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EFFECT OF SELECTED STORAGE CONDITIONS ON DEVELOPMENT OF HARD-TO-COOK PHENOMENON IN DRY BEANS

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Abstract

Effect of Selected Storage Conditions on Development of Hard-to-Cook Phenomenon in Dry Beans

By

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Four (*Phaseolus vulgaris L.*) cultivars: navy (Seafarer), black (Black Turtle Soup, BTS), pinto (Oletha) and kidney (Montcalm) were adjusted to various moisture levels and stored under nitrogen, carbon dioxide and air at 5, 20 and 35°C for up to nine months. Following storage, beans were canned under standard conditions and quality characteristics evaluated. Selected samples were evaluated for cellular structure and gelatinization properties under scanning electron microscope (SEM).

The temperature and moisture content of stored beans had significant effects on quality characteristics: soaked weight, drained weight, color coordinates, shear force and dried residue. The raw bean sections showed clear differences in cells and protein properties due to different storage conditions. The starch granules exhibited the same behavior upon different storage conditions, however, starch

from hard beans was unextractable by water, and well extracted by sodium hydroxide solution.

Beans were dry roasted using sand at 150 or 200°C for 1 to 10 minutes. The roasted beans were stored and then evaluated for quality characteristics. Roasting the beans before storage under high temperature and high moisture (35°C and 18%) improved the quality of beans by decreasing the development of hardness and improving the color as compared to the raw beans stored under the same storage conditions.

Also, representative samples of the hardness levels (soft, medium and hard) were cooked for one hour at two temperatures (60 and 90°C) in distilled water or 150 ppm Ca^{++} and evaluated under SEM. Results indicated that calcium ion significantly influenced cookability of 35°C stored beans (hard beans) in all cotyledon segments, however, only slight differences were shown for beans stored at 5°C (soft beans).

To My Family

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INTRODUCTION

Historically, dry edible beans have represented an important nuritional resource in the underdeveloped and developed countries. They have been used as an important dietary source of protein, vitamins and minerals, and calories. Further, it is important to study the quality of beans for processing because the state of Michigan is one of the leading states for dry bean production and a leader in the export market.

A majority of the edible dry beans belong to the genus Phaseolus. The common commercial classes include : 1- white beans (navy or pea and small white) and 2- A variety of colored beans (kidney, pinto, black and cranberry.) Considerable previous research has been conducted on the quality of dry and processed beans. The most important quality parameters in dry and processed beans include: 1- color, 2- flavor, 3- mold growth, 4- seed coat cracking, 5- hard cooking, 6-texture, 7- microstructure, 8- drained weight, 9- canned bean splits and appearance. A review of the available literature concerning various parameters and factors which affect quality of storage, soaking and processing conditions is presented.

The objectives of this research were to evaluate dry bean storage conditions and selected pre-storage roasting treatments on the quality and control of hard-to-cook phenomenon (HTC) of dry edible beans including : 1- cooking and canning quality, 2- compositional changes and 3- microstructure.

Four cultivars of beans, navy (Seafarer), black (Black Turtle Soup, BTS), pinto (Oletha), and kidney (Montcalm) were stored with various moistures (10, 14, 18%), temperatures (5, 20, 35^{o}C) and under selected gas environments (N_2, CO_2, and air) for up to 9 months.

Quality was assessed by "pin drop" cooking (Mattson procedure) and canning techniques. Microstructure and chemical compositional analyses of raw and cooked products were evaluated during these studies.

Navy (Seafarer), black (BTS) and kidney (Montcalm) beans were dry roasted in hot sand at (150 - 200^{o}C) for 1 - 10 minutes prior to storage at 5 and 35^{o}C at 18% moisture for five months.

REVIEW OF LITERATURE

Bean Damage

One factor which governs the keeping quality of beans in addition to storage conditions is the original quality of bean seeds. Starting with sound and intact seeds under suitable conditions (low temperature and low moisture) stored beans will remain at high quality for an extended storage time (1 - 2 years). Some beans arrive for storage in a damaged condition due to harvest and handling abuse. This decreases the overall quality and shelf life of stored beans and subsequently of the canned products.

Damage to beans may begin in the field due to improper growing or harvesting conditions. Further, sorting and cleaning may impart damage. Factors involved include insect, disease, mechanical and bin-burn damage, foreign material of 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 seed coats, 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.

The mechanical factors are mainly seed coat breakage and splitting of cotyledons resulting from handling in harvesting and cleaning. Because temperature, rainfall and other weather conditions during growth, dry bean are subject to cracking, hard seed coats and other problems that can affect processing procedures (Connie et al., 1979). Splits were affected by bean type,initial moisture content and storage time. Adams and Bedford (1975) stated that, as a general rule, the larger and more irregular shaped seeds are the more sensitive to mechanical damage they become. Thus, the smaller, more nearly rounded seeds, are more resistant to damage.

Seeds of soybean cultivars Williams and Clark 63 were imbibed at 10, 30, and 50^{o}C. After 12 hrs, up to 83%

of the cotyledons had cracked regardless of temperature. Seed imbibed in mannitol solutions (0.1 to 1.0 M) reduced the cotyledons cracking by about 80%, and 60% for Williams and Clark 63 respectively (Sorrells and Pappelies, 1976)

A comprehensive study of soaking and processing conditions for selected dry beans was conducted by Nordstrom and Sistrunk (1977). The percent splits were much higher in kidney, and there was change with treatment and storage time. Although differences in percent splits among the soak times were not significant, beans in the 14 hours soak had fewer splits. Beans canned in water had significantly more splits than those processed in tomato sauce. It was suggested that perhaps the insoluble complexes produced by the amylose component of starch with organic acids rendered more rigid starch helices (Nordstrom and Sistrunk., 1977).

Dry Bean Storage Conditions

Effect of Temperature, Relative Humidity and Time

Burr et al.(1968) suggested that as temperature increased the cooking time increased in Phaseolus vulgaris . Antunes and Sgarbieri (1979) indicated that a negative bean hydration correlation was observed when storage temperature was increased. They also introduced data which suggested a direct relationship between lower holding temperature and lower relative humidity with reduced bean cooking time.

In addition to storage temperature, storage time plays a vital role in bean quality. Burr and Kon (1966) observed that pinto beans, subjected to prolonged storage for one year, needed 62 minutes at 121^{o}C to cook until tender as opposed to a cooking time of 23 minutes for freshly harvested beans from same lot. This increase in cooking time with increased storage time has been consistently reported by other researchers (Morris, 1963 and 1964; Burr et al. 1968; Bedford, 1972).

As the length of dry bean storage increases, in addition to increased cooking time, a decline in the nutritive value may result. Antunes and Sgarbieri (1979) observed a drop in available methionine and cysteine with increased storage time. Burr (1973) reported that during prolonged storage, the thiamin concentration declined with no change in niacin or riboflavin. Molina et al.(1975) also reported a decrease in protein efficiency ratio (PER) for stored beans due to a long cooking time. Morris (1964) stated that the reduction of 15^{o}F in storage temperature had the same effect as the decrease of 0.6% moisture content to yield an equivalent short cooking time.

Uebersax and Bedford (1980) reported that deterioration rate both in discoloration and mold growth was minimized in beans stored at 55^{o}F under relative humidities ranging from 75 - 100%. The influence of increased storage temperature became greater at higher relative humidity.

Vongsarnipigoon et al. (1981) suggested that optimum bean quality was obtained from dry beans stored at 14% moisture and 70^{o}F. Recommendations to prevent storage loss of dry beans due to hardening (Mejia, 1980) include: 1- beans should be stored at the lowest possible moisture content and 2- beans should be stored in a dry and cool environment. Aeration with proper flow rate, relative humidity and temperature improve the stored bean quality. Aeration, is the practice of moving air at low flow rate to cool all beans in a bin to prevent moisture migration (Maddex, 1978)

Gloyer (1928) described a storage induced defected termed "hardshell" in which seeds did not imbibe water . It was reported by Gloyer (1928) that the lower the humidity of the storage atmosphere, the higher percentage of hardshell beans. These cooking features were characterized by Bourne (1967) who showed that hardshell beans tend to be smaller in size than the non-hardshell beans.

Molina et al.(1975) observed the hardness of black beans stored at 25^{o}C and 70% RH for nine months. They observed that if heat treatment was applied to beans prior to storage, the hard-to-cook phenomenon could be reduced. Varrino-Marston and Deomona (1979) reported that black beans stored at high relative humidities, such as 85%, underwent a greater rate of electrolyte leakage during soaking than beans stored at normal relative humidities. This suggested that, during high relative humidity storage, aging occured which resulted in cotyledon deterioration. This deterioration may contribute to the hard-to-cook phenomenon.

During storage of high moisture beans there may be a development off odor or off flavors, lipid oxidation, darkening in color and hard shell effect. Morris (1963) reported low moisture beans maintained good quality. As the moisture content rises, off-flavors are observed along with a large increases in free fatty acids. According to Muneta (1964) these off-flavors occurred because of the high concentration of polyunsaturated fatty acids which underwent autoxidation leading to off-flavors. Thus, storage conditions establishing low moisture beans should be maintained. Storage of low moisture beans containing a few localized high moisture beans could result in localized increased microbial activity and spoilage (McCurdy et al., 1980).

Burr and Kon (1966) reported that keeping beans at low moisture content is essential to preserve their cooking quality. Morris (1964) observed little change in cooking time of low moisture storage of pinto, navy, and large lima beans. Burr et al. (1968) reported an increase in cooking time with high moisture stored beans. This is in accord with the work of Rockland (1963) who observed that beans with an initial moisture content of 9.9% required only one fifth the time to cook than those stored for five months at 32.2°C with initial moisture content of 13.3%. VonMollendroff and Priestly (1979) also reported on this phenomenon, they concluded that the acceleration of hardness occurs rapidly as the moisture content is raised above 13%. Jackson and Varriano-Marston (1981) stated chemical deterioration as shown in samples held at high temperature and relative humidity. Varriano-Marston (1981) concluded that cooking time was inversely proportional to moisture content in black beans.

Mold Growth

Another important factor which affects bean quality is the mold growth on beans . Mold growth usually develops on bean exposed to severe storage conditions, such as high moisture content, high relative humidity and warm temperature of storage. Saettler (1972) suggested that production diseases such as bacterial blight and root rot may influence the mold level of beans after harvest. Bedford (1972) reported that the mold growth of beans stored in a closed constant relative humidity (RH) desiccator greatly increased at RH higher than 75%. As storage time and temperature increased, bean color deterioration, off-flavor, mold count and processed bean firmness also increased (Uebersax, 1972).

Prevention of mold development is done by control of storage conditions, such as storing beans at less than 17 -18% moisture and providing sufficient aeration. Aeration, the practice of moving air at low flow rates to cool all beans in a bin, prevents moisture migration and also reduces mold growth and development of musty odors and off-flavors(Maddex, 1978)

Chemicals may be used in mold inhibition. Kihan and Toa (1973) reported that a fungicide termed PCNP (penta chloronitrobenzene) dissolved in dichloromethane gave bean seed good resistance to storage fungi infection. A commercial mold inhibitor termed Grain Treet[R] which is a mixture of acetic, benzoic and propionic acid is under investigation for potential use with navy beans. It is tested to be effective in keeping animal feed high moisture grains stored under adverse conditions in excellent quality for over a year (Smith, 1977). Doyoe and Tu (1977) reported the successful application of Grain Treet[R] with high moisture soybeans and soy products.

Weston and Morris (1954) reported the equilibrium moisture values for seven varieties of beans at 25°C. Equilibrium moisture values were not obtained for the relative humidity range from 80 - 98% because of development of mold growth . The time required for mold growth to become visible ranged between 14 - 20 weeks. Morris et al. (1950) found that fungi growth did not occur at 70% RH, which corresponded to 15.2% moisture, but that mold growth did occur on beans stored at 80% RH.

Lopez and Christensen (1982) studied the invasion of bean seed by storage fungi and found that storage at 76% RH supported the growth of storage fungi. Bedford (1972) stated that beans should be less than 17 - 18% moisture content at 70°F and found that beans stored at 75% RH in a closed desicator at 70°F for 84 days developed about 100 fold increases in total mold count. Dexter et al (1955) found that molding in white pea beans decreased as temperature decreased below 70°F or above 100°F and was stable at relative humidity of 75% between these temperatures. A similar conclusion was drawn from another study (Dexter, 1968).

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%.

Hardshell and hard-to-cook phenomenon

Gloyer (1921) distinguished two types of bean hardness 1- Sclerma., a hardening of the cotyledon interior due to enzymatic changes produced by storage in a damp atmosphere with no ventilation and 2- Hardshell, a condition of impermeability of the seed coat produced by storage in artificially heated rooms with low relative humidity or acquired in the field harvest in hot, dry weather. The same researcher (1928) indicated that there was a great variation in the water permeability of the seed coat for different varieties and no correlation was observed between the color of the seed and the hard shell character. Bourne (1967) defined the "hard shell beans" as beans which did not imbibe water during a 16 - 18 hr soak in water at approximately

70^oF. He also explained that the incidence of hard shell beans in a lot of unsoaked dry beans can be reduced by size grading and rejecting the hard shell -rich smaller sizes.

Harrington (1963) reported that the seeds of different varieties, but of the same moisture content, may have different percentage of hard seeds. Thus, there is the genetic tendency toward hard seed which must be considered. The small hard soybeans, which are resistant to water absorption were examined by analysis and scanning electron microscopy. It was found that the hard beans contained higher amount of crude fiber and calcium than normal beans (Saio, 1976).

Vonmollendroff and Priestly (1979) observed that, hard cooking beans with high moisture content achieved a more rapid uptake of water than the normal beans. This property quite clearly differentiates the hard cooking from the hard shell beans.

Jackson and Varriano-Marston (1981) reported that the electrolyte leakage was greater from stored beans than from fresh samples, indicating that the cotyledon deteriorated during aging. Decorticated samples also indicated that the seed coat contribution to limiting cooking time exceeded that of cotyledon in the fresh samples, but that the cotyledons contributed to reduced cooking time increased with storage, which agrees with reports by Morris (1963).

Hard-to-Cook Beans

Morris and Seifert (1961) concluded that differences in the cookability of dry beans can not be attributed to varying content of phytic acid, calcium, phosphorus, and magnesium. Crean and Haisman (1963) indicated that cooking in extremely hard water complex only 60% of the total phytate in the peas, and showed that insoluble phytate account for only a proportion of the absorbed ions. They concluded that the influence of phytate ions on the texture is small. Rosenbaum and Baker (1966) reported that the cooking rate is not associated with higher phytic acid content, and there is no difference between distribution of calcium in slow and fast cooking peas, but there is a good relationships between the average loss of solids and cooking rate. It is suggested that several factors such as the diffusion of calcium from the seed coat into the cotyledon and the ease of hydration and solubility of certain pea components may determine the cookability of peas. Kon (1968) reported that the differences in the total pectic substances is not significant between normal and hard-to-cook beans.

El-Tabey Shehata et al. (1983) reported no significant correlation was found between the phytic acid /Ca^{++} ratio and the texture of the cooked faba beans, but the correlation was positive between phytic acid and texture. These results indicate that phytic acid content does not affect the texture of cooked faba beans directly, but rather through interrelationships with other seed constituents. These same researchers (1985) reported no consistent significant correlation between the pectic substance fractions and the texture of cooked faba beans for both 1980 and 1981 samples except for the water soluble pectin as a percentage of the total pectin content of decoated seeds.

However, Mattson (1946) reported that the cookability of different dry pea varieties is related to their content of phytic acid and calcium. He suggested that when the phytic acid content is low, the pectin in the middle lamella formed insoluble calcium and magnesium pectate, causing the poor cooking quality. Smithies (1960) reported good correlation, at low average phytic acid content, between the cooking quality of peas and their phytic acid content.

Kon and Sanshuck (1981) indicated that the storage of dry beans under conditions of relatively high moisture and temperature increased the cooking time of the beans about 5 fold. The reduction in phytic acid content was the best indicator of increased cooking time. Cooking time of various legumes studied correlated well with the ratio of %phytic acid/%Ca^{++} present in the beans. The phytin was present predominantly as phytic acid which acts as a chelating agent. The consequence of reduced phytic acid levels was reduced chelating capacity and thus enabling more calcium ions to accumulate within the pectin and desolubilize it.

Jones and Boulter (1983) studied the course of development of hard beans of Phaseolus vulgaris followed during storage at 34°C and 75% RH. After 40 days seed viability dropped rapidly and after 50 days leakage of solids which had remained constant up till 50 days, increased rapidly. Increased metabolic activity led to phytin hydrolysis and membrane deterioration leading to leakage of Ca^{++} and Mg^{++} and then to pectin desolubilization and textural deterioration. It was suggested that the calcium and magnesium component of the phytin would be released by the hydrolytic activity of phytase and thus enabling the cations to diffuse to the pectin, facilitated by the observed membrane degradation, and to desolubilize the pectin by the formation of cation bridges (Jones and Boulter, 1983). These same researchers

(1983) reported that reduced imbibition value and reduced pectin solubility can both cause reduction in the rate of cell separation during cooking in beans and hence an increase in their cooking time. Solute leakage during soaking due to membrane breakdown, phytin catabolism and pectin demethylation, are all key factors in the development of hard beans.

Moscoso et al. (1984) studied mature red kidney beans stored at high temperature and high humidity, and evaluated over a storage period of 9 months. The rate of softening of beans and the dissolution of pectin during cooking followed apparent first order kinetics and their apparent rate constants correlated highly with each other. These researchers stated that the loss of cookability in bean seeds during storage probably resulted from a decrease in phytic acid phosphorus and alteration in the ratio of monovalent to divalent cations in the tissue.

Rozo (1982) evaluated the hardness of the beans during different storage conditions and times ($0^{o}C$, $50^{o}C$ and 80% RH; $40^{o}C$ and 80% RH for 2, 3, and 6 months). The hardness of cooked beans as shown by individual puncture measurements increased significantly during storage. The cell wall content as neutral detergent residue (NDR) increased significantly in cotyledon at $40^{o}C$ but not at

30^{o}C. Hemicellulose and cell wall nitrogen contents increased significantly at 40^{o}C, showing high correlation with hardness of beans. Acid detergent residue (ADR), lignin and cellulose value did not change with any of the treatments. It is suggested that Millard polymeric material synthesis occured in cotyledons during storage. The increase in hemicellulose and the presence of the Millard polymeric substances probably contribute to the increase in hardness.

Morris (1963) and Varriano-Marston and Jackson (1981) hypothesized that a complex set of biochemical changes must occur to affect such structural alteration. It is reasonable to assume that numerous enzymes are involved including: phosphatase, peroxidase,and proteases. The observed structural alteration provide an explaination of the increased rate of electrolyte leakage from stored beans during soaking. Lignification of the middle lamella in stored legumes may be one explanation for their decreased cookability. Aguilera (1985) indicated that the hardening of legumes during adverse storage is a pervasive phenomenon which has economic and nutritional consequences among some of the poorer people in the world. The mechanism responsible for this defect might have both an enzymatic and non-enzymatic component.

Vindiola et al. (1986) found that the

correlation of cookability with phytate content, the reduced rate of hardening of blanched beans, and the inhibition of hardening by fluoride ion indicate that a phosphatase enzyme is involved. The interaction of calcium and magnesium ions with pectin in the middle lamella appears to be the second step in the hardening reaction. The content inside the cell, such as protein and starch can have nothing to do with cooking process because the cell wall is not ruptured, but the cells separate individually or in groups when the peas were cooked. The retardation of bean hardening by metaphosphate at an approximate pH of 4 is difficult to rationalize via a lignification mechanism, but does support the enzymes mechanisms involving phytate and pectin. According to Hahn et al.(1977) starch granules in lima beans maintained slight birefringence after cooking.

Bean Physical and Chemical Characterastics

Bean Color

Navy beans packed in the brine retain a normal white color, while beans packed in a sweetened tomato sauce become brownish. Color evaluation is done either by visual inspection or instrumental measurement. Uebersax (1972) used a Hunter color meter to determine the color of dry and processed beans. Consumers are more likely to react to and reject undesirable colors than to notice and object to slight variations within a standard color.

Bean seed coat color results from the presence of polyphenolic compounds, primarily anthocyanidins or tannins. Junek et al. (1980) ; Luh et al. (1975) observed that addition of citric acid during the soaking period improved the color of beans, due to decreased formation of gray color compounds. The ability of the citrate ions to bind trace elements (copper and iron), and inhibit those ions from reaction with phenolic compounds and sulfides control the discoloration in canned beans. Increased pH of canning brine allows increased formation of undesirable discoloration reactions to occur which may render the bean unacceptable to the consumer.

Luh et al. (1975) showed that calcium chloride addition to the brine improved bean color. The beans treated with calcium chloride had higher Hunter L color values (lightness) than the control samples. Burr et al. (1968) and Vonmollendroff and Priestly (1979) reported that higher moisture (above 10%) storage of beans causes a darkening in seed coat and cotyledon color. They concluded darkening was probably due to changes in the phenolic constituents generally classified as the tannins. Voisey (1971) working on the measurement of baked bean color found that large differences in color are evident from crop years and among recipes used.

Bean Flavor

During storage beans may develop chemical deteriorations such as change in overall flavor (taste and odor). Factors involved in the flavor deteriorations are the same as those discussed in previous types of quality degradations.

Studies revealed that extended storage and high temperature caused off flavors and darkening of stored beans. Water activity or moisture content play an important role in many chemical reactions which occur during storage. High moisture beans can undergo lipid oxidation, thus producing rancid off-flavor and color changes.

Discoloration and chemical deterioration of white (pea) beans held at high temperature and high relative humidity were reported by Dexter et al. (1955). Other studies found that beans of moisture content higher than 13% deteriorate significantly in flavor and texture in 6 months at $77^{\circ}F$ (Morris and Wood, 1956). Uebersax and Bedford

(1980) reported a decrease in lightness of beans stored at high relative humidity and temperature for up to 6 months with the greatest change in color occurring in beans stored at 92% relative humidity for 84 days. It was stated that the decrease in lightness and the increase in redness and yellowness corresponded to non enzymatic browning in beans, and that at higher relative humidity and temperature development of molds was partially responsible for color changes.

A comprehensive study on development of off-flavor was conducted by Sahasrabudhe (1974). He indicated that the off-flavor in canned beans was described as: musty, moldy, earthy, sacky, chemical and phenolic. Musty-moldy type is the most predominant off-flavor experienced in North America while the off-flavor of phenolic type is reported by bean users in United Kingdom. The musty flavor is known to be caused by mold growth. Sahasrabudhe indicated that the chemical or phenolic type flavor could result from interaction of chemicals which contact beans prior to harvesting or during handling, storage and processing, or by direct inadvertent contamination of the dry beans. Microbial degradation, formation and accumulation of metabolities from bacterial or fungal contamination can also be the cause. The phenolic compounds in the bean itself can be converted to compounds which produce unfavorable phenolic flavor. Sahasrabudhe (1974) stated that microbial contamination which might have influence on the development of phenolic off-flavor should be considered. The actual cause of this type off-flavor is still unknown.

Drained Weight

Drained weight is a function of the equilibrium of beans and brine in the can. It is therefore highly dependent on the moisture content of the soaked bean prior to filling, the fill weight, and the brine fill (Uebersax and Bedford, 1980). Nordstrom and Sistrunk (1979) studied the quality of eight types of canned dry beans. They found that the drained weights were higher in bean types that had lower shear press readings. Blanch method did not affect percentage splits, but bean type and storage time resulted in significant differences.

In canning pork and beans, generally, higher drained weights were obtained when beans were steamed rather than water blanched; blanching in water below the boiling point gave higher drained weight than blanching in boiling water (Davis, 1976). This researcher also reported that the blanching method affects firmness and wholeness. There were

no significant differences in wholeness of navy bean between blanch methods, however, red kidney beans blanched in water rather than steam had significantly fewer split beans.

Davis et al. (1980) reported that the storage times did not affect drained weights, but that unblanched and uncooled samples were significantly higher in drained weights than the samples cooled after blanching. The blanch method and post-blanch treatment had significant effect, which varied between bean types, for drained weight, shear value and percent split beans. Pintos which were not blanched or were steam blanched had higher drained weight and firmness than water blanched samples (Sistrunk, 1977 and Davis, 1976)

Nordstrom and Sistrunk (1977) reported that the beans canned in tomato sauce had significantly lower drained weight than those canned in water. They indicated that acidity reduced the rate of water imbibition , causing a reduction in hygroscopicity. Shear press values of those beans treated with sauce were 2 - 3 times higher in organic acids and tended to produce insoluble complexes with amylose components of starch.

Bean Texture

Texture may be expressed according to three parameters (Adams, 1975): a. firmness; measured by the force required to penetrate a substance, perceived on first bite. b. Gummness; measured by the force required to disintegrate a substance, perceived during chewing and c. Adhesiveness; measured by force required to remove the material from the mouth, perceived following chewing. These parameters could be evaluated with reasonable accuracy by a sensory panel and also measured quantitatively by quite a variety of methods. Those methods have been used by various investigators to study some basic quality characteristics of beans.

Powrie et al.(1960) raised the question of a possible relation between the seed structure and hardness. Rockland and Jones (1974) suggested that the separation of bean cells during cooking may be related to the transportation or removal of divalent cations, particularly calcium and magnesium, from bridge positions within the pectinaceous matrix of the middle lamella. There is no breakdown of the cell wall of cooked bean. Lee (1979) reported that calcium and magnesium ions decreased the drained weight and ultimately increased the shear resistance of processed beans. Thus, an increase in shear press values is in agreement with the observed inverse relationship of drained weight and firmness by the shear peak height as reported by

Nordstrom and Sistrunk (1979) and Hosfield and Uebersax (1980).

Lee (1979) employed treatments with α-amylase, glucoamylase, pectinase, cellulase and protease. These enzymes treatments showed no significant effects on the processes of water uptake or shear resistance in navy beans.

Anzaldua-Morales et al. (1982) studied the baked beans in brine and in tomato sauce prepared using samples from six different varieties of beans. When tomato sauce was used, some softening was observed. Voisey and Nonnecke (1972) used different methods to measure pea tenderness, including chemical and mechanical techniques with development of several instruments. They observed that, the method selected for further development was a wire extrusion cell because it was inexpensive and suitable as a quality control proceedure.

The major cause of texture change in the seed coats of peas and other legumes during maturation is the formation of a highly specialized epidermal structure composed of macrosclereid cells. The cuticle is considered to be of minor importance in texture. The resulting texture, which may be independent of total skin thickness, appears to be related to slight changes in pectic materials (Reeve, 1945).

Bean Microstructure

During normal cooking in boiling water, intercellular materials within the middle lamella soften and permits separation of adjacent whole cells. No apparent differences have been found between the cellular structure of cooked, water or salt water soaked beans observed with the scanning electron microscope (SEM). However, different cooking rates of the two types of bean soak treatments appear to be related primarily to different rates at which cell separation occurred (Rockland and Jones., 1974). During cooking of whole beans, mechanical stress imparted during starch gelatinization, protein denaturation, swelling and convection, may further facilitate cell separation and the development of the uniform, smooth texture in fully cooked beans. The middle lamella of plant tissue is generally considered to be composed of pectic substances (Kertesz, 1951) associated with divalent cations such as calcium and magnesium (Lethan, 1962)and possibly proteinaceous material (Ginzburg, 1961).

Sefa-Dedeh and Stanley (1979) reported that the cow pea (Vigna unguiculata) showed all the major anatomical characteristics of legume seed under the scanning electron microscope. Structures identified include an external cuticle, palisade and mesophyll cells,a double layer of hour glass cells, and distinct vascular bundles. The seed was characterized by a predominant cotyledon with parenchyma cells containing reserve materials in the form of elliptical starch granules embedded in a protein matrix contaning discrete protein bodies.

Youssef and Bushuk (1982) indicated that the SEM micrographs of the faba bean seed coat palisade cells of the hard-to-cook samples were thicker and longer than those of the soft samples. The samples of different cookability differed in thickness of the cell layer adjoining the micropyle and in width of the micropyle opening; hard-to -cook samples had smaller micropyle opening and thicker cell layers. The hard-to-cook faba bean samples had shorter hour glass cells. Some aspects of the microstructure control the rate of water penetration into the cotyledon during the early stage of cooking.

McEwen et al. (1974) reported a study in which the cotyledons and seed coat of faba bean (Vicia faba L.) cultivar Ackernerle were examined using the scanning electron microscope. Photomicrographs showed no discontinuity in the thick seed coat. A cross section of the seed coat showed characteristic palisade, parenchyma,trachid, and hour glass cells, similar to those of other legumes. Examination of the cells in the cotyledons revealed a variety of shapes for starch granules of about 25 to 40 um in diameter surrounded by irregularity shaped protein bodies of 1 to 5 um in diameter. The cells walls were about 2 um thick and had a ribbed or furrowed inner surface.

Sefa-Dedeh et al. (1978) studied the microstructure of cowpeas. Scanning electron microscopy was used to study changes in microstructure during the cooking process. The major effect observed was a breakdown of the middle lamella, while the cell wall remained intact. Heating the cowpeas from 25 - 90^{o}C had no major effect on the microstructure. Fracture occurred across the cell walls when the samples were sliced with razor blade, but at 100^{o}C fracture occurred in the middle lamella leaving most of the cells intact (Sefa-Dedeh et al., 1978). In the raw state, the middle lamella is usually stronger than the cell wall with the result that when stress is applied, the tissue breaks across the cell walls. The middle lamellas, become relatively softer with cooking, resulting in rupture along the middle lamella when stress is applied.

Hahn et al. (1977) employed light and scanning electron microscopy to characterize intracellular configurational changes of starch granules during gelatinization as well as to estimate any apparent differences in gelatinization temperatures between standard and quick-cooking lima bean cotyledons. Intracellular gelatinization of starch was indicated at about 76°C for water soaked and at 85°C for salt soaked (quick-cooking) beans and progressed successively through characteristic configurational changes until maximum expansion occurred at the boiling point (100°C). The stage of expansion was dependent only upon the temperature of the medium and independent of the time during which cells were held at any given temperature. Viewed under the microscope, each stage of gelatinization was populated by a distribution of granule configurations.

Rockland et al. (1977) determined the gelatinization temperature of freely dispersed lima bean starch in both pure water and a dilute aqueous salt solution. In either an excess of pure water or salt solution the dispersed granules expanded and exhibited a characteristic sequence of explicit configurations. Various stages of gelatinization were characterized in light or scanning electron photomicrographs and identified as : 1- swollen; 2- dimpled or indented; 3- dough nut or erythrocyte-like; 4- rubber-raft shaped; 5- pancake; and 6- dispersed or diaphanous. The dispersed granules retained a veil-or film-like residue which has been defined as a "membrelle". Gelatinization was initiated at a specific temperature and progressed to completion over a limited temperature, the proportion of granules affected increased until all the granules were dispersed. The gelatinization temperature range was 71 - 79°C in water and was 79 - 85°C in the salt solution.

Dry Bean Processing

Bean Soaking

The soaking process, in which beans imbibe water, is greatly dependent on the inherent physico-chemical composition of the bean. Sathe and Salunkhe (1981) reported that the polar amino groups of protein molecules are the primary water binding sites in Great Northern beans.

Kon et al (1973) atempted to develop an extensive mechanical means for making quick-cooking beans. He reported when soaked and unsoaked samples are compared, the peeling of the seed coats reduces the cooking time by 26% and 36%, respectively. This observation supports the theory that the seed coat is the primary barrier for water uptake. Varriano-Marston (1979) studied the effects of accelerated storage on water absorption and cooking time. She indicated that the seed coat was the major barrier in water uptake, thus supporting the work of Kon and his co-workers (1973). The removal of the seed coats produced a decrease in cooking time, from 80 minutes to 30 minutes, suggesting that the seed coat is the major barrier in water uptake in beans (Brown and Kon, 1970).

However, when subjective analyses (such as taste panels) were used the seed coat condition did influence the judgment of the judges (Muneta, 1964). The beans with an intact seed coat were found to be more firm than beans without a seed coat.

Several factors have been shown to influence water uptake. These include the age and composition of dry beans, storage conditions, moisture contents and production condition factors (Bedford, 1971). Pectic substances, hemicellulose and protein are functional components in absorbing water in plants (Ott and Ball, 1943). Hamad and Powers (1965) found rates of water imbibition were inversely related to the pectic content of dry peas and beans. Uebersax (1972) reported water uptake values decreased with high temperature and high humidity storage. Burr and Kon (1967) reported decrease in water absorption rate for 'Sanilac' navy beans with increased bean moisture content and storage time. Nordstrom and Sistrunk (1979) reported low original moisture levels before soaking resulted in higher hydration ratios.

Soak Water Additives

The use of various additives in the soak water have also been widely studied to evaluate their effects on processed bean quality. Examples of selected additives include: sodium bicarbonate, phosphate, sulfite, oxalic acid, hydrochloric acid, EDTA and others.

Hoff and Nelson (1965) reported that EDTA had no effect on water uptake. Luh et al. (1975) studying factors effecting color, texture and drained weight of canned dry lima beans, reported that EDTA prevented discoloration by its chelating action to immobilize metal ions. Junek et al. (1980) reported that EDTA had no pronounced effect on an increase in firmness among navy, pinto and kidney beans. They observed that addition of malic and citric acids in navy beans decreased the drained weight, due to decreased imbibed water in an acidic environment as a result of decreased starch swelling potential.

Lee (1979) found that the addition of sodium hexa meta phosphate (NaHMP) increased water uptake, softened the beans and resulted in leaching of soluble solids. Hoff and Nelson (1965) observed that polyphosphates greatly increased water uptake. These results were attributed to the chelating action of polyphosphates with divalent metal ions which form tough metal cross linked pectates. Polyphosphates also dramatically influence water binding of proteins.

Luh et al. (1975) reported that addition of calcium chloride to the canning brine produced a firmer bean due to the formation of firm calcium pectate. Davis and Cockrell (1976) and Quenzer et al. (1978) found that increased concentration of calcium chloride resulted in increased shear press values for canned lima beans, but decreased the rate of water uptake.

Nordstrom and Sistrunk (1977) reported an increase in shear press values of pinto and kidney beans in a acidic medium (pH 5.0 to 5.2). Synder (1936) showed the acidity of the soak water reduced the rate of water uptake. Luh et al. (1975) found that product texture became firmer and the drained weight decreased as pH decreased due to loss of hydration during the soaking period.

The addition of sodium salts to beans was suggested to produce quick cooking dry beans (Rockland and Metzler, 1967). Varraino-Marston and De'omana (1979) proposed that the addition of sodium salts produced an ion-exchange mechanism with the sodium ion replacing divalent ions, and could result in a solubilization of pectic substances during soaking and cooking. Rockland and Jones (1974) reported that a higher sodium chloride concentration resulted in an enhancement of bean flavor. Zaragosa et al. (1977) reported that refried beans prepared from the quick cooking beans had a more bland flavor than the commercial beans and a slightly darker color.

Dry Bean Cooking and Canning

Cooking of dry edible beans is necessary in order to bring about acceptability in flavor and texture. Junek et al. (1980) found that increasing the soak temperature from 15 to 35°C decreased the shear peak height, indicating increased tenderness of the beans. Moreover, Quast and Da-Silva (1977) found that raising the soaking temperature 10°C caused a 3.36 fold decrease in cooking time in black beans. Davis (1976) found blanching below the boiling point of water gave a higher drained weight than blanching at the boiling point, suggesting more water uptake and less solids leaching.

Quast and Da-Silva (1977) reported that cooking beans for nine minutes at 127°C gave the same results as cooking beans for 260 minutes at 98°C. However, these researchers reported that one must be careful to employ a process long enough to guarantee the commercial sterility of product. Rockland and Jones (1974) using the electron microscope, found that there were no observable differences in cellular structure of cooked, salt water soaked beans. therefore, the cooking rates must be related to the differential at which internal cell separation occurs.

Factors effecting cooking characteristics have been associated with seed coat (Synder, 1936; Gloyer, 1932) and cotyledon (Mattson, 1946). Adams (1975) by relating soaking time and cookability mentioned that the hilum and micropylar areas usually admit water readily, but seed coats differ strikingly in this regard. Powrie et al. (1960) stated that information of chemical composition of specific tissues and localization of chemical constituents in those tissues is a prerequisite for an explanation of and chemical changes in bean tissues during mechanical, thermal, chemical and enzymatic treatments.

Bressani and Elias (1974) reported a minimum of two hours for cooking soaked beans (Phaseolus vulgaris L.) at atmospheric pressure. There have been numerous attempts to find a way of lowering the cooking time for legumes (Esselen and Davis, 1941; Dorsey et al ., 1961).

Steinkraus et al. (1964) reported on a new process for preparation of quick-cooking dehydrated beans by hydration the dry beans through soaking in water for 15 minutes, followed by a precooking in steam and coating by dipping in 20% sucrose solution at 160^{o}F, then dehydration. Rockland and Metzler (1967) reported a process for quick-cooking large lima beans using an intermittent vacuum treatment for 30 to 60 minutes in a solution of inorganic salts (sodium chloride, triphosphate, bicarbonate and carbonate, soaking for 6 hours in the same salt solution, rinsing and drying. They indicated that this process facilitated infusion of the salt solution through the hilum and tissues in the hydrophobic outer layer of the seed coat. Wetted by the solution, the inner membrane hydrates, plasticizing the seed coat and causing it to expand to its maximum dimensions within a few minutes. As a result, cotyledons imbibe the solution rapidly. This caused about 80% reduction in the cooking time. However, this patented processed is not currently commercialized.

MATERIAL AND METHODS

Source of Beans

Four cultivars representing four commercial classes of dry beans were used in this study. "Seafarer" was a navy bean, "Black Turtle Soup" (BTS) was a small seeded black bean, "Oletha" was a pinto bean and "Montcalm" was a dark red kidney bean. They were produced at Saginaw Valley Bean and Sugar Beet Research farm near Saginaw, Michigan during the 1984 and 1985 growing seasons in a nursery. Four raw plots of the four cultivars were grown on a charity clay loam [Typic Haplaquolls, fine-silty, mixed (calcareous), frigid] soil. Herbicide and fertilizer applications were made on recommendations for commercial bean production.

Bean Handling and Moisture Adjustment

Dry beans were received immediatly following harvest, screened and hand picked to remove foreign material. Initial moisture was obtained using a Motomco Moisture Meter (Model No.919. Motomco Inc, Electronic Div., clark, N.J.) and initial moisture content ranged between 13 and 16%.

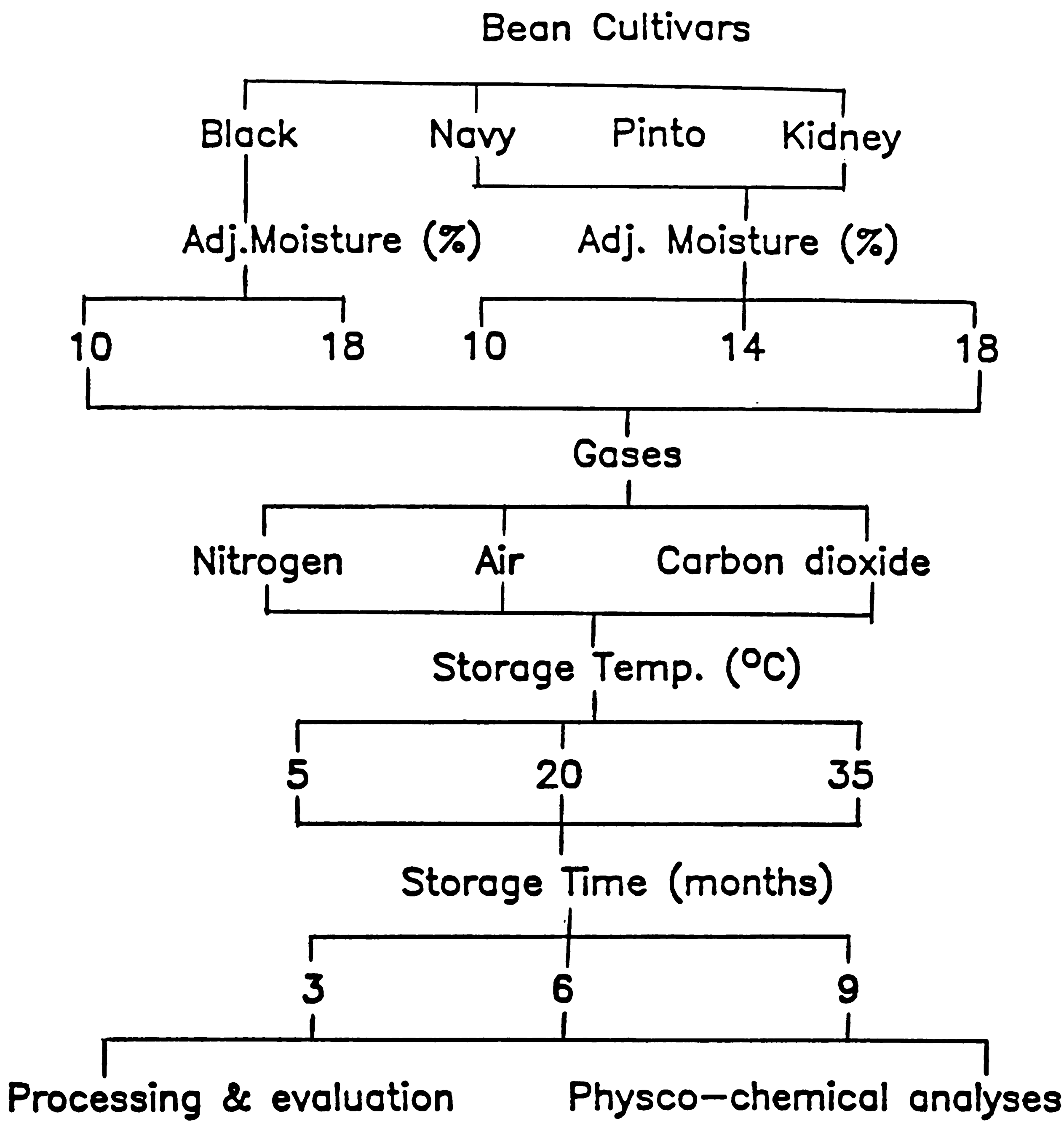
All beans were adjusted to appropriate designated moisture by: 1- Monolayer drying at room temperature (27^{o}C), or by; 2- Conditioning in saturated water vapor (100 RH) chamber mantained at 20^{o}C (Chrysler Refrigerator, Koppin Co, Detriot, MI). Beans were evenly distributed on screens to facilitate moisture adjustments. Upon attainment of desired moisture contents, all samples were twice sealed in double polyethylene bags and held at 5^{o}C for two weeks to provide equilibration among all seeds for a designated moisture treatment and to assume uniform moisture distribution within the seeds prior to initiating the storage experiments.

Experimental Procedure

Study 1: Effect of Storage Conditions on the Quality Characerstics of Raw and Processed Beans.

The moisture content of the four strains comprising the experimental material were adjusted as follows:

Commercial Classes (Cultivars)	Moisture
Navy (Seafarer)	10, 14, 18%
Pinto (Oletha)	10, 14, 18%
Kidney (Montcalm)	10, 14, 18%
Black (BTS)	10 and 18%



Flow chart (1) Procedural diagram of the dry bean storage

Each bean cultivar for each moisture content was stored in three different gas atmospheres (N_2, CO_2 and air) at three temperatures (5, 20 and 35^{o}C) and for three time periods (3, 6, and 9 months).

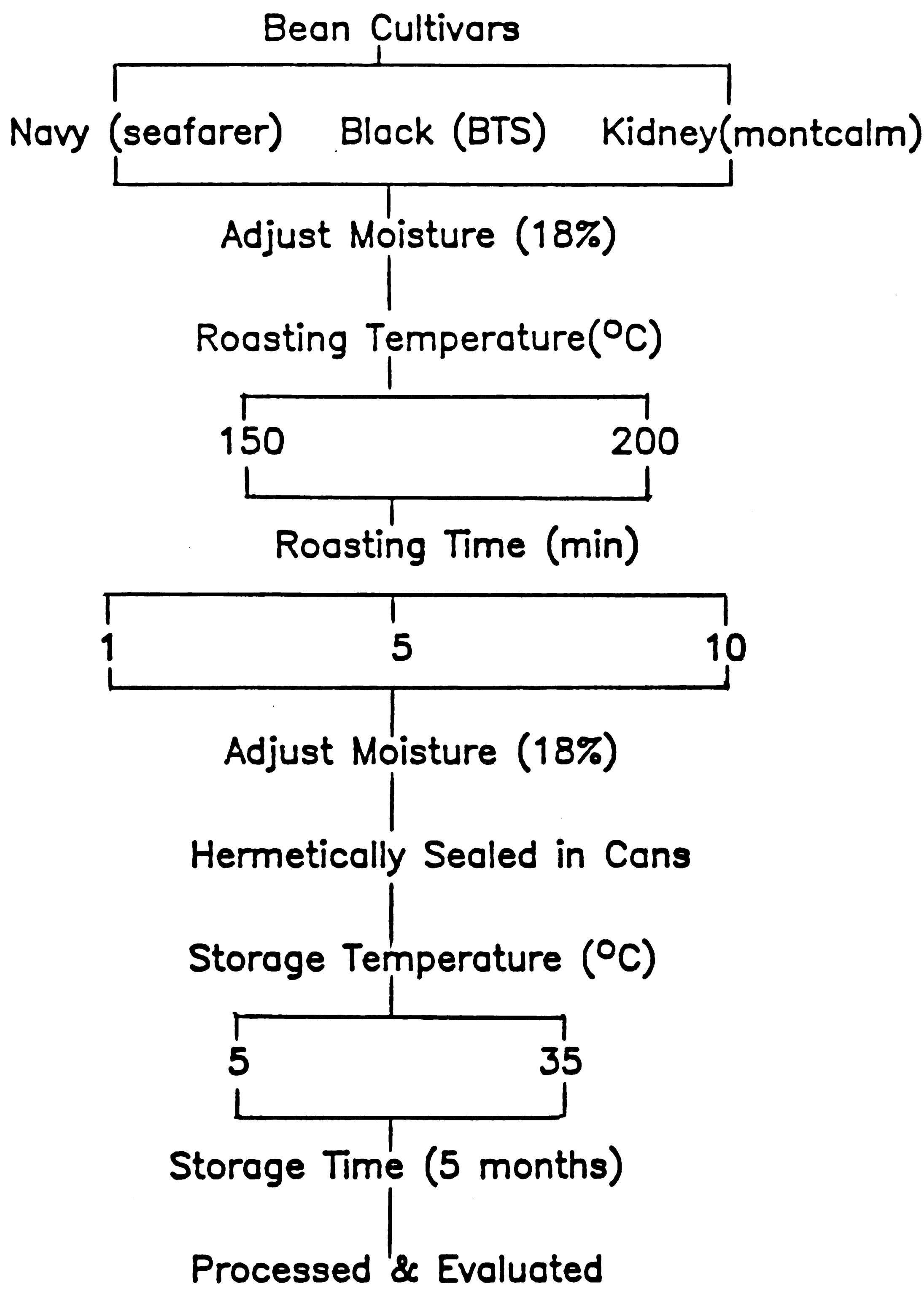
A fresh bean weight equivalent to 300(g) bean solids was placed in a labled enameled can (303 x 406) (each 100g bean solids per can), air evacuated from at 63.5 cm Hg and replaced with desired gas supplied from a pressurized cylinder. The process was repeated three times before the cans were double seamed using a Rooney Semi-Automatic can sealer (Rooney Machine Co.). Three replicate cans for each treatment (moisture, gas, temperature and time) were stored in controlled temperature cubicles maintained at the prescribed temperature. Beans were removed from storage at designated time intervals and evaluated for quality characterastics. The one hundred gram solids from the fresh beans was calculated as follow:

$$\text{100 (g) solid, fresh weight (g)} = \frac{\text{100 (g) fresh bean X 100 (g) bean solid}}{\text{100 - \%moisture}}$$

Study 2: Storage Stability of Freshly Harvested and Roasted Beans

Three beans classes (navy, kidney, and black beans) were sorted and cleaned by hand to prepare them for roasting at two different temperatures (150°C and 200°C).

Cleaned and washed fine high abrasive silica sand was used as a heat transfer medum. Four kilograms of sand were used to heat one kilogram of beans. Each roasting treatment was replicated three times. The sand was heated at two different temperatures (150°C and 200°C) in an air-oven (PS Precision Scientific Co., Chicago, IL.) and the temperature of sand was equilibrated to the appropriate temperature and measured by direct immersion of a mercury thermometer. Each four kilogram lot of sand was divided into two parts, and one kilogram of beans were distributed on the surface of one part (800 cm^2 area) and covered directly with the second portion of sand and kept in the oven for three different roasting periods (1, 5, and 10 minutes). The mixture (sand and beans) was separated by sieving and the beans were cooled directly with cold sand (5°C) for 10 minutes and



Flow chart (2) Procedural diagram of roasted dry bean then placed in plastic bags for moisture adjustment.

Beans were adjusted to 18% moisture to induce maximum hardening potential, divided into two equal parts, sealed in 303 x 406 cans and stored at 5°C and 35°C for 5 months. Following storage, beans were evaluated for canning quality.

Study 3: The Effect of Calcium Ions on Cookability of Beans Stored Under Different Conditions.

Navy (Seafarer) beans stored under conditions established in study 1 were selected to provide a qualtitative description for bean hardness. The following storage conditions were utilized in this experiment.

Designated Hardness	Storage Conditions (Temperature, Moisture, Time)
Soft	5°C, 10%moisture, 9 months
Medium	20°C, 14%moisture, 9 months
Hard	35°C, 18%moisture, 9 months

Beans were placed in a 50 ml test tube and cooked with 30 ml cooking solution for one hour at either 60 or 90°C.

Cooking solutions were either distilled deionized water or contained 150 ppm calcium ion prepared using reagent grade $CaCl_2$. The samples were sectioned after cooking and prepared for microstructure analysis by a scanning electron microscope.

Bean Processing and Analyses

At the end of the storage times (3, 6, and 9 months for the stored raw beans and 5 months for roasted beans) the stored cans were opened and bean color was measured before soaking and processing. The bean samples were placed in nylon mesh soak bags (10 x 15 cm) and held in individual polyethylene bags prior to processing.

Soaking and Blanching

All beans retained in nylon mesh bags were soaked for 30 minutes in 100 ppm of calcium ion water at room temperature. The samples were then transferred by hand to a steam jacketed kettle to hot soak for 30 minutes at 87.5°C in 100 ppm calcium ion water.

Soaked beans were removed from hot water and were submerged into cold tap water for 1 minute. Cooling was performed to insure termination of the hot soak cycle and to reduce vapor losses. Cooled beans were removed from the cooling water and drained on perforated screens prior to can filling.

Can Filling, Brining and Exhausting

Each drained nylon mesh bag was opened and the blanched beans were rapidly transferred to coded (303 x 406) cans. Beans and cans were weighed to the nearest 0.1 gram. Soaked bean weight was determined by subtraction of the can tare. Calculation of soaked bean moisture and hydration ratio were performed according to the equation below:

$$\frac{\text{Soaked bean wt(gm)} - \text{Initial bean wt(gm)}^{*}}{\text{Soaked bean wt(gm)}} \times 100 = \text{Soaked bean moisture(\%)}$$

* Equivalent to 100 gm solids

$$\frac{\text{Soaked bean wt(gm)}}{\text{Initial bean wt(gm)}} = \text{Hydration Ratio}$$

Cans were then transferred to an exhaust box conveyor and were hand filled until over flowing with heated brine (90^{o}C). The cans were exhausted for four minutes in 85^{o}C water. The heated brine solution contained 0.31% sucrose and 0.25% sodium chloride in 100 ppm calcium ion water heated to 90 - 95^{o}C.

Sealing and Thermal Processing

The headspace of the cans was automatically adjusted to 0.63 cm with a Number-00 Canco Vacuum closing Machine (Model 6, American can Co.) and the cans were double seamed to provide a hermetic seal.

The sealed cans were hand transferred to a still retort for thermal processing to ensure commercial sterility. Beans were processed at 115.6^{o}C for 45 minutes in a FMC Still Retort (Food Machinery Corp., Hooperston,IL), and all bean samples were cooled for 10 minutes in 20^{o}C water.

Canned Bean Storage

Dried processed cans were stored in a designated controlled temperature cabinet at 25^{o}C for three or four weeks prior to quality evaluation. This was necessary to ensure proper bean-brine equilibration.

Bean Evaluation

Bean Cookability

Cooking time of raw beans following storage was determined with a pin-drop cooking apparatus (PDCA) described by Mattson (1946) and Morris (1963). Forty seeds of each cultivar from each bean treatment were positioned individually in the cylindrical cells of the PDCA, so that the tip of the 90.4 gram rod was in contact with the surface of the bean. The PDCA was then placed into a water bath at 99°C and the water level adjusted to 10 cm above the seeds. Beans were judged as "cooked" when the tip of the rod passed through the bean. Cooking time was the time required to cook 50% of the sample (Morris, 1963), and was recorded from the point of submersion of the cooker.

Objective Color Measurements

Objective reflectance color measurements of beans were determined with a Hunter Lab Model D25 Colors and color Difference Meter (Hunter Associates, Fairfax, Virginia). The instrument was standardized using a standard white tile (L = +94.5, a = -0.9, b = 1.0). Beans were placed in an optically pure glass sample dish and covered to shield interfering light from activating photo cells. Coordinate values (L, $+a_L$ and $+b_L$) were recorded for each sample. Dry bean color measurements were performed for each sample treatment by placing a one hundred gram sample of bean solids into the sample dish. Two readings per sample were performed. Processed bean color measurements were performed on one hundred grams of washed drained beans. Duplicate samples were taken per processed can.

Drained Weight of Processed Beans

The contents of a can were poured onto an 20.32 cm diameter U.S. standard No.8 screen (0.239 cm opening). The screen was submerged and rotated in 21.0°C water to remove the free sauce and facilate even distribution of the beans on the surface of the mesh screen. The screen and contents were slowly agitated in the water for three rotations to uniformly distribute and wash the beans. The screen and contents were withdrawn from the water and positioned at a 20° angle for two minutes to facilitate drainage. The beans were weight (+0.1 gm) and the drained weight was recorded as grams of beans retained on the sieve and the drained weight ratio calculated according to equation below:

$$\frac{\text{Bean drained wt(gm)}}{\text{Soaked bean wt(gm)}} = \text{Drained wt ratio.}$$

One determination per can was made.

Visual Examination of Processed Beans

During the drained weight procedure, the beans were visually judged using hedonic scales for clumping (1 - 5) and splitting (1 - 5). Each can received a subjective clumping and splitting score (hedonic Scale: 1 = none, 5 = excessive).

Processed Bean Texture

After color determination, beans were evaluated for texture using an Allo-Kramer recording shear press (Model TR-1, Food Technology Corp., Reston,VA). The 3,000 pound transducer and No.C-15 standard shear compression cell were used. The rate of shear compression blade travel was 0.52

cm/sec and both range 1/3 and 1/10 full scale were employed. A sample size of 100 gm of processed beans was placed in the cell, evenly distributed, and sheared. The entire cell was cleaned and rinsed between each measurement. Two measures were made per can.

Firm beans required a greater force to shear than did soft beans. This was indicated by a higher peak height for firmer beans. Depending on the genotype, two types of peaks were produced: The type A peak indicated a predominant shear component and the type B peak indicated that mostly compression forces operated during bean deformation (Hosfield and Uebersax, 1980). For texture evaluation of samples in the current study, the compression peak height was recorded and the shear force (kg force/100 gm) was calculated as follow:

Shear Force (kg force/100 sample) = (Transducer lbs. x Range/100) = 1.3608 kg/100 gm x Shear value.

