Comparison of the Cookability and Texture Characteristics of Six Lines of Guatemalan Bush and Vine Black Beans (*Phaseolus vulgaris*) - As Determined by Trained and Untrained Sensory Panels and the Ottawa Texture Measuring System Extrusion Cell

by

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COMPARISON OF THE COOKABILITY AND TEXTURE CHARACTERISTICS OF SIX LINES OF GUATEMALAN BUSH AND VINE BLACK BEANS (*Phaseolus vulgaris*) - AS DETERMINED BY TRAINED AND UNTRAINED SENSORY PANELS AND THE OTTAWA TEXTURE MEASURING SYSTEM EXTRUSION CELL

BY

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A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

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ABSTRACT

Six lines of Guatemalan black beans, two vine and four bush types, were each cooked to 5 cooking stages: 50, 70, 90, 100% cooked and an extended cooked stage. These 30 samples were evaluated for sensory texture characteristics by an 8-member trained Texture Profile Analysis (TPA) panel, and were also rated for acceptability by a 30-member untrained in-house panel at the Institute of Nutrition for Central America and Panama (INCAP), Guatemala. Cooking times for each bean line were set during preliminary panel testing. TPA scores for hardness, particle size, seed coat toughness and chewiness declined significantly ($p<0.0001$) as cooking time increased, and had high negative correlations with acceptance score (r values ≥ -0.94, $p<0.001$) for all lines. Mean peak force to extrude 30 g portions of cooked beans (cooked 4 h without presoaking) through the grid of a 10 cm^2 Ottawa Texture Measuring System (OTMS) extrusion cell was recorded for each line and cooking time. Peak force values ranged from 160 newtons (N) for the Itzapa vine beans to 260 N for the Sesenteño bush bean. Samples considered by the in-house panel to have reached the acceptably cooked point had extrusion peak forces ranging from approximately 200 to 300 N; depending on the bean line. The two lines with the thinnest seed coats (6.6-6.7 mg/cm^2) were judged acceptable when peak force values were close to 300 N, but samples with thicker seed coats (7.7-8.0 mg/cm^2) were not judged as acceptable until they reached lower values of 180-220 N. Beans stored for six weeks at $35^{\circ}C$ and 16-17% moisture required longer cooking times than

the fresh beans or those stored at 5°C and 13-14% moisture for six weeks to achieve similar reductions in peak force values. Even after longer cooking, the hardened samples had poorer texture scores. Acceptability scores for both fresh and stored samples were negatively correlated with water absorption at 4 and 20 h (-0.58, $p=0.040$ and -0.73, $p=0.009$, respectively). No significant relationships were found between mean acceptability scores and mean seed weight, percent seedcoat, and seedcoat thickness values.

SUMARIO

Seis lineas de frijoles negros de Guatemala, dos enredos y cuatro tipos de suelo fueron cada uno cocidos en cinco niveles; 50, 70, 90 y 100% más un extendido estado de cocimiento. Estos 30 muestras de características de la textura sensorial fueron evaluadas por un panel de 8-miembros entrenados en el análisis de perfil de textura (APT) y fueron también evaluadas por aceptibilidad por un grupo de 30-miembros indisciplinado en un panel interno en el Instituto de Nutrición de Centro America y Panama (INCAP), Guatemala. Los tiempos de cocimiento para cada linea de frijoles fueron establecidos durante una investigación preliminar de el panel. Los valores de dureza, tamaño de la partícula, dureza de cáscara y la masticabilidad de APT declinaron significantemente ($p<0.0001$) cuando el tiempo de cocimiento aumentó, y tuvó altas correlaciones negativas con valores de aceptabilidad (r valores ≥0.94, $p<0.001$) para con toda las lineas. El promedio de la fuerza en su punto máximo para extruir porciones de 30 g de frijoles cocidos (que fueron cocidos por 4 h sin remojar) a través de la rejilla de una celda de extrución de el sistema de medición de textura de Ottawa (OTMS) fueron registrados para cada linea y tiempo de cocimiento. Los valores de la fuerza en su punto máximo variaron de 160 newtons (N) concerniente a los frijoles de enredo de Itzapa hasta 260 N concerniente a los frijoles de suelo de Sesenteño. Las muestras consideradas por el panel interno que obtuvieron el aceptado punto de cocimiento tuvieron fuerzas de extrución en su punto máximo las que variaron aproximadamente de 200 a 300 N; dependiendo de la linea de frijoles. Las dos lineas con las cáscaras mas ango-

stas (6.6-6.7 mg/cm^2) fueron juzgadas como aceptables cuando los valores de fuerza en su punto máximo estuvieron cerca de 300 N, pero muestras con cáscaras más gruesas (7.7-8.0 mg/cm^2) no fueron juzgadas como aceptables hasta que ellas alcanzaron valores menores de 180-220 N. Los frijoles que fueron almacenados por seis semanas a 35^{0}C y 16-17% de humedad requirieron mayor tiempo de cocimiento que los frijoles que aquellos almacenados a 5^{0}C y 13-14% de humedad por seis semanas para adquirir reducciones similares concerniente a los valores de fuerza en su punto máximo. Inclusive después de un cocimiento mayor las muestras duras tuvieron como resultado texturas más pobres. Valores de aceptabilidad para con ambas muestras esto es frescas y almacenadas, fueron correlacionadas negativamente con la absorpción de agua a 4 y 20 h (-0.58, p=0.040 and -0.73, p=0.009, respectivamente). No hubo relaciones significantes entre los promedios de los valores de aceptabilidad y los promedios de los valores de peso de grano, del porcentaje de cáscara, y del grueso de la cáscara.

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CONTENTS

Appendix page

LIST OF TABLES

LIST OF FIGURES

Chapter I

INTRODUCTION

Legume grains are consumed by humans in many regions throughout the world. They are important nutritionally because of their relatively high, but incomplete, protein content (Bressani, 1975) and the fact that they are one of the least expensive sources of protein for human consumption (Jalil, 1975). Legumes also supply a significant amount of energy from carbohydrates as well as fibre, minerals and vitamins (Bressani and Elías, 1974, 1978).

In Guatemala a number of population groups consume a high starch diet, with corn being the staple cereal and the main source of protein being from the common black bean (Phaseolus vulgaris). The relative proportions of these two staples in the diet does not provide the optimum protein quality and thus increasing the consumption of black beans seems warranted from a nutritional perspective (Bressani and Elías, 1977). Many factors, however, make this difficult to accomplish.

A hardening defect occurs in stored beans and is apparent in cooked beans that have failed to soften. This defect makes such beans unpalatable to consumers and reduces overall consumption of beans. Beans with the hardening defect take much longer to cook to an acceptable texture than unaffected beans and as a result, require the use of more fuel. This is a serious problem for people with low incomes. The nutritional content of the beans is also lower with longer cooking times (Burr et al., 1968; Lantz, 1938)

This study is part of a larger project funded by the International Development Research Centre (IDRC) in Ottawa for the development of a model to predict consumer acceptability of cooked black bean texture based on values from trained laboratory sensory panels, physical and instrumental tests. The development of such a relationship would be of benefit to researchers who would be able to predict human perception of a textural attribute of bean sample from knowledge of the physical magnitude of that attribute as determined by instrumental methods.

Bean texture evaluation is necessary to identify those varieties of beans that tend to develop the hardening defect. It is also important to determine those physical characteristics or storage conditions that promote the development of hardening. Cookability is reduced in beans that have hardened. The term cookability refers to the cooking time required to attain an acceptable cooked texture (Moscoso, 1981).

Instrumental evaluation has been the most common method of quantitating the textural defect of hardness in cooked beans. Instruments are, however, only useful for evaluating bean texture if they measure properties that are perceived or judged as important by the senses of a human (Bourne, 1982). The textural characteristics of hardness, particle size of the cotyledon, toughness of the seedcoat and chewiness were determined by panelists tasting black beans at both the University of Manitoba and at the Instituto de Nutrición de Centro America y Panama (Institute of Nutrition for Central America and Panama - INCAP), Guatemala, to be important characteristics in the evaluation of cooked bean texture. Sensory tests have been used to correlate with instrumental methods and have been considered to be the "ultimate method of calibrating instrumental methods of texture measurement" (Bourne, 1982). Sensory evaluation methods have been used by other researchers to evaluate bean texture in conjunction with instrumental and physical tests.

1.1 BACKGROUND

The development of the hardening defect in black beans is promoted by conditions such as high temperature and high humidity (Stanley and Aguilera, 1985). Storage under such conditions is a common occurrence in the Peten region of northern Guatemala. Since the bean crop in Guatemala is only harvested twice a year, storing beans for 6 months is not an uncommon practice. Farmers usually do not have access to environmentally controlled storage facilities. Consequently, the hard-to-cook phenomenon causes a considerable proportion of black beans stored in Guatemala to have an undesirable texture upon cooking.

Research has been undertaken to understand the mechanisms causing the hardening of beans in hopes of preventing (or reversing) the process and of developing superior varieties of black beans. The development of a model based on one or two instrumental tests to predict the acceptability of the cooked texture of a bean sample would be of benefit at this time.

It has been noted that much of the research has gone into the selection of bush type varieties of black beans. While bush beans are the predominant type of black beans produced in the developed areas of the world, vine or semi-vine varieties may be more suitable to the native agricultural patterns of Guatemala (Jalil, 1975). It seems more advisable, therefore, to investigate all three types of black beans grown in Guatemala with respect to the hardness of their cooked texture.

Since survey results have shown that Guatemalans who had a preference for a bean type preferred bush type over vine type beans (Watts et al., 1987), it would be beneficial to find out the reasons for this by means of evaluations by a trained sensory panel. Perhaps preferred characteristics of bush type black beans can be added to (or unacceptable characteristics of semi-vine and vine types can be selected out of) the semi-vine and vine types. This would promote the production and consumption of semi-vine and vine types of black beans in areas where they are more available and produce higher yields than bush type black beans.

The purpose of the proposed research, therefore, is to develop a method for predicting Guatemalan consumer acceptability of cooked black bean texture based on data from trained laboratory sensory panels, physical and instrumental tests. A comparison of the two basic bean types - vine and bush - will be made.

1.2 OBJECTIVES

1. To develop a method that could be used to determine cooking times needed to achieve an acceptable and comparable degree of doneness for black bean samples.

2. To examine the effect of cooking time on texture characteristics of black beans.

3. To compare the acceptability and texture of black beans cooked to an equivalent degree of doneness.

4. To establish an OTMS (Ottawa Texture Measuring System) peak force value for the 10 cm^2 extrusion cell that would correspond to an acceptable and equivalent cooking stage for all of the black bean lines tested.

5. To compare the effects of high temperature-high humidity (HT) and low temperature-low humidity (LT) storage on acceptability and texture of black beans.

6. To compare physical test results for both fresh and stored black bean samples.

Chapter II

LITERATURE REVIEW

2.1 BEAN TEXTURE EVALUATION

2.1.1 Cooking Time

Numerous methods have been used to evaluate the texture of cooked beans. These methods involved measuring the hardness of the beans after being cooked for a certain length of time or by measuring the cooking time required to reach a certain degree of softening (dos Santos Garruti and Bourne, 1985).

Aguilera and Ballivian (1987) used a cooking time of 2 h to evaluate the hardness of cooked black beans after roasting and storage treatments. A significantly greater hardness, as evaluated by a sensory panel, was noted in treated samples stored at 40°C when compared to the control samples stored at 25°C when all were cooked for the same length of time. Morris and Wood (1956) using samples of Great Northern, Large Lima, Michelite, Pinto, Red Kidney, Red Mexican and California small white beans stored under various moisture contents used a standard cooking time for each variety to evaluate flavour and texture changes after storage. Significant quality losses were observed through sensory texture evaluation in the high moisture samples stored for 6 months for all varieties when compared to their respective control sample cooked to the same cooking time (Morris and Wood, 1956).

Cooking time has been used as a measure of bean texture. The time required for 50% of the sample to cook to a certain degree of tenderness is commonly reported. This point is considered to be the most reliably defined due to the steepness of the cookability curve in this region which permits a relatively precise cooking time determination (Figure 2.1) (Burr et al., 1968; Morris, 1964). Both Burr et al. (1968) and Morris (1964) used a Mattson Bean Cooker to determine cookability curves which they used for comparing the relative cookability of various bean varieties. Burr et al. (1968) emphasized that only half the beans were cooked to a "done" stage at the 50% cooked stage and consequently, a considerably longer time would have been needed to cook the sample sufficiently for serving. The time required for 92% of the sample to cook was used by Proctor (1985) in an attempt to cook samples to a degree adequate for serving (Figure 2.2). The 92% cooked time as determined using the Mattson Bean Cooker (23 out of 25 plungers down) was chosen because it corresponded to the cooking time of the most preferred texture of navy beans as determined by a 9-member sensory panel. Proctor (1985) felt that since cookability is defined as the cooking time necessary for beans to attain a "cooked" texture according to a sensory panel, it seemed that the use of a 92% cooked point for comparison was appropriate.

Determining if the bean is cooked, that is, has reached an acceptable degree of tenderness has been carried out using a variety of techniques. Black beans (variety S-19-N) were soaked, boiled and evaluated for softness at intervals in studies by Jones and Boulter (1983) and Vindiola et

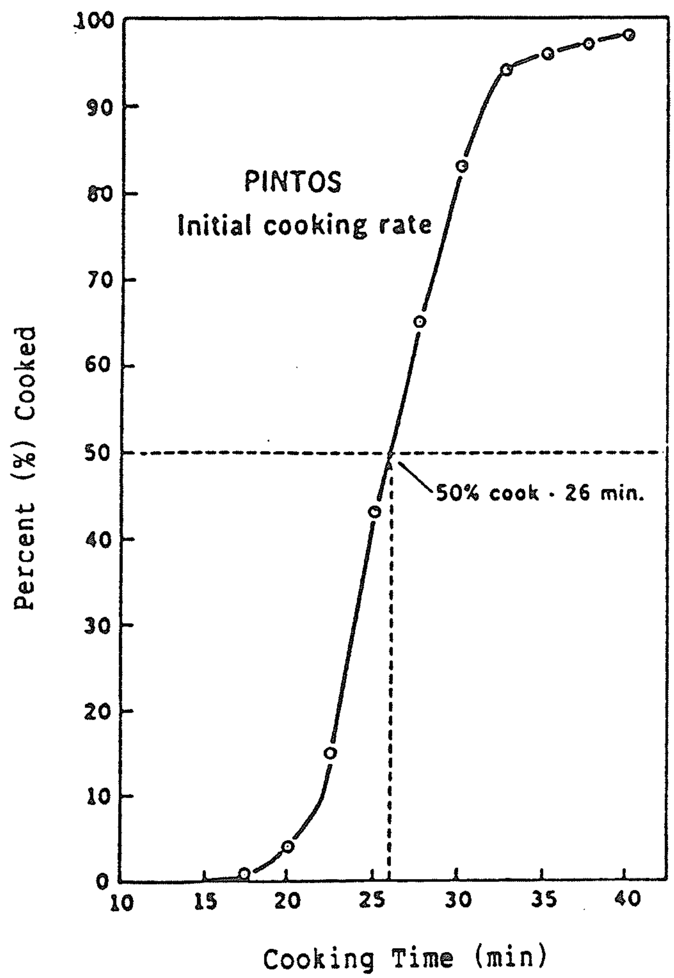


Figure 2.1: Typical cookability curve for pinto beans (Phaseolus vulgaris L.) as determined by the Mattson Bean Cooker (Morris, 1964).

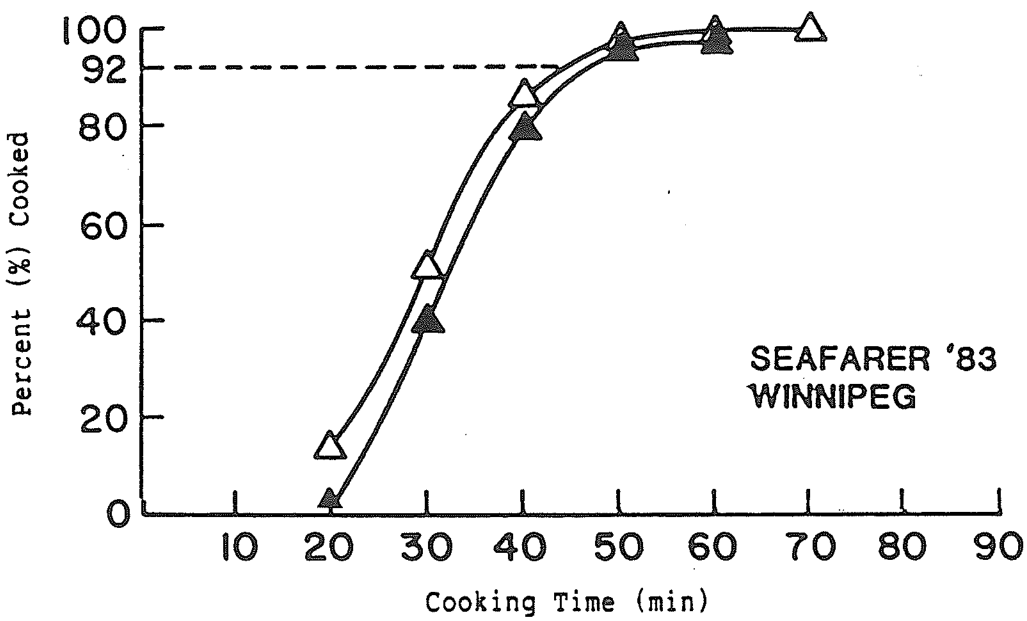


Figure 2.2: Cookability curves for 2 samples of navy beans as determined by the Mattson Bean Cooker with 48 g, 5 mm plungers and by a 9 member sensory panel (Proctor, 1985).

▲- MBC - Seafarer-1983-Wpg

△- Panel - Seafarer-1983-Wpg

al. (1986) using a non-oral or tactile sensory method of squeezing each bean between the forefinger and thumb. If the cotyledon of a bean yielded to only slight pressure the bean was considered cooked (Jones and Boulter, 1983). Beans were considered cooked when the cotyledons were soft and not grainy. Graininess was also detected using the teeth. Any beans containing grainy regions or that were hard were classified as not being cooked (Vindiola et al., 1986). This method seems to be appropriate as squeezing the cooked beans between the fingers was found to be the principal method used by almost 50% of Guatemalan consumers surveyed by Watts et al. (1987) for judging doneness of cooked black beans. In a study by Bueno et al. (1980) cooking time for a sample was determined to be the time for a bean to become sufficiently softened to enable it to be pressed between two glass slides. Sensory panels have also used acceptance scales to subjectively determine if the bean is cooked. An objective sensory evaluation was carried out by Proctor (1985) using a 9-member panel to determine the percentage of beans cooked in a given sample of navy beans. This panel was trained to base their decision on specific characteristics of cooked navy bean texture. Methods involving the use of such instruments as the Pea Tenderometer, Shear Press, compression and extrusion cells, puncture probe and the Mattson Bean Cooker, have been commonly used to objectively measure bean cookability. For most of these instruments (except the Mattson Bean Cooker), the force required to shear, compress, extrude or puncture the cooked bean sample is determined. For the Mattson Bean Cooker, since the force applied to the bean is constant, the cooking time required to soften the bean sufficiently so that it can be punctured, is of interest.

2.1.2 Instrumental Evaluation

Instrumental evaluation has been the most common method of quantifying the textural defect of hardness in cooked beans. Instruments are only useful for evaluating bean texture if they measure properties that are perceived or judged as important by the senses of a human (Bourne, 1982). A number of instruments have been used to evaluate cooked bean texture including the Pea Tenderometer, Shear Press, compression cell, extrusion cell, puncture probe and Mattson Bean Cooker. The wedge apparatus is a relatively recently-developed test cell for assessing the texture of raw and soaked beans. The puncture probe can also be used on uncooked beans.

2.1.2.1 Pea Tenderometer

The Pea Tenderometer was brought into use in the late 1930s. The mechanism of this instrument is based on the multi-blade shearing principle. A grid of blades rotate through a second grid at a constant speed. The force is recorded as the beans are cut by the blades (Voisey and deMan, 1976) (Figure 2.3). The force increases as the sample is settled and packed into the cell. The force rises rapidly to a peak as the sample is compressed and then decreases rapidly when the force is great enough to shear the peas and extrude them through the blades. This peak force is related to the shearing strength or cohesiveness of the pea sample (Szczesniak, 1963; Voisey and Larmond, 1971).

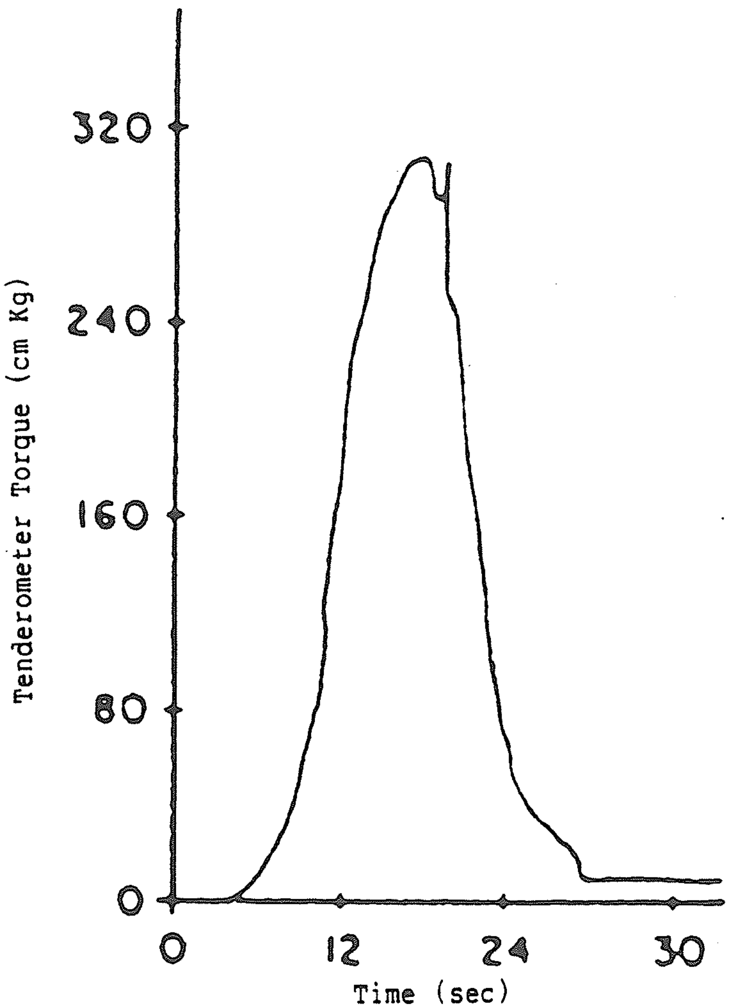


Figure 2.3: Typical record of force as a function of time (deformation) for Tenderometer (Voisey and Larmond, 1971).

Muneta (1964) used the Tenderometer to evaluate the firmness of cooked samples of 7 varieties of beans and Alaska pea grown in different locations. While cooking times to reach 50% cooked were considerably different for the same variety grown in two locations, the Tenderometer readings taken at the 50% cooked point were similar. Muneta (1964) noted, however, quite a large variation in Tenderometer readings among replicates and attributed these to problems with regards to the cooking technique.

The important disadvantage to the use of the Pea Tenderometer is that it is difficult to standardize (Voisey and Larmond, 1971) and is therefore not considered to be a reliable instrument (Voisey and deMan, 1976).

2.1.2.2 Shear Press

The Shear Press or shear compression cell consists of a stationary metal box having a grid with 10 slots for a bottom (Figure 2.4). Ten blades are guided and forced into the box where they compress, shear and extrude the bean sample through the grids at the bottom (Voisey and deMan, 1976).

The Shear Press or shear cell measurements are recorded in a similar manner to those of the Pea Tenderometer (Figure 2.5). At first the curve is non-linear as the bean sample is packed into the test cell. The curve becomes relatively linear as the sample is compressed and the force rises sharply. The force increases to a maximum point when the beans are sheared and the sample is extruded (Voisey and Larmond, 1971).

