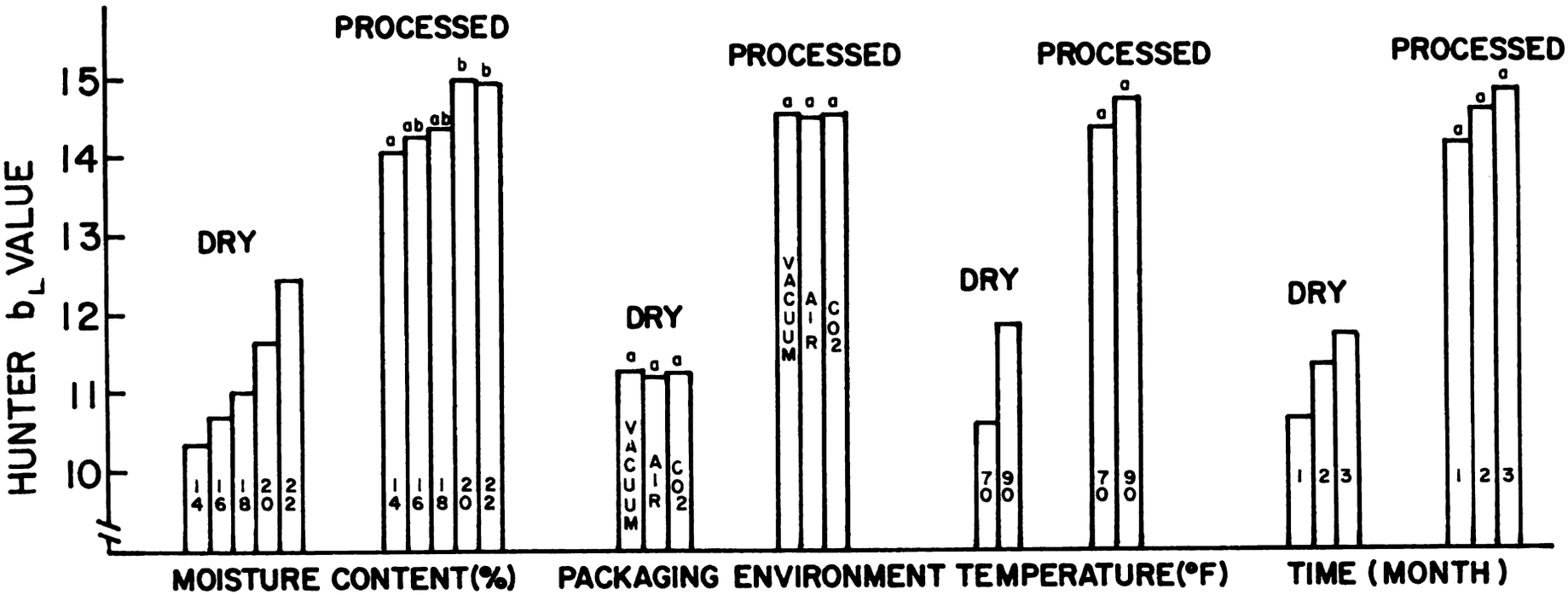

Figure 9. Overall main effect mean Hunter b_L value for dry and processed beans dry stored at varying initial moisture content (14-22%) under selected packaging environments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

was significantly correlated to processed bean drained weight (r = 0.40**) and shear resistance (r = -0.33**). Hunter L and a_L values were significantly correlated for both dry (r = -0.38**) and processed (r = -0.36**) beans. Hunter a_L and b_L values were significantly correlated for both dry (r = 0.22*) and processed (r = 0.39**) beans.

Bean moisture content, storage temperature and time resulted in greatest changes in bean color, texture and water uptake. Non-enzymatic browning may be implicated in causing these changes due to accelerated rates at increased moisture and temperature levels. Vacuum and CO_2 packaging environments were selected to provide reduced oxygen tension. However, these environments did not provide significant control of bean browning. The gas permeability of the Mylar® film may not have been sifficient to maximize the effect of these treatments during storage.

Sensory Evaluation. Examination of dry beans following storage indicated that darkening and molding occurred for high moisture samples.

Visual examination of beans during drained weight procedure indicated that all processed beans in this study were larger in size, more elongated in shape and contain less free starch in sauce and less clumping than the commercial sample used for comparison.

Sensory scores for processed bean quality attributes are summarized in Table 4. The analysis of variance, Tukey's HSD for these data are presented in Table 5.

High moisture beans (20%) were judged to be significantly darker in color and significantly more firm in texture than low moisture beans (16%) (Table 6). The scores for flavor and acceptability were not significantly different.

Table 4. Mean sensory scores for processed bean quality attributes dry stored under different packaging environments for selected bean moisture content at 70° and 90°F for up to 3 months prior to processing.[1]

Bean Moisture	Attributes			
	Color[2]	Flavor[3]	Texture[4]	Acceptability[5]
		70°F		
		Vacuum		
16	2.75±1.14	3.75±1.54	2.42±1.24	4.00±2.00
20	4.17± .83	3.75±1.06	2.83±1.34	4.75±1.36
		Air		
16	3.17± .94	4.00±1.71	4.00± .95	5.33±1.23
20	3.33± .89	3.92±1.24	4.17±1.03	4.75±1.14
		CO2		
16	2.75±1.36	3.75±1.96	2.83±1.34	4.50±1.62
20	4.58±1.00	3.91±1.51	4.17± .83	4.00±1.60
		90°F		
		Vacuum		
16	3.92±1.08	4.58±1.31	4.08±1.08	4.83±1.19
20	4.83± .83	4.08±1.62	5.33± .65	3.75±1.96
		Air		
16	3.17±1.19	4.33±1.78	3.50±1.51	5.17±1.40
20	3.75±1.29	3.67± .89	4.58±1.31	5.00±1.21
		CO2		
16	3.92±1.24	3.75±1.22	4.08±1.38	4.33±1.50
20	5.08± .90	3.91±1.56	5.58±1.08	3.58±1.93

[1]Mean values and standard deviation from 12 panelists.

[2]Seven = very dark (brown).

[3]Seven = very strong.

[4]Seven = very firm/dense.

[5]Seven = very acceptable.

Table 5. Analysis of variance of sensory scores for processed bean quality attributes dry stored under different packaging environments for selected bean moisture content at 70° and 90°F for up to 3 months prior to processing.

Source of Variation	df	Attributes			
		Color	Flavor	Texture	Acceptability
			Mean Squares		
Main Effects					
Treat(Tr)	2	7.01**	.55	1.22	12.02**
Temp(Tp)	1	13.34***	1.56	36.00***	.44
Moist(M)	1	37.01***	.84	42.25***	5.44
Two-Way					
Tr x Tp	2	1.80	1.27	10.19***	.34
Tr x M	2	4.01*	.97	2.02	.63
Tp x M	1	.56	1.17	1.36	2.78
Three-Way					
Tr x Tp x M	2	1.02	.30	.63	4.01
Residual	132	1.15	2.19	1.40	2.37
			Tukey's HSD		
Treatment		1.03	1.42	1.13	1.47
Temperature		.86	1.18	.95	1.23
Moisture		.86	1.18	.95	1.23
% CV		28.33	37.43	29.32	34.24

Table 6. Sensory scores under main effects of packaging environments, storage temperature and bean moisture for processed bean quality attributes after 3 month storage.[1]

Main Effects	Attributes			
	Color[2]	Flavor[3]	Texture[4]	Acceptability[5]
Packaging Environment				
Air	3.35[a]	3.98[a]	4.06[a]	5.06[a]
Vacuum	3.92[a]	4.04[a]	3.85[a]	4.33[a]
CO_2	4.08[a]	3.83[a]	4.17[a]	4.10[a]
Temperature				
70°F	3.46[a]	3.85[a]	3.53	4.56[a]
90°F	4.11[a]	4.06[a]	4.53	4.44[a]
Moisture				
16%	3.28	4.03[a]	3.49	4.69[a]
20%	4.29	3.88[a]	4.57	4.31[a]

[1]Mean values from 12 panelists.

[2]Seven = very dark (brown).

[3]Seven = very strong.

[4]Seven = very firm/dense.

[5]Seven = very acceptable.

Chemical Treatment Study

Mean values of dry and processed bean characters following treatment with SO_2 and Grain Treet® prior to storage at varying bean moisture and temperature conditions are summarized in Table 7. The analysis of variance, Tukey's HSD and coefficient of variability of data are presented in Table 8. Response to bean moisture and storage time treatment are shown in Table 9.

Moisture levels selected for this study were higher than those practical for dry storage of beans due to the development of the excessive mold and discoloration. The chemical treatments were applied to these high moisture beans in an attempt to control these deteriorative reactions.

Initial dry bean moisture content prior to storage ranged from 18-22% and bean moisture following storage was 18%. Soaked bean moisture was 53% and processed bean moisture was 68%. These data were similar to those reported in the packaging environment study (Figure 10). Significant differences were shown in the processed but not in the soaked bean moisture. These data indicate that beans with high moisture lose water absorption capacity during storage, possibly attributable to changes in protein/starch matrix of the cotyledons.

The application of Grain Treet® resulted in significantly lower moisture contents for dry, soaked, and processed beans than SO_2 treated and control beans (Figure 11). This suggests that the organic acids of Grain Treet® suppressed water uptake capacity of beans. Increased storage temperature and time prior to processing also reduced the final processed bean moisture content (Figures 12 and 13).

Table 7. Dry and processed navy bean characteristics dry stored at varying moisture content under selected chemical treatments and at 70° and 90°F for up to 3 months prior to processing.[1]

Time month	% Initial Bean Moisture 18	20	22
Dry Bean Moisture (%)			
		70°F	
		Control (Air)	
1	17.60± .00	19.60± .14	21.40± .00
2	17.30± .14	19.25± .07	20.90± .00
3	17.20± .14	19.00± .00	20.40± .00
		Grain Treet ®	
1	17.40± .00	19.15± .21	20.85± .07
2	17.05± .07	18.80± .14	20.10± .14
3	16.70± .00	18.55± .07	19.80± .28
		SO2	
1	17.80± .14	19.75± .07	21.30± .14
2	17.55± .07	19.25± .07	21.25± .07
3	16.65± .78	19.20± .00	20.75± .21
		90°F	
		Control (Air)	
1	17.40± .14	19.20± .00	20.90± .14
2	16.50± .00	18.30± .14	20.10± .00
3	15.60± .00	17.70± .00	18.60± .00
		Grain Treet ®	
1	16.90± .00	18.80± .14	20.25± .07
2	15.95± .07	17.95± .21	19.40± .14
3	15.40± .14	17.20± .28	18.40± .00
		SO2	
1	17.45± .07	19.30± .00	21.05± .07
2	16.75± .21	18.70± .14	20.10± .00
3	15.35± .35	17.90± .14	10.05± .07

Table 7. (cont'd.)

Time month	% Initial Bean Moisture 18	20	22
Soaked Bean Moisture (%)			
		70°F	
		Control (Air)	
1	53.15± .07	52.90± .57	52.70± .28
2	53.95± .49	53.75± .49	53.65± .35
3	54.45± .35	54.55± .07	53.70± .14
		Grain Treet®	
1	51.40± .14	51.95± .07	51.15± .07
2	53.05± .21	53.30± .42	52.80± .14
3	53.10± .14	53.50± .14	52.40± .28
		SO_2	
1	53.15± .49	53.05± .21	52.45± .35
2	53.65± .35	53.20± .28	53.25± .35
3	54.50± .00	54.50± .14	53.85± .21
		90°F	
		Control (Air)	
1	52.90±1.13	52.85± .07	52.45± .35
2	53.20± .14	54.00± .70	53.80± .14
3	54.25± .49	53.85± .35	53.45± .21
		Grain Treet®	
1	51.65± .21	51.65± .21	50.70± .00
2	53.10± .28	53.15± .07	52.55± .07
3	52.70± .42	52.95± .07	52.45± .21
		SO_2	
1	53.00± .14	52.55± .35	52.45± .21
2	53.40± .57	53.80± .28	53.70± .00
3	53.80± .42	53.85± .07	53.30± .71

Table 7. (cont'd.)

Time month	% Initial Bean Moisture 18	20	22
Processed Bean Moisture (%)			
		70°F	
		Control (Air)	
1	71.09±1.08	71.23± .11	70.45± .07
2	69.60± .00	69.55± .35	69.05± .14
3	69.48± .32	68.46± .22	68.05± .35
		Grain Treet®	
1	69.63± .18	69.38± .46	68.83± .25
2	68.35± .28	68.28± .25	67.63± .11
3	67.98±1.10	68.13± .18	67.80± .42
		SO_2	
1	71.23± .04	70.90± .14	70.68± .11
2	69.65± .28	69.08± .46	68.63± .32
3	69.40± .28	68.63± .11	68.10± .14
		90°F	
		Control (Air)	
1	70.38± .25	70.00± .00	69.40± .21
2	68.23± .18	67.95± .07	67.18± .32
3	67.53± .11	66.73± .11	66.30± .35
		Grain Treet®	
1	69.00± .42	68.05± .14	69.43± .67
2	66.85± .14	66.95± .21	67.18± .18
3	67.18± .39	66.40± .00	66.43± .39
		SO_2	
1	70.55± .21	69.08± .17	69.43± .67
2	68.53± .25	67.78± .11	67.18± .18
3	67.77± .18	66.85± .07	66.43± .39

Table 7. (cont'd.)

Time month	% Initial Bean Moisture 18	20	22
Processed Bean Drain Weight (g)			
		70°F	
		Control (Air)	
1	300.5± .0	294.8± .0	289.1±4.0
2	283.5± .0	280.7± .0	277.8± .0
3	293.5±2.1	284.8± .7	275.5± .7
		Grain Treet ®	
1	287.7±2.0	282.0±6.0	279.2±2.0
2	276.4±1.9	269.3± .0	265.1±1.9
3	281.3± .8	275.5± .7	264.9±1.7
		SO_2	
1	296.2±2.0	290.6±1.9	287.7±2.0
2	287.7±2.0	282.1±1.9	280.7± .0
3	286.4± .1	281.1± .6	276.0±1.4
		90°F	
		Control (Air)	
1	286.3± .0	286.3± .0	279.2±2.0
2	276.4±1.9	272.2± .0	265.1±1.9
3	273.0±2.8	267.0± .0	258.8±1.2
		Grain Treet ®	
1	277.8±4.0	275.0± .0	266.5± .0
2	263.6±4.0	262.2±2.0	256.6±1.9
3	268.1±2.3	258.3± .4	251.6± .9
		SO_2	
1	290.6±1.9	284.9±1.9	277.8± .0
2	276.4±1.9	269.3± .0	265.1±1.9
3	273.9±2.4	266.8± .4	255.4±3.6

Table 7. (cont'd.)

Time month	% Initial Bean Moisture 18	20	22
Shear Resistance (g/100 g)			
		70°F	
		Control (Air)	
1	61.5± 2.9	67.1± 9.3	72.1± 4.0
2	103.3± 1.4	132.7± 5.3	120.9± 9.7
3	76.6±13.3	113.2±37.1	115.2±14.4
		Grain Treet®	
1	102.0± 2.5	132.0± 6.3	142.8±36.4
2	173.7± 2.5	167.4± 2.5	181.2±15.2
3	108.4± .6	134.8±12.5	146.8± 1.0
		SO_2	
1	74.1± 9.5	61.3± 6.5	104.7±21.2
2	151.8±62.4	113.7± 3.8	128.4±11.8
3	94.2±30.5	109.8±31.4	160.5± 7.2
		90°F	
		Control (Air)	
1	112.6±10.9	88.9± 5.7	127.2± 1.7
2	131.5± 0.2	219.6± .8	244.8±22.9
3	175.9± 8.7	231.0± 8.4	261.7±11.2
		Grain Treet®	
1	150.0±22.0	155.5± 4.8	201.4±21.8
2	281.4±11.4	257.4±26.3	275.1± 4.6
3	192.0± 8.4	228.9± 4.6	226.0± .6
		SO_2	
1	89.9± 3.1	86.2± 5.3	132.7±18.8
2	160.2± 4.2	213.3± 8.0	240.3± 8.0
3	188.8±12.5	235.3± 2.3	238.4± 4.1

Table 7. (cont'd.)

Time month	% Initial Bean Moisture 18	20	22
Hunter L Value of Dry Beans			
		70°F	
		Control (Air)	
1	61.0± .0	60.3± .1	59.5± .2
2	60.7± .1	59.4± .4	58.1± .2
3	60.7± .0	59.7± .2	58.7± .1
		Grain Treet®	
1	61.5± .2	60.8± .2	59.5± .0
2	60.8± .1	59.3± .4	58.0± .0
3	60.7± .2	60.1± .4	58.5± .2
		SO_2	
1	61.1± .0	60.8± .2	60.3± .1
2	60.7± .0	59.5± .0	58.8± .0
3	60.8± .2	60.5± .0	59.5± .0
		90°F	
		Control (Air)	
1	60.5± .0	59.9± .1	58.6± .0
2	59.7± .2	58.3± .1	56.2± .2
3	59.6± .2	57.9± .0	55.0± .0
		Grain Treet®	
1	60.4± .3	59.7± .0	58.1± .1
2	59.2± .1	56.8± .2	54.2± .2
3	58.2± .3	55.7± .1	52.0± .1
		SO_2	
1	61.0± .4	60.4± .0	59.7± .0
2	59.9± .0	58.4± .0	56.6± .2
3	59.8± .1	58.4± .0	55.0± .4

Table 7. (cont'd.)