Chemical Analyses

Moisture

In addition to the Motomco moisture meter method previously described, the following oven drying method was used for moisture determination. Approximately three grams of ground bean meal (356 microns diameter) were weighed into previously dried and tared aluminum dishes and dried to a constant weight at 105 for 5 hours in an air oven. The sample weight and the moisture was determined from the weight loss on the fresh weight basis (AACC. method 44 - 15):

$$\%\text{Moisture} = \frac{\text{Moisture loss (gm)}}{\text{Sample fresh wt(gm)}}$$

Total Protein

Approximately two grams of ground bean meal were analyzed by the Macro-Kjeldahl procedure. Percent nitrogen was multiplied by 6.25 to obtain % total protein (AOAC method 2.057, 1984)

$$\%\text{N} = \frac{(\text{mL HCl x N. of HCl}) - (\text{mL NaOH x N. of NaOH})}{\text{Sample weight (gm)}} \times 1.4007$$

Where N. = Normality of solution

Protein content (%dry basis) = 6.25 x %N

Total Soluble Protein

Six grams of ground bean meal were mixed with 100 ml of distilled water in a 250 ml centrifuge tube. The mixture was shaken for 1 hr at 300 rpm by using a Junior Orbit Shaker (Cat. No. 3520. Lab Line Instruments, INC. Metrose Park, IL) then centrifuged for 15 minutes at 2500 gm. and filtered (AOAC method 14.027, 1984). The nitrogen in 25 ml filtrate was determined by Macro-kjeldahl procedure according to AOAC method 2.057, 1984.

Total Soluble Solids

A ten gram sample of the soluble protein filtrate was placed into a dry, pre-weighed aluminum pan and dried to a constant weight at 100^{o}C for 3 hours in a air-oven. The samples were cooled in a desicator and the final weights were measured. The total soluble solids were determined as follows:

$$\%\text{Total soluble solids} = \frac{\text{wt. of residue after drying (gm.)}}{\text{wt. of filtrate sample (gm.)}} \times \text{D.F.} \times 100$$

Where D.F. = Dilution Factor

Soluble Pectin

Pectin content was determined by measuring the levels of their main component unit galacturonic acid, as uronic acid (Jones and Boulter, 1983).

Cold water soluble uronic acids were extracted by soaking 5 gm. of half bean cotyledons for 18 hours in 100 ml distilled deionized water at room temperature. The cotyledons were drained by filtration (using 18.5 cm Whatman No. 3 Filter paper) and the filtrate was kept refrigeratated ($5^{o}C$) prior to pectin analysis. The cotyledons were then refluxed for 20 minutes with 125 ml distilled water in a 250 ml flask to remove the water soluble uronic acids. After filtration, the residue was finally stirred for 15 minutes in 50 ml 0.05 N NaOH at room temperature to remove the water insoluble uronic acids, the filtrate was washed with 0.05 N NaOH and the uronic acids determined using the technique of

Blumenkrantz and Asboe-Hansen(1973) except that O-hydroxyl diphenyl was used instead of M-hydroxyl diphenyl.

Bean Microstructure

Raw Bean Microstructure

Two methods were used to prepare the samples for Scanning Electron Microscope(SEM): 1)- Unfixed samples or air drying method: Horizontal and cross sections were taken from the seed cotyledon using a razor blade after adjusting the moisture content to approx. 15%. Sections were dried at room temperature for 48 hours, then mounted on stubs using television tub koat (Gc Electronics). Mounted samples were coated with gold using a Mini-Coater Maclin (Film-VAC INC) for 5 minutes. 2)- Fixed samples: one half of bean seeds were fixed in gluteraldehyde (4% in 0.2% phosphate buffer, pH 7.2) at 4°C for 24 hours. Horizontal sections were taken from those seeds and transferred to the buffer at 4°C. Buffer was changed four times over a two hour period to remove the gluteraldehyde.

The fixed tissues were dehydrated in four; 30 minute changes of 25, 50, 75, and 95% ethanol and three 30 minute changes of 100% ethanol. The dehydrated samples were dried by using the critical point drying technique (Anderson, 1951). Samples were mounted on stubs and coated with gold. The coated samples were examined and photographed in the MSU electron optics laboratory using a Super III Scanning Electron Microscope with an accelerating voltage of 15 KV. Selected tissue sections or positions were examined at various magnifications.

Extracellular Starch Microstructure

Purified starch was prepared from dry kidney and navy beans. Both distilled water and 0.05% NaOH solution were used for the starch purification. The procedure of Rockland et al. (1977) was followed with some modification. One hundred grams dry beans were soaked overnight in distilled deionized water. The rehydrated raw beans were ground to a slurry with 1 liter of water in a large Waring blender. The slurry was filtered through three layers of cheese cloth to remove seed coat residue and other fiber which are undispersed solids. The dense starch granules were allowed to settle for 5 hours at 5^{o}C and the turbid supernatant was removed by decantation. Fresh water was added and the crude starch sediment was resuspended. The sedimentation, decantation and redispersion was repeated six additional times. Clear supernatant and turbid/solid starch sediments were obtained. The final starch sediment was redispersed in water, filtered under vacuum on Whatman No.3 analytical filter paper and washed with several volumes of water. The same procedure was repeated by using the 0.05% NaOH solution instead of distilled water for the extraction , sedimentation, decantation and redispersion. A clear supernatant and white starch sediment was obtained using this alkaline extraction.

The starch cake was spread into a shallow layer in an aluminum dish and dried for 48 hours at room temperature. The dried starch aggregate was crushed gently into a powder with the broad side of a stainless steel spatula in order to minimize fragmentation of granules. The powdered starch was screened on a standard metal sieve (opening 297 microns). The fraction containing starch granules and small aggregates were employed for the gelatinization studies.

Approximately 100 mg portions from each treatment of dry bean starch were placed in 15 x 150 mm pyrex test tubes containing 10 ml of water. The dispersion were held at 20^{o}C for 20 minutes to allow rehydration of the starch granules. Six tubes for each treatment containing 10 ml distilled deionized water were placed in a glycerin bath maintained at a constant temperature in an air-oven. The temperature of the water was measured by direct immersion of a mercury thermometer. A 2 ml aliquot of the prehydrated starch dispersions was added to its corresponding preheated tube (the same label) previously adjusted to a constant temperature. The above heating process was repeated with both navy and kidney beans at different temperatures 65°C, 70°C, 77°C, 80°C and 85°C.

At 1, 15, and 45 minute intervals, two tube starch dispersion from each treatment were poured onto a petridish and the dispersion was concentrated to 2 ml at room temperature. Three to four drops of each dispersion were centered on an Avery-Spot-O-Glue covered stub. Stubs were held at room temperature for drying. The dried samples were coated with gold and examined with the JEOL scanning electron microscope.

Calcium Ion and Bean Microstructure

The navy bean samples were heated in distilled deionized water and 150 ppm calcium solution at two different temperatures (60°C and 90°C) for one hour by using the glycerin bath in an air-oven.

One hundred mililiters of 0 and 150 ppm Ca solutions were placed in 150 ml flasks and heated in a glycerin bath which was adjusted to the desired temperature in an air oven. The temperatures of the solutions were directly measured by using a mercuric thermometer. Three grams of the navy beans were placed in each solution for 1 hr and then cooled in a refrigerator at 5^{o}C.

The cross sections and the seed coat were prepared from each treatment by sectioning with a razor blade and then drying them at room temperature for 48 hours. The dried samples were fixed on the stubs by using Avery-O-Glue and Tube Coat then coated with the gold by using a Mini-Coater Maclin before examination under the JEOL JSM-35CF Scanning Electron Microscope.

Statistical Analysis

All data were subjected to analyses of variance to ascertain differences between treatments. The "statistical package for the social science" computer programs described by Nie et al. (1975) for use on the CDS 6500 computer laboratory and Sharp EL-51005 scientific calculator were used to assist statistical analyses.

Multivariant analysis of variance was used to determine the effect of treatments with subprogram ANOVA. Single classification analysis of variance and Tukey mean separations were determined with the subprogram ONEWAY.

The treatment means with like letters in Tukey separation indicated no significant differences at $P<0.05$. Mean squares with significant F ratio were reported with probability levels of $P<0.05$ (*) and $P<0.01$ (**). The cofficient of variation (CV) which expresses the standard deviation as a percent of the mean was calculated for the various treatments (Little and Hills, 1972). Pearson correlations among measures were reported.

RESULTS AND DISCUSSION

Study 1: Effect of Storage Conditions on the Quality Characteristics of Raw and Processed Beans

1.1 Effect of Storage Conditions on Cooking Time of Raw Beans

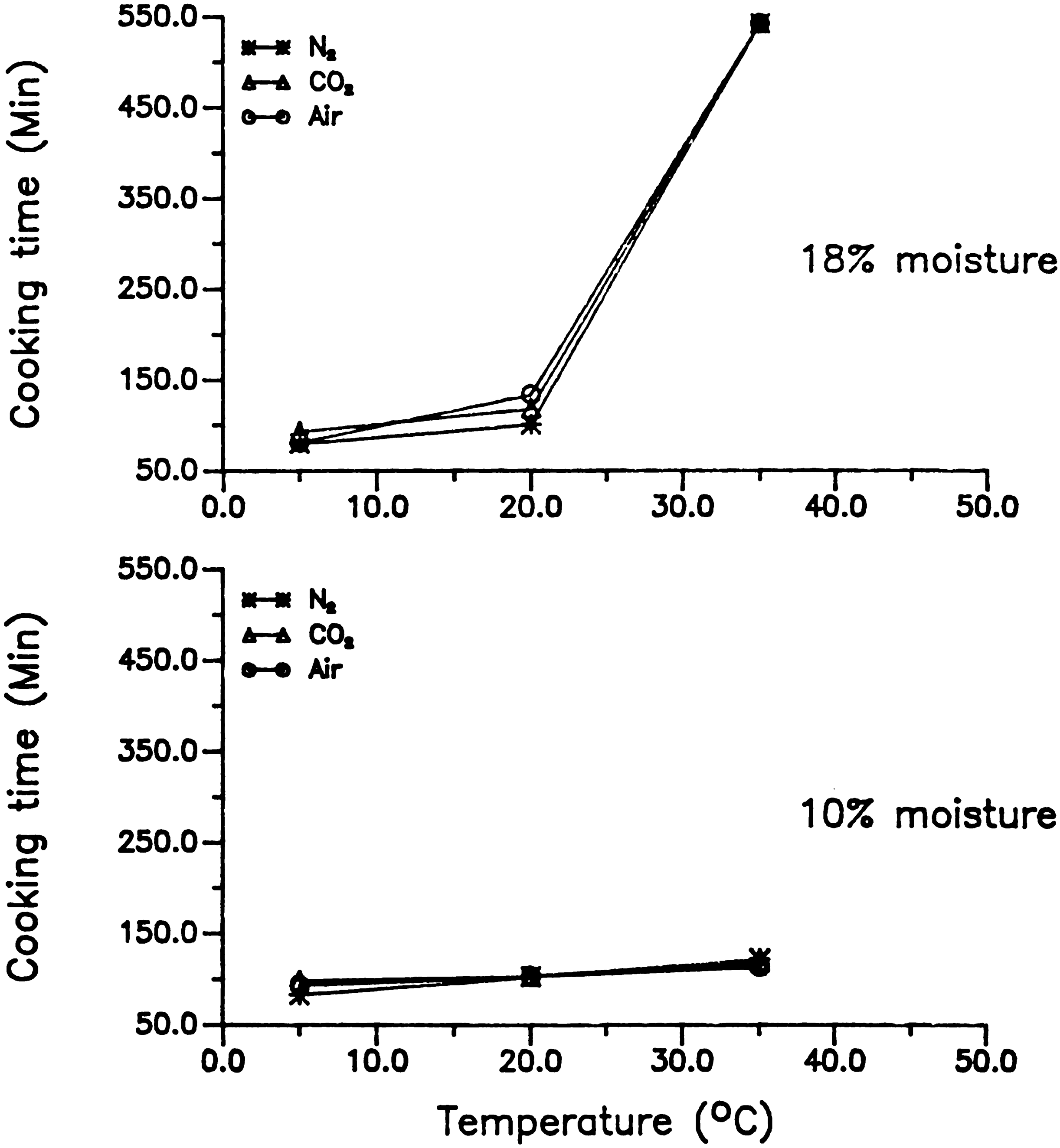
The cooking time of three bean cultivars stored for three months was determined by using a Mattson cooker instrument (Mattson, 1946). Cooking time results are presented in Tables 1, 2, 3 and 4, and Figures 1, 2, 3 and 4. Mean squares from the analysis of variance (Table 1) showed significant differences among temperatures, various moistures and cultivars, but no differences among gases (blocks). Observations on treatment means showed, that as the temperature and moisture during storage increased, the cooking time also increased. These data show a short cooking time (80 - 135 minutes) following low temperature (5°C) and low moisture (10%) storage, while the cooking time increased to greater than 9 hours (540 minutes) for beans stored under high temperature (35°C) and high moisture (18%). It is observed from Tables 2, 3 and 4 that the navy (Seafarer) beans had a shorter cooking time, than that obtained for

Table(1) Analysis of variance of cooking time (min.) of three bean cultivars stored under three gas atmospheres at two temperatures and three moistures for three months

Source of variation	df	Cooking Time (min.)
		Mean Squares
Total	53	1663.23
Main Effects	17	4675.01**
Temperature (Temp.)	1	13442.66**
Moisture (Mois.)	2	3012.07**
Cultivar (Cult.)	2	7940.52**
2-way Interactions		
Temp. x Mois.	2	6216.00**
Temp. x Cult.	2	3284.22**
Mois. x Cult.	4	2673.85**
3-way Interactions		
Temp. x Mois. x Cult.	4	3607.88
Blocks (Gas atmosphere)	2	153.35
Error	34	246.16
% CV		13.33

Table (2) Mean values of cooking time of navy (Seafarer) beans stored under three gas atmospheres at three temperatures and moistures for three months

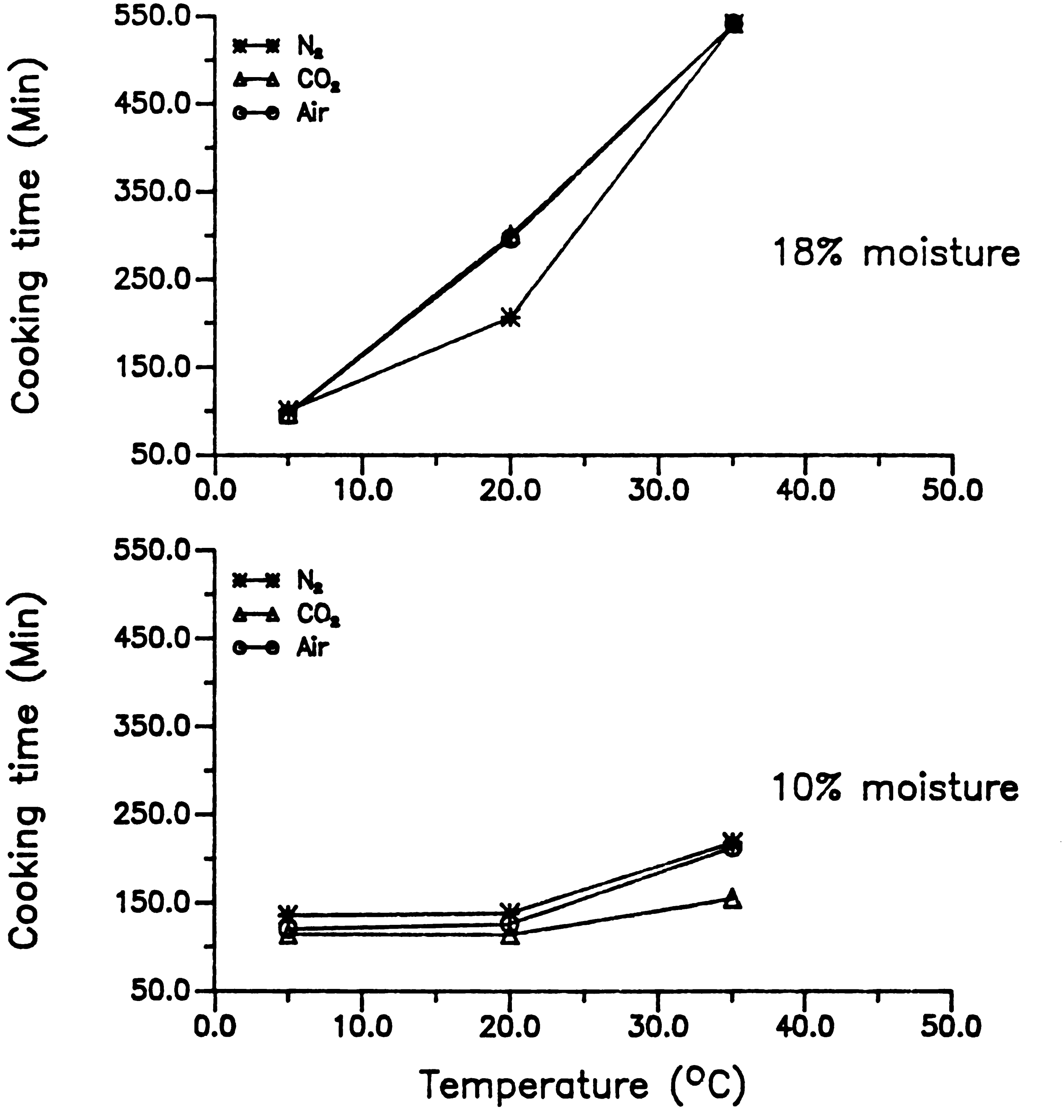
Moisture (%)	Temperature (^oC)	Cooking Time (min.)		
		Nitrogen	Carbon Dioxide	Air
10	5	82	97	92
	20	102	102	102
	35	121	117	112
14	5	83	95	79
	20	105	111	108
	35	179	207	190
18	5	79	92	80
	20	100	117	132
	35	>540	>540	>540



Fig(1) Cooking time for navy beans stored under three gas atmospheres at three temperatues and two moistures for three months

Table (3) Mean values of cooking time for pinto (Oletha) beans stored under three gas atmospheres at three temperatures and moistures for three months

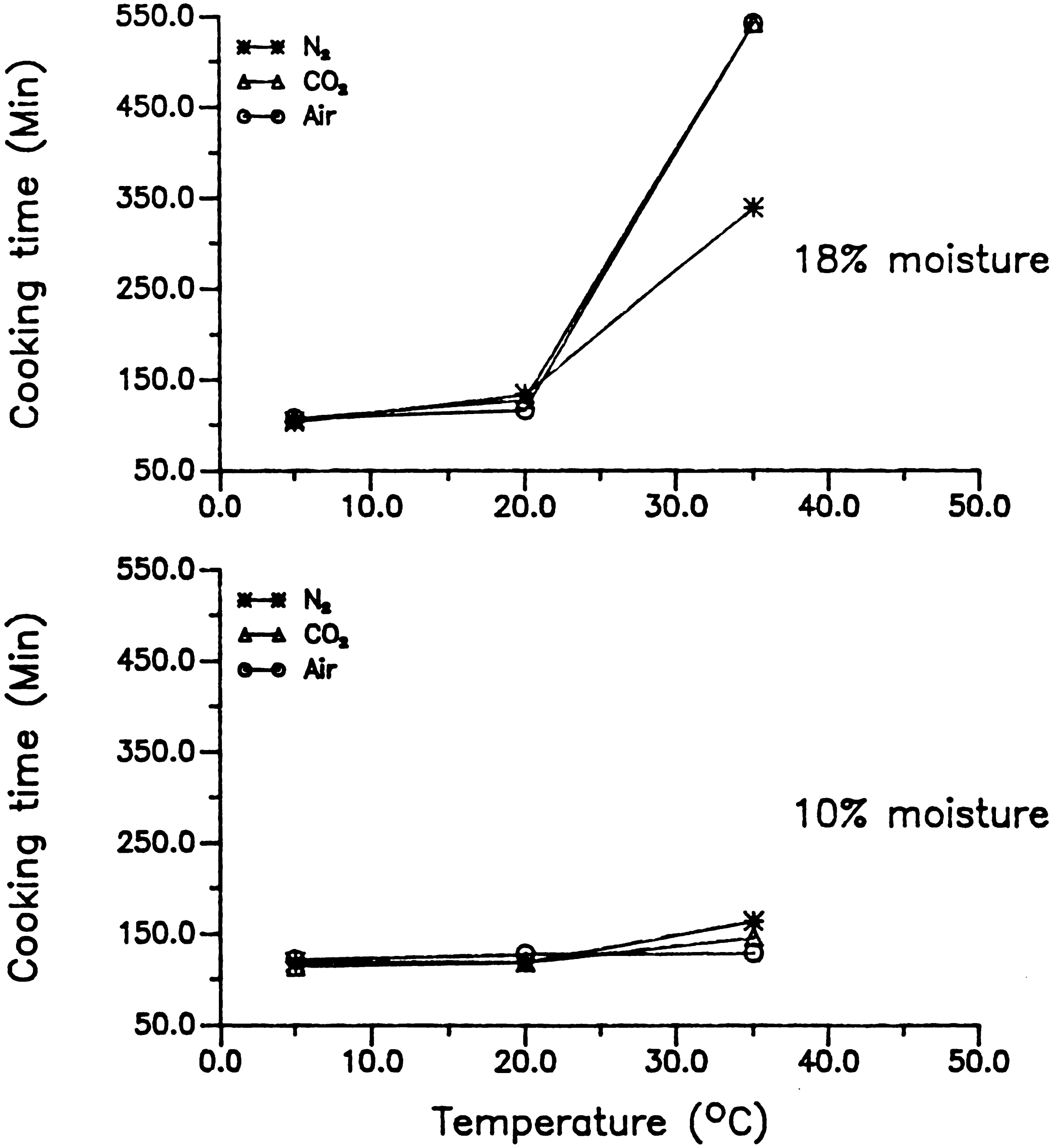
Moisture, (%)	Temperature (^{o}C)	Cooking Time (min.)		
		Nitrogen	Carbon Dioxide	Air
10	5	135	113	119
	20	138	113	125
	35	218	154	212
14	5	120	106	93
	20	135	118	105
	35	>540	>540	>540
18	5	100	96	95
	20	206	300	295
	35	>540	>540	>540



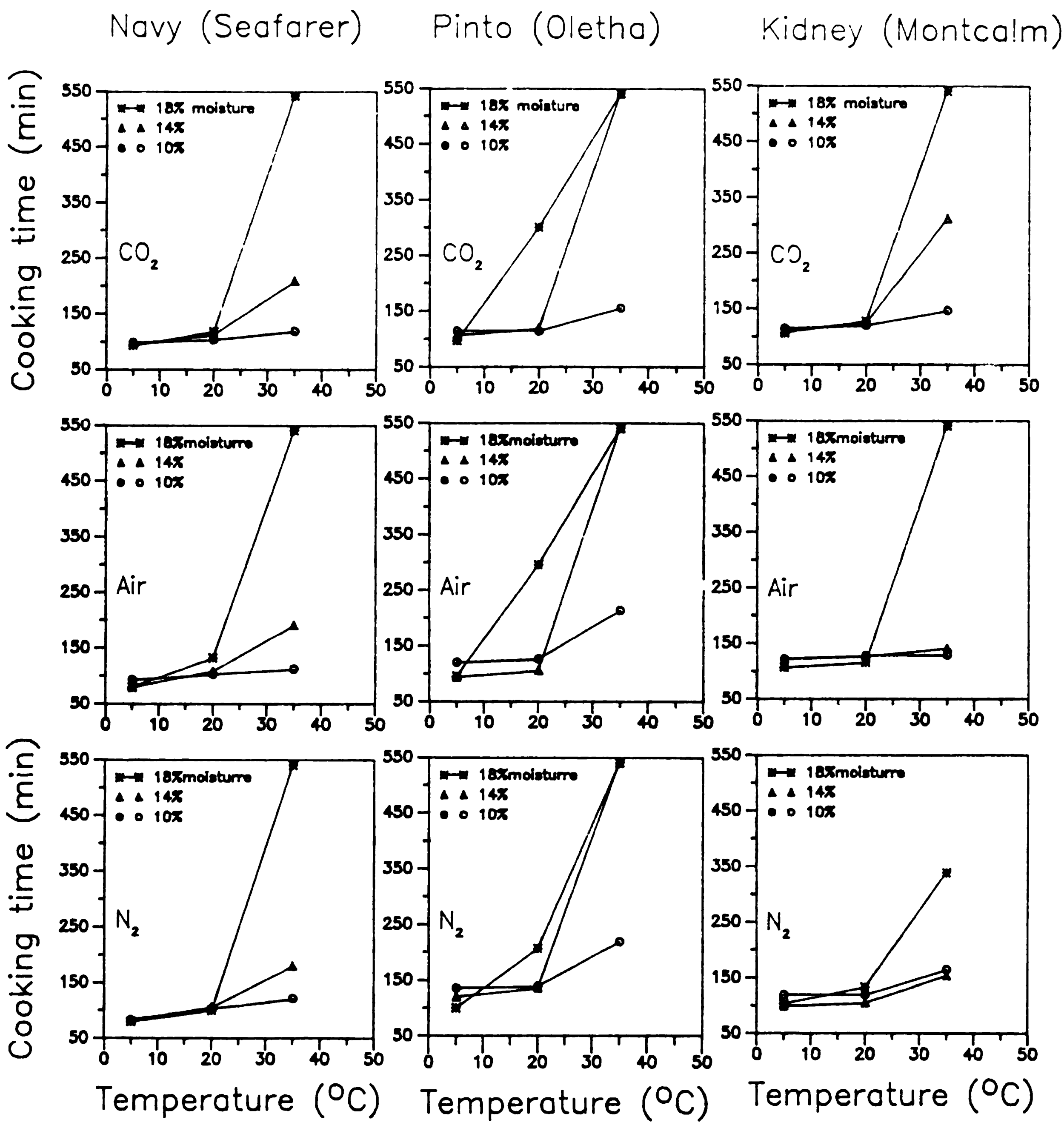
Fig(2) Cooking time for pinto beans stored under three gas atmospheres at three temperatures and two moistures for three months

Table (4) Mean values of cooking time for kidney (Montcalm) beans stored under three gas atmospheres at three temperatures and moistures for three months

Moisture (%)	Temperature (°C)	Cooking Time (min.)		
		Nitrogen	Carbon Dioxide	Air
10	5	118	113	120
	20	118	118	127
	35	163	145	126
14	5	98	111	121
	20	104	123	125
	35	153	310	140
18	5	103	106	106
	20	133	127	115
	35	338	>540	>540



Fig(3) Cooking time for kidney beans stored under three gas atmospheres at three temperatures and two moistures for three months



Fig(4) Cooking time for three bean cultivars stored under three gas atmospheres at three temperatures and moistures for three months pinto (Oletha) and kidney (Montcalm) beans.

The observed increased of cooking time with storage, could be due to the interactions between minerals (primarily calcium and magnesium from the cells) and the pectin molecules in the middle lamella, causing a more complex structure of the middle lamella. This hard cooking could also be partially due to interactions between protein molecules which form rigid structures around individual starch granules. This encapsulation prohibits water absorbtion by starch and delays or inhibits the separation of the cells during cooking. Correlations of cooking time and canned product shear force were established and are presented in part 1.2.

1.2 Effect of Storage Conditions on Canned Bean Product

Navy (Seafarer) Beans

Analysis of variance results of Hunter lab color coordinate data for navy (Seafarer) are presented in Table 5. The mean values of Hunter Lab color coordinates are presented in Table 6. Mean squares from the analysis of variance of Hunter lab coordinates (L, a_L, and b_L) for dry and processed navy (Seafarer) bean generally showed

Table (5) Analysis of variance of surface color of dry and processed navy (Seafarer) beans stored under three gas atmospheres at three temperatures and three moistures for up to nine months

Source of Variation	df	Dry bean L	Dry bean a_L	Dry bean b_L	Processed Bean L	Processed Bean a_L	Processed Bean b_L
		Mean Squares					
Total	161	5.820	0.638	4.912	18.639	1.398	0.750
Main Effects	8	76.490**	10.527**	85.857**	186.305**	10.128**	3.099**
Moisture (Mois.)	2	79.879**	2.011**	62.439**	96.174**	15.199**	1.201**
Gas	2	0.247**	0.081**	0.527**	0.401	0.845**	0.054
Temperature (Temp.)	2	208.936**	38.527**	267.982**	485.477**	21.432**	8.709**
Time	2	16.900**	1.487**	12.479**	163.169**	3.034**	2.432**
2-Way Interactions	24	11.930**	0.503**	3.558**	48.989**	4.971**	2.032**
Mois. x Gas	4	0.476**	0.067**	0.017	0.196	0.145**	0.021
Mois. x Temp.	4	49.305**	2.454**	16.986**	176.385**	24.612**	2.573**
Mois. x Time	4	4.819**	0.220**	1.054**	38.641**	2.151**	4.298**
Gas x Temp.	4	0.798**	0.049**	0.148**	0.106	0.086**	0.043
Gas x Time	4	0.072	0.009	0.042	0.334	0.025	0.168**
Temp. x Time	4	16.111**	0.221**	3.102**	78.274**	2.807**	5.089**

Table (5) (Cont'd.)

Source of Variation	df	Hunter Lab Color Coordinates					
		Dry Bean			Processed Bean		
		L	a_L	b_L	L	a_L	b_L
		Mean squares					
3-way Interactions	32	1.067**	0.145**	0.510**	9.962**	0.716**	1.309**
Mois. x Gas x Temp.	8	0.482**	0.048**	0.052**	0.451**	0.148**	0.056
Mois. x Gas x Time	8	0.299**	0.056**	0.124**	0.274	0.020	0.027
Mois. x Temp. x Time	8	3.444**	0.431**	1.839**	38.966**	2.689**	5.098**
Gas x Temp. x Time	8	0.043	0.045**	0.027	0.155	0.007	0.053
4-way Interactions	16	0.091**	0.039**	0.043**	0.217	0.013	0.141**
Mois. x Gas x Temp. x Time	16	0.091**	0.039**	0.043**	0.217	0.013	0.141**
Explained	80	11.673**	1.269**	9.866**	37.355**	2.793**	1.471**
Error	81	0.038	0.013	0.019	0.153	0.021	0.039
CV (%)		0.31	2.01	1.12	0.77	3.09	1.29

Table (6) Mean values of surface color for navy (Seafarer) beans stored under nitrogen gas atmosphere at three temperatures and moistures for nine months

Moisture, (%)	Temperature (^oC)	Hunter Lab Color Coordinates					
		Dry bean			Processed Bean		
		L	a_L	b_L	L	a_L	b_L
10	5	64.75	-4.90	10.30	52.40	-4.90	15.20
	20	64.50	-5.15	10.65	51.40	-4.70	14.45
	35	63.65	-6.70	13.20	49.60	-4.70	14.80
14	5	64.75	-4.90	10.40	53.15	-4.85	15.10
	20	64.35	-5.85	11.95	51.80	-4.80	15.05
	35	59.20	-7.60	17.15	47.90	-5.20	16.20
18	5	64.45	-5.20	10.85	53.85	-5.05	15.10
	20	63.20	-6.25	13.10	51.95	-5.05	15.30
	35	55.30	-6.20	16.10	34.00	0.05	13.35

significant differences among moisture levels, various gas atmospheres, temperatures and time of storage. Exceptions that show no significant differences in processed beans include lightness (L) and yellowness (b_L) for gas atmosphere effects. The beans became more dark (decreased L), more green (decreased a_L) and more yellow (increased b_L) as the moisture content, temperature, and time of storage increased (Table 6).

The mean squares from the analysis of variance for navy (Seafarer) bean soaked weight, drained weight and dried residue (Table 7) showed significant differences among moistures, temperatures, and times of storage for soaked weight, drained weight and dry residue, but no differences among gas atmosphere effects for all three of these quality parameters.

The treatment mean values for navy (Seafarer) bean soaked weight increased in the first three months of storage at 5 and 20^{o}C for medium and high levels of moisture (14 and 18%), but decreased at low moisture content (10%) (Figures 5 and 6). Storage of these beans at 35^{o}C and 10% moisture resulted in decreased soaked weight, while beans stored at 35^{o}C and 14 or 18% moisture decreased only slightly in soaked weight.

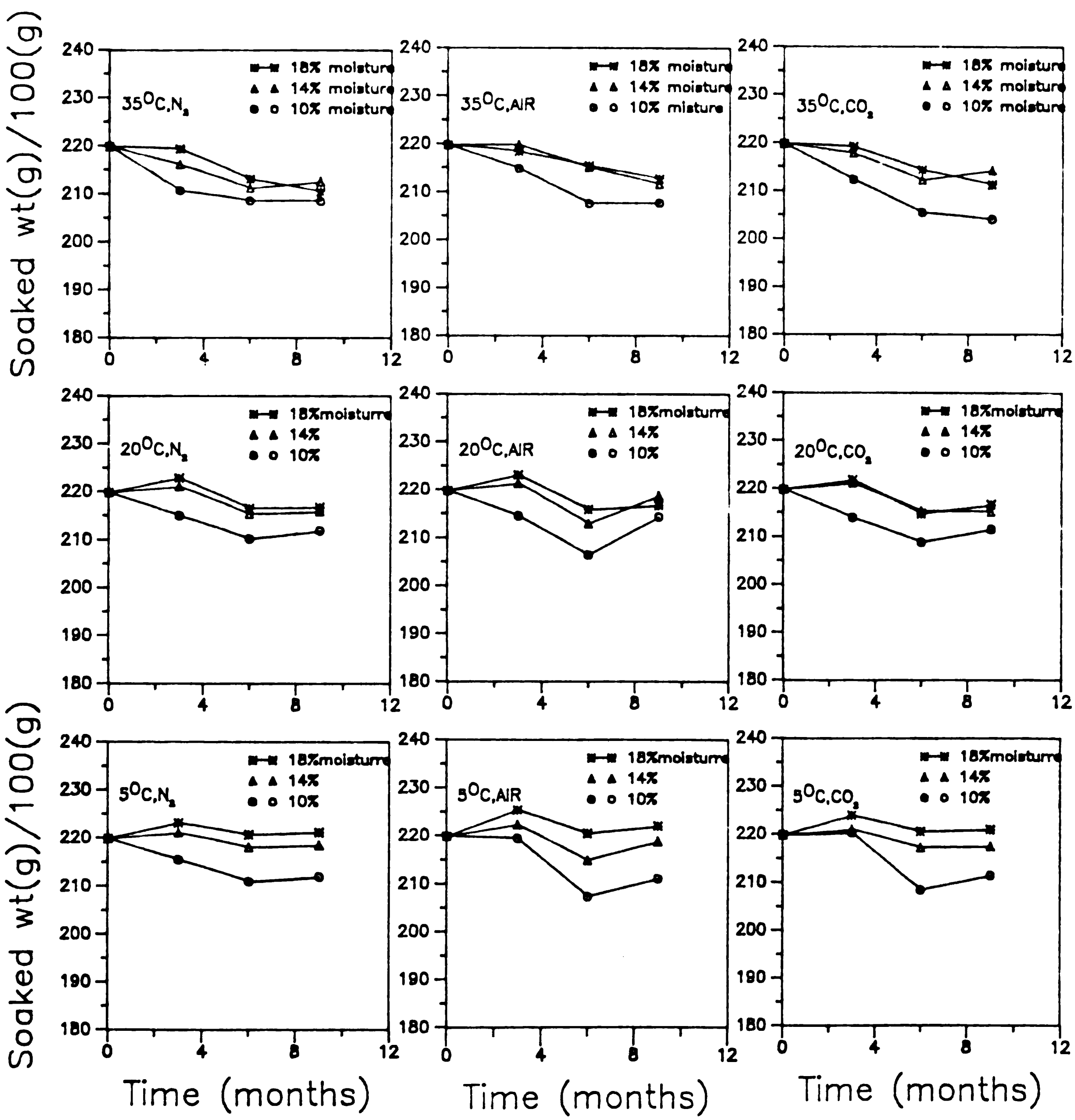
In the second three month period (6 months storage)

Table (7) Analysis of variance of quality characterastics of dry, soaked and processed navy (Seafarer) beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

Source of Variation	df	Bean Weight (g)			Visual		Shear Force (kg/100g)
		Soaked	Drained	Dried Residue	Clumps	Splits	
				Mean Squares			
Total	161	24.629	436.960	4.952	0.600	0.674	3537.614
Main Effects	8	420.495**	6739.620**	68.981**	6.210**	5.949**	40437.412**
Moisture (Mois.)	2	778.824**	6809.514**	58.901**	4.488**	0.074	38348.496**
Gas	2	5.718	8.867	0.362	0.599	7.019**	549.029**
Temperature (Temp.)	2	365.654**	18213.450**	202.282**	11.969**	14.685**	98922.117**
Time	2	531.782**	1926.647**	14.380**	7.784**	2.019**	23930.006**
2-way Interactions	24	8.765**	524.927**	8.770**	0.613**	1.426**	7532.819**
Mois. x Gas	4	1.323	28.269	0.165	0.302	2.287**	370.678**
Mois. x Temp.	4	14.956**	2664.990**	44.824**	0.701*	2.815**	24626.308**
Mois. x Time	4	8.103**	151.300**	2.157**	0.765*	0.537**	5233.910**
Gas x Temp.	4	4.292	79.683**	0.087	0.617*	0.370**	487.586**
Gas x Time	4	8.583**	37.720	0.068	0.377	2.509**	943.807**
Temp. x Time	4	15.336**	187.596**	5.318**	0.914**	0.037	13534.624**

Table (7) (Cont'd.)

Source of Variation	df	Bean Weight (g)			Visual		Shear Force (kg/100g)
		Soaked	Drained	Dried Residue	Clumps	Splits	
		Mean squares					
3-way Interactions	32	5.375**	74.367**	0.710**	0.346	0.462**	1558.630**
Mois. x Gas x Temp.	8	3.003	7.007	0.147	0.765**	0.236*	530.905**
Mois. x Gas x Time	8	3.815	22.369	0.086	0.191	1.264**	863.302**
Mois. x Temp. Time	8	9.312**	258.247**	2.254**	0.298	0.111	3923.279**
Gas x Temp. x Time	8	5.373*	9.844	0.356**	0.131	0.236*	917.035**
4-way Interactions	16	3.033	21.175	0.141	0.161	0.275**	806.193**
Mois. x Gas x Temp. x Time	16	3.033	21.175	0.141	0.161	0.275**	806.193**
Explained	80	47.436**	865.422**	9.841**	0.976**	1.263**	7088.279**
Error	81	2.104	13.788	0.122	0.228	0.093	30.785
CV (%)		0.67	1.31	1.14	26.98	11.68	7.64



Fig(5) Soaked weight of navy beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

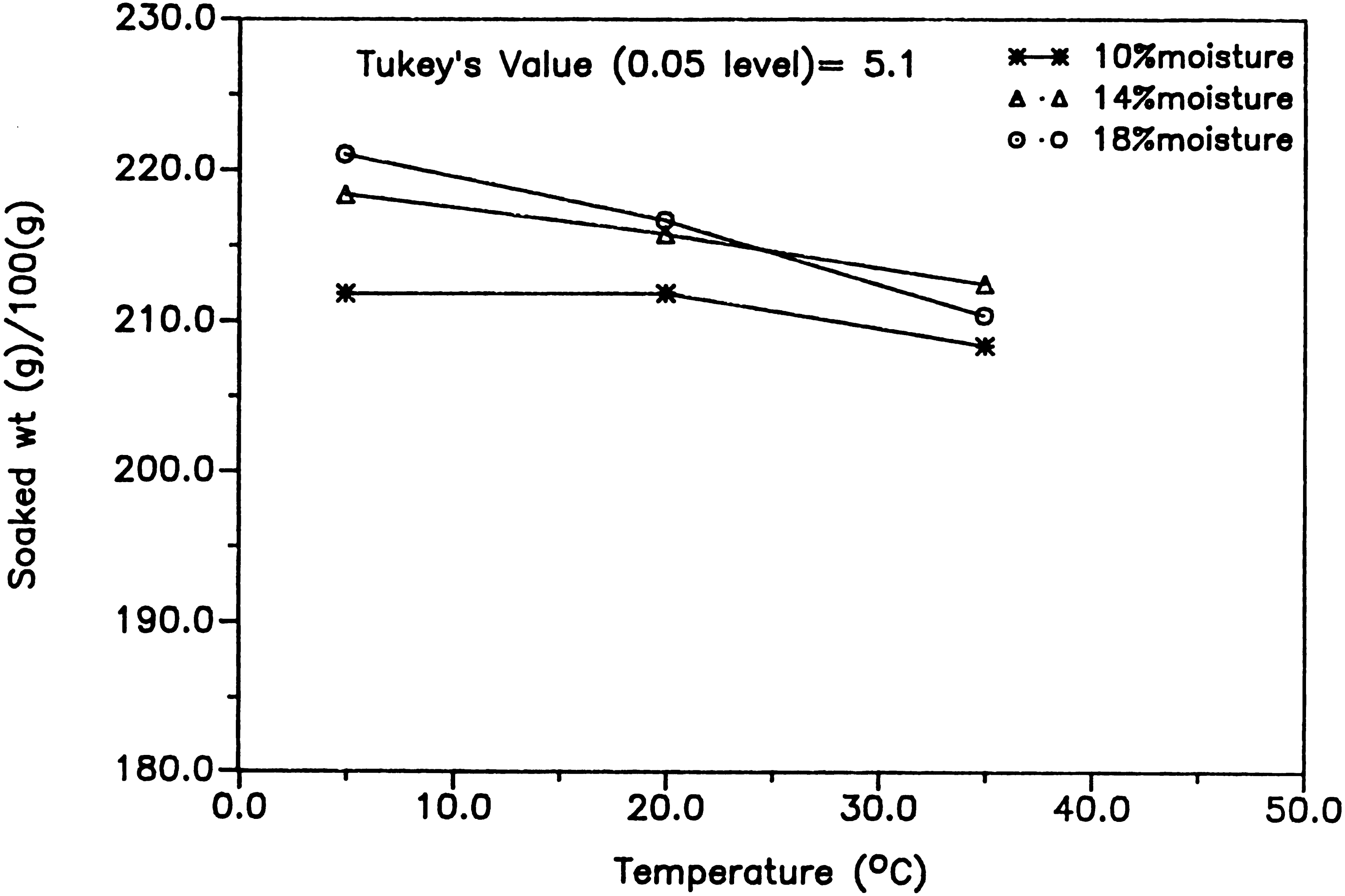
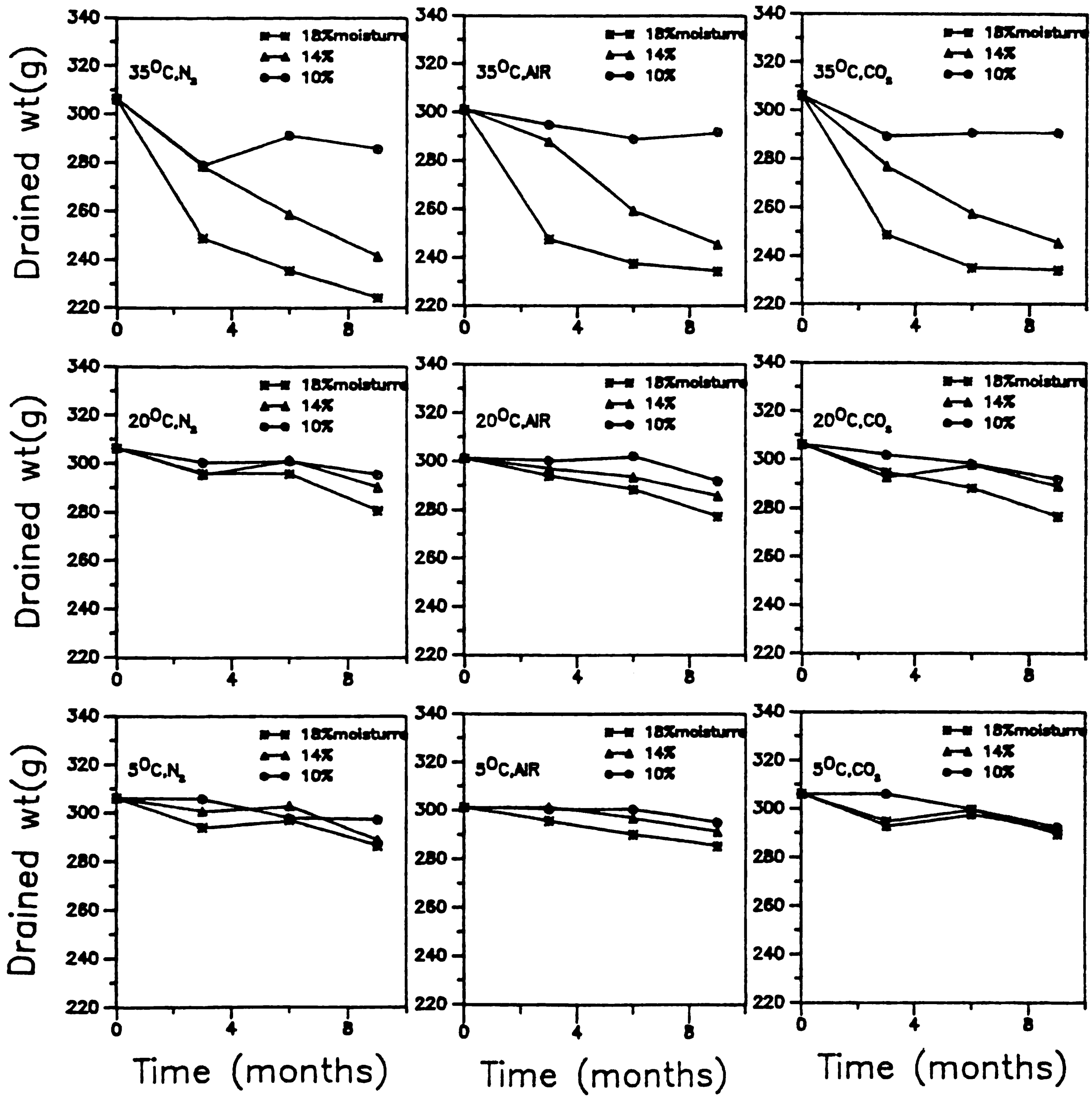


Fig (6) Soaked weight of navy beans stored under nitrogen atmosphere at three temperatures and moistures for nine months the soaked weight decreased for all temperatures (5, 20 and 35°C) and all moisture levels (10, 14 and 18%). In the third period of storage (9 months) the soaked weight increased slightly or remained the same, while beans stored at 35°C showed soaked weight decreases for all three moisture levels.

The drained weight of navy (Seafarer) beans stored at three temperatures, moistures, gases and periods of time (Figures 7 and 8) decreased during storage for all variables compared to initial mean values. These data indicate that as the storage temperature increased from 5 to 35°C, and moisture content increased from 10 to 18% and time of storage increased from 3 to 9 months the drained weight values decreased.

The dried residue per 100g solids of processed navy (Seafarer) beans are presented in Figures 9 and 10. These Figures indicate, that the dried residue increased during storage, particularly as the storage temperature, moisture content and time of storage increased for all three gases. At low temperature (5°C) the increase in dried residue was limited compared to high storage temperature (35°C) which was very high for all three moisture levels and all three periods of time.

Mean squares from the analysis of variance for clumps



Fig(7) Drained weight of navy beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

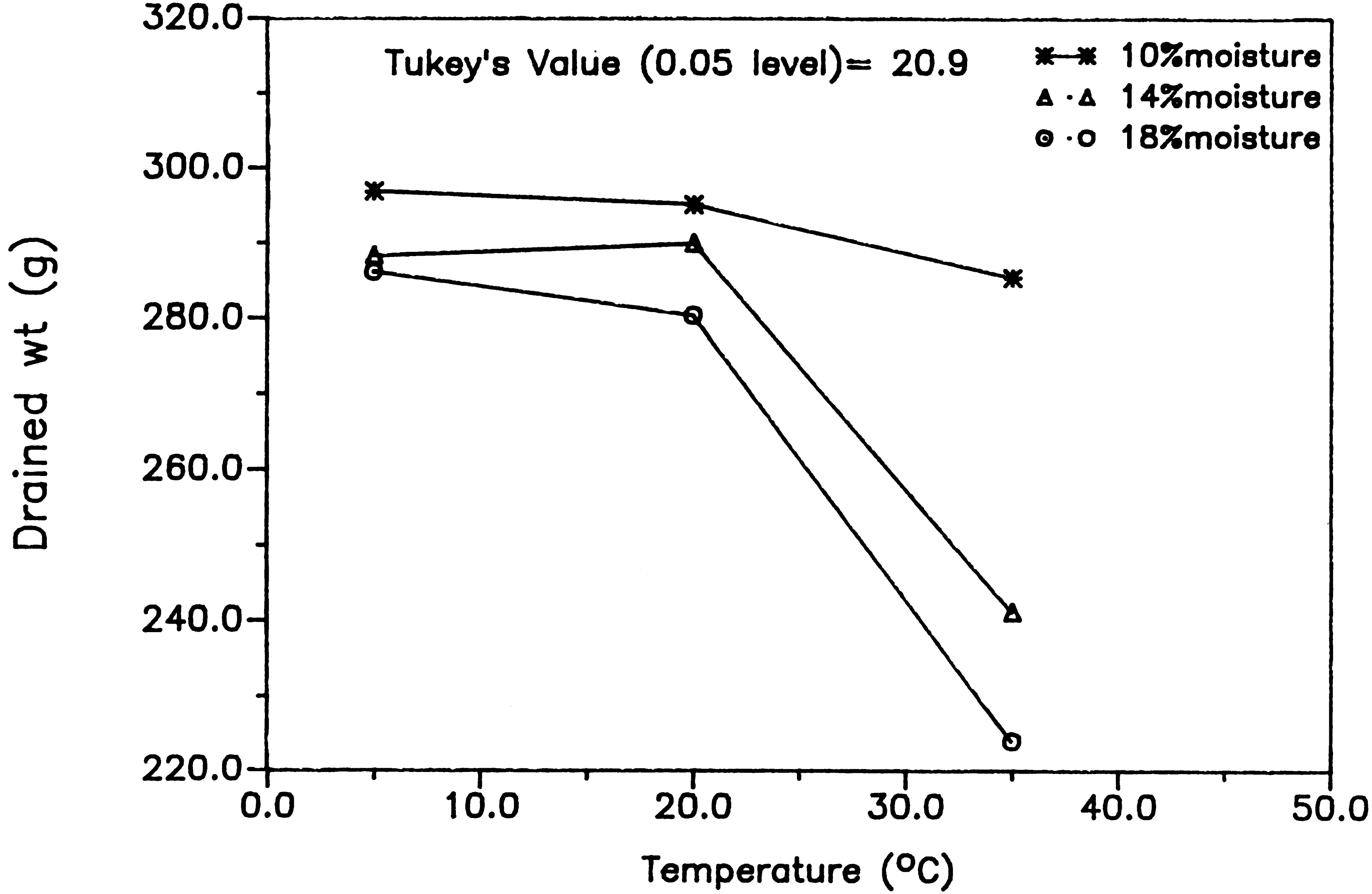
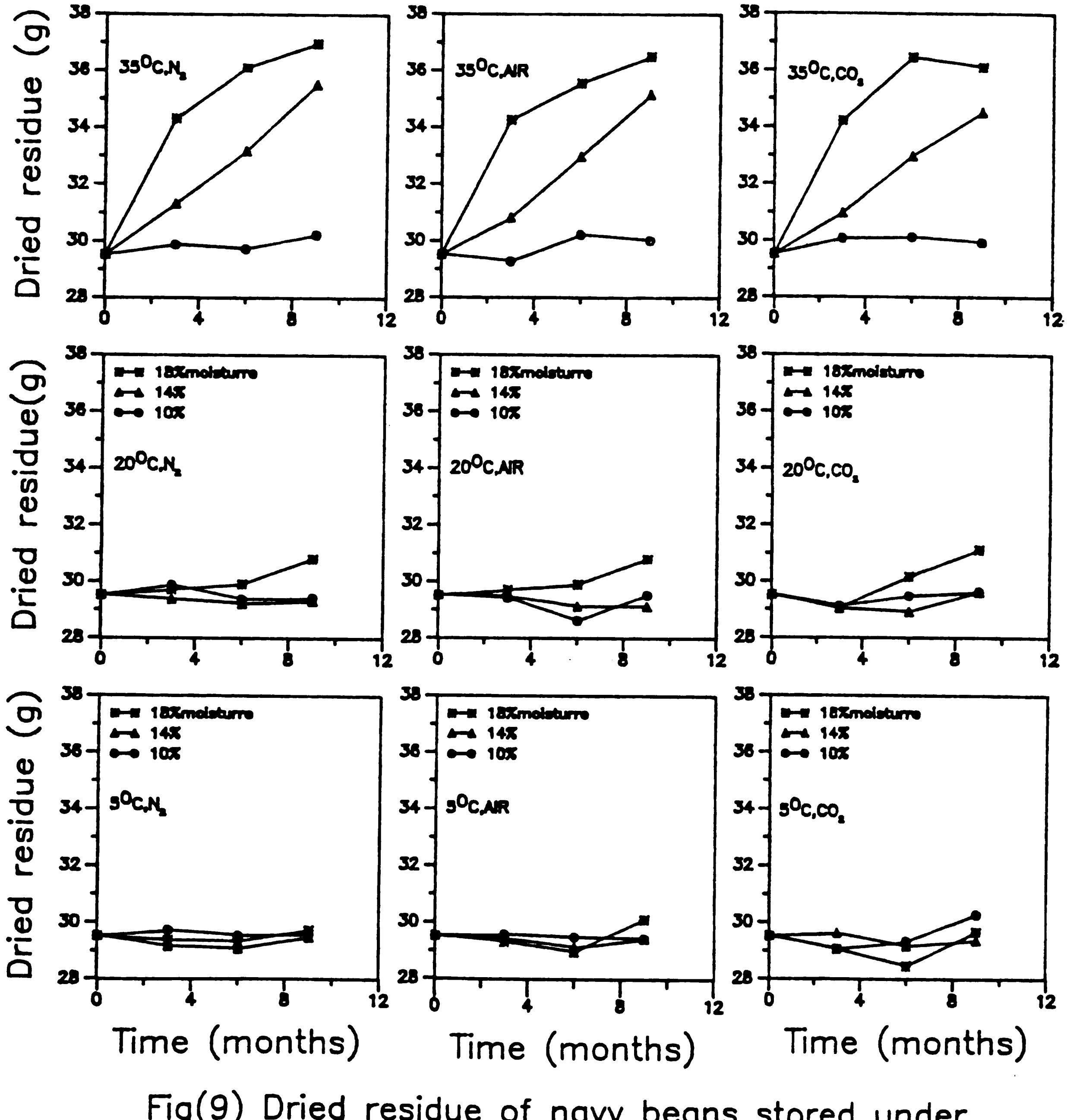


Fig (8) Drained weight of navy beans stored under nitrogen atmosphere at three temperatures and moistures for nine months



Fig(9) Dried residue of navy beans stored under three gas atmospheres at three temperatures. and moistures for up to nine months

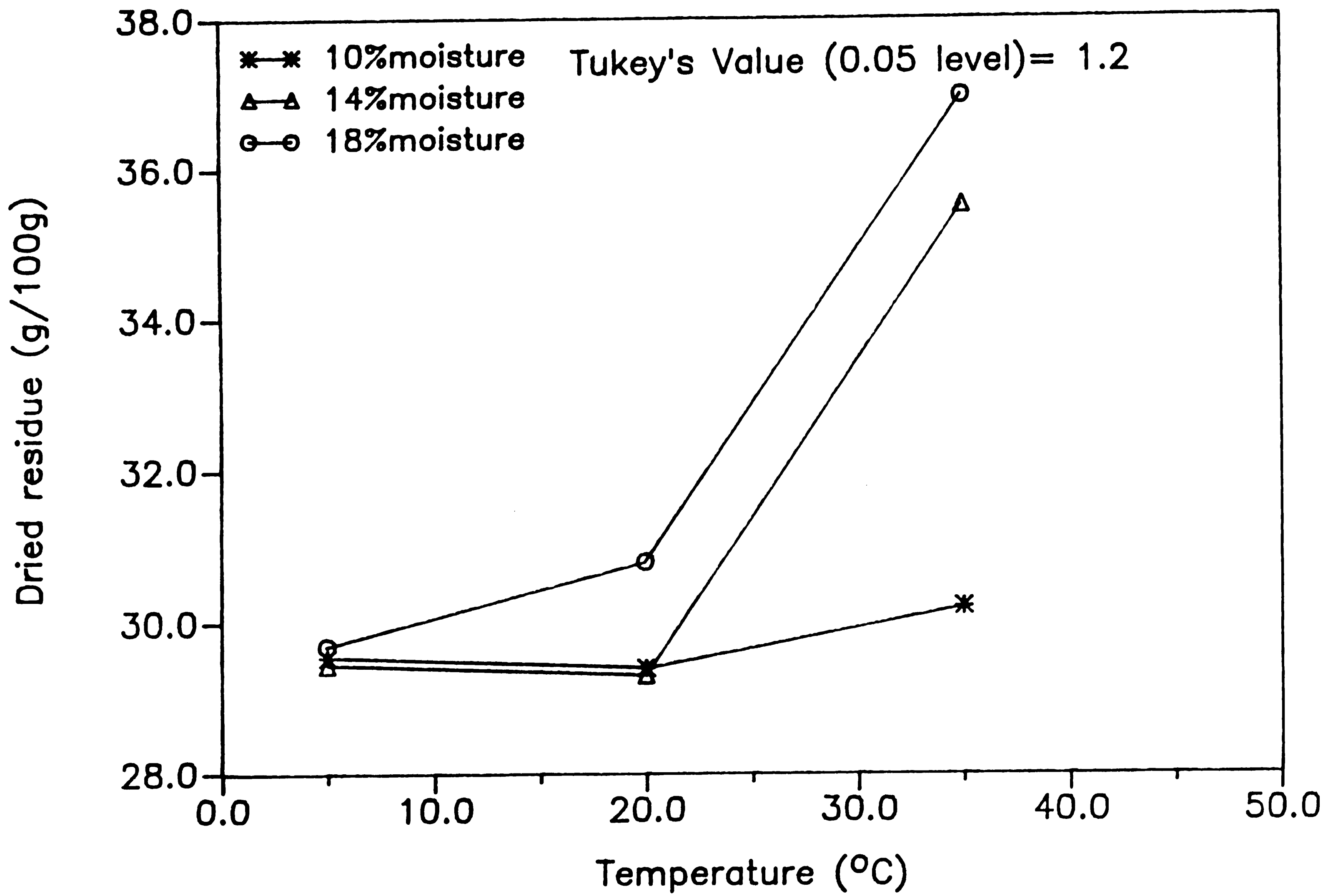


Fig (10) Dried residue of navy beans stored under nitrogen atmosphere at three temperatures and moistures for nine months and splits of navy (Seafarer) beans are presented in Table 7. The treatment mean values for clumps and splits are presented in Table 8.