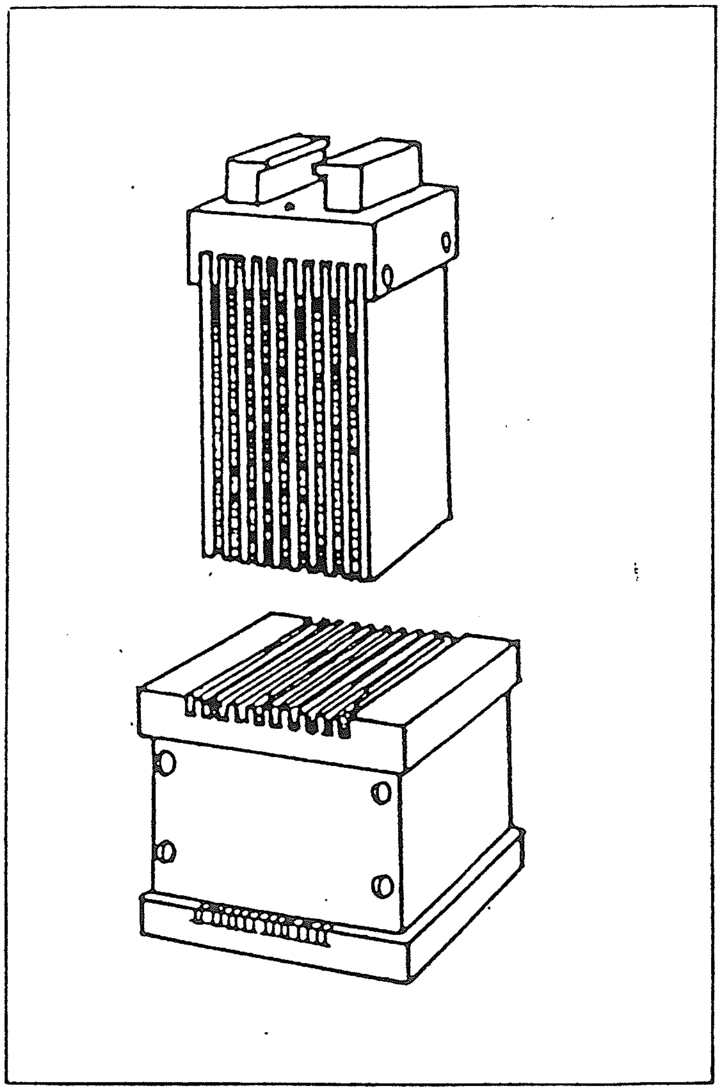


Figure 2.4: Type CS-1 cell for Kramer Shear Press model TP-1 (Quast and da Silva, 1977a).

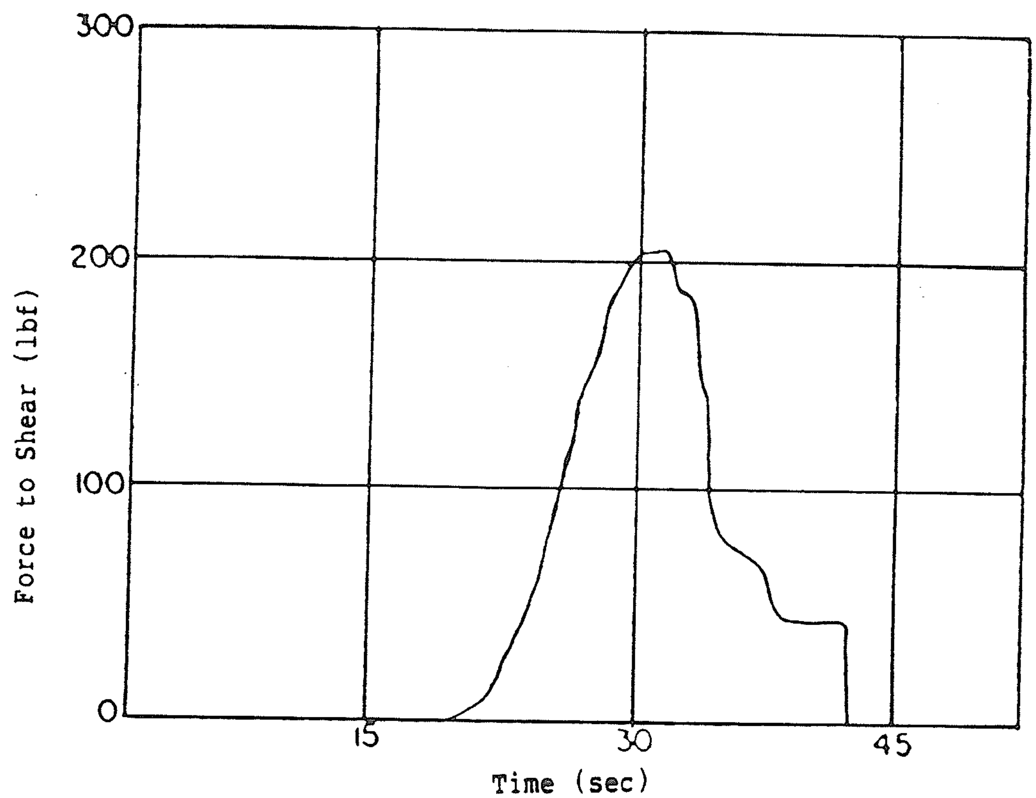


Figure 2.5: Typical response curve of cooked black beans in Shear Press (Quast and da Silva, 1977a).

A Kramer TP-1 Shear Press was used by Quast and da Silva (1977a,b) in two studies to measure the hardness of black beans, brown beans, soybeans and Alaska dried peas cooked for various cooking times and at 3 cooking temperatures. One hundred grams of sample was used in the CS-1 cell which had ten 1/8 in (3.18 mm) blades. The results were expressed as lb pressure per unit weight of test material (lbf/g). The maximum shear force (lbf/g) was plotted as a function of cooking time on semi-logarithmic paper (Figure 2.6). The time-temperature combinations that gave the same texture, as measured by the Kramer Shear Press, were plotted to determine the Z-values of 19°C, 18°C, 16°C and 16°C for the softening of black beans, brown beans, soybeans, and Alaska dried peas, respectively (Quast and da Silva, 1977a).

An Allo-Kramer Shear Press was used by Quenzer et al. (1978) to obtain shear values of stored samples of 3 pinto bean cultivars in order to evaluate the effect of water imbibition on the tenderness of samples cooked for 90 minutes. A 13-blade multipurpose shear cell was used to shear a 75 g sample of cooked beans. Total peak area was measured. Quenzer et al. (1978) concluded that maximum imbibition did not result in the most tender product as measured by shear values. Bean firmness was measured by Nordstrom and Sistrunk (1977, 1979) in two studies by shearing a 100 g sample of drained beans using the standard cell of an Allo Qualitometer. Nordstrom and Sistrunk (1977, 1979) compared the firmness of a number of bean types, including Navy, Pinto and Red Kidney under various soaking, blanching, processing and storage treatments.

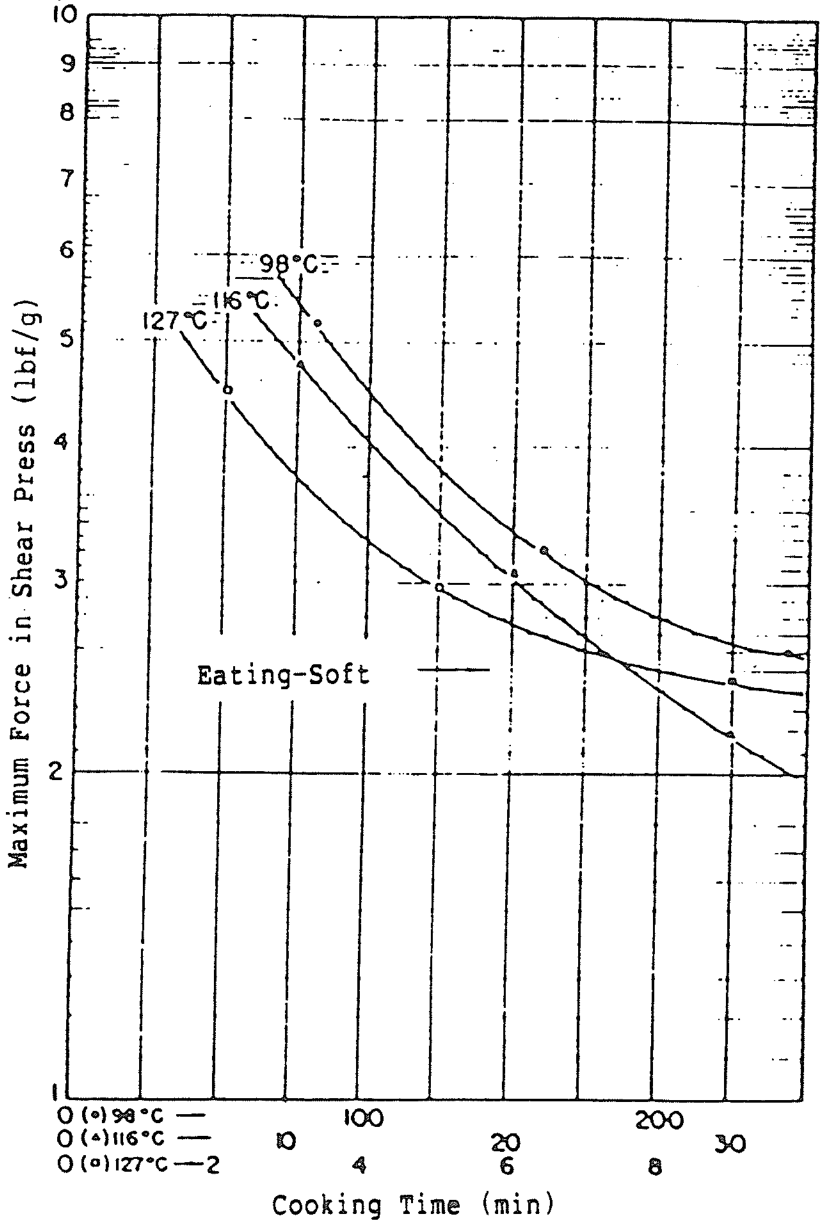


Figure 2.6: Degree of cooking of black beans (Phaseolus vulgaris L.), measured using a Kramer Shear Press, as a function of time and temperature (Quast and da Silva, 1977).

2.1.2.3 Extrusion

Voisey and Larmond (1971), in their study comparing methods of evaluating baked bean texture, mounted a wire extrusion cell on an Instron Universal Testing Machine. The wire extrusion cell used had a bottom closed with five parallel stainless steel wires. The sample size used in the cell was not documented.

The force used in the test was recorded on chart paper (Figure 2.7). The non-linear part of the curve was created as the force increased while the product was packed and settled into the cell's volume. The approximately linear portion occurred when the force rose rapidly as the sample was compressed, that is, deformed. The rate of force increase with deformation decreased relatively suddenly as extrusion began. This force is related to the shearing strength or cohesiveness of the sample. A plateau was formed, in which, while the force fluctuated, the average force was relatively constant. This occurred after shearing and extrusion had begun. Compression of the sample had stopped at this point as the sample was escaping from the bottom of the cell. The presence of plateau in the force deformation curve produced by the wire extrusion cell facilitates a more precise measurement of the shear strength of a sample. Since the sample is only compressed to the degree required to produce the pressure needed for shearing at the wires, the height of the plateau does not indicate the compression or elasticity related to hardness (Voisey and Larmond, 1971).

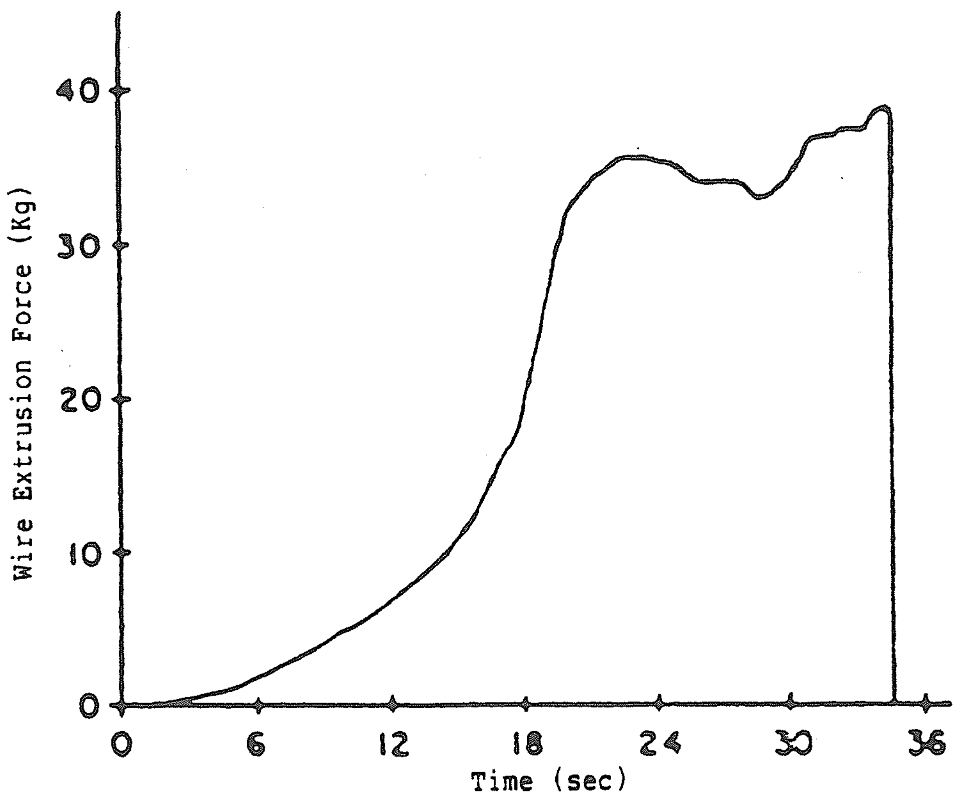


Figure 2.7: Typical record of force as a function of time (deformation) for a wire extrusion cell (Voisey and Larmond, 1971).

Aguilera and Ballivian (1987) used an OTMS 10-cm^2 extrusion cell mounted on an Instron Universal Testing machine to evaluate the hardness of 48 g samples of stored black beans (Phaseolus vulgaris cv. Orfeo) roasted under various temperature and moisture level combinations and cooked for 2 hours. They used a crosshead speed of 10 cm/s with a plunger stroke to 5 mm from the bars. Hardness was expressed as maximum force (F) relative to force at time 0 (F/F0). Relative hardness was shown to increase with increases in moisture and temperature. At 8.5^{0}C and 25^{0}C, hardening developed almost linearly for 4 to 6 mo and then reached a constant value. The hardness curve for the 40^{0}C storage treated beans was sigma-shaped (Aguilera and Ballivian, 1987).

Nelson and Hsu (1985) evaluated the effect of leachate accumulation on cooked texture of navy beans. A 100.0 g sample of beans was extruded through a 50-cm^2, 8-bar Ottawa extrusion wire grid cell which was mounted on an Instron. The cooked texture of cow peas was measured using an Instron and a 10 cm^2 Ottawa Texture Measurement System (OTMS) test cell with an eight-bar wire extrusion grid in the study by Sefa-Dedeh et al. (1978) (Figure 2.8). Forty-eight beans were used in the cell.

2.1.2.4 Puncture Probe

While the previous four methods of instrumental testing involve evaluating a large number of beans in a single test it may be desirable to evaluate beans individually. By measuring the texture of individual beans, the within sample variability can be determined.

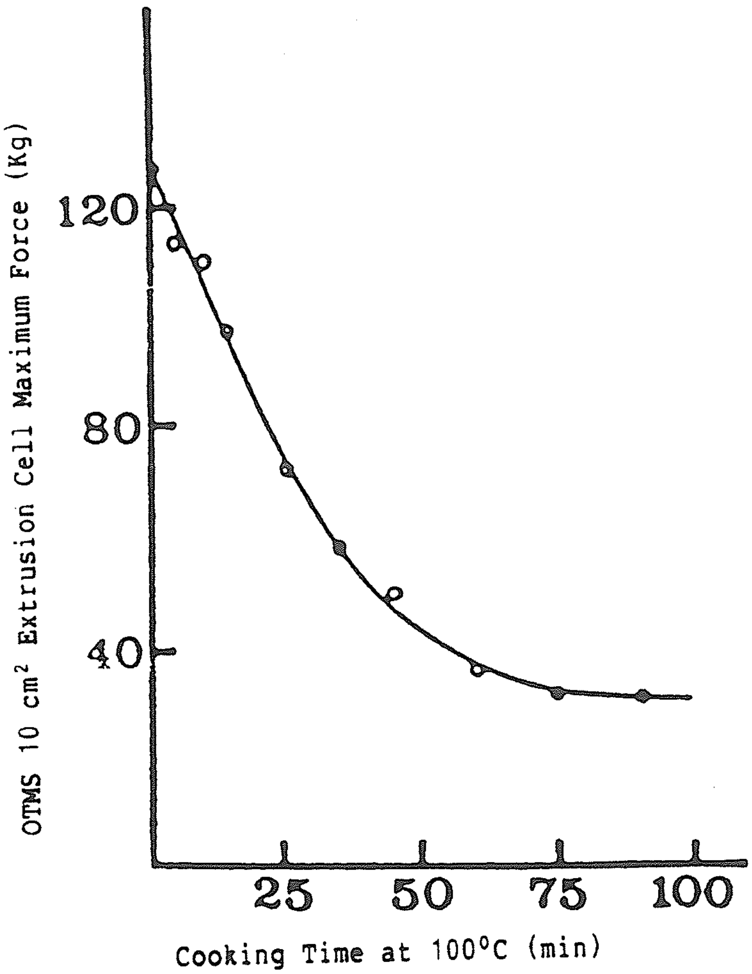


Figure 2.8: Effect of cooking conditions on texture as measured by a 10 cm^2 extrusion cell of cowpeas (Vigna unguiculata): Effect of heating at 100°C (Sefa-Dedeh et al., 1978).

One such technique is the puncture test. The apparatus used consists of a flat-faced circular punch mounted to an Instron. The diameter of the punch can vary. Bourne (1972) reported the use of a 16 mm diameter punch. A bean is centered below the punch and the punch is lowered and penetrates the bean. The maximum force required to penetrate the bean to a specific depth is determined. One disadvantage of this method is that it is time-consuming. For example, it takes longer to carry out 200 tests on 200 beans than to run one test at one time on 200 beans, since only about 10 beans can be punctured per minute (Bourne, 1972).

In a study conducted by Bourne (1972) using cooked pea beans, marrow beans and soybeans, 500 beans of each sample were punctured using the puncture probe apparatus (1/8" diameter punch). Bourne (1972) determined how many maximum force peaks were in each force range and was able to illustrate the distribution of bean hardness within a sample (Figure 2.9). The curves obtained for soybeans, pea beans and marrow beans all approximated normal distributions. The use of the puncture probe by dos Santos Garruti and Bourne (1985) to assess the firmness of red kidney beans further demonstrated that puncture forces follow a normal distribution curve. Aguilera and Steinsapir (1985) noted in their study where individual cooked black beans were puncture tested, that within a class, the texture values of individual cooked beans followed a normal distribution with standard deviations being relatively large. They suggested that causes of this variaton may genetic or due to harvest maturity differences. The presence of hard beans is indicated by beans having high peak puncture force readings and illustrates the advantage of using the puncture probe over multi-unit testing procedures. The presence of a

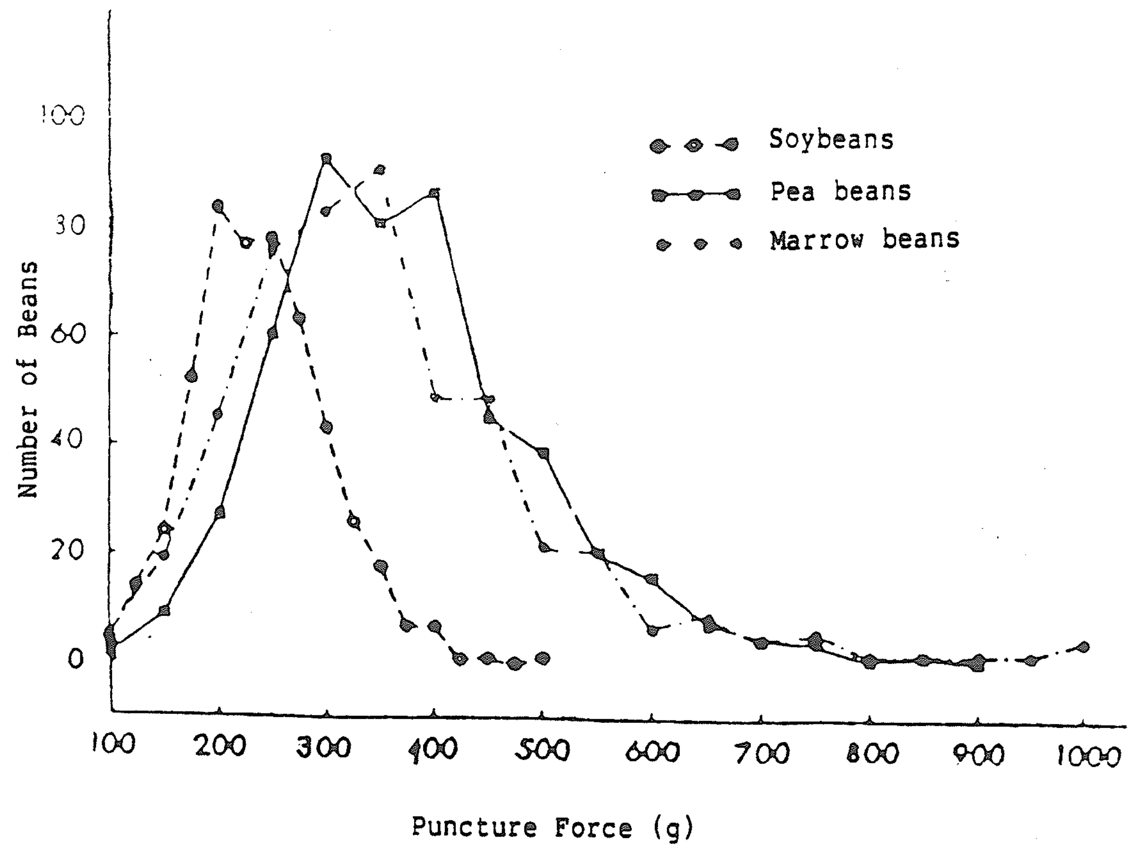


Figure 2.9: Number of beans in each puncture force range using 1/8 in. diameter punch: 50 g force range increments for pea beans and marrow beas, 25 g force range increments for soybeans (Bourne, 1972).

few hard beans would not be identified as readily by using the Tenderometer, the Shear Press, compression or extrusion cells as these instruments cannot determine how widely single beans vary from the average value (Bourne, 1972). The average value from these instruments would rise, however. The puncture probe, like the human mouth, is able to detect small numbers of hard beans.

The rate of softening of individual pea beans was also evaluated by puncture testing using 120 beans from each of 8 cooking times (Bourne, 1972). It was shown that the pea beans softened with increased cooking time. The difference in maximum puncture force between the hardest and softest bean of the same cooking time decreased as the length of cooking time was increased (Bourne, 1972) (Table 2.1). Moscoso (1981) and Moscoso et al. (1984) used the puncture test to evaluate the degree of softening of red kidney beans. A 2.38 mm diameter, circular flat faced punch was used and was mounted on an Instron. The results obtained by Moscoso (1981) and Moscoso et al. (1984) confirmed those of Bourne (1972) that firmness of cooked beans, as measured with the puncture probe, decreased with increased cooking time (Figure 2.10).

Silva et al. (1981b), using black beans treated to various soaking and cooking treatments, found that the bean softening rate, as measured using a 1.36 mm punch, did not follow first-order kinetics (Figure 2.11). When compared to no soaking or a distilled water soak, a salt combination soaking solution promoted bean softening during cooking more effectively as measured by a 1.36 mm punch (Silva et al., 1981a). Plhak et al. (unpublished) investigated the effect of storage conditions, wa-

TABLE 2.1

Puncture test on individual cooked pea beans (Bourne, 1972).

	Puncture force†			
Cook Time (min)	Highest‡ (g)	Lowest (g)	Difference H-L	Mean (g)
30	1525	280	1245	523
60	503	68	435	201
90	372	70	302	165
120	262	39	223	139
150	236	32	204	123
180	301	52	249	129
240	200	35	165	96
300	207	30	177	89

† Puncture force values determined using Instron with 1/8 in diameter flat faced steel punch.

‡ Highest puncture force is that of the hardest bean in the sample while the lowest puncture force is that of the softest bean in the sample.