Time month	% Initial Bean Moisture 18	20	22
Hunter a_L Value of Dry Beans			
		70°F	
		Control (Air)	
1	0.2± .0	0.4± .0	0.6± .0
2	0.3± .0	0.6± .0	1.0± .0
3	0.2± .1	0.3± .0	0.6± .0
		Grain Treet ®	
1	-0.2± .1	-0.1± .0	0.1± .0
2	0.1± .0	0.3± .0	0.6± .0
3	0.0± .0	0.1± .1	0.7± .0
		SO2	
1	0.3± .0	0.4± .0	0.5± .0
2	0.4± .1	0.7± .1	0.8± .0
3	0.3± .0	0.3± .0	0.5± .0
		90°F	
		Control (Air)	
1	0.5± .0	0.6± .0	1.1± .0
2	0.6± .0	0.9± .0	1.9± .0
3	0.3± .0	1.1± .0	2.0± .0
		Grain Treet ®	
1	0.2± .1	0.4± .0	1.0± .0
2	0.6± .0	1.3± .0	2.5± .0
3	0.8± .0	1.7± .0	2.4± .0
		SO2	
1	0.3± .0	0.6± .0	1.0± .0
2	0.5± .0	1.1± .0	1.9± .0
3	0.3± .0	1.1± .1	1.9± .3

Table 7. (cont'd.)

Time month	% Initial Bean Moisture 18	20	22
Hunter b_L Value of Dry Beans			
		70°F	
		Control (Air)	
1	10.2± .0	10.6± .1	11.1± .0
2	10.6± .0	11.1± .0	11.9± .1
3	10.7± .0	11.3± .0	12.6± .0
		Grain Treet®	
1	10.6± .0	10.9± .0	11.4± .0
2	11.2± .1	11.8± .0	12.7± .2
3	11.5± .2	12.6± .0	13.8± .0
		SO_2	
1	10.1± .0	10.3± .0	10.8± .0
2	10.5± .0	11.0± .1	11.7± .0
3	10.6± .1	11.1± .2	12.5± .0
		90°F	
		Control (Air)	
1	11.0± .0	11.5± .0	13.0± .0
2	11.8± .0	12.7± .0	14.5± .0
3	14.7± .0	14.0± .0	14.8± .0
		Grain Treet®	
1	11.9± .0	12.7± .1	13.9± .0
2	13.3± .0	14.2± .0	15.1± .0
3	14.2± .0	14.7± .0	14.9± .1
		SO_2	
1	10.7± .0	11.3± .0	12.9± .0
2	11.7± .0	12.8± .0	14.5± .0
3	12.4± .0	14.0± .0	14.9± .1

Table 7. (cont'd.)

Time month	% Initial Bean Moisture 18	20	22
Hunter L Value of Processed Beans			
		70°F	
		Control (Air)	
1	50.4±1.3	49.8± .2	49.3± .0
2	49.6± .0	49.1± .3	48.8± .0
3	48.7± .9	49.3± .1	48.1± .8
		Grain Treet ®	
1	50.2± .2	50.5± .3	49.3± .0
2	50.3± .2	49.3± .0	46.3± .2
3	49.4± .7	46.9±1.0	41.5± .4
		SO_2	
1	49.6± .0	49.8± .6	49.9± .8
2	49.5± .5	49.3± .0	49.1± .3
3	49.4± .4	49.2± .6	48.7± .7
		90°F	
		Control (Air)	
1	49.6± .2	48.9± .3	49.2± .3
2	49.6± .0	48.6± .0	46.7± .4
3	47.7±1.2	47.2± .0	41.0±1.6
		Grain Treet ®	
1	50.0± .2	47.8± .2	43.3± .2
2	47.0± .2	41.8± .3	36.1± .0
3	43.3± .9	35.4± .9	30.5± .7
		SO_2	
1	50.1± .0	49.8± .1	49.7± .5
2	49.4± .2	48.8± .0	46.2± .3
3	48.8± .8	46.3±1.0	38.7± .7

Table 7. (cont'd.)

Time month	% Initial Bean Moisture 18	20	22
Hunter a_L Value of Processed Beans			
		70°F	
		Control (Air)	
1	2.4± .3	2.8± .0	2.9± .0
2	3.3± .2	3.2± .1	3.7± .0
3	3.2± .6	3.5± .4	3.8± .5
		Grain Treet ®	
1	3.2± .3	3.1± .2	3.6± .0
2	3.1± .2	3.9± .0	5.4± .0
3	4.1± .8	5.5± .9	7.2± .9
		SO_2	
1	2.6± .0	2.5± .0	2.5± .4
2	3.2± .2	3.5± .0	3.3± .0
3	3.3± .3	3.7± .6	3.9± .7
		90°F	
		Control (Air)	
1	2.6± .3	2.8± .2	2.9± .0
2	2.8± .0	3.6± .0	4.5± .0
3	3.4± .4	4.6± .7	7.2±1.2
		Grain Treet ®	
1	3.3± .1	4.3± .0	6.2± .0
2	4.3± .1	6.7± .0	7.6± .0
3	6.3±1.0	8.1± .9	7.9± .7
		SO_2	
1	2.9± .1	2.7± .1	2.8± .1
2	3.1± .0	3.8± .0	5.0± .1
3	3.3± .6	5.1± .9	8.1± .4

Table 7. (cont'd.)

Time month	% Initial Bean Moisture 18	20	22
Hunter b_L Value of Processed Beans			
		70°F	
		Control (Air)	
1	15.1±1.1	15.0± .2	14.5± .4
2	15.5± .0	14.8± .0	14.3± .0
3	13.9± .1	14.6± .2	14.4± .1
		Grain Treet ®	
1	14.4± .0	14.9± .2	15.3± .0
2	15.1± .1	15.8± .1	15.9± .0
3	15.5± .3	16.1± .4	15.6± .7
		SO_2	
1	14.4± .2	13.8± .1	13.5± .4
2	14.8± .2	14.3± .0	13.9± .0
3	13.8± .0	14.4± .7	14.6± .4
		90°F	
		Control (Air)	
1	14.7± .0	14.3± .1	14.8± .1
2	15.3± .5	14.8± .0	15.5± .0
3	14.2± .0	15.6± .7	15.1± .4
		Grain Treet ®	
1	15.3± .0	16.2± .0	15.8± .1
2	15.8± .0	15.7± .1	13.5± .0
3	15.8± .4	13.8± .4	11.9± .2
		SO_2	
1	14.8± .0	14.4± .0	14.6±1.0
2	14.9± .1	15.0± .2	15.4± .1
3	14.3± .2	15.5± .4	14.6± .7

[1]Mean values and standard deviation (n = 2 replicate samples).

Table 8. Analysis of variance of dry and processed navy bean characteristics dry stored at varying moisture content under selected chemical treatments and at 70° and 90°F for up to 3 months prior to processing.

Source of Variation	df	Dry and Processed Bean Characteristics: Dry Bean Moisture (%)	Soaked Bean Moisture (%)	Processed Bean Moisture (%)	Drained Weight (g)	Shear Resistance (g/100 g)
				Mean Squares		
Main Effects						
Moist(M)	2	107.55***	2.44***	7.95***	1193.88***	13332.53***
Treat(Tr)	2	3.41***	13.42***	14.04***	1144.99***	20565.90***
Temp(Tp)	1	21.96***	1.14**	51.07***	3933.73***	147533.97***
Time(Tm)	2	14.26***	16.94***	46.80***	1988.66***	55637.68***
Two-Way						
M x Tr	4	.14***	.18	.26	2.35	645.70
M x Tp	2	.06	.05	.35	12.63*	1610.23**
M x Tm	4	.16***	.27	.14	40.51***	1111.33**
Tr x Tp	2	.01	.00	.13	5.57	589.58
Tr x Tm	4	.05	.64**	1.26***	20.02**	3677.52***
Tp x Tm	2	2.50***	.46*	.60*	120.56***	10327.34***
Three-Way						
MxTrxTp	4	.02	.09	.03	9.64	956.70**
MxTpxTm	4	.02	.18	.10	3.46	1081.50**
MxTrxTm	8	.09**	.07	.18	1.75	879.05**
TrxTpxTm	4	.02	.12	.09	15.74**	621.55
Four-Way						
MxTrxTpxTm	8	.04	.09	.10	8.30	457.65
Residual	54	.03	.12	.13	3.81	11.38
				Tukey's HSD		
Moisture		.39	.83	.87	4.71	38.84
Treatment		.39	.83	.87	4.71	38.84
Temperature		.33	.69	.73	3.92	32.31
Time		.39	.83	.87	4.71	38.84
% CV		.88	.65	.53	.71	10.48

Table 8. (cont'd.)

Source of Variation	df	Dry and Processed Bean Characteristics					
		Dry Bean Color[1]			Processed Bean Color[1]		
		L	a_L	b_L	L	a_L	b_L
		Mean Squares					
Main Effects							
Moist(M)	2	69.95***	6.78***	27.83***	141.01***	21.51***	1.06***
Treat(Tr)	2	9.06***	.03*	10.07***	146.78***	32.62***	3.71***
Temp(Tp)	1	92.78***	12.88***	95.20***	299.00***	32.45***	.51
Time(Tm)	2	34.65***	2.08***	23.13***	167.59***	36.60***	1.19***
Two-Way							
M x Tr	4	1.06***	.06***	.15***	24.48***	1.27***	.53**
M x Tp	2	7.21***	1.67***	1.04***	40.25***	4.28***	.32
M x Tm	4	3.14***	.28***	.30***	19.14***	2.33***	.47*
Tr x Tp	2	5.43***	.79***	.15***	68.29***	2.94***	3.37***
Tr x Tm	4	1.10***	.27***	.08***	21.08***	.82**	.51**
Tp x Tm	2	12.70***	.80***	1.44***	49.56***	3.38***	1.01**
Three-Way							
MxTrxTp	4	.19**	.02*	.36***	3.43***	.71*	2.61***
MxTpxTm	4	1.74***	.18***	.74***	4.56***	.30	.55**
MxTrxTm	8	.06	.01	.04***	1.95***	.53*	1.31***
TrxTpxTm	4	.57***	.02**	.25***	3.87***	.57*	2.79***
Four-Way							
MxTrxTpxTm	8	.06	.03***	.11***	2.83***	1.43***	.48**
Residual	54	.05	.01	.01	.34	.22	.14
		Tukey's HSD					
Moisture		.52	.20	.22	1.41	1.14	.90
Treatment		.52	.20	.22	1.41	1.14	.90
Temperature		.44	.16	.19	1.18	.95	.75
Time		.52	.20	.22	1.41	1.14	.90
% CV		.37	11.11	.75	1.24	11.41	2.51

[1]Hunter Value L, a_L, b_L.

Table 9. Response of dry bean moisture content and storage time intervals for beans stored at varying moisture under selected chemical treatments and at 70° and 90°F for up to 3 months prior to processing.[1]

Source of Variation	df	Range of Contrast: Dry Bean Moisture (%)	Soaked Bean Moisture (%)	Processed Bean Moisture (%)	Drained Weight (g)	Shear Resistance (g/100 g)
Moisture	2					
Linear	1	2.4 to 2.5	-.4 to - .2*	- .8 to - .5*	- 8.9 to -7.3*	20.4 to 34.0*
Quadratic	1	- .3 to - .1*	-.4 to - .0*	- .1 to .2*	- 1.2 to .5	- 5.6 to 7.9
Time	2					
Linear	1	-1.0 to - .8*	.8 to 1.0*	-1.7 to -1.4*	-10.3 to -8.6*	39.6 to 49.0*
Quadratic	1	- .1 to .1	-.5 to - .2*	.3 to .6*	3.8 to 8.4*	-42.9 to -29.4*

[1]Scheffe's Contrast $(\hat{\Psi}) \pm \sqrt{(t-1)(F_{.05;t-1,\nu})}$ standard error$_{(\hat{\Psi})}$.

*Significant at 5% level.

Table 9. (cont'd.)

Source of Variation	df	Range of Contrast					
		Dry Bean Color			Processed Bean Color		
		Hunter L	Hunter a_L	Hunter b_L	Hunter L	Hunter a_L	Hunter b_L
Moisture	2						
Linear	1	-2.1 to -1.9*	.5 to .6*	1.2 to 1.3*	-3.0 to -2.5*	.9 to 1.3*	-.3 to -.1*
Quadratic	1	- .3 to - .1*	.0 to .1*	.0 to .2*	- .7 to - .2*	- .2 to .2	-.3 to -.1*
Time	2						
Linear	1	-1.4 to -1.2*	.2 to .3*	1.1 to 1.2*	-3.3 to -2.8*	1.2 to 1.6*	-.2 to .0
Quadratic	1	.5 to .7*	-.3 to -.2*	- .2 to - .1*	- .6 to - .1*	- .2 to .2	-.4 to -.1*

[1]Scheffe's Contrast $(\hat{\Psi}) \pm \sqrt{(t-1)(F_{.05;t-1,\nu})}$ standard error$_{(\hat{\Psi})}$.

*Significant at 5% level.

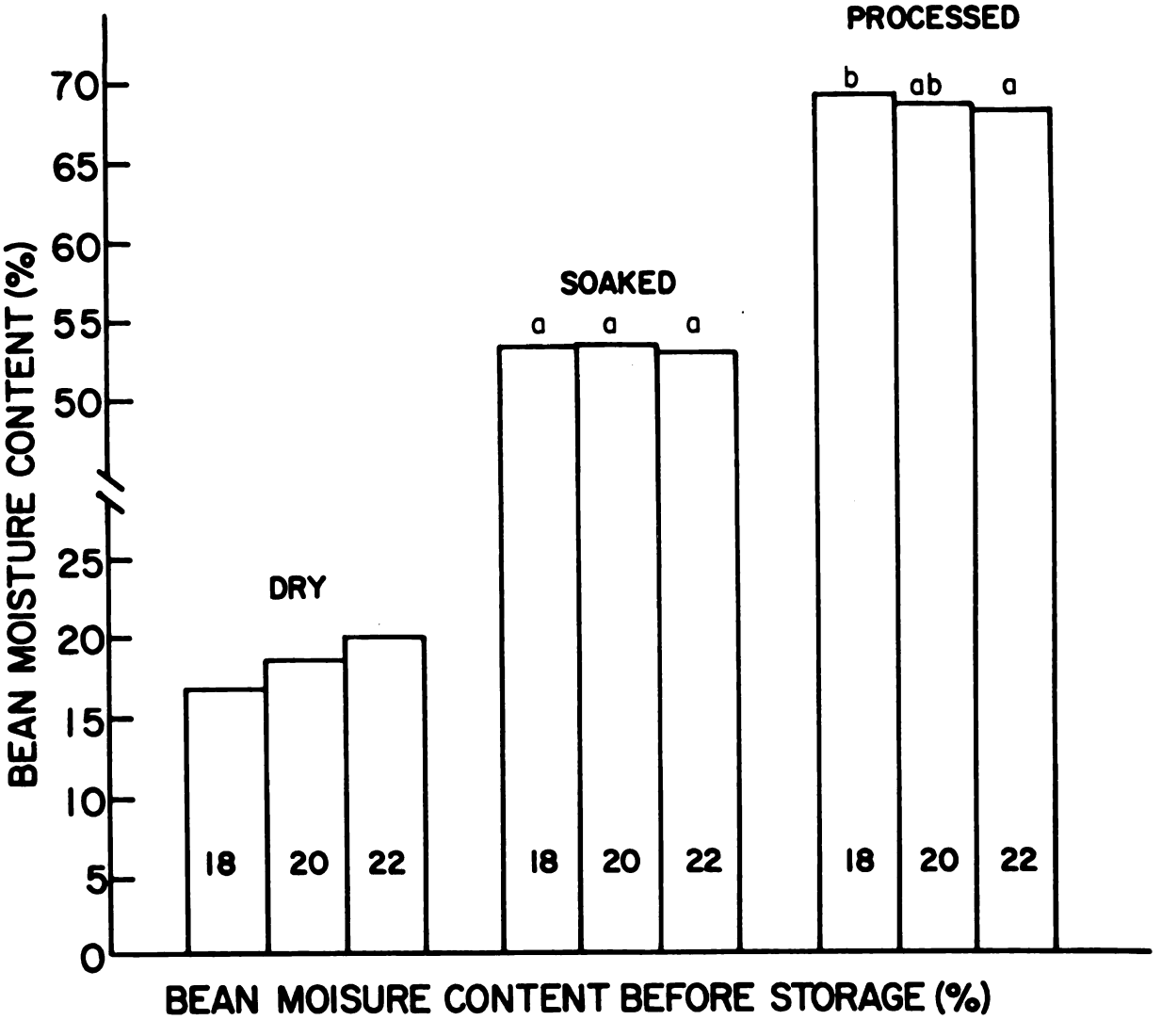

Figure 10. Mean moisture contents (over chemical treatment, storage temperature and time) for beans dry stored at varying initial moisture content (18-22%) under chemical treatments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