The navy (Seafarer) bean mean squares of clumps show significant variations among different moistures, temperatures, and times of storage. No significant differences were found among different atmospheric gases. There were significant differences among all above variables except the moisture content was not shown for splits.

The treatment mean values for clumps and splits decreased after storage, as the storage temperature, moisture content and storage time increased (Table 8). This could be due to storage inducted cell hardening.

The shear force mean squares for navy (Seafarer) beans (Table 7) showed highly significant differences among all four storage variables (moisture, gas, temperature and time). The response of the navy (Seafarer) beans (Figures 11 and 12) indicate, as the temperature, moisture and time of storage increased, the shear force also increased. Shear force values were low (50 - 100kg/100g) following 5^{o}C storage, whereas at 35^{o}C and 18% moisture for nine months storage resistance to shear increased dramatically (300kg/100g). The shear force values obtained from this study were in general agreement with those of previous

Table (8) Mean values[1] of clumps and splits for navy (Seafarer) beans stored under nitrogen gas atmosphere at three temperatures and moistures for nine months

Moisture (%)	Temperature (°C)	Storage Time (Months)					
		3		6		9	
		Clumps	Splits	Clumps	Splits	Clumps	Splits
10	5	3.0	2.0	2.5	2.0	1.5	2.0
	20	2.5	2.0	2.0	2.0	1.5	2.0
	35	2.0	2.0	2.5	2.0	1.0	1.5
14	5	3.0	3.0	3.0	3.0	2.0	1.0
	20	2.5	2.5	2.5	3.0	1.0	2.0
	35	1.0	2.0	1.0	2.0	1.0	1.0
18	5	2.5	3.0	2.0	3.0	1.5	3.0
	20	2.5	3.0	3.0	2.5	1.0	3.0
	35	1.0	2.0	1.0	1.5	1.0	2.0

1. n = 2 cans; 5 points rating scale for clumps and splits; 1 = none, 5 = extreme

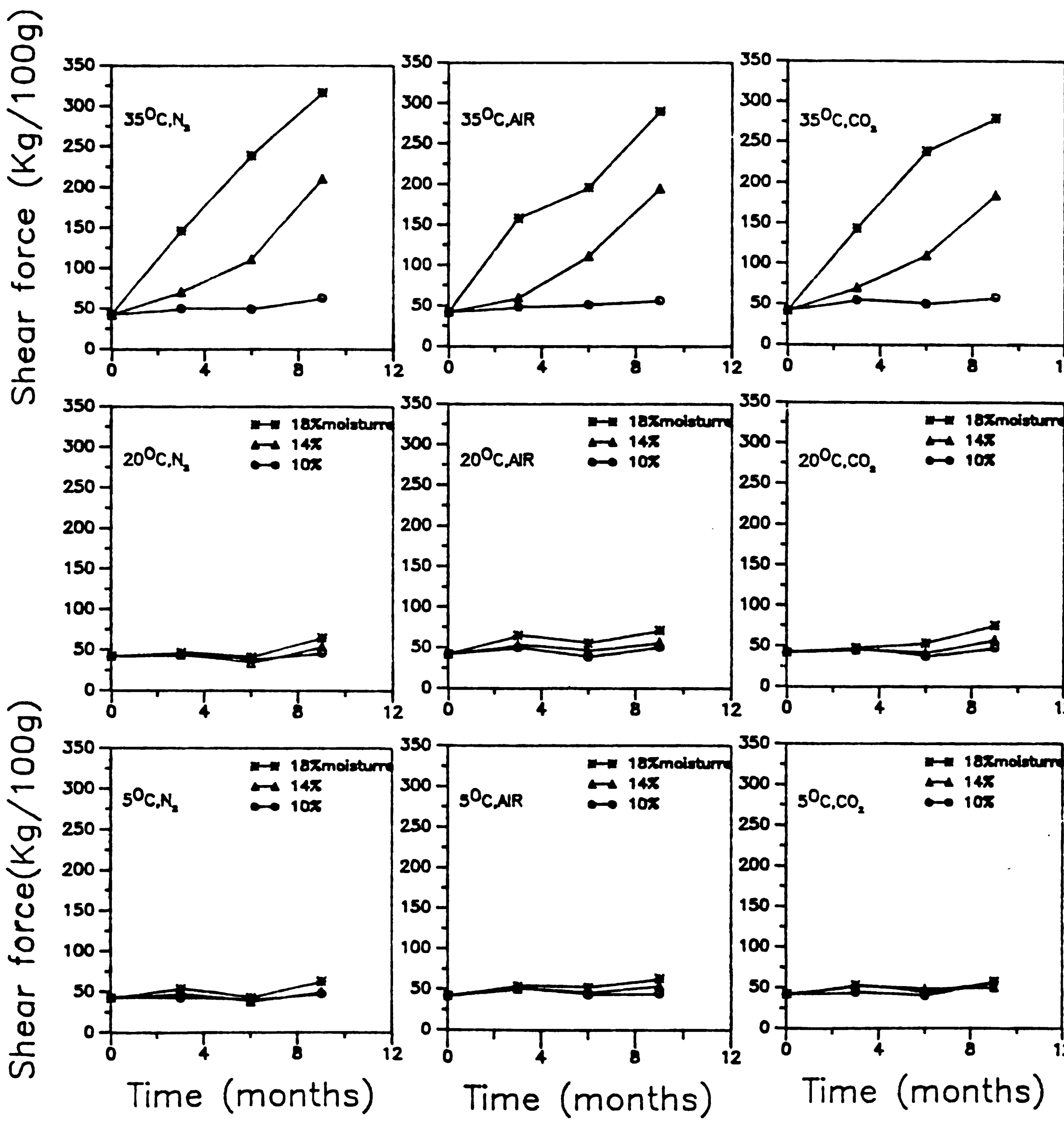


Fig (11) Shear force of navy beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

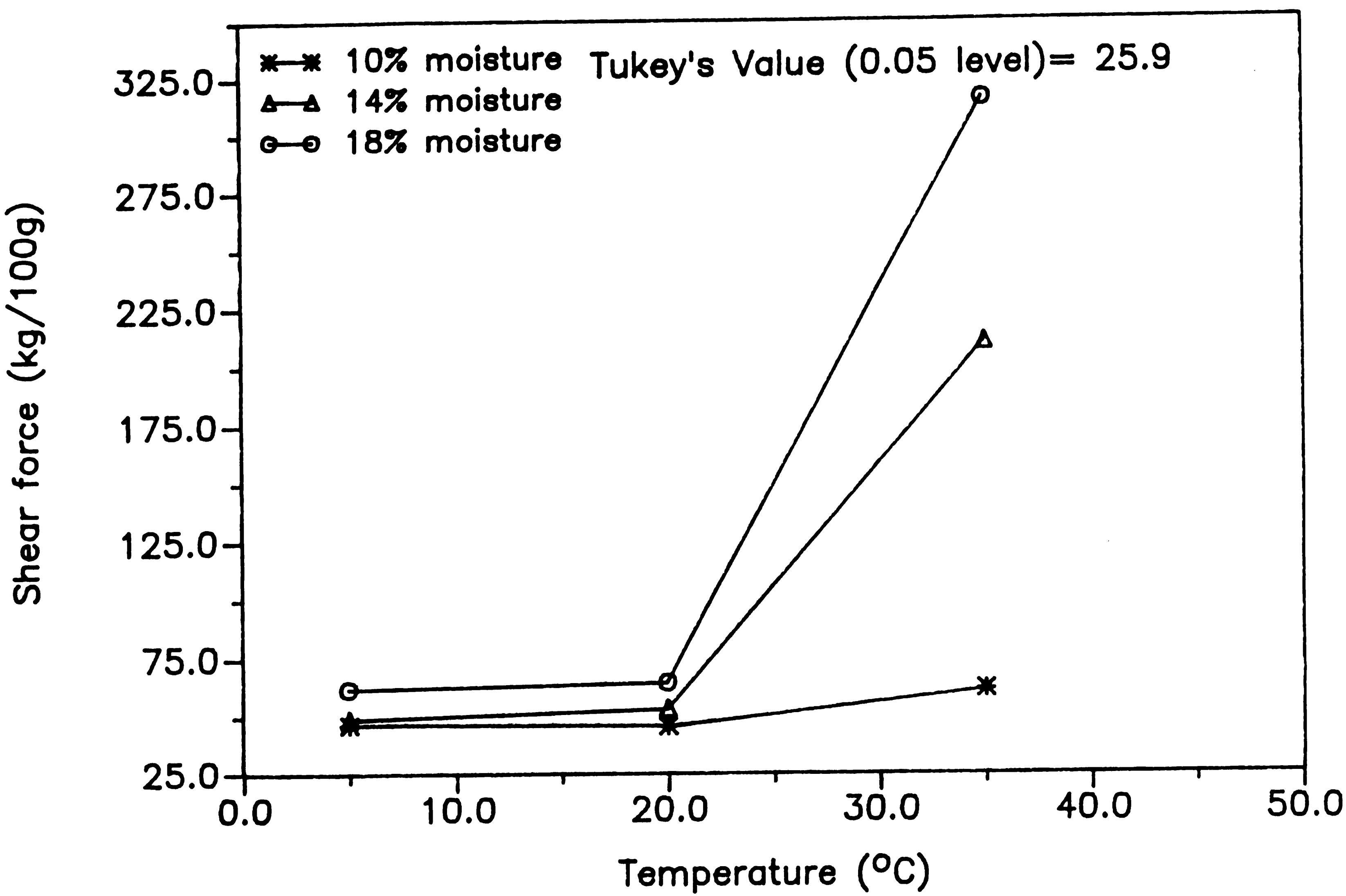


Fig (12) Shear force of navy beans stored under nitrogen atmosphere at three temperatures and moistures for nine months studies (Morris, 1961; El-Tabey Sheahata, 1983; Kon and Sanshuck, 1981 and Rozo, 1982).

The navy (Seafarer) bean mean squares from the analysis of variance for soaked moisture, processed moisture and mass ratio index of hydration and drained weight (Table 9) indicated significant variations among various moistures, temperatures and periods of time, but no statistical significance among gases.

Black (Black Turtle Soup, BTS) Beans

Analysis of variance mean squares of Hunter lab coordinates for black (BTS) beans (Table 10) showed significant variations among moisture content for both dry and processed beans, except for yellowness (b_L) of the processed beans. Significant differences among gas atmospheres and time of storage for both dry and processed beans were also shown for these color coordinates. Significant variations in color due to temperatures of storage were shown for both dry and processed beans. Darkness (L) was differentiated only in processed beans. Yellowness (b_L), but not greenness were different for dry and processed beans.

The bean color increased in darkness, greenness and

Table (9) Analysis of variance of moisture and mass ratio index measurments of dry, soaked and processed navy (Seafarer) beans stored under three gas atmospheres at three tempatures and moistures for up to nine months

Source of Variation	df	Bean Moisture (%)		Mass Ratio Index	
		Soaked	Processed	Hydration	Drained Weight
		Mean squares			
Total	161	1.157	4.952	0.004	0.011
Main Effects	8	19.697**	68.981**	0.066**	0.160**
Moisture (Mois.)	2	37.025**	58.901**	0.191**	0.323**
Gas	2	0.248	0.362	0.000	0.000
Temperature (Temp.)	2	16.885**	202.282**	0.039**	0.290**
Time	2	24.631**	14.380**	0.036**	0.025**
2-way Interactions	24	0.414**	8.770**	0.002**	0.014**
Mois. x Gas	4	0.075	0.165	0.000	0.002
Mois. x Temp.	4	0.636**	44.824**	0.001	0.064**
Mois. x Time	4	0.462**	2.157**	0.002*	0.005**
Gas x Temp.	4	0.192	0.087	0.002	0.002
Gas x Time	4	0.361*	0.068	0.003*	0.000
Temp. x Time	4	0.756**	5.318**	0.005**	0.012**

Table (9) (Cont'd.)

Source of Variation	df	Moisture		Mass Ratio Index	
		Soaked	Processed	Hydration	Drained Weight
		Mean Squares			
3-way Interactions	32	0.256**	0.710**	0.002**	0.004**
Mois. x Gas x Temp.	8	0.142	0.147	0.001	0.000
Mois. x Gas x Time	8	0.196	0.086	0.002*	0.003**
Mois. x Temp. x Time	8	0.436**	2.254**	0.004**	0.010**
Gas x Temp. x Time	8	0.251*	0.356**	0.001	0.001
4-way Interactions	16	0.146	0.141	0.001	0.002**
Mois. x Gas x Temp. x Time	16	0.146	0.141	0.001	0.002**
Explained	80	2.226**	9.841**	0.008**	0.022**
Error	81	0.102	0.122	0.001	0.001
CV (%)		0.60	0.50	1.72	2.40

Table (10) Analysis of variance of surface color of dry and processed black (BTS) beans stored under three gas atmospheres at three temperatures and two moistures for up to nine months

Source of Variation	df	Hunter Lab Color Coordinates					
		Dry bean			Processed Bean		
		L	a_L	b_L	L	a_L	b_L
		Mean Squares					
Total	107	0.148	0.106	0.116	2.462	0.106	0.400
Main Effects	7	1.642**	0.751**	1.366**	28.851**	0.983**	3.975**
Moisture (Mois.)	1	9.901**	0.563**	1.820**	25.133**	1.470**	0.058
Gas	2	0.214**	0.280**	0.106*	15.345**	0.213**	3.462**
Temperature (Temp.)	2	0.002	0.002	0.075*	67.190**	0.006	7.536**
Time	2	0.579**	2.066**	4.010**	5.877**	2.485**	2.886**
2-Way Interactions	18	0.075**	0.145**	0.061**	2.563**	0.147**	0.590**
Mois. x Gas	2	0.068*	0.080	0.007	3.025**	0.372**	0.691**
Mois. x Temp.	2	0.006	0.235**	0.169**	13.493**	0.338**	1.879**
Mois. x Time	2	0.438**	0.003	0.005	0.424	0.006	0.171*
Gas x Temp.	4	0.029	0.276**	0.073*	1.737**	0.263**	0.506**
Gas x Time	4	0.039	0.138**	0.054*	0.063	0.033*	0.050
Temp. X Time	4	0.016	0.079*	0.057*	1.263**	0.008	0.729**

Table (10) (Cont'd.)

Source of Variation	df	Hunter Lab Color Coordinates					
		Dry Beans			Process Beans		
		L	a_L	b_L	L	a_L	b_L
		Mean Squares					
3-way Interactions	20	0.059**	0.071**	0.025	0.301*	0.053**	0.095**
Mois. x Gas x Temp.	4	0.043	0.012	0.007	0.091	0.124**	0.200**
Mois. x Gas x Time	4	0.068*	0.049	0.002	0.318	0.022	0.090
Mois. x Temp. x Time	4	0.025	0.123**	0.039	0.765**	0.089**	0.159**
Gas x Temp. x Time	8	0.079**	0.086**	0.039	0.167	0.015	0.012
4-way Interactions	8	0.088**	0.055	0.012	0.172	0.009	0.048
Mois. x Gas x Temp. x Time	8	0.088**	0.055	0.012	0.172	0.009	0.048
Explained	53	0.278**	0.184**	0.213**	4.821**	0.201**	0.768**
Error	54	0.021	0.030	0.021	0.147	0.012	0.039
CV (%)		0.93	10.25	19.32	2.36	2.77	6.43

yellowness as the temperature and moisture increased (Table 11).

Analysis of variance mean squares for black (BTS) bean soaked weight, drained weight and dried residue are summarized in Table 12. The treatment mean values are presented in Figures 13 and 14. The mean squares of these data showed significant variations among moistures, temperatures and time of storage for all three quality characters (soaked weight, drained weight and dried residue). The effect of gases showed significant differences in soaked weight, but not in drained weight or dried residue.

The soaked weight of black (BTS) beans (Figures 13 and 14) increased at 18% moisture for all storage temperatures, storage periods and gas atmospheres, while in general, it decreased for bean stored at 10% moisture during the first three months and increased during subsequent storage when compared to initial values.

The treatment mean values of drained weight and dried residue of black (BTS) bean are presented in Figures 15, 16, 17, and 18. The drained weight decreased with increasing temperature, moisture and time of storage, while the dried residue increased.

Black (BTS) bean clumps and splits (Table 12) showed

Table (11) Mean values of surface color for black (BTS) beans stored under nitrogen gas atmosphere at three temperatures and two moistures for nine months

Moisture (%)	Temperature (°C)	Hunter Lab Color Coordinates					
		Dry bean			Processed Bean		
		L	a_L	b_L	L	a_L	b_L
10	5	15.95	1.60	-1.20	16.90	3.67	3.10
	20	15.90	1.60	-1.05	16.17	3.55	2.90
	35	15.80	1.40	-0.95	15.37	3.42	2.57
18	5	15.40	1.40	-0.95	17.75	3.60	3.70
	20	15.35	1.15	-0.85	15.67	3.75	3.15
	35	15.45	1.20	-0.75	14.07	4.30	2.62

Table (12) Analysis of variance of quality characterastics of dry, soaked and processed black (BTS) beans stored under three gas atmostheres at three temperatures and two moistures for up to nine months

Source of Variation	df	Bean Weight (g)			Visual		Shear Force (kg/100g)
		Soaked	Drained	Dried Residue	Clumps	Splits	
		Mean Squares					
Total	107	83.369	278.802	4.444	0.918	0.918	8862.899
Main Effects	7	1053.282**	2934.372**	42.643**	9.409**	9.229**	77644.330**
Moisture (Mois.)	1	6317.370**	8423.467**	95.203**	18.750**	9.780**	1206622.511**
Gas		208.231**	2.300	0.226	2.111**	0.340*	39.924
Temperature (Temp.)	2	53.733**	5827.763**	84.738**	15.083**	12.424**	2158442.466**
Time	2	265.839**	228.506**	16.685**	6.361**	14.646**	9961.510**
2-way Interactions	18	55.646**	476.081**	8.707**	0.895**	0.954**	20104.796**
Mois. x Gas	2	133.514**	37.690*	0.597*	0.111	0.600*	11.318
Mois. x Temp.	2	67.175**	3936.305**	67.517**	4.861**	3.127**	2143826.295**
Mois. x Time	2	111.666**	207.278**	4.991**	0.194	0.016	15635.938**
Gas x Temp.	4	6.054	13.736	0.138	0.153	0.462*	63.042
Gas x Time	4	4.316	1.654	0.736**	0.306	0.694**	211.866*
Temp. x Time	4	83.859**	36.337**	1.757**	0.986**	1.267**	10459.898**

Table (12) (Cont'd.)

Source of Variation	df	Bean Weight (g)			Visual		Shear Force (kg/100g)
		Soaked	Drained	Dried Residue	Clumps	Splits	
				Mean Squares			
3-way Interactions	20	13.759**	7.945	0.498**	0.264	0.378**	1973.789**
Mois. x Gas x Temp.	4	5.325	5.065	0.444*	0.431	0.499*	158.445*
Mois. x Gas x Time	4	6.885	4.786	0.653**	0.139	0.231	102.479
Mois. x Temp. x Time	4	35.577**	14.558	0.829**	0.347	0.874**	9568.338**
Gas x Temp. x Time	8	10.506**	7.657	0.281	0.201	0.144	19.841
4-way Interactions	8	9.905*	13.086	0.270	0.188	0.188	36.765
Mois. x Gas x Temp. x Time	8	9.905*	13.086	0.270	0.187	0.188	36.765
Explained	53	164.699**	554.220**	8.818**	1.675**	1.714**	17833.331**
Error	54	3.599	8.486	0.152	0.176	0.137	58.587
CV (%)		1.98	1.13	1.32	25.38	19.05	4.78

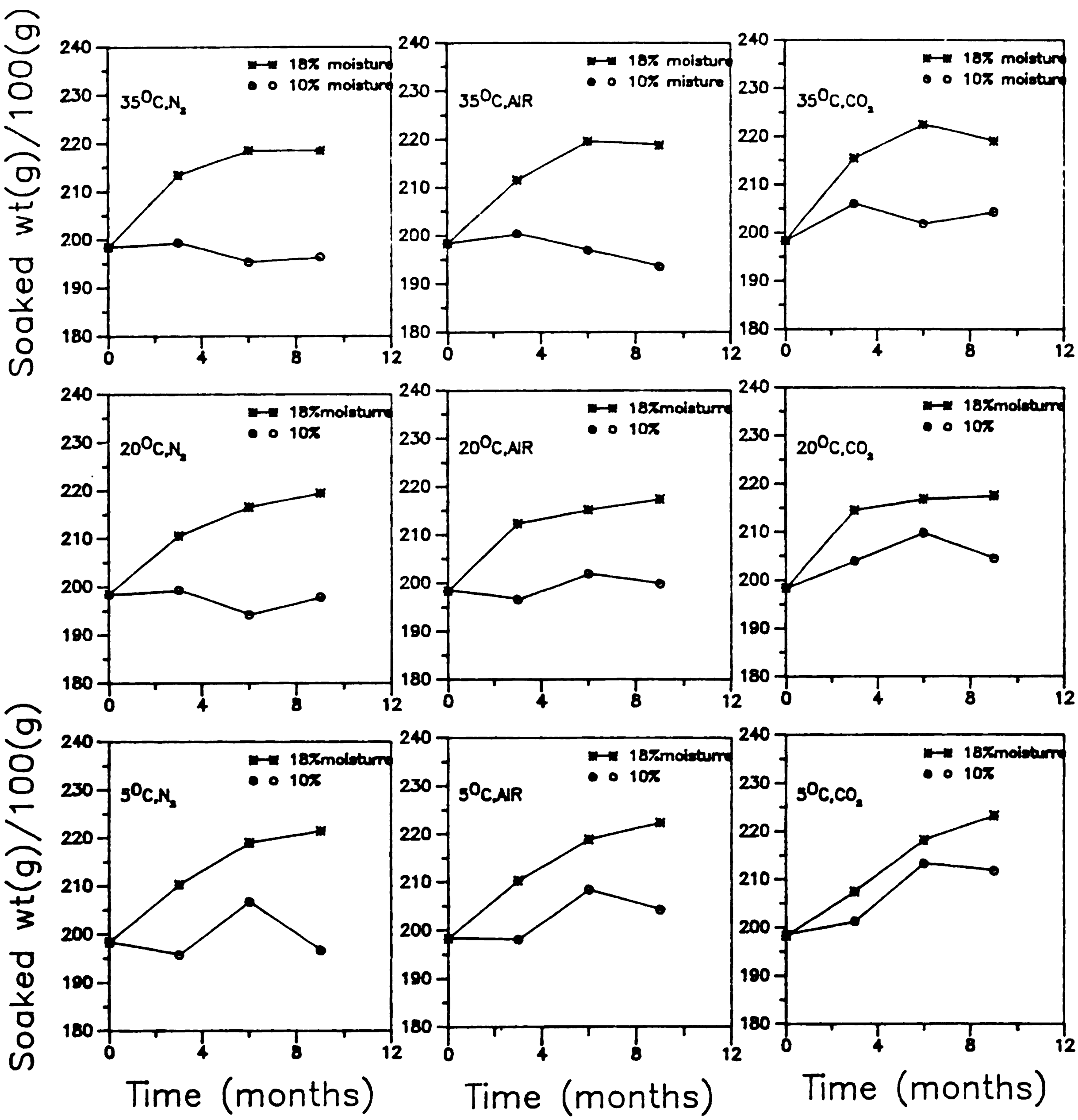


Fig (13) Soaked weight of black beans stored under three gas atmospheres at three temperatures and two moistures for up to nine months

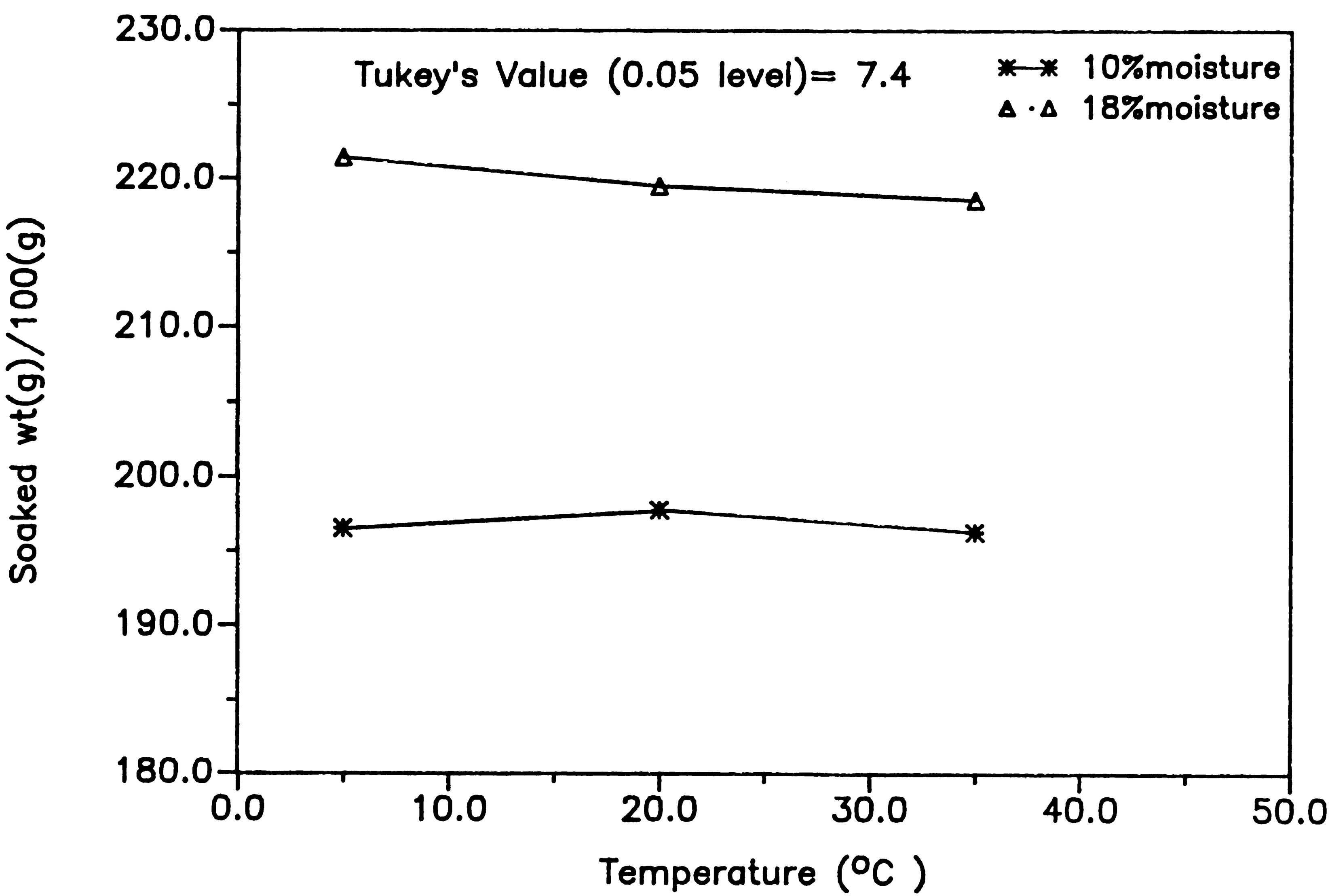
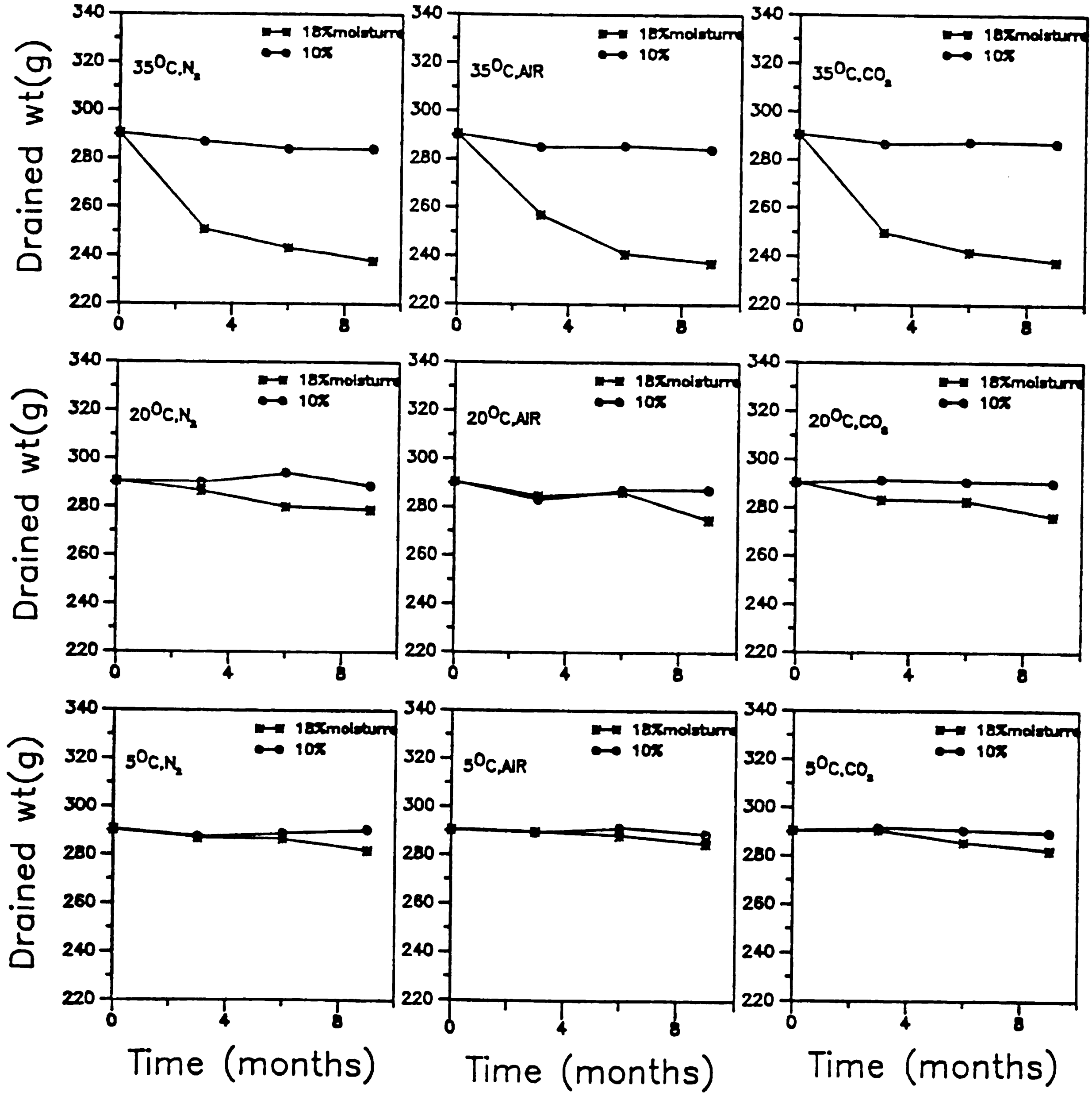


Fig (14) Soaked weight of black beans stored under nitrogen atmosphere at three temperatures and two moistures for nine months



Fig(15) Drained weight of black beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

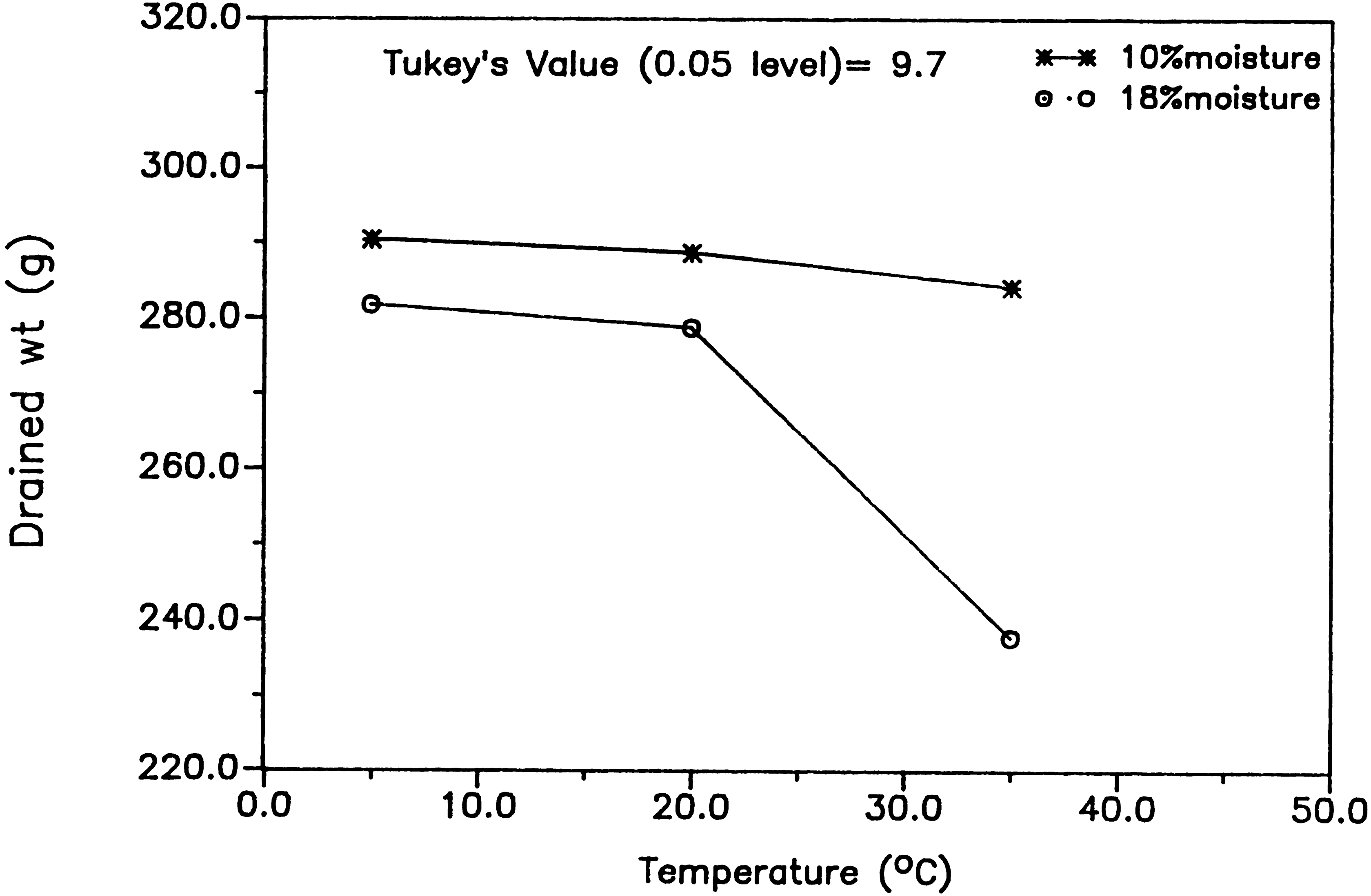
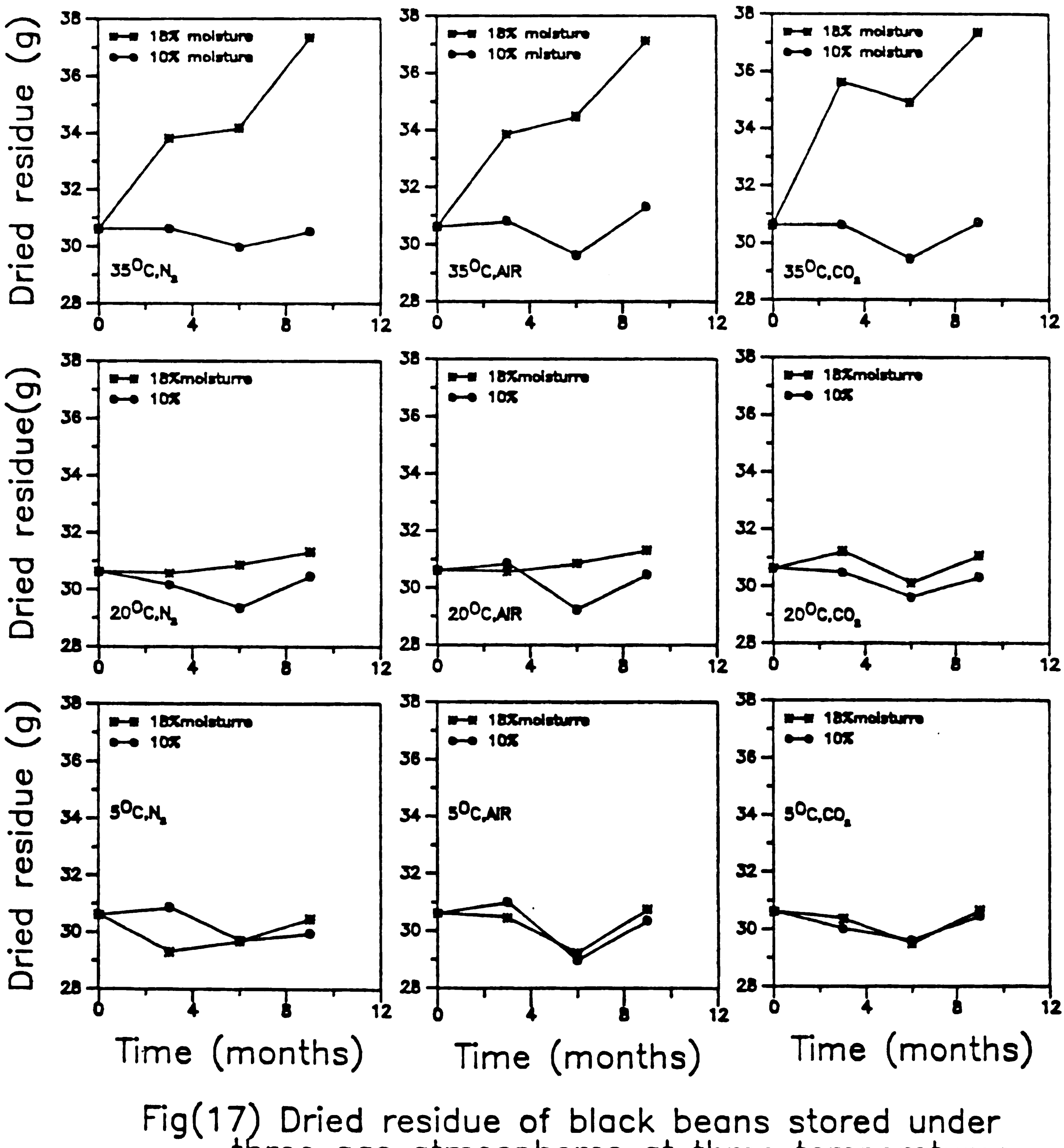


Fig (16) Drained weight of black beans stored under nitrogen atmosphere at three temperatures and two moistures for nine months



Fig(17) Dried residue of black beans stored under three gas atmospheres at three temperatures and two moistures for up to nine months

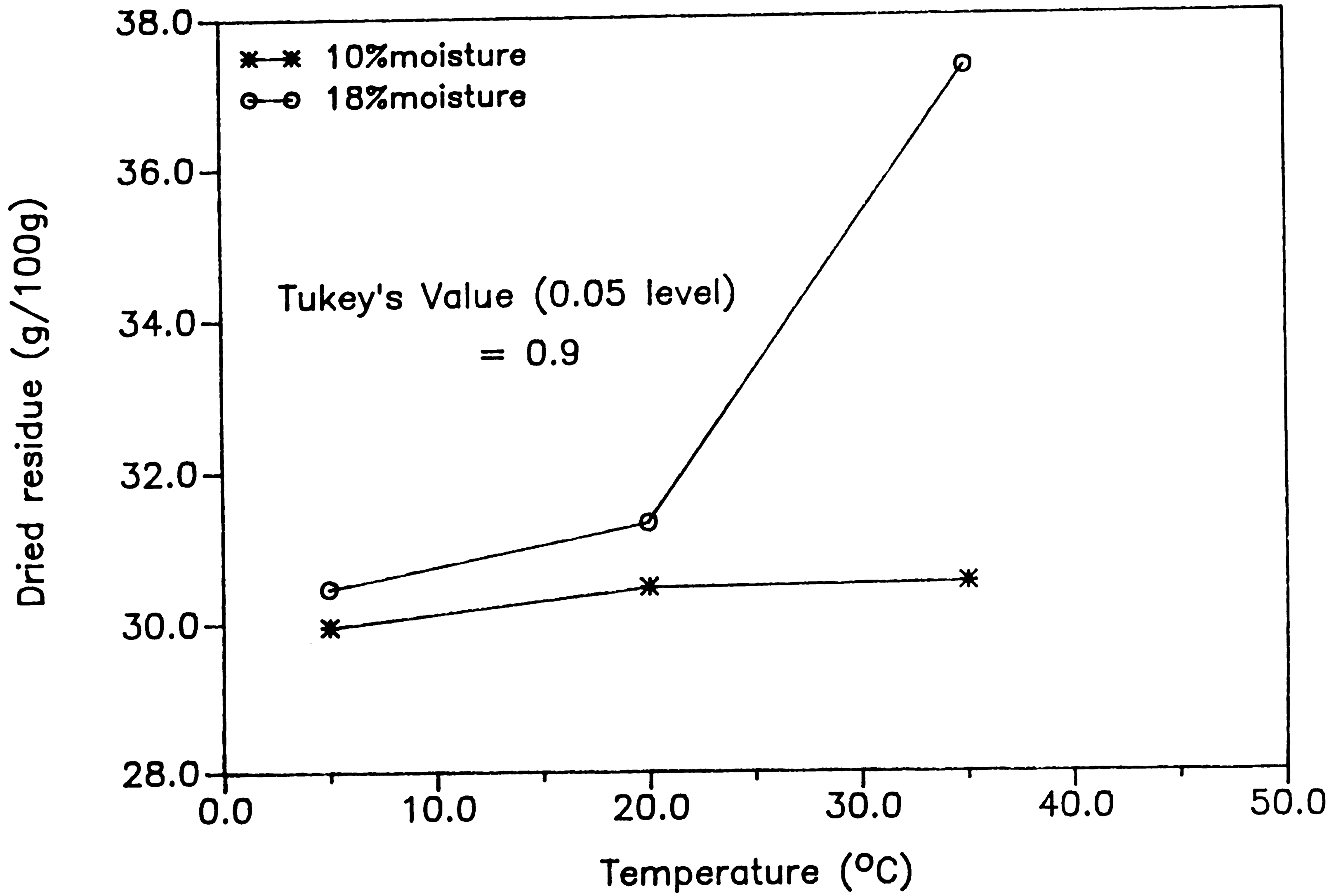


Fig (18) Dried residue of black beans stored under nitrogen atmosphere at three temperatures and two moistures for nine months variations among all experimental variables. Black bean clumps and splits (Table 13) decreased as the storage temperature, bean moisture and storage time increased.

The shear force mean squares from the analysis of variance of black (BTS) beans (Table 12) showed highly significant differences among temperatures, moistures, and times of storage, but no significant differences among gases. The response of the black (BTS) beans (Figures 19 and 20) indicated that, as the temperature, moisture and time of storage increased, the shear force also increased.

Variations were observed with black (BTS) bean soaked moisture, processed moisture and mass ratio index of hydration and drained weight (Table 14) for all variables except hydration ratio and processed moisture were not effected by temperature and gas environment, respectively.

Pinto (Oletha) Beans

Pinto bean (Oletha) Hunter lab coordinate mean squares from the analysis of variance (Table 15) showed high variations among all variables (moistures, gas atmospheres, temperatures and time of storage) for both dry and processed beans. Moisture effects on greenness of the processed pinto beans were not significant.

Table (13) Mean values[1] of clumps and splits for black (BTS) beans stored under nitrogen gas atmosphere at three temperatures and two moistures for nine months

Moisture (%)	Temperature (^{o}C)	Storage Time (Months)					
		3		6		9	
		Clumps	Splits	Clumps	Splits	Clumps	Splits
10	5	3.0	3.0	3.5	3.0	3.5	4.0
	20	3.0	2.5	4.0	2.0	4.0	3.0
	35	2.5	2.0	3.5	2.5	3.0	3.0
18	5	2.5	2.5	4.0	2.5	4.0	4.0
	20	2.0	2.0	3.0	2.0	2.5	4.0
	35	1.0	1.0	1.0	1.0	1.5	1.5

1. n = 2 cans; 5 points rating scale for clumps and splits; 1 = none, 5 = extreme

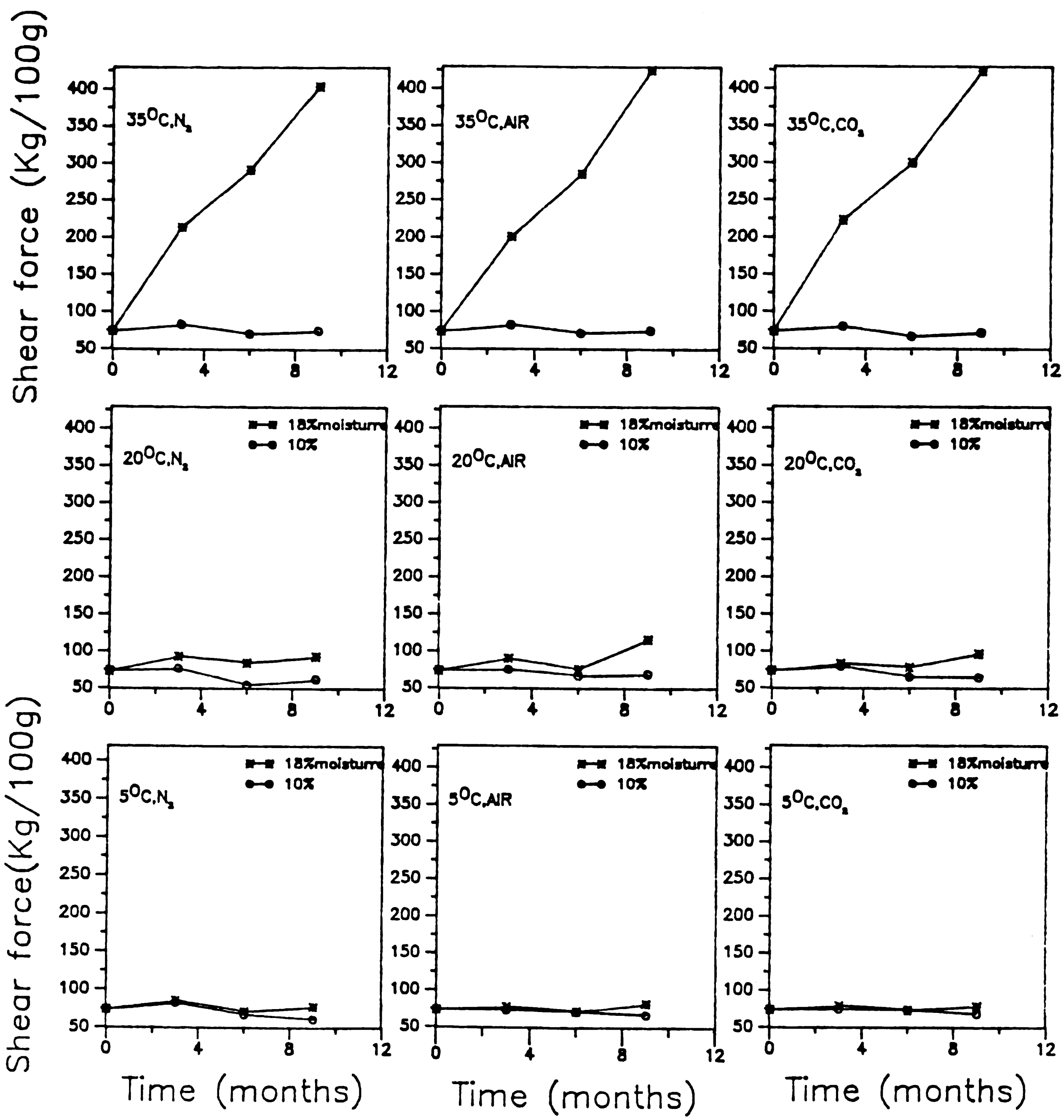


Fig (19) Shear force of black beans stored under three gas atmospheres at three temperatures and two moistures for up to nine months

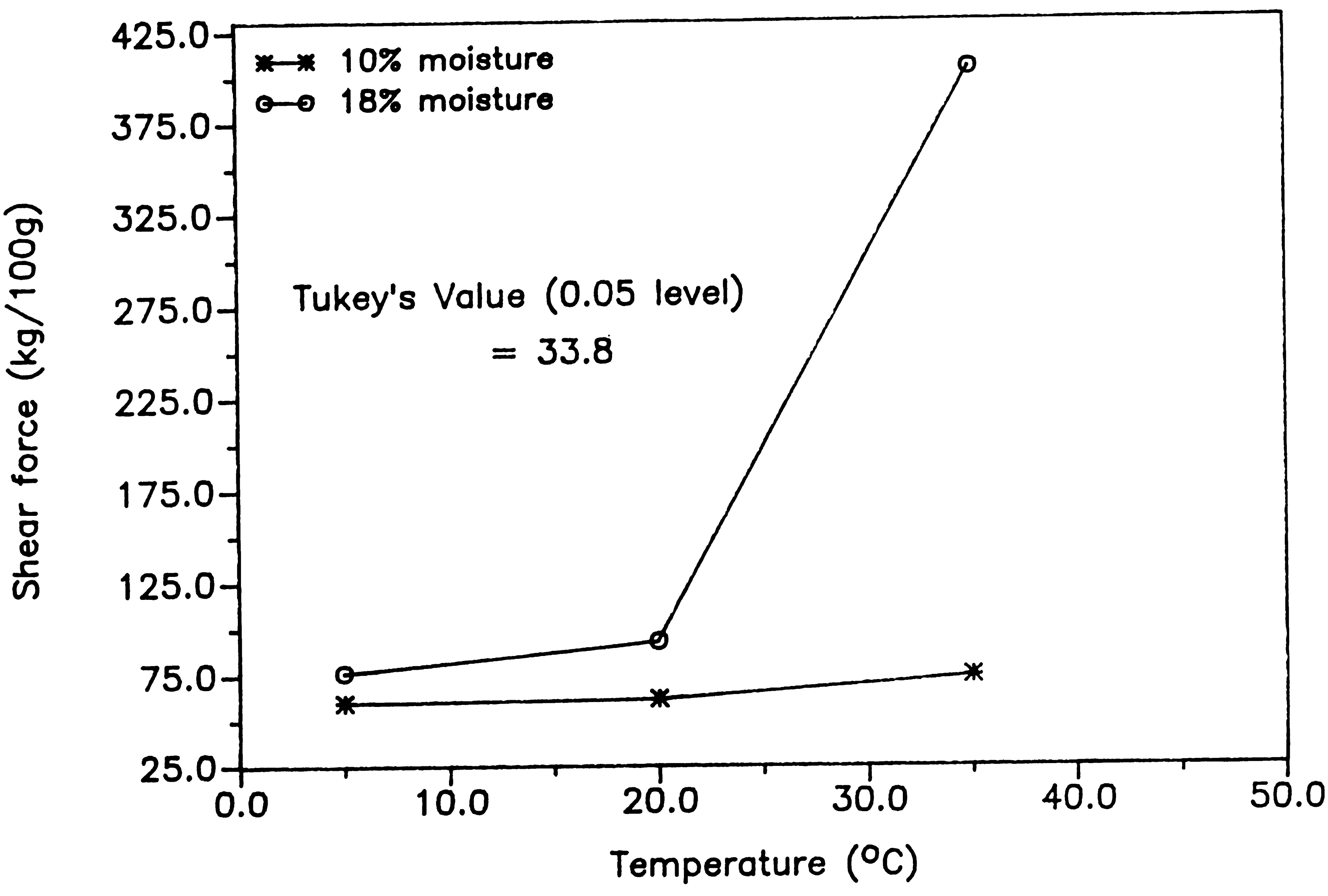


Fig (20) Shear force of black beans stored under nitrogen atmosphere at three temperatures and two moistures for nine months

Table (14) Analysis of variance of moisture and mass ratio index measurments of dry, soaked and processed black (BTS) beans stored under three gas atmospheres at three temperatures and two moistures for up to nine months

Source of Variation	df	Bean Moisture (%)		Mass Ratio Index	
		Soaked	Processed	Hydration	Drained Weight
		Mean Squares			
Total	107	4.490	4.444	0.003	0.014
Main Effects	7	56.217**	42.643**	0.018**	0.159**
Moisture (Mois.)	1	337.080**	95.203**	0.045**	0.784**
Gas	2	12.100**	0.226	0.013**	0.007**
Temperature (Temp.)	2	3.107**	84.738**	0.002	0.127**
Time	2	13.103**	16.685**	0.026**	0.032**
2-way Interactions	18	3.085**	8.707**	0.004**	0.014**
Mois. x Gas	2	8.374**	0.597*	0.003*	0.003
Mois. x Temp.	2	3.727**	67.517**	0.008**	0.097**
Mois. x Time	2	4.927**	4.991**	0.008**	0.012**
Gas x Temp.	4	0.386	0.138	0.001	0.002
Gas x Time	4	0.255	0.736**	0.000	0.000
Temp. x Time	4	4.726**	1.757**	0.008**	0.003

Table (14) (Cont'd.)