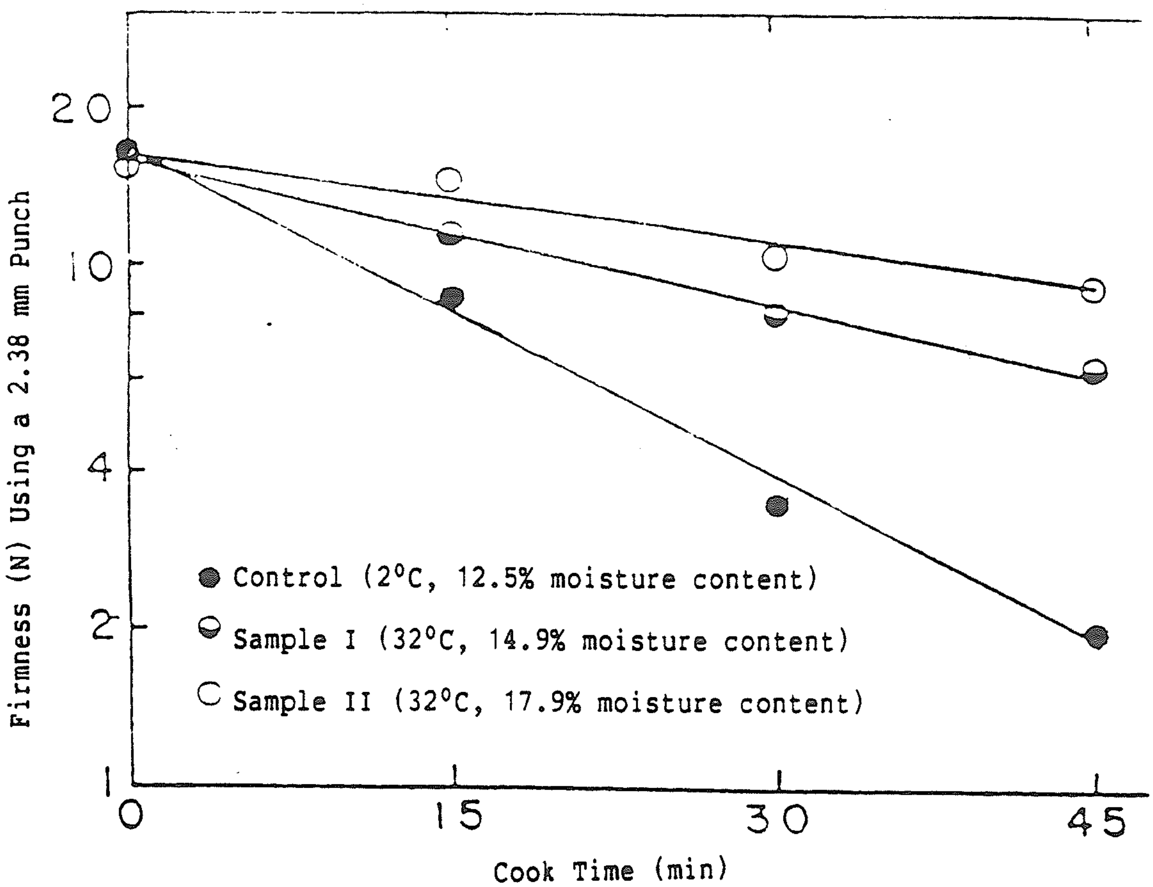


Figure 2.10: Softening of dry beans stored for six months as measured by a 2.38 mm punch (Moscoso, 1981).

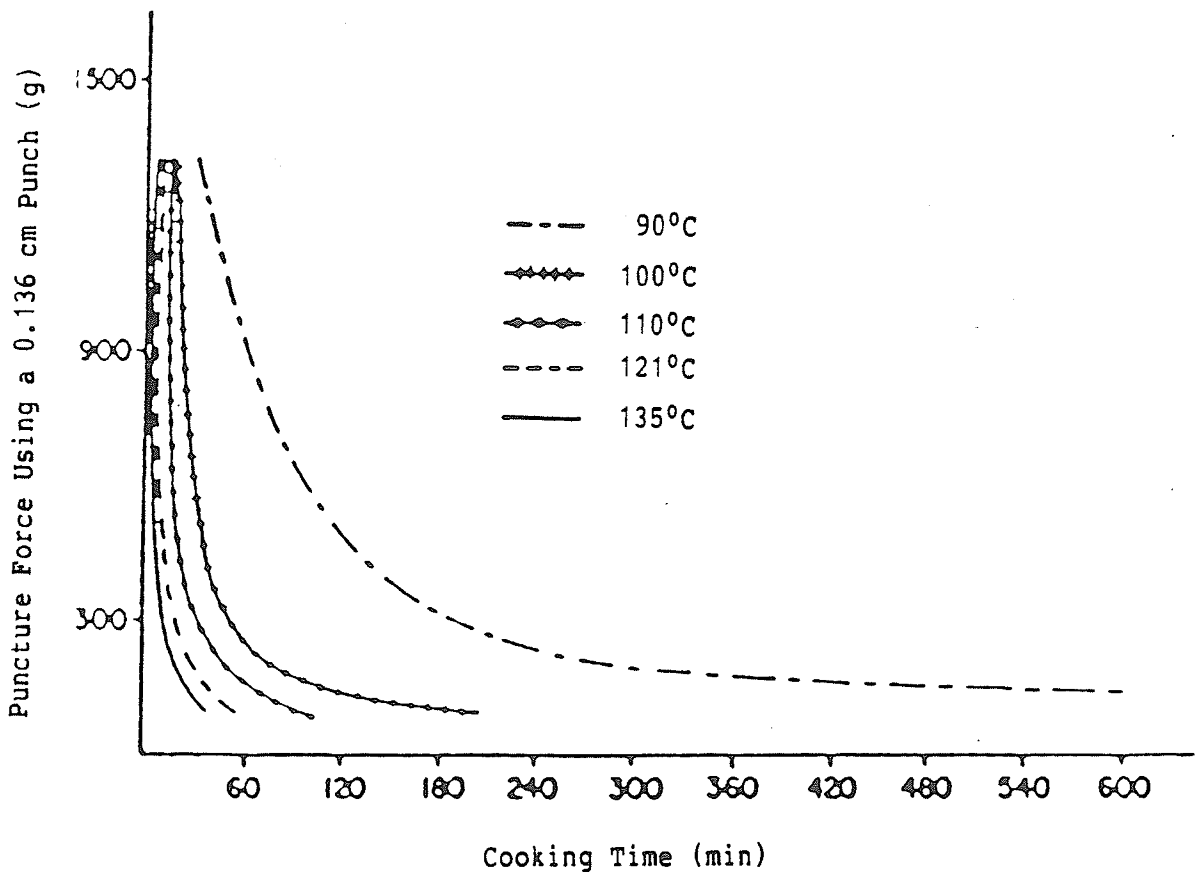


Figure 2.11: Puncture force as measured by a 0.136 cm punch as a function of cooking time for black beans (Phaseolus vulgaris L.) cooked at different temperatures (Silva et al., 1981b).

ter content, soaking and cooking times on puncture force using a 1.6 mm diameter flat-ended cylindrical probe on peeled black beans. High temperature-high humidity (30°C, 80% RH) stored samples required a cooking time of approximately 3.5 h to become sufficiently softened to have equivalent puncture forces to low temperature-low humidity (15°C, 35% RH) stored beans cooked for 1 h. Molina et al. (1976) evaluated the effect of heat treatments on the development of the hardening defect in black beans using the puncture test. The testing was done on a locally built texture testing machine using a flat-faced, cylindrical steel punch with a diameter of 2.16 mm. All puncture force readings were taken on black bean samples (variety S-19-N) cooked for 20 minutes. Beans receiving the heat treatments before storage had lower puncture force values than the untreated samples (Molina et al., 1976).

2.1.2.5 Mattson Bean Cooker

Numerous studies on bean texture have been done using the Mattson Bean Cooker or modifications of it (Figure 2.12) (Jackson and Varriano-Marston, 1981). The Mattson Bean Cooker method of evaluating bean texture can be thought of as a variation of the puncture probe technique (Bourne, 1972). The Mattson Bean Cooker, developed by Mattson in 1946 for evaluating the cookability of peas, consists of 100 metal rods or "punches", 8 mm in diameter and weighing 82 g, mounted in a stand (Mattson, 1946). Modifications have included the number of plungers used, the weight of the individual plungers and the shape of the plunger tips. The apparatus is lowered into boiling water to allow the beans to cook. The rod penetrates the bean when the bean has reached a certain degree of softness. The number of rods which have dropped, that is, the number of beans that are cooked, are recorded at regular intervals (Burr, 1968). The Mattson Bean Cooker indicates relative cookability by producing a sigmoidal curve that shows percent beans cooked as a function of cooking time (Figure 2.1) (page 8). The time corresponding to 50% cooked is commonly used as a reference time for comparison of relative cookability.

The percent beans cooked can also be plotted as a function of time on log-probability paper. When this is done the points obtained fall approximately in a straight line. Using this procedure it is thought that cooking time determined for 50% cooked would be more accurate than one obtained from an sigmoidal curve resulting from the use of rectilinear graph paper (Burr, 1976).

In the study by Burr et al. (1968) a Mattson Bean Cooker with 100 rods weighing 90 g was used to assess cookability of pinto, large Lima and Sanilac beans. The plunger weight had been adjusted to 90 g because preliminary tests had indicated that a plunger of 90 g would penetrate the bean at approximately the same cooking time as was required for the bean to be judged as done by a human taster. Burr et al. (1968) determined that beans subjected to high temperature, high moisture content and lengthy storage had reduced cookability, that is, they took a longer time to cook to 50% cooked than did the control beans.

Kon (1968) used the same method as Burr (1968) to correlate pectic substance content of Sanilac beans to their cooking times and again in

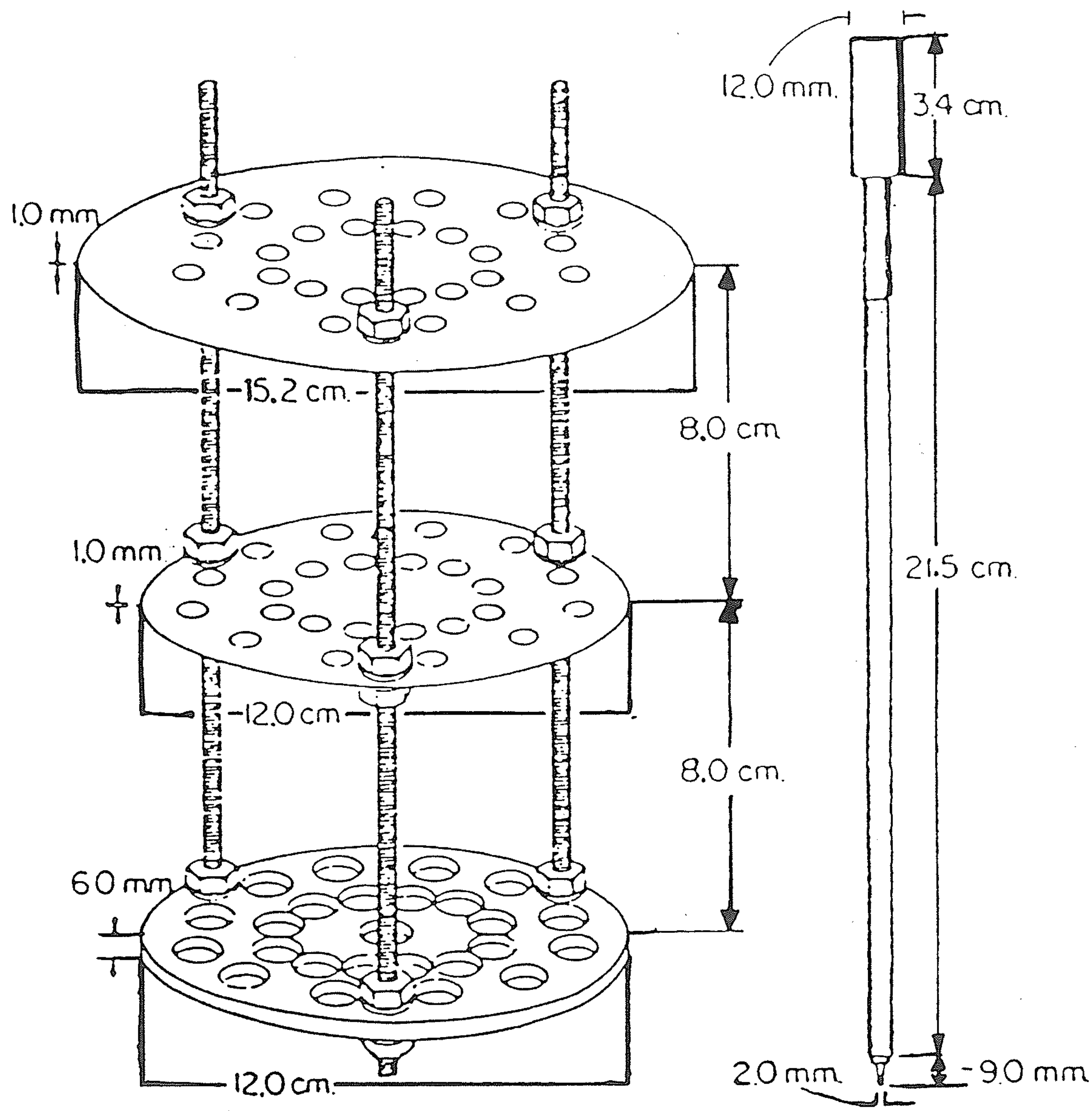


Figure 2.12: Dimensions of rack and plungers of Mattson Bean Cooker (Jackson and Varriano-Marston, 1981).

1979 to relate soaking temperature to cooking quality of California small white beans. Jackson and Varriano-Marston (1981) used a modified Mattson Bean Cooker with 25 rods weighing 82 g. The time for 50% cooked was recorded. Proctor (1985) used plungers weighted to 49.75 g and 48 g and having a 5 mm end in order to produce a cookability curve that matched the cookability determined by a sensory panel (Figure 2.2- page 9).

The use of the Mattson Bean Cooker seems only to be supported, however, if its cookability curve corresponds well to that produced by human evaluators. While modifications to the plungers are possible to facilitate this occurring, this method may be too tedious and time-consuming to be practical.

2.1.2.6 Wedge

Sefa-Dedeh et al. (1978) developed a method, using a wedge-type blade mounted on an Instron, to measure the texture of raw and soaked cowpeas (Figure 2.13). The maximum force required for the blade to cut across the cotyledons was measured and the average maximum force for 20 beans was calculated.

The wedge force-time curves for raw unsoaked beans differ from those of raw soaked beans (Figure 2.14). The curve for raw unsoaked beans rises rapidly to a peak and abruptly falls (Figure 2.14a). This indicates that the seedcoat and the two cotyledons were split at the same time. The peak force, therefore, represents the maximum force to cut

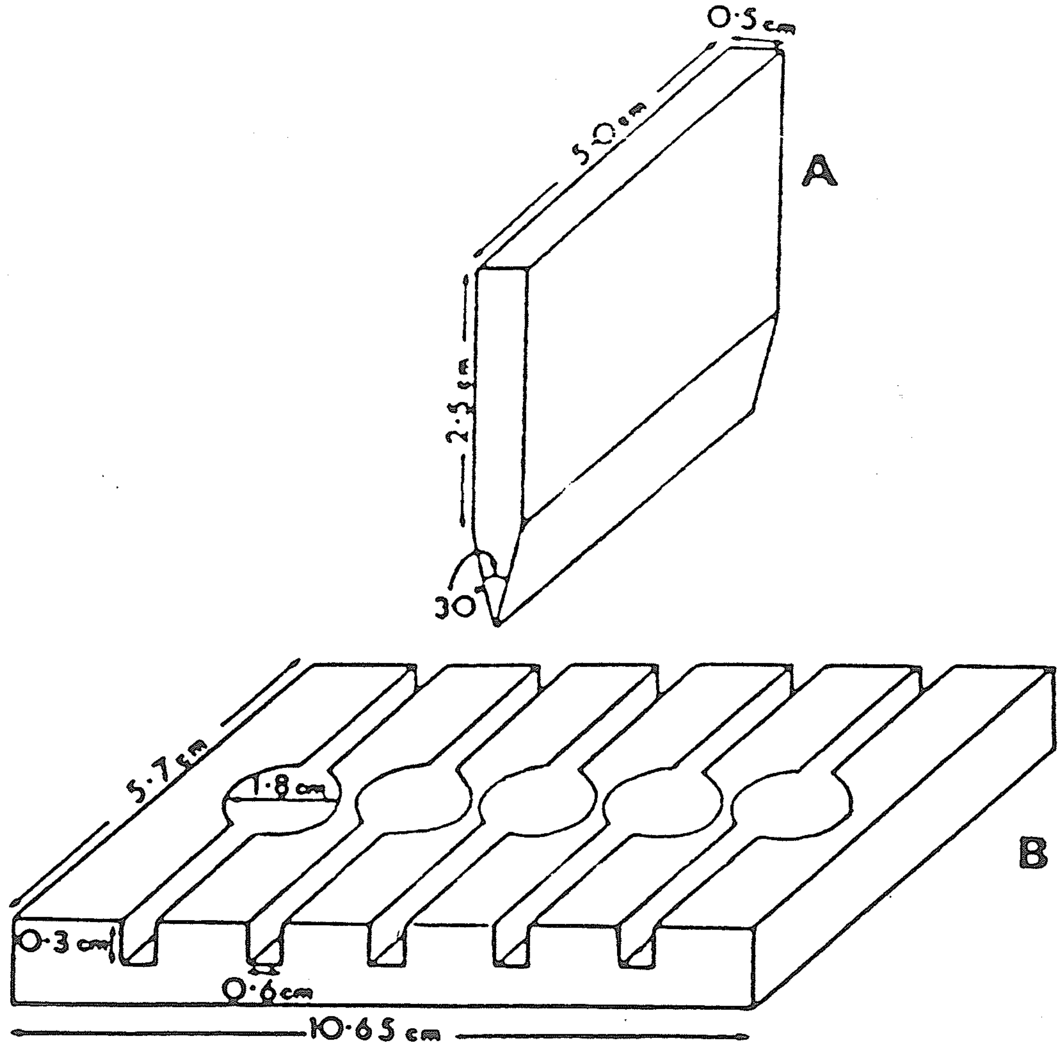


Figure 2.13: Dimensions of stainless steel wedge (A) and aluminum plate test cell (B) (Sefa-Dedeh et al., 1978).

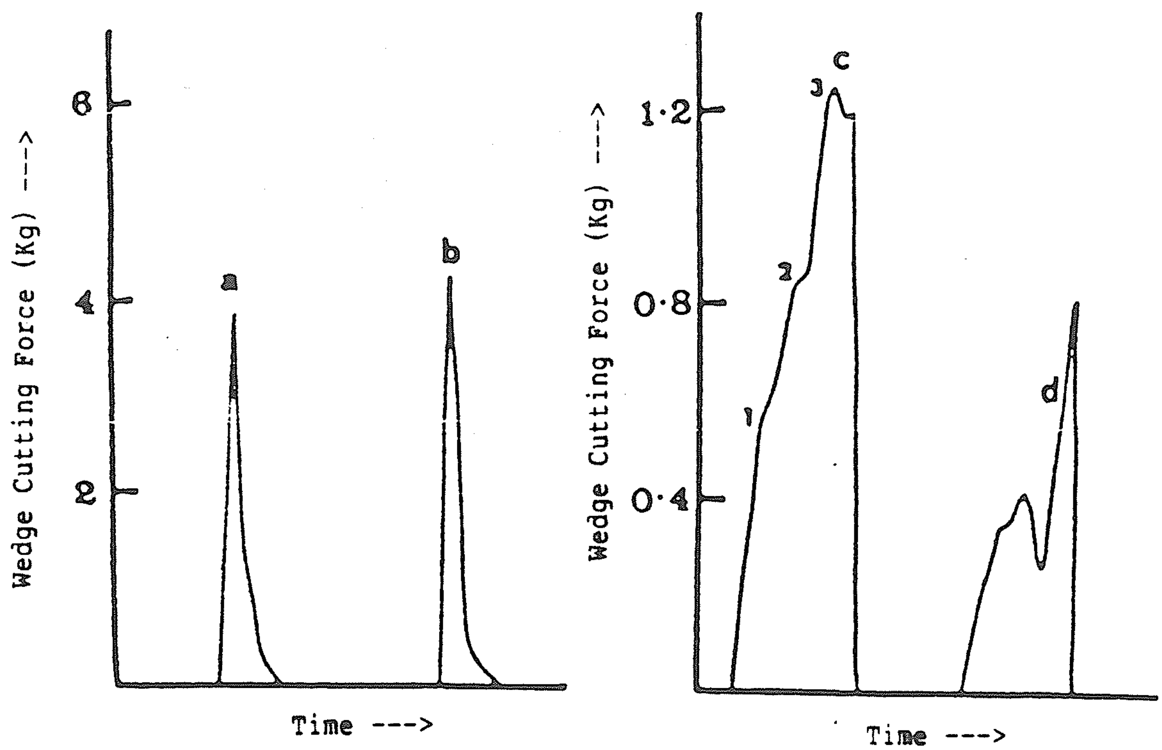


Figure 2.14: Typical force-time (deformation) results using the wedge apparatus obtained for cowpeas (Vigna unguiculata) (Sefa-Dedeh et al., 1978). a) raw unsoaked, b) soaked for 1 hr, c) soaked for 24 h, d) soaked for 24 hr, seedcoat removed (Sefa-Dedeh et al., 1978).'

the whole bean. The curve for raw soaked beans, on the other hand, has more distinctive features (Figure 2.14b,c,d). The slope of the curve increases as the wedge meets the seedcoat and the force applied increases. The slope suddenly changes as the seedcoat is cut. The force increases again as the first cotyledon is met and decreases sharply when the first cotyledon is cut. The peak obtained is a record of the force required to cut through the seedcoat and the first cotyledon. A second peak is created as the second cotyledon is met and cut by the wedge.

Sefa-Dedeh et al. (1978) also demonstrated the use of the wedge apparatus on soaked soybeans, white beans, adzuki, and pinto beans (Figure 2.15). Sefa-Dedeh et al. (1979) used the same apparatus to evaluate the effect of storage time and conditions on the hardening defect in cowpeas.

In a study by Voisey and Larmond (1971) a Kramer Shear-compression cell, the Pea Tenderometer, a back extrusion cell, a plate extrusion cell and a wire extrusion cell were compared with respect to their ability to objectively measure the textural characteristics of baked beans. Results from all instruments were highly correlated with each other and with sensory hardness and cohesiveness rating. They concluded that the choice of an instrumental method could be based on practical considerations and the available equipment (Voisey and Larmond, 1971).

The Pea Tenderometer is not used commonly for cooked bean texture evaluation because it is a cumbersome instrument that is difficult to standardize (Voisey and Larmond, 1971). The choice of of the Kramer

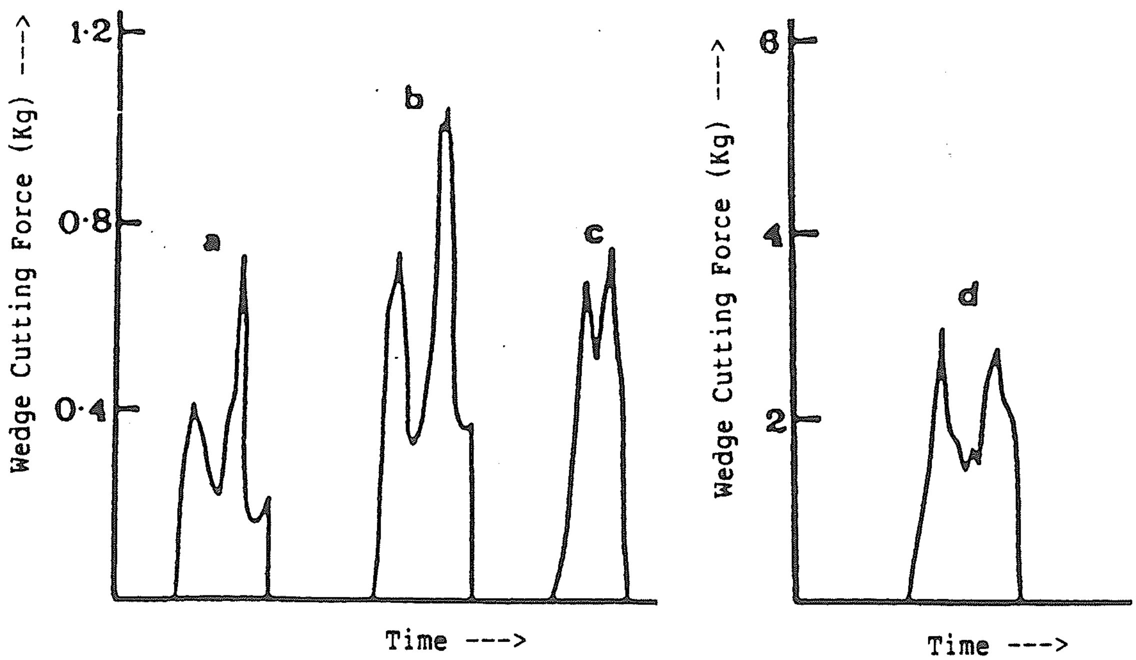


Figure 2.15: Typical force-time (deformation) results using the wedge apparatus obtained for different legumes soaked for 24 h (Sefa-Dedeh et al., 1978). a) Soybean (Glycine max), b) White beans (P. vulgaris), c) Adzuki (P. angularis), d) Pinto beans (P. vulgaris) (Sefa-Dedeh et al., 1978).'

shear or wire extrusion cells for use in evaluating multi-bean samples may be based on operating efficiency and cost. The Kramer shear cell, because of its multi-blade design, is more difficult to clean than a wire extrusion cell. A wire extrusion cell mounted on an Ottawa Texture Measuring System (OTMS) was available at both the University of Manitoba and INCAP and so was used in this study.