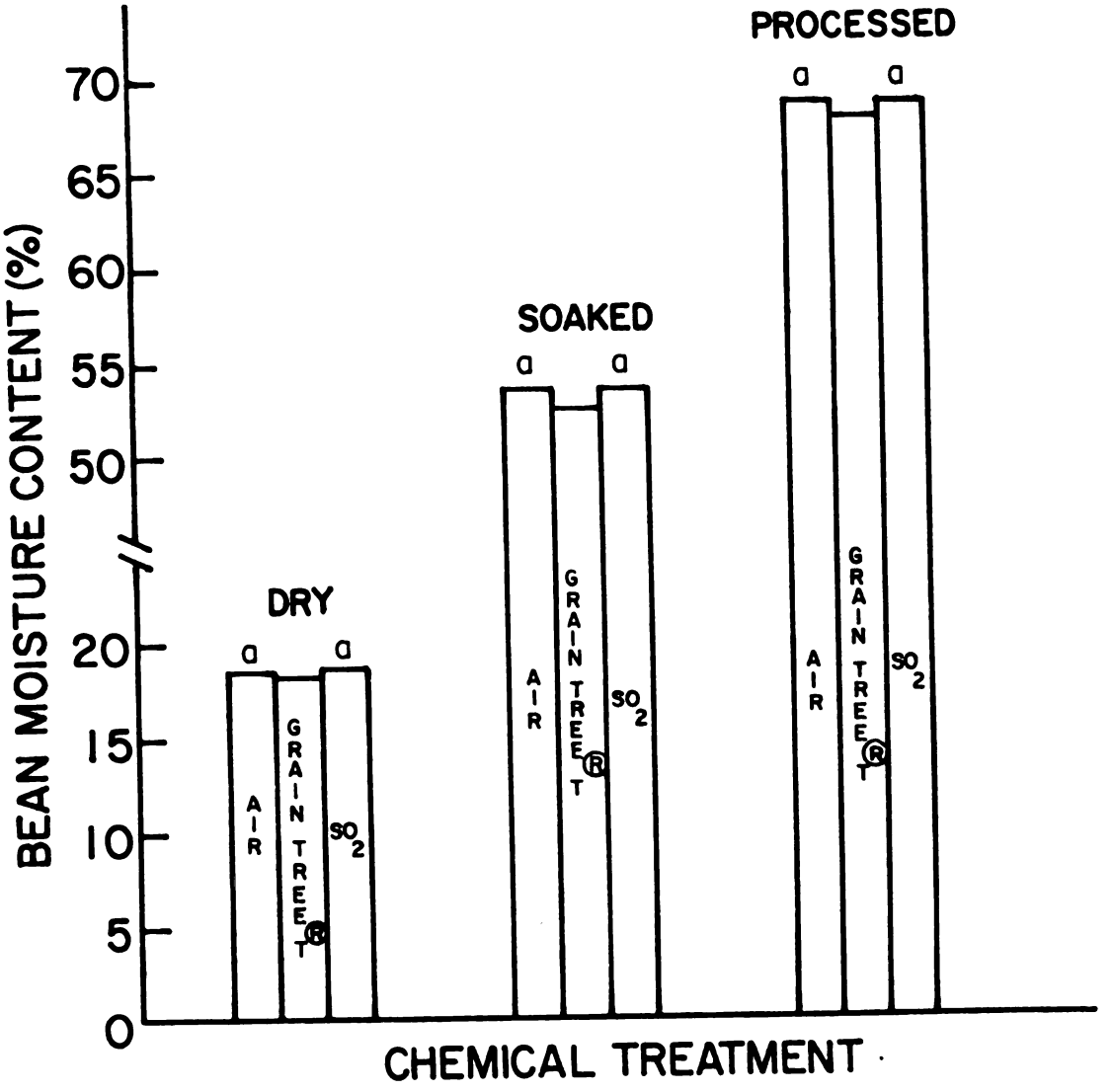

Figure 11. Mean moisture contents (over bean moisture, storage temperature and time) for beans dry stored at varying initial moisture content (18-22%) under chemical treatments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

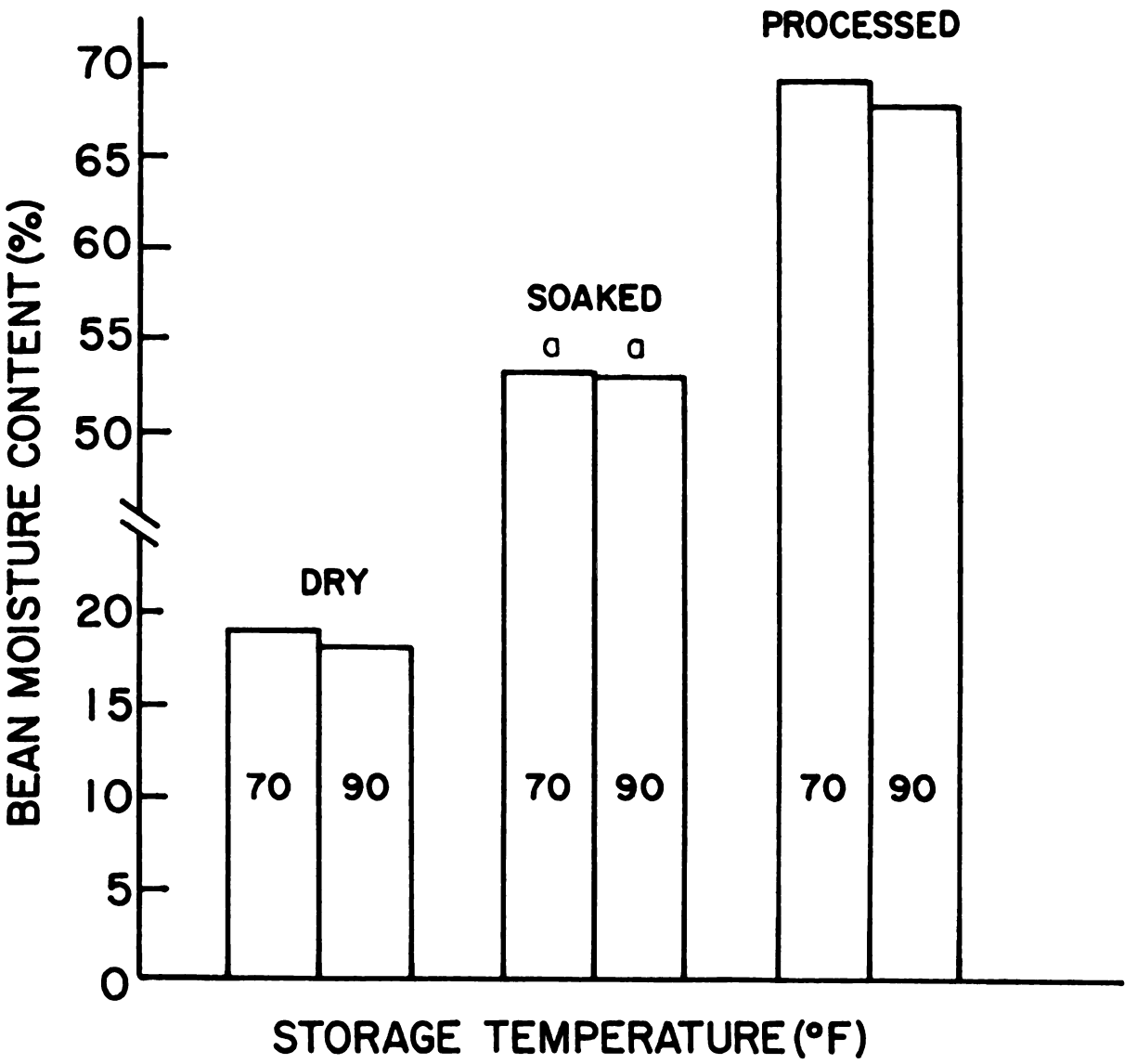

Figure 12. Mean moisture contents (over bean moisture, chemical treatment and storage time) for beans dry stored at varying initial moisture content (18-22%) under chemical treatments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

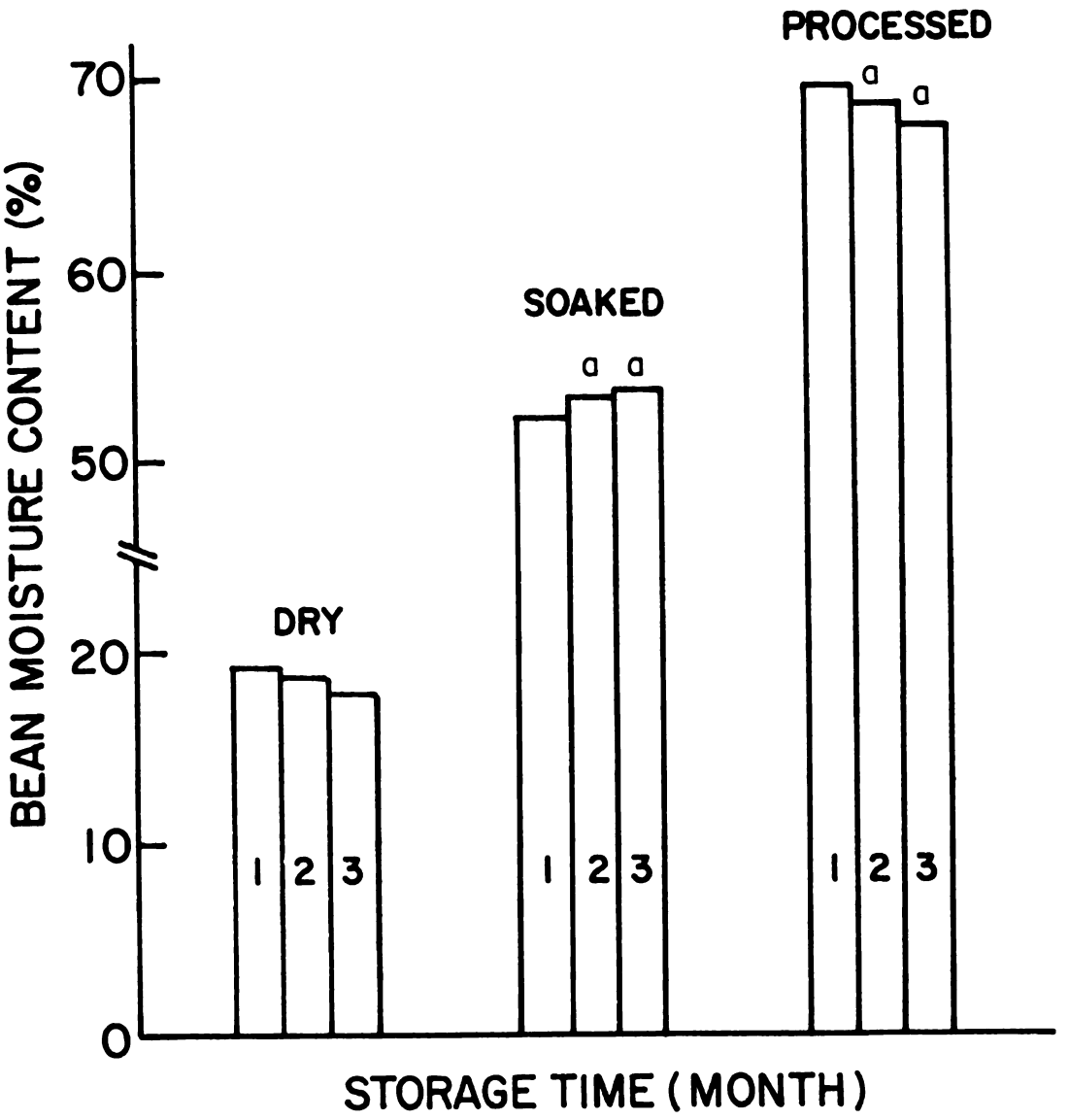

Figure 13. Mean moisture contents (over bean moisture, chemical treatment and storage temperature) for beans dry stored at varying initial moisture content (18-22%) under chemical treatments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

Dramatic decreases in drained weight were shown for increased initial dry bean moisture, increased storage temperature and time (Figure 14). No significant differences were shown between air-packaged (control) and SO_2 treated beans. The drained weight of beans treated with Grain Treet® was significantly lower than other treatments, further implicating organic acid suppression of water holding capacity.

Shear resistance was 154 g/100 g with a 277 g drained weight in average. Significant differences in shear resistance were shown with increased initial dry bean moisture, storage temperature and time (Figure 15). These data are similar in relationship and magnitude to data obtained in the packaging environment study.

The shear resistance of beans treated with Grain Treet® was significantly higher than that of control but not significantly higher than SO_2 treated beans. Nordstrom and Sistrunk (1977) reported lower drained weight and higher shear resistance of beans canned in tomato sauce than those canned in salt brine and stated that organic acids tended to produce insoluble complexes with the amylose components of starch, making rigid and low soluble starch helices. In addition, the acidity reduced the water imbibition of starch and protein.

No significant differences were shown in shear resistance between SO_2 treated and air-packaged (control) beans.

Beans prior to storage had Hunter values of L 65.3, a_L -0.3 and b_L +12.2. Following dry storage and processing the L, a_L, and b_L values were 59, +1 and +12, and 47, +4 and +15, respectively. Bean darkening increased during storage and processing. Decreased Hunter L and increased Hunter a_L and b_L values were shown in both dry and processed beans held at increased moisture, temperature and time (Figures 16 through 18).

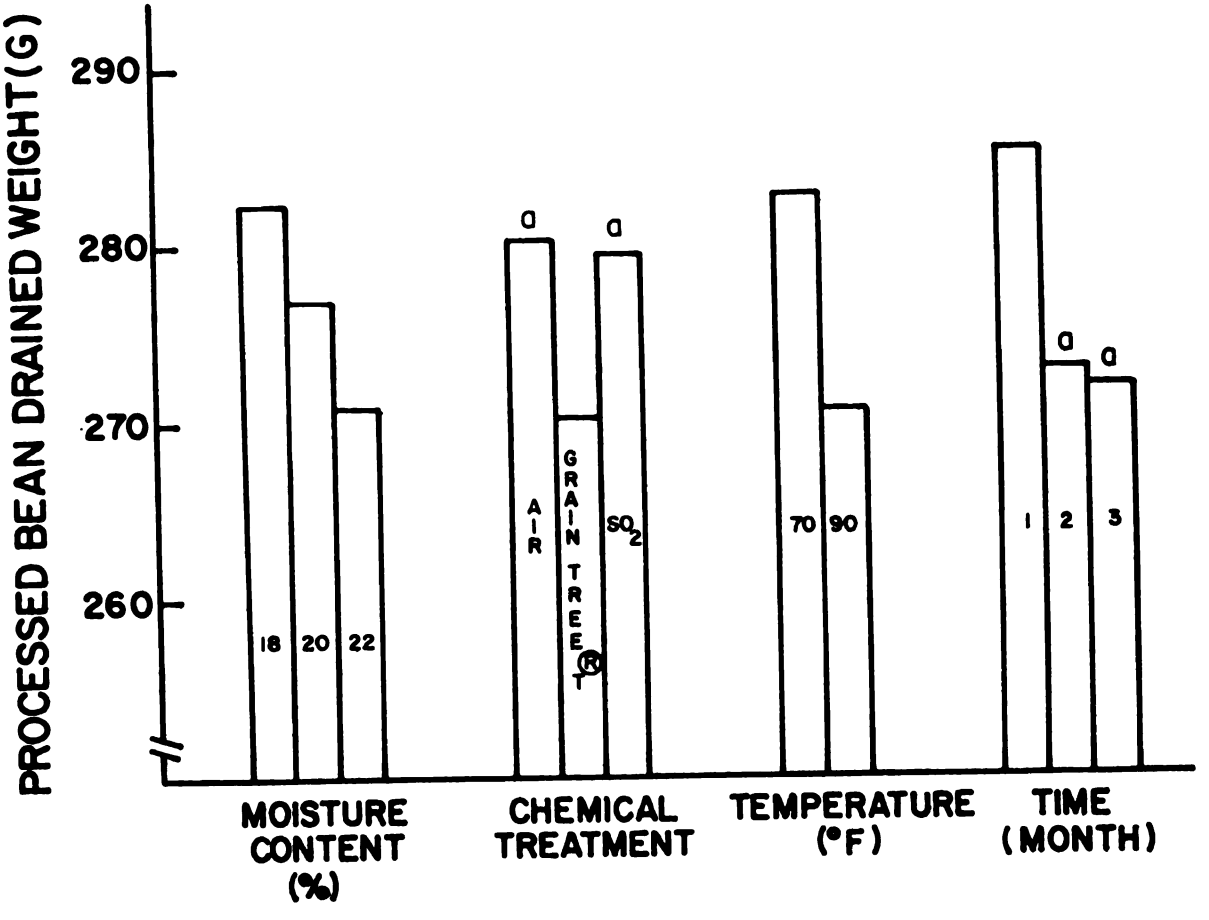

Figure 14. Overall main effect mean processed bean drained weight for beans dry stored at varying initial moisture content (18-22%) under chemical treatments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

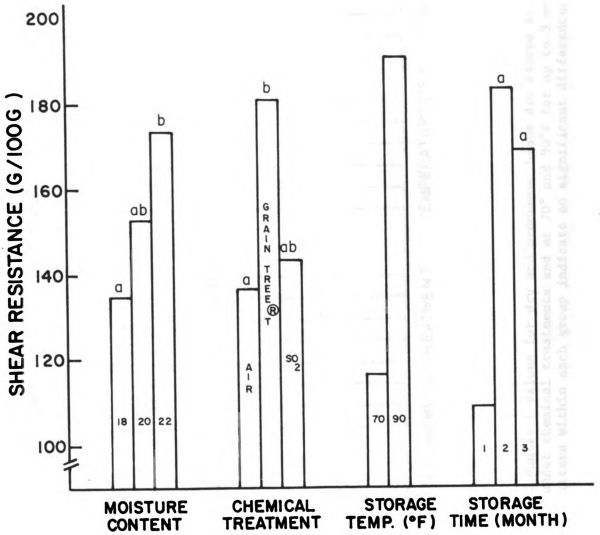

Figure 15. Overall main effect mean shear resistance for beans dry stored at varying initial moisture content (18-22%) under chemical treatments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