Source of Variation	df	Moisture		Mass Ratio Indexes	
		Soaked	Processed	Hydration	Drained Weight
		Mean Squares			
3-way Interactions	20	0.769**	0.498**	0.002**	0.001
Mois. x Gas x Temp.	4	0.261	0.444*	0.000	0.001
Mois. x Gas x Time	4	0.406	0.653**	0.003**	0.001
Mois. x Temp. x Time	4	2.019**	0.829**	0.002*	0.002
Gas x Temp. x Time	8	0.580*	0.281	0.002**	0.001
4-way Interactions	8	0.621**	0.270	0.002*	0.002
Mois. x Gas x Temp. x Time	8	0.621**	0.270	0.002*	0.002
Explained	53	8.857**	8.818**	0.005**	0.026**
Error	54	0.204	0.152	0.001	0.001
CV (%)		0.87	0.57	0.177	2.34

Table (15) Analysis of variance of surface color of dry and processed pinto (Oletha) beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

Source of Variation	df	Hunter Lab Color Coordinates					
		Dry Bean			Processed Bean		
		L	a_L	b_L	L	a_L	b_L
		Mean Squares					
Total	161	20.278	2.145	2.675	10.502	213.300	9.973
Main Effects	8	316.390**	28.145**	48.132**	187.773**	4212.899**	191.342**
Moisture (Mois.)	2	21.198**	13.826**	35.511**	2.479*	0.512	0.334*
Gas	2	128.064**	16.108**	2.974**	43.480**	7.536**	17.838**
Temperature (Temp.)	2	1090.395**	54.407**	144.950**	593.607**	84.636**	20.316**
Time	2	25.904**	28.240**	9.095**	111.528**	16758.914**	726.882**
2-Way Interactions	24	17.464**	3.208**	1.39**	3.4**	20.489**	2.285**
Mois. x Gas	4	14.201**	1.321**	1.034**	2.378*	2.502**	0.571**
Mois. x Temp.	4	53.093**	8.496**	4.318**	3.041**	1.088	0.507**
Mois. x Time	4	8.988**	2.989**	0.972**	0.905	1.629	0.789**
Gas x Temp.	4	24.296**	3.851**	0.630**	6.581**	5.562**	1.910**
Gas x Time	4	1.596	0.327**	0.049	0.786	9.400**	0.587**
Temp. x Time	4	2.614	2.266**	1.334**	6.711**	102.753**	9.346**

Table (15) (Cont'd.)

Source of Variation	df	Hunter Lab Color Coordinates					
		Dry Bean			Processed Bean		
		L	a_L	b_L	L	a_L	b_L
		Mean Squares					
3-way Interactions	32	5.864**	1.072**	0.230**	1.314**	2.299**	0.331**
Mois. x Gas x Temp.	8	3.761**	0.400**	0.398**	0.941	1.227	0.679**
Mois. x Gas x Time	8	1.337	0.101	0.187**	0.342	2.554**	0.610
Mois. x Temp. x Time	8	16.285**	3.670**	0.265**	3.448**	2.597**	0.434**
Gas x Temp. x Time	8	2.076	0.116	0.069	0.524	2.819**	0.151
4-way Interactions	16	1.627	0.174**	0.105**	0.620	0.984	0.064
Mois. x Gas x Temp. x Time	16	1.627	0.174**	0.105**	0.620	0.984	0.064
Explained	80	39.550**	4.240**	5.343**	20.447**	428.553**	19.965**
Error	81	1.244	0.076	0.039	0.680	0.704	0.105
CV (%)		2.57	11.21	1.51	2.83	6.12	2.37

The darkness (L) and yellowness (b_L) increased for dry pinto beans, but the greenness decreased at 10 and 14% moisture and increased at 18% moisture as the storage temperature increased (Table 16).

Mean squares from the analysis of variance for pinto (Oletha) bean quality parameters (soaked weight, drained weight and dried residue) are summarized in Table 17 and the treatment mean values are presented in Figures 21 through 26. The mean squares from the analysis of variance for soaked weight, drained weight and dried residue of pinto (Oletha) beans indicated high variability among various bean moistures, storage temperatures and times of storage. Selected gas atmospheres significantly effected the soaked and drained weight, but not the dried residue.

Figures 21 and 22 present the treatment mean soaked weight values of pinto (Oletha) beans during storage under differential conditions. The response trend of soaked weight for pinto beans soaked weight showed slight fluctuation during storage. It decreased in the first three months with all temperatures, moistures, and gases. The soaked weight of pinto beans stored at 5°C decreased for all periods of storage time and under all atmospheric gases. Similarly, the soaked weight of pinto beans stored at 20°C and 35°C decreased following 6 months of storage. At 9

Table (16) Mean values of surface color for pinto (Oletha) beans stored under nitrogen gas atmosphere at three temperatures and moistures for nine months

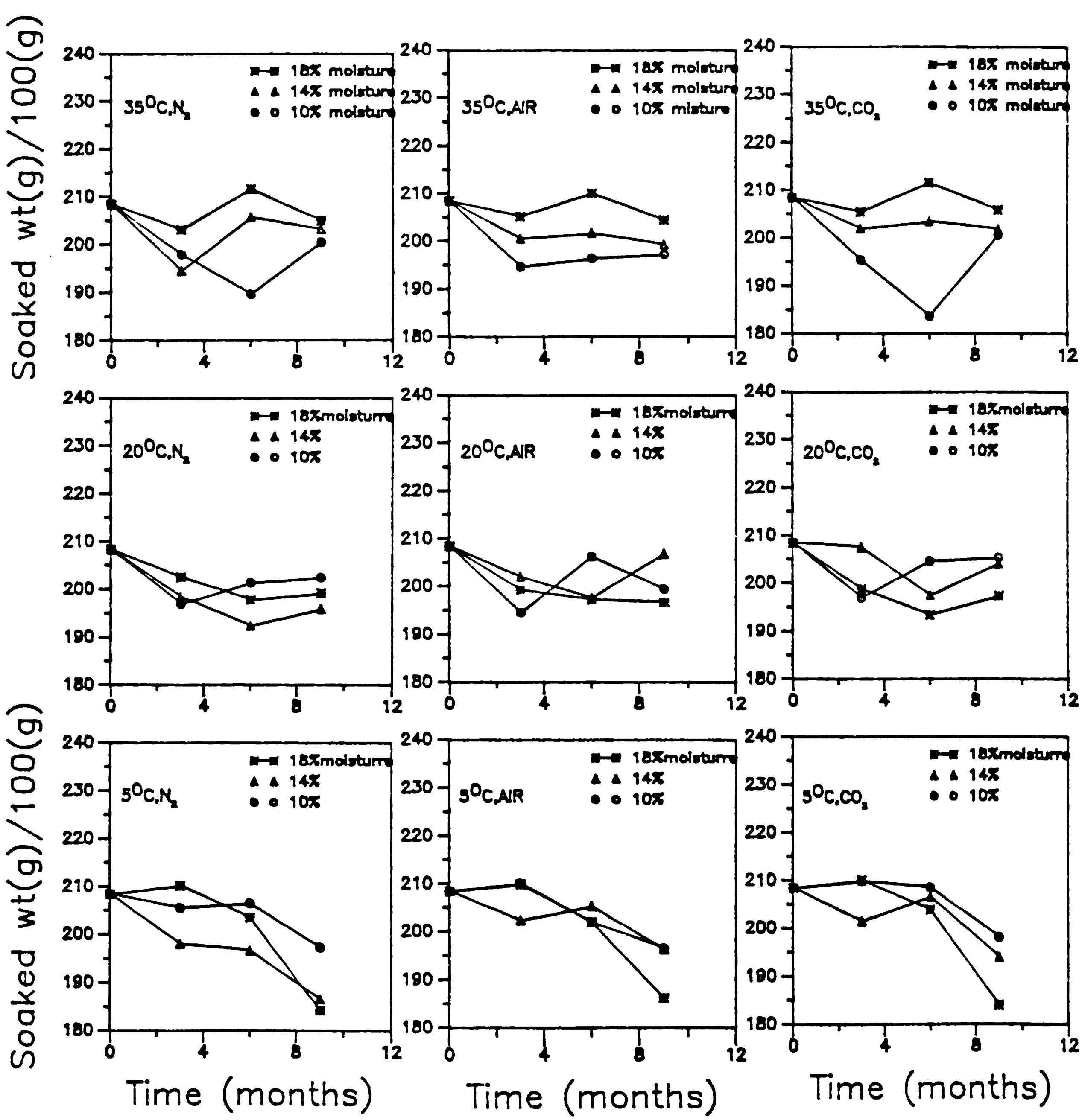
Moisture (%)	Temperature (^{o}C)	Hunter Lab Color Coordinates					
		Dry bean			Processed Bean		
		L	a_L	b_L	L	a_L	b_L
10	5	48.55	-2.75	11.25	32.05	2.00	12.37
	20	45.75	-2.05	12.65	29.37	2.90	11.95
	35	36.65	0.75	14.00	25.20	4.02	10.35
14	5	48.25	-2.85	11.40	32.35	1.90	12.35
	20	43.55	-1.60	13.75	27.87	3.70	11.85
	35	41.60	-2.50	16.40	26.12	3.50	10.77
18	5	47.50	-3.30	12.30	31.37	2.15	12.05
	20	45.80	-2.95	13.75	28.15	3.52	12.40
	35	43.90	-4.45	16.75	24.60	3.60	10.15

Table (17) Analysis of variance of quality characteristics of dry, soaked and processed pinto (Oletha) beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

Source of Variation	df	Bean Weight (g)			Visual		Shear Force (kg/100g)
		Soaked	Drained	Dried Residue	Clumps	Splits	
		Mean Squares					
Total	161	43.526	162.710	2.545	0.896	0.251	5965.334
Main Effects	8	84.689**	2839.432**	42.405**	13.764**	2.015**	92100.443**
Moisture (Mois.)	2	39.690**	1204.104**	14.198**	15.130**	0.784**	46714.147**
Gas	2	38.937**	20.618*	0.004	0.019	0.414*	99.625
Temperature (Temp.)	2	26.696*	8532.446**	152.565**	32.722**	6.784**	299295.787**
Time	2	233.432**	1600.562**	2.852**	7.185**	0.080	22292.212**
2-way Interactions	24	175.183**	86.544**	1.676**	0.602**	0.228*	8487.604**
Mois. x Gas	4	54.474**	51.911**	0.444*	0.370**	0.238	93.487
Mois. x Temp.	4	388.389**	366.712**	7.274**	0.852**	0.386*	30685.342**
Mois. x Time	4	107.555**	33.699**	0.243	0.343*	0.182	1686.855**
Gas x Temp.	4	14.685	5.431	0.121	0.130	0.349*	26.658
Gas x Time	4	4.375	20.119*	0.389	0.509**	0.117	16.554
Temp. x Time	4	481.623**	41.449**	1.587**	1.407**	0.099	18416.731**

Table (17) (Cont'd.)

Source of Variation	df	Bean Weight (g)			Visual		Shear Force (kg/100g)
		Soaked	Drained	Dried Residue	Clumps	Splits	
				Mean Squares			
3-way Interactions	32	41.620**	26.029**	0.418**	0.299**	0.227**	485.747**
Mois. x Gas x Temp.	8	22.546**	9.514	0.033	0.495**	0.423**	52.309
Mois. x Gas x Time	8	8.527	39.752**	0.158	0.236*	0.108	50.577
Mois. x Temp. x Time	8	118.160**	30.894**	1.132**	0.245*	0.201	1799.493**
Gas x Temp. x Time	8	17.246*	23.957**	0.350*	0.218*	0.177	40.607
4-way Interactions	16	14.299*	6.032	0.226	0.104	0.127	40.465
Mois. x Gas x Temp. x Time	16	14.299*	6.032	0.226	0.104	0.127	40.465
Explained	80	80.532**	321.528**	4.956**	1.697**	0.389**	11958.717**
Error	81	6.977	5.853	0.165	0.105	0.117	45.943
CV (%)		1.32	0.93	1.22	15.21	22.50	5.77



Fig(21) Soaked weight of pinto beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

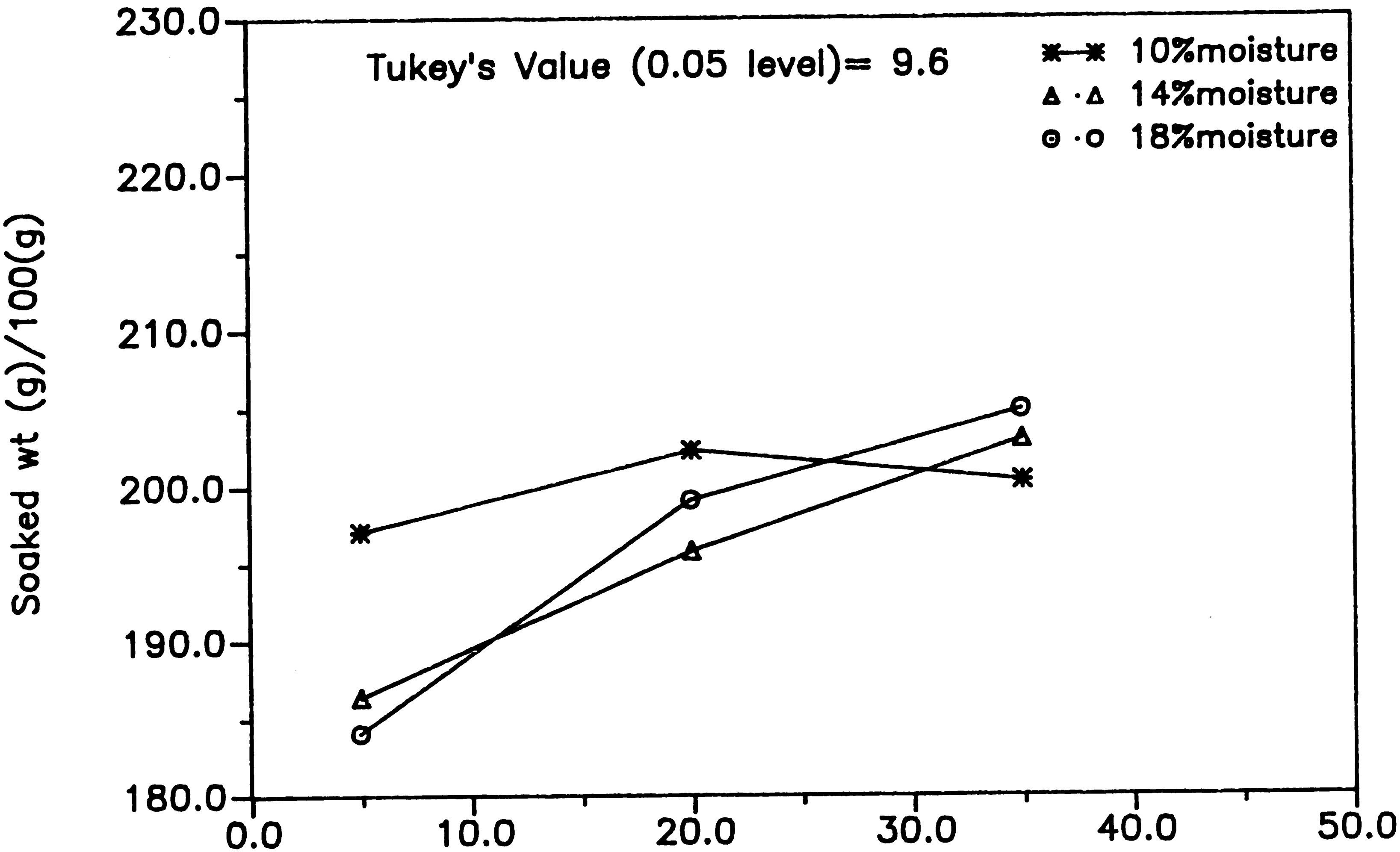


Fig (22) Soaked weight of pinto beans stored under nitrogen atmosphere at three temperatures and moistures for nine months

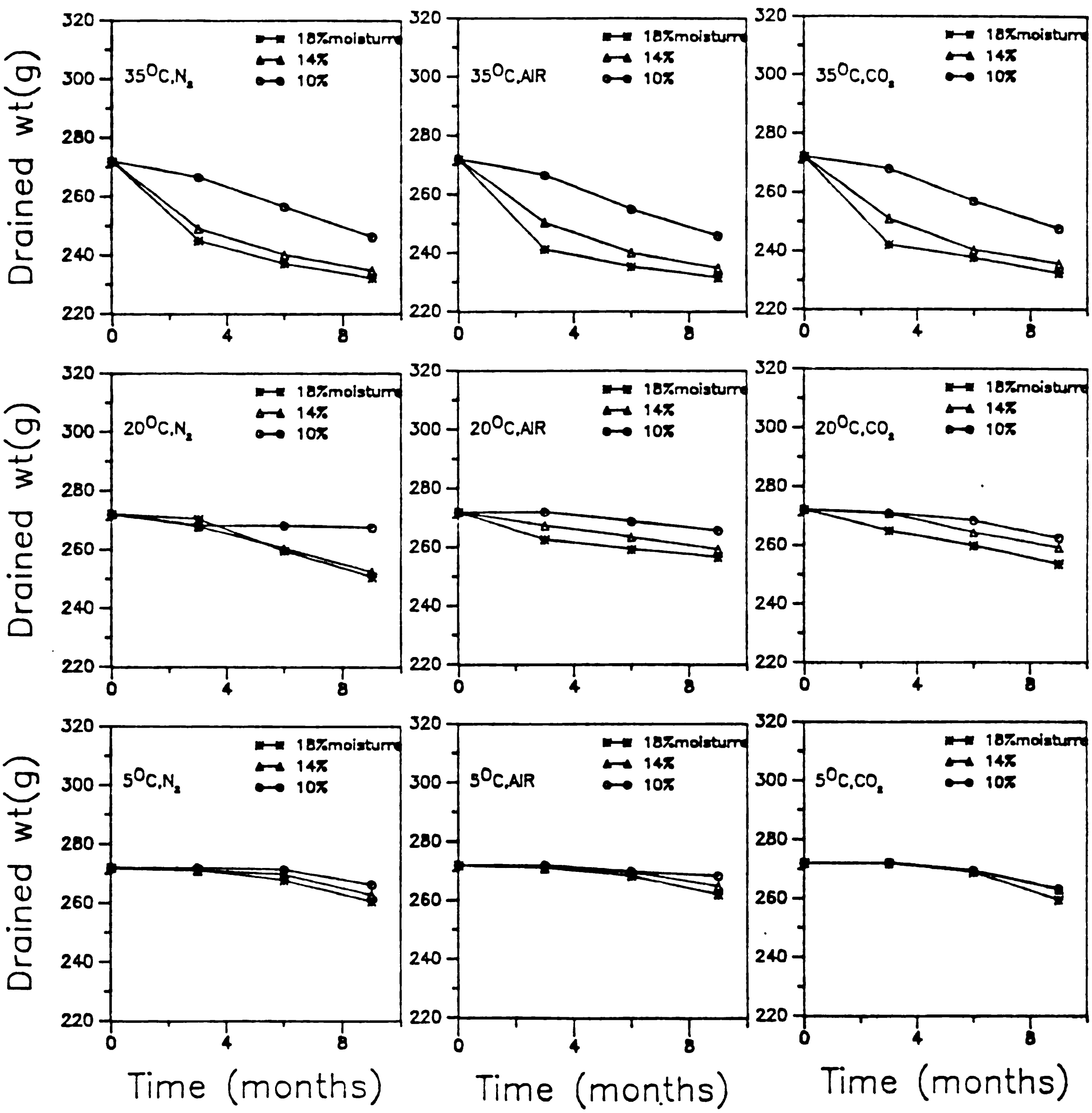
months this trend stabilized or increased.

Pinto (Oletha) bean drained weight and dried residue treatment mean values are presented in Figures 23, 24, 25 and 26. Pinto bean drained weight decreased and the dried residue increased as the temperature, moisture and time of storage increased for all gas environments.

Pinto (Oletha) bean clumps and splits (Table 17) showed significant variations among all experimental variables except the effects on clumps and splits by gases and storage times, respectively. The clumps and splits of pinto beans decreased with increased storage temperature, bean moisture and storage time (Table 18).

The shear force mean squares from the analysis of variance of pinto (Oletha) beans (Table 17) showed highly significant differences among three storage variables (temperature, moisture and time) but not for storage environment gases. The results of the pinto (Oletha) beans (Figures 27 and 28) indicated that, as the temperature, moisture and time of storage increased, the shear force also increased.

Mean squares from the analysis of variance of pinto (Oletha) bean soaked moisture, processed moisture and mass ratio index of hydration and drained weight (Table 19) showed significant differences among various moistures and



Fig(23) Drained weight of pinto beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

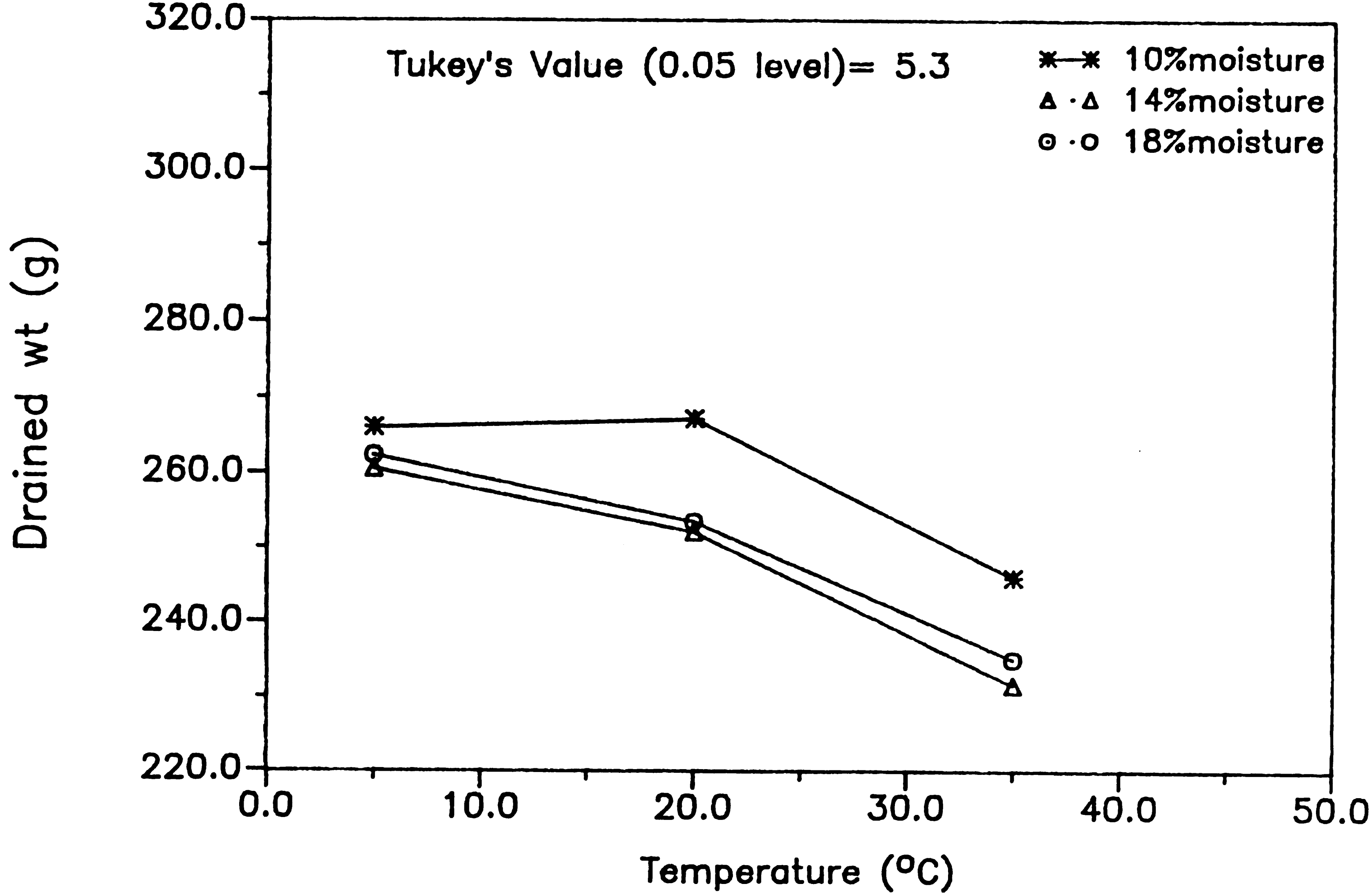
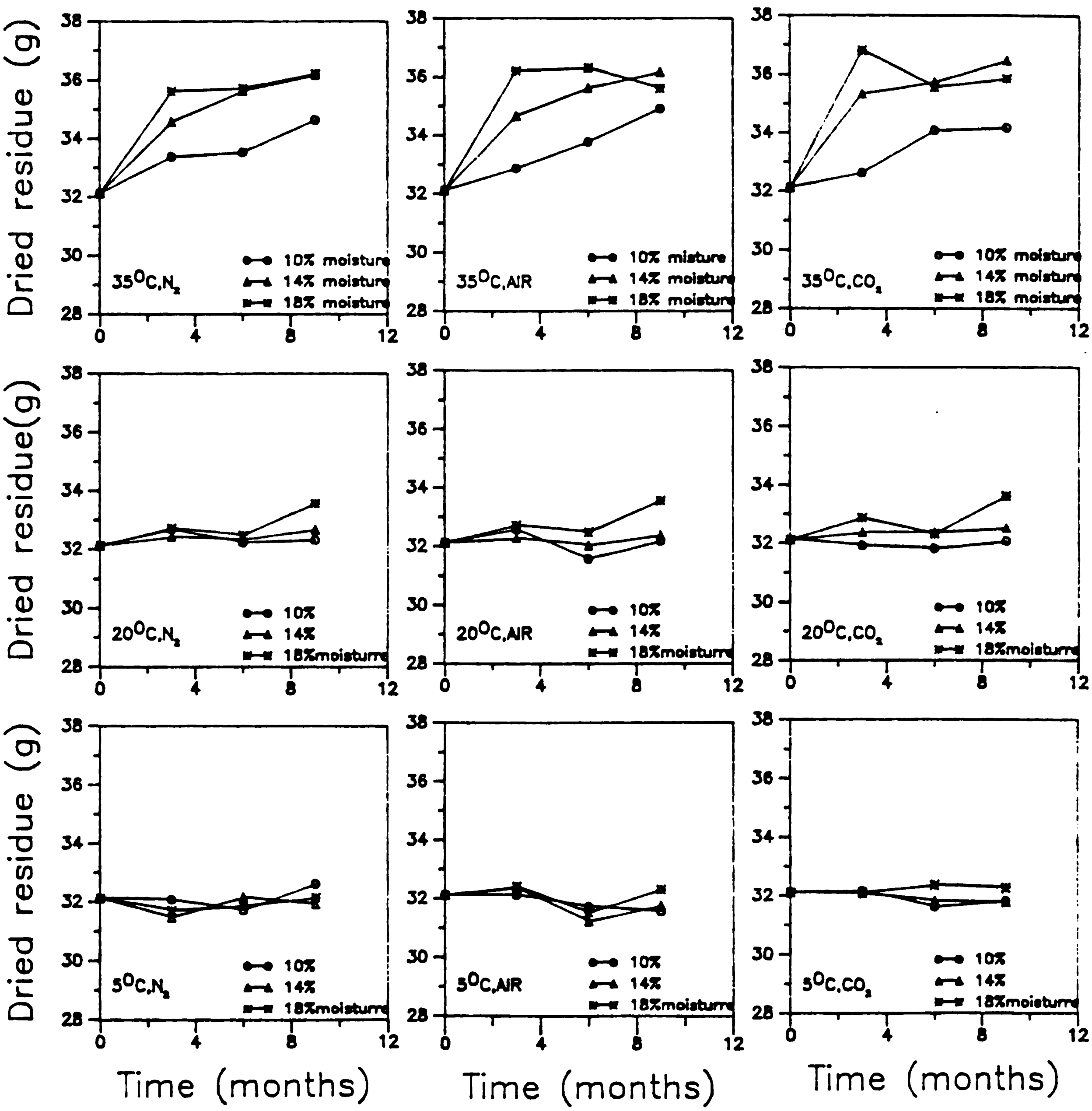
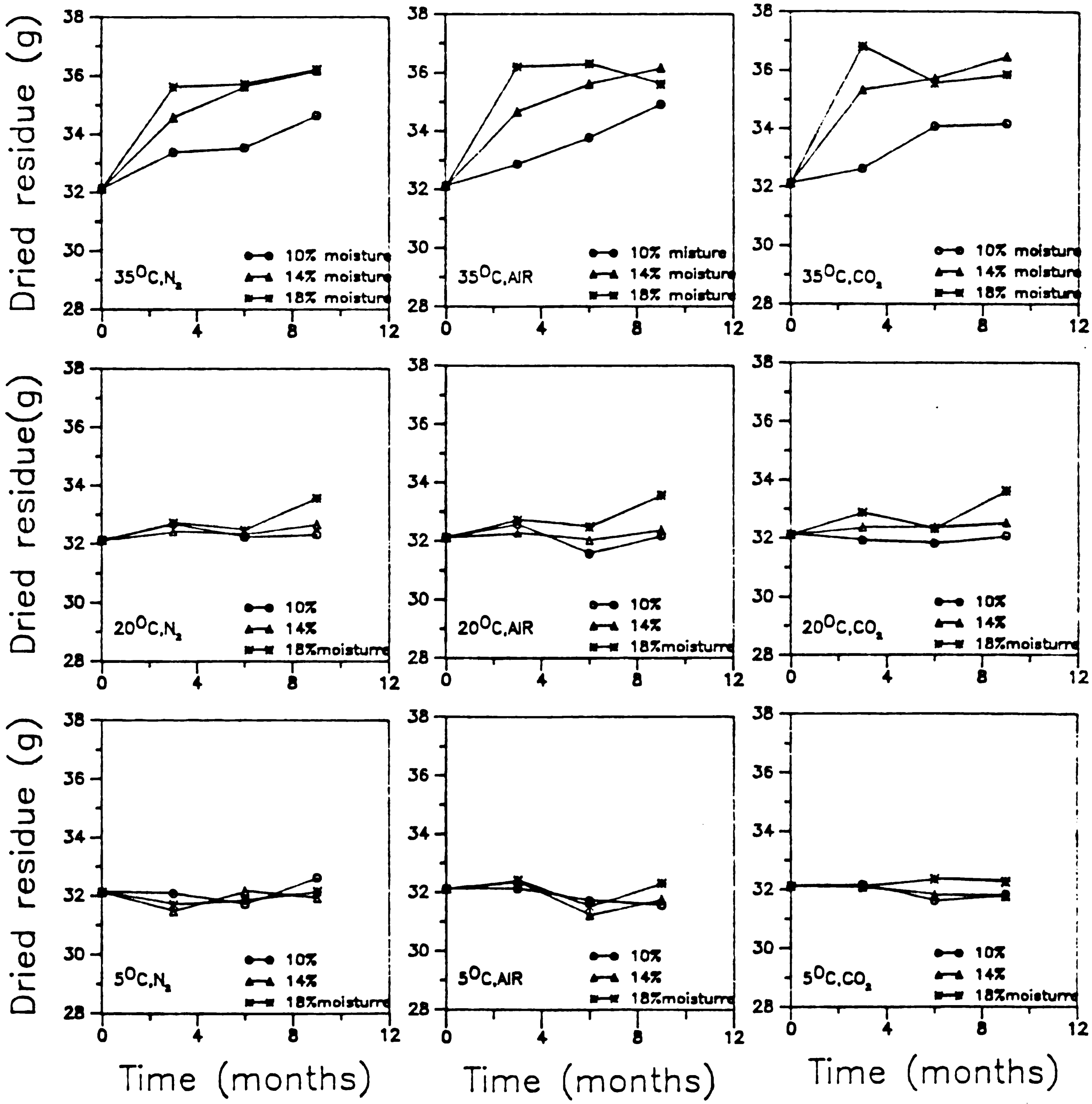


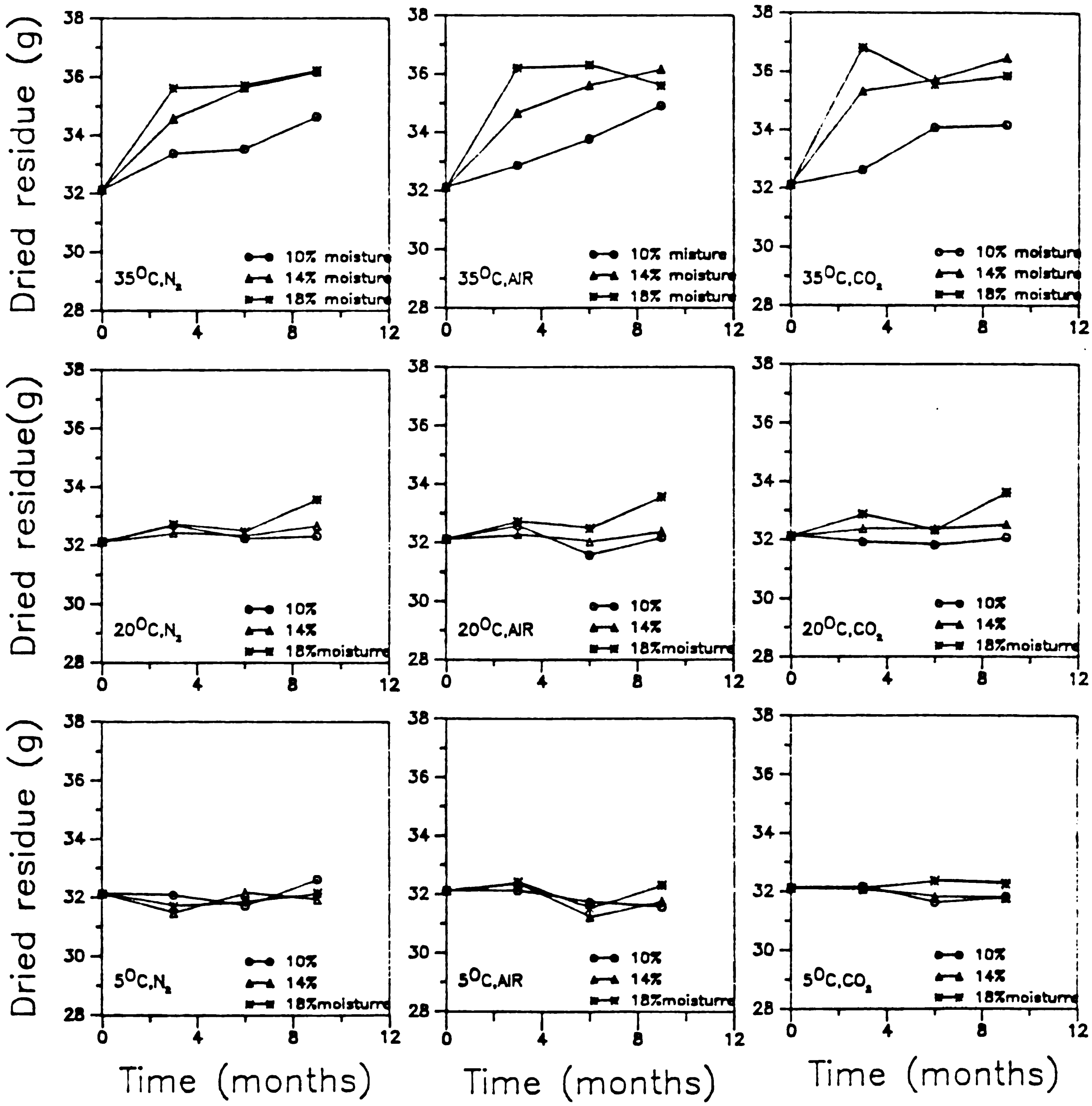
Fig (24) Drained weight of pinto beans stored under nitrogen atmosphere at three temperatures and moistures for nine months



Fig(25) Dried residue of pinto beans stored under three gas atmospheres at three temperatures and moistures for up to nine months



Fig(25) Dried residue of pinto beans stored under three gas atmospheres at three temperatures and moistures for up to nine months



Fig(25) Dried residue of pinto beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

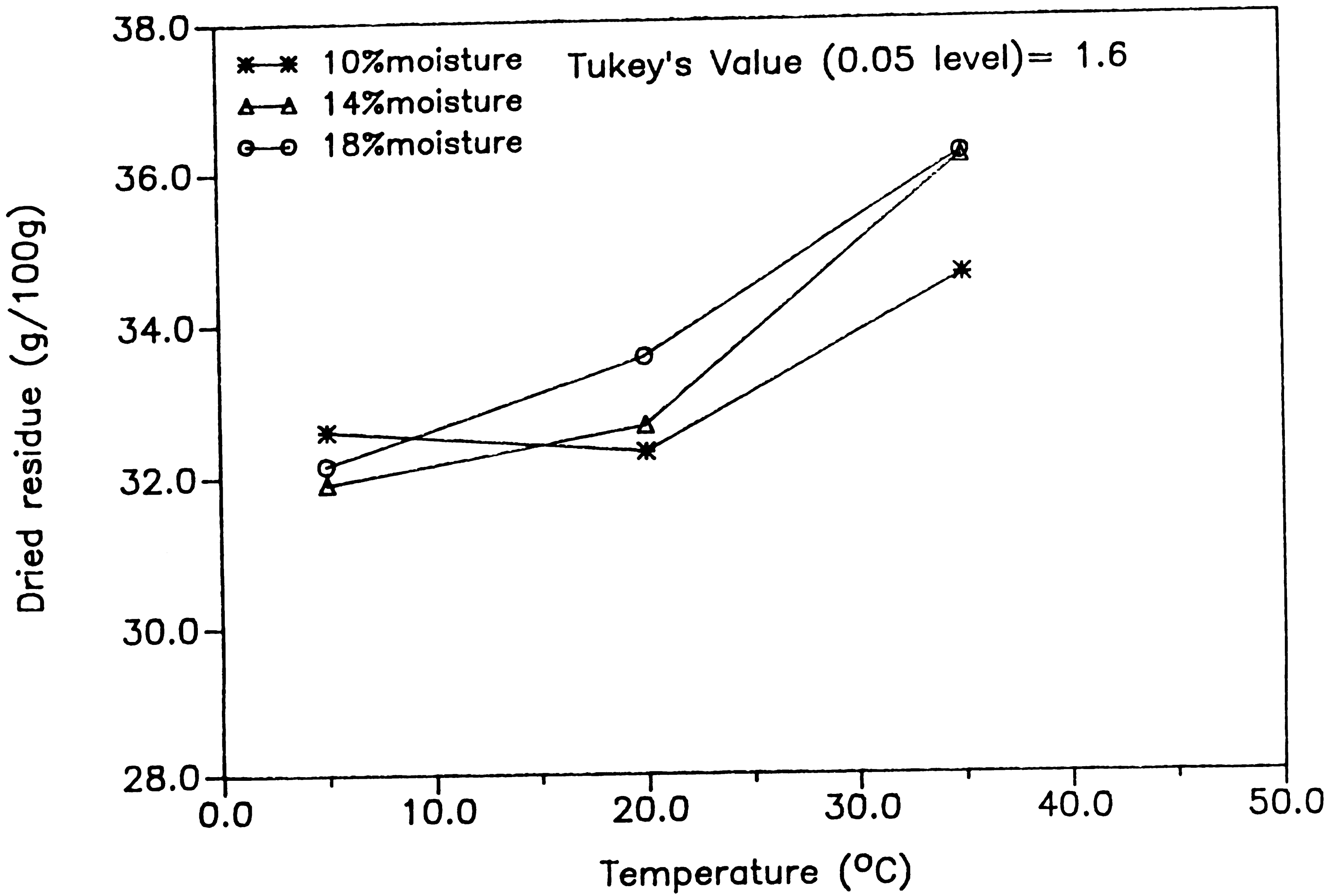


Fig (26) Dried residue of pinto beans stored under nitrogen atmosphere at three temperatures and moistures for nine months

Table (18) Mean values[1] of clumps and splits for pinto (Oletha) beans stored under nitrogen gas atmosphere at three temperatures and moistures for nine months

Moisture (%)	Temperature (°C)	Storage Time (Months)					
		3		6		9	
		Clumps	Splits	Clumps	Splits	Clumps	Splits
10	5	3.5	1.5	3.5	2.0	4.0	2.0
	20	2.5	1.0	3.0	2.0	3.5	1.0
	35	2.0	1.5	2.0	1.5	2.0	1.5
14	5	2.0	2.0	2.0	2.0	2.5	1.5
	20	2.0	2.0	2.0	1.0	2.0	2.0
	35	1.0	1.0	1.0	1.0	1.5	1.0
18	5	2.5	1.0	2.5	1.5	3.0	1.5
	20	1.5	1.5	1.0	1.0	2.0	1.5
	35	1.0	1.0	1.0	1.0	1.0	1.0

1. n = 2 cans; 5 points scale for clumps and splits; 1 = none, 5 = extreme

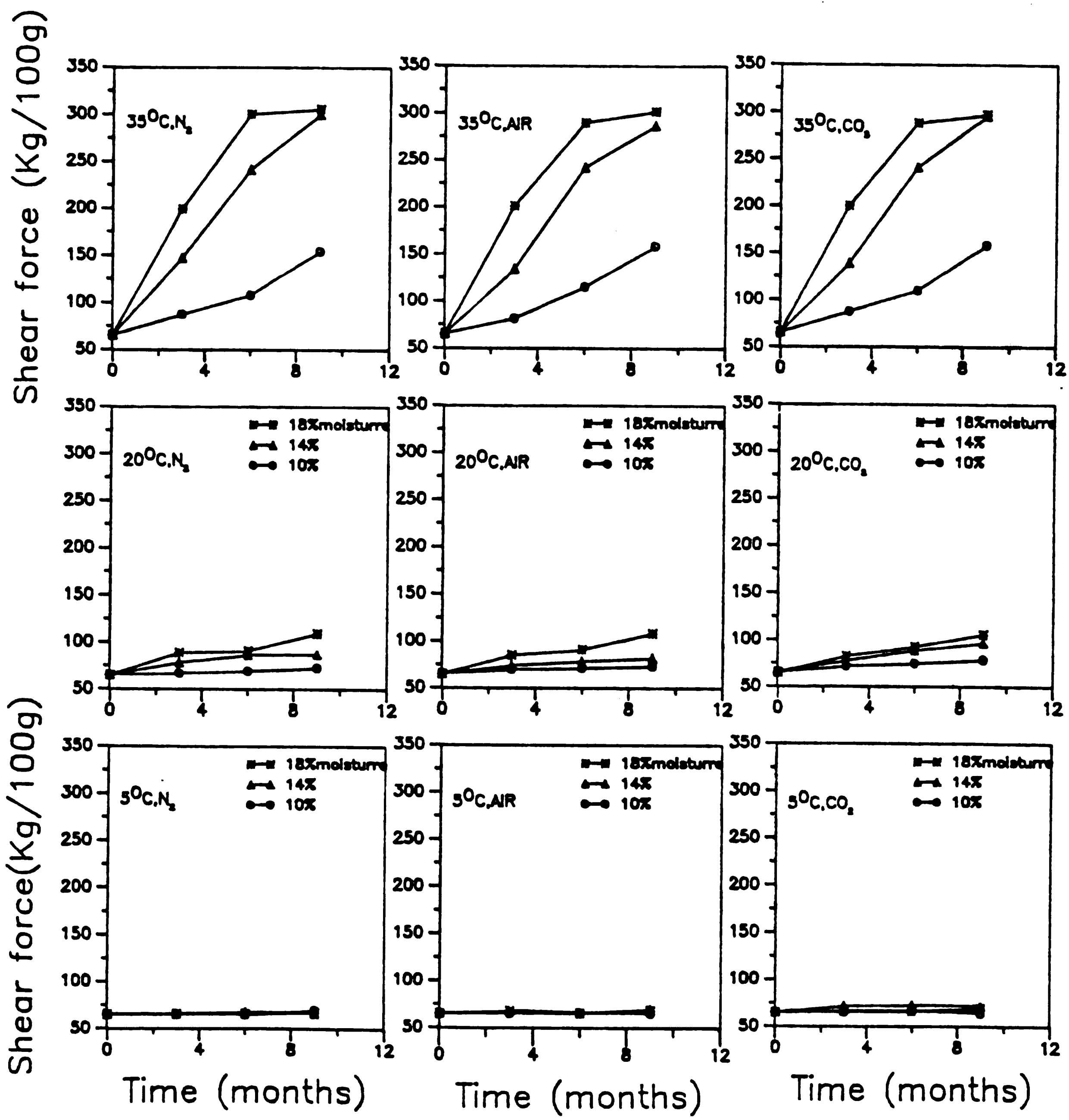


Fig (27) Shear force of pinto beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

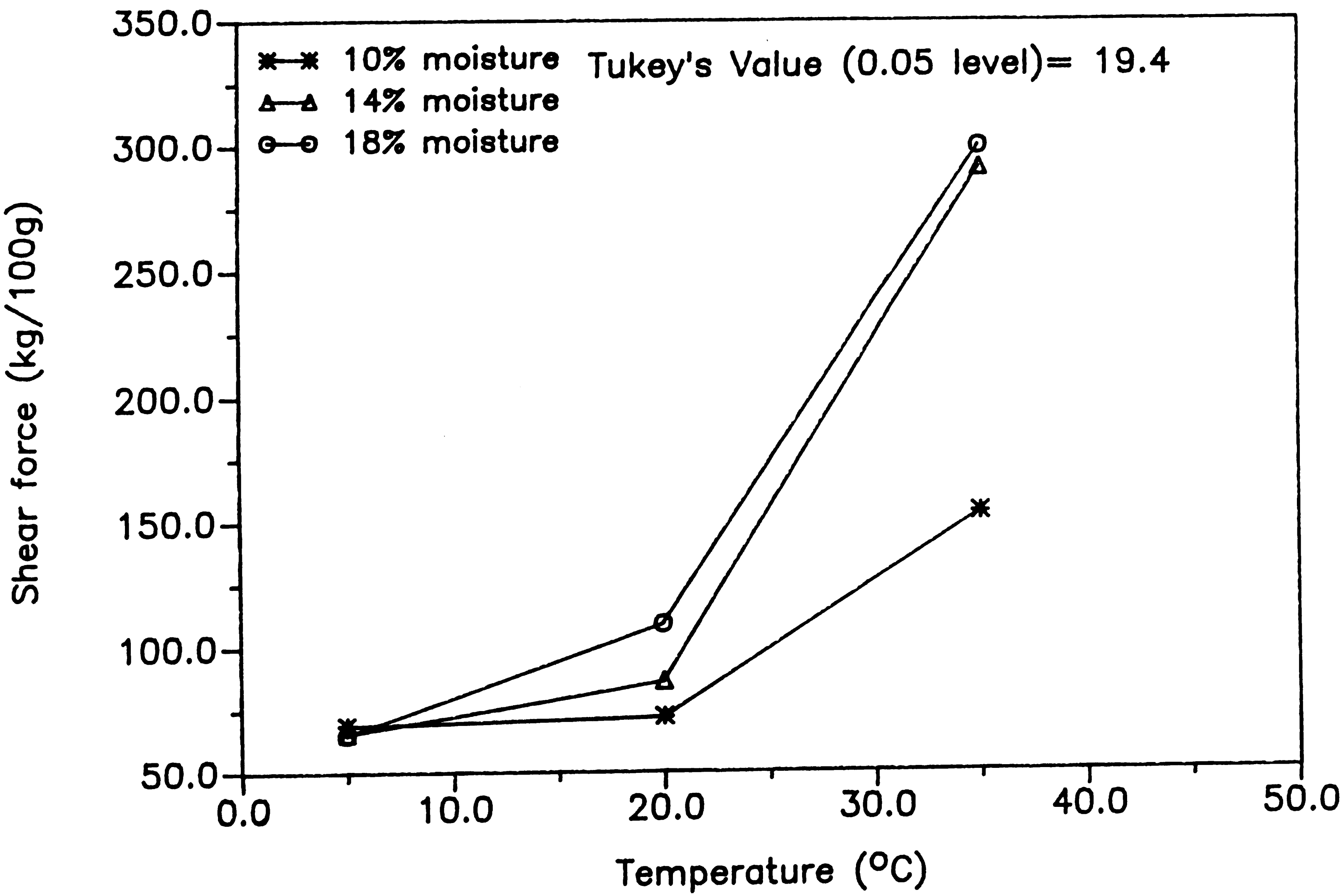


Fig (28) Shear force of pinto beans stored under nitrogen atmosphere at three temperatures and moistures for nine months

Table (19) Analysis of variance of moisture and mass ratio index measurments of dry, soaked and processed pinto (Oletha) beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

Source of Variation	df	Bean Moisture (%)		Mass Ratio Index	
		Soaked	Processed	Hydration	Drained Weight
		Mean Squares			
Total	161	2.835	2.545	0.006	0.007
Main Effects	8	5.227**	42.405**	0.036**	0.074**
Moisture (Mois.)	2	2.014*	14.198**	0.125**	0.038**
Gas	2	2.421**	0.004	0.002	0.001
Temperature (Temp.)	2	1.390	152.565**	0.002	0.234**
Time	2	15.085**	2.852**	0.015**	0.021**
2-way Interactions	24	11.510**	1.676**	0.015**	0.015**
Mois. x Gas	4	3.492**	0.444*	0.005**	0.003*
Mois. x Temp.	4	25.137**	7.274**	0.029**	0.046**
Mois. x Time	4	7.460**	0.243	0.013**	0.005**
Gas x Temp.	4	0.919	0.121	0.002	0.002
Gas x Time	4	0.334	0.389	0.000	0.001
Temp. x Time	4	31.720**	1.587**	0.039**	0.033**

Table (19) (Cont'd.)

Source of Variation	df	Bean Moisture (%)		Mass Ratio Index	
		Soaked	Processed	Hydration	Drained Weight
				Mean Squares	
3-way Interactions	32	2.720**	0.418**	0.004**	0.003**
Mois. x Gas x Temp.	8	1.488**	0.033	0.002	0.001
Mois. x Gas x Time	8	0.594	0.158	0.003*	0.003*
Mois. x Temp. x Time	8	7.680**	1.132**	0.010**	0.007**
Gas x Temp. x Time	8	1.120*	0.350*	0.003*	0.001
4-way Interactions	16	0.929*	0.226	0.001	0.002
Mois. x Gas x Temp. x Time	16	0.929*	0.226	0.001	0.002
Explained	80	5.249**	4.956**	0.010**	0.013**
Error	81	0.450	0.165	0.001	0.001
CV (%)		1.34	0.61	1.86	2.45

times for all characters, and also among temperatures for processed bean moisture and drained weight mass ratio index. The gas environments were significantly different for soaked moisture, but not for processed moisture and not for hydration and drained weight ratio.

Kidney (Montcalm) Beans

Mean squares from the analysis of variance of kidney (Montcalm) bean Hunter lab coordinates (Table 20) showed significant variations among all variables for both dry and processed beans. No significant differences were demonstrated among differential gas atmospheres for yellowness of dry beans.

Surface color observations on treatment mean values of kidney beans stored for nine months is presented in Table 21. The kidney beans increased in darkness, greenness and yellowness as the temperature and moisture increased during storage.

Mean squares from the analysis of variance of kidney (Montcalm) bean quality parameters (soaked weight, drained weight and dried residue) are presented in Table 22. Mean values are presented in Figures 29 through 34. The mean squares showed highly significant variations among various

Table (20) Analysis of variance of surface color of dry and processed kidney (Montcalm) beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

		Hunter Lab Color Coordinates					
Source of Variation	df	Dry bean			Processed Bean		
		L	a_L	b_L	L	a_L	b_L
		Mean Squares					
Total	161	0.423	2.084	0.367	0.645	0.429	0.091
Main Effects	8	4.297**	27.337**	3.562**	7.355**	4.719**	0.753**
Moisture (Mois.)	2	2.470**	2.685*	2.067**	3.528**	3.834**	0.159**
Gas	2	2.064**	22.256**	0.376	6.464**	1.810**	0.661**
Temperature (Temp.)	2	4.657**	51.048**	5.346**	16.549**	3.847**	1.218**
Time	2	7.998**	33.359**	6.459**	2.881**	9.384**	0.973**
2-way Interactions	24	0.466**	1.506**	0.331**	0.657**	0.652**	0.170**
Mois. x Gas	4	0.129	0.710	0.380*	0.376*	0.790**	0.169**
Mois. x Temp.	4	1.344**	4.325**	0.906**	0.454*	0.867**	0.378**
Mois. x Time	4	0.343	1.280	0.378*	1.317**	0.347**	0.105**
Gas x Temp.	4	0.572*	2.408**	0.139	0.701**	1.105**	0.202**
Gas x Time	4	0.202	0.205	0.055	0.944**	0.555**	0.079*
Temp. x Time	4	0.204	0.108	0.130	0.148	0.247**	0.087*

Table (20) (Cont'd.)

Source of Variation	df	Dry Bean			Processed Bean		
		L	a_L	b_L	L	a_L	b_L
		Mean Squares					
3-way Interactions	32	0.207	0.742	0.268**	0.465**	0.254**	0.067**
Mois. x Gas x Temp.	8	0.170	0.198	0.490**	0.781**	0.223**	0.058*
Mois. x Gas x Time	8	0.257	0.559	0.142	0.165	0.228**	0.062*
Mois. x Temp. x Time	8	0.308	1.656**	0.324*	0.785**	0.475**	0.116**
Gas x Temp. x Time	8	0.094	0.555	0.117	0.129	0.088	0.030
4-way Interactions	16	0.120	0.545	0.209	0.233	0.143*	0.020
Mois. x Gas x Temp. x Time	16	0.120	0.545	0.209	0.233	0.143*	0.020
Explained	80	0.676**	3.591**	0.605**	1.165**	0.797**	0.157**
Error	81	0.173	0.595	0.131	0.132	0.065	0.025
CV (%)		2.06	3.79	8.98	2.46	3.12	5.90

Table (21) Mean values of surface color for kidney (Montcalm) beans stored under nitrogen atmosphere at three temperatures and moistures for nine months

Moisture (%)	Temperature (°C)	Hunter Lab Color Coordinates					
		Dry bean			Processed Bean		
		L	a_L	b_L	L	a_L	b_L
10	5	20.00	21.10	3.60	17.75	6.82	2.05
	20	19.75	20.40	4.20	14.85	8.02	2.85
	35	19.95	19.40	4.25	13.77	7.80	2.62
14	5	19.85	21.05	4.95	14.57	8.22	3.02
	20	19.85	20.20	4.45	14.45	7.77	2.90
	35	19.00	18.30	3.90	13.40	7.30	2.65
18	5	20.30	21.35	5.10	14.97	8.30	3.05
	20	19.75	20.20	4.35	14.35	8.07	2.85
	35	19.35	20.15	4.25	15.22	7.37	2.52

Table (22) Analysis of variance of quality characteristics of dry, soaked and processed kidney (Montcalm) beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

Source of Variation	df	Bean Weight (g)			Visual		Shear Force (kg/100g)
		Soaked	Drained	Dried Residue	Clumps	Splits	
		Mean Squares					
Total	161	139.888	128.888	1.967	0.463	0.338	1539.888
Main Effects	8	1554.627**	2024.405**	26.708**	5.509**	2.344**	18206.990**
Moisture (Mois.)	2	4936.801**	1730.723**	11.812**	0.241	0.154	25910.150**
Gas	2	522.205**	20.420	1.340**	0.519*	0.043	98.871*
Temperature (Temp.)	2	226.486**	5179.770**	78.363**	20.389**	6.117**	44068.651**
Time	2	533.017**	1166.707**	15.317**	0.889**	3.062**	2750.288**
2-way Interactions	24	275.180**	141.544**	3.134**	0.319*	0.492**	3543.769**
Mois. x Gas	4	357.622**	32.919*	0.815**	0.398	0.340	8.911
Mois. x Temp.	4	56.498*	757.620**	13.3550**	0.019	0.219	14685.249**
Mois. x Time	4	463.277**	13.764	1.438**	0.435*	0.497*	2707.460**
Gas x Temp.	4	15.693	4.350	0.213	0.380	0.247	19.362
Gas x Time	4	26.233	1.787	0.180	0.296	0.719**	132.338**
Temp. x Time	4	731.758**	38.821**	2.803**	0.389	0.932**	3709.294**

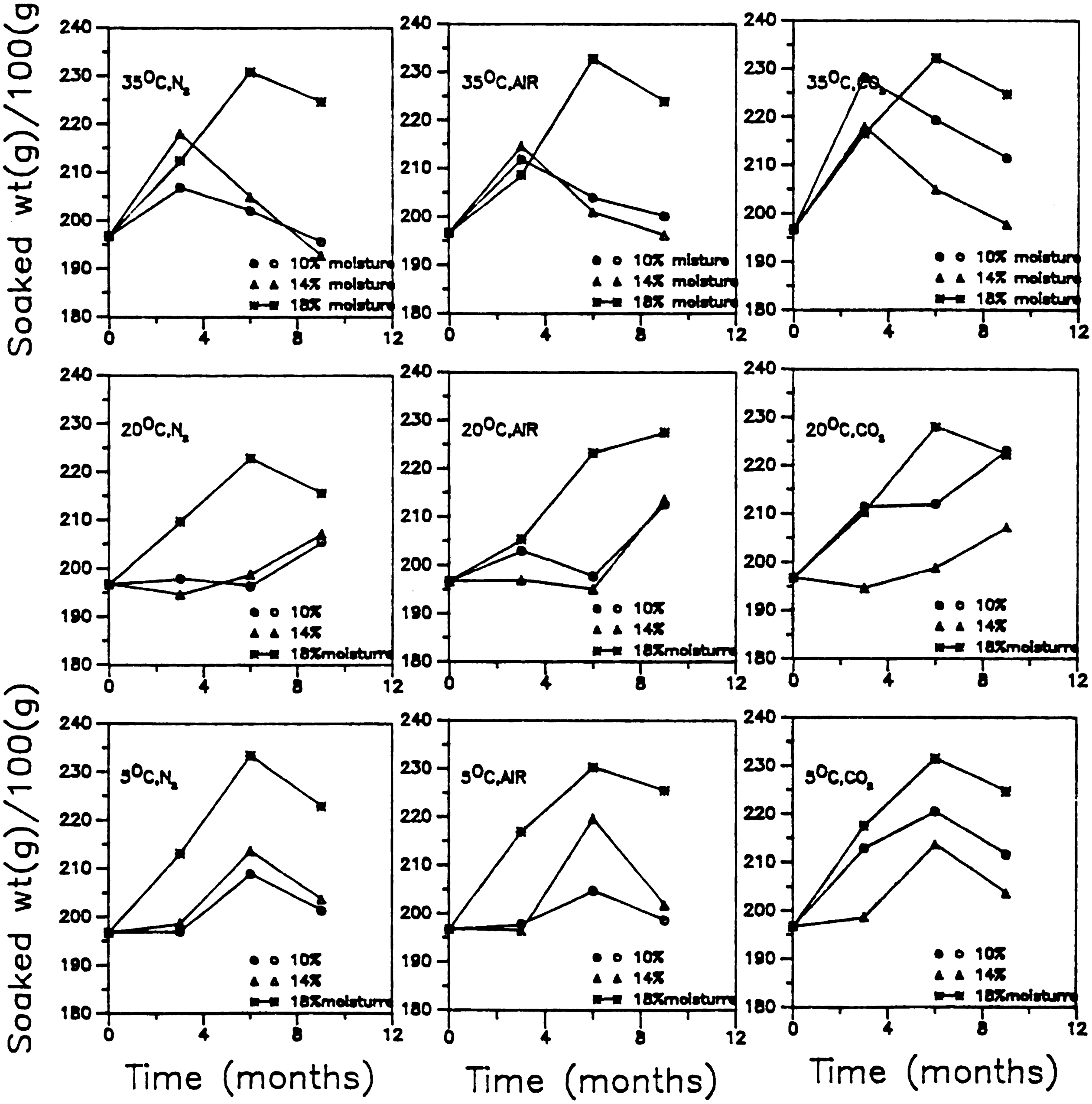
Tabl(22) (Cont'd.)