Those instruments that evaluate cookability by measuring forces to compress, shear, and extrude multibean samples have the disadvantage of failing to indicate how widely single beans within a sample vary from the average value. The Mattson Bean Cooker, puncture probe and wedge apparatus give information on individual beans but are quite tedious and time-consuming to carry out. The Mattson Bean Cooker produces a sigmoidal cookability curve which can correspond closely to that produced from data from human evaluators. In Guatemala, however, even after some modifications, a good correspondence between the Mattson Bean Cooker's and the sensory panel's cookability curves was not obtained during preliminary testing and was, therefore, not used in this study.

In a survey of 600 Guatemalan consumers (Watts et al., 1987), over 50% of the respondents, when selecting beans, tested the hardness of the raw beans by biting them between their teeth or by cutting them with their fingernails. A good quality bean was considered by these consumers to be one that was easy to bite or cut (Watts et al., 1987). The measurement of raw bean hardness using the wedge apparatus would seem to measure the same property that is considered important to consumers. This method had the distinct advantage that it does not involve a cooking period. However, correlation of raw bean hardness test values with cookability test values has not been done.

2.1.3 Sensory Evaluation

2.1.3.1 Subjective Sensory Evaluation

Sensory testing of beans has frequently involved the subjective assessment of "doneness" in the mouth based on preference by small laboratory panels. Hedonic or acceptability scales have been used to evaluate texture of cooked beans. Iyer et al. (1980) used a panel of 15 judges to assess texture quick-cooking and conventionally cooked Great Northern, kidney and pinto beans. Although a number of samples having a range of cooking times had been prepared for instrumental testing Iyer et al. (1980) neglected to state the cooking times of the samples evaluated by the sensory panel. A 9-point hedonic scale was used with 9 equal to extremely like and 1 equal to extremely dislike. A nine-member sensory panel was used by Quenzer et al. (1978) to indicate preference using a 7-point hedonic scale for different pinto bean cultivars cooked for 90 minutes. Voisey and Larmond (1971) had 14 panelists evaluate the acceptability of baked bean texture using a 9-point hedonic scale. All samples had been processed under the same conditions. Panelists were requested not to base their preference on flavour but rather on texture. Seven of the 14 judges were trained panelists also participating in another portion of their study (Voisey and Larmond, 1971). In a study by Perry et al. (1976) four to five members of their food research staff were used on a panel to subjectively evaluate the texture of the soybeans, cooked to a range of times, on a 5-point scale ranging from 1= very poor, to 5= very good in order to identify the cooking times to approximate the same stage of doneness for a number of varieties and treatments. The preference data obtained from such small, experienced panels should not be used to draw inferences about consumer preferences. Stone and Sidel (1984) recommend the use of a laboratory panel of at least 24 members for acceptance testing. Preference, however, varies from person to person and is affected by such factors as socio-economic background and region. The practice of using laboratory acceptance panels which are unrepresentative of the consuming population to estimate consumer preference is, therefore, questionable.

2.1.3.2 Objective Sensory Evaluation

An objective method of evaluation is usually thought of as being carried out by an instrument or chemical technique. Sensory methods, however, can also be used for obtaining objective measurements (Bourne, 1982). The basic characteristics of an objective test are: "that data obtained are independent of the individual observer; that is, the result is fair, impartial, factual, and unprejudiced by the personal characteristics of the observer" and: "that the results are repeatable and verifiable by others; that is, other laboratories can obtain the same results within the limits of experimental error." (Bourne, 1982, p. 272).

Intensity scaling is an estimation method in which subject use interval or ratio scales to measure attribute intensity. The procedure involves the presentation of a series of stimuli to a subject who is instructed to give quantitative judgements of the magnitude or intensity of the attribute as produced by each stimulus. Repeated judgements are necessary, either over trials with a single subject or over subjects, due to variability in judgement, in order to obtain good estimates of the values. Specifying two points on the continuum fixes the unit of measurement and may also be able to fix the origin. Under such conditions, and assuming no error exists, the scale values given by the different panelists should agree perfectly, i.e., y=x (Torgerson, 1985).

Of the few studies done to objectively measure cooked bean texture, the majority involve the use of simple methods of sensory evaluation to objectively assess bean texture. Morris and Wood (1956) used a panel of 9 to 13 trained judges to evaluate cotyledon and skin texture of 7 different bean varieties (Great Northern, Large lima, Michelite, Pinto, Red kidney, Red Mexican and California small white). The purpose of the study conducted by Morris and Wood (1956) was to evaluate the changes in cooked quality of each variety kept under different moisture conditions for different storage times. Each variety was cooked a specific but different length of time. The reasoning behind the choice of a cooking time was not given. The judges scored samples on a 7-point rating scale with 1=firm cotyledons and 7=soft cotyledons. A labelled standard with a score of 5 was given. Morris and Wood (1956) realized the inadequacies of their method in that a judge could not be counted on to remember over a period of time exactly what score he had given to a particular quality. Another disadvantage was that only the samples which were tasted together could be compared directly (Morris and Wood, 1956). This may result when judges are not trained to identify specific characteristics or do not have a reference to which all samples can be related.

Overall hardness, or degree of cooking has been estimated in a number of studies. A 9-point rating scale was used by Silva et al. (1981a) to determine texture of cooked black beans. A panel of 20 Brazilian students and spouses who consumed black beans on a regular basis used a scale ranging from 1=extremely soft to 9=extremely tough. Aguilera and

Steinsapir (1985) used a panel of 10 people who were familiar with the texture properties of beans to describe the hardness of cooked beans. The panelists used a 7-point scale with 1 = very soft and 7 = very hard. The minimum acceptable texture for consumption was determined to have the hardness score of 5. Muneta (1964) used a 7-member panel to evaluate 5 cooking times of 7 varieties of dry beans and Alaska pea which had been stored. Panelists were required to indicate whether the sample was undercooked, cooked or overcooked. However, it was not mentioned whether the panelists were trained to identify characteristics in order to make their decisions.

Few studies have been carried out using sensory procedures to objectively measure cooked bean texture, although a texture profile procedure for evaluation of cooked bean texture was reported by dos Santos Garruti and dos Santos Garruti (1983). A more complex method, Texture Profile Analysis, developed by Szczesniak (1963) and Szczesniak et al. (1963), while time-consuming, is objective, and gives reproducible results. Sensory Texture Profile Analysis begins with the identification of important sensory characteristics or attributes. Intensity scales, with standards representing the low and high ends of the scale, are established for each attribute, and the position of a reference sample on the scale is determined by the panelists. Repeated evaluation of standards and samples is done until variation among panelists is minimal. The texture profile panel is considered to be an objective method because panelists are trained to take an analytical approach and use their mouths as a scientific instrument. The use of intensity scaling, rather than acceptability scaling, should minimize the influence of personal preferences (Bourne, 1982).

The results from different texture profile panels have been shown to be reproducible to a high degree. Bourne (1982) noted that texture profile panels in Ithaca, New York and in Bogota, Colombia (Bourne et al., 1975) produced nearly identical texture profiles for soda crackers. A texture profile panel trained by Szczesniak et al. (1963) was able to reproduce their score on the same product in a second test carried out almost a year and a half after the first test.

Use of Texture Profile Analysis has been reported by Voisey and Larmond (1971), dos Santos Garruti and dos Santos Garruti (1983) and dos Santos Garruti and Bourne (1985). Preliminary tests conducted by Voisey and Larmond (1971) determined that hardness, gumminess and adhesiveness were important parameters in the testure of baked beans. A panel consisting of 7 judges was trained, according to the method defined by Szczesniak (1963) and Szczesniak et al. (1963), to recognize these three parameters. The judges prepared a descriptive scale for each parameter. An 8-point hardness scale was used which raned from extremely soft to extremely firm. The gumminess and adhesiveness scales each had 6 points ranging from very mealy to very gummy and from little or no adhesiveness to very gooey, respectively. dos Santos Garruti and dos Santos Garruti (1983) evaluated 8 different textural characteristics of cooked common bean texture such as skin hardness, chewiness, and rate of breakdown (Figure 2.16). The texture profile panel in the study by dos Santos Garruti and Bourne (1985) was trained to use 26 different texture characteristics for evaluating red kidney beans. An instrumental texture profile was also carried out based on 6 parameters (dos Santos Garruti and Bourne, 1985).

Name: ________________ Date: ________________ Product ________________

Sample No. ______________

I. INITIAL SENSATION (perceived in the first bite)

(a) Mechanical characteristics — Score

- Hardness (1-8 scale) (skin) ______

(b) Geometrical characteristics ______

(c) Other characteristics (skin nature)

Harsh	Smooth	Thin	Thick
____	____	____	____

II. MASTICATORY SENSATION (perceived during mastication)

(a) Mechanical

	Score	No. chews
- Chewiness (1-6 scale)	____	____

(b) Geometrical (particles size and shape)

Grainy	Creamy	Soft
____	____	____

(particles shape/orientation)

Homogeneous (cellular)	Non-homogeneous
____	____

(c) Other characteristics (humidity)

Slight	Moderate	Strong
____	____	____

III. RESIDUAL SENSATION (before, during, after swallow)

	None	Slight	Moderate	Strong
rate of breakdown	____	____	____	____

Figure 2.16: Sensory Texture Profile Analysis score sheet for common beans (dos Santos Garruti and dos Santos Garruti, 1983).

2.1.4 Correlation of Sensory and Instrumental Methods

Instruments are calibrated in absolute units but their readings do not mean very much unless they are correlated with sensory evaluation of quality (Bourne, 1982). The objective of a number of studies has been to find a good correlation between a sensory test and an instrumental test related to it. By developing a model using such a correlation, a specific instrumental test could be used to predict sensory cooked bean texture. Instrumental testing has the advantage of being relatively less time-consuming and expensive than sensory testing. A model based on one or two quick instrumental tests would benefit plant breeders, for example, or anyone involved with evaluating a large number of bean samples.

2.1.4.1 Puncture Testing

Aguilera and Steinsapir (1985) related perceived hardness by a panel to force measured by puncture testing of cooked Phaseolus vulgaris beans cv. Tortola Diana. A control and five dry-processed (irradiated and roasted) samples were evaluated after 2.5 to 10 mo of storage. The technique used by the panelists to assess hardness was not described, i.e., whether the panelist made their hardness determinations on a single- or multi-bean sample. They observed that the phenomenon of hardening as perceived by the panel followed the same trend as measured by the Instron in the puncture test. They were able to develop a linear regression equation to describe this relationship (Equation 1):

$(P<0.05,\ r^2= 0.93)$

$$SC = 2.95 \ln (FI) - 11.44 \qquad (1)$$

where: SC = score in sensory evaluation (1=very soft to 7=very hard)
FI = puncture force measured using a 3 mm diameter punch (g).

Aguilera and Steinsaper (1985) found that the minimum acceptable texture had a sensory hardness score of 5 (on a 7-point scale) which corresponded to a puncture force of 263 g as measured using the Instron (Figure 2.17).

Silva et al. (1981a) were able to correlate puncture force of cooked black beans (Black Turtle Soup beans, variety T-39) to cooked bean texture as measured by a sensory panel (Figure 2.18). They developed a model to predict sensory texture values using the instrumental data (Equation 2):

$$\text{Sensory texture} = 2.54 \ln(\text{Force}) - 7.82 \qquad (r^2 = 0.91) \qquad (2)$$

where: Sensory texture = 9-point scale with 1=extremely soft and 9=extremely tough
Force = puncture force as measured using a 0.136 cm punch

Silva et al. (1981a) also checked the predictability of their model (Table 2.2).

It was determined in the study by Silva et al. (1981a) that a sensory texture score of 5 (on a 9-point rating scale) was the minimum rating for acceptable cooked black bean texture. A puncture force of 150 g was calculated to correspond to this value (Figure 2.18). This value of 150 g puncture force was used in a subsequent study by Silva et al. (1981b) as a reference for determining if a black bean sample was adequately cooked.

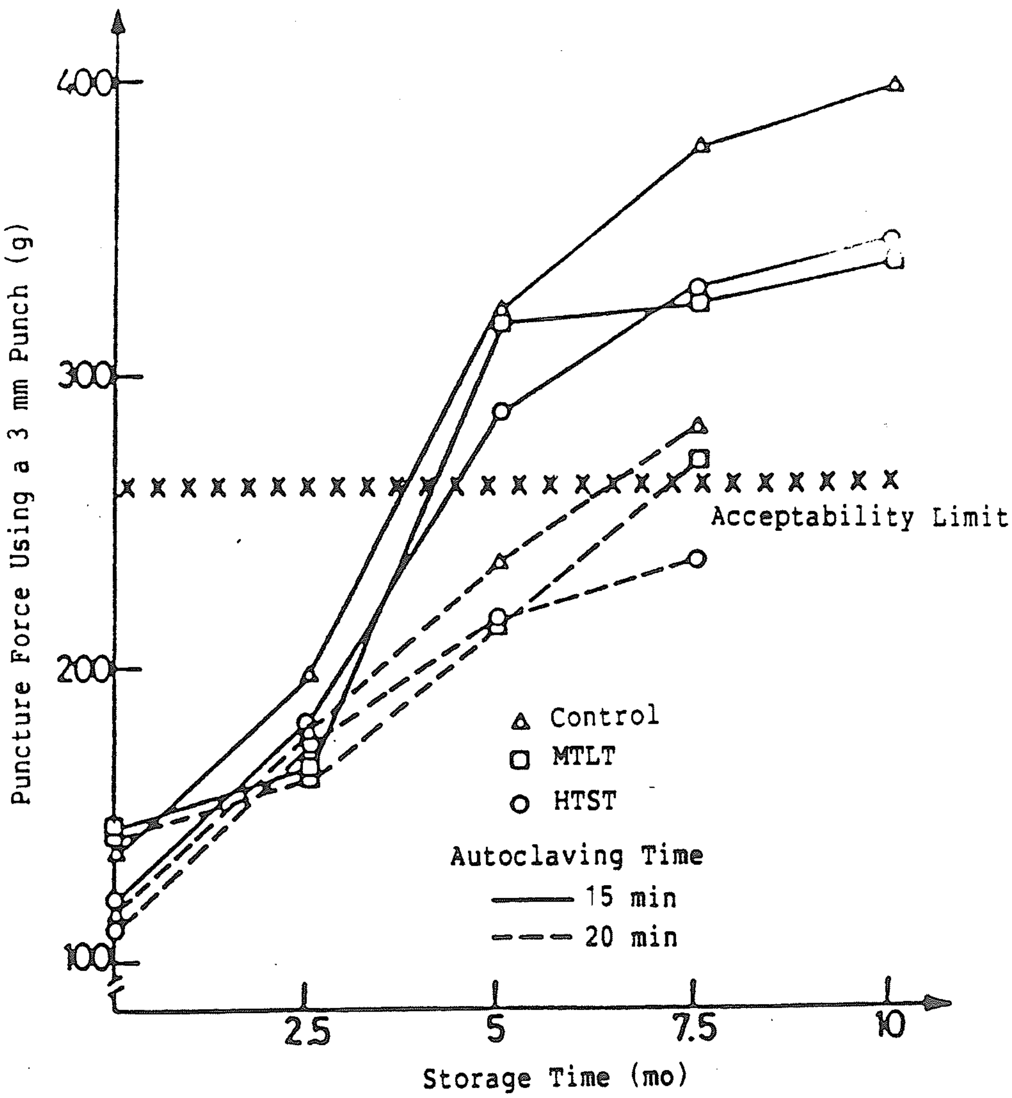


Figure 2.17: Effect of storage time on the hardness of heat-treated and control beans as measured by puncture force using a 3 mm punch (Aguilera and Steinsapir, 1985).

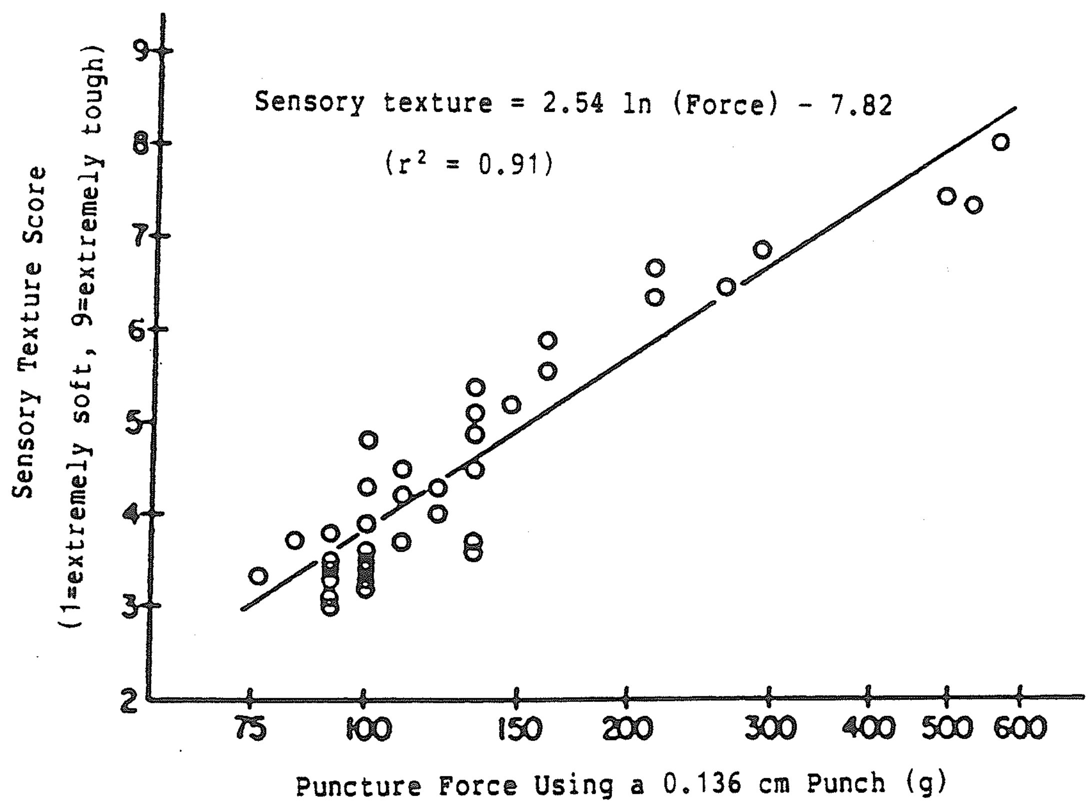


Figure 2.18: Sensory texture score as a function of ln puncture force of cooked black beans (Silva et al., 1981a).

TABLE 2.2

Predicted and observed values for sensory texture based on puncture force (Silva et al., 1981a).

Puncture force† (g)	Sensory score observed‡	Predicted sensory score
116	4.0	4.2
148	5.2	4.9
547	7.4	8.1

† Puncture force measured by a 0.136 cm diameter punch.

‡ Each value is the mean of two replicates, each consisting of greater than 10 observations.

Proctor (1985) used a Mattson Bean Cooker (MBC) with 25 plungers weighted to 48 g to obtain a curve that showed percent beans cooked as a function of cooking time (Figure 2.2, page 9). A trained panel of 9 members was used to assess doneness (percent cooked) by mouth and preference of a number of navy bean samples of the same variety cooked to different cooking times. The 92% cooked time, as determined by the MBC corresponded to the cooking time of the most preferred texture of navy beans (Proctor, 1985).

2.1.4.2 Raw Bean Hardness

Sefa-Dedeh et al. (1978) determined that the texture of soaked cowpeas as measured with the wedge apparatus could be used to predict the texture of the corresponding cowpeas after 2 h of cooking (Equation 3):

$$Y = 45.8088 - 0.7968\ X_1 + 5.775\ X_3 \qquad (3)$$

where X_1 = soaking time (h)
X_3 = maximum force on soaked bean (g) as determined using the wedge apparatus
Y = maximum force of cooked beans (Kg) as determined using the 10 cm^2 extrusion cell.

In order to test the predictability of the regression equations, Sefa-Dedeh et al. (1978) soaked fresh cowpea samples for 24 h, measured their maximum hardness using the wedge apparatus, cooked the cowpeas for 2 h and measured their hardness using the 10 cm^2 extrusion cell. Both equations were found to predict cooked bean texture well (Table 2.3).

TABLE 2.3

Experimental and predicted cooked cowpea texture (Sefa-Dedeh et al., 1978).

Experimental				Predicted Y	
X_1†	X_2	X_3	Y	Equation 3	Equation 4
24	107	0.9565	31.65	36.08	32.21

† X_1 = soaking time (h); X_2 = g H_2O/100 g dry bean; X_3 = maximum force on soaked bean (g) as determined using the wedge apparatus; Y = maximum force of cooked beans (Kg) as determined using the 10 cm^2 extrusion cell.

Silva et al. (1981) using Black Turtle Soup beans under various soaking and cooking treatments were unable to predict the puncture puncture force of cooked black beans using force of soaked raw beans (r= 0.044).

2.1.4.3 Shear Press Testing

Priestly and Mollendorff (1980) used a 35-member untrained panel to evaluate small haricot and Michigan beans for canning. The panel results using canned beans were related to Shear Press readings and it was determined that only samples with a Shear Press reading of 60 (units not indicated) were considered to be hard by the panel. The methods used by Priestly and Mollendorff (1980) were not clearly defined in their article which makes drawing conclusions from their data difficult. Shehata et al. (1983) reported relationships between scores for sensory softness and maximum Kramer shear forces to be significant at $p \leq 0.01$.

2.1.5 Physical Characteristics and Relationship to Cooked Texture

If a relationship can be established between physical characteristics and cooked texture perhaps future evaluation of black bean varieties might involve the generally simpler and less time-consuming tests of physical characterization rather than the more complex and time-consuming mechanical tests. Any knowledge attained concerning the relationship of physical characteristics of the raw bean to cooked texture would benefit breeders and agrologists in the development and promotion of the production of black bean varieties with good cooked texture quality.

INCAP has categorized common black beans into 3 size groups based on the average bean weight of a sample. A sample of black beans is considered to be small if its average bean weight is less than 0.193 g. A bean sample is classed as being of medium size if its mean bean weight is between 0.193 and 0.217 g. Large black beans are considered to be those with an average bean weight greater than 0.217 g (Elías et al., 1986).

Bean size was shown to be related to texture by Bourne (1967) who used size grading to remove beans with poor texture. Bourne (1967) reported, using dry pea, marrow, and red kidney beans, that the size distribution of a given lot of dry beans corresponded to a normal distribution pattern with hardshell beans being concentrated at the smaller end of the scale. Since hardshell beans do not imbibe water and swell as do normal beans during soaking, soaking would accentuate the size difference between hardshell and normal beans.

2.1.5.1 Water Absorption

Measurement of water absorption, that is, of water uptake by the beans during a soaking period, has been shown to be of use in identifying hardshell beans. Its value in measuring changes related to the hard-to-cook defect, however, are questionable (Plhak et al., unpublished).

A number of studies have shown a good relationship between total amount of water absorbed and cooked bean texture (Burr et al., 1968; Sefa-Dedeh et al., 1978, 1979; Quenzer et al., 1978; Jackson and Varriano-Marston, 1981). The moisture content of black beans was found, by Jackson and Varriano-Marston (1981) to be related to cooking time as determined by the Mattson Bean Cooker (Figure 2.19). They stated that, generally, the higher the water content after soaking, the shorter the cooking time. They noted, however, that fresh and aged samples had different cooking times regardless of the moisture content of the beans. Sefa-Dedeh et al. (1978) developed a model using soaking time and amount of water absorbed to predict extrusion force of cooked cowpeas (Equation 4 and Tables 2.3 and 2.4).

$$Y = 77.67 - 0.5086\ X_1 - 0.2746\ X_2 \qquad (4)$$

where X_1 = soaking time (h)
X_2 = water absorption (g H_2O/100 g dry bean)
Y = extrusion force of cooked beans (Kg).