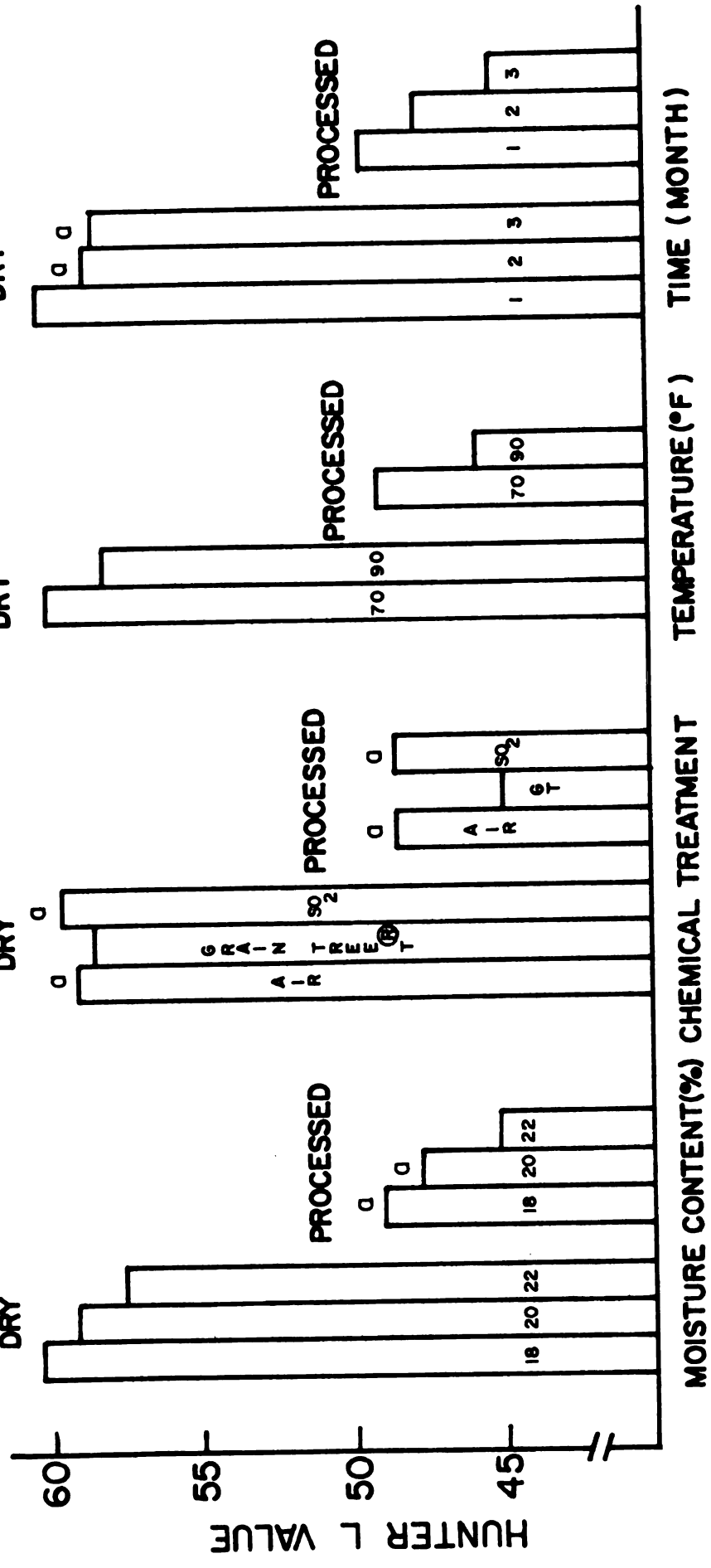

Figure 16. Overall main effect Hunter L values for dry and processed beans dry stored at varying initial moisture (18-22%) under chemical treatments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

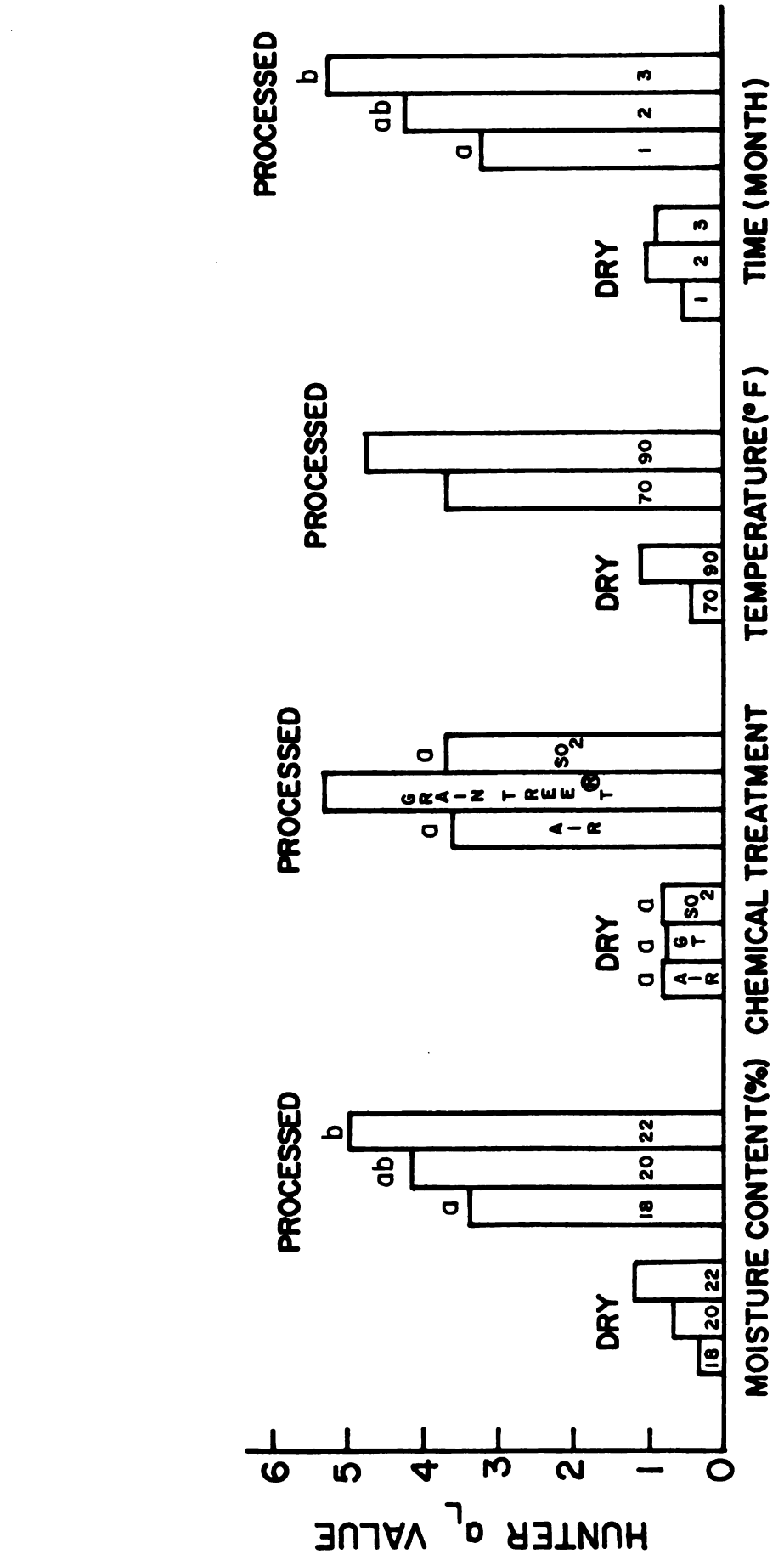

Figure 17. Overall main effect Hunter a_L values for dry and processed beans dry stored at varying intial moisture content (18-22%) under chemical treatments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

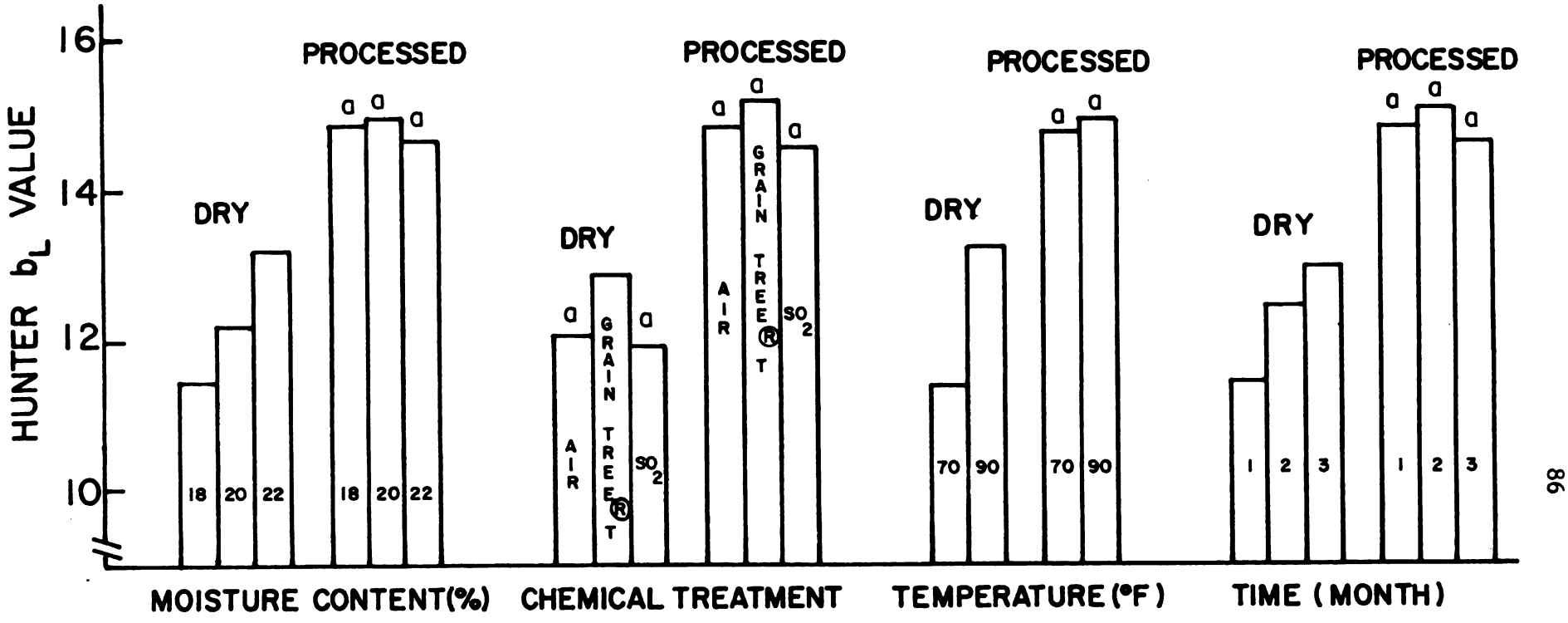

Figure 18. Overall main effect Hunter b_L values for dry and processed beans dry stored at varying initial moisture (18-22%) under chemical treatments and at 70° and 90°F for up to 3 months prior to processing (like letters within each group indicate no significant differences).

Sulfur dioxide provided good retention of bean color. Beans treated with SO_2 and stored at 70°F were whiter than all other treatments, however, no control of discoloration was attained for SO_2 treated beans stored at 90°F. The overall Hunter values of SO_2 treated and air-packaged (control) beans were not significantly different. In contrast, browning of beans treated with Grain Treet® was obviously recognized in both dry and processed samples.

Hunter L and a_L values were significantly correlated for both dry ($r = -0.35^{**}$) and processed ($r = -0.84^{**}$) beans. In processed beans, significant correlations were shown between Hunter L and b_L values ($r = -0.35^{*}$) and between Hunter a_L and b_L values ($r = 0.56^{**}$).

The effects of initial dry bean moisture content, storage temperature, and time in increasing darkening and hardening and decreasing water uptake capacity of stored beans were observed in this study as in the packaging environment study. Changes of bean cotyledonary constituents from nonenzymatic browning reaction may be associated with these quality alterations.

In this study, SO_2 treatments gave beans with comparable quality attributes to control in addition to improved color retention at low storage temperature. The application of Grain Treet® was undertaken to aid in control of mold growth quality deterioration of high moisture beans in a manner similar to its application in high moisture soybeans. This treatment was not effective in stabilizing quality deterioration of navy beans due to increased firmness and increased discoloration as compared to untreated beans. Further work is necessary to elucidate the mechanism for this increased quality loss.

Sensory Evaluation. Visual examination of dry beans following storage indicated that high moisture beans were darker and molded. Beans treated with Grain Treet® had strong acidic odor, obvious browning with yellow spots and limited mold mycelium.

Processed beans were examined during the drained weight procedure. Grain Treet® resulted in fewer splits and cracks and strong acidic odor than both control and SO_2. Sulfur dioxide treatment resulted in whiter processed beans than control.

Sensory scores for processed bean quality attributes are summarized in Table 10. The analysis of variance, Tukey's HSD for these data are presented in Table 11.

No significant differences were shown in bean flavor, texture and acceptability for all conditions tested in this evaluation (Table 12). Twenty-two percent moisture beans were judged significantly darker than other moisture levels. Beans stored at 90°F were darker than those stored at 70°F. Grain Treet® beans were significantly darker than control. No significant differences were shown in color between SO_2 and control.

Long-Term Storage Study

Mean values of dry and processed bean characteristics following dry storage in cans at various initial moisture and storage temperature are summarized in Table 13. The analysis of variance, Tukey's HSD and coefficient of variability of data are presented in Table 14. Response to bean moisture and storage temperature treatment are shown in Table 15.

Table 10. Mean sensory scores for processed bean quality attributes dry stored under different chemical treatments at varying moisture and at 70° and 90°F for up to 3 months prior to processing.[1]

Bean Moisture	Attributes			
	Color[2]	Flavor[3]	Texture[4]	Acceptability[5]
			70°F	
			Control (Air)	
18	4.25±1.14	4.08±1.44	3.75±1.42	5.00±1.28
20	3.33± .89	3.92±1.24	4.17±1.03	4.75±1.14
22	4.25±1.54	3.83±1.85	5.42±1.08	4.67±1.61
			Grain Treet ®	
18	3.50±1.24	4.58±1.24	4.42± .67	5.33±1.15
20	5.25± .75	4.42±1.24	4.58±1.51	4.17±1.85
22	6.58± .67	5.33±1.87	5.08±1.24	2.42±1.88
			SO_2	
18	4.33±1.23	4.00±1.60	3.75±1.66	4.67±1.61
20	4.33±1.07	4.58±1.51	4.17±1.53	4.83±1.64
22	4.33±1.37	4.25±1.36	4.00±1.71	5.33±1.15
			90°F	
			Control (Air)	
18	4.50± .90	3.92± .90	5.08± .90	5.33±1.23
20	3.75±1.29	3.67± .89	4.58±1.31	5.00±1.21
22	6.42± .79	5.42±2.07	6.00±1.13	2.08±2.11
			Grain Treet ®	
18	5.00±1.04	4.75± .97	4.92± .90	3.75±1.82
20	6.42± .51	5.75±1.14	5.42± .90	2.67±2.06
22	7.00± .00	5.75±1.96	6.08± .67	1.92±1.44
			SO_2	
18	3.67± .78	4.25±1.22	4.42±1.16	3.58±1.62
20	5.42±1.00	5.42±1.08	5.42± .67	3.58±1.44
22	6.83± .39	5.33±1.44	5.75±1.06	2.83±1.75

[1]Mean values and standard deviation from 12 panelists.

[2]Seven = very dark (brown).

[3]Seven = very strong.

[4]Seven = very firm/dense.

[5]Seven = very acceptable.

Table 11. Analysis of variance of sensory scores for processed bean quality attributes dry stored under different chemical treatments at varying moisture and at 70° and 90°F for up to 3 months prior to processing.

Source of Variation	df	Attributes			
		Color	Flavor	Texture	Acceptability
			Mean Squares		
Main Effects					
Treat(Tr)	2	27.25***	16.54***	4.50*	22.78***
Temp(Tp)	1	52.02***	18.38**	46.30***	72.34***
Moist(M)	2	53.92***	9.39*	18.67***	37.00***
Two-Way					
Tr x Tp	2	.03	.54	1.19	4.03
Tr x M	4	10.00***	2.37	2.42	9.57
Tp x M	2	8.12***	4.06	.46	6.70
Three-Way					
Tr x Tp x M	4	7.80***	2.87	1.56	7.81*
Residual	198	.99	2.05	1.40	2.52
			Tukey's HSD		
Treatment		.95	1.37	1.13	1.52
Temperature		.80	1.15	.95	1.27
Moisture		.95	1.37	1.13	1.52
% CV		20.07	30.97	24.53	39.69

Table 12. Mean sensory scores under main effects of chemical treatments, storage temperature and bean moisture for processed bean quality attributes after 3 month storage.[1]

Main Effects	Attributes			
	Color[2]	Flavor[3]	Texture[4]	Acceptability[5]
Chemical Treatment				
Control (Air)	4.42[a]	4.14[a]	4.83[a]	4.47[a]
Grain Treet [R]	5.63[b]	5.10[a]	5.08[a]	3.38[a]
SO_2	4.82[ab]	4.64[a]	4.58[a]	4.14[a]
Temperature				
70°F	4.46	4.33[a]	4.37[a]	4.57[a]
90°F	5.44	4.92[a]	5.30[a]	3.42[a]
Moisture				
18%	4.21[a]	4.26[a]	4.39[a]	4.61[a]
20%	4.75[a]	4.63[a]	4.72[a]	4.17[a]
22%	5.90	4.99[a]	5.39[a]	3.21[a]

[1]Mean values from 12 panelists.