Source of Variation	df	Bean Weight (g)			Visual		Shear Force (kg/100g)
		Soaked	Drained	Dried Residue	Clumps	Splits	
				Mean Squares			
3-way Interactions	32	58.768**	8.462	0.414**	0.191	0.243	465.212**
Mois. x Gas x Temp.	8	7.395	5.667	0.119	0.106	0.321	71.241**
Mois. x Gas x Time	8	3.622	8.466	0.328	0.231	0.127	11.379
Mois. x Temp. x Time	8	206.377**	15.931	1.101**	0.282	0.270	1754.994**
Gas x Temp. x Time	8	17.677	3.783	0.109	0.144	0.256	23.233
4-way Interactions	16	11.565	3.334	0.051	0.197	0.191	17.846
Mois. x Gas x Temp. x Time	16	11.565	3.334	0.051	0.197	0.191	17.846
Explained	80	263.837**	248.955**	3.787**	0.762**	0.518**	3073.484**
Error	81	17.468	10.303	0.169	0.167	0.160	25.225
CV (%)		1.98	1.13	1.32	25.38	19.05	4.78

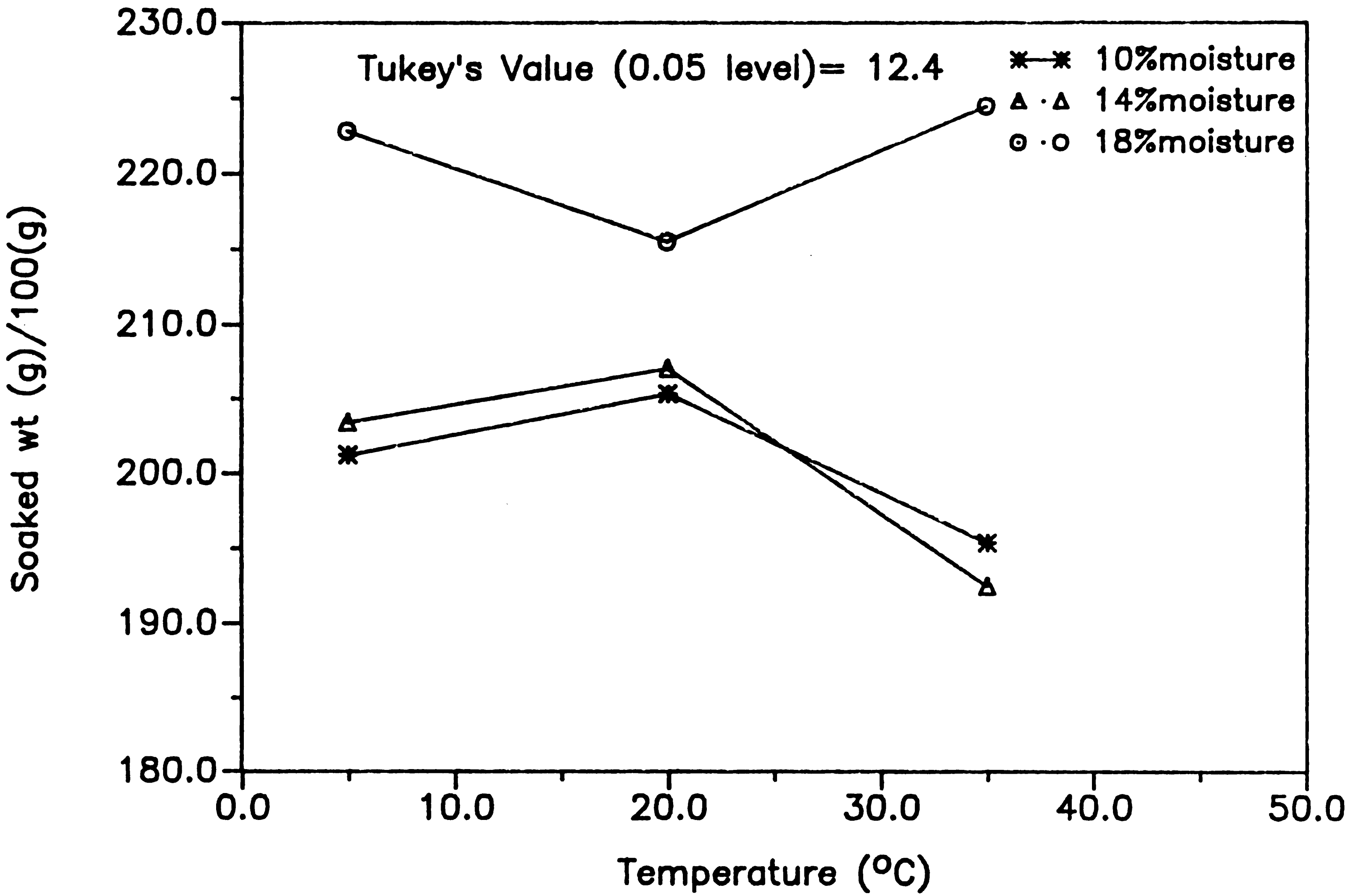
storage temperatures, bean moistures, gas atmospheres and time of storage for all three characters (soaked weight, drained weight and dried residue), except the gas effect on drained bean weight was not significant.

In general, the soaked weight (Figures 29 and 30) increased as the bean moisture increased during storage. The kidney bean soaked weights increased during the first three months for all temperatures and moistures. Soaked weight increased further during the second three months for all treatments except for those beans stored at 35°C. Also, a slight decrease in soaked weight for 10% moisture and 20°C stored beans under nitrogen or air environment was observed. In the final three months of storage the soaked weight mean values decreased at 5°C storage for all gases and moistures. Soaked weight of kidney beans stored at 20°C in 10 or 14% moisture increased for all gases. Kidney beans stored at 20° and 18% moisture under the air atmosphere exhibited an increase in soaked weight compared to nitrogen and carbon dioxide atmospheres which showed a decreased soaked weight. Soaked weight of beans stored at 35°C for nine months decreased under all gas environments and moisture conditions.

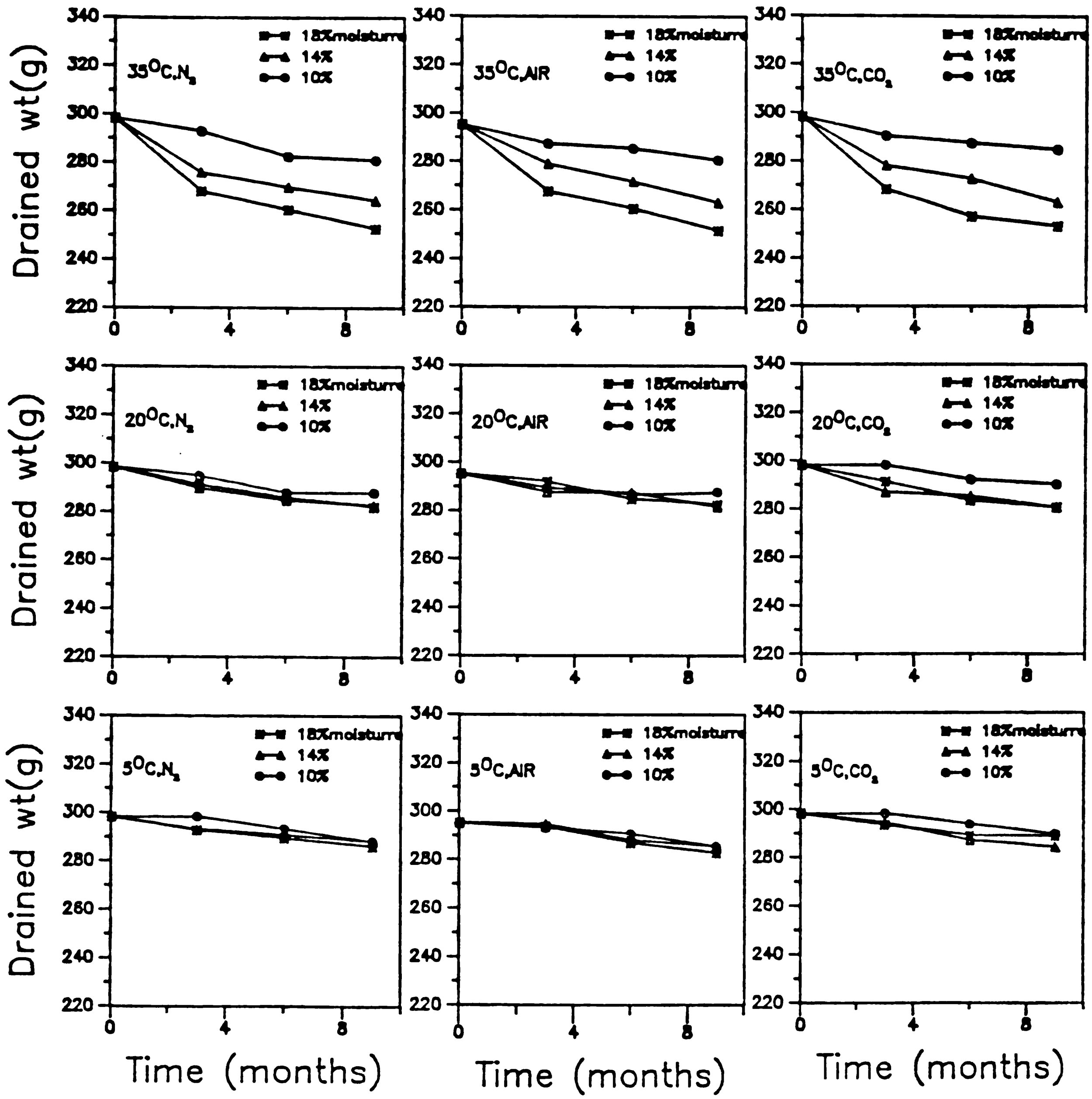
Both drained weight (Figures 31 and 32) and dried residue (Figures 33 and 34) for kidney (Montcalm) beans



Fig(29) Soaked weight of kidney beans stored under three gas atmospheres at three temperatures and moistures for up to nine months



Fig(30) Soaked weight of kidney beans stored under nitrogen atmosphere at three temperatures and moistures for nine months



Fig(31)Drained weight of kidney beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

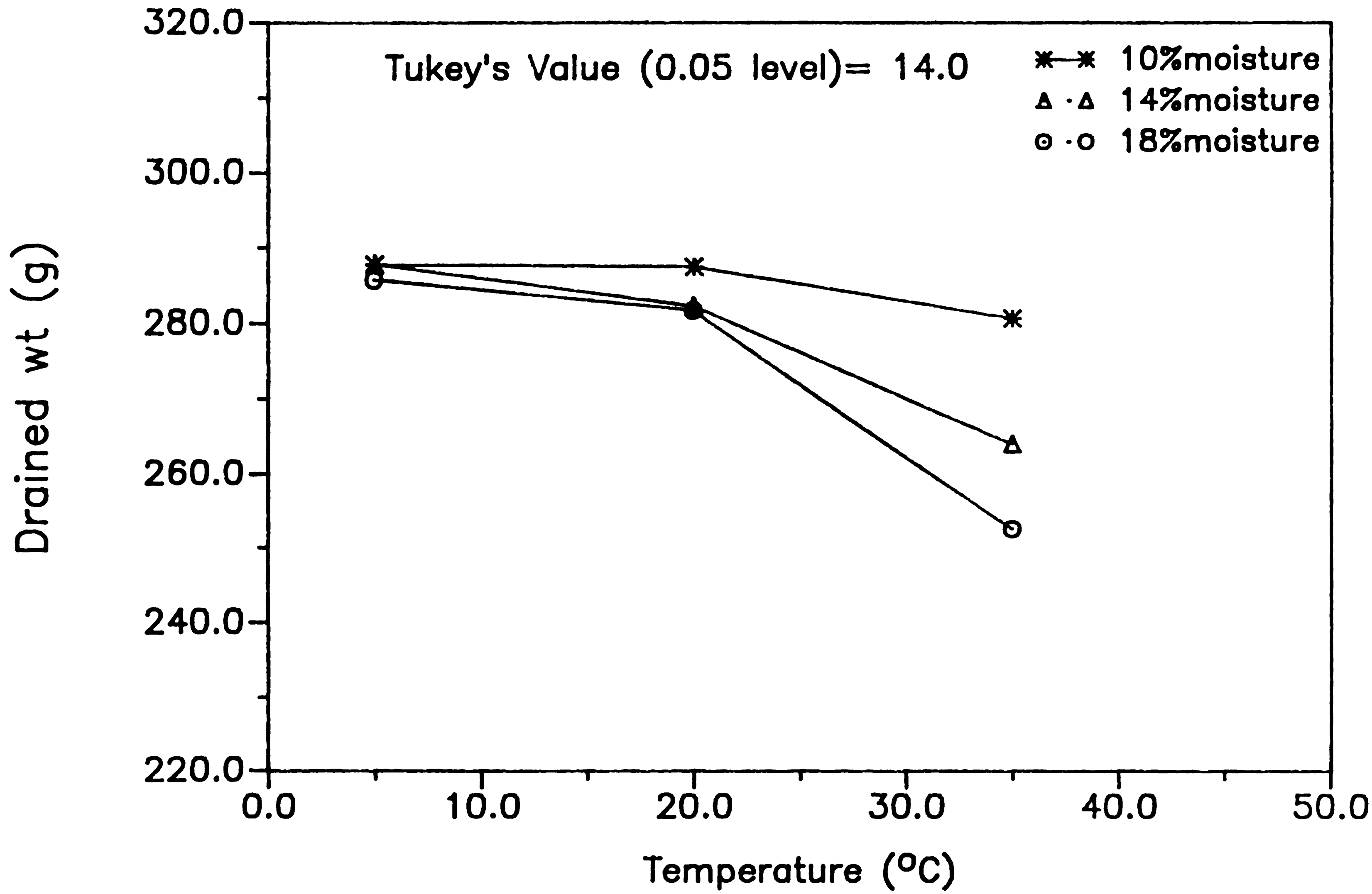
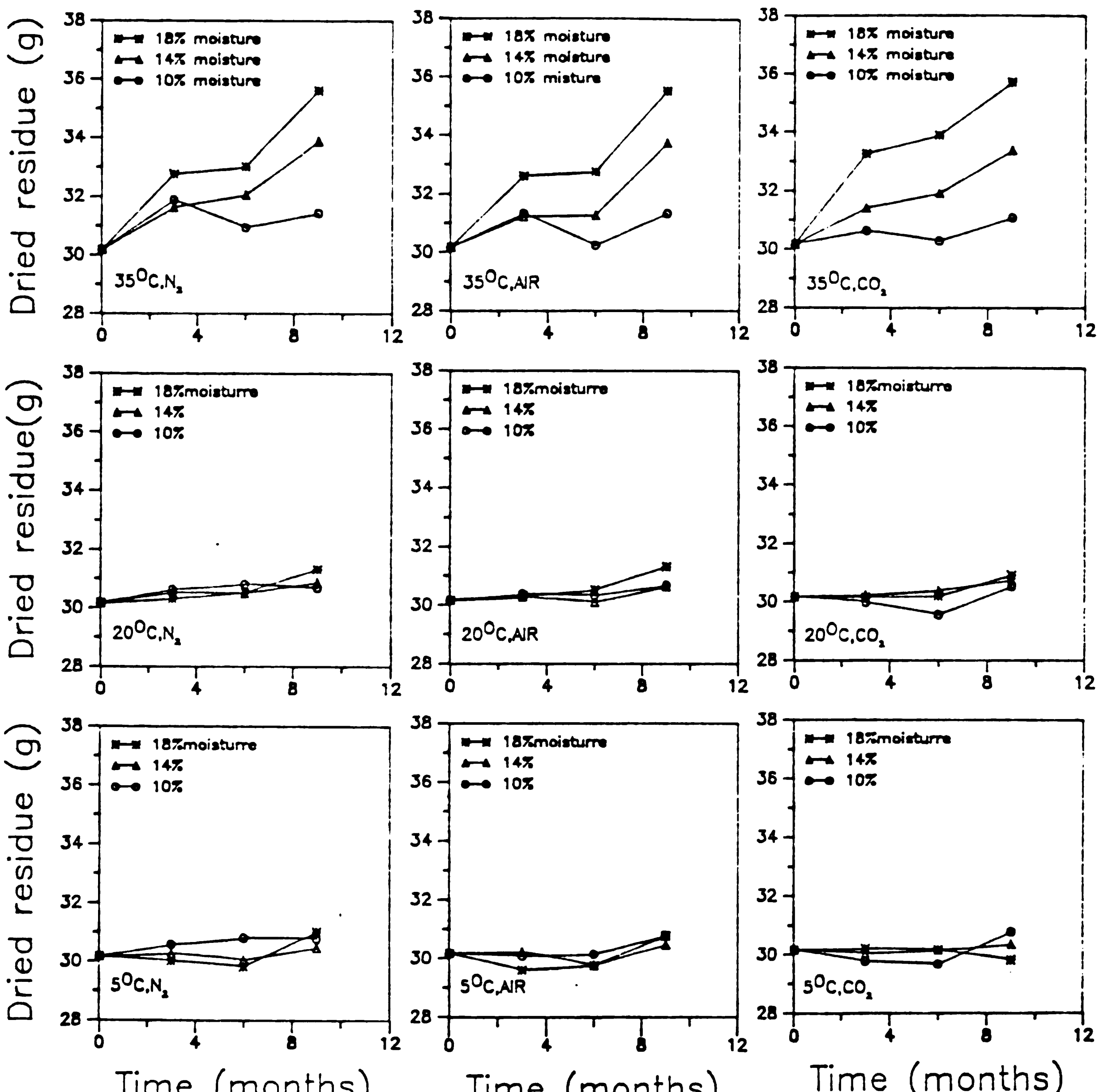
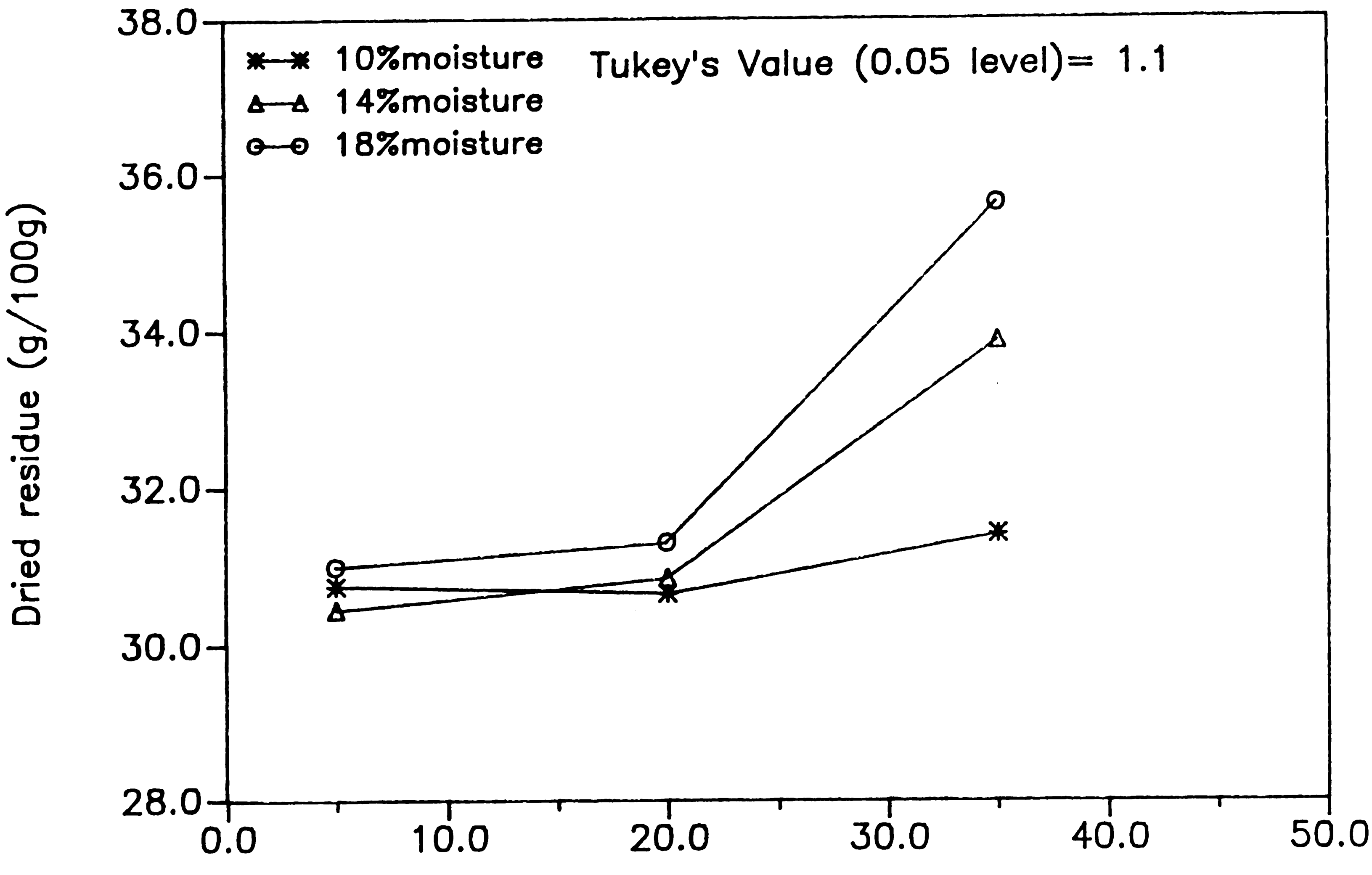


Fig (32) Drained weight of kidney beans stored under nitrogen atmosphere at three temperatures and moistures for nine months



Fig(33) Dried residue of kidney beans stored under three gas atmospheres at three temperatures and moistures for up to nine months.



Fig(34) Dried residue of kidney beans stored under nitrogen atmosphere at three temperatures and moistures for nine months showed similar behavior as the other cultivars, decreased drained weight and increased dried residue as the temperature, moisture content and time of storage increased.

Mean squares from the analysis of variance of kidney bean clumps and splits data are summarized in Table 22. Variations were observed among temperatures, and times, but not among moisture levels for both splits and clumps. Also, the gases did not show any significant effect on split characteristic (Table 22). Both bean clumps and splits were decreased, as the temperature, moisture and storage time increased (Table 23).

The shear force mean squares from the analysis of variance of kidney (Montcalm) beans (Table 22) showed significant differences among all four storage variables (moisture, gas, temperature and time). The results (Figures 35 and 36) indicated, as the temperature, moisture and time of storage increased, the shear force also increased.

Mean squares from the analysis of variance of kidney bean soaked moisture, processed moisture and mass ratio index of hydration and drained weight (Table 24) indicated no variations for all variables except soaked moisture which was affected by moisture variations.

Table (23) Mean values[1] of clumps and splits for kidney (Montcalm) beans stored under nitrogen gas atmosphere at three temperatures and moistures for nine months

Moisture (%)	Temperature (°C)	Storage Time (Months)					
		3		6		9	
		Clumps	Splits	Clumps	Splits	Clumps	Splits
10	5	2.5	2.0	3.0	2.0	3.0	2.5
	20	2.0	1.5	2.0	2.0	1.5	3.0
	35	1.0	2.0	1.5	1.5	1.0	2.5
14	5	2.0	2.0	2.5	2.5	2.5	3.0
	20	1.0	2.5	1.0	2.0	1.5	3.0
	35	1.0	1.5	1.0	1.5	1.0	2.0
18	5	2.5	2.0	2.5	2.0	2.5	3.0
	20	2.0	2.0	1.5	1.5	1.5	3.0
	35	1.0	1.5	1.0	1.0	1.0	1.0

1. n = 2 cans; 5 points rating scale for clumps and splits; 1 = none, 5 = extreme

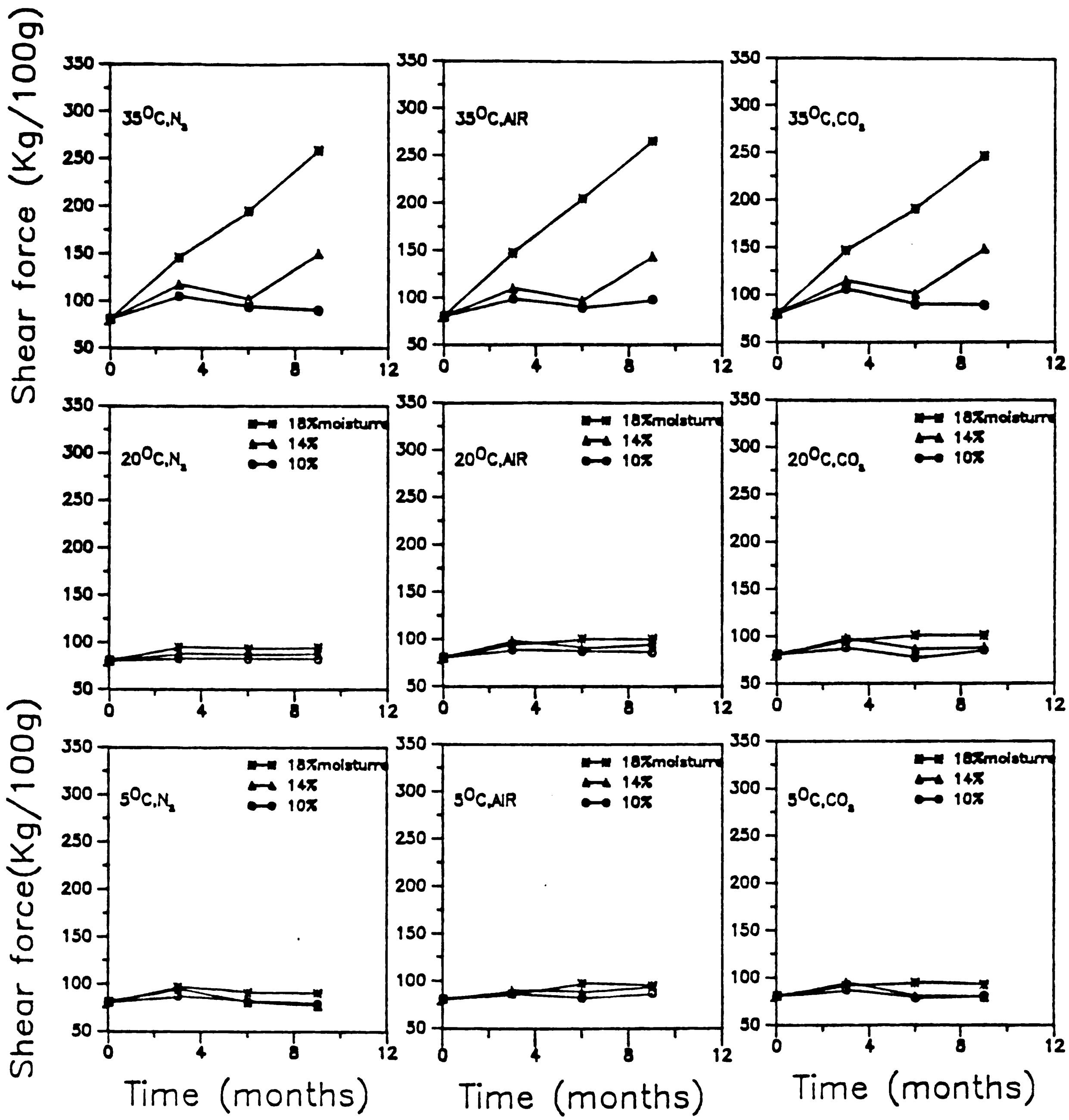


Fig (35) Shear force of kidney beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

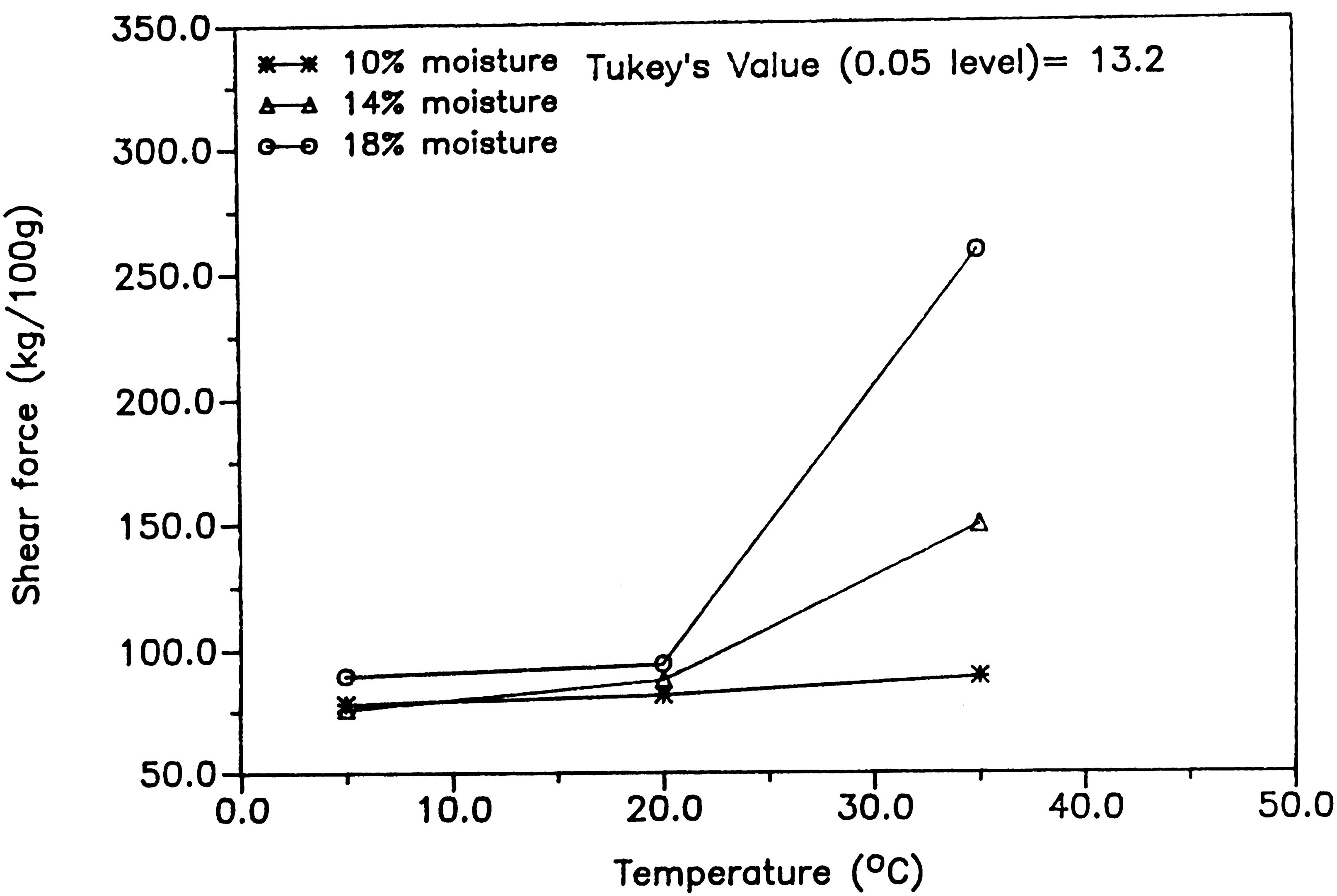


Fig (36) Shear force of kidney beans stored under nitrogen atmosphere at three temperatures and moistures for nine months

Table (24) Analysis of variance of moisture and mass ratio index measurments of dry, soaked and processed kidney (Montcalm) beans stored under three gas atmospheres at three temperatures and moistures for up to nine months

Source of Variation	df	Bean Moisture (%)	
		Soaked	Processed
		Mean Squares	
Total	161	8.394	0.080
Main Effects	8	6.580	0.096
Moisture (Mois.)	2	14.712*	0.201
Gas	2	8.772	0.043
Temperature (Temp.)	2	1.087	0.011
Time	2	1.751	0.130
2-way Interactions	24	21.086**	0.046
Mois. x Gas	4	5.505	0.095
Mois. x Temp.	4	14.351**	0.058
Mois. x Time	4	49.550**	0.011
Gas x Temp.	4	2.992	0.008
Gas x Time	4	2.930	0.038
Temp. x Time	4	51.186**	0.066

Table (24) (Cont'd.)

Source of Variation	df	Bean Moisture	
		Soaked	Processed
		Mean Squares	
3-way Interactions	32	10.455**	0.085
Mois. x Gas x Temp.	8	1.083	0.093
Mois. x Gas x Time	8	3.023	0.032
Mois. x Temp. x Time	8	25.359**	0.142
Gas x Temp. x Time	8	12.353**	0.075
4-way Interactions	16	8.201*	0.081
Mois. x Gas x Temp. x Time	16	8.201*	0.081
Explained	80	12.806**	0.074
Error	81	4.037	0.087
CV (%)		45.36	65.55

Analysis of All Bean Cultivars

Statistical analyses for all cultivars stored under common conditions were conducted using factorial design. These selected variables included: cultivars (navy, black, pinto and kidney); bean moisture (10 and 18%); storage temperature (5, 20 and 35^{o}C); and storage time (3, 6 and 9 months).

Mean squares from the analysis of variance of surface color of dry and processed bean for four bean cultivars (navy, black, pinto and kidney) are summarized in Table 25. The mean squares show significant differences among cultivars, moistures, temperatures and storage time, except the effect of moisture and temperature on greenness (a_L) which showed no significant effect.

While the darkness and the yellowness increased for all dry bean cultivars in this study (Tables 6, 11, 16 and 21), the greenness increased for navy (Seafarer), black (BTS), kidney (Montcalm), but it decreased for pinto beans (Table 10) at 10% and 14% moisture level and increased at 18% moisture. These data showed high variations among four cultivars, at two moistures (10 and 18%) and three temperatures of storage (5, 20, and 35^{o}C).

The bean seed coat color is a function of the presence of polyphenolic compunds, described primarily as tannins

Table (25) Analysis of variance of surface color of dry and processed bean cultivars: navy (Seafarer), black (BTS), pinto (Oletha) and kidney (Montcalm) stored under three temperatures and two moistures for up to nine months

Source of Variation	df	Hunter Lab Color Coordinates: Dry bean L	Dry bean a_L	Dry bean b_L	Processed Bean L	Processed Bean a_L	Processed Bean b_L
		Mean Squares					
Total	431	374.957	102.997	33.823	216.871	124.22	36.784
Main Effects	8	19921.068**	5483.275**	1762.644**	11371.221**	4502.677**	1880.289**
Moisture (Mois.)	1	148.169**	0.460	78.968**	92.871**	10.862**	1.246*
Cultivar (Cult.)	3	52732.566**	14618.372**	4608.146**	29732.231**	10194.579**	4898.570**
Temperature (Temp.)	2	490.413**	0.578	93.017**	704.768**	3.556**	8.994**
Time	2	20.926**	4.732**	5.854**	135.337**	2709.852**	163.685**
2-Way Interactions	23	65.387**	13.905**	16.146**	52.972**	741.126**	29.073**
Mois. x Cult.	3	22.513**	1.014	20.762**	25.461**	5.067**	0.540*
Mois. x Temp.	2	35.625**	1.463*	10.884**	111.874**	15.149**	0.079
Mois. x Time	2	0.255	2.518**	0.324	16.375**	0.806	1.168**
Cult. x Temp.	6	215.615**	35.315**	42.455**	94.930**	30.572**	5.287**
Cult. x Time	6	7.698**	15.970**	4.692**	32.927**	2785.621**	100.162**
Temp. x Time	4	6.179**	0.260	0.940**	29.585**	25.408**	7.968**

Table (25) (Cont'd.)

Source Variation	df	Hunter Lab Color Coordinates					
		Dry Bean			Processed Bean		
		L	a_L	b_L	L	a_L	b_L
		Mean Squares					
3-way Interactions	28	9.167**	0.946**	1.9543**	27.918**	10.089**	1.752**
Mois. x Cult. x Temp.	6	28.241**	1.947**	7.695**	67.950**	7.422**	1.509**
Mois. x Cult. x Time	6	7.538**	0.986*	0.498**	15.040**	1.057*	1.128**
Mois. x Temp. x Time	4	1.214	0.565	0.220	6.461**	1.816**	1.138**
Cult. x Temp. x Time	12	3.096**	0.552	0.386**	21.494**	18.697**	2.389**
4-way Interactions	12	7.827**	1.976**	0.759**	21.740**	2.155**	2.080**
Mois. x Cult. x Temp. x Time	12	7.827**	1.976**	0.759**	21.740**	2.155**	2.080**
Explained	71	2270.747**	623.045**	204.736**	1313.109**	751.770**	222.324**
Error	360	1.065	0.431	0.116	0.668	0.453	0.192
CV (%)		0.87	19.99	3.79	1.75	33.07	2.95

(Junek et al. 1980). Labuza et al. (1970) stated that non-enzymatic browning increased in food products as water activity (a_w) increased reaching a maximum and then decreased due to the dilution of the reactants. The increase of darkness and yellowness of beans demonstrated in this study could be due to increased the browning reactions as a result of increased moisture, temperaure and time of storage.

Mean squares from the analysis of variance of quality characteristics of dry, soaked and processed beans for all four bean cultivars are summarized in Table 26. The treatment mean values of those characters are represented by Figures 5 through 36.

Mean squares from the analysis of variance of soaked weight, drained weight and dried residue (Table 26) showed significant variations among bean cultivars, bean moistures, storage temperatures and storage times. These results were in agreement with other researchers (Bourne, 1967; Burr et al., 1968; Bedford, 1971 and Nordstrom and Sistrunk, 1979).

The navy (Seafarer) beans had higher soaked weight values, then kidney, black and pinto beans. For the drained weight, both navy and kidney beans had similarly high values. Black and pinto beans were lower in drained

Table (26) Analysis of variance of quality characteristics of dry, soaked and processed bean cultivars: navy (Seafarer), black (BTS), pinto (Oletha) and kidney (Montcalm) stored under three temperatures and two moistures for up to nine months

Source of Variation	df	Bean Weight (g)			Visual		Shear Force (kg/100g)
		Soaked	Draine	Dried Residue	Clumps	Splits	
				Mean Squares			
Total	431	105.559	354.537	4.300	0.855	0.704	5070.304
Main Effects	8	3202.927**	14678.459**	157.821**	25.413**	19.074**	155117.355**
Moisture (Mois.)	1	9303.757**	23515.929**	204.876**	37.336**	5.445**	341370.089**
Cultivar (Cult.)	3	5212.478**	13874.559**	113.505**	20.465**	21.616**	36556.893**
Temperature (Temp.)	2	231.163**	23433.151**	331.102**	50.694**	28.200**	360309.056**
Time	2	109.948**	2710.880**	27.488**	1.590**	12.950**	34369.979**
2-way Interactions	23	372.777**	1140.550**	19.273**	2.564**	1.726**	31227.152**
Mois. x Cult.	3	1362.534**	1160.489**	13.758**	4.194**	1.723**	12478.984**
Mois. x Temp.	2	84.907**	9243.601**	168.128**	1.287**	7.160**	223388.181**
Mois. x Time	2	340.836**	388.254**	8.983**	0.225	0.098	26680.307**
Cult. x Temp.	6	105.711**	447.827**	2.192**	1.046**	0.538	8107.510**
Cult. x Time	6	395.549**	79.341**	2.481**	5.896**	2.445**	2269.768**
Temp. x Time	4	156.805**	81.115**	4.935**	0.431	0.527	29596.729**

Table (26) (Cont'd.)

Source of Variation	df	Bean Weight (g)			Visual		Shear Force (kg/100g)
		Soaked	Drained	Dried Residue	Clumps	Splits	
		Mean Squares					
3-way Interactions	28	137.613**	160.028**	2.402**	0.885**	0.520**	5665.089**
Mois. x Cult. x Temp.	6	133.979**	604.218**	7.951**	1.219**	0.841**	9694.959**
Mois. x Cult. x Time	6	188.803**	29.616*	0.840**	0.814**	0.389	1959.754**
Mois. x Temp. x Time	4	127.051**	72.411**	1.557**	0.801**	0.404	17852.434**
Cult. x Temp. x Time	12	117.355**	32.343**	0.689**	0.782**	0.464*	1440.374**
4-way Interactions	12	81.367**	31.055**	0.557**	0.131	0.356	1271.261**
Mois. x Cult. x Temp. x Time	12	81.367**	31.055**	0.557**	0.131	0.356	1271.261**
Explained	71	549.674**	2091.743**	25.067**	4.065**	2.974**	30042.831**
Error	360	17.970	11.921	0.204	0.222	0.256	145.167
CV %		1.78	1.26	1.42	24.65	23.02	16.61

weight. The relationship between dried residue and drained weight was inverse. As expected dried residue was highest in pinto beans, followed by black, kidney and navy beans which were significantly lower.

Gloyer (1928) reported that hardshell, a condition of impermeability of the seed coat is produced by storage of beans in artificially heated rooms with low relative humidity (RH) or harvested in hot, dry weather. He indicated that there are great variations in the permeability of seed coats of different bean varieties to the entrance of water. Vonmollendroff and Priestly (1979) found that the cell walls of sound beans appeared to be more porous, contained large openings compared to hard samples which had been stored under high temperature and high moisture.

The soaked weight results of the navy (Seafarer) and black (BTS) beans in this study (Figures 5, 6, 13 and 14) were in agreement with the above observations. That is the navy beans soaked weight decreased with increasing temperature, moisture and length of storage.

The drained weight is a function of the equilibrium of beans and brine in the can. It is, therefore, highly dependent on the following factors: moisture content of soaked beans prior to filling, fill weight and on brine composition and fill volume (Uebersax and Bedford, 1980).

Davis (1976) reported that the storage time did not effect the drained weight. Drained weight decreases during storage observed in this study could be due to intermolcular binding of cell components thus decreasing the hygroscopicity of cells, particularly as the temperature and moisture content increased during storage.

The results from dried residue determinations paralleled the drained weight. Both parameters determine the ability of the beans to absorb and retain the water during and after processing. The higher the drained weight, the lower the dried residue. This negative correlation between dried residue and drained weight was observed with this study. Results from this study showed decreased drained weight and increased dried residue with increasing temperature, moisture and time of storage.

Mean squares from the analysis of variance of visual characters (clumps and splits) for all four cultivars (Table 26) showed significant differences among all variables (cultivars, moistures, temperatures and times).

The treatment mean values of clumps and splits for all four bean cultivars during storage indicated that, as the temperature, moisture, and time of storage increased, the clumps and splits decreased (Tables 8, 13, 18 and 23). Thus, more clumps and splits were observed at low temperature and moisture storage (5^{o}C and 10% moisture) than at high temperature and moisture storage (35^{o}C and 18% moisture). When the beans are stored at or greater than 20^{o}C and moisture level at or exceeding 14%, cells will be more rigid in structure (suggesting lignified middle lamella and more bound protein surrounding the starch granules). The hard cells are less suseptible to cracking during processing, thus less leakage of the cell component is observed compared to the cells of the soft beans after processing. The leakage of cell components (mostly starch and protein) will cause clumps of the beans and firm gelatinization of the sauce.

The shear force mean squares from the analysis of variance for all four cultivars are presented in Table 26. The mean values are presented in Figures 11, 12, 19, 20, 27, 28, 35, and 36. The shear force showed highly significant differences among cultivars, moistures, temperatures and times of storage.

The shear force for all cultivars increased, as the temperature, moisture and storage time increased.

The shear force is the most important charateristic that determines consumer acceptability and relates directly to the cookability of the beans. The higher the shear force the higher the cooking time will be for the bean. This study indicated the correlation coefficients determined for navy, pinto and kidney were r = 0.988, 0.952, and 0.925 respectively (Figure 37).

The shear force increased as the bean moisture, storage temperature and the time of storage increased. This observation could be due to mineral (calcium and magnesium) interactions with pectin molcules forming a firm cross linked middle lamella.

Calcium and magnesium are present as free ions and combine with cell constituents. Phytic acid could interact with these minerals to form phytic acid chelate. Calcium and magnesium ions may be liberated from the phytate molcules as the product of phytase activity. The phytase enzyme could act as a factor in the hardening process (Kon, 1981; Jones and Boulter, 1983 and Vandiolo et al., 1986).

Mean squares from the analysis of variance of soaked moisture, processed moisture and the mass ratio index for hydration and drained weight of all four bean cultivars are summarized in Table 27. The analysis of variance of all cultivars show highly significant variations among all variables (cultivar, moisture content, storage temperature and time) for all characteristics, except soaked weight moisture and hydration mass ratio index which were not affected significantly by the storage time.

The correlation coefficients for both drained

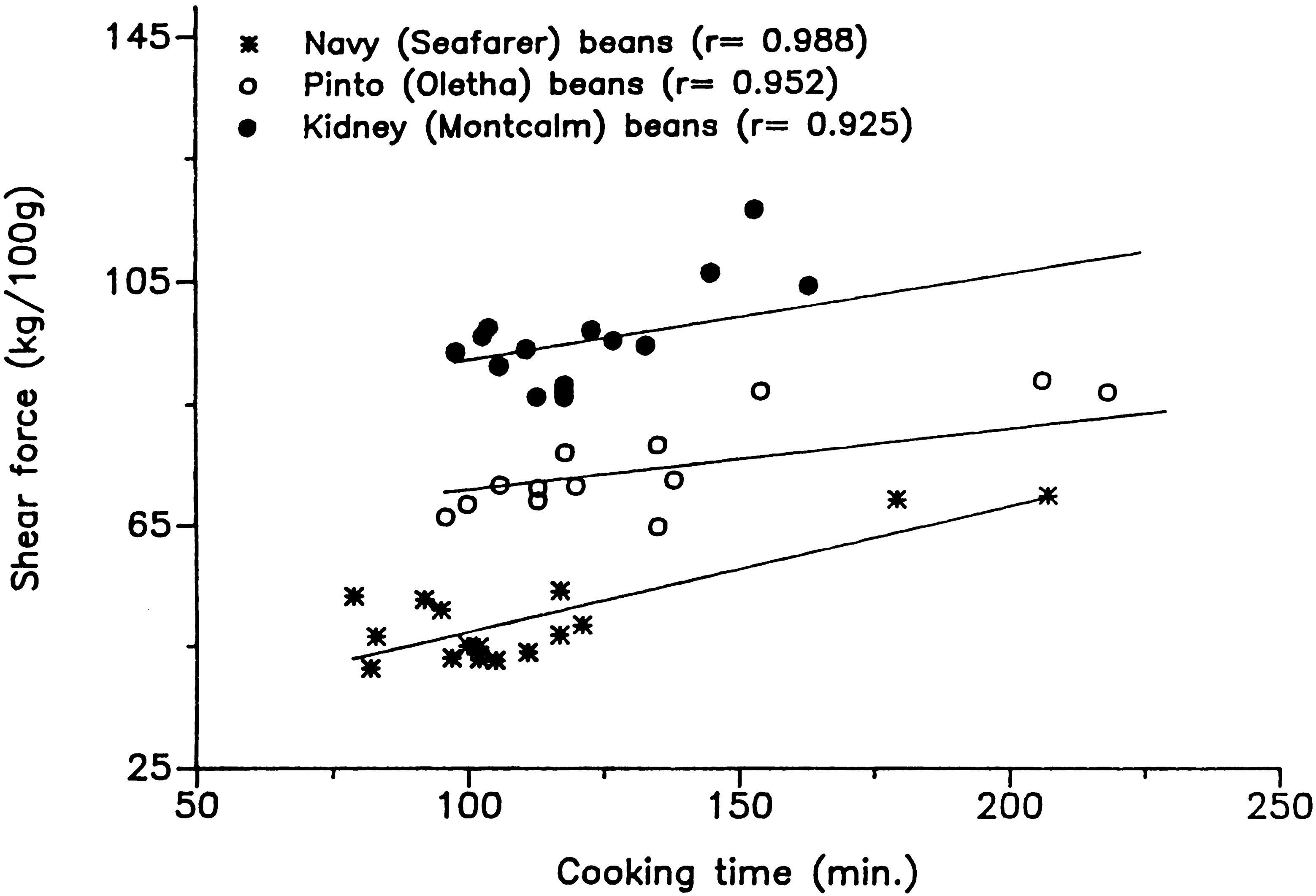


Fig (37) The relationship between the cooking time and the shear force for three cultivars stored under nitrogen for 3 months

Table (27) Analysis of variance of moisture and mass ratio index measurments for dry, soaked and processed navy (Seafarer), black (BTS), pinto (Oletha) and kidney (Montcalm) stored under three temperatures and two moistures for up to nine months.

Source of Variation	df	Bean Moisture (%)		Mass Ratio Index	
		Soaked	Processed	Hydration	Drained weight
		Mean Squares			
Total	431	428.481	872.291	0.121	0.337
Main Effects	8	22926.621**	46908.616**	6.385**	17.892**
Moisture (Mois.)	1	253.154**	148.762**	0.285**	0.898**
Cultivar (Cult.)	3	61040.268**	124892.130**	16.915**	47.223**
Temperature (Temp.)	2	17.834**	209.014**	0.024**	0.260**
Time	2	1.672	12.875**	0.001	0.023**
2-way Interactions	23	16.267**	21.489**	0.016**	0.054**
Mois. x Cult.	3	58.616**	24.722**	0.063**	0.189**
Mois. x Temp.	2	9.418**	109.690**	0.011**	0.187**
Mois. x Time	2	22.297**	4.542**	0.001	0.003*
Cult. x Temp.	6	3.256*	25.112**	0.005**	0.033**
Cult. x Time	6	14.225**	4.123**	0.015**	0.014**
Temp. x Time	4	7.493**	4.053**	0.007**	0.006**

Table (27) (Cont'd.)

Soruce of Variation	df	Moisture		Mass Ratio Index	
		Soaked	Processed	Hydration	Drained weight
		Mean Squares			
3-way Interactions	28	10.496**	4.603**	0.007**	0.010**
Mois. x Cult. x Temp.	6	5.660**	18.553**	0.004**	0.025**
Mois. x Cult. x Time	6	13.188**	1.371**	0.004**	0.004**
Mois. x Temp. x Time	4	15.096**	0.353	0.008**	0.004**
Cult. x Temp. x Time	12	10.034**	0.660**	0.009**	0.008**
4-way Interactions	12	4.605**	0.466**	0.005**	0.003**
Mois. x Cult. x Temp. x Time	12	4.605**	0.466**	0.005**	0.003**
Explained	71	2593.468**	5294.333**	0.728**	2.038**
Error	360	1.497	0.166	0.001	0.001
CV %		2.73	0.76	1.95	3.16

weight and shear force and each quality character are presented in Tables 28 and 29 respectively.

1.3 Physico-Chemical Analyses of Dry Beans Stored under Selected Conditions for Nine Months

Effect of Storage on Protein Fractions and Soluble Solids.

Mean squares from the analysis of variance of total protein, soluble protein and total soluble solids for all four bean cultivars stored at 18% moisture for nine months are presented in Table 30. The observations on treatment mean values for these constituents are presented in Table 31 and also shown in Figure 38.

The mean squares from the analysis of variance of all three above analyses exhibited highly significant differences among storage temperatures and cultivars, but no variations were found among gases (blocks). The interactions between temperatures and cultivars showed significant effect on soluble protein, but not on total protein or soluble solids.