Predicted cooked bean extrusion force values by equations using soaking time and soaked bean hardness (Equation 3) and using soaking time

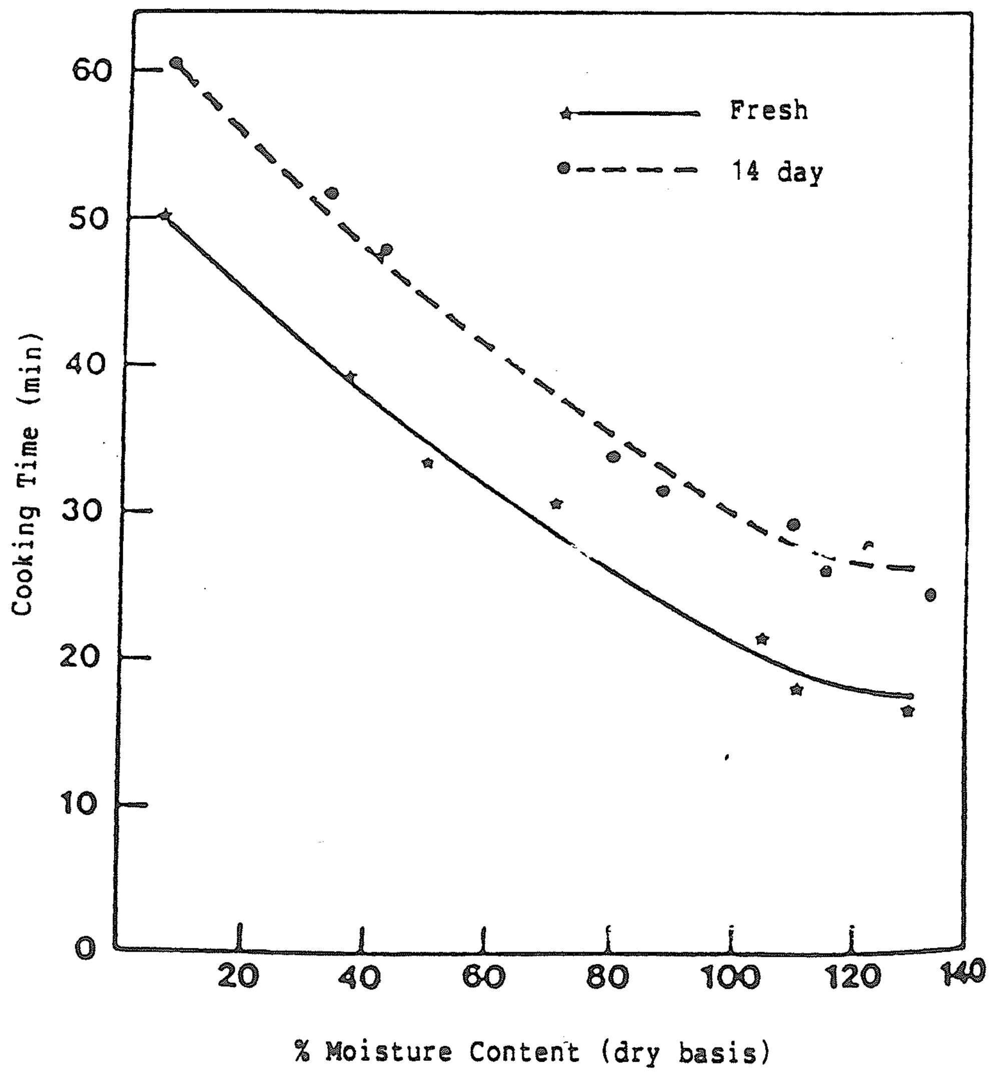


Figure 2.19: Cooking times of fresh and 14-day aged black beans as affected by moisture contents (Jackson and Varriano-Marston, 1981).

TABLE 2.4

Correlation coefficients between parameters investigated (Sefa-Dedeh et al., 1978).

Parameter A	Parameter B	R(A,B)†
1‡	2	0.9295
1	3	-0.9409
1	4	-0.8597
1	5	-0.9493
2	3	-0.9698
2	4	-0.9412
2	5	-0.9832
3	4	0.8532
3	5	0.9593

† 1=soaking time; 2=water absorption; 3=soaked bean texture; 4=cooked bean texture (1/2 scale shear-compression cell); and 5=cooked bean texture (OTMS 10 cm^2 cell).

‡ Significant at $p<0.05$.

and water absorption (Equation 4) were similar to the actual experimental values (Table 2.3). Soaking time and water absorption were shown to be highly negatively correlated to cooked bean texture as measure by an OTMS 10 cm^2 extrusion cell (-0.9493 and -0.9832, respectively) (Table 2.4).

Jones and Boulter (1983) measured the water-holding capacity or the imbibition value of Guatemalan black beans (var S-19-N) after soaking for 18 h. The original moisture content of the beans was taken into account in the calculation of wet weight over dry weight. The imbibition value of the hardbeans was reported to be much lower than that of the soft beans (Jones and Boulter, 1983).

In some bean varieties, however, a higher water absorption capacity was not always correlated with a shorter cooking time (Molina, 1976). The results of Silva et al. (1981) were in agreement with those of Quast and da Silva (1977b) in that the amount of water imbibed by black beans had little or no effect on the degree of cooking once a minimum level of water absorption had been reached. The puncture force of cooked black beans did not correlate well with water absorption (r= 0.155). A study by Quenzer et al. (1978) on pinto beans showed that maximum imbibition did not result in the most tender product.

The lack of agreement among the results of these studies may be due to a lack of standardization in the methodology used to measure water absorption. Consideration of the loss of solids in the gravimetric water uptake method has been inconsistent as has been the method used for the surface drying of the soaked beans. The initial moisture content of the beans should also be considered (Plhak et al., unpublished).

Plhak et al. (unpublished) found that initial moisture content affected the initial rate of water uptake but did not have an effect on equilibrium values. Burr et al. (1968) noted that Pinto beans stored at a high moisture content (16.0%) absorbed water faster than beans stored at low moisture (8.2%). No difference was, however, observed in the rate of water absorption in Sanilac beans stored at 16.0% (high) and

9.0% (low) moisture levels. No explanation was given to explain these results. Both bean types had been stored for 2-1/2 years at $70^{0}F$ ($21^{0}C$) and were soaked in $113^{0}F$ ($45^{0}C$) water (Burr et al., 1968). The rate of water absorption during cooking was evaluated by Burr et al. (1968) following the method of Morris et al. (1950) (i.e., 3 h at $45^{0}C$).

Seedcoat thickness was shown to be important for the water absorption in cowpeas (Sefa-Dedeh and Stanley, 1979b). Using a number of varieties of legume they noted that seeds with thinner seedcoats absorbed water at a faster rate during the first 6 h of soaking. During longer periods of soaking all varieties of legumes absorbed water at approximately the same rate (Sefa-Dedeh and Stanley, 1979a).

2.2 GROWTH TYPES

The growth of the bean plant can be of either the determinate or indeterminate form (Debouck and Hidalgo, 1985). According to studies by CIAT (Centro Internacional de Agricultura Tropical) in Colombia, the growth of the bean plant can be further grouped into four basic types (Figure 2.20). Type I is a determinate bush growth pattern while Type II is an indeterminate bush form. Types III and IV also have indeterminate growth patterns with Type III having a postrate formation and Type IV have a climbing or vine habit. Variations or intermediates of these formations also occur, depending on the growing conditions (Debouck and Hidalgo, 1985). The different types of beans have different quality characteristics that may be important to consumers (Watts et al., 1987).

Determinate	Determinate	Indeterminate	Indeterminate
Bush	Bush	Semi-vine	Vine
Type I	Type II	Type III	Type IV

Figure 2.20: Schemes for the four types of growth patterns. (Debouck and Hidalgo, 1985).

Environmental conditions, such as light and temperature, influence the growth habit of the bean. A particular bean variety can grow in different forms under different conditions (Debouck and Hidalgo, 1985). The photoperiodic effect of light can cause dramatic changes in the plant's growth pattern. Temperature also has an effect which can be compounded by photoperiod (White, 1985). The actual effects of these factors on bean characteristics have not been determined.

2.3 STORAGE CONDITIONS

Controlled storage conditions are essential for the preservation of bean quality. Moisture content of the seeds or relative humidity of the air and storage temperature are the most critical parameters (Morris and Wood, 1956; Muneta, 1964; Kon, 1968; Burr et al., 1968). The cooking qualities of the beans deteriorate very rapidly with elevation of the temperature, particularly at moisture contents of the beans above 10%. Hardshell in beans was promoted by their storage at 25°C and 65-70% RH (Antunes and Sgarbieri, 1979). A study by Hohlberg and Stanley (1987), however, could not duplicate these results. Burr et al. (1968) demonstrated that Pinto beans stored for 7 months at 32°C showed a 14-fold increase in the cooking time, i.e., from 24 to 340 min, whereas storage of the beans with moisture contents below 10% and at 8°C did not affect cooking time even after 2 years (Antunes and Sgarbieri, 1979). An increase in required cooking time was observed in beans held under conditions often encountered in distribution, eg. one year at 70°F and a moisture content below 18% (Burr et al., 1968). Morris and Wood (1956), who used a standard cooking time for each variety, reported that beans with a moisture content above 13% deteriorated significantly in texture as well as flavour after 6 months at 77°F. Beans stored at less than 10% moisture content maintained their cooking quality for 2 years almost as well as control samples stored at -10°F (Burr et al., 1968). Jones and Boulter (1983) obtained hard beans by storing at 34±1°C and 70-75% RH for 6 months.

2.3.1 Hardening

Two types of hardening defects occur in bean cotyledons, which can be distinguished somewhat by imbibitional behaviour. A condition of the cotyledon whereby this portion of the bean does not imbibe water properly has been called sclerema (beans that would not imbibe water even though the seedcoat was scarified or removed) (Gloyer, 1932). The "hard-to-cook" defect, on the other hand, refers to imbibed beans that do not become tender during a reasonable cooking period (Stanley and Aguilera, 1985). It is suggested that this condition is caused by chemical changes during the storage of seeds in high humidity and high temperatures. Agronomic conditions such as fertilizer composition and amounts may also be important.

The second defect, called hardshell, is related to an impermeable seedcoat and related structures. It occurs when beans fail to imbibe a sufficient amount of water during soaking (Stanley and Aguilera, 1985). Hardshell has been shown to be an inheritable physical defect which is only partially affected by agronomic conditions such as storage temperature and humidity (Rolston, 1978; Lebedeff, 1943). Unfavorable environmental factors following planting, such as drought, are recognized as factors that cause a progeny to contain a higher percentage of hardshell beans than would result if normal conditions prevailed during the germination period (Gloyer, 1932; Morris et al., 1950). The climatic conditions under which beans have grown probably affect the degree of hardshell present in a given lot of beans at harvest time. The effect of soils on bean quality should not be overlooked (Morris et al., 1950).

Hardshell can be induced by a rapid drying of the beans (Rolston, 1978). The storage environment is another very important factor that influences degree of hardshell in some varieties of beans. High storage temperature promotes hardshell development. Lower levels of relative humidity in the storage atmosphere increase hardshell (Gloyer, 1928a, 1932; Morris et al., 1950).

2.4 SUMMARY

A variety of instrumental methods have been used to evaluate raw and cooked bean texture. Instrumental testing is relatively quick as compared to sensory testing which is an important consideration if a method is to be of practical use to plant breeders for the evaluation of large numbers of bean lines. Instruments, however, are only useful if they measure properties that are perceived or judged as important by human senses. In the few studies which have correlated instrumental and sensory data, the sensory methodology use has been questionable. Improper training of panelists and the failure to anchor intensity scales used have commonly occurred which prevents results from being considered truly objective and valid. The preparation of samples evaluated by both instrumental and sensory methods can also be criticized. It has been common practice when comparing texture of different bean lines to cook all lines to the same cooking time rather than cooking them to the same degree of doneness before evaluations are made. Valid research relating physical test measurements to sensory perceptions is also lacking. The effect of hardening in stored beans to physical, instrumental and sensory measurements and their relationships should also be investigated further.

Chapter III

MATERIALS AND METHODS

3.1 MATERIALS

Six Guatemalan black bean lines were used in this study. An attempt was made to select two bean lines of each of the three groups or types: bush, semi-vine, and vine, which are grown in Guatemala. Due to the difficulty in obtaining true semi-vine beans, however, the beans were classified as being of either the bush or vine type. The location, condition and type of growth of the 6 lines of Guatemalan black bean (*Phaseolus vulgaris*) samples used in this study are given in Table 3.1. Seventy kilograms of each of the six bean lines used were purchased from their growing location approximately one month after their harvest in December, 1985. The Tamazulapa lot contained beans from two growers. What is known about the beans prior to purchase is shown in Table 3.2.

TABLE 3.1

Location, condition and type of growth of Guatemalan black beans (*Phaseolus vulgaris*) samples.

Variety	Location	Condition	Growth Type	Brilliance
Chichicaste	Jutiapa	native	bush	opaque
Criollo A	Chimaltenango	native	vine	brilliant
Criollo B	Chimaltenango	native	bush	opaque
Itzapa	Chimaltenango	native	vine	brilliant
Sesenteño	Jutiapa	native	bush or semi-vine	opaque
Tamazulapa	Jutiapa	improved (ICTA)	bush	opaque

TABLE 3.2

Pre-experimental handling and initial moisture contents of 6 lines of Guatemalan black beans.

Variety	Drying and storage methods	Arrival moisture content %
Chichicaste	Stored with trash from field	13.84-16.84
Criollo A	Beans dried with the whole plant in the field and stored in a wooden box under roofed structure without walls	15.86-16.84
Criollo B	Beans dried with the whole plant on the patio for approximately 30 days and stored in a plastic container.	16.84-17.61
Itzapa	Not available	16.02-17.15
Sesenteño	Stored with trash from field	13.10-14.20
Tamazulapa	Stored with trash from field	13.45-17.31

3.1.1 Preparation of Materials

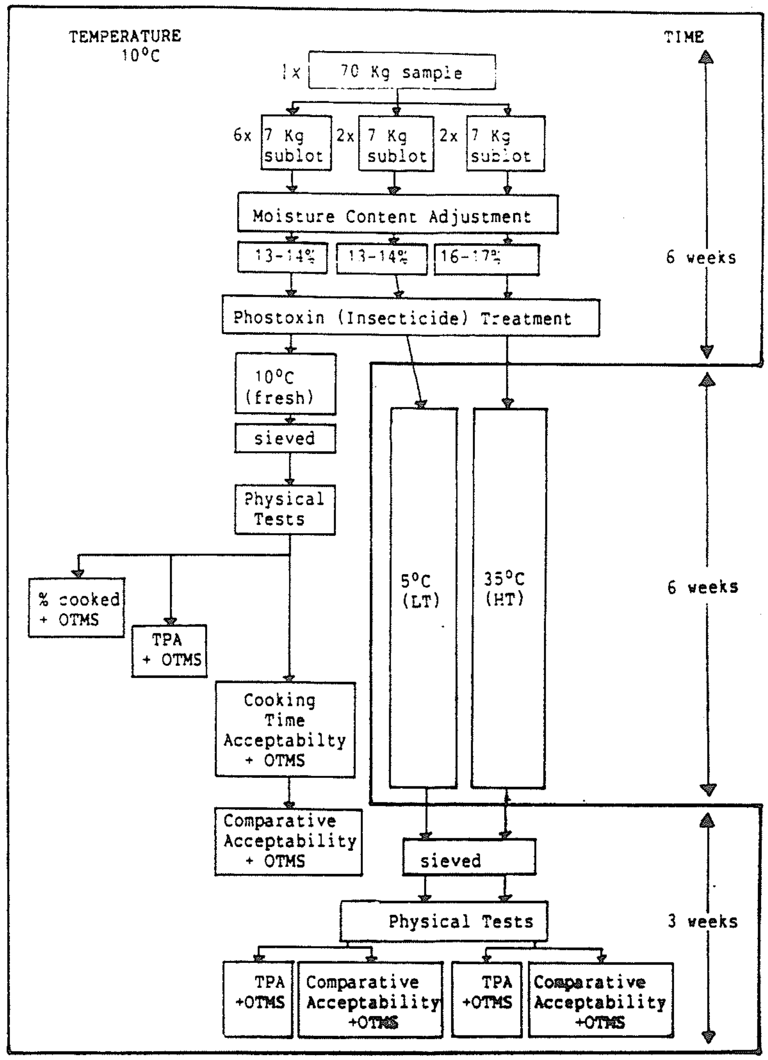
A flow chart describing the preparation of materials is shown in Figure 3.1. The 70 Kg bean lots were each divided into 10 sublots of 7 Kg which were packaged in sealed polyethylene bags. Beans were hand-cleaned to remove broken and diseased seeds and foreign material. The moisture content of each sublot was determined on a 142 g sample using the Dole 400-B Moisture Tester.[1] An insect problem was noted in the Chichicaste, Sesenteño and Tamazulapa lines and consequently these samples

[1] James Dole Corporation, 1400-T Industrial Way, Redwood City, CA. 94063

were given an insolation treatment to remove the insects. The insolation treatment involved spreading the beans out in a single layer on newspaper laid on the roof of the building or on the sidewalk outside of the building in the sunlight for periods of about 4 to 6 hours. This insolation treatment decreased the moisture content of some bean samples to approximately 8%.

The water content of the beans in 8 bags of each bean line was adjusted to be in the range of 13-14%. The water content of the beans in the remaining 2 bags was adjusted to be in the range of 16-17%. Percent moisture readings were taken after each moisture adjusting treatment using the Dole 400-B Moisture Tester. To increase moisture content, beans were spread in a single layer on damp newspaper in a warm oven (50°C) and sprayed at intervals over a 4-6 hour period with distilled water from an atomizer. To decrease moisture, beans were placed out of doors in the sun for a number of hours as required. The fumigant Phostoxin, commonly used for commercially stored beans, was finally applied to all bean lines to eliminate the insect problem which reappeared a few weeks after the insolation treatment.

During these preparatory steps, which required approximately 6 weeks (Figure 3.1), the beans were kept in the basement laboratory where temperatures were cool (10-15°C). Four bags of each bean line, were placed in temperature-controlled storage rooms on March 26, 1986. Two with water contents of 13-14% were placed in a storage room maintained at a temperature of 5°C, while two with water contents of 16-17% were placed in a storage room heated to 35°C. After 6 weeks (May 9, 1986) these sublots were placed in 10°C storage with the remaining 6 bags of each



Physical Tests = for fresh samples includes:
- seed weight
- seed size distribution
- percent seedcoat
- seedcoat thickness
- water absorption
- raw bean hardness (instrumental)

= for stored samples includes:
- seed weight
- seed dimensions
- percent seedcoat
- seedcoat thickness
- water absorption
- raw bean hardness (instrumental)

LT = low temperature - low humidity storage treatment (5°C, 13-14% moisture content)

HT = high temperature - high humidity storage treatment (35°C, 16-17% moisture content)

OTMS = extrusion of cooked beans using the 10 cm^2 extrusion cell of the Ottawa Texture Measuring System

TPA = Texture Profile Analysis Panel

Figure 3.1: Research design.

bean line which were kept in a 10°C-storage room during the entire study.

Before use in physical, instrumental or sensory testing (except during the training of the % cooked panel), each bag of beans was sieved using 11/64, 12/64, 13/64, and 14/64 inch sieves. Beans which remained on the 11/64, 12/64 and 13/64 inch sieves were used in the study, that is, those beans ranging in width from than 11/64 inch to less than 14/64 inch. This procedure aided in the removal of broken seeds , trash and other foreign matter from the sample material.

3.2 PHYSICAL TESTS

Physical tests were run on all six bean lines for all 3 treatments. Seed weight, seed size distribution, percent seedcoat, seedcoat thickness and water absorption determinations were carried out on the fresh samples while seed weight, seed dimensions, percent seedcoat, seedcoat thickness, and water absorption measurements were made on the stored samples. Seed weight, seedcoat percent, 4 hour and 24 hour water absorption determinations were carried out according to the methods used by INCAP (Elías et al., 1986). Seed weight and both water absorption determinations were on an "as is" moisture basis while seedcoat percentage was determined on a dry weight basis. Four replications of these tests were carried out. The distribution of seed sizes within the six bean samples was also determined.

3.2.1 Seed Weight

Seed weight was calculated as the mean weight of 100 randomly selected beans measured on an analytical balance (Elías et al., 1986). Four replications were made on each of the 6 bean lines for all 3 storage treatments.

3.2.2 Seed Dimensions

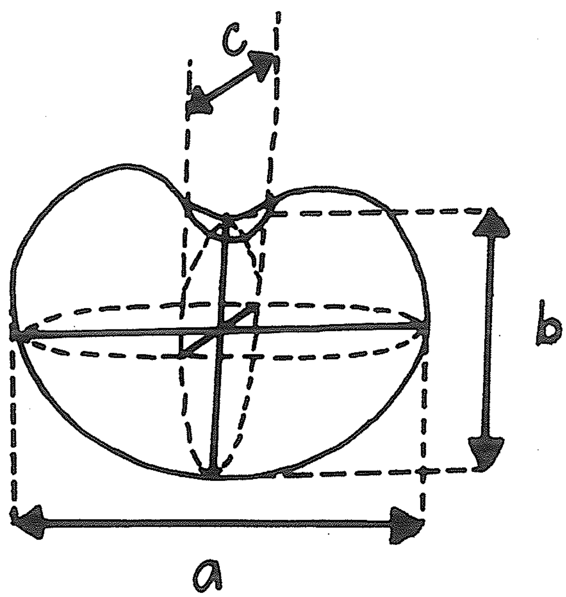
The length, breadth and height of 30 randomly selected beans of each of the 6 bean lines from both the low temperature (LT) and high temperature (HT) storage samples were measured in centimeters to 2 decimal places (Figure 3.2). Seed dimensions measurements were not taken on the fresh samples. Measurements were made with a pair of vernier calipers. Mean measurements for each sample were calculated. Lareo (1986) recommended the use of a nonium or micrometer to obtain measurements in micrometers, however, such instruments were unavailable.

These values were used to calculate surface area (cm^2) where:

$$\text{Surface area} = 2\Pi A^2 + \Pi B^2/E\ [\ln\ (1+E)/(1-E)] \tag{7}$$

where:

$A = a/2$
a = length (cm) (Figure 3.2)
$B = c/2 + b/4$
c = height (cm) (Figure 3.2)
b = breadth (cm) (Figure 3.2)
$E = (A^2 - B^2)^{0.5}/A$



a: Length (cm)
b: Breadth (cm)
c: Thickness (cm)

Figure 3.2: Basic size dimensions measured - for use in seedcoat thickness calculations (Lareo, 1986).

3.2.3 Seed Size Distribution

Seed size distribution was determined using a set of 6 sieves,[2] each 13 in (33.02 cm) in diameter with oblong slots 3/4 in (19 mm) long. Slot widths ranged from 9/64 to 14/64 inch (in increments of 1/64 inch). One raw, unsoaked 7 kg sublot of each of the 6 samples of only the fresh beans was passed through the set of sieves placed on a mechanical shaking device. The weight of beans remaining on each of the six sieves and in the bottom pan were measured to the nearest gram. The percentage of the original total weight that each size represented was determined.

3.2.4 Percent Seedcoat

Percent seedcoat was determined following the method used by INCAP (Elías et al., 1986). Twenty-five beans were taken from a representative sample of 100 g of beans obtained from one 7 kg bag of each of the fresh, LT, and HT storage treatments for all 6 bean lines. The 25 beans were soaked overnight (16-18 h) in 50 mL of room temperature distilled water. The beans were then dried with a paper towel. The seedcoat was removed manually from the cotyledon of each soaked bean. Both the cotyledons and seedcoats were dried in a vacuum oven at 60°C and 25 mm Hg for 4 h. The dry weights of seedcoat and cotyledon were measured to a precision of 0.1 mg after the seed parts had been allowed to cool in a desiccator. The percentage of seedcoat was determined using the following equation:

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[2] The Clipper Grain Seed and Bean Cleaners. Manufactured by A.T. Ferrel & Co. Saginaw, MI.

$$\% \text{ seedcoat} = \frac{\text{Seedcoat dry weight (g)}}{\text{Cotyledon dry wt (g)} + \text{Seedcoat dry wt (g)}} \times 100 \qquad (5)$$

3.2.5 Seedcoat Thickness

Seedcoat thickness was calculated from an equation derived by Lareo (1986) using mean bean size dimensions (length, breadth and height) (from section 3.2.2) (Figure 3.2), mean seed weight (from section 3.2.1) and mean percent seedcoat (from section 3.2.4) for all 6 bean lines under all 3 treatments:

$$\text{Thickness} = \frac{\text{seed weight (mg)} \times \% \text{ seedcoat}/100}{\text{surface area (cm}^2\text{)}} \qquad (6)$$

$$= \text{mg/cm}^2$$

3.2.6 Water Absorption

Percent water absorption was determined after 4 h and 20 h of soaking following the procedure used by INCAP (Elías et al., 1986). A 4 h soaking is commonly used for this method at INCAP while a 20 h soaking is used at the University of Manitoba. Samples from all 6 bean lines under all 3 treatments: fresh and the two storage regimes, were evaluated. Twenty-five beans were removed from a representative 100 g sample for testing. The sample of 25 beans was weighed twice and the mean was recorded (W1). The beans were then soaked in 75 mL of room temperature distilled water for 4 h, towel-dried, and weighed immediately (W2). The beans were replaced into the soaking water for an additional 16 h (for a total soaking time of 20 h), dried with a paper towel and reweighed

(W3). Percent water absorption was calculated using the following equation:

$$\% \text{ Water absorption at 4 h} = \frac{W2 - W1}{W1} \times 100 \qquad (8)$$

$$\% \text{ Water absorption at 20 h} = \frac{W3 - W1}{W1} \times 100 \qquad (9)$$

3.3 INSTRUMENTAL TESTS

3.3.1 Raw Bean Hardness

Unsoaked raw bean hardness was determined using the wedge apparatus mounted on the 100-lb load cell of the Ottawa Texture Measurement System[3] (OTMS). Thirty beans, randomly selected from each bean line and for the fresh and both storage treatments, were used. The peak force required to cut each bean was recorded and averaged for each bean line and each treatment.