[2]Seven = very dark (brown)

[3]Seven = very strong.

[4]Seven = very firm/dense.

[5]Seven = very acceptable.

Table 13. Dry and processed navy bean characteristics dry stored at varying moisture content at 50°, 70° and 90°F for up to 1 year prior to processing.[1]

Time month	Initial Bean Moisture (%) 8	10	12	14	16	18
Dry Bean Moisture (%)						
			50°F			
1	7.0± .0	9.9± .1	11.2± .1	12.9± .1	15.0± .1	16.7± .0
12	6.5± .0	9.8± .1	11.2± .4	12.4± .0	15.0± .1	16.4± .1
			70°F			
1	7.0± .0	9.9± .1	11.2± .2	12.9± .2	14.8± .1	16.9± .1
12	6.6± .0	9.9± .0	11.0± .3	13.0± .3	14.6± .1	16.1± .0
			90°F			
1	7.0± .0	9.6± .3	10.9± .1	12.9± .1	14.7± .1	16.1± .0
12	6.5± .1	9.8± .1	11.0± .1	12.8± .1	14.4± .0	15.7± .1
Soaked Bean Moisture (%)						
			50°F			
1	48.5± .9	49.6± .1	50.7± .3	51.9± .5	52.1± .3	52.3± 1.4
12	52.2± .1	53.8± .4	53.9± .9	53.2± .5	54.0± 1.4	54.1± .2
			70°F			
1	47.6± .4	50.6± .1	50.9± .2	51.7± .4	52.3± .3	52.4± .5
12	52.7± .4	53.7± .1	53.6± .1	52.9± 1.0	53.0± 1.0	54.2± .5
			90°F			
1	47.2± .1	50.1± .1	51.6± .1	52.3± .4	51.4± .1	52.0± .3
12	52.4± 1.0	53.9± .1	52.9± 1.2	52.7± .4	51.9± .6	51.7± .1

Table 13. (cont'd.)

Time month	Initial Bean Moisture (%) 8	10	12	14	16	18
Processed Bean Moisture (%)						
			50°F			
1	68.2± .2	68.4± .2	68.7± .6	68.3± .0	69.1± .2	68.8± .6
12	70.1± .1	69.9± .1	69.7± .1	70.0± .0	69.6± .1	69.4± .2
			70°F			
1	67.2± .0	68.7± .4	68.5± .5	69.3± .6	69.5± .3	69.1± .6
12	70.1± .0	69.9± .2	68.6± .1	69.2± .2	67.5± .2	66.7± .3
			90°F			
1	67.9± .4	68.6± .1	69.0± .6	69.3± .4	68.7± .8	68.6± .1
12	70.0± .1	69.2± .4	67.0± .4	65.8± .5	64.0± .2	64.1± .4
Processed Bean Drained Weight (g)						
			50°F			
1	289.2± .0	283.2± 2.5	285.0± 6.0	282.8± 7.1	287.8± .0	284.1± 4.7
12	298.4± 1.0	298.9± 2.3	299.8± 3.0	294.7± 6.3	294.2± 5.0	293.0± 1.3
			70°F			
1	276.4± 2.0	291.9± .2	285.7± 3.0	275.8±17.0	291.3± 1.0	288.8± 2.6
12	300.5± .0	298.8± 6.4	297.7± 6.0	283.7± 2.2	275.7± 1.0	265.9± 1.0
			90°F			
1	280.7± 4.0	289.8± 1.1	293.5± 4.0	286.6± 4.4	281.4± 5.0	281.9± 2.3
12	297.0± 1.0	296.4± .1	282.8± 3.0	261.0± 2.3	246.0± 1.1	256.2±14.6

Table 13. (cont'd.)

Time month	Initial Bean Moisture (%) 8	10	12	14	16	18
Shear Resistance (g/100 g)						
			50°F			
1	144.5±21.0	152.3±10.8	130.9±17.2	131.6±19.7	114.0±14.9	118.5±61.5
12	69.0± 4.3	81.3± 6.0	85.8± 3.3	86.6± 7.9	95.7± 2.6	87.0± .4
			70°F			
1	182.6± 7.4	134.5±21.1	126.7± 2.8	111.4± .6	116.6±20.4	155.3±43.9
12	69.3± .7	74.5±10.9	81.1± 9.6	146.6±12.5	206.1± 2.2	288.0± 2.1
			90°F			
1	159.2±23.5	132.1±23.5	89.7±12.7	130.2± 8.9	152.5±25.5	200.4±22.9
12	77.0± 1.5	88.0± 2.7	142.5± 9.8	339.7±20.5	535.6± 2.8	546.5±13.4
Hunter L Value of Dry Bean						
			50°F			
1	65.3± .0	65.5± .0	65.7± .1	65.5± .1	65.3± .0	65.6± .1
12	65.0± .1	65.5± .1	65.4± .1	65.5± .0	65.7± .1	65.4± .1
			70°F			
1	65.2± .0	65.9± .1	65.5± .1	65.5± .1	65.5± .1	65.4± .3
12	64.8± .3	65.5± .1	65.3± .4	64.7± .2	64.0± .1	63.7± .0
			90°F			
1	65.3± .0	65.6± .1	65.4± .0	65.2± .0	65.9± .0	64.6± .1
12	65.3± .1	65.1± .2	64.4± .1	62.5± .2	60.3± .0	57.4± .4

Table 13. (cont'd.)

Time month	Initial Bean Moisture (%) 8	10	12	14	16	18
Hunter a_L Value of Dry Bean						
			50°F			
1	- .3± .0	- .3± .1	- .3± .0	- .3± .1	- .1± .0	- .2± .1
12	- .3± .0	- .3± .0	- .3± .0	- .3± .0	- .2± .0	- .2± .0
			70°F			
1	- .3± .0	- .3± .1	- .3± .1	- .3± .1	- .2± .0	- .1± .0
12	- .3± .1	- .3± .0	- .3± .1	- .2± .1	.2± .1	1.0± .0
			90°F			
1	- .4± .0	- .3± .1	- .3± .1	- .3± .1	- .1± .0	- .1± .0
12	- .5± .1	- .3± .1	.1± .0	.8± .1	1.8± .1	1.7± .1
Hunter b_L Value of Dry Bean						
			50°F			
1	12.2± .0	12.1± .1	12.1± .0	12.0± .1	12.0± .1	12.1± .1
12	11.8± .1	12.1± .1	11.9± .1	12.1± .1	12.2± .0	12.6± .0
			70°F			
1	12.1± .0	12.2± .1	12.2± .1	12.3± .1	12.3± .1	12.5± .1
12	12.1± .1	12.7± .1	13.0± .1	13.8± .1	14.9± .1	16.0± .1
			90°F			
1	12.3± .0	12.5± .1	12.6± .1	12.7± .1	13.2± .0	13.6± .1
12	12.4± .1	13.8± .1	14.9± .2	16.7± .1	17.3± .3	16.8± .0

Table 13. (cont'd.)

Time month	Initial Bean Moisture (%) 8	10	12	14	16	18
Hunter L Value of Processed Bean						
			50°F			
1	47.7± .3	48.2± .3	49.1± .0	49.3± .3	49.7± .2	49.9± .8
12	51.2± .1	50.9± .1	50.9± .1	51.7± .2	51.2± .1	51.0± .0
			70°F			
1	46.9± .1	48.5± .9	48.8± .5	49.9± .1	50.1± .0	49.8± .4
12	50.6± .1	50.4± .1	50.8± .2	50.3± .2	50.0± .1	48.7± .1
			90°F			
1	47.4± .3	48.1± .1	48.9± .0	49.7± .6	49.3± .7	49.4± .3
12	50.7± .2	49.8± .1	49.3± .2	47.9± .4	42.9± .7	33.9± .2
Hunter a_L Value of Processed Bean						
			50°F			
1	2.5± .4	2.2± .1	2.1± .1	2.0± .1	1.9± .0	1.8± .0
12	3.3± .0	3.4± .1	3.4± .1	3.3± .0	3.4± .1	3.5± .1
			70°F			
1	2.5± .2	2.4± .0	2.2± .1	1.9± .1	1.6± .0	1.8± .1
12	3.8± .1	3.6± .0	3.4± .0	3.6± .1	3.5± .1	4.8± .1
			90°F			
1	2.4± .2	2.4± .1	2.1± .1	1.9± .1	2.0± .0	1.9± .1
12	3.7± .1	3.7± .0	3.7± .1	3.9± .4	7.0± .1	8.8± .1

Table 13. (cont'd.)

Time month	Initial Bean Moisture (%) 8	10	12	14	16	18
Hunter b_L Value of Processed Bean						
			50°F			
1	14.2± .3	14.3± .0	14.2± .1	14.0± .1	14.1± .1	14.2± .1
12	15.1± .0	15.3± .2	15.2± .1	15.3± .1	15.4± .1	15.4± .3
			70°F			
1	14.2± .1	14.3± .0	14.0± .1	14.2± .1	13.8± .1	14.2± .4
12	15.3± .0	15.1± .0	15.2± .1	15.8± .1	16.0± .1	16.5± .1
			90°F			
1	14.0± .0	14.0± .1	14.1± .1	14.3± .1	14.5± .0	14.5± .2
12	15.3± .2	15.0± .1	15.5± .0	16.2± .1	16.0± .0	12.7± .1

[1]Mean values and standard deviation (n = 4 replicate samples).

Table 14. Analysis of variance of dry and processed navy bean characteristics dry stored at varying moisture content and at 50°, 70° and 90°F for up to 1 year prior to processing.

Source of Variation	df	Dry and Processed Bean Characteristics: Dry Bean Moisture (%)	Soaked Bean Moisture (%)	Processed Bean Moisture (%)	Drained Weight (g)	Shear Resistance (g/100 g)
				Mean Squares		
Main Effects						
Moist(M)	5	143.28***	11.37***	3.06***	530.99***	33366.37***
Temp(Tp)	2	.35***	1.92**	14.28***	795.61***	73487.47***
Time(Tm)	1	.96***	96.37***	2.01***	1.31	21108.28***
Two-Way						
M x Tp	10	.11***	.67	1.65***	136.84***	16298.92***
M x Tm	5	.15***	7.52***	9.14***	478.45***	32515.19***
Tp x Tm	2	.01	1.16*	15.41***	846.30***	58828.74***
Three-Way						
M x Tp x Tm	10	.04	.64	1.53***	132.16***	8213.14***
Residual	36	.19	.36	.12	25.13	329.11
				Tukey's HSD		
Moisture		1.31	1.80	1.05	15.10	54.65
Temperature		1.07	1.46	.85	12.26	44.38
Time		.89	1.21	.71	10.17	36.82
% CV		1.16	1.15	.51	1.76	11.70

Table 14. (cont'd.)

Source of Variation	df	Dry and Processed Bean Characteristics					
		Dry Bean Color			Processed Bean Color		
		Hunter L	Hunter a_L	Hunter b_L	Hunter L	Hunter a_L	Hunter b_L
				Mean Squares			
Main Effects							
Moist(M)	5	5.63***	.93***	5.54***	11.14***	1.62***	.34***
Temp(Tp)	2	17.44***	1.16***	23.09	53.12***	5.18***	.29***
Time(Tm)	1	25.56***	2.17***	31.73***	.08	73.00***	25.21***
Two-Way							
M x Tp	10	3.56***	.27***	1.36***	13.17***	1.52***	.74***
M x Tm	5	3.68***	.48***	3.11***	28.55***	3.48***	.54***
Tp x Tm	2	10.91***	1.16***	9.21***	46.04***	4.78***	.70***
Three-Way							
M x Tp x Tm	10	2.28***	.23***	.67***	11.17***	1.29***	.85***
Residual	36	.03	.00	.01	.09	.01	.02
				Tukey's HSD			
Moisture		.48	.16	.31	.95	.36	.40
Temperature		.39	.13	.25	.77	.30	.32
Time		.33	.11	.21	.64	.25	.27
% CV		.25	.32	.78	.64	3.93	.90

Table 15. Response of dry bean moisture content and storage temperature intervals for beans stored at various moisture and at 50°, 70° and 90°F for up to 1 year prior to processing.[1]

Source of Variation	df	Range of Contrast: Dry Bean Moisture (%)	Soaked Bean Moisture (%)	Processed Bean Moisture (%)	Drained Weight (g)	Shear Resistance (g/100 g)
Moisture	5					
Linear	1	7.5 to 7.8*	1.2 to 2.4*	-1.4 to -.7*	-18.4 to - 8.3	-89.9 to 126.7*
Quadratic	1	- .7 to - .4*	-1.6 to - .4*	- .6 to .1	- 6.7 to 3.5	21.4 to 58.3*
Cubic	1	.3 to .6*	.1 to 1.3*	- .2 to .5	.6 to 10.7*	-38.2 to - 1.4*
Quartic	1	- .7 to - .4	- .5 to .2	- .5 to .2	- 6.2 to 3.9	-29.5 to 7.4
Quintic	1	- .1 to .28	- .5 to .7	- .2 to .6	- 7.8 to 2.4	-10.1 to 26.8
Temperature	2					
Linear	1	- .2 to - .1*	- .7 to .1*	-1.3 to -.9*	-10.7 to - 5.5*	66.9 to 95.3*
Quadratic	1	- .2 to - .1*	- .5 to .2	- .3 to .1	- 3.3 to 1.9	7.7 to 26.7*

[1]Scheffe's Contrast $(\hat{\Psi}) \pm \sqrt{(t-1)(F_{.05;t-1,\nu})}$ standard error$_{(\hat{\Psi})}$.

*Significant at 5% level.

Table 15. (cont'd.)

Source of Variation	df	Range of Contrast					
		Dry Bean Color			Processed Bean Color		
		Hunter L	Hunter a_L	Hunter b_L	Hunter L	Hunter a_L	Hunter b_L
Moisture	4						
Linear	1	-1.5 to -1.2*	.6 to .7*	1.4 to 1.6*	-1.6 to -1.0*	.4 to .7*	-.1 to .2
Quadratic	1	- .8 to - .5*	.1 to .2*	- .1 to .1	-1.9 to -1.3*	.5 to .7*	-.4 to -.1*
Cubic	1	.1 to .4*	-.1 to .0	- .2 to .1	- .9 to - .3*	.1 to .3*	-.4 to -.2*
Quartic	1	- .2 to .1	-.1 to .0	- .2 to .0	- .2 to .4	.3 to .0	-.2 to .1
Quintic	1	- .2 to .2	-.1 to .0	- .1 to .2	- .2 to .4	-.2 to .1	-.1 to .2
Temperature	2						
Linear	1	-1.2 to -1.1*	.3 to .4*	1.3 to 1.4*	-2.1 to -1.8*	.6 to .7*	-.1 to .0
Quadratic	1	- .4 to - .3*	.1 to .2*	.1 to .2*	- .9 to - .6*	.2 to .3*	-.2 to -.1*

[1]Scheffe's Contrast $(\hat{\Psi}) \pm \sqrt{(t-1)(F_{.05;t-1,\nu})}$ standard error$_{(\hat{\Psi})}$.

*Significant at 5% level.

Dry stored beans with the initial moisture between 8-18% averaged 12% moisture after storage. Soaked and processed bean moisture was 52% and 68%, respectively. These data were similar to those observed in the packaging environment and chemical studies.

Processed bean moisture decreased significantly as initial bean moisture and storage temperature increased (Figures 19 and 20). No significant differents were shown in processed bean moisture after 1 and 12 month storage of dry beans (Figure 21).

No significant differences were shown in soaked bean moisture with varying storage temperature. Significant increases in soaked bean moisture content occurred with increased initial dry bean moisture and storage time. This relationship was attributed to soaking of a constant 100 g of bean solids (dry weight) per can rather than soaking a constant fresh weight of dry beans.

No significant differences in drained weight were shown for moisture content, storage temperature and time (Figure 22).

Long-term stored beans had higher average shear resistance (155 g/100 g) and drained weight (285 g) than beans in the packaging environment and chemical studies. Significant increase of shear resistance was shown with increased moisture content and storage temperature but not with storage time. Dramatic increase of bean firmness was apparently indicated by high shear resistance values for beans stored with initial moisture greater than 12%, at temperature greater than 70°F and with increased storage time (12 months) (Figure 23).