The observations on treament mean values of total protein for navy, black, pinto and kidney beans indicated

Table (28) Correlation coefficients between drained weight and other quality characteristics for four bean cultivars stored under three gas atmospheres at three temperatures and two moistures for up to nine months

Characters	Navy (Seafarer)	Black (BTS)	Pinto (Oletha)	Kidney (Montcalm)	All
Surface color of dry beans					
L-coordinate	0.932	0.373	0.665	0.517	0.016
aL-coordinate	0.678	0.289	-0.472	0.421	0.211
bL-coordinate	-0.923	-0.211	0.880	0.116	-0.409
Surface color of proceesed beans					
L-coordinate	0.780	0.773	0.791	0.464	0.157
aL-coordinate	-0.695	-0.264	-0.075	0.333	0.296
bL-coordinate	-0.351	0.553	0.440	0.436	-0.169
Quality characters					
Initial weight	-0.439	-0.531	-0.268	-0.397	-0.395
Soaked weight	0.160	-0.509	-0.073	-0.187	0.208
Drained weight	- - -	- - -	- - -	- - -	- - -
Dried residue	-0.969	-0.936	-0.896	-0.891	-0.946
Clumps	0.573	0.661	0.600	0.502	0.344
Splits	0.489	0.550	0.539	0.317	0.595
Shear force	-0.873	-0.952	-0.912	-0.849	-0.773
Moisture content					
Initial moisture	-0.440	-0.531	-0.271	-0.399	-0.408
Soaked moisture	0.152	-0.500	-0.074	-0.154	-0.206
Processed moisture	0.969	0.936	0.896	-0.082	-0.171
Hydration ratio	0.620	0.081	0.152	- - -	-0.107
Dried weight ratio	0.919	0.882	0.792	- - -	-0.116
Number of samples	162	108	162	162	594

Table (29) Correlation coefficients between shear force values and other quality characterastics for four bean cultivars stored under three gas atmospheres at three temperatures and two moistures for up to nine months

Characters	Navy (Seafarer)	Black (BTS)	Pinto (Oletha)	Kidney (Montcalm)	All
Surface color of dry beans					
L-coordinate	-0.920	-0.301	-0.559	-0.470	-0.251
aL-coordinate	-0.477	-0.285	0.291	-0.330	0.074
bL-coordinate	0.776	0.194	0.880	-0.123	0.057
Surface color of proceesed beans					
L-coordinate	-0.822	-0.719	-0.712	-0.257	-0.325
aL-coordinate	0.754	0.252	0.015	-0.138	0.016
bL-coordinate	0.054	-0.529	-0.345	-0.283	-0.182
Quality characters					
Initial weight	0.367	0.467	0.299	0.443	0.370
Soaked weight	-0.150	0.462	0.287	0.332	0.076
Drained weight	-0.873	-0.952	-0.912	0.849	-0.774
Dried residue	0.884	0.944	0.910	0.877	0.862
Clumps	-0.436	-0.627	-0.623	0.381	0.432
Splits	-0.389	-0.553	-0.553	-0.394	-0.486
Shear force	— — —	— — —	— — —	— — —	— — —
Moisture content					
Initial moisture	0.367	0.467	0.301	0.441	0.375
Soaked moisture	-0.143	0.454	0.285	0.208	-0.027
Processed moisture	-0.884	-0.944	-0.910	-0.058	0.085
Hydration ratio	-0.564	-0.056	-0.017	— — —	-0.091
Drained weight ratio	-0.805	-0.828	-0.830	— — —	-0.143
Number of samples	162	108	162	162	594

Table (30) Analysis of variance of total and soluble protein and solids of four bean cultivars stored at three temperatures and 18% moisture for nine months

Source of Variation	df	Protein Total	Protein Soluble	Soluble Solids
		Mean Squares		
Total	35	0.8428	9.0933	7.1453
Blocks (gases)	2	0.0984	0.02117	1.0428
Treatments	11	2.5949**	28.6930**	21.1294**
Temperature (Temp.)	2	0.3971**	120.968**	84.8428**
Cultivar	3	9.0939**	19.8480**	17.2549**
Temp.x Cultivar	6	0.0782	2.2650**	1.8289
Error	22	0.0344	0.1258	0.6172
CV (%)		0.81	4.11	4.51

Table (31) Total and soluble protein and solids of four bean cultivars stored at 18% moisture and three temperatures for nine months

Bean Cultivars/ Storage Temp. (°C)		% Total Protein	% Soluble Protein	% Soluble Solids
	5	23.70ab	12.82a	20.04a
Navy	20	23.65ab	12.11ab	18.96ab
(Seafarer)	35	23.94a	5.20e	13.92de
	5	22.85c	9.79c	17.52bc
Black	20	22.76c	9.09cd	17.16bc
(BTS)	35	23.27bc	5.57e	13.72de
	5	21.27d	8.53d	15.96cd
Pinto	20	21.47d	8.13d	16.68cb
(Oletha)	35	21.87d	3.65f	12.60e
	5	23.67ab	12.06ab	20.16a
Kidney	20	23.41ab	11.15b	19.80a
(Montcalm)	35	23.56ab	5.55e	14.40de

* Mean values (like letters within each character indicate no significant differences at $P<0.05$ by Tukey mean separations)

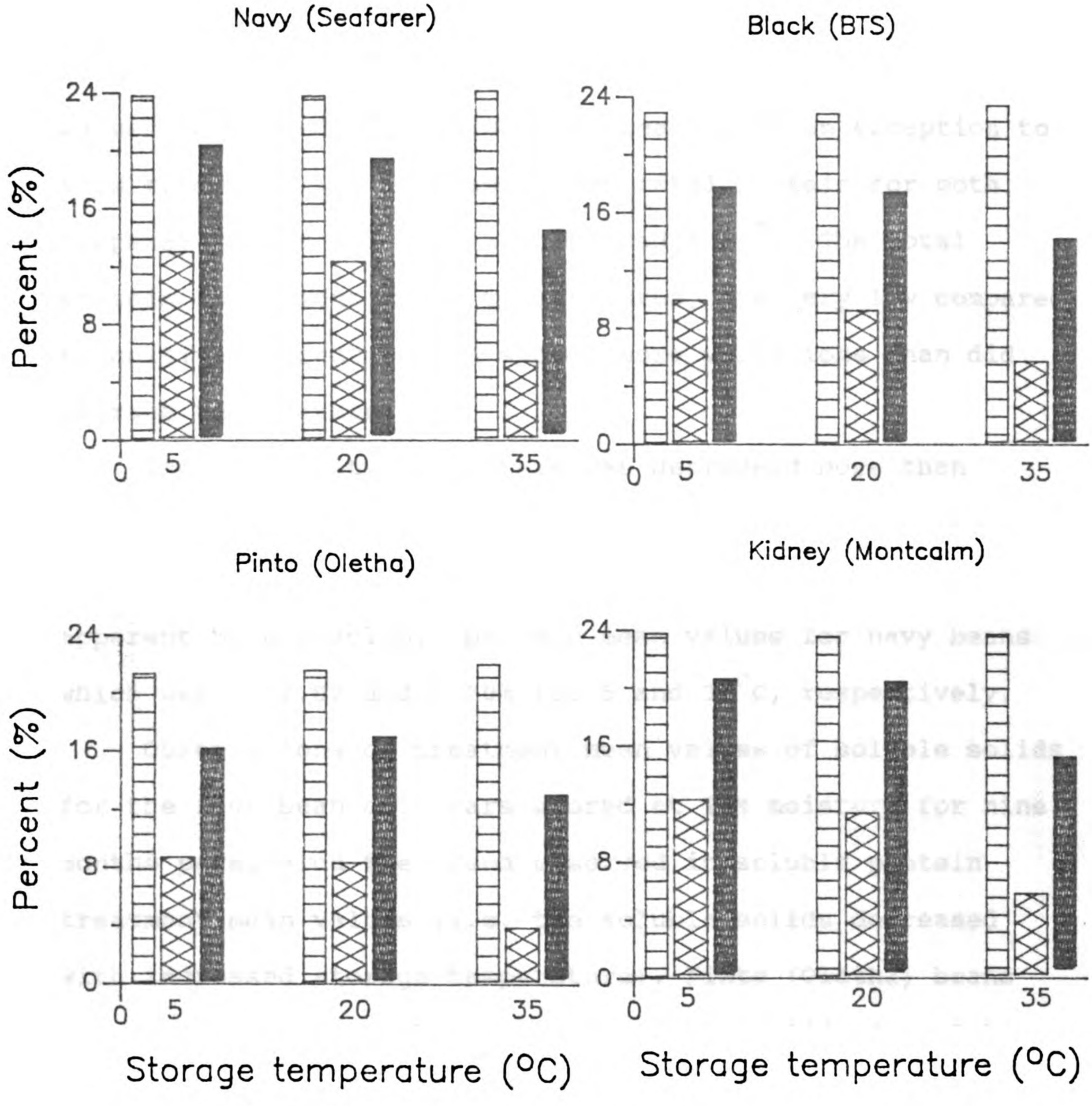


Fig (38) Total and soluble protein and solids of four bean cultivars (18% moisture) stored at three temperatures for nine months that as the storage temperature increased from 5 to 20°C, the total protein decreased, conversely, as the storage temperature increased from 20 to 35°C total protein mean values increased. Pinto (Oletha) beans were an exception to this trend showing increased mean total protein for both temperatures 20 and 35°C as compared to 5°C. The total protein variations among temperatures, are very low compared to cultivar effects which showed more variations than did storage temperature.

The solubility of protein was decreased more than two fold as the storage temperature increased from 5 to 35°C for all four cultivars. For example, this trend was readily apparent by the soluble protein mean values for navy beans which were, 12.82 and 5.20% for 5 and 35°C, respectively.

Observations on treatment mean values of soluble solids for the four bean cultivars stored at 18% moisture for nine months paralleled the trend observed in soluble protein treatment mean values (i.e. the soluble solids decreased with increased storage temperature). Pinto (Oletha) beans were an exception with increased soluble solids from 5 to 20°C and decreased values from 20 to 35°C.

These data indicated that navy (Seafarer) beans had the highest mean values for total and soluble protein (23.7 and 12.82%), while the mean values of soluble solids for kidney (Montcalm) beans was the highest among the four cultivars (20.16%). Pinto (Oletha) bean was the single cultivar that depicted the lowest values for all three measures when stored at 5°C (21.27, 8.53, and 15.96% for total protein, soluble protein and soluble solids, respectively).

The decreasing values of soluble protein and soluble solids could be due to the interactions between protein and protein with other cellular components forming more complex structures which are less soluble in water. The scanning electron microscope studies also indicated that the protein molcules have a more complex structure and were less soluble in the beans stored at high moisture and temperature.

Effect of Storage Conditions on Pectin Solubility

Mean squares from the analysis of variance of pectin solubility is presented in Table 32. The mean values are presented in Table 33 and illustrated in Figure 39. The mean squares indicated that there are significant variations among temperatures, cultivars and the interaction on cold water, hot water, total water soluble, alkali soluble and total soluble pectin.

Table (32) Analysis of variance of soluble pectin of four bean cultivars stored at three temperatures and 18% moisture for nine months

Source of Variation	df	Water soluble pectin			Alkali soluble pectin	Total soluble pectin
		Cold water	Hot water	Total		
Total	23	21.07	35.72	24.49	5.28	37.20
Treatment	11	43.15**	74.69**	48.78**	10.70**	74.91**
Temperature (Temp.)	2	178.85**	313.38**	57.47**	36.20**	137.34**
Cultivar (Cult.)	3	14.09**	37.75**	75.28**	12.97**	126.90**
Temp.x Cult.	6	12.44**	11.33**	32.64**	1.08**	28.10**
Error	12	0.83	1.12	2.21	0.30	2.64
CV %		17.48	10.30	9.38	7.66	7.08

Table (33) Soluble pectin of four bean cultivars stored at three temperatures and 18% moisture for nine months *

Bean cultivars/	Storage temp. (°C)	Pectin content (mg/g)				
		Water soluble pectin			Alkali soluble pectin	Total soluble pectin
		Cold	Hot	Total		
Navy (Seafarer)	5	1.42e	11.50b	12.92cde	7.56bcd	20.47bcd
	20	1.20e	10.24b	11.44de	6.61d	18.04d
	35	7.06bc	1.22c	8.27e	3.01e	11.28e
Black (BTS)	5	1.29e	18.64a	19.93b	7.37ed	27.23a
	20	4.41cde	13.78b	18.19bc	8.30bcd	26.48ab
	35	14.08a	4.07c	18.15bc	4.03e	22.18abcd
Pinto (Oletha)	5	3.61de	12.55b	16.16bcd	9.15abc	25.31abc
	20	1.40e	10.73b	12.13de	7.54bcd	19.67cd
	35	13.62a	5.40c	19.02b	4.43e	23.45abcd
Kidney (Montcalm)	5	5.06bcd	21.66a	26.72a	9.62ab	36.33f
	20	1.45e	13.37b	14.81bcd	10.70a	25.51abc
	35	7.83b	4.52c	12.34cde	7.21cd	19.55cd

* Mean values (like letters within each character indicate no significant differences by Tukey mean separation, $P<0.05$)

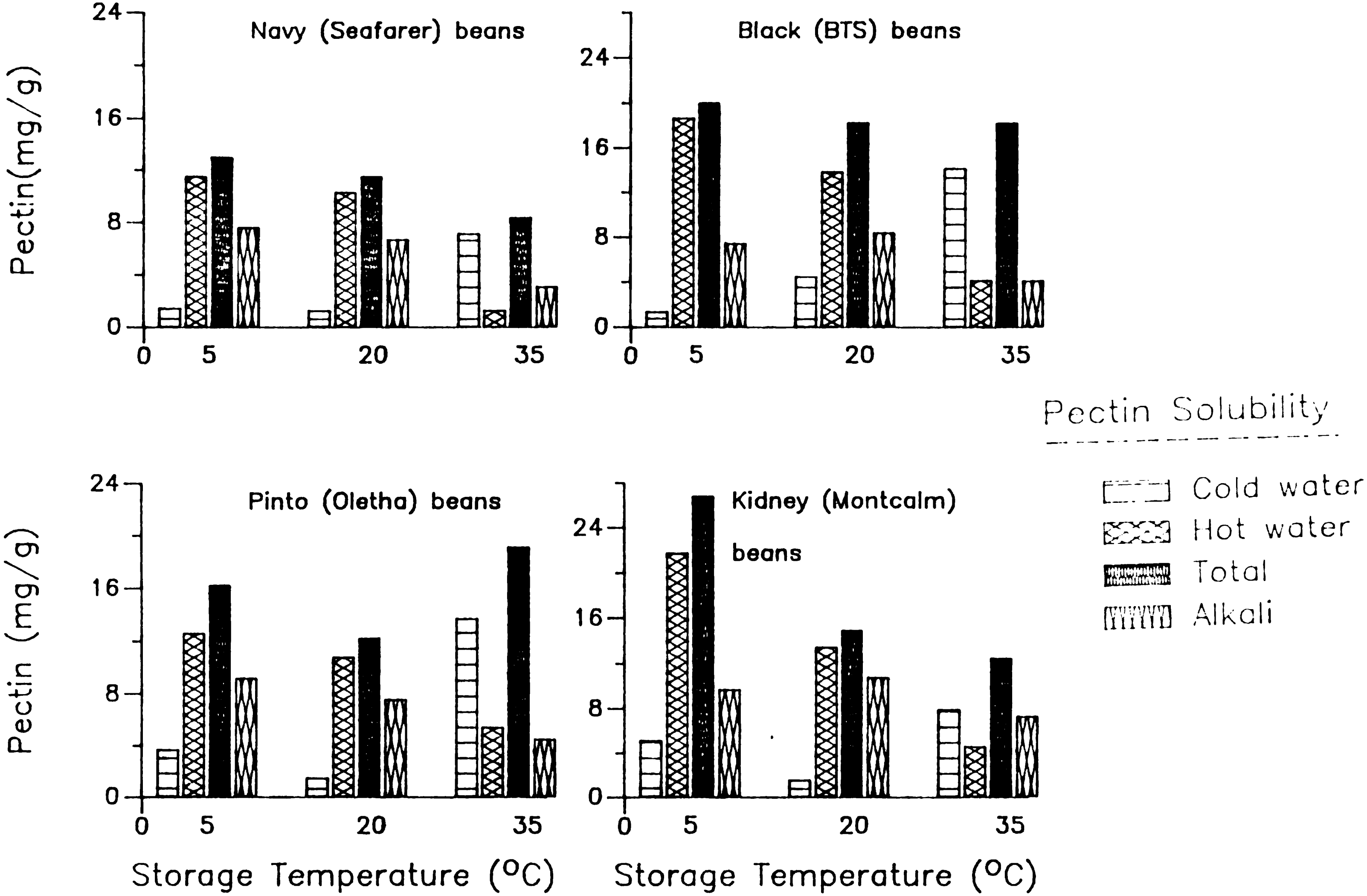


Fig (39) Soluble pectin of four bean cultivars (18% moisture) stored at three temperatures for nine months

The observations on treatment mean values of cold water soluble pectin decreased, as the temperature of storage increased from 5 to 20^{o}C, and increased as the temperature increased from 20 to 35^{o}C. Black beans did not follow this trend, rather exhibiting a continuous increased response of water soluble pectin to increased temperature. The mean values of hot water and alkali soluble pectin decreased as the temperature of storage increased from 5 to 35^{o}C, except for alkali soluble pectin of the black (BTS) and kidney (Montcalm) beans which increased only slightly as the temperature increased from 5 to 20^{o}C, then decreased between 20 and 35^{o}C.

The total soluble pectin of kidney beans was determined to be 36.33 mg/g which was the highest mean value among the four cultivars. Black, pinto and navy showed lower total soluble pectin values of 27.23, 25.31 and 20.47 mg/g, respectively. The reported values of soluble pectin for soft and hard beans from this study agreed with the previous work of Jones and Boulter (1983). Their findings indicate that hard beans (beans stored under high temperature and high moisture) had higher cold water, but lower hot water soluble pectin. Jones and Boulter (1983) reported total soluble pectin mean values for soft and hard beans 32.9 and 25.7 mg/g respectively. The above total soluble pectin values for soft and hard beans falls within the range determined in this study (20-36 mg/g).

When the temperature and moisture content increase during storage, the pectin molcules interact with minerals to form more complex pectin structure, which contributes to bean hardness. The decreased pectin solubility with increased temperature and moisture in storage could be due to the pectin molcules (primarily in middle lamella) interaction with minerals (calcium and magnesium).

<u>Effect of Storage Conditions on Raw Bean Microstructure</u>

The effect of storage conditions on bean cellular structure was investigated using scanning electron microscopy. Samples used for electron microscopy should be observed under conditions as close to the original state as possible, therefore an air drying method was used in this study. The air dried sections of bean seeds generally showed disorganized structure. The cell wall and the middle lamella are not observed. The cells sizes and shapes are dependent upon the distance from the seed coat (Corner, 1951)

The photomicrographs of gluteraldehyde fixed samples showed more organized structure than unfixed samples. Similar observations were reported for faba beans (Vicia faba L) (McEwen et al., 1974), lima beans (Phaseolus lunatus) (Rockland and Jones, 1974) and Cowpea (Vigna unguilata) (Sefa-Dedeh and Stanley, 1979). In these reports the samples were not fixed and the protein bodies were not clearly identified.

The micrographs showed some differences between the sections as a result of storage conditions (plates 1, 2, 3, and 5). In all four cultivars of beans, the micrographs of samples which were stored at 35°C and 18% moisture content, for all three time periods (3, 6 and 9 months) showed more compact structure with the cell contents appearing separated from the cell wall and middle lamella. These observations contrast with micrographs of samples stored at the same moisture content and same storage times, but lower temperatures (5 and 20°C). Generally, the higher storage temperature and bean moisture during storage, the more compact the cellular structure appeared.

The more compact structure which appeared with high moisture and temperature at storage could be due to the interaction between the protein and/or the protein with other cell components.

The chemical analysis for protein showed that samples stored at high moisture and temperature resulted in lower soluble protein content compared to samples stored at low

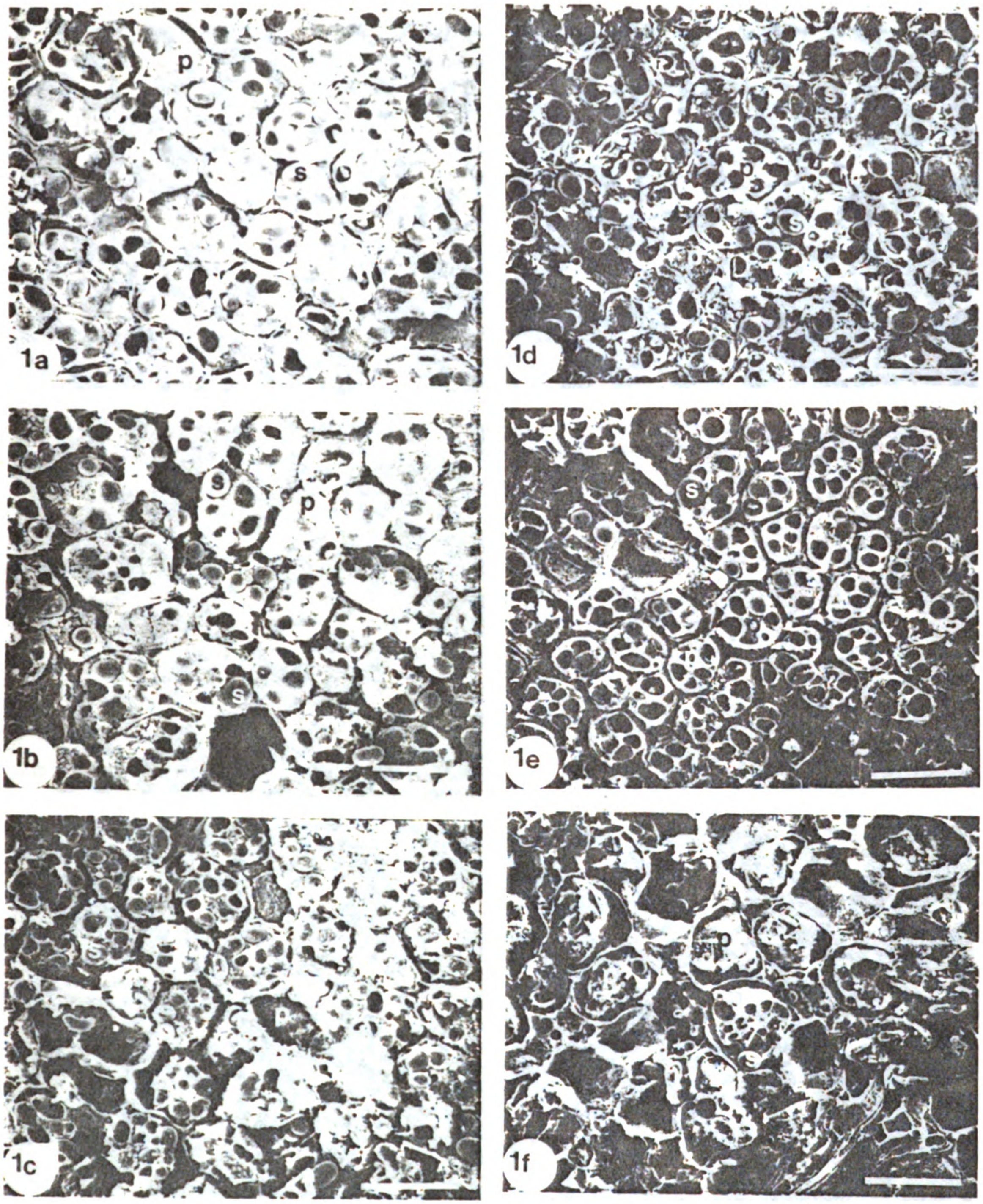


Plate (1) Horizontal sections of kidney (Montcalm) bean cotyledon, fixed with 4% glutaraldehyde for 24 hours at $4^{\circ}C$ before critical point drying. Seed storage conditions: 9 months at (X%) moisture and ($Y^{\circ}C$) temperature. 1a= 14%, $5^{\circ}C$; 1b= 14%, $20^{\circ}C$; 1c= 14%, $35^{\circ}C$; 1d= 18%, $5^{\circ}C$; 1e= 18%, $20^{\circ}C$; 1f= 18%, $35^{\circ}C$. Bar= 100 um

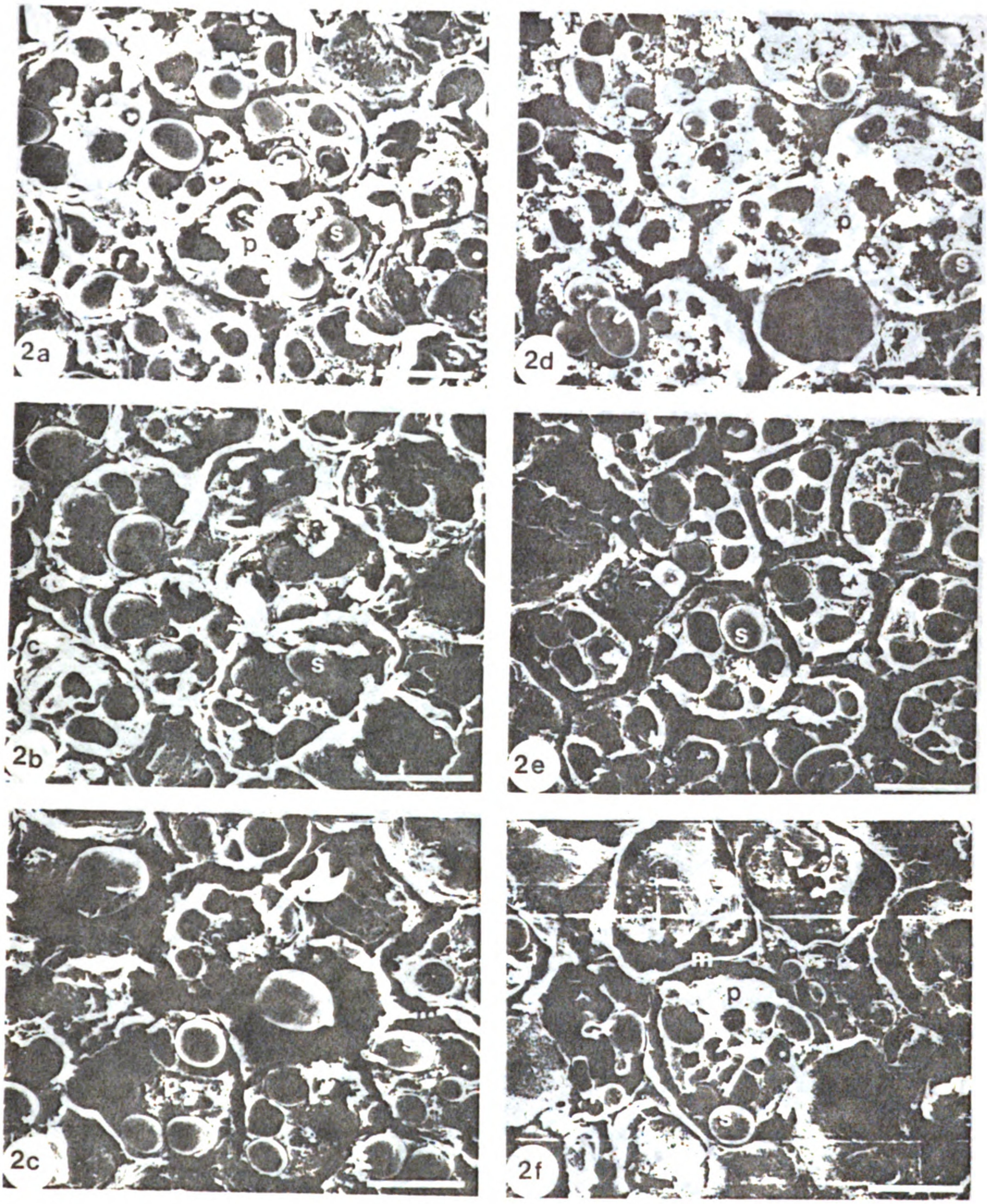


Plate (2) Horizontal sections of kidney (Montcalm) bean cotyledon, fixed with 4% glutaraldehyde for 24 hours at 4 $^{\circ}$C before critical point drying. Seed storage conditions: 9 months at (X%) moisture and (Y $^{\circ}$C) temperature. 2a= 14%, 5 $^{\circ}$C; 2b= 14%, 20 $^{\circ}$C; 2c= 14%, 35 $^{\circ}$C; 2d= 18% moisture, 5 $^{\circ}$C; 2e= 18%, 20 $^{\circ}$C; 2f= 18%, 35 $^{\circ}$C. Bar= 50 um

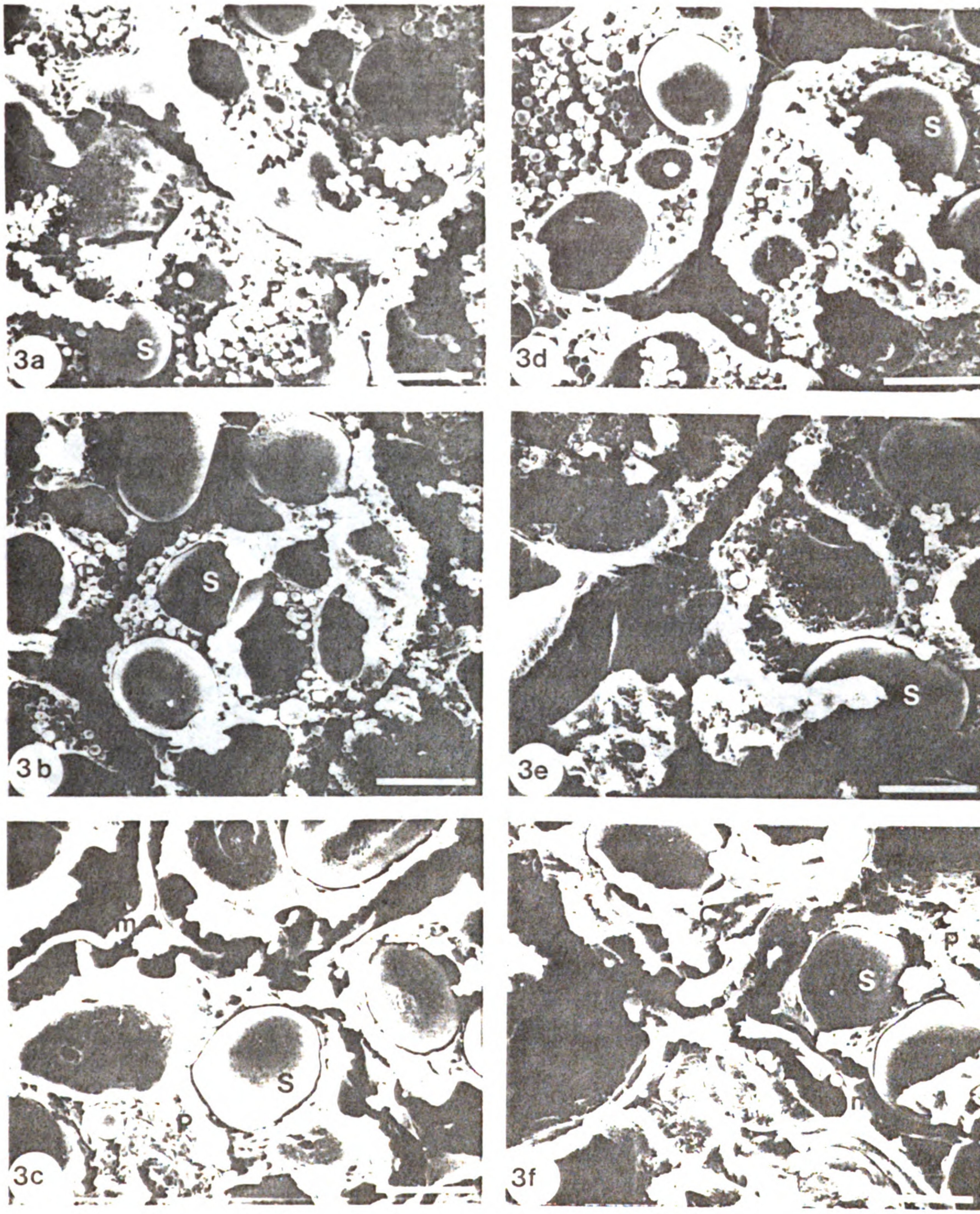


Plate (3) Horizontal sections of pinto (Oletha) bean cotyledon, fixed with 4% glutaraldehyde for 24 hours at 4°C before critical point drying. Seed storage conditions: 9 months at (X%) moisture and (Y°C) temperature. 3a= 14%, 5°C; 3b= 14%, 20°C; 3c= 14%, 35°C; 3d= 18%, 5°C; 3e= 18%, 20°C; 3f= 18%, 35°C. Bar = 20 um

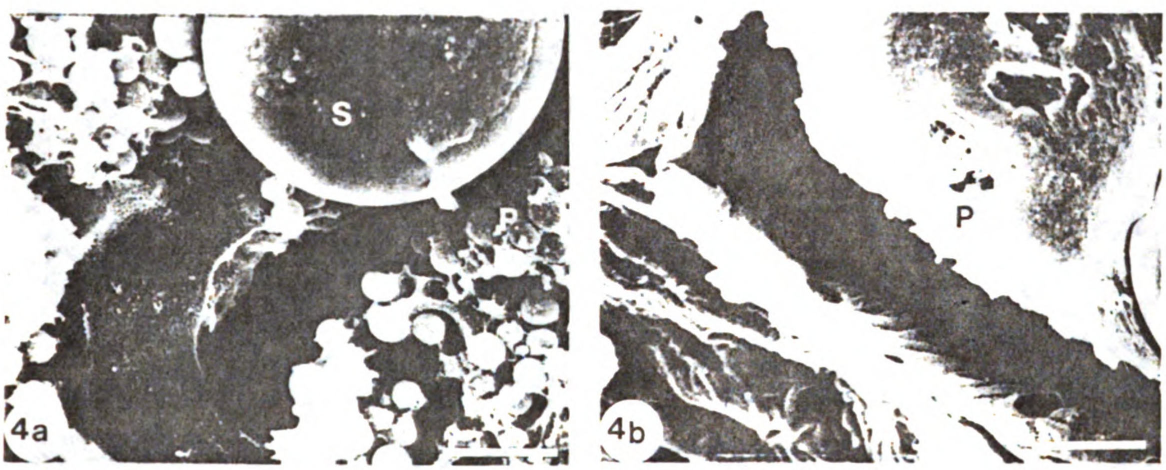


Plate (4) Horizontal sections of pinto (Oletha) bean cotyledon, fixed with 4% glutaraldehyde for 24 hours at $4^{\circ}C$ before critical point drying. Seed stored for 3 months with 18% moisture and two temperatures (4a= $5^{\circ}C$, 4b= $35^{\circ}C$). Bar= 7 um

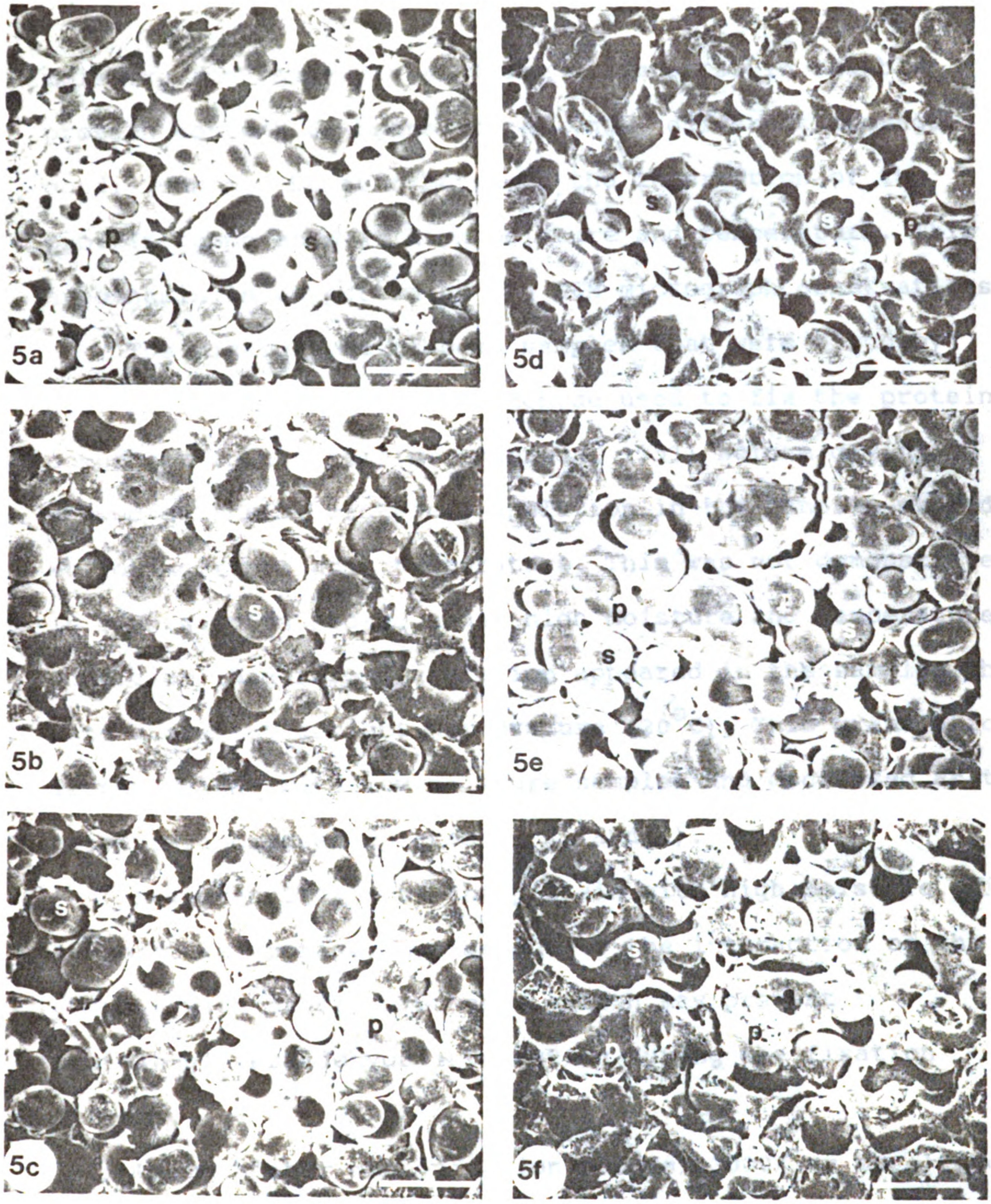


Plate (5) Horizontal sections of navy (Seafarer) bean cotyledon, air dried without fixation. Seed storage conditions: 9 months at (X%) moisture and (Y ^{o}C) temperature. 5a= 14%, 5 ^{o}C; 5b= 14%, 20 ^{o}C; 5c= 14%, 35 ^{o}C; 5d= 18%, 5 ^{o}C; 5e= 18%, 20 ^{o}C; 5f= 18%, 35 ^{o}C. Bar= 50 um moisture and temperature. These differences in soluble protein content of beans stored under different storage conditions may be attributed to the interaction of the protein components at high moisture and temperature. This hypothesis is supported by the SEM micrograph observations.

The micrographs of bean samples that were fixed by gluteraldehyde (the gluteraldehyde used to fix the protein component in the sample. Anderson, 1951) before drying, showed extensive protein granulation in the samples stored at low moisture and temperature. This was not demonstrated in bean samples stored under high moisture and temperature condition. Moderate granulation appeared in the samples that were stored at ambient temperature (20°C). This granulation is more clear with low moisture samples and decreased as the moisture increased (plates 2, 3, and 4).

Low granulation of the protein with high moisture, high temperature storage, may be due to the interaction of the protein with other components, which may prevent protein-gluteraldehyde interaction during the fixation process.

Using higher magnification powers (3000X or more) the low temperature, low moisture stored samples showed smooth surfaces, while high temperature, high moisture samples showed coarse surfaces (plates 4 and 6). Structural

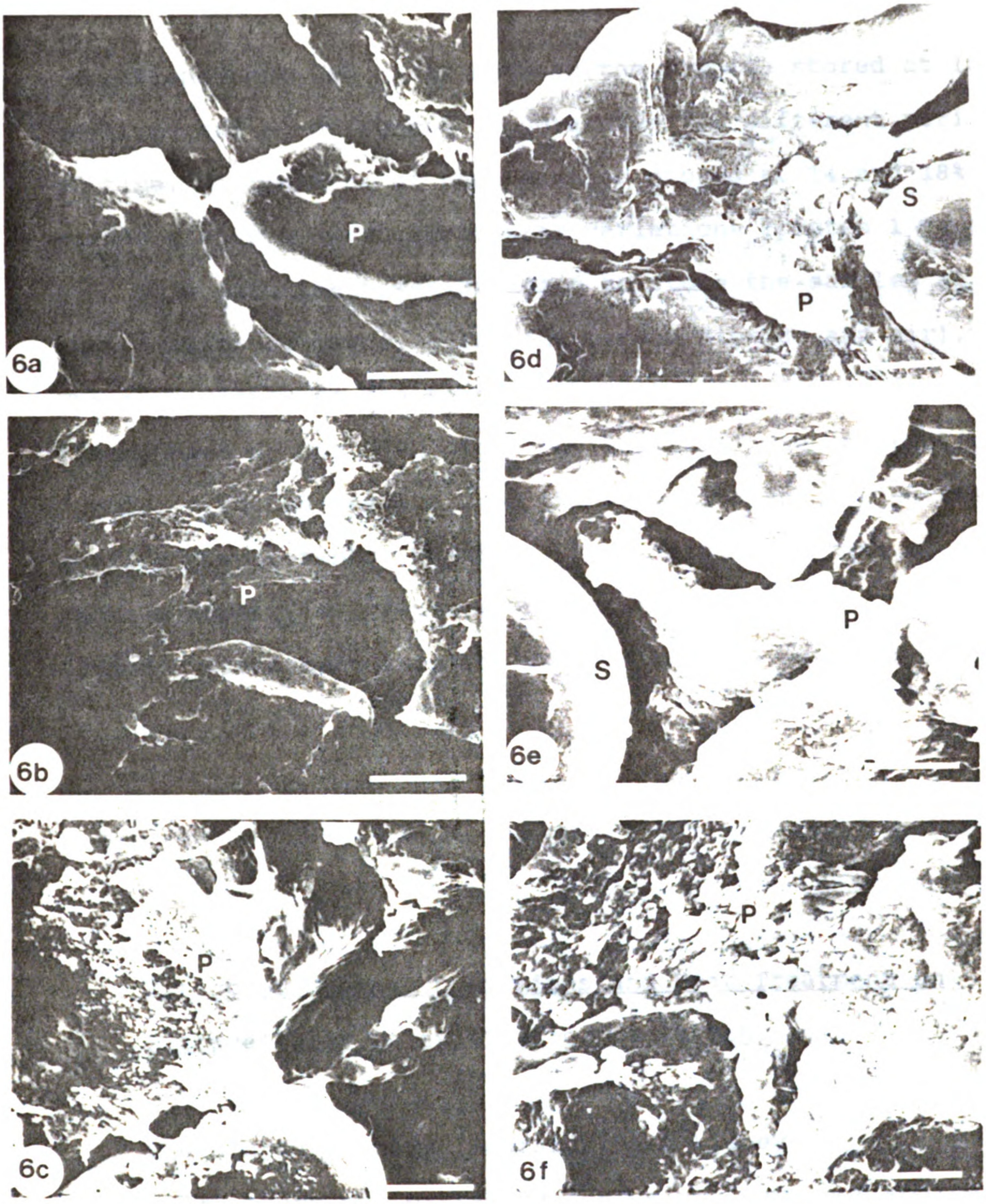


Plate (6) Horizontal sections of black (BTS) beans and navy (Seafarer) bean cotyledon, air dried without fixation. Seed storage conditions: 9 months at (18%) moisture and (X $^{\circ}$C) temperature. Navy/Black: 5 $^{\circ}$C, 6a/6d; 20 $^{\circ}$C, 6b/6e; 35 $^{\circ}$C, 6c/6f. Bar= 7 variations were not clear between the samples stored at 10% moisture and at different temperatures for different periods of time. Micrographs of bean samples stored at 14 and 18% moisture showed clear structural variations (plates 1 to 6).

This experiment was designed to store the samples at three different gases (nitrogen, carbon dioxide and air). The micrographs of the samples that stored under various gas atmospheres do not show clear variations. These observations concide with the results from the objective and subjective quality measurements. Moisture, temperature and time of storage appear to influence objective tests and microstructure more than the gaseous storage environment.

Effect of Storage Conditions and Heat Treatment on Extracellular Gelatinization of Starch.

The starch of navy (Seafarer) and kidney (Montcalm) beans was extracted by using water or sodium hydroxide (0.05%) solution. These extracts were then dried in air, crushed and sieved before preparation for electron microscopic observation.

Effects of water and sodium hydroxide extraction on starch are shown in plate 7. Extracted starch from soft beans (stored at 5°C and 10% moisture) by water (micrograph plate 7: 1a, 1c, and 1e) and extracted by sodium hydroxide solution (micrograph plate 7: 1b, 1d, and 1f) indicated no apparent effect of solvent on starch microstructure. Therefore, both solvents have the same extraction efficiency for soft beans. The bean samples stored under medium temperature and moisture conditions (20°C and 14% moisture), and those stored under high temperature and moisture conditions (35°C and 18% moisture) were extracted with sodium hydroxide (micrographs plate 7: 1d and 1f) and showed similar results when compared to the soft beans. The extracted starch by using the water as the solvent was completely different compared to the soft bean starch (micrographs plate 7: 1c and 1e). As the stored beans became hard, the starch granules became unextractable by using the water solvent system.

From these micrographs (plate 7) it was hypothesized that the proteins effect the extractability of the starch. The protein molcules of the hard beans become more complex and surround and protect the starch from extraction, while the sodium hydroxide solution has the ability to dissolve

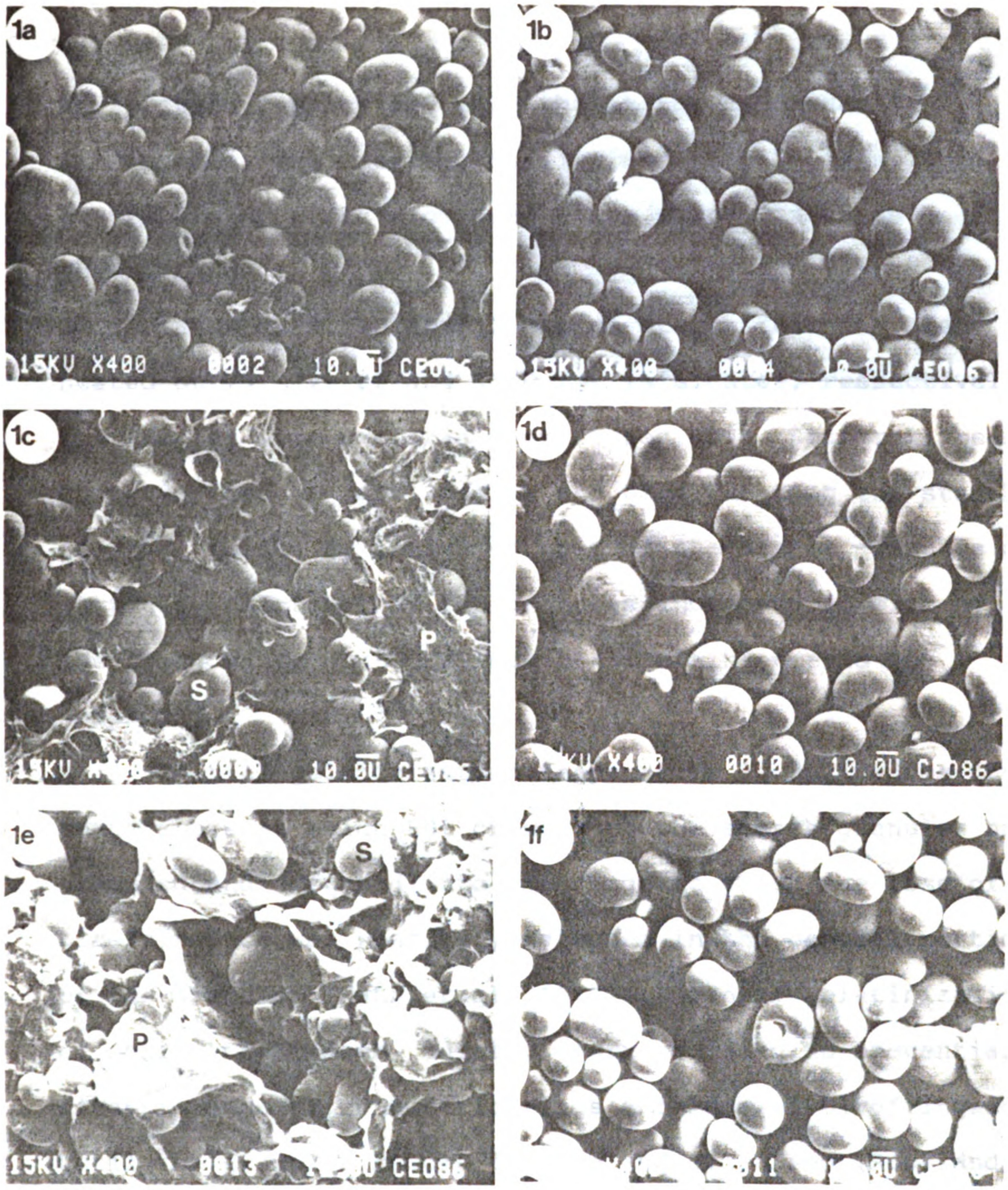


Plate (7) Scanning electron micrographs of raw starch extracted with water (1a, 1c, and 1e) and NaOH (1b, 1d and 1f) from navy (Seafarer) beans stored at three temperatures (5, 20 and 35 °C) and 18% moisture for nine months. 1a, 1b = 5 °C; 1c, 1d= 20 °C; 1e, 1f= 35 °C the protein complex and make the starch more readily extractable. The unextractability and relative insolubility of protein obtained from hard beans supported these observations.

Plates 8, 9, 10 and 11 depict starch that had been heated at 75, 77, 80 and 85°C for 15 minutes, respectively. The samples were prepared from stored navy (Seafarer) beans characterized as soft, medium and hard. Heating the starch to 75°C, (plate 8) indicates most of the starch granules are partially gelatinized, the granules increased in size by absorbing water, but the loss of birefringence is not completed.

Initial gelatinization temperature is defined as the temperature at which 80% or more of the starch granules have expanded and deformed into the stage at which the loss of birefringence was postively detected in the central portion of the granules (Hahn et al. 1977). Further, gelatinization of starch progresses radially, corresponding to sequential disappearance of concentric rings and loss of birefringence until the granules become diffuse and dispersed (Rockland et al., 1977).