The OTMS and the signal conditioner were switched on at least 1/2 h before use to allow them to warm up. The Apple II computer system was turned on just before use. The OTMS-Apple II system was calibrated using 0.5 and 1.0 Kg metal weight balanced on the end of the calibration arm of the OTMS. Weights were converted to Kg force using the calibration factor of 4 as given in the OTMS manual (Agriculture Canada, 1986). Settings for the Apple II testing program[4] were as shown in Table 3.3.

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[3] Canners Machinery Limited. P.O. Box 190, Simcoe, Ontario, Canada.

[4] ESRC Texture Program (1985). Engineering and Statistical Research Institute (ESRI), Canada Agriculture, Ottawa.

TABLE 3.3

Program settings for the Apple II-OTMS system with the 100-lb load cell for measuring raw bean hardness.

Transducer Capacity (Kg)	45.4
Experiment test time (sec)	30
Experiment maximum force (Kg)	20
Crosshead speed (cm/min)	6.6†
Baseline offset	.1
Allowable maximum force (Kg)	42.64

† A crosshead speed of 6.6 cm/min was chosen as this is the setting used with the OTMS at the University of Manitoba.

3.3.2 Cooked Bean Hardness

The hardness of cooked bean samples was determined using a 10-cm^2 extrusion cell[5] and a 1000-lb load cell mounted on the OTMS. This extrusion cell is composed of a box cell with a removable wire grid insert. A chamfered square plate attached to a shaft make up the piston that compresses, shears and extrudes the sample through the grid. The OTMS and the signal conditioner were switched on at least 1/2 h before use to allow them to warm up. The Apple II computer system was turned on just before use. Calibration was performed as described in section 3.3.1. Settings for the Apple II testing program[6] were as shown in Table 3.4.

[5] Canners Machinery Limited. P. O. Box 190, Simcoe, Ontario, Canada.

[6] ESRC Texture Program (1985). Engineering and Statistical Research Institute (ESRI), Canada Agriculture, Ottawa.

TABLE 3.4

Program settings for the Apple II-OTMS system with the 1000-lb load cell for measuring cooked bean hardness.

Transducer Capacity (Kg)	200
Experiment test time (sec)	90
Experiment maximum force (Kg)	30
Crosshead speed (cm/min)	6.6†
Baseline offset	.2
Allowable maximum force (Kg)	134.50

† A crosshead speed of 6.6 cm/min was chosen as this is the setting used with the OTMS at the University of Manitoba.

After calibration the compression plunger was mounted on the moving crosshead of the OTMS. The 10-cm^2 wire grid extrusion cell was mounted on the base. Limits were set on the movement of the crosshead so that descent of the compression plunger would be arrested 1 mm from the wire grids of the extrusion cell plate.

Cooked bean samples of at least 60 g were taken from those cooked for sensory analysis and were drained and placed in covered plastic cups (to reduce sample moisture losses and changes in texture). Samples were tested 1-1/2 to 2 h after cooking had been completed. For each test a thirty-gram sample of beans was placed in the extrusion cell for analysis. The sample was compressed to 1 mm above the wire grid. Peak force (N), firmness (N/mm) and energy to first bite (J) were recorded and a curve of force as a function of time was printed out for each test. All tests were performed in duplicate. The extrusion cell was cleaned out with water and a test tube brush and towel dried after each test.

3.4 SENSORY PANELS

Three sensory panel groups were required for this study. The first panel group, called the % cooked panel, carried out testing to determine cooking times for each of the 6 bean lines which corresponded to varying degrees of doneness. An in-house acceptability panel formed by a second group of panelists, representative of black bean consumers, evaluated acceptability of cooked black bean samples. No extensive training was given to this latter group. The third group of panelists was trained in the procedures of Texture Profile Analysis and characterized the samples for four texture characteristics.

3.4.1 Panel Selection for Trained Panels

Panelists were selected from staff and students of the Institute of Nutrition of Central America and Panama (INCAP) in Guatemala City, Guatemala, Central America. Approximately 40 people completed questionnaires giving information on their interest in participation, the presence of physical problems, food and flavour likes and dislikes and time availability. The questionnaire is shown in Appendix A.

Thirty-one persons who were able to attend the selection sessions were screened for their sensory acuity. Five exercises in all were carried out including recognition tests for the four basic tastes, for 10 selected odour compounds, and for 10 selected flavourants; tests for aroma perception and recognition, and for use of a hardness-texture scale. Although the focus of this project was the evaluation of texture, testing was done on the other senses in order to introduce panelists to the basic concepts of sensory analysis. The newly constructed sensory facilities at INCAP, Guatemala, were used for the first time in this experiment. Samples with varying concentrations of sucrose, sodium chloride, citric acid and caffeine were presented for identification in the four basic tastes test. Panelists were asked to identify or describe the odour present in a number of samples in the odour recognition test. A number of fruit flavours in odd-coloured liquids were presented for identification in the flavour recognition test. The physiology of aroma perception was demonstrated through an exercise in which panelists were asked to identify samples of red wine and unsweetened black coffee with their eyes closed and their noses pinched shut. Panelists were asked to identify different fruit flavours by sniffing and smelling (aroma recognition test). Food samples varying in hardness (cream cheese, cooked egg white, cheddar cheese, olive, peanuts, carrots and hard candy) were presented to panelists who were asked to rank them in order of degree of hardness. A detailed description of testing procedures as well as ballots can be found in Appendix B.

Twenty-two panelists were selected, on the basis of these tests as well as on the panelists' availability to participate in the rest of the study. These panelists were divided into two groups, one to serve on the % cooked panel, and the second on the texture profile panel. As the % cooked panel met in the morning and the TPA panel in the afternoon, the division of panelists was based on availability.

3.4.2 Panel Selection for In-house Acceptability Panel

Approximately 40 staff and students from a number of departments at INCAP were involved as panelists in the in-house acceptability panel. Requirements for participation in this panel were availability and literacy. Although panelists were not asked directly if they were bean eaters, it was assumed, based on the fact that black beans are a staple food item in the Guatemalan diet (Bressani and Elías, 1977), that they were.

3.4.3 % Cooked Panel

The purpose of the % cooked panel was to identify cooking times that corresponded to the 50, 70, 90 and 100% cooked stages, and to an extended cooked stage, for each of the 6 fresh samples of Guatemalan black beans. These cooking times were used to prepare the samples for the acceptability and texture profile panels. Approximate cooking times were determined through preliminary testing by the % cooked panel and were confirmed through replicated testing by the % cooked panel, in which the 5 cooking times for each of the 6 bean lines were evaluated 3 times.

Fifteen panelists served on the % cooked panel. During each panel session panelists were presented with fresh beans of one bean line only, cooked for 5 cooking times. Panelists were asked to test samples of 10 beans from each of the 5 cooking times and indicate the number of cooked and the number of uncooked beans in each sample. Panelists were trained to base their judgements on characteristics of cotyledon texture, such as smoothness and starchiness, using methods previously developed by panelists in the Department of Foods and Nutrition, University of Manitoba and later modified by the Guatemalan panel. The ballot used by the Guatemalan panel to determine "% cooked" is given in Appendix C. The English version is in Figure 3.3.

Name:__________________________

Date:__________________________

Black Bean Texture

Instructions:

Evaluate 10 beans at random from each sample and record on the ballot the numbers that you consider, according to the following method, are "cooked" or "undercooked".

Method:

1. Place 1 bean between your molars (back teeth) and bite down on it.

2. Press the same bean onto the roof of your mouth with your tongue.

3. Consider the bean "cooked" if when you bite down on it, it is soft and when you press it onto the roof of your mouth the bean texture is smooth and not starchy.

Sample Code	# of beans UNDERCOOKED	# of beans COOKED

Comments:

Gracias

Figure 3.3: English translation of the % cooked ballot used in Guatemala.

3.4.4 Texture Profile Panel

The texture profile panel (TPA) was composed of 12 panelists. Five panelists served on both the TPA and % cooked panels. Initial training of this panel was conducted in the same way as the training for the % cooked panel. The cooked bean samples presented in the training session of the TPA panel were those which were to be used for the rest of the study and thus provided the range of intensity of the characteristics that would be found in the remainder of the study. Usually only 2 textural characteristics and 3 bean samples were involved in each session of panel training. Nine sessions, of approximately 30 to 45 minutes, were held to train panelists with regards to the TPA methodology. Training was considered adequate when panelists were in agreement with regards to vocabulary, use of the line scale and food standards, evaluation techniques and rating of samples.

The ballot and the accompanying definitions used for evaluating the textural characteristics of cooked black beans were developed by a trained sensory panel in the Department of Foods and Nutrition, University of Manitoba and translated into Spanish for use in Guatemala (Figure 3.4, 3.5 and Appendices D and E, respectively). The Guatemalan panelists agreed that hardness of the whole bean, particle size of the cotyledon, skin toughness and chewiness of the whole bean were were important in evaluating cooked bean texture, as had been determined by the Manitoba panelists.

An unstructured line scale was used to evaluate 3 of the 4 characteristics: hardness, particle size, and skin toughness. Food reference standards (not beans) were used to anchor the endpoints of the line

Name: ________________________

Date: ________________________

TEXTURE EVALUATION OF BEANS

Using the techniques provided in the definitions for evaluating texture, evaluate the samples according to the following parameters. First, evaluate the standard samples to establish reference points, and then evaluate the coded samples and mark the relative intensity of the coded bean samples on each scale.

INITIAL BITE

HARDNESS

soft (cream cheese) — hard (Almond) (or parmesan cheese)

MASTICATORY PHASE

PARTICLE SIZE

smooth (butter) — chunky (chopped peanuts)

SKIN TOUGHNESS

soft barely distinguishable from cotyledons — tough, leathery

CHEWINESS

Sample code	Number of chews
____	____
____	____
____	____
____	____

Figure 3.4: English translation of Texture Profile Analysis ballot used in Guatemala.

DEFINITIONS FOR EVALUATING TEXTURAL PARAMETERS

HARDNESS	- Bite down once with the molar teeth on the sample of beans (2) and evaluate the force required to penetrate the sample.
PARTICLE SIZE	- Chew the sample (2 beans) for 2-3 chews only between the molar teeth, and then rub the cotyledon between tongue and palate and assess the size of the particles which are most apparent.
SKIN TOUGHNESS	- Separate the skin from the cotyledon by biting the beans (2) between the molar teeth and rubbing the cotyledon out between the tongue and palate. Then evaluate the force required to bite through the skin with the front teeth.
CHEWINESS	- Place a sample of beans (2) in your mouth and chew at a constant rate (1 chew per second), counting the number of chews until the sample is ready for swallowing.

Figure 3.5: English translation of definitions used for the four characteristics evaluated by the Guatelamalan texture analysis panel.

scales, and an additional midpoint reference standard was provided for the hardness and particle size scales (Table 3.5). The position of the midpoint reference standard was not fixed on the line. Panelists indicated their rating for these characteristics by placing a vertical line on the line scale at the point representing the perceived score for that attribute. The fourth characteristic, chewiness, was evaluated by counting the number of chews required before the sample was ready to be swallowed.

At each panel session each panelist was presented with a ballot, a list of definitions, the food standards and the 5 or 6 cooked bean samples to be evaluated. After the ballots were completed, the panelists determined their own scores for hardness, particle size and seedcoat toughness by placing scaled transparent templates over the line scales. The line scales were thus divided into equal intervals from 0 to 30 from which a score for a particular sample could be obtained. Panelists' results during the training session were written on the board for comparison and discussion purposes but the results of later sessions were not.

TABLE 3.5

Preparation of food reference standards for the Texture Profile Analysis (TPA) of cooked bean texture ballot.

Characteristic	Reference sample
Hardness	soft - cream cheese - Parma brand - cut into 1 cm cubes, kept in refrigerator until just before serving.
	medium - cheddar cheese - cut into 1 cm cubes, kept in refrigerator until just before serving.
	hard - parmesan cheese - Paiz brand - unpackaged, cut into 1 cm cubes. - whole almond†
Particle Size	smooth - butter - cut in 1 cm cubes, kept in refrigerator until just before serving.
	medium - cream of wheat (instant) - prepared according to package directions, cooled and kept refrigerated until just before serving.
	chunky - chopped peanuts (unsalted, dry-roasted)- chopped coarsely in a blender and sieved - small pieces being discarded.
Skin Toughness	soft - white beans - cooked for 180 minutes.
	tough - red beans - cooked for 140 minutes.

† A whole almond replaced a cube of parmesan cheese as the standard for hard on the hardness scale after a few panel sessions when it was evident that the hardness of the cheese was too inconsistent.

3.4.5 In-house Acceptability Panel

The in-house acceptability panel was composed of forty panelists. Six acceptability panels were held, called cooking time acceptability panels, each evaluating 1 of the 6 lines of fresh beans cooked to 5 different cooking times. The 5 different cooking times used for each bean line were those determined by the % cooked panel to provide 50, 75, 90, 100% cooked and an extended cooked sample. The purpose of this panel was to identify sample or samples which were acceptably cooked for each of the 6 lines. Panelists were given basic instructions on how to fill out the ballot. Panelists were asked to indicate how acceptable the textures of each of the 5 cooked beans samples were using an 8-point category scale with 1 = extremely unacceptable and 8 = extremely acceptable. The English translation of the ballot used is shown in Figure 3.6. The original ballot used in Guatemala is found in Appendix F. Panelists based their decisions on a sample of 10-15 beans. The mean value was calculated from all panelists' scores for each sample and were compared using the Kruskal-Wallis one-way ANOVA procedure based on a significance of 5%.

A seventh acceptability panel, called the comparative acceptability panel, was carried out involving all 6 lines of fresh beans. A samples of each line, cooked to a comparable stage of doneness as determined from the cooking time acceptability panel data, was presented to each panelist. These samples were rated using a ballot which was similar to Figure 3.6 but had space for the evaluation of 6 samples rather than 5.

Comparative acceptability panels were also carried out using the stored samples of black beans. Low temperature and high temperature stored sets were evaluated in two separate panels.

Name:____________________

Date:____________________

Product: Cooked Black Beans

Please taste each of following samples of beans. Check off the category which best describes your assessment of the cooked texture. Try to give a reason or comment if you did not like the texture of a sample.

Sample Code	Extremely Acceptable Cooked Texture	Very Acceptable Cooked Texture	Moderately Acceptable Cooked Texture	Slightly Acceptable Cooked Texture	Slightly Unacceptable Cooked Texture	Moderately Unacceptable Cooked Texture	Very Unacceptable Cooked Texture	Extremely Unacceptable Cooked Texture	Comments

Figure 3.6: English translation of in-house acceptability ballot.

3.5 PREPARATION AND PRESENTATION OF SAMPLES FOR SENSORY TESTING

Beans used in this study were not given a soaking treatment before cooking to permit a better comparison between laboratory technique and actual practice in Guatemala. Only 15% of the 600 Guatemalan consumers surveyed by Watts et al. (1987) soaked their beans before cooking. Watts et al. (1987) suggested that the custom of not soaking black beans before cooking them may be due to the poor quality of the water and to fermentation during the soaking period.

Five 190 g samples of unsoaked beans were prepared for each texture profile panel. The five 190-g samples were taken from the upper middle portion of the bag of beans. The 190 g samples were washed in tapwater, placed in a 1.5 L Corningware "Visions" pots, and covered with 1000 mL of distilled water. Each pot was coded with a 3-digit random number and the time that the sample was to begin boiling. Each pot was heated on an element of an electric stove at high power until the water began to boil. A pot full of room-temperature distilled water and beans required 10 minutes on high power to come to a boil. The heat was then reduced to a low setting ("1 notch above low") such that the water and beans remained simmering throughout the cooking period. The starting times for each pot of beans were staggered so that all 5 samples reached the completion of their cooking period at the same time (10 minutes before the scheduled panel session). The original level of water in each pot was maintained at the level of the base of the handle of the pot by the occasional addition of simmering distilled water. A full pot of distilled water was kept simmering specifically for this purpose throughout the entire period of time that samples were being cooked. The beans were stirred at least every 1/2 hour to prevent them from adhering to and burning on the bottom of the pot.

One hundred and ten g of unsoaked beans were required for each in-house acceptability panel. When the in-house acceptability panels were run in conjunction with the texture profile panel, 300 g of unsoaked beans were cooked to provide sufficient sample for both (110 + 190 g). Beans for the in-house acceptability and texture profile panels were cooked as described above for the texture panel. Less than 1000 mL of distilled water, however, was required to fill the pot to the required level. When the bean samples completed their cooking period their broth was drained from them using a metal sieve and discarded. Drained beans were replaced into their respective pots, covered and set on the counter next to the appropriate 3-digit coded sample cups.

Portions of fifteen to twenty beans were placed in each coded styrofoam cup (60 mL) for the % cooked and Texture Profile Analysis. For the acceptability panels, each coded cup contained a sample of at least 30 beans. The five coded samples were presented to the panelists in a tortillera (a styrofoam dish [10 cm in diameter, 6 cm high] with a tight-fitting styrofoam lid) at each % cooked, Texture Profile Analysis and cooking-time acceptability panel. Six coded samples were presented to the comparative acceptability panels. Only four to six sets of samples were prepared at one time, in assembly-line fashion, in an attempt to reduce the heat loss by the bean samples. A tray containing a sample-filled tortillera and a ballot was placed in front of each panelist. Pencils, napkins, water and expectoration cups, and pitchers of distilled water were available at the table or booth.

The Texture Profile Analysis and % cooked panels were carried out under fluorescent lighting in a sensory panel room at INCAP. For all sessions for both panels, the panelists evaluated the samples while sitting around a large table. The in-house acceptability panel members evaluated samples under red light while sitting in individual booths in the sensory panel room.

Samples were evaluated by the panelists in a randomized order as indicated on each ballot. The results from each panelist in the % cooked panel were combined to determine the average % cooked value for each of the 5 samples presented. The results for each bean line were plotted as percent cooked as a function of cooking time. Such graphs were displayed to allow the panelists the opportunity to see their progress. The results from the Texture Profile Analysis (TPA) and the in-house acceptability panels were not displayed.

3.6 STATISTICAL ANALYSIS

The data from this study were analyzed using the programs of the Statistical Analysis System (SAS) (SAS, 1985). For the physical measurements of seed weight, seed size dimensions, and the instrumental test of raw bean hardness, the means and standard deviations were determined from 30 observations from each sample. The means and standard deviations of percent seedcoat and 4h and 24 h water absorptions percentages were calculated from the 4 determinations for each sample. Means and standard deviations were calculated using Proc Means procedures (SAS, 1985).

Means for all cooking time samples were calculated from preliminary and actual testing by the % cooked panel by hand calculator. The distributions of individual scores for panelists on the cooking time and comparative acceptability panels was prepared using Proc Chart (SAS, 1985). The relationships between cooking time and mean acceptability scores were determined using Proc GLM procedures (SAS, 1985). The relationships between cooking time and OTMS extrusion peak force values were determined using Proc Reg (SAS, 1985). The relationships between acceptability score and OTMS extrusion peak force values were calculated using Proc Means and Proc GLM procedures (SAS, 1985). Proc Means and Proc Reg procedures (SAS, 1985) were used to determine the relationships between TPA characteristics and mean acceptability scores, OTMS extrusion peak forces and cooking times. Prediction lines for all relationships investigated were drawn using Proc GPLOT (SAS, 1985). Where prediction lines were parallel, comparisons among the bean lines were carried out using the Bonferroni (Dunn) T-test procedure (SAS, 1985).

Proc ANOVA (SAS, 1985) was used to perform analysis of variance on in-house acceptability panel results for both fresh and stored beans to determine the effect of cooking time on mean acceptability score. Bonferroni procedures (SAS, 1985) were used to compare means. Proc ANOVA (SAS, 1985) was also used to analyze TPA panel results.

Variance among the TPA panel scores during training was determined using Proc Means and Proc Discrim (SAS, 1985). SAS (1985) Proc Rank procedures were carried out on TPA panel results to show if panelists were ranking samples in the same order. Consistency of judgement for individual TPA panelists was expressed by the coefficient of variation calculated using Proc Means procedures (SAS, 1985).

SAS (1985) Proc Means and Proc Corr procedures were used to determine Pearson correlation coefficients among data from instrumental, physical and sensory testing.

Chapter IV

RESULTS AND DISCUSSION

The data obtained from the fresh samples will be reported separately from those of the 2 storage regimes. Results will be grouped under the headings of physical tests, sensory analysis and instrumental tests.

4.1 PHYSICAL TESTS

All physical measurements, except seed dimensions were made on the fresh samples. Mean dimensions of the low temperature-low humidity (LT) stored samples were used for the data reported in Table 4.1.

4.1.1 Seed Weight

The mean 100-bean weight for the 6 lines of fresh samples of beans ranged from 20.33 g for the Tamazulapa sample to 28.74 g for an Itzapa bean (Table 4.1). When size categories used by INCAP (Elías et al., 1986) were adjusted to refer to 100-bean weights rather than single beans, Tamazulapa was classified as a medium-size bean sample with a mean 100-bean weight (20.33) which fell between the 19.30 and 21.70 g range for a medium size bean. The other 5 bean lines were considered to be large-grained as their mean 100-bean weights were all greater than 21.70 g. Sesenteño was the smallest of the large-grained lines with a 100-bean weight of 23.67 g. The Chichicaste beans were a little larger (24.46 g) followed by Criollo A and Criollo B, which had similar 100-bean weight means (26.14 and 26.28 g, respectively). The three samples with the largest proportion of small beans were bush type beans from the Jutiapa region (Tamazulapa, Sesenteño and Chichicaste). Those grown in the Chimaltenango region (Criollo A, Criollo B and Itzapa) contained a higher proportion of large-sized beans. Criollo A and Itzapa were vine beans while Criollo B was a bush type.

The 100-bean weights of 10 dry bean cultivars of <u>Phaseolus vulgaris</u> L. were determined by Deshpande et al. (1984). The weight of 100 beans ranged from 15.03 to 50.33 g. The seed weight of the bean lines used in the present study fell into the general range of seed weights for beans as reported by Deshpande et al. (1984). White (1985) reported the 100-bean weights of 5 black bean varieties. The three indeterminate bush varieties (Type II) had the lowest weight (18 to 21 g). The indeterminate vine variety (Type IV) had a 100-bean weight of 21 g. The variety with the highest 100-bean weight of the five samples, at 23 g, had a Type III or indeterminate semi-vine habit (White, 1985). Three of the four bush type beans used in the present study (Chichicaste, Sesenteño and Tamazulapa) had lower mean seed weights than the vine type of beans, represented by the Criollo A and Itzapa samples. Criollo B, a bush bean had, however, a slightly higher seed weight than the Criollo A (vine) sample.

TABLE 4.1

Physical properties for 6 lines of fresh samples of Guatemalan black beans.

Bean line	100-bean weight† (g)	Dimensions (cm)‡ Length	Breadth	Thickness	L/B ratio‡	Seedcoat percent†	Seedcoat thickness‡* (mg/cm^2)	Water absorption percent†** 4 hr	24 hr
Chichicaste	24.46±0.52	1.135±0.067	0.673±0.028	0.485±0.026	1.69	8.77±0.05	6.6	89.7±4.1	102.1±2.7
Criollo A	26.14±0.12	1.130±0.055	0.713±0.036	0.496±0.024	1.58	9.73±0.12	7.7	7.1±1.3	93.0±4.0
Criollo B	26.28±0.39	1.065±0.060	0.686±0.035	0.487±0.031	1.55	9.70±0.11	8.4	6.9±2.0	94.0±1.6
Itzapa	28.74±0.82	1.144±0.048	0.769±0.041	0.487±0.028	1.49	9.62±0.20	8.1	3.6±1.7	100.1±1.3
Sesenteno	23.67±0.67	1.084±0.055	0.650±0.031	0.469±0.022	1.69	9.10±0.10	6.7	88.1±1.6	99.6±1.9
Tamazulapa	20.33±0.49	0.939±0.044	0.655±0.030	0.470±0.021	1.43	9.48±0.19	8.0	85.7±2.3	103.2±1.5

† Means and standard deviations based on 4 determinations.

‡ Means and standard deviations based on determinations from 30 beans.

* Freshly-harvested samples after storage under low temperature-low humidity (LT) conditions.