Hunter L, a_L and b_L values varied from 65.3, -0.3 and +12 for dry beans prior to storage to 64.8, +0.2 and +13 after storage, and to 49, +3 and +15 after processing. These data indicate increased bean

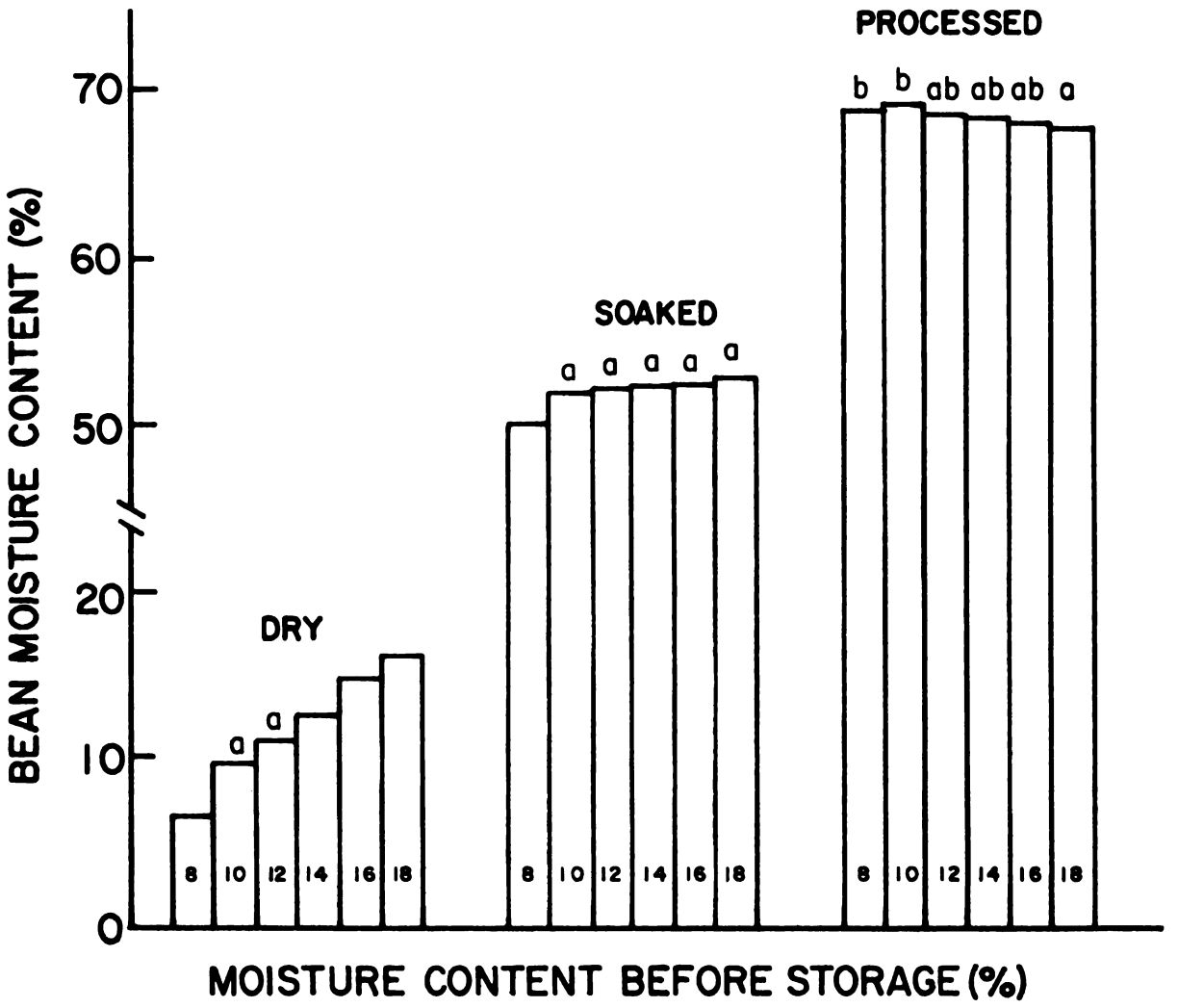

Figure 19. Mean moisture contents (over storage temperature and time) for beans dry stored at varying initial moisture content (8-18%) and at 50°, 70° and 90°F for up to 1 year prior to processing (like letters within each group indicate no significant differences).

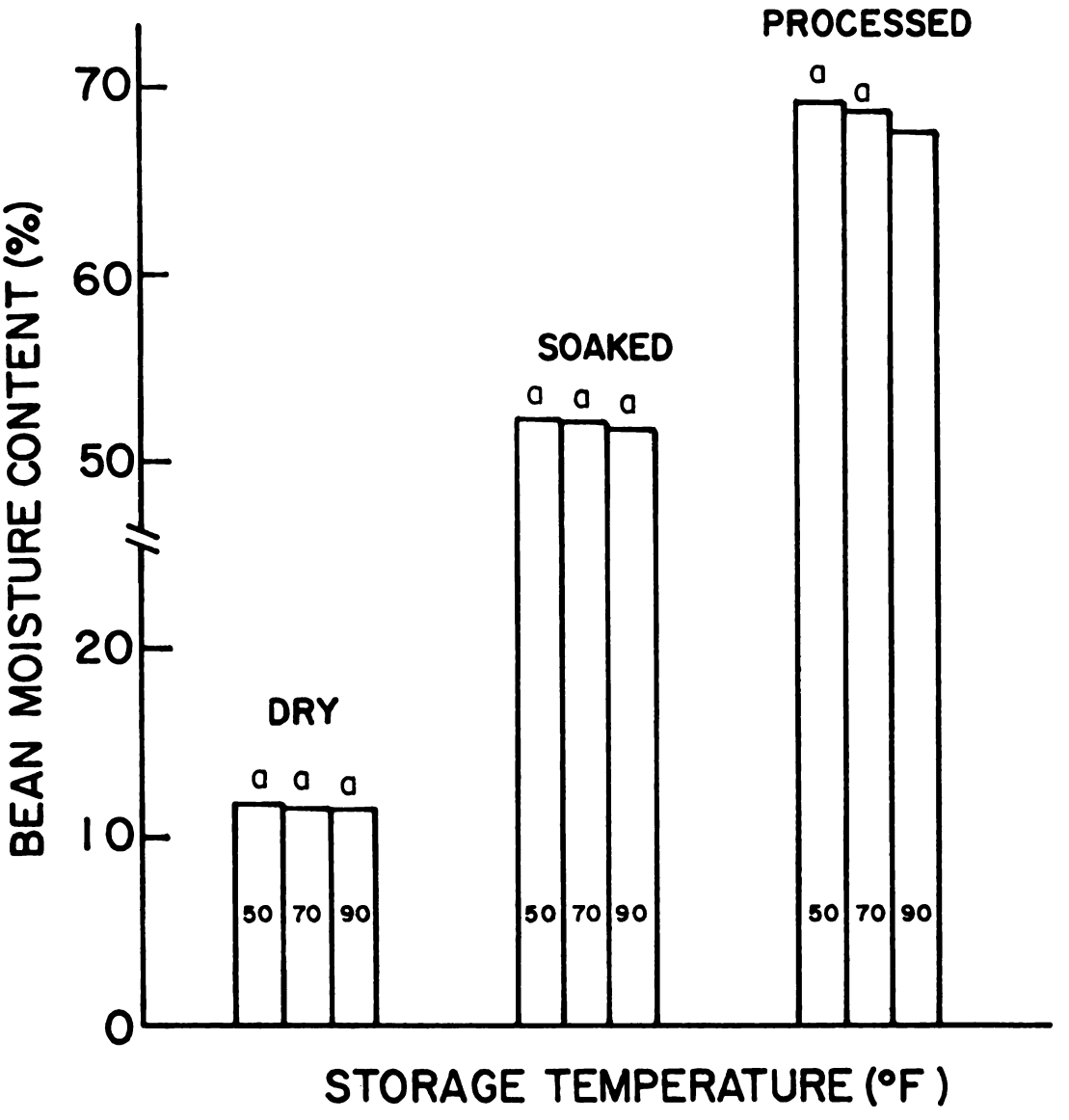

Figure 20. Mean moisture contents (over bean moisture and storage time) for beans dry stored at varying initial moisture content (8-18%) and at 50°, 70° and 90°F for up to 1 year prior to processing (like letters within each group indicate no significant differences).

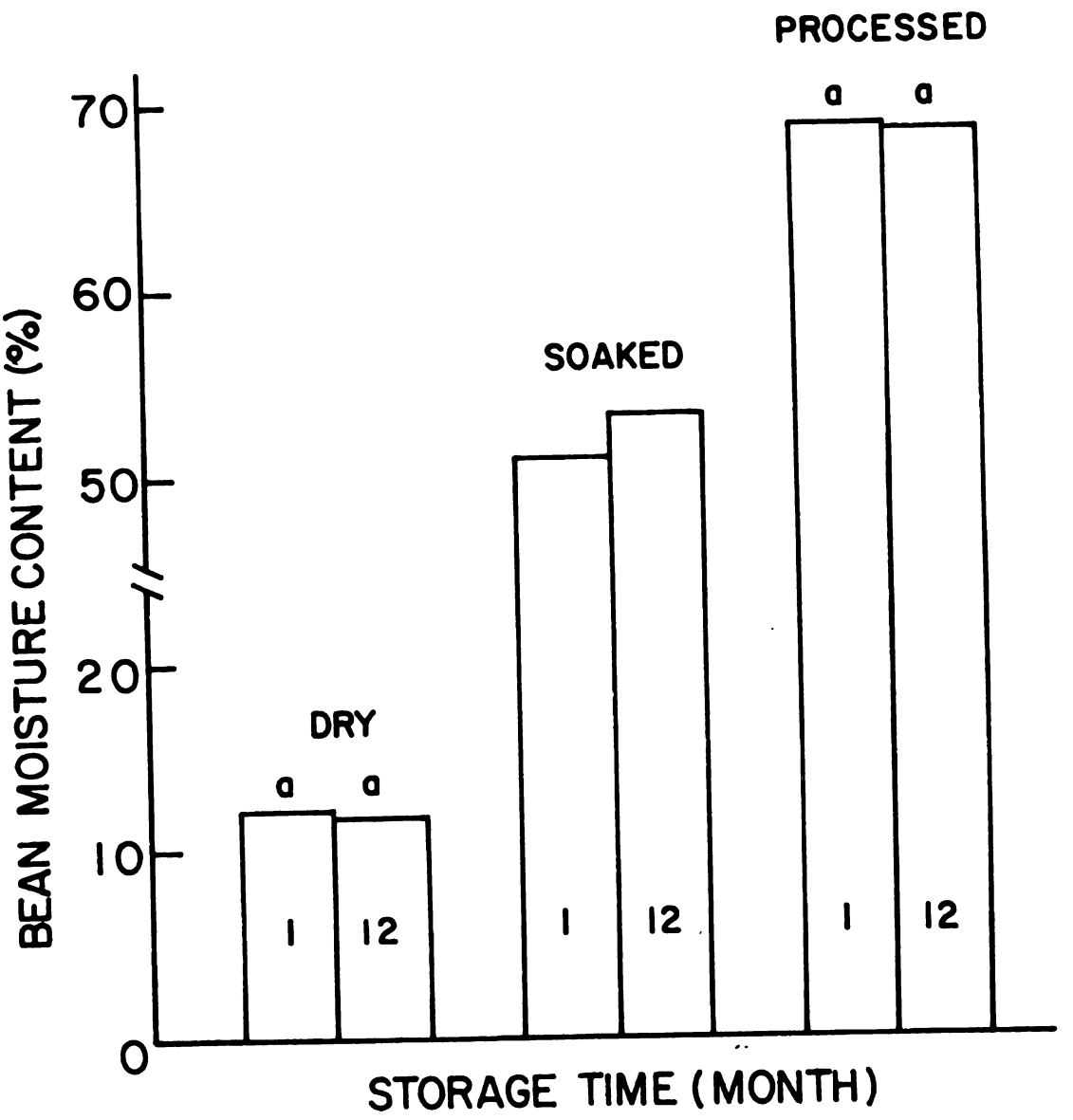

Figure 21. Mean moisture contents (over bean moisture and storage temperature) for beans dry stored at varying initial moisture content (8-18%) and at 50°, 70° and 90°F for up to 1 year prior to processing (like letters within each group indicate no significant differences).

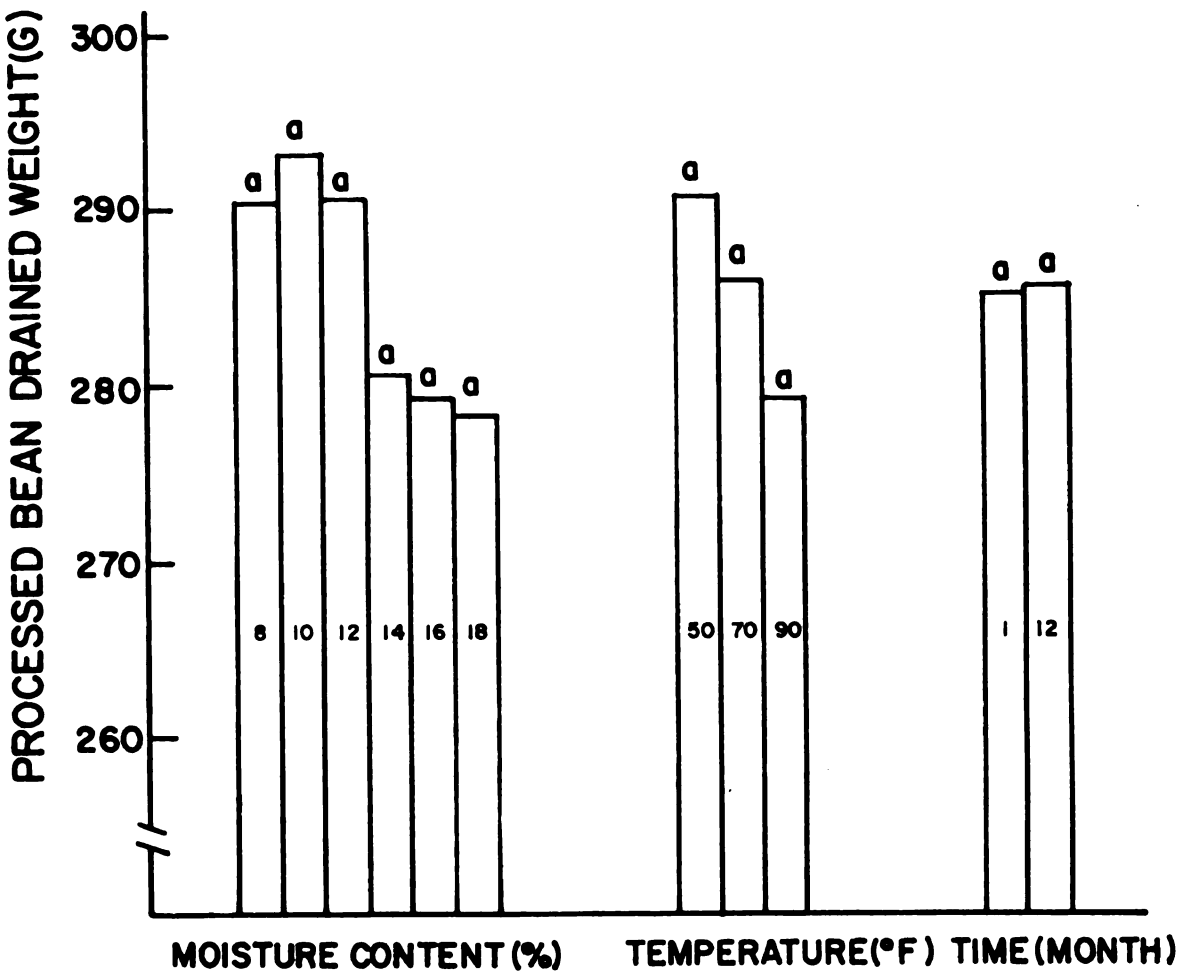

Figure 22. Overall main effect mean processed bean drained weight for beans dry stored at varying initial moisture content (8-18%) and at 50°, 70° and 90°F for up to 1 year prior to processing (like letters within each group indicate no significant differences).