Most of the granules were gelatinized, the size had increased to the maximum and most of the birefringence had disappeared when the starch granules were heated to 77°C

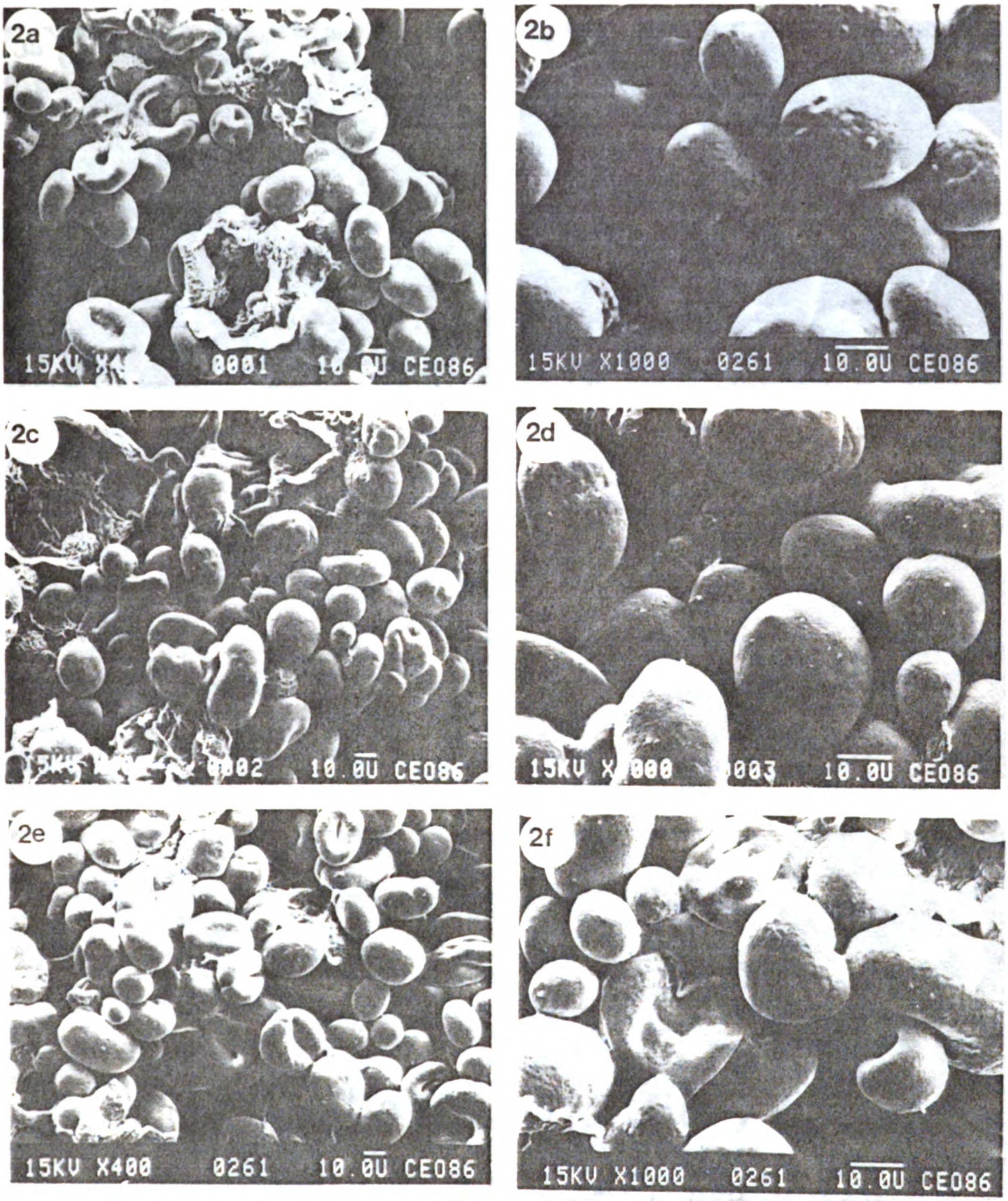


Plate (8) Scanning electron micrographs of starch cooked in water at 75°C for 15 minutes following extraction from navy (Seafarer) beans stored at three temperatures (5, 20, and 35°C) and 18% moisture for nine months. 2a, 2b= 5°C; 2c, 2d= 20°C; 2e, 2f= 35°C

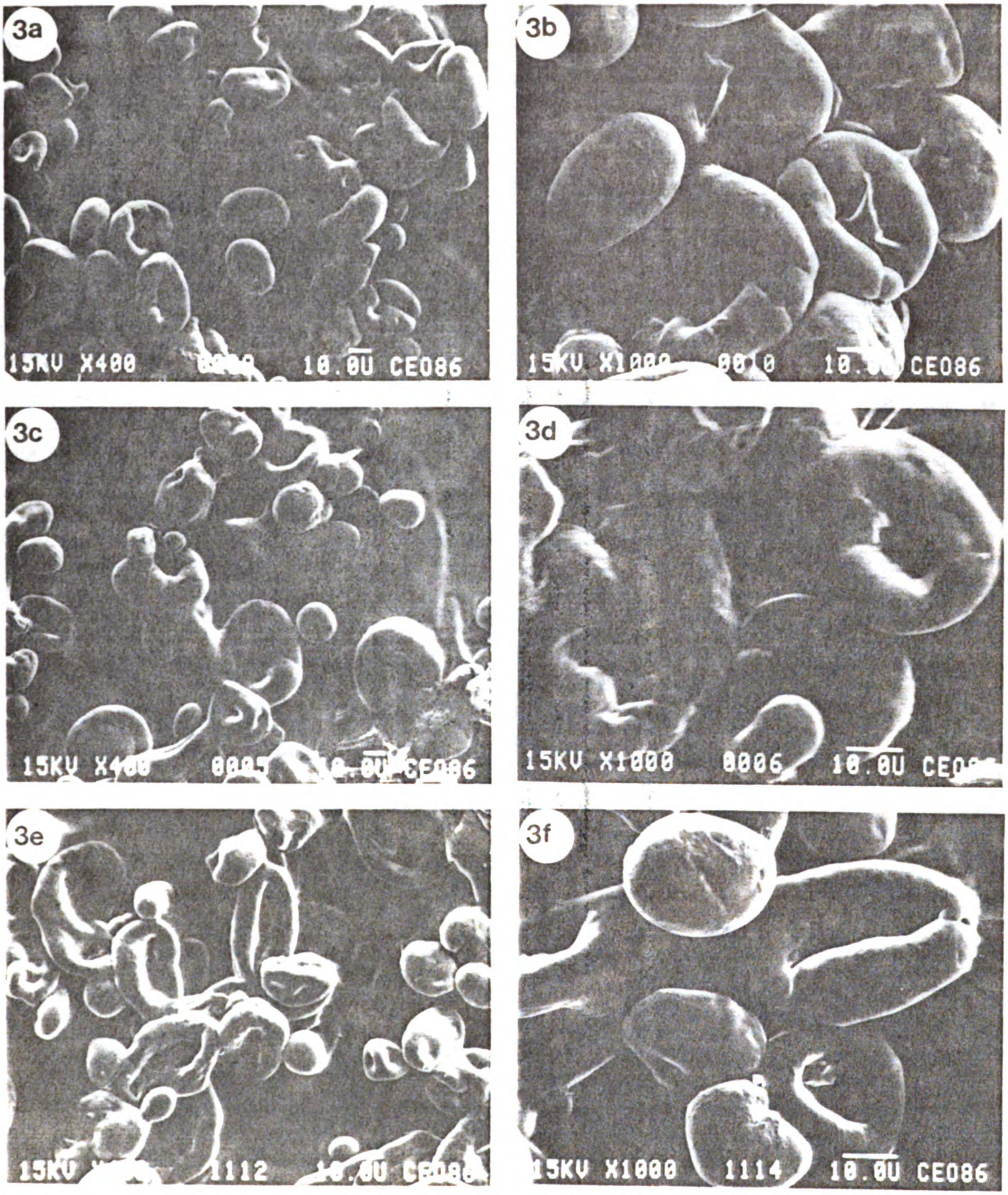


Plate (9) Scanning electron micrographs of starch cooked in water at $77^{\circ}C$ for 15 minutes following extraction from navy (Seafarer) beans stored at three temperatures (5, 20, and $35^{\circ}C$) and 18% moisture for nine months. 3a, 3b= $5^{\circ}C$; 3c, 3d= $20^{\circ}C$; 3e, 3f= $35^{\circ}C$

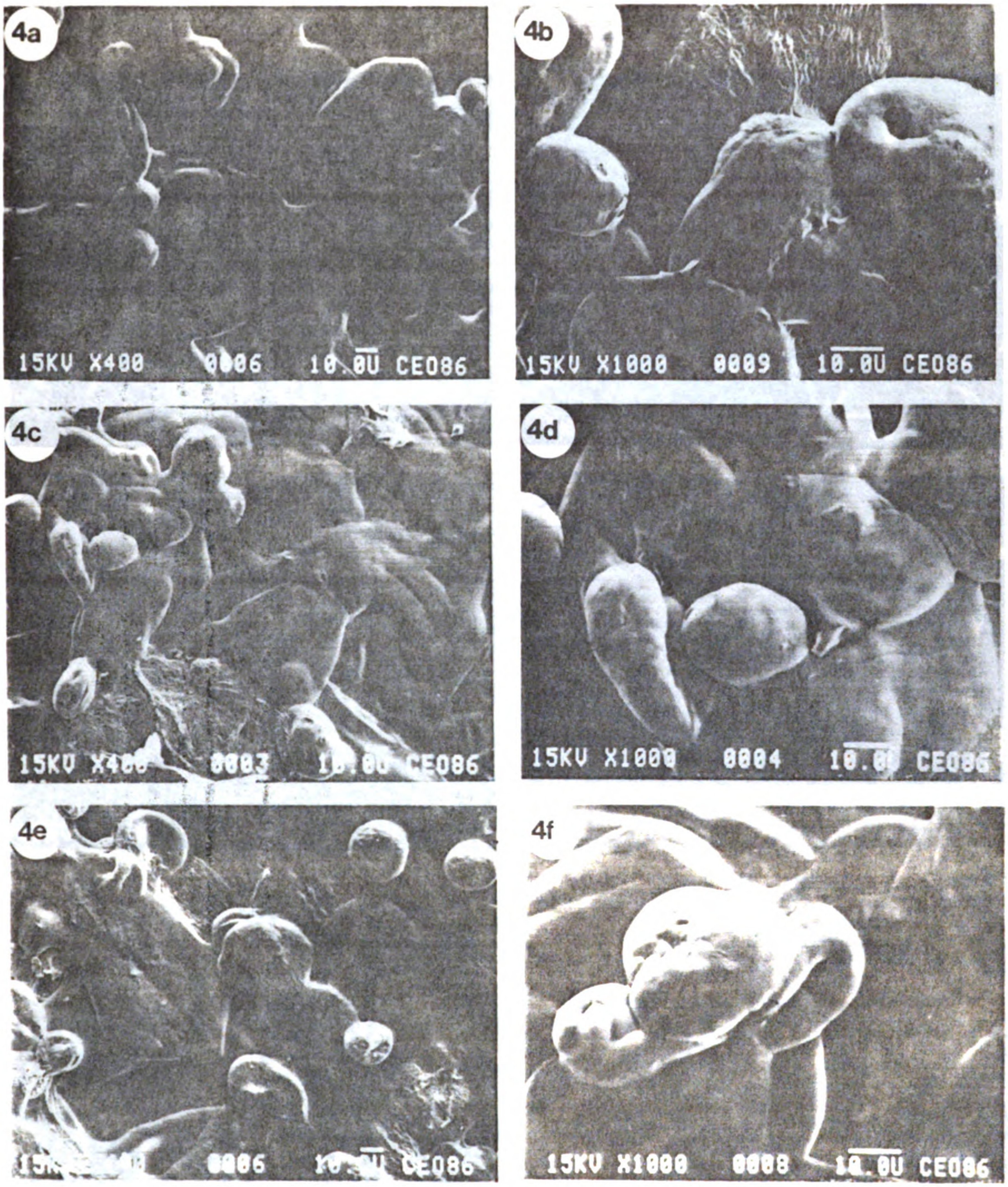


Plate (10) Scanning electron micrographs of starch cooked in water at 80°C for 15 minutes following extraction from navy (Seafarer) beans stored at three temperatures (5, 20, and 35°C) and 18% moisture for nine months. 4a, 4b= 5°C; 4c, 4d= 20°C; 4e, 4f= 35°C

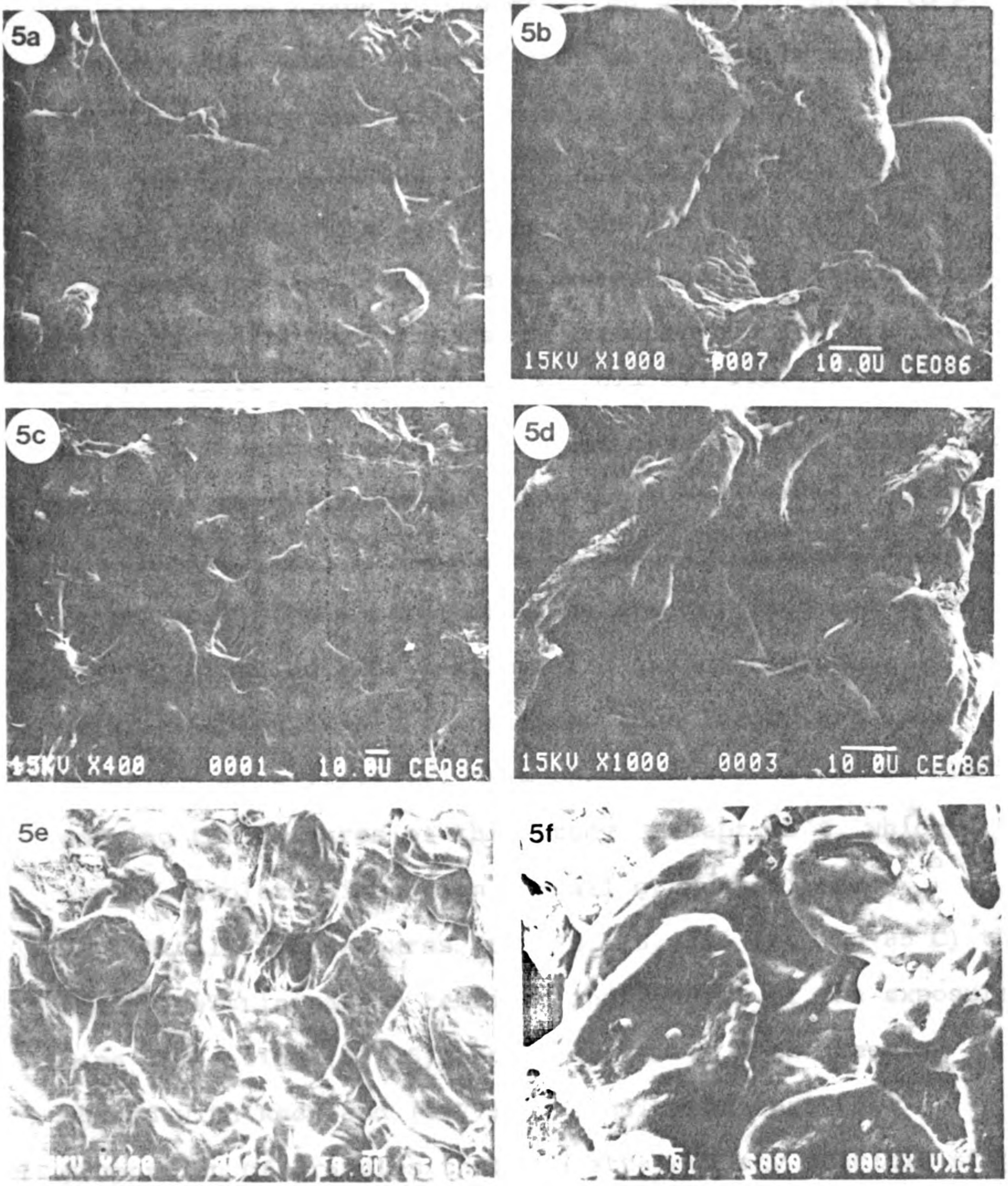


Plate (11) Scanning electron micrographs of starch cooked in water at $85^{\circ}C$ for 15 minutes following extraction from navy (Seafarer) beans stored at three temperatures (5, 20, and $35^{\circ}C$) and 18% moisture for nine months. 5a, 5b= $5^{\circ}C$; 5c, 5d= $20^{\circ}C$; 5e, 5f= $35^{\circ}C$

(plate 9). The shape of the granules appear similar to a doughnut. The starch samples from soft, medium and hard beans were very comparable in size and shape.

Heating the starch at 80^{o}C (plate 10) indicated a different gelatinization stage than shown at 77^{o}C. Most granules were completely gelatinized and have started to lose some water and dispersion was observed for all three samples (soft, medium and hard). For all samples at 85^{o}C (plate 11) most granules have lost most of their water and were completely dispersed.

At any given temperature within the gelatinization range, most of the large granules are deformed before the smaller granules. The smaller size granules usually gelatinized at higher temperature than larger granules (Rockland et al., 1977). This phenomenon appeared at all cooking temperatures of this study, except 85^{o}C, which showed complete dispersion for all granule sizes.

At all temperatures (65, 70, 75, 77, 80, and 85^{o}C) the starch gelatinization remained independent of the exposure time of heating (5, 15, and 50 minutes). These results agreed with Rockland (1977) who indicated that the proportion of granules that had attained any specific stage of gelatinization did not change with time of exposure in either water or salt solution.

Most of the starch granules were gelatinized at 80°C, and completly dispersed at 85°C. These results were similar to observations of Rockland et al., (1977) which indicated no birefringence was observed in dried starch granules of lima beans gelatinized in water at 79°C.

These micrographs indicated that the storage conditions had no clear effect on starch gelatinization. The reason could be due to limited starch involvment in the hardening process during storage.

Short chains packed side by side in amylopectin or parts of the amylose molcules, result in oriented crystallities that make the starch granules birefringent and have distinct X-ray diffraction patterns. The amorphous regions are those areas where chain folding or multiple branching occur and prevents the formation of an ordered polymeric structure. Recent evidence suggests that the water absorbed by the granules is associated only with its amorphous parts. When starch granules are heated in the presence of water gelatinization takes place. This phenomenon is associated with: (a) - loss of crystallinity. (b) - extensive swelling of the granules (Biliaderis et al., 1980).

Conclusions of Study 1

The cooking time showed significant differences among storage temperatures, moisture contents and bean cultivars, but not among gases. The cooking time of high moisture beans increased more than six times as the temperature of storage increased from 5 to 35°C. Cooking time also increased as the moisture content increased.

The Hunter lab color coordinate mean squares from the analysis of variance of dry and processed beans showed significant differerences among cultivars, moistures, temperatures and times of storage, except a_L (greenness) coordinate for moisture and temperatures. The darkness (L), greenness (a_L) and yellowness (b_L) values of the stored beans were increased for all cultivars as the temperature, moisture and time of storage increased for the dry beans. The processed beans showed increased darkness and decreased yellowness.

The quality characteristics of dry, soaked and processed beans showed significant differences among cultivars, moistures, temperatures and times of storage, but showed partial significance among gas atmospheres. The soaked weight were increased and decreased dependent on moisture levels and time of storage. The drained weight, clumps and splits decreased, while the shear force and dried residue increased as the storage temperature, moisture content and storage time increased.

Bean moisture for soaked and processed beans were significantly affected by all storage variables, except the effect of time on soaked moisture which showed no significant differences.

The mean squares from the analysis of variance of mass ratio index for hydration and drained weight showed significant variations among cultivars, storage temperatures, moisture contents and times of storage, except the effect of time on hydration ratio index, which was not significant.

The total protein content decreased between 5^{o}C and 20^{o}C, but increased between 20^{o}C and 35^{o}C for navy, black and kidney. Protein increased continuously with increasing temperature for pinto beans. The soluble proteins decreased up to 40% of the fresh beans, as the temperature of storage increased from 5 to 35^{o}C for the beans stored at high moisture level (18%). The soluble solids and total soluble pectin decreased significantly with increasing storage temperature for all cultivars.

Raw bean sections for all cultivars showed clear variations betweeen low and high storage temperatures and moisture contents when examined under the SEM. More compact structures were found with high temperature and high moisture stored beans (hard beans) compared to low temperature and low moisture stored samples (soft beans).

The protein granules were unrecognizable for the high storage temperature and high moisture content of stored samples when the raw bean sections were fixed using gluteraldehyde. The protein granules were clear for the samples stored at low temperature and low moisture when the samples were fixed in this manner.

The starch granules were unextractable by water for hard beans, while they were readily extracted in water for soft beans. Protein molcules associated with starch granules reduced extraction and hydration for high temperature stored beans. However, the starch granules were almost completely gelatinized at 80°C and dispersed at 85°C for both low and high temperature storage samples.

Study 2: Storage Stability of Freshly Harvested and Roasted Beans

Freshly harvested beans were roasted (particle to particle contact) using hot sand at two temperatures (150 and 200^{o}C) for three different times (1, 5, and 10 minutes). Moisture content of fresh and roasted beans was adjusted to 18% for the three cultivars and for all roasting treatments prior to storage. The samples were stored at 5 and 35^{o}C for five months before processed and evaluated.

Stored and processed fresh and roasted beans were evaluated for soaked weight, drained weight, color, texture and dried residue. Results are presented in Tables 34 through 38 and Figures 40 through 54. The mean squares from the analysis of variance (Table 34) showed highly significant differences among various cultivars, temperatures of storage, roasting temperatures and times, for all four bean quality parameters (soaked weight, drained weight, shear force and dried residue).

Soaked weights (Table 35 and Figure 40) of navy (Seafarer) beans roasted at 150 or 200^{o}C and stored at 5^{o}C were less than unroasted beans stored under the same conditions. These data for the high temperature storage

Table (34) Analysis of variance of beans evaluation parameters of three bean cultivars roasted at two temperatures for three periods of time an stored at 5 & 35 °C for five months

Source of Variation	df	Beans evaluation parameters			
		Sheare Force	Drained Weight	Soaked Weight	Dried Residue
		Mean Squares			
Total	83	10289.14	786.41	53.09	10.20
Treatments	41	20770.11**	1566.04**	103.08**	20.56**
Storage Temperature (A)	1	66195.46**	51688.16**	1645.92**	782.02**
Heat Treatment (B)	6	10383.31**	148.74**	148.17**	0.93**
Cultivar (C)	2	9224.14**	1815.78**	317.56**	5.03**
A x B	6	14296.63**	308.34**	12.74	5.72**
A x C	2	8760.66**	2502.44**	358.00**	4.352**
B x C	12	214.30**	38.41	12.37	0.11
A x B x C	12	250.08**	56.62	9.37	0.09
Error	42	57.71	25.34	4.30	0.09
CV %		3.58	1.92	1.03	0.90

Table (35) Soaked weight of three bean cultivars (18% moisture) roasted at two temperatures for three periods of time and stored at 5 & 35°C for five months *

Roasting (Temp.&Time) (°C & min.)	Navy (Seafarer)		Black (BTS)		Kidney (Montcalm)	
	Storage temperature (°C)					
	5	35	5	35	5	35
Control	208.8a	203.7abcd	220.1a	199.7cde	203.5a	199.8ab
Roasted at 150°C						
1	207.3ab	201.8bcde	220.4a	201.3cde	202.5a	200.4ab
5	206.9ab	200.1cde	215.2a	194.0e	203.3a	194.8abc
10	206.4abc	195.9e	213.0ab	195.5e	199.4ab	201.3ab
Roasted at 200°C						
1	203.1abcd	197.8de	214.5a	196.8de	201.0ab	195.4abc
5	201.6bcde	195.5e	206.4bc	193.7e	191.8bc	189.0c
10	202.8abcd	197.2de	203.9cd	194.2e	196.7abc	195.3abc

Bean cultivars

* Mean values (like letters within each cultivar indicate no significant differences by Tukey mean separation, $P<0.05$)

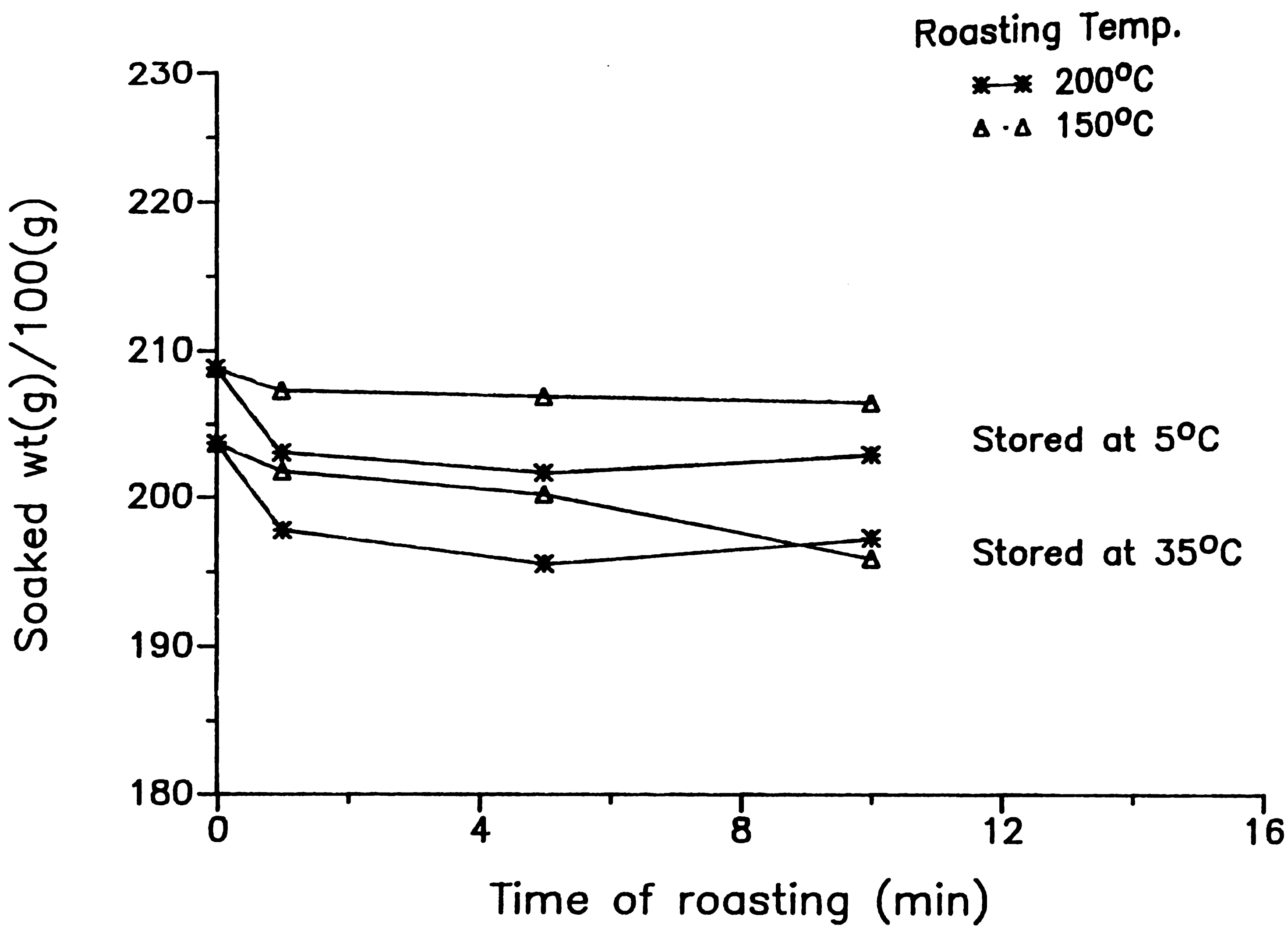


Fig (40) Soaked weight of navy beans (18% moisture roasted at two temperatures for three times and stored at 5 & 35°C for five months

(35^{o}C) showed the same patterns, the values of the roasted beans were less than the raw beans stored under the same conditions.

As the temperature of roasting increased from 150 to 200^{o}C, the soaked weight generally decreased over all storage temperatures. Beans roasted for 10 minutes and stored at 35^{o}C did not exhibit this trend. Soaked weight of beans roasted at 200^{o}C was greater than beans roasted at 150^{o}C. Soaked weight of beans roasted at 150 or 200^{o}C and stored at 5 or 35^{o}C decreased as roasting time increased from 1 to 5 minutes. Beans roasted for 5 or 10 minutes resulted in an inverse relationship. Beans roasted at 150^{o}C and stored at either 5 or 35^{o}C showed decreased soaked weight with increased roasting time. Roasting at 200^{o}C resulted in stable or increasing soaked weight. The soaked weight (g/100g) decreased significantly as the temperature of storage increased from 5 to 35^{o}C for both raw and roasted navy beans.

The soaked weight of black (BTS) beans (Table 35 and Figure 41) decreased as the temperature of roasting increased for both storage temperatures. Other observations similar to those for navy beans were noted except the soaked weight decreased from 206.4 to 203.9 g/100g for beans roasted at 200^{o}C as the time of roasting increased from 5 to

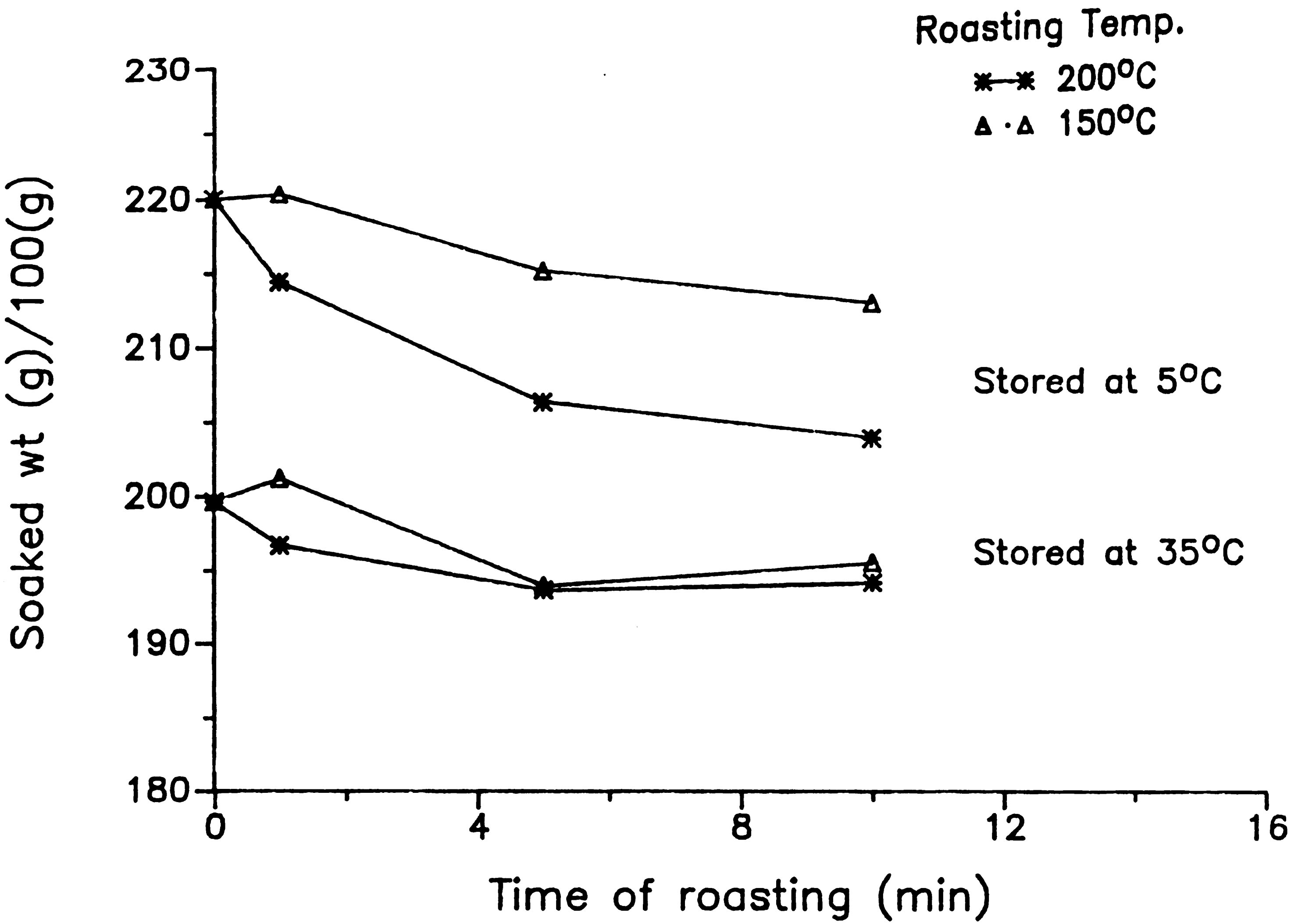
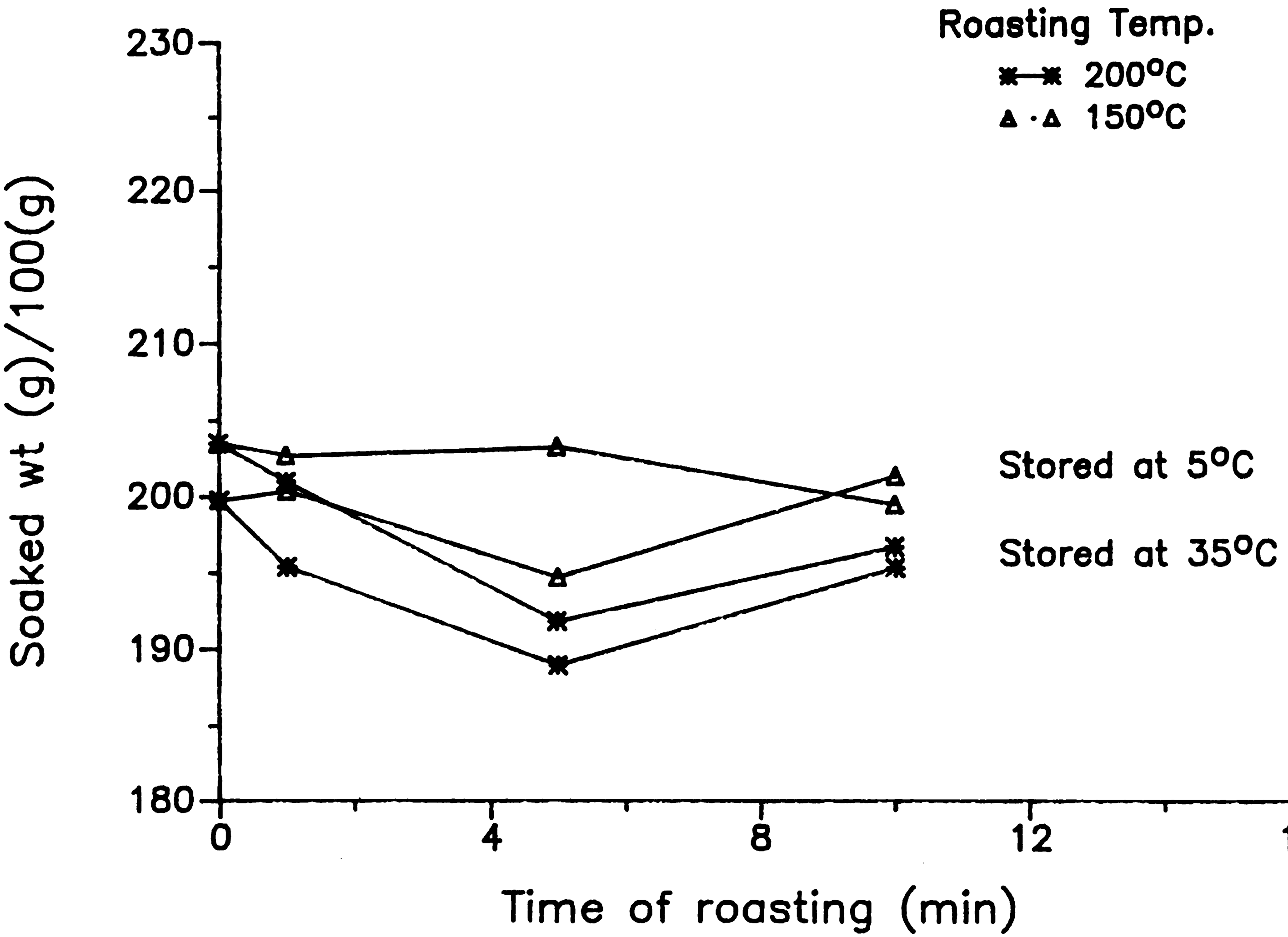


Fig (41)Soaked weight of black beans (18% moisture roasted at two temperatures for three times and stored at 5 & 35°C for five months

10 minutes.

Slight differences were observed among kidney, navy and black beans for the soaked weight. The soaked weight of kidney beans (Table 35 and Figure 42) stored at 5°C was very similar to navy beans. The soaked weight of kidney beans roasted at 150°C increased as the roasting time increased from 1 to 5 minutes, an opposite trend was observed for kidney beans roasted at 200°C. As the roasting time increased from 5 to 10 minutes the soaked weight decreased for the beans roasted at 150°C and increased for the beans roasted at 200°C. At 35°C storage, the soaked weight of the roasted beans at 150°C for 1 minute was higher than raw beans. Otherwise, kidney beans responded similarly to other cultivars. The soaked weight decreased as the temperature of roasting increased from 150 to 200°C.

The decreasing of soaked weight as the storage temperature increased from 5 to 35°C could be due to decreased cell wall permeability. Vonmollendroff and Priestly (1979) used the scanning electron microscope, and found that the cell walls of normal beans appeared more porous, contained large openings compared to hard-to-cook samples. These published results agreed with the results of this study. Thermal denaturation of protein may account for decreased soaked weight of roasted beans.



Fig(42)Soaked weight of kidney beans (18% moisture roasted at two temperatures for three times and stored at 5 & 35°C for five months

The drained weight of the navy (Seafarer) beans are presented in Table 36 and Figure 43. In this study, the drained weight of roasted navy beans was higher than the raw beans, except at 200^{o}C roasting for 10 minutes which was less than the raw beans at 5^{o}C storage. At 35^{o}C, the drained weight mean values were very similar between the raw and roasted beans stored under the same conditions. There was no significant difference between both means (Tukey test). As the roasting time increased at 150^{o}C the drained weight also increased. Drained weight of navy beans roasted at 200^{o}C and stored at 5^{o}C was decreased with increased roasting time and was the minimum following 10 minutes. The storage temperature had a highly significant effect on the drained weight. As the storage temperature increased from 5 to 35^{o}C, the drained weight decreased for both raw and roasted beans.

The drained weight treatment mean values for black beans (BTS) are presented in Table 36 and Figure 44. Black beans showed very similar behavior compared to navy beans. An exception to this was noted in the black beans roasted at 150^{o}C and stored at 5^{o}C. The drained weight decreased rather than increased as the time of roasting increased. This was similar to roasting at 200^{o}C. Also, no differences in drained weight were detected between raw and roasted beans stored at 35^{o}C.

Table (36) Drained weight of three beans cultivar (18% moisture) roasted at two temperatures for three periods of time and stored at 5 & 35 °C for five months *

Roasting Temp. & Time (°C & min.)	Bean cultivars					
	Navy (Seafarer)		Black (BTS)		Kidney (Montcalm)	
	Storage temperature (°C)					
	5	35	5	35	5	35
Control (raw)	297.05ab	236.50c	282.70a	227.90e	285.10a	242.35d
Roasted at 150°C						
1	312.35a	226.05c	283.35a	230.30e	284.95a	239.80d
5	312.85a	233.85c	278.80ab	231.30e	282.40ab	244.30d
10	318.30a	235.80c	275.15bc	233.45e	280.45abc	251.35d
Roasted at 200°C						
1	315.50a	234.95c	280.45ab	233.60e	280.50abc	244.35d
5	301.80ab	237.55c	269.65c	233.60e	269.90e	244.50d
10	279.50b	238.35c	262.45d	232.10e	270.95bc	250.05d

* Mean valus (like letters within each cultivar indicate no significant differences by Tukey mean separation, $P<0.05$).

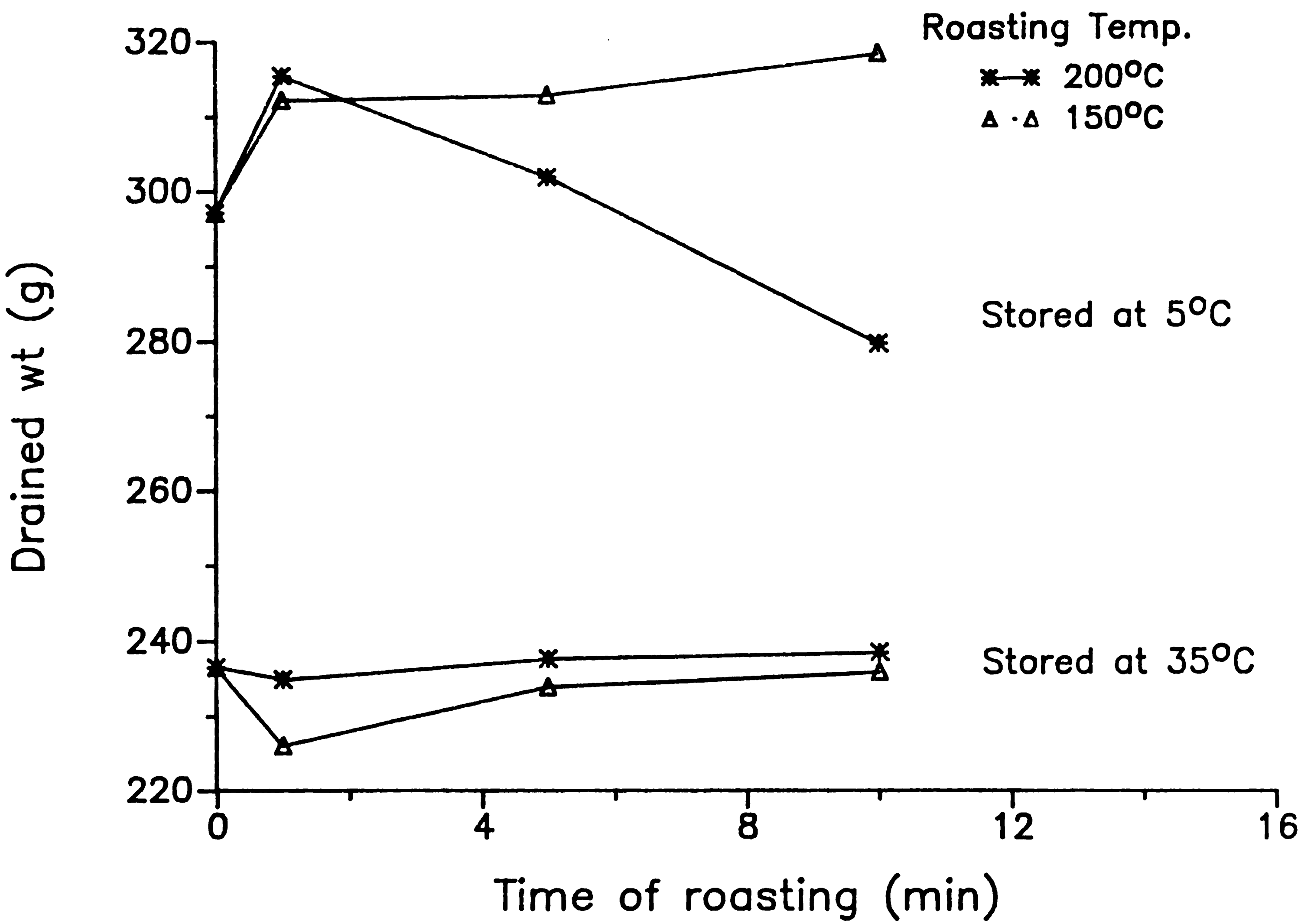
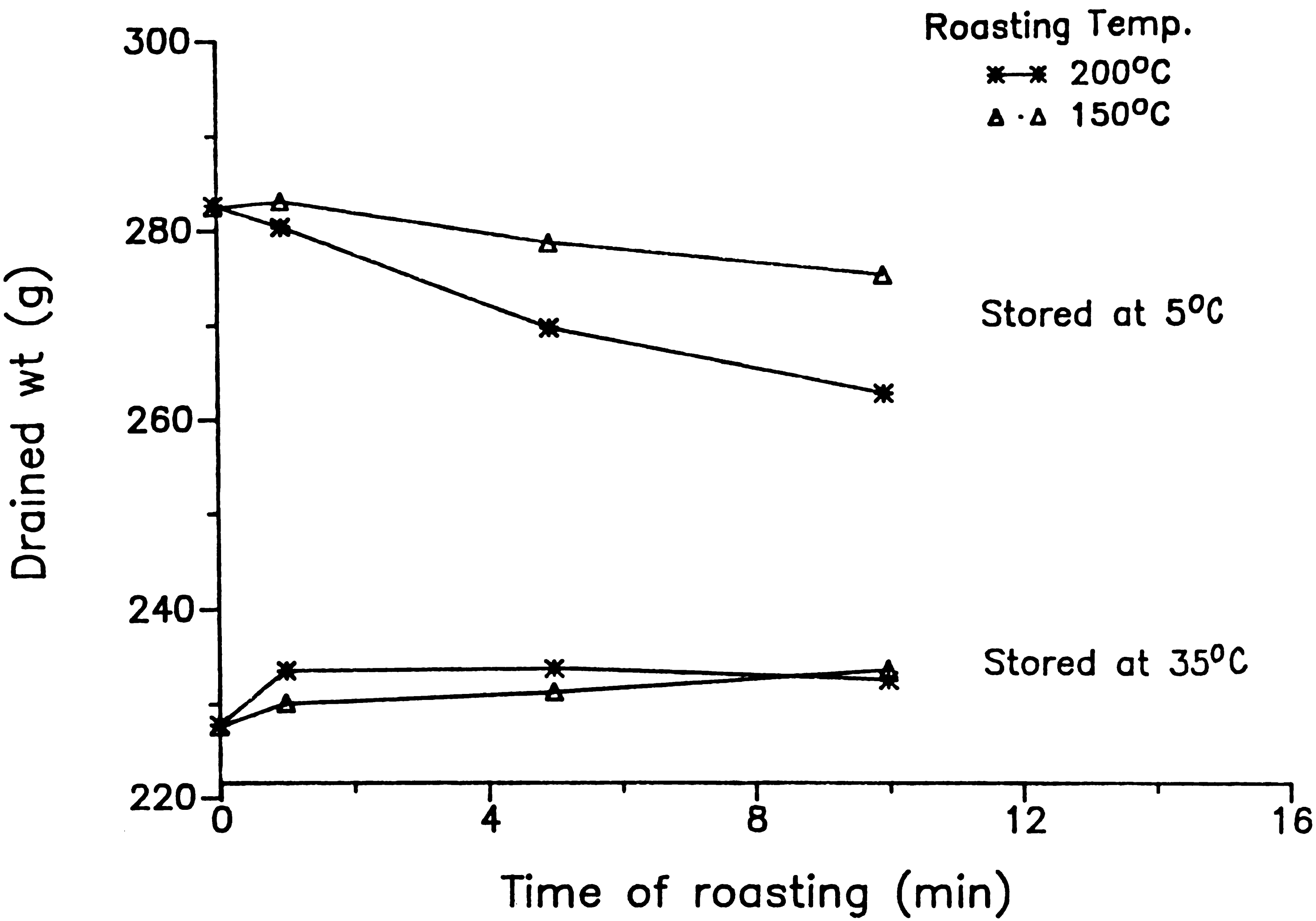


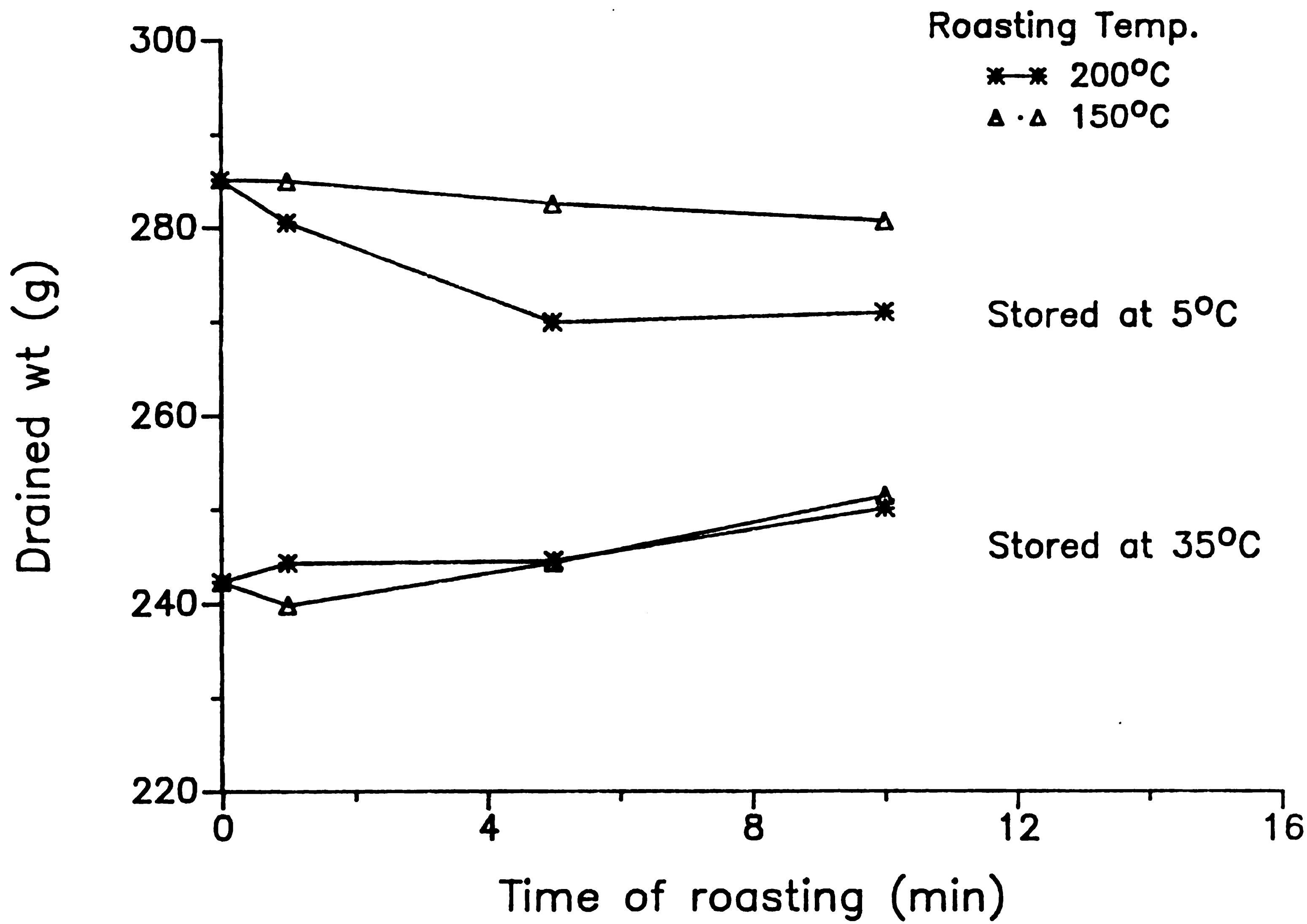
Fig (43) Drained weight of navy beans (18% moisture roasted at two temperatures for three times and stored at 5 & 35°C for five months



Fig(44)Drained weight of black beans (18% moisture roasted at two temperatures for three times and stored at 5 & 35°C for five months

The drained weight observations on treatment means for kidney (Montcalm) beans are presented in Table 36 and Figure 45. These observations showed similar behavior to both the black and navy beans. The drained weight for kidney beans was very similar to black beans at 5°C storage. Thus, the mean values decreased with increasing time of roasting. Overall, navy beans had the highest drained weight values ranging between 226.5 and 318.3 grams. Black and kidney beans had similar mean values with the range for the black beans between 230.3 and 282.7 grams and the range for kidney beans between 239.8 and 285.1 grams.

The drained weight depends upon the water absorption during soaking and cooking. The more water absorbed the higher the drained weight. The change in cell components hygroscopicity during storage could effect the absorption capacity of the beans. At 5°C storage, a difference in drained weight between the raw beans and roasted beans was observed. However, as the storage temperature increased, the drained weight decreased. At 35°C, no significant difference between the drained weight of raw and roasted beans was reported. The differences in drained weight between the raw and roasted beans at low storage temperature, could be attributed to the effect of the roasting process on physical and chemical characteristics of cellular protein including



Fig(45)Drained weight of kidney beans (18% moistur roasted at two temperatures for three times and stored at 5 & 35°C for five months denaturation.

To illustrate the effect of roasting and storage on the color of beans, Hunter lab L values of the processed navy (Seafarer) beans were plotted against the roasting time, for both roasting temperatures (Figure 46).

This Figure reveals the effect of the storage temperature on the color of both raw and roasted beans. The beans stored at high storage temperature, 35^{o}C, have a color darker than the color of the beans stored at low storage temperature, 5^{o}C. In addition, the values indicate that roasting had an effect on the color of the beans only at high storage temperature. Except for the beans roasted at 150^{o}C for 1 minute, roasted beans stored at 35^{o}C exhibited a lighter color than raw beans stored under the same conditions. The differences in color became less significant when the storage temperature was maintained at 5^{o}C. Except for the beans roasted at 200^{o}C for 10 minutes which were slightly darker, both roasted and raw beans stored at 5^{o}C had similar colors.

Similar discoloration effects were reported by Burr et al. (1968) and Vonmollendroff and Priestly (1979). They indicated that higher moisture content at storage caused a darkening in seed coat and cotyledon color. They attributed the darkening to the change in the phenolic constituents

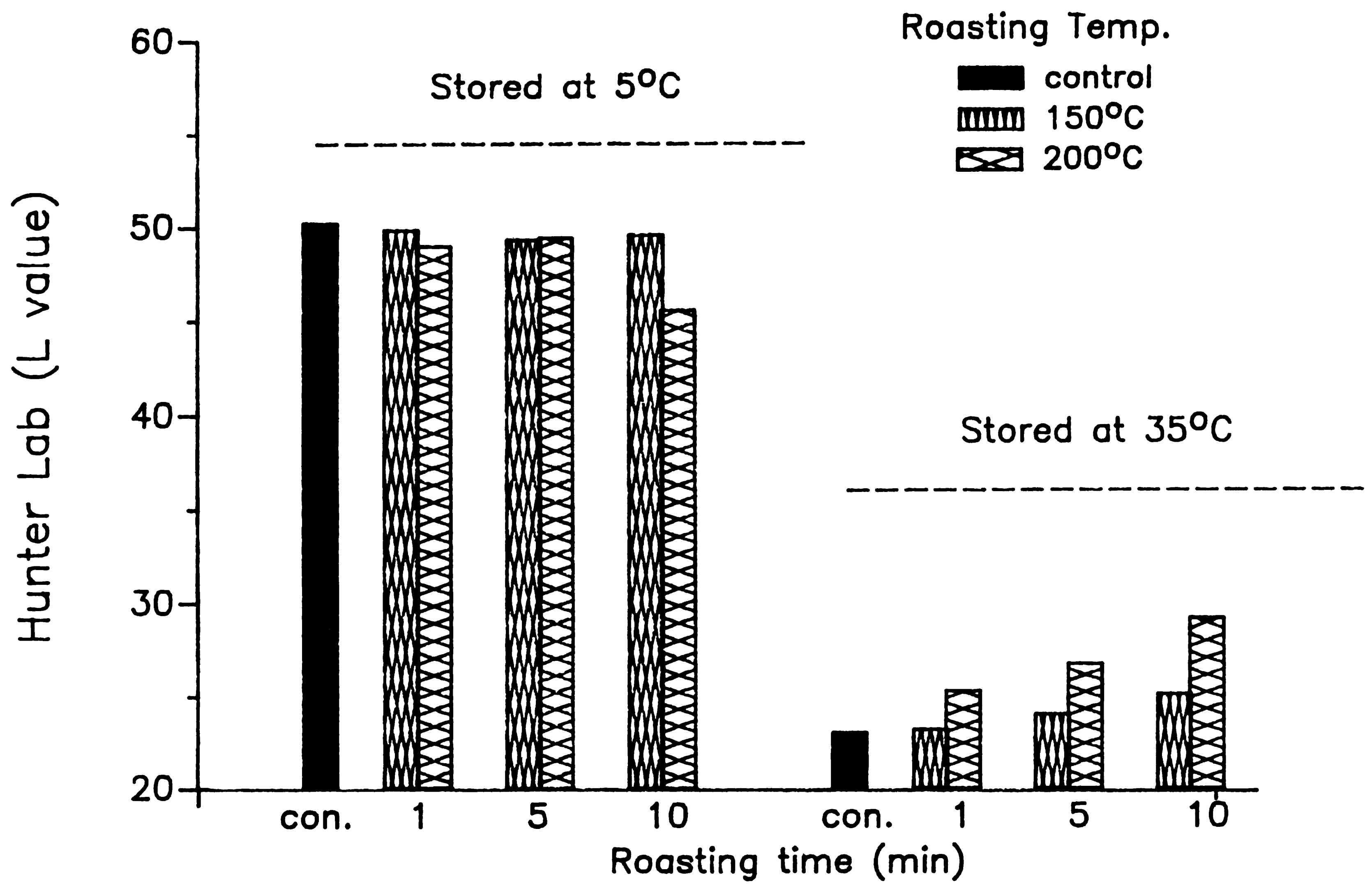
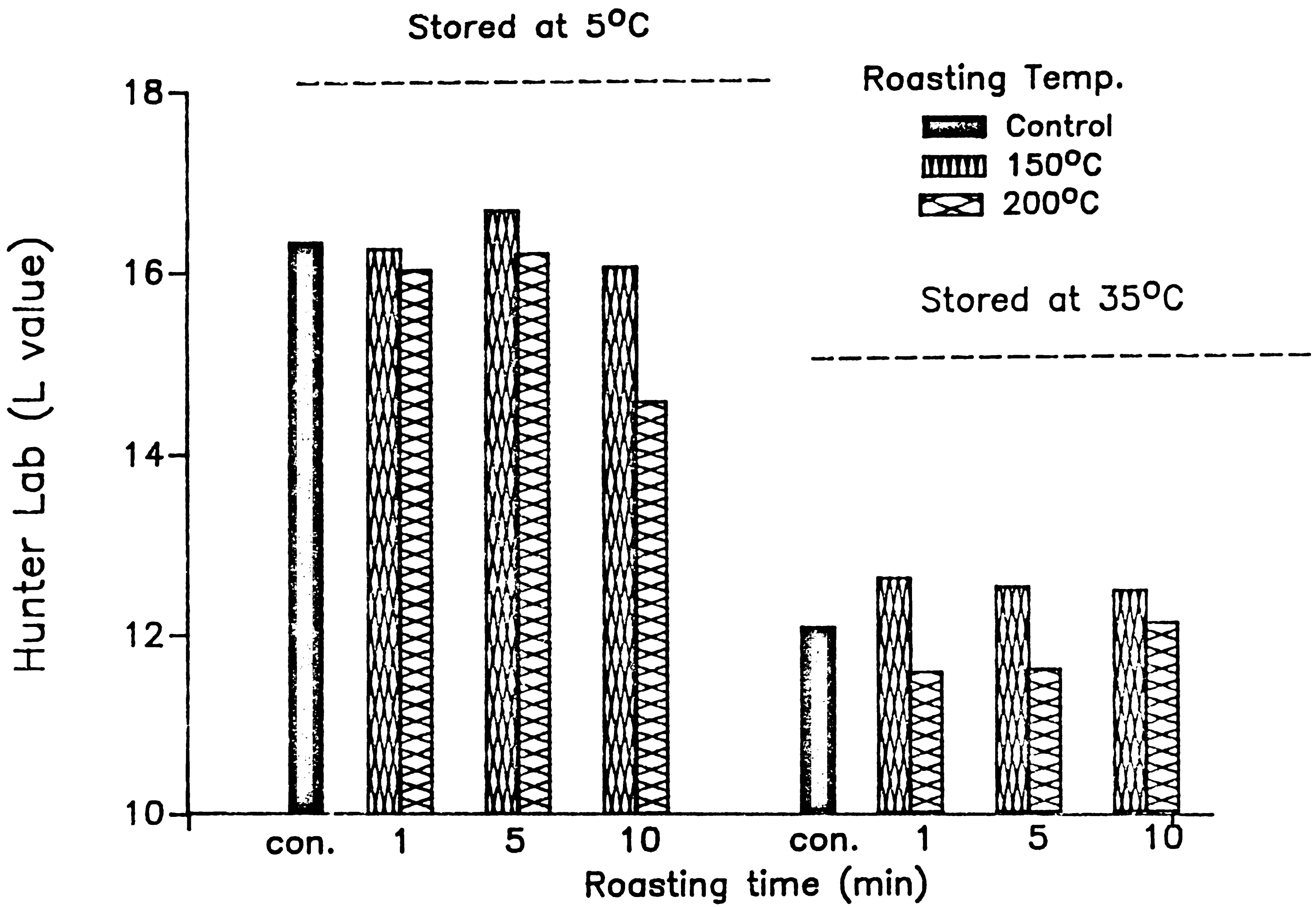


Fig (46)Surface color of navy beans (18% moisture) roasted at two temperatures for three times and stored at 5 & 35°C for five months such as tannins. The same phenomena was reported earlier by Lee and White (1948). They found that dry skim milk with high moisture readily discolored and showed the greatest insolubility. They concluded that this fact was due to the reaction of amino acids with reducing sugar in the product. Lee (1984) confirmed that an increased browning reaction, which occurred at higher water activity in bean flour, was responsible for the darkening. The above observations suggest that the lighter roasted beans at 35^{o}C storage may be due to the destruction of some phenolic components involved in the darkening process during the storage. At low storage temperatures, the roasting of beans resulted in darker beans from the browning reaction occuring during the heating treatment. Thus, the darker color exhibited by beans roasted at 200^{o}C for 10 minutes.

The effect of the roasting process on black (BTS) beans color are reported in Figure 47. The result obtained indicated that roasted black beans at 200^{o}C, stored at both low and high temperatures, exhibit a darker color than the raw beans stored under the same conditions. However, at 150^{o}C roasting temperature, the darkness of the black beans stored at 35^{o}C decreased, while very little change in color was noticed for the black beans stored at 5^{o}C.