** Based on an original water content of 13-14%.

4.1.2 Seed Dimensions

Average measurements for length, breadth and thickness for the 6 lines of black beans are listed in Table 4.1 and were used to calculate seedcoat thickness (section 4.1.5). Actual dimensions were not taken of fresh bean samples. The measurements taken on low temperature-low humidity bean samples were used for the fresh samples and used in conjunction with seed weight and percent seedcoat data from fresh samples to calculate seedcoat thickness values for the fresh samples.

The Tamazulapa sample had the smallest measurements of all samples for all three dimensions (0.938, 0.655, and 0.470 cm, respectively, for length, breadth and thickness) while Itzapa had the largest measurements for the length (1.144 cm) and breadth (0.769 cm) dimensions.

An unspecified variety of black beans used in a study by Quast and da Silva (1977a) had mean length, breadth and thickness measurements of 0.96, 0.61 and 0.41 cm, respectively. All bean lines studied had larger measurements for breadth and thickness dimensions than the variety used by Quast and da Silva (1977a). Only the Tamazulapa sample had a smaller length measurement.

The shape of the beans is indicated by the length/breadth (L/B) ratio. Lower L/B ratios correspond to rounder seeds while more slender seeds have higher L/B ratios (Deshpande et al., 1984). The length-to-breadth (L/B) ratios for the 6 bean lines are listed in Table 4.1 and ranged from 1.43 (Tamazulapa) to 1.69 (Chichicaste and Sesenteño). Shape did not seem to be related to bean type or growing location.

Deshpande et al. (1984) determined the L/B ratios of ten cultivars of dry beans (Phaseolus vulgaris L.). Length/breadth ratios ranged from 1.37 to greater than 2.0, with 8 of the 10 cultivars have ratios between 1.51 and 1.65. The 6 samples used in the present study provided a relatively wide range of shapes, considering the smaller sample size, although the range of L/B ratios was within those reported by Deshpande et al. (1984).

4.1.3 Seed Size Distribution

The seed size distributions of unsoaked raw 7 kg black bean samples of the 6 lines of fresh samples are shown in the form of bar graphs in Figure 4.1. Itzapa contained the highest proportion of large beans, followed by Criollo B. Both of these samples were from the Chimaltenango area. Chichicaste and Criollo A had similar distributions of seed sizes. The Sesenteño and Tamazulapa samples seemed to be generally composed of smaller beans than the other samples, with Tamazulapa having the highest proportion of the smallest beans. Both Sesenteño and Tamazulapa are classified as bush beans. Beans grown in the Chimaltenango region tended to have a higher proportion of large-sized beans (Itzapa and Criollo B) than those samples grown in the Jutiapa region (Chichicaste, Sesenteño and Tamazulapa). In general, the bush beans tended to be composed of smaller seeds than the vine samples.

Using the reference values developed by INCAP to classify the beans by their sizes aids in the evaluation of the beans in this study (Table 4.2). The lower critical values of 3.18 mm (8/64 in) used to define the small- from the medium-sizes beans was adjusted to 3.57 mm (9/64 in) to accommodate the data. Since a 3.18 mm (8/64 in) sieve was not available

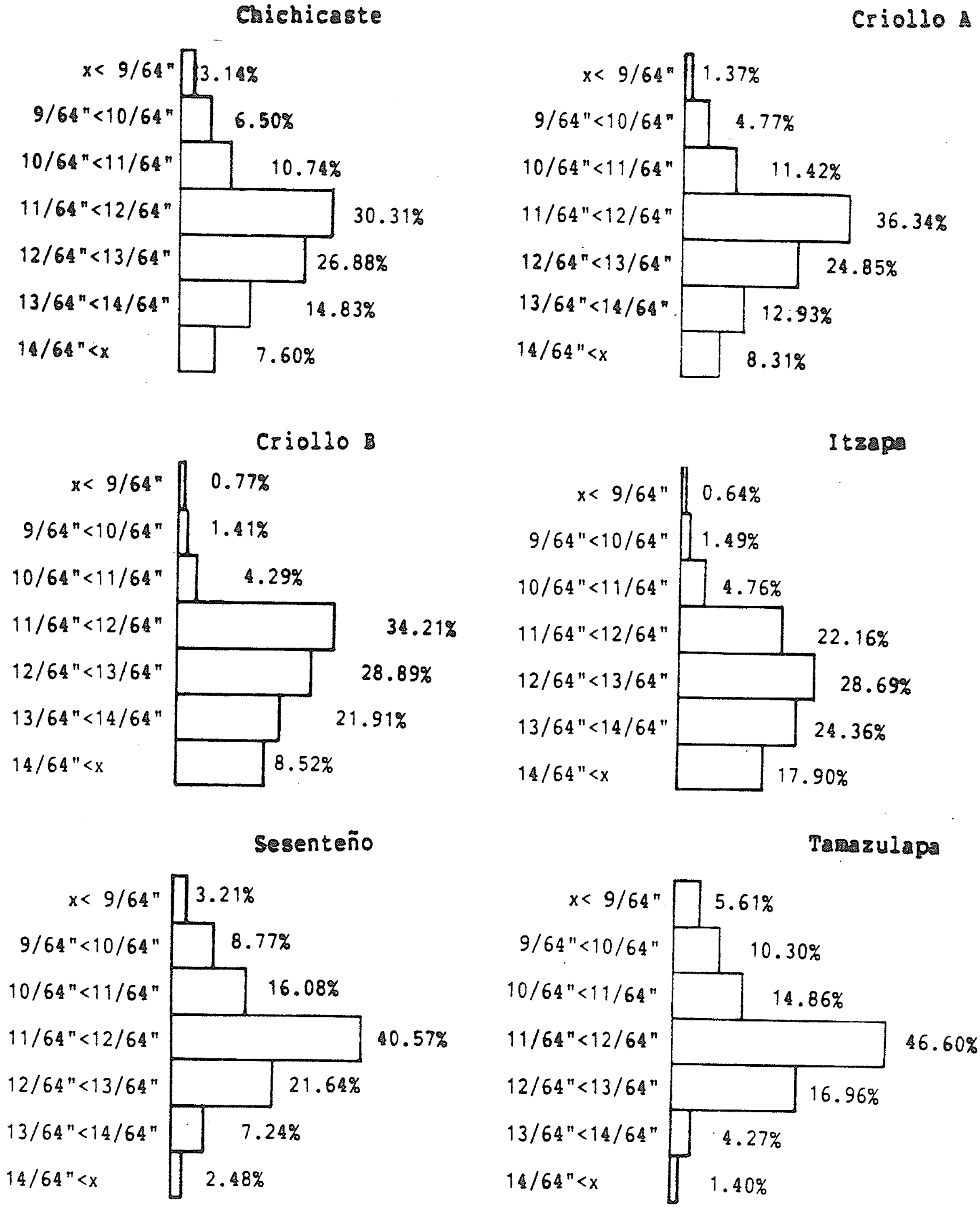

Figure 4.1: Bar graphs showing the seed size distribution for each of the 6 lines of samples of Guatemalan black beans.

for use in this study the beans that passed through the smallest sieve available (3.57 mm [9/64 in]) represented the smallest classification.

The Itzapa sample contained the highest proportion of large beans (70.95%) followed by Criollo B (59.32%). Both Chichicaste and Criollo A contained approximately one-half large- (49.31% and 46.09%, respectively) and one-half medium-sized beans (47.55% and 52.53%, respectively). Almost two-thirds (65.42%) of the Sesenteño sample was composed of medium-sized beans while almost one-third (31.36%) were large-sized. The largest portion (almost three-quarters) of the Tamazulapa sample were medium-sized beans (71.76%). Tamazulapa had the highest percentage of small beans (5.61%) followed by Sesenteño (3.21%) and Chichicaste (3.14%). The Criollo A sample contained 1.37% small beans while Criollo B and Itzapa had less than 1% (0.77% and 0.64%, respectively).

TABLE 4.2

Classification of the 6 lines of fresh samples of Guatemalan black beans using reference values for size categories (Elías et al., 1986).

	Percentage		
Bean line	Small†	Medium‡	Large*
Chichicaste	3.14	47.55	49.31
Criollo A	1.37	52.53	46.09
Criollo B	0.77	39.91	59.32
Itzapa	0.64	28.41	70.95
Sesenteño	3.21	65.42	31.36
Tamazulapa	5.61	71.76	22.63

† Small - beans ≤ 9/64 in (3.57 mm)

‡ Medium - beans larger than 9/64 in (3.57 mm) but smaller or equal to 12/64 in (4.76 mm)

* Large: beans larger than 12/64 in (4.76 mm) (Elías et al., 1986).

4.1.4 Percent Seedcoat

The percent seedcoat values for the 6 lines of fresh samples are shown in Table 4.1. Percent seedcoat values ranged from 8.77% for the Chichicaste sample to 9.73% for the Criollo A sample. In general, the seedcoat of the bean is approximately 9% of the total dry weight of the seed (Debouck and Hidalgo, 1985). All bean lines' seedcoat percentages approximated this reported value. Criollo B and Itzapa samples had similar seedcoat percentages (9.70% and 9.62%, respectively) to Criollo A. The Tamazulapa sample had a slightly lower percent seedcoat (9.48%), followed by the Sesenteño sample (9.19%). The three samples from the Chimaltenango region (Criollo A, Criollo B and Itzapa) and the Tamazulapa sample had similar values which were higher than the Chichicaste and Sesenteño samples (grown in Jutiapa).

4.1.5 Seedcoat Thickness

Seedcoat thickness or seedcoat amount (mg/cm^2) for the 6 lines of fresh samples is reported in Table 4.1. Thickness values ranged from 6.6 mg/cm^2 for Chichicaste to 8.4 mg/cm^2 for Criollo B. Chichicaste and Sesenteño had similar seedcoat thicknesses (6.6 and 6.7 mg/cm^2, respectively). The thickness of Criollo A's seedcoat was higher (7.7 mg/cm^2) than those for Chichicaste and Sesenteño. Tamazulapa and Itzapa had seedcoats with similar thickness values (8.0 and 8.1 mg/cm^2, respectively. Seedcoat thickness values did not seem to be related either to bean type or growing location.

4.1.6 Water Absorption

Percent water absorption was determined after 4 h and 20 h of soaking on 6 lines of fresh black bean samples. The three bean lines grown in the Chimaltenango region, Criollo A, Criollo B and Itzapa had lower levels of water absorption at 4 h than those of the Chichicaste, Sesenteño and Tamazulapa samples from Jutiapa (Table 4.1). At 24 h Criollo A, Criollo B and Sesenteño had the lowest water absorption levels. The Criollo A, Criollo B and Itzapa samples had water absorption percentages of 3.6 to 7.1% at 4 h and 93.0 to 100.1% at 24 h. Water absorption values of Chichicaste, Sesenteño and Tamazulapa samples ranged from 85.7 to 89.7% at 4 h and 99.6 to 103.2% at 24 h. The three Chimaltenango bean lines had slower water absorption rates than the beans from the Jutiapa region.

Deshpande et al. (1984), in an investigation of the physical properties of 10 common bean cultivars, found that water uptake rates during the first 6 h of soaking were characteristic of the cultivar. They noted, however, by the end of the 24 h soaking period, that similar amounts of water (approximately 1 g/g bean) had been absorbed by all cultivars (Deshpande et al., 1984). In the current study, the water absorption values obtained after 4 h soaking allowed a grouping of similar bean lines to be made which was not apparent at 24 h for these 6 lines.

Vine beans generally have lower water absorption percentages than bush beans (García-Soto, 1986). At 4 h, two of the three lines with the lowest water absorption were the vine type beans (Criollo A and Itzapa). After 24 h of soaking, Criollo A had the lowest and Itzapa the fourth lowest water absorption values.

In a study using cowpeas, Sefa-Dedeh and Stanley (1979b) noted the importance of seedcoat thickness to water absorption. Using a variety of legume species it was observed that within a species seeds with thinner seedcoats absorbed water more rapidly during the initial 6 h of soaking. For longer periods of soaking, all species had similar rates of water absorption (Sefa-Dedeh and Stanley, 1979a).

The two bean lines with the lowest seedcoat thickness values (Chichicaste with 6.6 mg/cm^2 and Sesenteño with 6.7 mg/cm^2) had the highest water absorption values at 4 h. Criollo B and Itzapa, which had the highest seedcoat thickness values (8.4 and 8.1 mg/cm^2, respectively) had the lowest 4 h water absorption percentages (6.9 and 3.6%, respectively). The Criollo A samples had a relatively thick seedcoat with a seedcoat thickness value of 7.7 mg/cm^2 which corresponded to a low 4 h water absorption level of 7.1%. The Tamazulapa sample did not follow this pattern in that it had a high seedcoat thickness (8.0 mg/cm^2) and a high water absorption level at 4 h. After 24 h of soaking the pattern between seedcoat thickness and water absorption was not well-defined as the water absorption levels of all 6 bean lines were similar.

4.2 SENSORY ANALYSIS

4.2.1 Cooking Time Determination

Fresh samples of the 6 black bean lines were cooked to various cooking times and presented to the % cooked panel which identified the samples cooked to 50, 75, 90, and 100% cooked. Table 4.3 shows the cooking times determined by the % cooked panel that corresponded to 5 degrees of doneness: 50, 75, 90, 100% and an extended cooking stage. The extended cooking stage was obtained by cooking the bean sample approximately 60 minutes beyond the time required to cook the beans to the 100% stage. The cooking times that corresponded to these 5 degrees of doneness differed for the 6 bean lines.

TABLE 4.3

Cooking times required to give 50, 75, 90, 100% and extended cooking samples for 6 lines of fresh samples of Guatemalan black beans.

	Cooking Stage				
Bean line	50%	75%	90%	100%	Extended Cooking[1]
Chichicaste	60†	95	155	240	300
Criollo A	100	140	170	240	300
Criollo B	90	155	205	240	300
Itzapa	95	120	180	225	300
Sesenteño	90	100	170	240	300
Tamazulapa	90	110	150	200	250

[1] Cooked approximately 60 minutes beyond the time required for 100% cooked.

† Cooking time in minutes.

4.2.2 In-house Cooking Time Acceptability Panel

Samples of each of the 6 lines of fresh beans cooked to 5 degrees of doneness, based on cooking times determined by the % cooked panel, were presented to the in-house cooking time acceptability panel for evaluation. The distribution of individual scores for panelists on the cooking time acceptability panel is shown in Appendix G for each bean line cooked to five cooking times.

A linear relationship was shown to exist between cooking time and acceptability scores for each variety (Table 4.4). The prediction lines for the bean lines were parallel and thus a comparison among the 6 bean lines could be made using the Bonferroni test (SAS, 1985). Sesenteño and Tamazulapa were not significantly different from each other with regard to their cooking time to cooking time acceptability score relationship, α=0.05, but both were significantly different from the other four bean lines (α=0.05, α=0.10, respectively). Chichicaste, Criollo A, Criollo B and Itzapa were not significantly different from each other in this relationship at the significance level of α=0.05. Sesenteño and Tamazulapa become more acceptable with increasing cooking time at a faster rate than did Chichicaste, Criollo A, Criollo B and Itzapa. See Figures 4.2 and 4.3.

The in-house acceptability panel was able to distinguish between the 5 different samples of a given bean line and gave less-cooked samples a lower acceptability score than longer cooked samples (Table 4.5). The one-way analysis of variance (ANOVA) table for the effect of cooking time on cooking time acceptability panel mean acceptability score is given in Appendix H. Mean acceptability scores were determined from in-

TABLE 4.4

Relationship between cooking time and mean cooking time acceptability score for 6 lines of fresh samples of Guatemalan black beans.

Bean line	Equation	R^2
1. Chichicaste	Y†= 1.91419587 + 0.01784367 CT‡	0.507980
2. Criollo A	Y = 1.56860119 + 0.01763393 CT	0.413979
3. Criollo B	Y = 1.97317359 + 0.01523612 CT	0.283034
4. Itzapa	Y = 1.49532185 + 0.01778858 CT	0.427731
5. Sesenteño	Y = 2.95807346 + 0.01392436 CT	0.355686
6. Tamazulapa	Y = 2.22652152 + 0.01781296 CT	0.274450

† Y = mean cooking time acceptability score.

‡ CT = cooking time in minutes.

dividual panel scores and were compared using the Kruskal-Wallis one-way ANOVA procedure based on a significance of 5%. It was not possible to statistically measure the effect of panelist on mean acceptability score because of a lack of independence of panelists over the different cooking times. The same panelist did not necessarily participate in all tests and there were not always the same number of panelists participating in each test. Panelist effect was, therefore, included as part of the error term.

In order to make a comparison between the bean lines it was necessary to select cooking times that prepared the beans to an equivalent and acceptable degree of doneness according to the acceptability panel. This point was chosen to be the lowest cooking time which had an acceptabili-

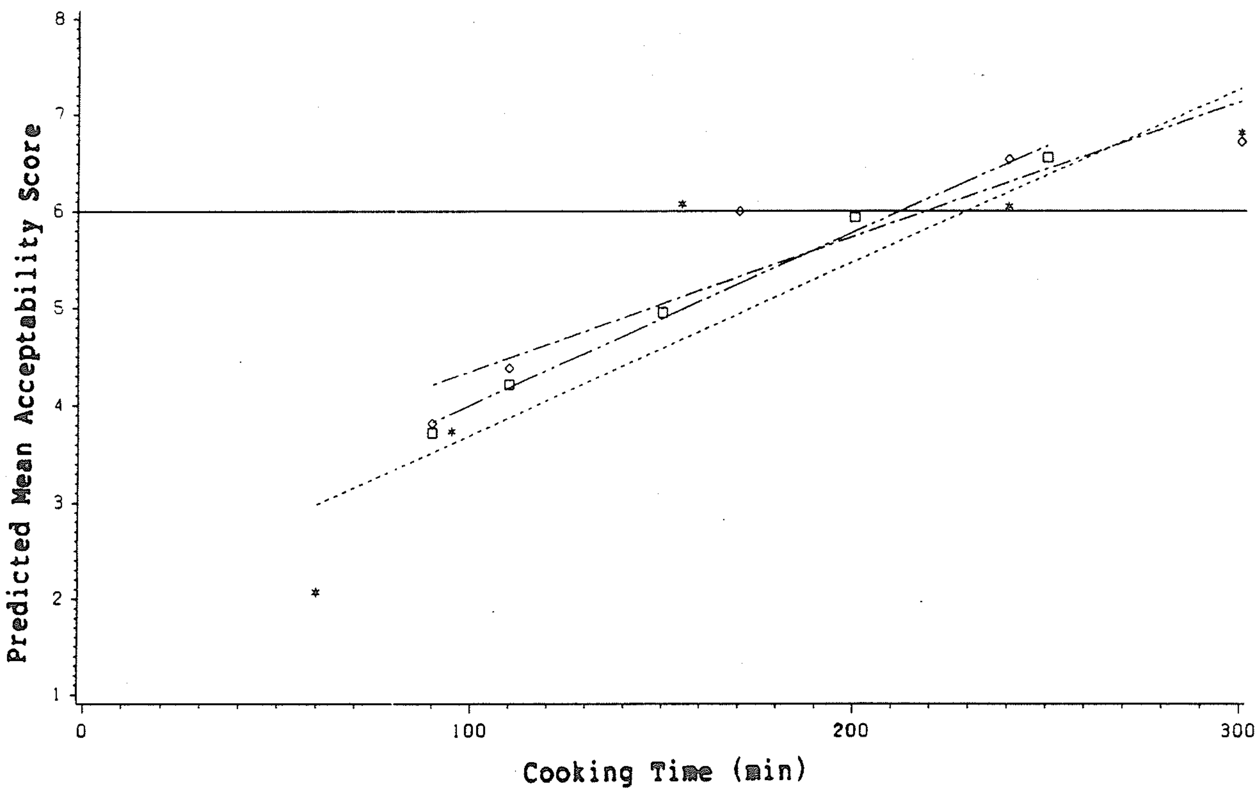

Figure 4.2: Predicted mean acceptability score as a function of cooking time (min) (cooking time acceptability) for fresh Chichicaste, Sesenteño, and Tamazulapa samples.

---- Chichicaste
◇ -—◇ Sesenteño
□--—□ Tamazulapa

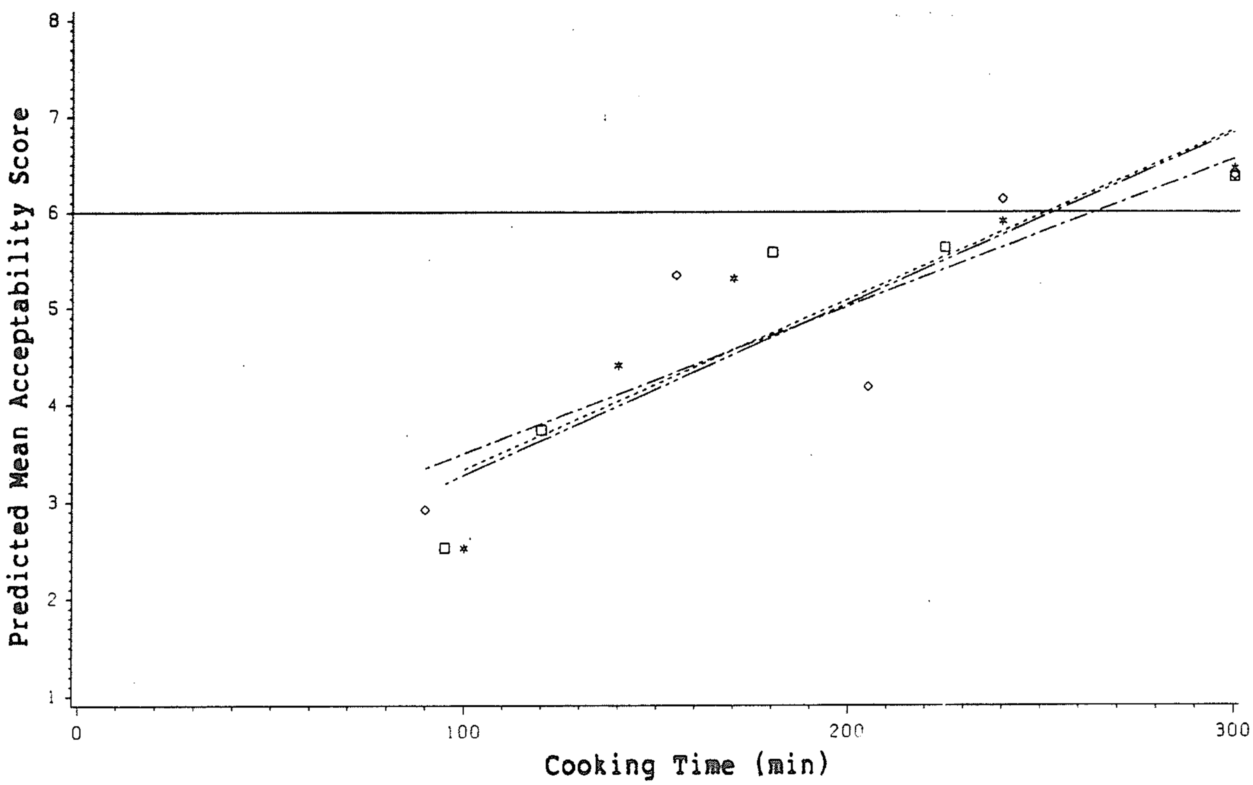

Figure 4.3: Predicted mean acceptability score as a function of cooking time (min) (cooking time acceptability) for fresh Criollo A, Criollo B, and Itzapa samples.

---- Criollo A
◇ -—◇ Criollo B
□--—□ Itzapa

TABLE 4.5

Cooking time acceptability panel mean acceptability scores† for 6 lines of fresh Guatemalan black beans cooked to 5 cooking stages.

	Cooking Stage				
Bean line	50%	75%	90%	100%	Extended Cooking
Chichicaste	2.0a‡*	3.7b	<u>6.0c</u>**	6.0c	6.8c
Criollo A	2.5a	4.4b	5.3bc	<u>5.9cd</u>	6.4d
Criollo B	2.9a	4.2b	5.3bc	<u>6.2c</u>	6.3c
Itzapa	2.5a	3.7b	<u>5.6c</u>	5.6c	6.4c
Sesenteño	3.8a	4.4a	<u>6.0b</u>	6.6b	6.7b
Tamazulapa	3.8a	4.2ab	5.0b	<u>6.0c</u>	6.5c

† Means based on # determinations.

‡ For texture acceptability: 1=extremely unacceptable and 8=extremely acceptable. A score of 6 represents moderately acceptable.

* In each row, means with the same letter are not significantly different ($\alpha = 0.05$).