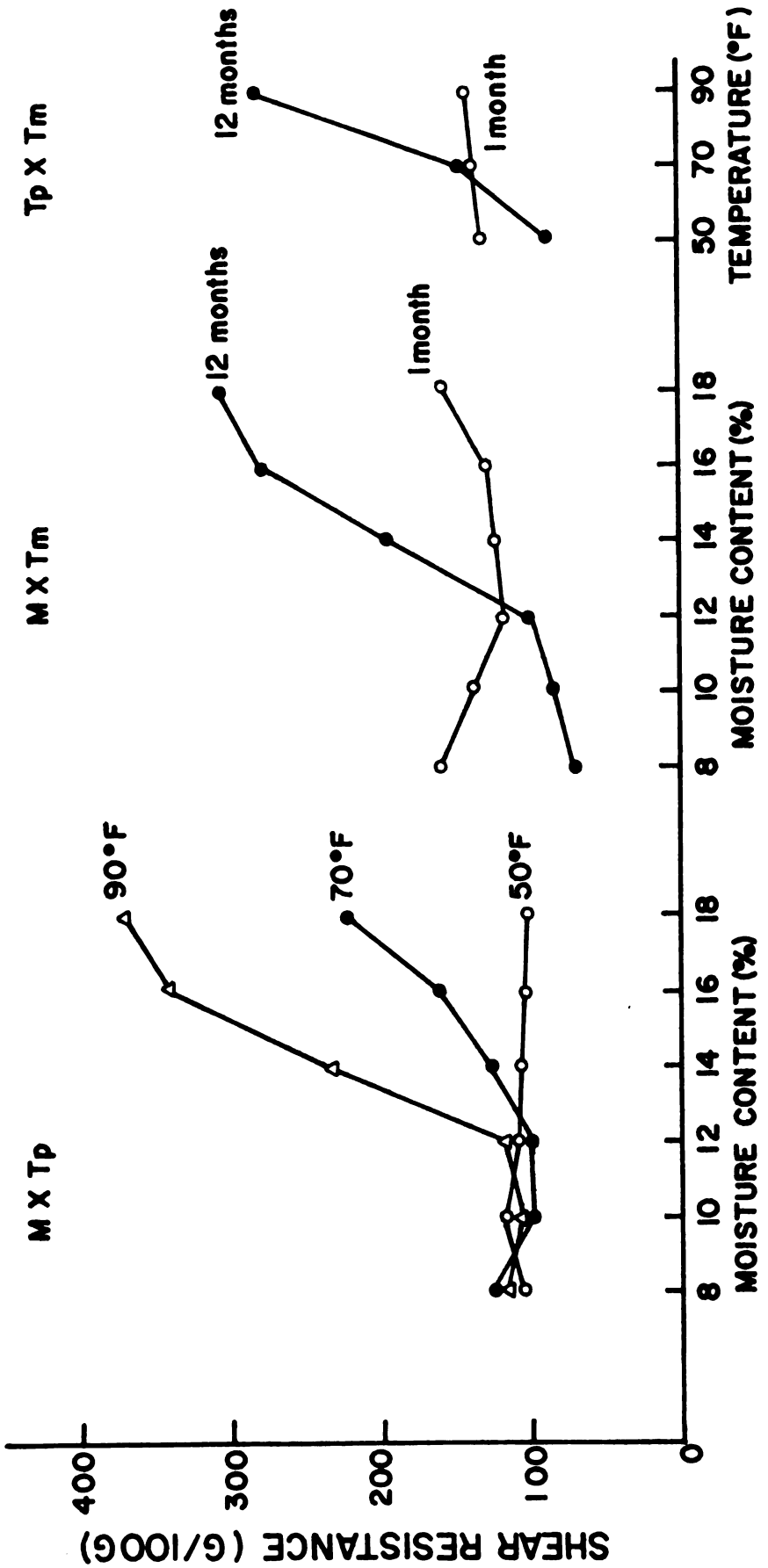

Figure 23. Shear resistance for beans dry stored at varying initial moisture content (8-18%) and at 50°, 70° and 90°F for up to 1 year prior to processing.

darkening from storage and processing. Increased moisture, temperature and time of storage decreased L value and increased a_L and b_L values for both dry and processed beans as reported in the packaging environment and chemical treatment studies. Such changes in Hunter L, a_L and b_L values were most apparent at dry bean moistures greater than 14% when stored at 90°F for 12 months (Figures 24 through 26). The storage temperature of 50°F and 70°F did not contribute much change to color except for beans with extremely high initial moisture (18%).

For dry beans Hunter L and a_L values were significantly correlated ($r = -0.47^{**}$) and for processed beans Hunter a_L and b_L values were significantly correlated ($r = 0.45^{**}$). Shear resistance was significantly correlated to soaked bean moisture ($r = -0.37^{*}$) and to processed bean moisture ($r = -0.65^{**}$).

Increase in bean discoloration and firmness with increase in initial dry bean moisture content, storage temperature and time was affirmed in this study. These data indicate that minimum bean discoloration and hardness occurred in beans stored at 70°F or less at less than 14% moisture. Long-term storage of beans at high temperature (90°F) and greater than 12% moisture resulted in loss of bean quality. These data suggest that holding beans during the summer season may deteriorate color and increase firmness though not to the extent exhibited in this long-term constant temperature experiment.

Sensory Evaluation. Visual examination following storage indicated that high moisture beans were red brown in color. Musty odor and mold appearance were also detected.

Processed beans examined during drained weight procedure showed discoloration when initial dry bean moisture was greater than 14%.

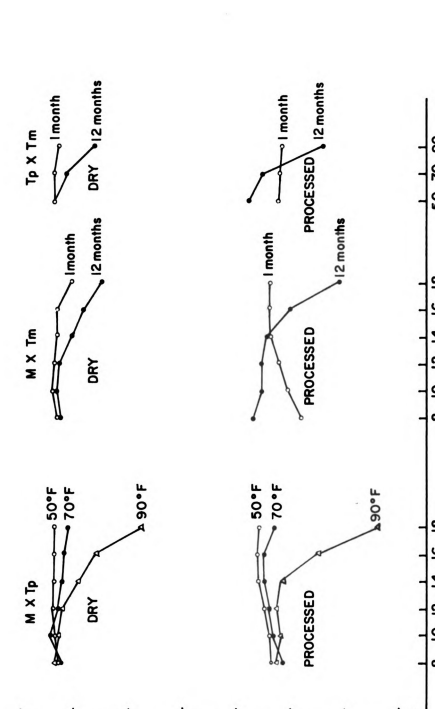

Figure 24. Hunter L value for beans dry stored at varying initial moisture content (8-18%) and at 50°, 70° and 90°F for up to 1 year prior to processing.

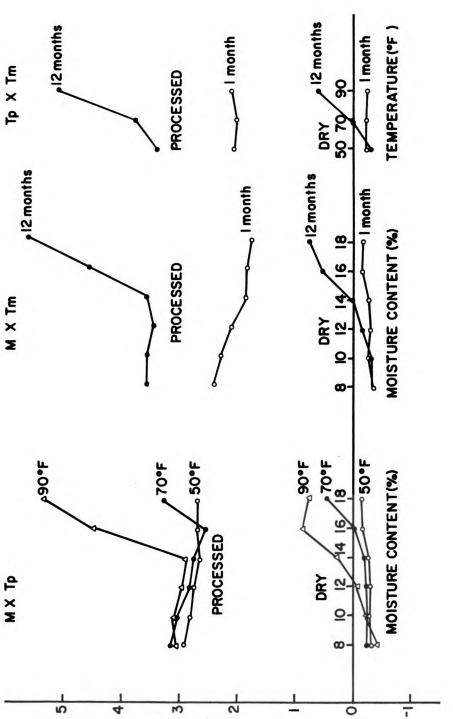

Figure 25. Hunter a_L value for beans dry stored at varying initial moisture content (8-18%) and at 50°, 70° and 90°F for up to 1 year prior to processing.

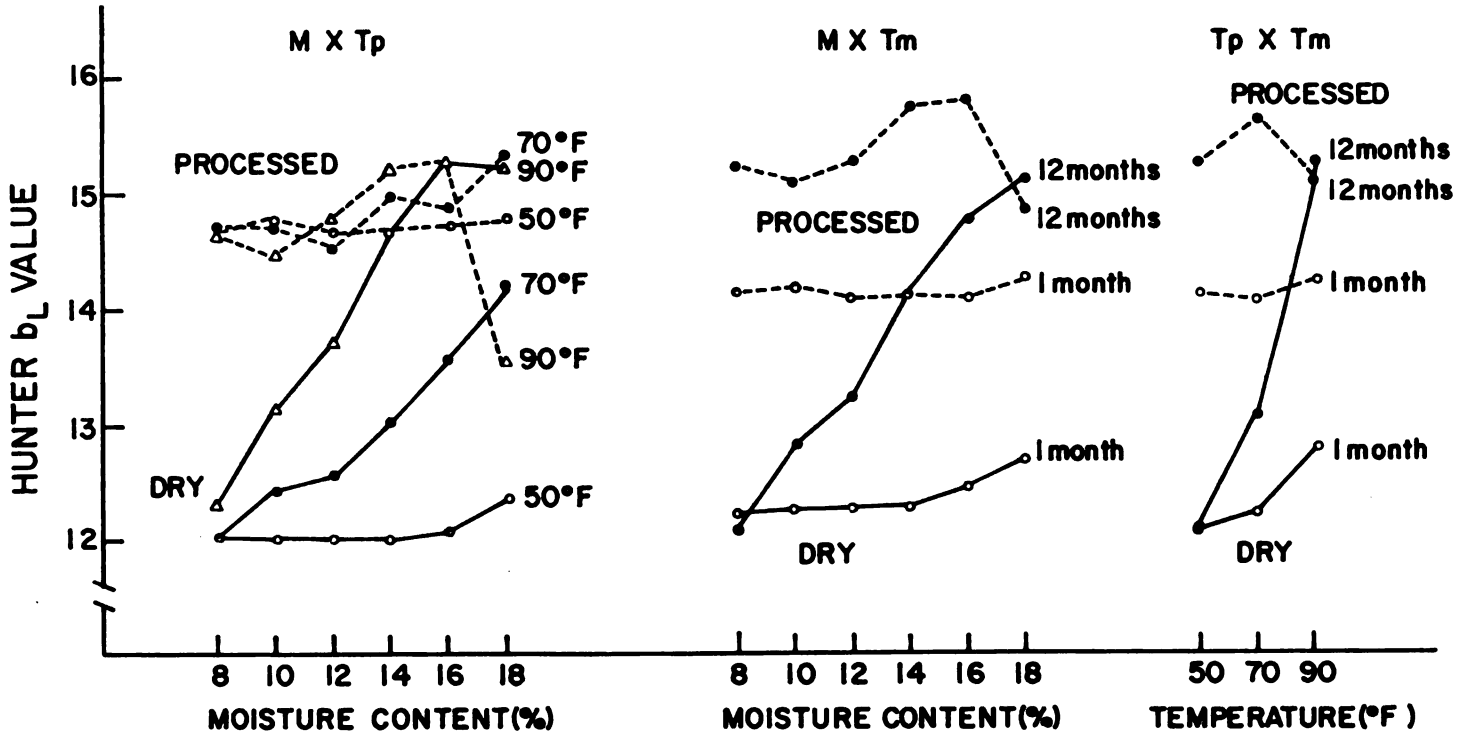

Figure 26. Hunter b_L value for beans dry stored at varying initial moisture content (8-18%) and at 50°, 70° and 90°F for up to 1 year prior to processing.

Strong odor was still detectable. Low moisture beans which are susceptible to crack and splits had higher degree of clumping, splitting and graininess of the sauce than high moisture beans.

Sensory scores for processed bean quality attributes are summarized in Table 16. The analysis of variance, Tukey's HSD for these data are presented in Table 17.

Significant differences were shown only in bean texture and acceptability under the temperature effect. Hard texture increased and acceptability decreased with increased temperature (Table 18).

Equilibrium Moisture Study

Changes in bean moisture content (dry and fresh weight basis) held under various RH in sealed desiccators with time are shown in Figure 27. The analysis of variance, Tukey's HSD and coefficient of variability are presented in Table 19.

Bean moisture content increased by adsorption of water with storage humidities greater than 64% and increased time. With storage humidities less than 64% bean moisture changes occurred by desorption. A dramatic change in moisture content occurred between 12 and 53 days of storage, however, no intermediate values were obtained during this time.

End-point equilibrium moisture content (dry and fresh weight basis) of beans are shown in Figure 28. Dexter et al. (1954) and Dexter (1968) reported the higher equilibrium moisture content using sulfuric acid solutions or sawdust-salt mixtures to control relative humidity.

Table 16. Mean sensory scores for processed bean quality attributes dry stored at varying moisture content at 50°, 70° and 90°F for up to 1 year prior to processing.[1]

Bean Moisture	Attributes			
	Color[2]	Flavor[3]	Texture[4]	Acceptability[5]
			1 Month	
			50°F	
10	3.50±1.57	4.17±1.34	4.00±1.48	5.42± .90
14	3.67±1.44	4.42±1.44	3.92±1.44	4.92±1.24
18	3.25±1.14	4.25± .97	4.33±1.15	5.25±1.06
			70°F	
10	3.92±1.31	4.08±1.08	4.58±1.16	5.17±1.34
14	3.92±1.16	4.25±1.22	4.25±1.36	5.08± .79
18	3.75±1.22	4.00±1.04	4.33± .98	5.08± .90
			90°F	
10	4.33±1.44	4.58±1.38	4.58±1.08	4.83±1.40
14	3.58±1.51	3.58±1.44	5.25±1.06	5.08±1.24
18	3.92±1.16	4.17±1.53	4.50±1.24	4.67±1.30
			12 Months	
			50°F	
10	3.50±1.31	4.25±1.66	4.00±1.48	5.00±1.35
14	3.58±1.16	3.67±1.07	3.75±1.22	5.17±1.40
18	3.50±1.31	3.33±1.15	4.08±1.38	5.67±1.07
			70°F	
10	3.42± .79	4.33±1.30	39.2±1.08	5.33±1.15
14	3.83± .94	4.58±1.16	4.75±1.22	4.67±1.23
18	5.42± .51	5.42±1.62	6.25± .75	3.00±1.65
			90°F	
10	3.08± .90	3.92±1.44	3.67± .98	5.00±1.21
14	4.50±1.00	4.75±1.48	6.08± .67	2.92±1.31
18	6.92± .29	5.25±2.30	6.92± .29	1.17± .39

[1]Means values and standard deviation from 12 panelists.

[2]Seven = very dark (brown).

[3]Seven = very strong.

[4]Seven = very firm/dense.

[5]Seven = very acceptable.

Table 17. Analysis of variance of sensory scores for processed bean quality attributes dry stored at varying moisture content at 50°, 70° and 90°F for up to 1 year prior to processing.

Source of Variation	df	Attributes			
		Color	Flavor	Texture	Acceptability
			Mean Squares		
Main Effects					
Time(Tm)	1	10.23**	2.67	6.69*	38.34***
Temp(Tp)	2	14.45***	3.85	27.92***	30.45***
Moist(M)	2	13.41***	.85	19.31***	17.50***
Two-Way					
Tm x Tp	2	3.20	7.68*	6.00**	16.59***
Tm x M	2	22.69***	1.85	19.03***	12.98***
Tp x M	4	6.09**	1.88	4.38**	8.39***
Three-Way					
Tm x Tp x M	4	6.26**	4.42	3.94*	8.52***
Residual	198	1.36	1.96	1.27	1.43
			Tukey's HSD		
Time		.93	1.12	.90	.96
Temperature		1.12	1.34	1.08	1.14
Moisture		1.12	1.34	1.08	1.14
% CV		29.33	32.75	24.51	25.77

Table 18. Mean sensory scores under main effects of storage time and temperature and moisture for processed bean quality attributes after long-term storage.[1]

Main Effects	Attributes			
	Color[2]	Flavor[3]	Texture[4]	Acceptability[5]
Time				
1 month	3.76[a]	4.17[a]	4.42[a]	5.06[a]
12 months	4.19[a]	4.39[a]	4.77[a]	4.21[a]
Temperature				
50°F	3.50[a]	4.01[a]	3.93[a]	5.24[b]
70°F	4.04[a]	4.44[a]	4.68[ab]	4.72[ab]
90°F	4.39[a]	4.38[a]	5.17[b]	3.94[a]
Moisture				
10%	3.63[a]	4.22[a]	4.04[a]	5.13[a]
14%	3.85[a]	4.21[a]	4.67[a]	4.64[a]
18%	4.46[a]	4.40[a]	5.07[a]	4.14[a]

[1]Mean values from 12 panelists.

[2]Seven = very dark (brown).

[3]Seven = very strong.

[4]Seven = very firm/dense.

[5]Seven = very acceptable.

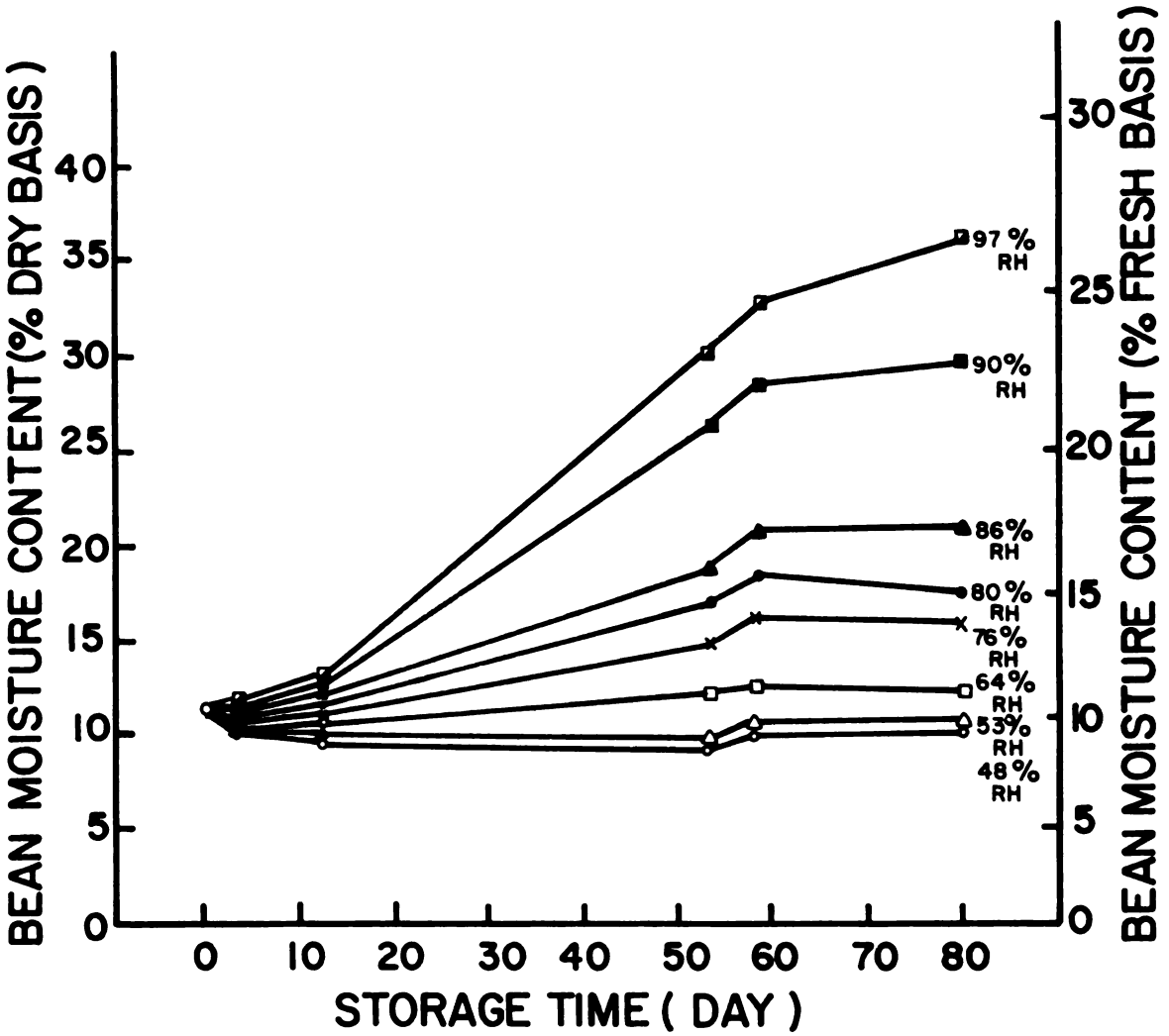

Figure 27. Bean moisture content (dry and fresh basis) after storage in desiccators at various relative humidity controlled by saturated salt solutions at 70°F.