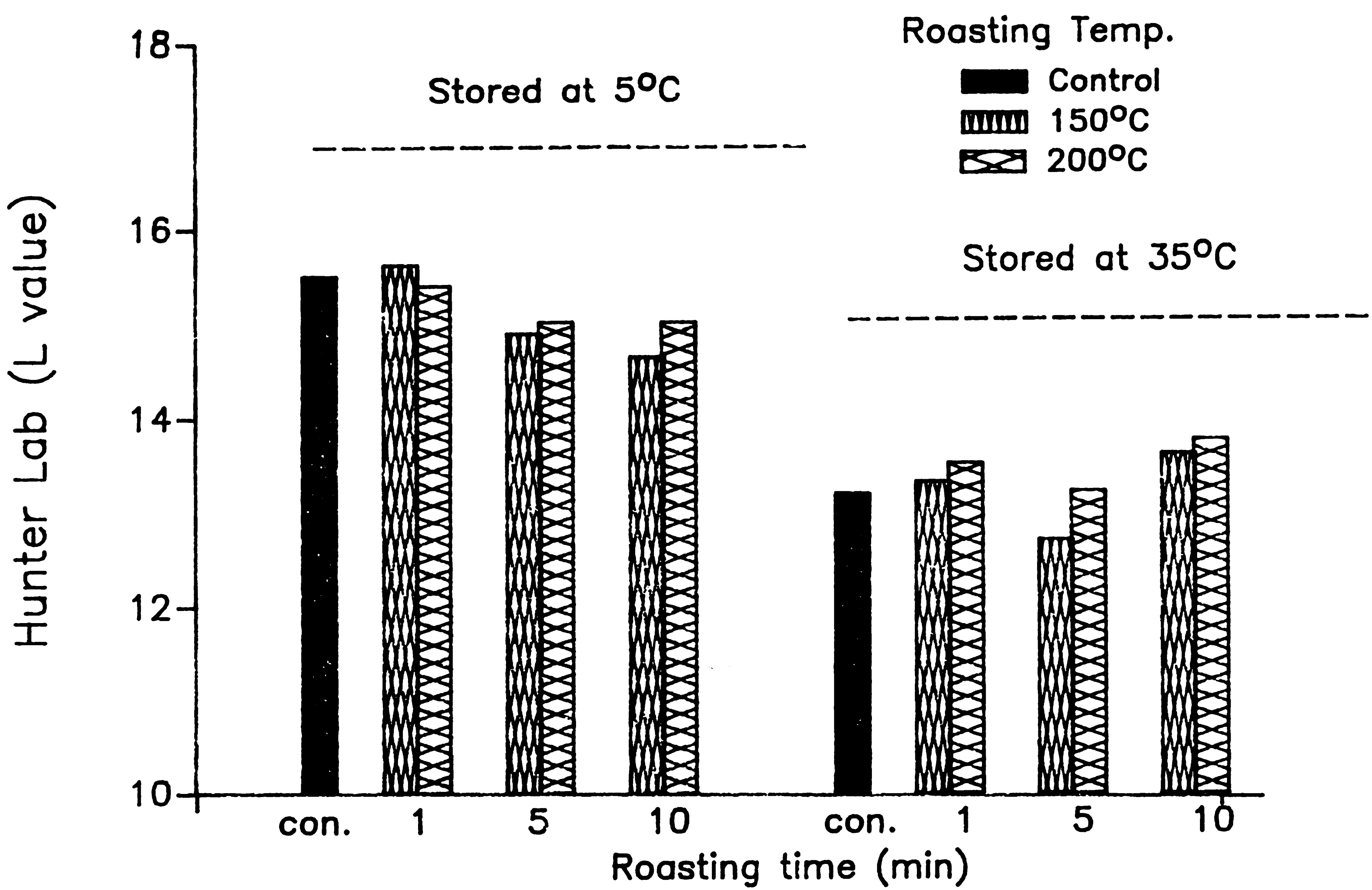
Among the three bean cultivars, navy beans have



Fig(47)surface color of black beans (18% moisture) roasted at two temperatures for three times and stored at 5 & 35°C for five months the highest mean L values which ranged between 23.02 and 50.17. The mean L values of the black beans, which ranged between 11.57 and 16.32 are similar to the mean L values of the kidney beans (Figure 48) which ranged between 13.22 and 15.62.

The above results demonstrate a similar behavior for both kidney and navy beans (Figures 46 and 48). The roasting process improved the quality of the stored bean color at 35°C storage. However, a different behavior was exhibited by black beans. The improvment in black bean color was observed when the beans were roasted at 150°C and stored only at 35°C.

The effect of roasting process on shear force characteristics of navy (Seafarer) beans after canning is presented in Table 37 and Figure 49. These results showed that the shear force increased from 109.54 to 346.29 kg/100(g) as the temperature of storage increased from 5 to 35°C. In addition, these results indicated that the shear force of the roasted beans increased as the storage temperature increased. Compared to raw beans stored at high temperature, the roasted beans showed significantly lower shear force values. However, no significant differences was noticed, at 5°C. The shear force of roasted beans stored at 35°C decreased as the time and temperature of roasting



Fig(48)surface color of kidney beans (18% moisture roasted at two temperatures for three times and stored at 5 & 35°C for five months

Table (37) Shear force of three bean cultivars (18% moisture) roasted at two temperatures for three periods of time and stored at 5 & 35 °C for five months *

Roasting Temp. & Time (°C, min)	Bean Cultivars					
	Navy (Seafarer)		Black (BTS)		Kidney (Montcalm)	
	Storage Temperature (°C)					
	5	35	5	35	5	35
Control (raw)	109.54e	346.29a	114.01e	441.79a	126.45e	410.15a
Roasted at 150°C						
1	112.12e	320.23a	118.97e	401.42b	120.77e	391.22a
5	115.45e	254.23b	122.87e	343.14c	124.10e	325.64b
10	121.38e	235.86bc	131.58e	261.95d	119.81e	279.42c
Roasted at 200°C						
1	134.98e	241.30b	123.35e	315.66c	114.37e	308.10b
5	126.61e	212.00cd	128.70e	264.90d	132.06e	249.81d
10	134.20e	204.11d	115.44e	254.69d	138.63e	250.03d

* Mean values (like letters within each cultivar indicate no significant difference by Tukey mean separation, $P<0.05$)

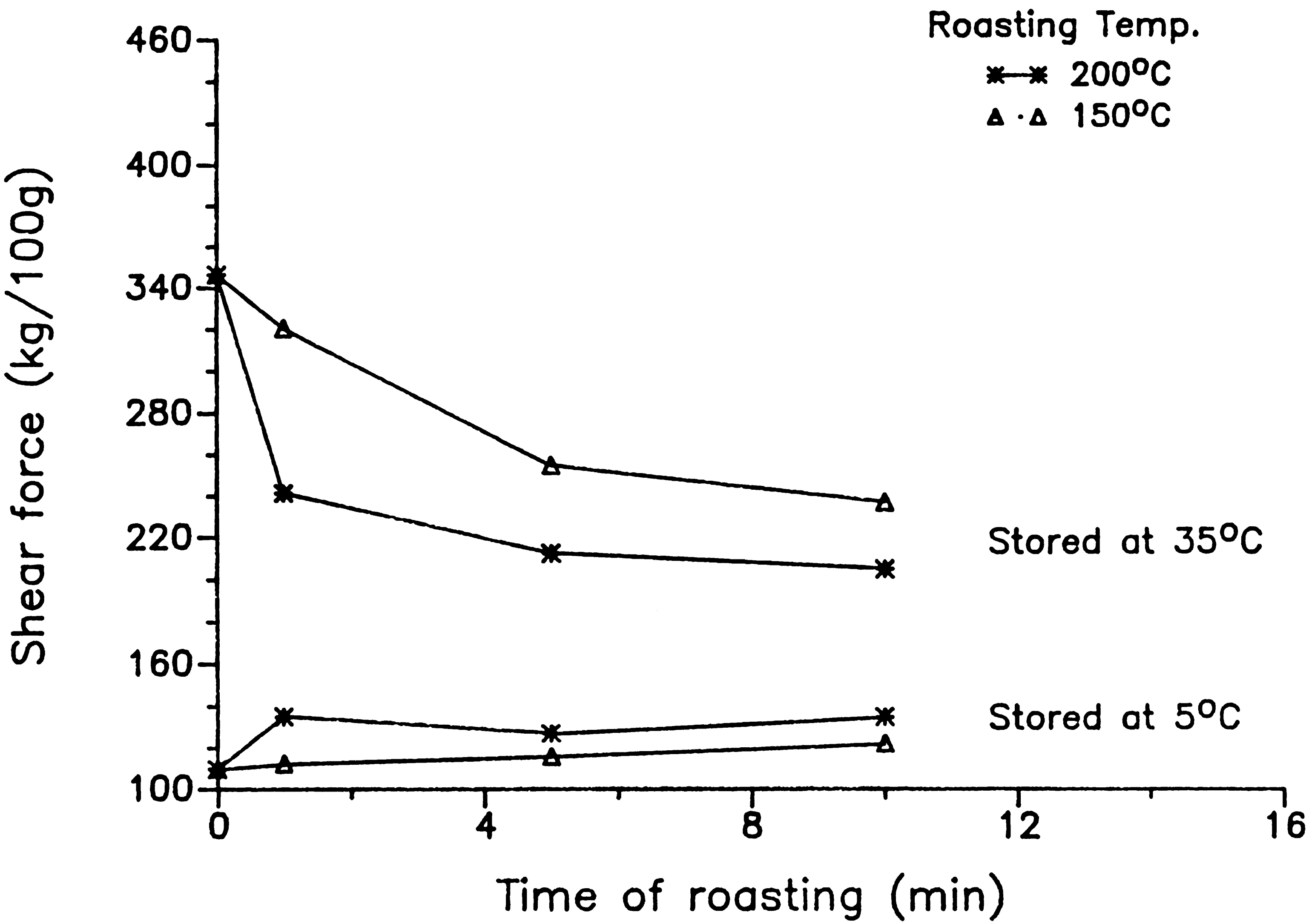


Fig (49) Shear force of navy beans (18% moisture) roasted at two temperatures for three times and stored at 5 & 35°C for five months increased.

The effect of roasting process on the black (BTS) beans shear force was similar to the effect reported for the navy beans, for both storage temperatures, 5°C and 35°C, and for both roasting temperatures 150°C and 200°C. These results for black are summarized in Table 37 and illustrated by Figure 50.

The behavior of the kidney beans was very similar, except when the beans were roasted at 200°C for 5 minutes. The results presented in Table 37 and Figure 51 demonstrate the effect of the roasting on the shear force of the kidney beans. However, when roasted at 200°C for 5 minutes. The shear force value obtained (249.81) was slightly lower than the value (250.03) obtained for the beans roasted for 10 minutes at the same roasting temperature and stored under the same conditions.

As indicated in the first study, the shear force values could be used to measure the hardness of the beans, thus higher shear force values are indicative of harder beans. The above results indicate that pre-roasting beans stored at high temperature lowers the shear force of the beans considerably compared to unroasted (raw) stored beans.

It has been reported (Morris, 1963; Jones and Boulter, 1983; and Moscoso et al. 1984) that the middle lamella of

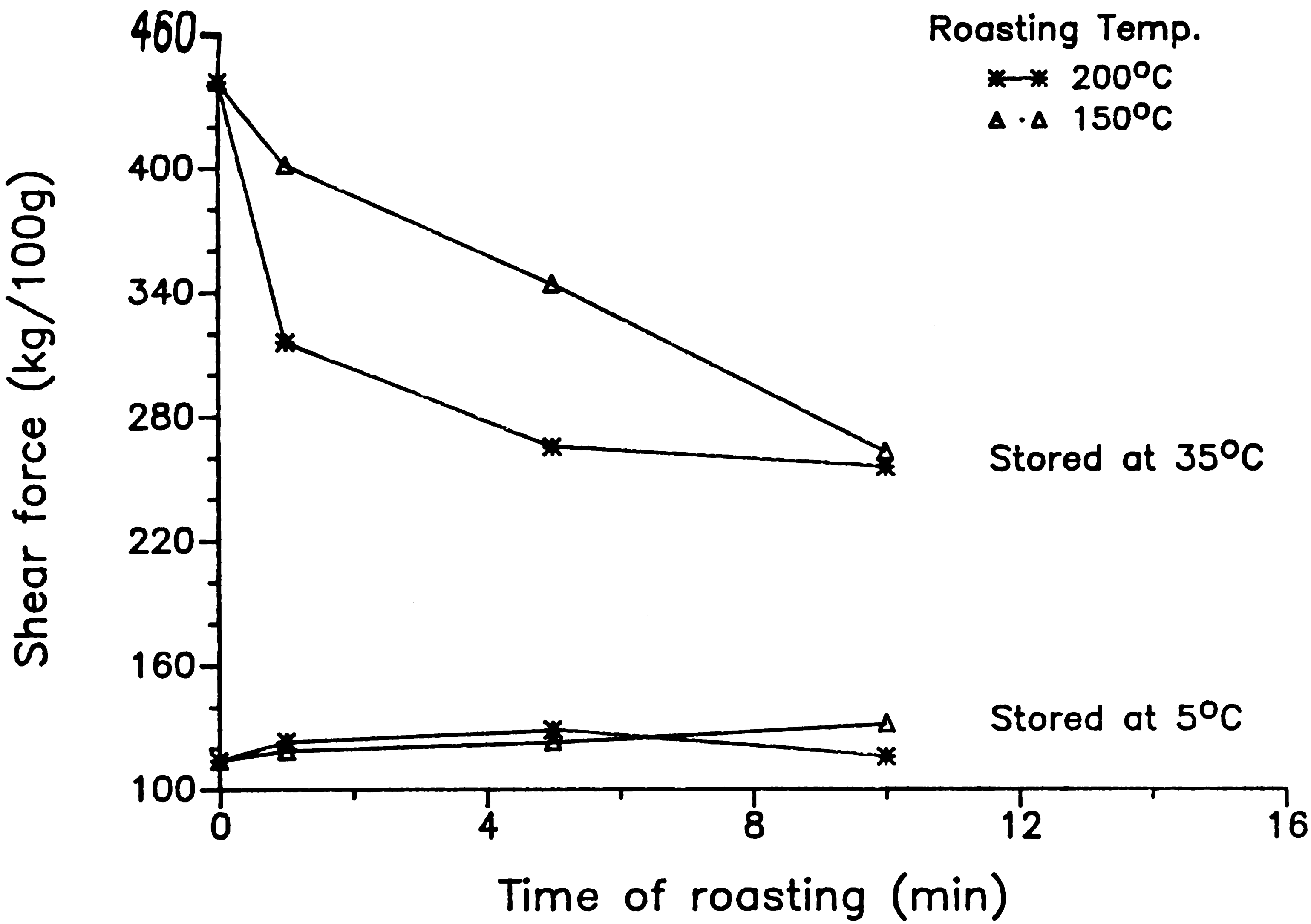
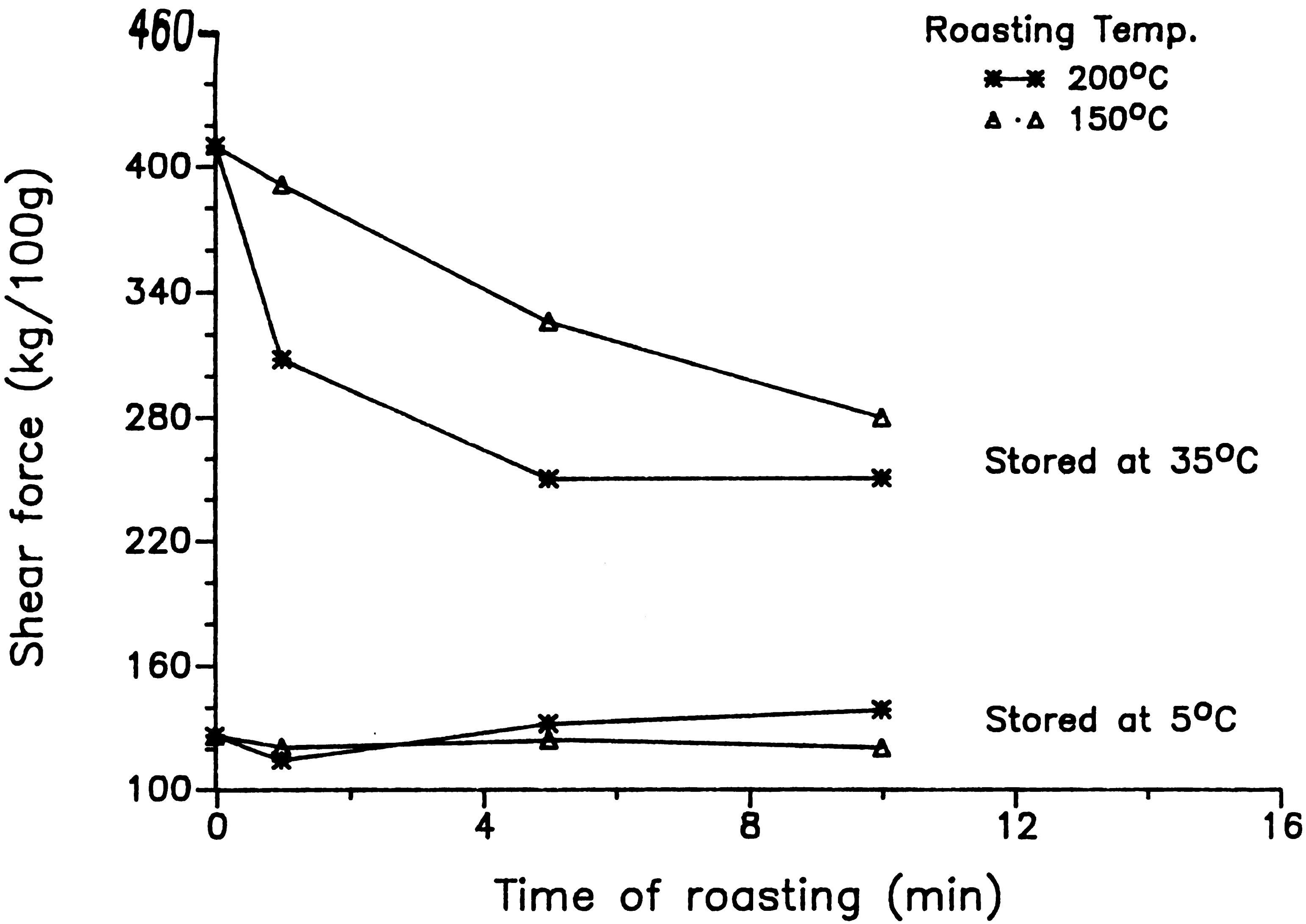


Fig (50)Shear force of black beans (18% moisture) roasted at two temperatures for three times and stored at 5 & 35°C for five months



Fig(51)Shear force of kidney beans (18% moisture) roasted at two temperatures for three times and stored at 5 & 35°C for five months the cotyledon cell of the beans stored at high temperatures and moistures for long periods of time become harder. This hardness was attributed to the formation of more pectin bridges resulting from divalent cation mineral interaction, mainly calcium and magnesium. Some of these minerals are liberated by the action of phytase enzymes on phytate. Therefore, preventing further hardness of the beans could be realized by eliminating the phytase activity on phytate. Data from this study suggests that roasting achieved this purpose for all three cultivars. The roasting process resulted in destruction the enzyme activity as demonstrated by negative phosphotase activity for all roasted beans. This action is consistent with prevention of increased mineral liberation during storage. Consequently, roasted beans exhibited less hardness compared with the raw beans stored under the same conditions.

The observations on treatment means of dried residue obtained for navy (Seafarer) beans are summarized in Table 38 and Figure 52. These observations demonstrate the effect of the storage temperature on the dried residue values, for both raw and roasted beans. As the storage temperature increased from $5^{o}C$ to $35^{o}c$, the dried residue values for both raw and roasted canned beans increased significantly.

These observations of dried residue also demonstrate

Table (38) Dried residue of three bean cultivar (18% moisture) roasted at two temperatures for three periods of time and stored at 5 & 35°C for five months *

Roastindg Temp. & Time (°C, min)	Bean cultivars: Navy (Seafarer)		Black (BTS)		Kidney (Montcalm)	
	Storage temperature (°C)					
	5	35	5	35	5	35
Control (raw)	29.95f	39.10a	31.30e	39.05a	31.25d	38.35a
Roasted at 150°C						
1	30.30ef	38.75a	31.45e	38.85a	31.60cd	38.35a
5	30.30ef	37.30b	31.55e	38.25ab	31.90cd	37.65ab
10	30.25ef	37.15bc	31.60de	37.10c	32.00cd	37.05ab
Roasted at 200°C						
1	30.70def	37.20bc	31.35e	37.60bc	31.80cd	36.95b
5	31.00def	36.35bc	32.15de	37.20bc	32.55cd	36.30b
10	31.60d	36.20c	32.70d	37.30bc	32.90c	36.30b

* mean values (like letters within each cultivar indicate no significant differences by Tukey mean separation, $P<0.05$)

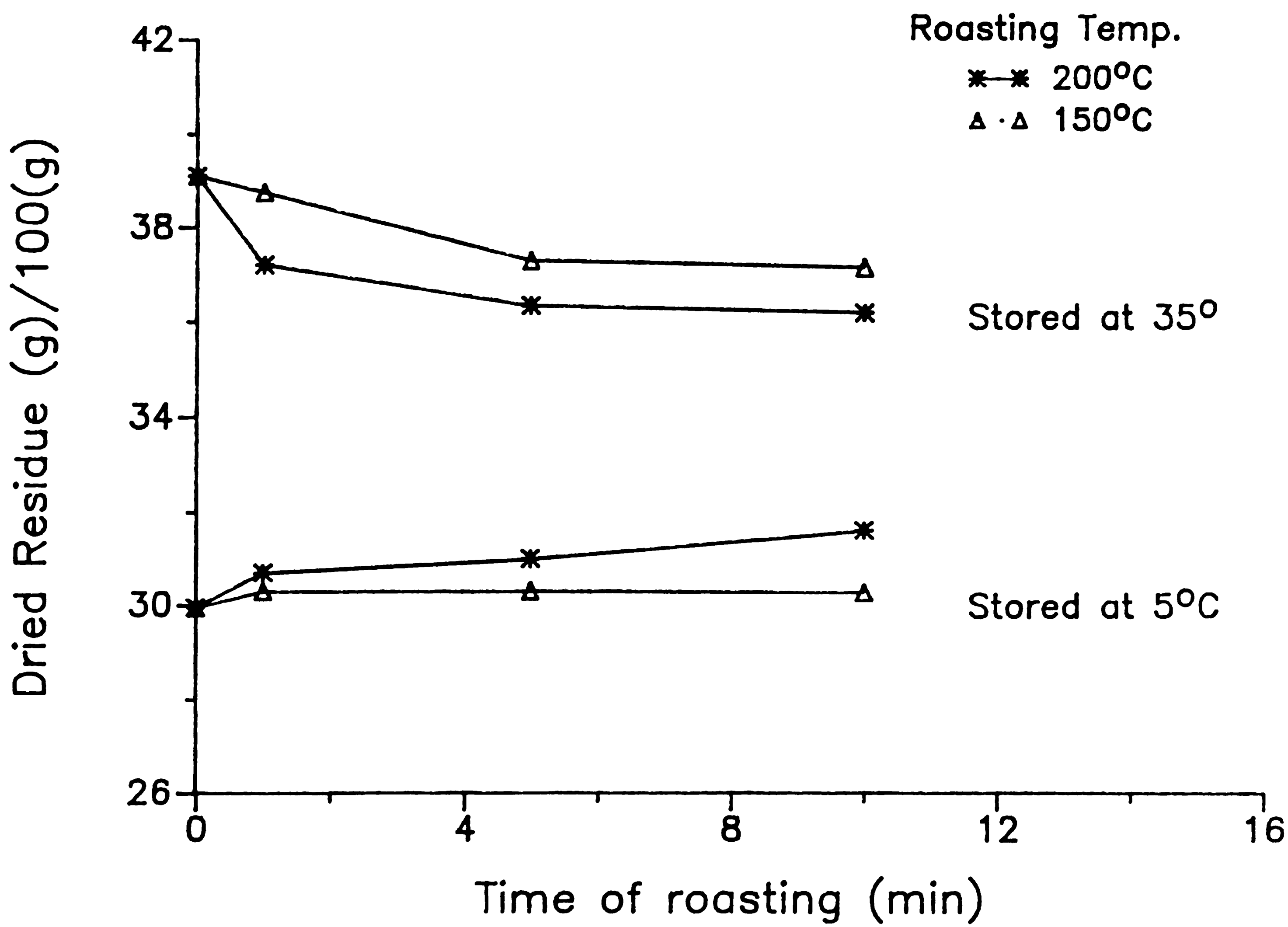


Fig (52) Dried residue of navy beans (18% moisture roasted at two temperatures for three times and stored at 5 & 35°C for five months the effect of the roasting time and temperature on the dried residue values of the beans stored at higher temperature. As the roasting time and temperature increased from 1 minute to 10 minutes and from 150^{o}C to 200^{o}C, respectively, the dried residue values of the beans stored at 35^{o}C decreased. However, at 5^{o}C storage, heat treatment had a lesser effect on the dried residue values, compared to the effect observed at 35^{o}C storage temperature. Furthermore, a Tukey test performed on the samples stored at 5^{o}C detected that the effect of roasting time on dried residue was not significant at 150^{o}C, but the dried residue increased significantly at 200^{o}C roasting temperature.

Similar observations obtained for the dried residue values for both black (BTS) and kidney (Montcalm) beans. The results for these cultivars are summarized in Table 38 and Figures 53 and 54. The dried residue values and the curves obtained for both cultivars exhibit a similar behavior to navy beans. Compared to raw beans the roasted beans showed lower dried residue values at 35^{o}C and higher values at 5^{o}C storage temperature.

The decreased dried residue values of the roasted beans may be explained by the increase in moisture content of the processed beans. The increase in moisture content of the processed beans was achieved by roasting and storing the

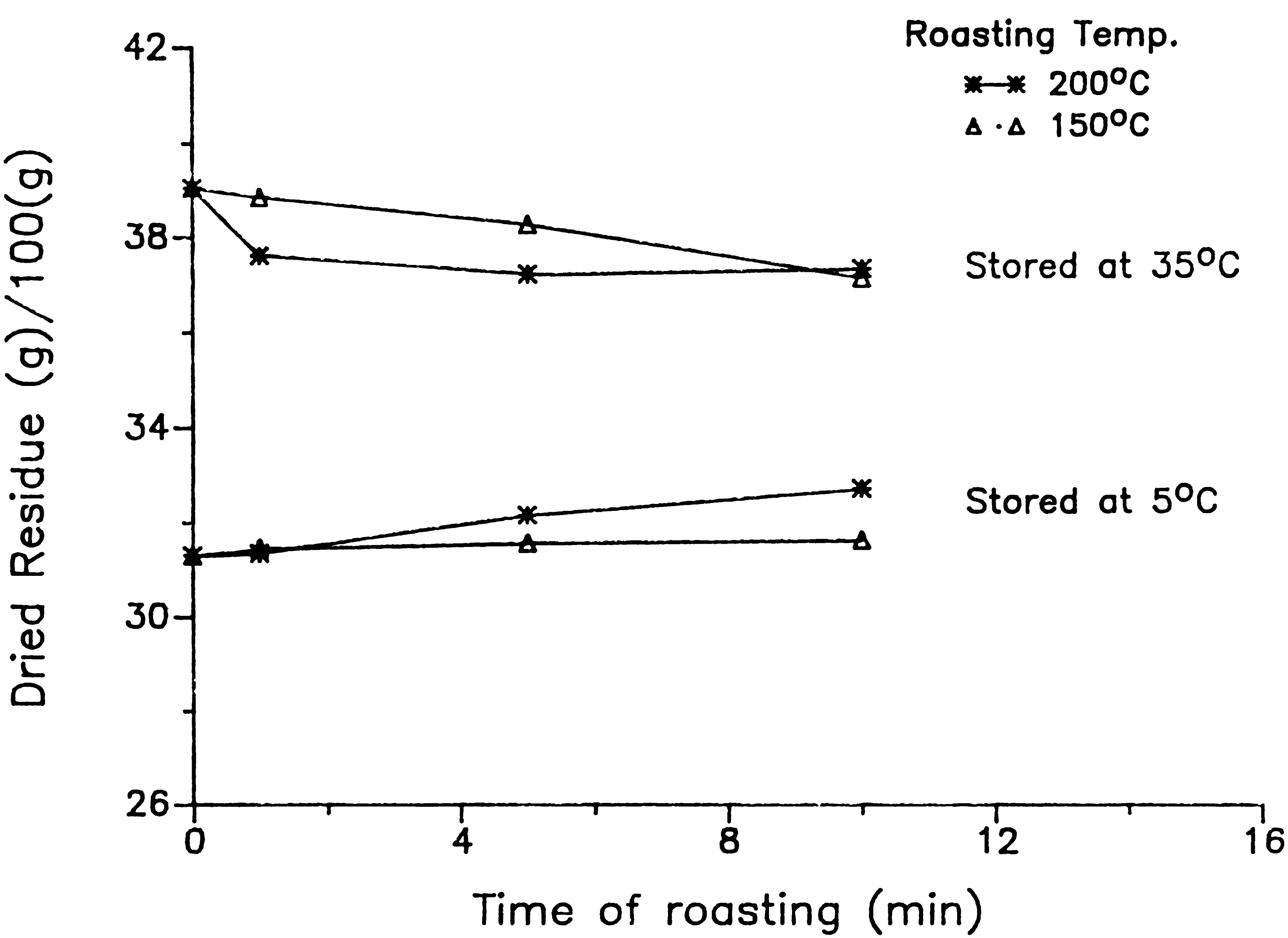
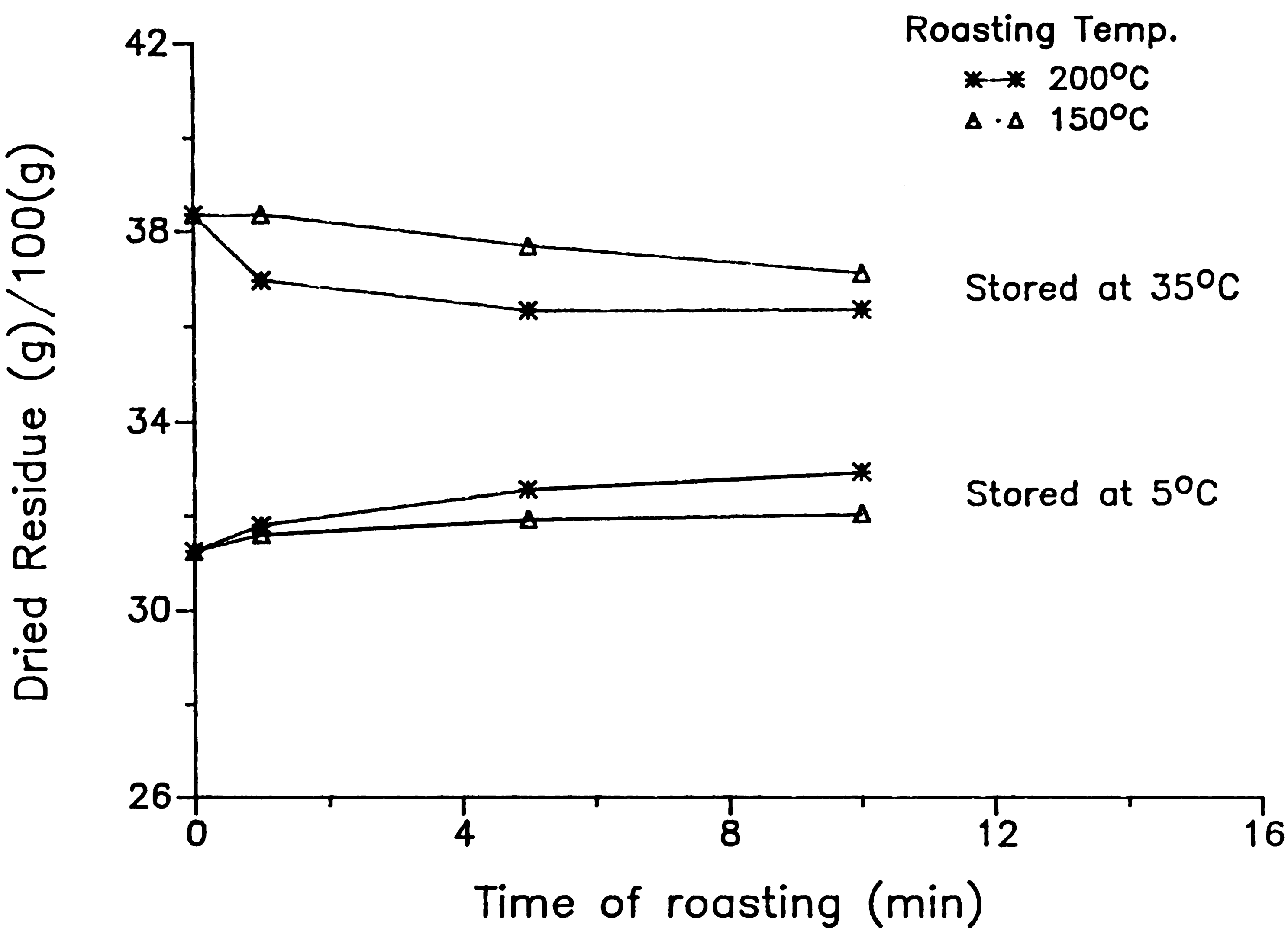


Fig (53)Dried residue of black beans (18% moisture roasted at two temperatures for three times and stored at 5 & 35°C for five months



Fig(54)Dried residue of kidney beans (18% moisture roasted at two temperatures for three times and stored at 5 & 35°C for five months beans at high temperature (35°C). This process produced beans of higher acceptability than the raw beans stored under the same conditions.

Study 3: The Effect of Calcium Ions on Cookability of Beans Stored under Different Conditions.

The objective of this study was to evaluate heating temperature and calcium ion during cooking of beans possessing varying degrees of storage induced hardening. Three representative samples of navy beans (18% moisture) were stored at low (5^{o}C), medium (20^{o}C) and high (35^{o}C) storage temperatures, for nine months. After storage, all three samples were heated at 60 or 90^{o}C for one hour in distilled water or 150 ppm Ca^{++} solution.

Following these treatments, cooled beans were sliced with razor blade and air dried at room temperature. The dried samples were fixed on SEM support stubs, coated with gold and were examined under the scanning electron microscope (SEM). A micrograph of each sample was taken from outer, middle and inner part of the cotyledon to observe the differences among these cotyledon parts.

The cotyledon micrographs of the navy beans heated at 60^{o}C in both 0 and 150 ppm Ca^{++} solutions are reported in plate 12. The results demonstrate that the cells remain in contact with one another at all storage temperatures (5, 20 and 35^{o}C) and for both 0 and 150 ppm Ca^{++} solutions.

These results suggest that 60^{o}C heating temperature was

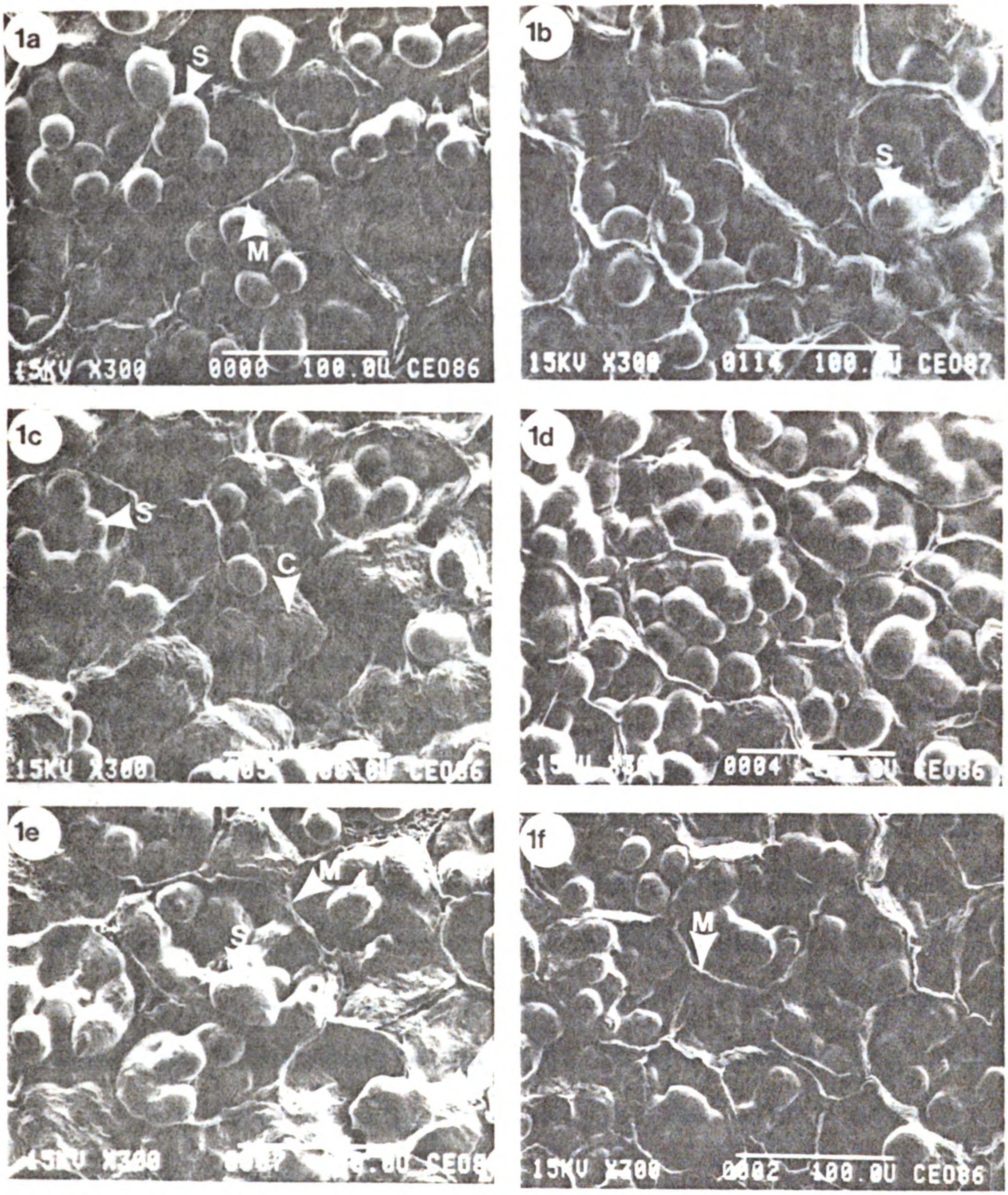


Plate (12) Scanning electron micrographs of cotyledon mid sections of navy (Seafarer) beans stored at three temperatures and moistures (M) (5 and 10; 20 and 14; 35°C and 18% moisture respectively) for nine months and cooked at 6o°C for 1 hour in 0 and 150 ppm Ca^{++} solutions. 1a= 5°C at 10%M, 0 Ca^{++}; 1b= 5°C at 10%M, 150 Ca^{++}; 1c= 20°C at 14%M, 0 Ca^{++}; 1d= 20°C at 14%M, 150 Ca^{++}; 1e= 35°C at 18%M, 0 Ca^{++}; 1f= 35°C at 18%M, 150 Ca^{++}

not high enough to disperse the middle lamella between the cells and cause their separation. The absence of effect of the above heating temperature on the starch granules of the beans could also be observed. The rounded and oval shaped starch granules remained embedded in the protein matrix with no noticeable increase in size.

Increasing the heating temperature to 90^{o}C, and heating for one hour in both 0 and 150 ppm Ca^{++} solutions exhibited dramatically different behavior. The results obtained for this treatment are represented in plate 13. The cells, all of the same shapes, show multifaced surfaces covered with wrinkled cell walls. At low and medium storage temperatures, the results indicate a complete separation of the cells (micrographs 2a, 2b and 2c). The heat treatment loosened the intercellular matrix of the middle lamella sufficiently to separate the individual cells without rupturing the cell walls. In addition, the micrographs demonstrate a noticeable increase in the size of the cells, due to the water absorption mainly by the starch granules contained in the cells.

At high storage temperature (35^{o}C), the results demonstrate the effect of the calcium concentration on the structure of the cotyledon. Beans which were heated in distilled water (0 ppm Ca^{++}) at 90^{o}C, resulted in very little

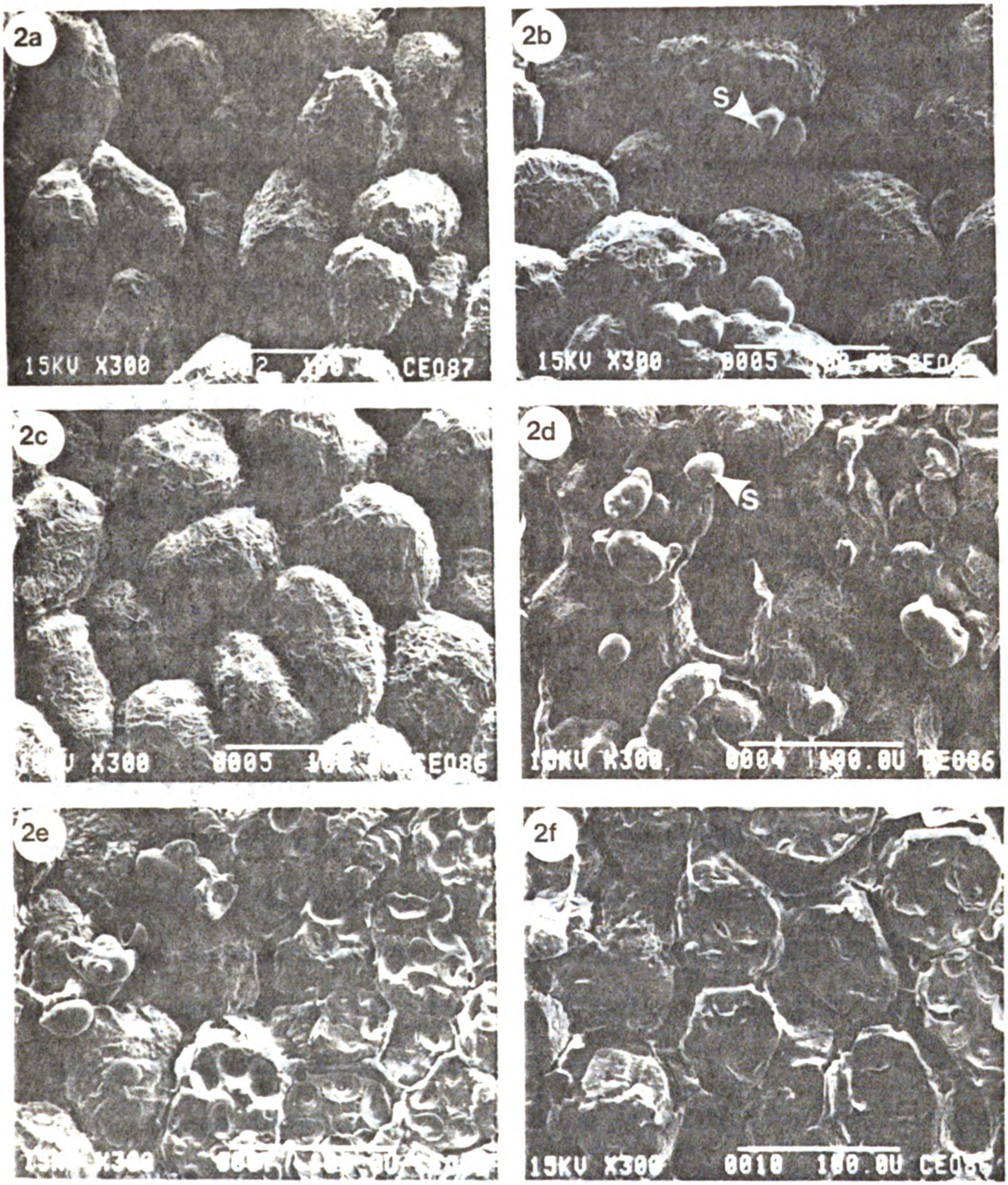


Plate (13) Scanning electron micrographs of cotyledon mid sections of navy (Seafarer) beans stored at three temperatures and moistures (M) (5 and 10; 20 and 14; 35 ^{o}C and 18% moisture respectively) for nine months and cooked at 90 ^{o}C for 1 hour in 0 and 150 ppm Ca^{++} solutions. 2a= 5 ^{o}C at 10%M, 0 Ca^{++}; 2b= 5 ^{o}C at 10%M, 150 Ca^{++}; 2c= 20 ^{o}C at 14%M, 0 Ca^{++}; 2d= 20 ^{o}C at 14%M, 150 Ca^{++}; 2e= 35 ^{o}C at 18%M, 0 Ca^{++}; 2f= 35 ^{o}C at 18%M, 150 Ca^{++}

separation between the cells. Furthermore, some cells did not show any separation and remained in close contact (micorgraph 2e). Cells from beans heated in 150 ppm Ca^{++} solution did not show any separation. The cells remained flat shaped and water absorption was not noticeable (micrograph 2f). It was further observed, that the fracture of the sliced samples stored at 35°C occurred across the cell walls. The occurrence of the fracture at this level differs from the previous low and medium storage temperature treatments (migrographs 2a, 2b, 2c and 2e) where the fracture occurred through the middle lamella, leaving all the cells intact.

Bourne (1967) attributed this phenomenon to the effect of the heating temperature on the cotyledon. In the raw state, the middle lamella is usually stronger than the cell wall. Consequently, the slicing causes the break to occur across the cell walls. However, the middle lamella of the cooked beans becomes softer than the cell wall. Therefore, any stress applied on the cooked cell causes the rupture to occur along the middle lamella.

It is known that the middle lamella of plant tissue is composed of pectic substances associated with the divalent cations (Lethan 1962). Rockland and Jones (1974), reported that the separation of bean cells during cooking may be related to the transportation or removal of divalent cations, particularly calcium and magnesium, from bridge positions within the pectinous matrix of the middle lamella. Lethan (1962) also stated that the removal of divalent ions from the middle lamella using alkaline conditions shortened the cooking time and helped tenderize the dry beans during cooking. The above observations suggest that the low cookability of samples heated in 0 and 150 ppm Ca^{++} solutions and stored at high temperature (35°C) was due to the formation of pectin bridges between the pectin contained in the middle lamella and calcium and magnesium, during storage. An additional formation of these bridges between pectin and calcium from the solution was also observed during the cooking process. The formation of these bridges causes the middle lamella to become firmer and prevents its dispersion, even at 90°C heating temperature.

The results for beans heated at 90°C are presented in plate 14 (distilled water) and plate 15 (150 ppm Ca^{++}).

The results reveal the importance of the cotyledon segments involved in the cooking process (namely outer, middle and inner segments). These micrographs were subjectivley rated for degree of cellular distortiion (bean cookability) as reported in Table 39 . The micrographs show that the outer, middle and inner parts of the cotyledon of the samples stored at 5°C were fully cooked (micrographs 3a,

Plate (14) Scanning electron micrographs of outer (3a and 3b) middle (3c and 3d) and inner (3e and 3f) cotyledon parts of navy (Seafarer) beans stored at two temperatures and moistures (M) (5 and 10; 35 ^{o}C and 18% moisture respectively) for nine months and cooked at 90 ^{o}C for 1 hour in water (0 ppm Ca^{++}). 3a, 3c and 3e= 5 ^{o}C at 10%M; 3b, 3d and 3f= 35 ^{o}C at 18%M

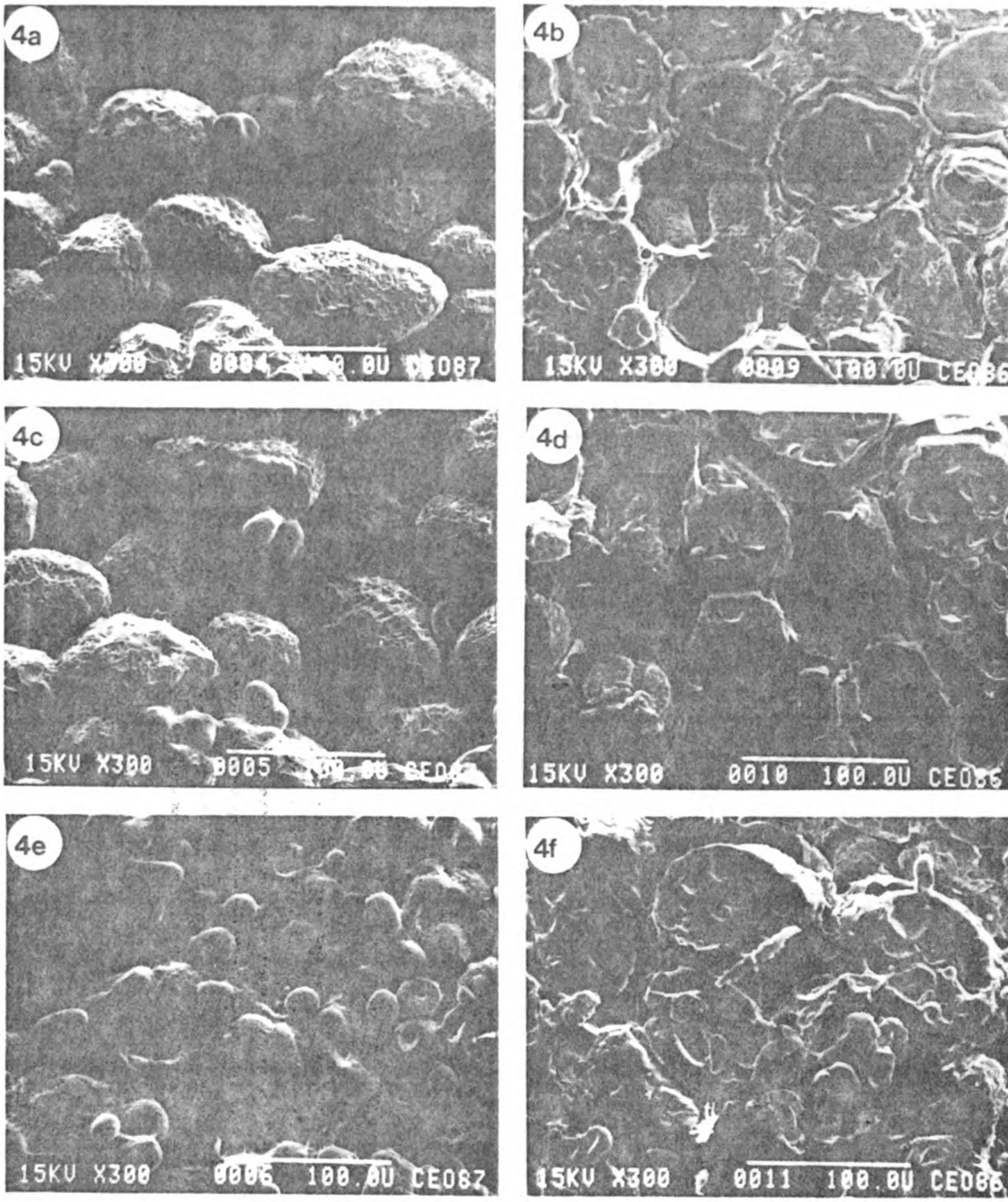


Plate (15) Scanning electron micrographs of outer (4a and 4b) middle (4c and 4d) and inner (4e and 4f) cotyledon parts of navy (Seafarer) beans stored at two temperatures and moistures (M) (5 and 10; $35^{\circ}C$ and 18% moisture respectively) for nine months and cooked at $90^{\circ}C$ for 1 hour in 150 ppm Ca^{++} solutions. 4a, 4c and 4e= $5^{\circ}C$ at 10%M; 4b, 4d and 4f= $35^{\circ}C$ at 18%M

Table (39) Subjective rating[1] of bean cookability at 90°C for one hr. from SEM micrographs

	Heating solution			
	Distilled water		150 ppm Ca^{++}	
Storage temp./	5°C	35°C	5°C	35°C
<u>Cotyledon segment</u>				
Outer	5	4	5	1
Middle	5	2	5	1
Inner	5	1	2	1

1. 5 points scale; 1 = uncooked, 5 = fully cooked

3c, 3e). In all three cases, the cells were also separated from each other along the middle lamella. However, the samples stored at 35^{o}C showed different stages of cooking. The outer part of the cotyledon was partially cooked (micrograph 3b). The cells of this part were partially separated from each other. However, the middle and inner cells part remained in contact with each other. Additional time was obviously required to bring the cells to a fully cooked stage. The uncooked middle and inner parts, due to the decreased hydration and heating received, exhibit more hardness compared to outer part. This observation differs from what was reported for the beans stored at 5^{o}C. Thus, the temperature of storage had an impact on the hardness of the cotyledon. High storage temperature causes the cotyledon to become harder, thereby increasing the cooking time of the beans.

Similar observations regarding the effect of storage temperature are reported for the beans heated in 150 ppm calcium solution. These micrographs indicated that the outer and middle parts of the samples stored at 5^{o}C were fully cooked, while the corresponding parts of the samples stored at 35^{o}C were partially cooked. The results further demonstrated the effect of the presence of calcium in the solution during heating on the inner part of the cotyledon.

The results of the samples stored at 5^{o}C indicated that the inner part of the cotyledon was partially cooked. This behavior differs from what was observed for the samples stored under the same conditions but heated in a calcium free solution. It was also noted in this case that the inner part of the cotyledon samples stored at 35^{o}C were still uncooked.

Based on the above observations, it was concluded that the storage temperature and the presence of the calcium ion in the heating solution had an effect on the cookability of the cotyledon. However, this effect varies depending on the part of the cotyledon considered.

CONCLUSION

The cooking time of stored dry beans showed significant differences among temperatures , moistures and cultivars, but not among atmospheric gases. The cooking time of high moisture beans increased more than six times as the temperature of storage increased from 5 to 35^{o}C, further it also increased as the moisture content increased.

The Hunter lab color coordinate treatment mean values of dry and processed beans showed significant differences among moisture, cultivars, temperature and time of storage, except a_L (greenness) coordinate for moisture and temperatures. The darkness(L), greenness (a_L) and yellowness (b_L) of the stored beans increased for all cultivars as the temperature, moisture and time of storage increased for the dry beans, while the processed beans showed increased darkness and decreased yellowness.

The quality characteristics mean squares from the analysis of variance of dry, soaked and processed beans showed highly significant differences (P>0.01) among cultivars, temperatures, moistures, and times of storage. Gas atmospheres also were significant (P>0.05). The total soaked weight increased or decreased depending on storage temperature, bean moisture level and time of storage. Drained weight, clumps and splits decreased, and the shear force and dried residue increased as the temperature, moisture and time of storage increased.

Bean moistures for soaked and processed beans were significantly effected by all storage variables, except the storage time.

The mean squares from the analysis of variance of mass ratio index for hydration and drained weight showed significant variations among cultivars, temperatures, moistures and time of storage.

Total protein content decreased between 5°C and 20°C, but increased between 20°C and 35°C for navy, black and kidney, while it increased continuously for pinto beans. The soluble protein decreased up to 40% of the original as the temperature of storage increased from 5 to 35°C for beans stored at high moisture level (18%). Also the soluble solids and total soluble pectin decreased significantly with increasing storage temperature for all cultivars.

Raw bean sections for all cultivars showed clear differences between low and high temperatures and moistures storage when examined under the SEM. More compact structures were found with high temperature and high moisture beans compared to low temperature and low moisture stored samples. Also, the protein granules were unrecognizable for the high temperature and high moisture stored samples, when the raw bean sections were fixed by using gluteraldehyde, however granules were clear for the samples stored at low temperature and low moisture.

Starch from soft beans was readily extracted by water. The starch granules from high temperature stored beans were unextractable by water, however were solubilized using alkaline conditions. It was observed that protein molecules interacted with starch granules causing hydration and extraction problems following high temperature storage. The starch granules were nearly gelatinized at 80^{o}C and dispersed at 85^{o}C for both low and high temperature storage samples.

Roasting the beans before storage significantly improved the quality characteristics of canned beans (total soaked weight, drained weight, color, shear force and dried residue). The total soaked weight decreased for roasted beans held at 5 and 35^{o}C storage temperature for all three cultivars (navy, black and kidney). Drained weight of the roasted beans decreased at 5^{o}C, but remained unchanged at 35^{o}C temperature storage compared to raw (unroasted) beans.

The shear force decreased significantly for the roasted beans stored at 35^{o}C compared to the raw beans stored under the same conditions. Raw and roasted beans stored at 5^{o}C had similar shear force. The dried residue of beans roasted decreased significantly following 35^{o}C storage and increased slightly following 5^{o}C storage.

The calcium treatment showed significant effect of the calcium ions on the beans during cooking. As the calcium concentration increased from 0 to 150 ppm, the cookability of the beans decreased. The middle lamella of the cooked bean cells were broken down during cooking, and the cells were separated through the middle lamella, while the cells remained unseparated for beans which were not softened during heating.

A gradient of softening was demonstrated from the outer to the inner portion of the cotyledon, and calcium ion decreased bean cookability for beans stored at 35°C, however produced no observable differences in outer and middle segments of beans stored at 5°C.

The results obtained from these studies indicated that the hard-to-cook phenomena is a complex physico-chemical mechanism.

Both enzymatic and non enzymatic reactions are likley to be responsible. Heating to inactivate enzymes activity was only partially beneficial in controlling hardening.

Moisture and temperature control had greatest influence on bean stability. The modification of atmosphere to reduce oxygen provided no added stability.

Although the characteristic hard-to-cook bean was not different in starch gelation characteristics, it was observed that changes in starch, protein, pectin and calcium are associated with hard beans.

The proper control of physical storage conditions will provide stability of bean cooking characteristics, however further research is needed to eludicate the mechanism involved. Additional research directed at protein and starch interactions and complexing of polyphenolic compounds during storage are recommended.

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