Table 19. Analysis of variance of dry bean moisture content (fresh basis) dry stored at varying relative humidity controlled by saturated salt solutions at 70°F.

Source of Variation	df	Moisture Content (% Fresh Basis)
		Mean Squares
Main Effects		
Relative Humidity	7	115.15***
Time	5	151.18***
Two-Way		
Relative Humidity x Time	35	17.44***
Residual	48	.16
		Tukey's HSD
Relative Humidity		1.28
Time		1.20
% CV		3.25

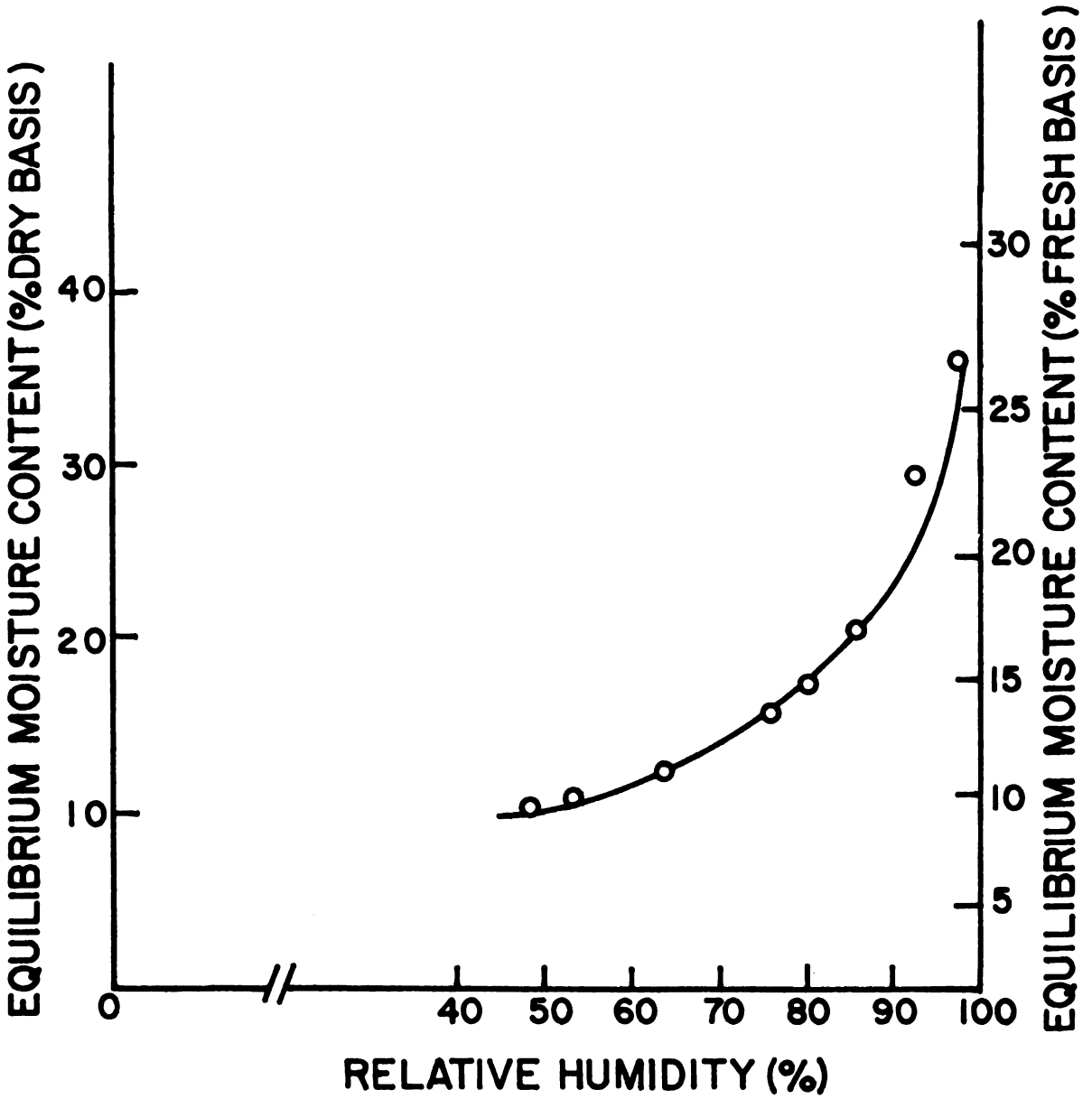

Figure 28. Water sorption isotherm of navy beans at 70°F.

The mean values and statistical summary of dry and processed bean quality characteristics after 80 day equilibration in various RH conditions are reported in Table 20.

Soaked and processed bean moisture and drained weight significantly decreased with increased RH. These data indicate the reduction of bean water uptake capacity at high RH storage. Processed beans from high humidity storage showed significant higher shear resistance than those stored at lower humidities. Dramatic increases in firmness occurred in beans stored above 80% RH.

Hunter L, a_L and b_L values changed from 60.3, 0 and +10.2 before dry storage to 58.2, +0.4 and +10.9 after storage, and to 49.4, +3.8 and +14.5 after processing. These data indicate bean darkening during storage at various RH and during processing. Significant changes among all Hunter values occurred with increased storage RH indicating an overall deterioration of bean surface color under these conditions.

Visual examination of dry beans following storage indicated discoloration, extensive mold mycelium and musty odor at RH greater than 86%.

Examination of processed beans during drained weight procedure indicated that beans stored at low RH (48-64%) had high degree of clumping due to the cracking of low moisture cotyledons. The presence of molds and musty odor was detected from beans held at high RH.

Bean moisture content increased with increased storage RH. Therefore, the effect of storage RH on keeping and processed qualities of beans were identical to that of bean moisture content as reported in the packaging environment, chemical treatment and long-term storage studies. Browning and hard texture of beans increased with high

Table 20. Dry and processed navy bean characteristics and analysis of variance of the characteristics dry stored at varying relative humidity controlled by saturated salt solutions at 70°F.

Relative Humidity(%)	Dry and Processed Bean Characteristics				
	Dry Bean Moisture (%)	Soaked Bean Moisture (%)	Processed Bean Moisture (%)	Drained Weight (g)	Shear Resistance (g/100 g)
	Mean Values + Standard Deviation[1]				
48	9.2± .1^{a}	54.9± .1^{cd}	71.1± .1^{bc}	296.3±2.1^{c}	43.5±1.3^{a}
53	9.7± .1^{a}	55.0± .1^{cd}	71.6± .4^{c}	294.8± .0^{c}	38.0±2.6^{a}
64	11.1± .1	54.9± .4^{cd}	71.6± .0^{c}	289.9±1.0^{bc}	51.1± .8^{ab}
76	13.7± .1	55.3± .1^{d}	71.6± .2^{c}	287.1±3.0^{bc}	56.2±6.5^{ab}
80	14.7± .0	54.3± .3^{bc}	71.2± .1^{c}	282.8±1.0^{ab}	66.1±9.0^{b}
86	17.1± .1	53.9± .0^{ab}	69.8± .1^{ab}	276.5±6.0^{ab}	71.0±1.2^{b}
92	23.0± .1	53.4± .2^{a}	69.3± .1^{ab}	275.0±2.0^{a}	112.9±1.8
97	26.5± .4	53.7± .1^{ab}	69.1± .3^{a}	274.3±3.0^{a}	134.9±8.1
	Mean Squares				
Relative Humidity (df=7)	79.41***	.94***	2.35***	154.79***	2376.47***
Residual (df=8)	.03	.04	.04	8.03	25.18
	Tukey's HSD				
	.71	.77	.80	11.22	19.86
%CV	1.14	.36	.29	1.00	7.00

[1]n = 4 replicate samples.

Table 20. (cont'd.)

	Dry and Processed Bean Characteristics					
	Dry Bean Color			Processed Bean Color		
	Hunter L	Hunter a_L	Hunter b_L	Hunter L	Hunter a_L	Hunter b_L
	Mean Values + Standard Deviation[1]					
Relative Humidity(%)						
48	$60.3 \pm .1^{b}$	$.6 \pm .0^{b}$	$10.4 \pm .0^{a}$	$50.2 \pm .1^{b}$	$4.3 \pm .1^{b}$	$14.5 \pm .1^{abc}$
53	$60.5 \pm .4^{b}$	$.5 \pm .1^{b}$	$10.5 \pm .1^{a}$	$50.2 \pm .0^{b}$	$4.2 \pm .1^{b}$	$14.8 \pm .1^{c}$
64	$59.6 \pm .0^{b}$	$1.1 \pm .0^{b}$	$10.4 \pm .0^{a}$	$50.5 \pm .1^{b}$	$2.5 \pm .1^{b}$	$14.7 \pm .4^{bc}$
76	$60.3 \pm .1^{b}$	$.5 \pm .0^{b}$	$10.7 \pm .1^{a}$	$50.6 \pm .2^{b}$	$4.1 \pm .1^{ab}$	$14.7 \pm .1^{abc}$
80	$60.1 \pm .1^{b}$	$.5 \pm .0^{ab}$	$10.9 \pm .2^{a}$	$50.4 \pm .1^{b}$	$3.9 \pm .1^{b}$	$14.6 \pm .1^{bc}$
86	$59.0 \pm .2^{b}$	$.3 \pm .1^{a}$	$10.9 \pm .0^{a}$	$49.7 \pm .1^{a}$	$4.1 \pm .1^{ab}$	$14.7 \pm .1^{ab}$
92	52.3 ± 1.1^{a}	$.3 \pm .0^{a}$	$11.5 \pm .1$	$47.1 \pm .9^{a}$	$3.6 \pm .1^{a}$	$14.1 \pm .1^{a}$
97	53.5 ± 1.6^{a}	$.0 \pm .3^{a}$	$12.2 \pm .4$	$46.8 \pm .1^{a}$	$3.5 \pm .1^{a}$	$14.0 \pm .2^{a}$
	Mean Squares					
Relative Humidity (df=7)	22.09***	.35***	.77***	4.93***	.72***	.18**
Residual (df=8)	.48	.01	.03	.12	.15	.03
	Tukey's HSD					
	2.73	.42	.63	1.35	.51	.67
%CV	1.18	27.21	1.45	.69	3.39	1.17

[1]n = 4 replicate samples.

humidity storage. Beans stored at RH less than 75% did not undergo rapid deterioration for the quality characteristics evaluated in this experiment. The water sorption isotherm (70°F) indicates that this RH corresponds to a final bean moisture content of approximately 14%. This moisture content and storage RH are critical values in minimizing quality deterioration during dry storage.

SUMMARY AND CONCLUSION

The data obtained in the packaging environment study indicated that dry beans stored with high initial moisture content developed dark color and hard texture and lost water uptake capacity. The quality loss of dry and processed beans were accelerated with increase in storage temperature and time. Changes in protein/starch constituents of bean cotyledons perhaps due to nonenzymatic browning reaction may have caused these quality deteriorations. Vacuum and CO_2 packaging environment did not stabilize bean color perhaps due to the insufficient levels of vacuum and CO_2 used or due to the gas permeability properties of Mylar® or imperfections in film and seal.

In the chemical treatment study, the effects of initial dry bean moisture, storage temperature and time in increasing bean discoloration and firmness were similar to those observed in the packaging study. Grain Treet® provided limited benefit on mold inhibition in this study and resulted in beans with brown color and firm texture. Sulfur dioxide treatment stabilized stored bean color at low temperature without alteration in other bean properties. However, the efficiency of SO_2 was reduced with increased moisture and temperature.

The data from the long-term storage study reconfirms that storage of high moisture beans at high temperatures causes severe destruction of dry and processed bean qualities. Bean discoloration and firm

texture were obvious following long-term storage. The data suggest bean storage with initial moisture less than 14% at temperatures below 70°F should be maintained to assure good quality retention.

Increased storage RH resulted in high moisture content, mold mycelium, darkening and hardening of beans. Changes in bean quality characteristics were observed at RH greater than 75% which corresponded to an equilibrium bean moisture of 14% (fresh weight basis) obtained from the water sorption isotherm at 70°F.

Overview

The data from these studies indicated that browning and hard texture of beans increased with increased initial bean moisture, storage temperature, time and RH. These storage conditions also decreased water uptake capacity and drained weight of beans which will adversely affect the potential canned bean yield.

Sulfur dioxide treatment showed potential as a dry bean treatment prior to storage at low temperature since SO_2 maintained both color and texture quality during storage. However, limited benefit was obtained from SO_2 treatment at high temperature storage. Other physical and chemical treatments may also be effective in improving storage stability of dry navy beans, but they require further investigation prior to recommendation for use.

Low moisture beans exhibited a high degree of clumping and splitting due to seedcoat and cotyledonary rupture. High moisture beans developed discoloration and firm texture, and favored mold growth during storage. The bean moisture critical value during dry storage was suggested to be 14%. Recommended optimum bean storage conditions were below 70°F temperature and less than 75% RH with minimized storage time.

RECOMMENDATION FOR FURTHER RESEARCH

1. Utilization of other types of packaging material providing varied permeabilities for storage of beans and evaluation of bean keeping quality.

2. Continuation of the Grain Treet® study for mold inhibition in beans and the effect of Grain Treet® on bean color and texture.

3. Examination of the practical use of SO_2 for dry bean storage.

4. Emphasis on bean low temperature (50°F) storage and the shelf life prediction.

5. Establishment of the water sorption isotherm of navy beans at other temperatures to determine critical shifts in equilibrium moisture.

APPENDIX

Table 21. Composition of navy beans (values per 100 g dry beans).[1]

Water	10.9%
Energy	340 cal
Protein	22.3 g
Fat	1.6 g
Carbohydrate	61.3 g
Calcium	144 mg
Phosphorus	425 mg
Iron	7.8 mg
Sodium	19 mg
Potassium	1196 mg
Vitamin A	0 IU
Thiamin	0.65 mg
Riboflavin	0.22 mg
Niacin	2.4 mg
Ascorbic acid	0 mg

[1]Values from Adams (1972).

Dry Bean Processing
Canned Bean Evaluation
Subjective Quality Difference[1]

Uebersax
FSC 128
Operator:_____
Date:_____

Sample Code/ _____
Conditions: _____

Control Sample:_____

1 Can Code	2 Color +lighter -darker	3 Size +larger -smaller	4 Shape +rounder -elongate	5 Free Starch +more -less	6 Gen. Accept. +better -worse	7 Clumping (1-5)	8 Splits (1-5)	9 Comments

[1] Scale columns 2-6 (+3 to -3; 0 equals no difference from control); columns 7 and 8, rating scale 1=none, 2=slight, 3=moderate, 4=very, 5=severe.

Figure 29. Attributes and hedonic scales used in visual examination of canned navy beans.

Instructions: Evaluate color, flavor, texture, and general acceptability of each sample according to the appropriate 7 point rating scale for each attribute. Record results in table below each attribute.

	Color	Flavor	Texture	General Acceptability
	7 very dark (brown)	7 very strong	7 very firm/dense	7 very acceptable
	6 mod. dark (brown)	6 moderately strong	6 mod. firm/dense	6 mod. acceptable
	5 slt. dark (brown)	5 slightly strong	5 slt. firm/dense	5 slt. acceptable
	4 neither dark/light	4 neither strong/mild	4 neither firm/soft	4 neither acceptable/unacceptable
	3 slt. light (white)	3 slightly mild	3 slt. soft/mushy	3 slt. unacceptable
	2 mod. light (white)	2 moderately mild	2 mod. soft/mushy	2 mod. unacceptable
	1 very light (white)	1 very mild	1 very soft/mushy	1 very unacceptable
Sample No.				

Figure 30. Attributes and hedonic scales used in sensory evaluation of canned navy beans.

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