** Underlined scores indicate the cooking stage used in further testing considered to be acceptably cooked.

ty score that was not significantly different from the most acceptable sample but was at least greater than 5.5. The value of 5.5 on the category scale corresponded to a position between slightly acceptable and moderately acceptable. Thus for Chichicaste, Itzapa and Sesenteño, it was the 90% cooked samples which corresponded to 155, 180, and 170 minutes, respectively, and it was the 100% cooked samples for Criollo A, Criollo B and Tamazulapa which which corresponded to 240, 240, and 200 minutes, respectively. The cooking times for each variety that corresponded to the acceptably-cooked point were used later in the comparative acceptability panel. The cooking times for the acceptably-cooked point ranged from 155 min for Chichicaste to 240 min for Criollo A and Criollo B.

4.2.3 Texture Profile Analysis Panel

Training of the Texture Profile Analysis (TPA) panel was shown to have an effect as variance among panelists' scores tended to decrease over time (Table 4.6). There was a significant difference (α=0.05) among the variances for particle size (p=0.0074) and chewiness scores (p=0.0001) over time while there was not a significant difference among variances for hardness and seedcoat toughness scores. Variances for hardness scores ranged from 22.940 to 12.324 with variances in the latter tests lower than those in the first two. Particle size score variances ranged from 23.977 to 9.131 but did not consistently decrease over time. Variances for seedcoat toughness scores ranged from 50.692 to 10.451. Although the variance did not consistently decrease over time the variance at the end of the training period was less than at the beginning. Variances for chewiness scores ranged from 21.472 to 1.871.

Highest variances occurred in the first five tests and lower variances in the last four tests.

Analysis of Texture Profile Analysis (TPA) panel results showed that all panelists were ranking the cooking times for all four characteristics evaluated in the study in the same order, that is, panelists were shown to be in agreement. The consistency of judgement for individual panelists is expressed by the coefficent of variation for each of the four texture profile characteristics in Table 4.7. It was not possible to statistically measure the effect of panelist on mean TPA characteristic scores because of a lack of independence of panelists over the different cooking times. A particular panelist did not participate in all tests and there were not always the same number of panelists for all tests. Panelist effect was, therefore, included as part of the error term.

The texture profile panel results showed significant decreases in hardness, particle size, toughness of seedcoat and chewiness as cooking times increased, for all bean lines (Tables 4.8, 4.9, 4.10, and 4.11). Analysis of covariance (ANCOVA) tables for the effect of cooking time on mean TPA panel scores for hardness, particle size, toughness of seedcoat and chewiness are given in Appendices I, J, K and L, respectively. A significant but negligible rep effect was shown for some bean lines (Tamazulapa, Criollo A).

Samples cooked to their acceptably-cooked points had hardness scores that ranged from 6.1 (Tamazulapa) to 8.8 (Chichicaste, Itzapa and Senseteño) (Table 4.8). Chichicaste, Itzapa and Sesenteño which were all

TABLE 4.6

Variance among Texture Profile Analysis (TPA) panelists' scores during training period.

	VARIANCE Variable evaluated				
Test Number	Hardness	Particle Size	Seedcoat Toughness	Chewiness	Bean Line Tested
1	22.607	19.599	38.872	10.607	Tamazulapa
2	22.940	--	--	16.261	Sesenteño
3	--	23.977	--	21.472	Itzapa
4	--	--	50.692	9.267	Chichicaste
5	14.922	5.422	10.451	13.275	Tamazulapa
6	12.324	9.131	25.685	6.417	Tamazulapa
7	16.291	12.735	26.256	4.162	Criollo A
8	15.429	9.814	37.200	1.871	Criollo A
9	17.505	17.359	28.331	3.190	Criollo B
Probability	0.6817	0.0074*	0.0711	0.0001*	

* $p \leq 0.100$.

TABLE 4.7

Individual Texture Profile Analysis (TPA) panelist mean and standard deviation† of the coefficient of variation for each of the 4 TPA characteristics.

Panelist Number	Hardness	Particle Size	Seedcoat Toughness	Chewiness
1	30.01±21.51	22.25±16.65	45.38±41.60	32.00±20.33
2	23.15±21.20	19.21±15.84	32.72±23.07	28.85±18.56
3	32.86±28.17	34.94±30.35	36.31±31.76	22.48±17.94
7	19.70±13.64	19.31±10.89	20.18±17.70	19.35±11.46
22	27.76±14.83	23.21±13.63	26.53±24.75	24.27±14.78
24	26.20±15.13	24.00±13.68	24.11±18.13	22.12±12.63
26	32.58±26.49	28.06±25.41	33.23±23.60	13.83±11.81
27	30.91±17.87	28.04±15.94	30.77±19.18	13.59±10.92
30	31.24±18.56	23.33±13.67	38.52±28.40	17.20±11.59

† Means and standard deviations are based on 3 replications of 30 determinations (5 cooking stages x 6 bean lines).

TABLE 4.8

Texture Profile Analysis (TPA) mean scores† for hardness for 6 lines of fresh samples of Guatemalan black beans cooked to 5 cooking stages.

	Cooking Stage				
Bean line	50%	75%	90%	100%	Extended Cooking
Chichicaste	22.8‡a*	14.3b	8.8c**	6.3c	5.8c
Criollo A	19.6a	14.0b	9.3c	6.9cd	5.7d
Criollo B	18.2a	11.8b	8.2c	6.9c	5.6c
Itzapa	18.3a	15.0a	8.8b	7.6b	5.5b
Sesenteño	17.0a	13.7b	8.8c	6.6cd	5.3d
Tamazulapa	15.2a	12.8a	9.2b	6.1b	5.9b

† Mean of 3 replications.

‡ Higher scores indicate greater hardness. Maximum= 30.

* In each row, means with the same letter are not significantly different ($p<0.05$) as determined using the Bonferroni (Dunn) T-test procedure.

** Underlined scores indicate the cooking stage considered to be acceptably cooked.

TABLE 4.9

Texture Profile Analysis (TPA) mean scores† for particle size for 6 lines of fresh samples of Guatemalan black beans cooked to 5 cooking stages.

Bean line	Cooking Stage 50%	75%	90%	100%	Extended Cooking
Chichicaste	24.7‡a*	15.6b	<u>8.1c</u>**	6.8c	6.1c
Criollo A	21.6a	14.0b	9.8c	<u>7.0cd</u>	5.7d
Criollo B	21.0a	13.5b	8.8c	<u>7.2c</u>	6.9c
Itzapa	19.1a	14.7b	<u>8.9c</u>	7.0c	5.6c
Sesenteño	17.9a	14.4b	<u>8.9c</u>	6.7c	6.1c
Tamazulapa	16.5a	12.4b	9.6bc	<u>6.0c</u>	6.0c

† Mean of 3 replications.

‡ Higher scores indicate larger particle size. Maximum= 30.

* In each row, means with the same letter are not significantly different ($p<0.05$) as determined using the Bonferroni (Dunn) T-test procedure.

** Underlined scores indicate the cooking stage considered to be acceptably cooked.

TABLE 4.10

Texture Profile Analysis (TPA) mean scores† for seedcoat toughness for 6 lines of fresh samples of Guatemalan black beans cooked to 5 cooking stages.

	Cooking Stage				
Bean line	50%	75%	90%	100%	Extended Cooking
Chichicaste	24.2‡a*	17.2b	<u>9.2c</u>**	7.0c	6.5c
Criollo A	24.1a	18.4b	13.0c	<u>10.0cd</u>	8.1d
Criollo B	24.2a	16.2b	12.2bc	<u>9.4c</u>	8.5c
Itzapa	26.1a	19.2a	<u>11.6b</u>	10.9b	9.3b
Sesenteño	23.0a	17.7b	<u>10.0c</u>	8.3c	7.1c
Tamazulapa	18.4a	14.5a	9.7b	<u>5.2c</u>	4.9c

† Mean of 3 replications.

‡ Higher scores indicate greater seedcoat toughness. Maximum= 30.

* In each row, means with the same letter are not significantly different ($p<0.05$) as determined using the Bonferroni (Dunn) T-test procedure.

** Underlines scores indicate the cooking stage considered to be acceptably cooked.

TABLE 4.11

Texture Profile Analysis (TPA) mean scores† for chewiness for 6 lines of fresh samples of Guatemalan black beans cooked to 5 cooking stages.

	Cooking Stage				
Bean line	50%	75%	90%	100%	Extended Cooking
Chichicaste	13.1‡a*	8.7b	<u>5.3c</u>**	4.3c	4.0c
Criollo A	10.2a	7.2b	5.4bc	<u>4.3</u>	3.8c
Criollo B	11.2a	6.8b	5.4bc	<u>4.9c</u>	4.7c
Itzapa	9.4a	7.2b	<u>4.9c</u>	4.4c	3.7c
Sesenteño	8.4a	6.8b	<u>4.9c</u>	4.1c	3.9c
Tamazulapa	8.7a	6.7b	5.9bc	<u>4.4cd</u>	4.0d

† Mean of 3 replications.

‡ Higher scores indicate greater chewiness. No maximum score.

* In each row, means with the same letter are not significantly different ($p<0.05$) as determined using the Bonferroni (Dunn) T-test procedure.

** Underlines scores indicate the cooking stage considered to be acceptably cooked.

cooked to their 90% cooked point had the higher hardness scores while Criollo A, Criollo B and Tamazulapa, which had been cooked to their 100% point had the lower scores (6.9, 6.9 and 6.1, respectively). Therefore, the texture profile panel can be said to reflect panelists' acceptability choice where texture profile scores for hardness are at 8.8 or less, if it assumed that hardness influenced the acceptability panel.

Particle size scores for samples cooked to their acceptably-cooked points were from 6.0 for Tamazulapa to 8.9 for Itzapa and Sesenteño (Table 4.9). The samples with the lower particle size scores, Criollo A, Criollo B and Tamazulapa (7.0, 7.2, and 6.0, respectively) were cooked to their 100% point. The samples cooked to 90%, Chichicaste, Itzapa and Sesenteño, had the higher particle size scores (8.1, 8.9, and 8.9, respectively). Mean particle size scores of 8.9 or less, therefore, corresponded to acceptably cooked beans.

TPA mean scores for seedcoat toughness ranged from 5.2 for Tamazulapa to 11.6 for Itzapa for acceptably cooked beans (Table 4.10). Samples' seedcoat toughness scores could not be grouped by the degree of cooking the samples had received. Both Criollo A and Sesenteño had seedcoat toughness scores of 10.0 while being 100% and 90% cooked, respectively. Chichicaste, being cooked to its 90% cooked stage, had the second lowest score of 9.2 which was very similar to the 9.4 score of Criollo B, cooked to its 100% cooked stage. Seedcoat toughness values of 11.6 or less corresponded to acceptable beans. Toughness of the seedcoat may therefore be a measure of an inherent characteristic of the bean variety rather than a measure of degree of doneness.

Chewiness mean scores for acceptably cooked beans ranged from 4.3 for Criollo A to 5.3 for Chichicaste (Table 4.11). Itzapa (90%), Sesenteño (90%) and Criollo B (100%) all had the same mean chewiness score of 4.9.

Pearson correlation coefficients for the mean scores of the four textural characteristics were determined over the 6 black bean lines for all cooking times (Table 4.12). All correlations were significant at $p<0.001$. The mean scores for hardness and particle size were highly correlated (0.99). Seedcoat toughness correlated well with both hardness and particle size (0.97 and 0.96, respectively). Mean chewiness correlated well with hardness (0.97), particle size (0.99) and seedcoat toughness (0.93). Such high correlations between hardness and particle size and between seedcoat toughness and chewiness and hardness or particle size, would indicate that both variables need not be evaluated in future work.

Individual Pearson correlation coefficients for the mean scores of the four textural characteristics are listed for each of the 6 black bean lines in Table 4.13. The correlation between hardness and particle size scores was highest for the variety Chichicaste (0.89) and lowest for Criollo B (0.82). The correlation between hardness and toughness of the seedcoat scores was highest for Sesenteño (0.81) and lowest for Tamazulapa (0.61). Chichicaste had the highest correlation between hardness and chewiness scores (0.68). Tamazulapa had the lowest correlation between these two variables (0.49). The highest correlation between particle size and toughness of seedcoat was found with Chichicaste (0.87). The lowest correlation occurred with Itzapa (0.60). The correlation between particle size and chewiness was highest for Criollo A

TABLE 4.12

Pearson correlation coefficients for Texture Profile Analysis mean scores and cooking time acceptability panel mean acceptability scores for 6 lines of fresh samples of Guatemalan black beans cooked to 5 cooking stages.

	Variable				
Variable	Hardness	Particle Size	Seedcoat Toughness	Chewiness	Accept-ability
Hardness	1.00	0.99	0.97	0.97	-0.97
Particle Size		1.00	0.96	0.99	-0.96
Seedcoat Toughness			1.00	0.93	-0.95
Chewiness				1.00	-0.94

All correlations are significant ($p<0.001$).

TABLE 4.13

Pearson correlation coefficients for Texture Profile Analysis (TPA) mean scores for each of 6 lines of fresh samples of Guatemalan black beans cooked to 5 cooking stages.

	Bean line†					
Variables	CHI	CRA	CRB	ITZ	SES	TAM
Hardness-Particle Size	0.89	0.89	0.82	0.86	0.84	0.86
-Seedcoat Toughness	0.79	0.71	0.77	0.67	0.81	0.61
-Chewiness	0.68	0.67	0.66	0.57	0.64	0.49
Particle-Seedcoat Size Toughness	0.87	0.78	0.82	0.60	0.81	0.62
-Chewiness	0.69	0.70	0.66	0.57	0.67	0.52
Seedcoat-Chewiness Toughness	0.66	0.56	0.51	0.50	0.75	0.55

† Bean line code names of CHI, CRA, CRB, ITZ, SES, and TAM correspond to Chichicaste, Criollo A, Criollo B, Itzapa, Sesenteño and Tamazulapa, respectively.

(0.70) and lowest for Tamazulapa (0.52). Sesenteño had the highest correlation between toughness of seedcoat and chewiness (0.75). Itzapa provided the lowest (0.50).

Such high correlations of hardness with particle size as compared to seedcoat toughness and chewiness indicated that TPA hardness determinations were related more to cotyledon texture, and thus, were more similar to particle size, than to seedcoat texture measurements of seedcoat toughness and chewiness. The variable correlation coefficients for particle size with seedcoat toughness and with chewiness suggested that these are independent characteristics. Both seedcoat toughness and chewiness reflected seedcoat texture while particle size and hardness were related to cotyledon texture.

The mean scores for the four textural characteristics were all highly correlated to acceptability mean scores. Hardness was the most highly correlated (-0.97). Particle size had the second highest correlation (-0.96) and was followed by seedcoat toughness (-0.95) and chewiness (-0.94). Such high correlations between texture profile parameters and in-house acceptability support the use of trained TPA panels to predict acceptability scores. Cooked beans categorized as being acceptable, according to the criteria previously defined, had mean hardness scores of 8.8 or less (Table 4.8), mean particle size scores of less than 9.0 (Table 4.9), mean seedcoat toughness scores of 11.6 or less (Table 4.10), and mean chewiness scores of less than 5.4 (Table 4.11). Prediction lines for the relationship between the means of each of the 4 characteristics' Texture Profile Analysis (TPA) scores and cooking time acceptability panel mean acceptability score are given in Appendix M.

4.2.4 In-house Comparative Acceptability Panel

The comparative acceptability panel was carried out to determine if differences existed among the bean lines when a direct comparison was made among the bean lines cooked to their acceptably-cooked point, that is, under the assumption of equal doneness. At one session the in-house comparative acceptability panel was presented with 6 samples, each cooked to their most acceptably cooked point (1 sample of each of the 6 fresh lines). Comparative acceptability panel mean scores are given in Table 4.14. The one-way analysis of variance (ANOVA) table for the effect of bean line on comparative acceptability panel mean acceptability score is given Appendix N. Criollo A had a significantly higher acceptability score (5.89) than Itzapa (4.47). The acceptability scores for Criollo A, Criollo B and Tamazulapa were higher (5.89, 5.36, and 5.69, respectively), although not significantly, than those of Chichicaste (4.92) and Sesenteño (4.89). The mean acceptability scores for Criollo B and Tamazulapa were not significantly higher than the mean acceptability score for Itzapa. Since the Chichicaste, Itzapa and Sesenteño lines were only cooked to their 90% cooked point while Criollo A, Criollo B and Tamazulapa had been cooked to their 100% point it seems quite possible that the Chichicaste, Itzapa and Sesenteño samples did not receive adequate cooking to be equivalent to Criollo A, Criollo B and Tamazulapa. The differences in the amount of cooking received by the samples would seem to account for the differences in acceptability between the bean lines and would therefore mask any differences in inherent varietal characteristics that might affect acceptability. The distribution of individual panelists' scores for the in-house comparative acceptability panel are shown in Appendix O.

TABLE 4.14

Comparison of the comparative acceptability mean acceptability scores† for 6 lines of fresh samples of Guatemalan black beans each cooked to their acceptably-cooked point.

Bean Line	Acceptability Rank	Acceptability Mean Score	Cooking Time (min)	Cooking Stage
Chichicaste	4	4.92‡ab*	155	90%
Criollo A	1	5.89 a	240	100%
Criollo B	3	5.36 ab	240	100%
Itzapa	6	4.47 b	180	90%
Sesenteño	5	4.89 ab	170	90%
Tamazulapa	2	5.69 ab	200	100%

† Mean of 36 individual panelist scores.

‡ For texture acceptability: 1=extremely unacceptable and 8=extremely acceptable.

* Means with the same letter are not significantly different at $p<0.05$ as determined using the Bonferroni (Dunn) T-test procedure.

Samples cooked to their acceptably-cooked cooking time and presented to the in-house panel for acceptability rating with 4 other samples of the same line cooked to different degrees of doneness (cooking time acceptability panel tended to receive different scores than when presented in the comparative acceptability panel). The absolute mean acceptability scores were similar for the Criollo A samples (5.9 and 5.89 for cooking time and comparative acceptability, respectively) for both acceptability panels but were higher in the cooking time acceptability for the remaining 5 lines. The Itzapa sample had the lowest absolute mean score among the lines for both acceptability panels (5.6 in the cooking time acceptability panel). Mean acceptability score from the cooking time acceptability panel for the Chichicaste, Sesenteño and Tamazulapa samples was 6.0 while Criollo B obtained the highest acceptability score of 6.2.

For future comparisons of cooked bean texture quality, a better method of determining cooking times is needed. Using the same data as were used initially, equivalent and acceptable cooking times for the bean lines can be determined from predictive equations describing the relationship between cooking time and acceptability score (Table 4.4, page 106). Although the R^2 values for these predictive equations were not high, due to the inherent variability of the samples, to differences in the acceptability criteria of the panelists (Stevens and Albright, 1980), and the fact that other factors other than texture affected acceptability, the equations are useful. The cooking times required to reach a certain level of acceptability can be derived from these lines.

These lines were parallel which indicated that the rate of increase of mean acceptability score with increase in cooking time was similar for all 6 bean lines although their intercepts differed. These prediction lines are illustrated in Figures 4.2 and 4.3 (pages 107 and 108). Since the lines were parallel the bean lines could be compared. Criollo A and Itzapa, the two vine beans, were the slowest cooking of the 6 bean lines.

If cooking time to reach an acceptability score of 6 were derived from the prediction equations (Table 4.4, page 106), cooking times would be as shown in Table 4.15. Using this method for cooking time determination, Criollo A, Criollo B and Tamazulapa would have approximately the same cooking times as were arrived at initially, but Chichicaste, Itzapa and Sesenteño, the three samples that appeared not to have been cooked sufficiently to enable valid texture comparisons to be made, would have longer cooking times.

The times determined from the predictive equations were similar to those determined by the % cooked panel for the 100% cooked stage (Table 4.3, page 104). These times would therefore provide a better comparison among the bean lines than those times used in this study.

If samples cooked to the times calculated from the prediction equations were evaluated by the texture profile panel, mean hardness, particle size, seedcoat toughness and chewiness scores for equally acceptably cooked samples would vary less among the bean lines than previously determined (Tables 4.8, 4.9, 4.10 and 4.11, pages 114-117) and would fur-

TABLE 4.15

Comparison of acceptably-cooked cooking times used in this study† and those determined from prediction equations for 6 lines of fresh samples of Guatemalan black beans cooked to 5 cooking stages.

	Cooking time (min)		
Bean line	From equation‡	90%	100%
Chichicaste	230	<u>155</u>	240
Criollo A	250	170	<u>240</u>
Criollo B	270	205	<u>240</u>
Itzapa	250	<u>180</u>	225
Sesenteño	220	<u>170</u>	240
Tamazulapa	210	150	<u>200</u>

† Acceptably cooked cooking times used in this study are underlined.

‡ Using an acceptability score of 6.

ther support the use of a small trained panel for predicting a larger panels' acceptability score. The texture profile panel would be able to reflect panelists' acceptability choice where mean scores for hardness were less than 7.6 rather than less than 8.8. Mean particle size scores corresponding to acceptably cooked sample would be less than 7.2 instead of 8.9. The mean seedcoat toughness score that corresponded to an acceptably cooked sample would be reduced from 11.6 or less to 10.9 or less. Likewise, the critical mean chewiness score would be lowered from 5.3 to 4.9.

4.3 INSTRUMENTAL TESTS

4.3.1 Raw Bean Hardness

Raw bean hardness peak force values for the 6 fresh black bean lines are given in Table 4.16. Peak force values ranged from 81.953 N (Senseteño) to 134.206 N (Criollo A). The lowest raw bean peak force values corresponded to the bean lines with the lowest 100-bean weights, i.e., the smallest sized beans (Sesenteño and Tamazulapa). The highest peak forces were found with the Criollo A and Itzapa samples which had been classified as having the largest beans of the 6 bean lines studied. Raw bean hardness values did not relate to predicted cooking time.

TABLE 4.16

Mean raw bean peak force values as measured by the wedge apparatus for 6 lines of fresh samples of Guatemalan black beans.

Bean line	Raw bean peak force† (N)
Chichicaste	103.380±14.790
Criollo A	134.206±19.213
Criollo B	116.051±19.674
Itzapa	133.730±18.591
Sesenteño	81.953± 8.646
Tamazulapa	81.988±10.649

† Means and standard deviations based on 30 determinations.

4.3.2 Cooked Bean Hardness

A sample curve from the OTMS-Apple IIe showing force over time required to extrude a cooked bean sample through a 10 cm^2 extrusion cell is shown in Appendix P.

Duplicate OTMS peak force values were obtained for all cooked bean samples prepared in this study. With increasing cooking times, peak force values tended to decrease, initially and then remain the same and/or slightly increase as cooking continued (Figures 4.4 and 4.5). Different bean lines softened at different rates. At 240 minutes, for example, a cooking time commonly used in the literature, peak force values ranged from 160 N (Itzapa) to 260 N (Sesenteño).

There was a strong quadratic relationship between cooking time and OTMS peak force for each of the 6 bean lines (Table 4.17). The lines describing the relationship for the bean lines were parallel and therefore permitted comparisons to be made among the bean lines using the Bonferroni test (SAS, 1985). The prediction line for Chichicaste was significantly different from (higher than) all other bean lines (Figures 4.4 and 4.5). The lines for Criollo A, Criollo B, Sesenteño and Tamazulapa were not significantly different from each other (α=0.05). Itzapa's prediction line was significantly different from (lower than) the other five bean lines'. Itzapa cooked to the softest texture. See Figures 4.4 and 4.5.

A comparison of the bean lines can be made using the cooking times required to reach a point considered generally to be soft. Using the cooking times required to reach a peak force of 250 newtons it is appar-

TABLE 4.17

Relationship between cooking time and mean peak force as measured by the OTMS extrusion cell for each of 6 lines of fresh samples of Guatemalan black beans.

Bean line	Equation	R^2
Chichicaste	$Y^{\dagger} = 828.40430 - 4.83878469\ CT^{\ddagger} + 0.009598293\ CT^2$	0.9639
Criollo A	$Y = 589.88125 - 2.86792279\ CT + 0.005729648\ CT^2$	0.9439
Criollo B	$Y = 707.40911 - 3.50189023\ CT + 0.006565257\ CT^2$	0.9783
Itzapa	$Y = 664.67304 - 4.16055979\ CT + 0.008545532\ CT^2$	0.9553
Sesenteño	$Y = 522.98829 - 1.98449542\ CT + 0.003541685\ CT^2$	0.9472
Tamazulapa	$Y = 656.33870 - 3.78556894\ CT + 0.007605934\ CT^2$	0.9620

† Y = Peak force in newtons.

‡ CT = cooking time in minutes.

ent that the different bean lines have different requirements for cooking time length. To soften to 250 newtons Itzapa required the shortest time of 130 minutes while Criollo B and Sesenteño needed the longest time of 240 minutes. The Tamazulapa sample needed 150 minutes and the Chichicaste and Criollo A samples required 190 minutes to soften to the same peak force.

Linear relationships existed between peak force, as measured by the OTMS, and the cooking time acceptability score for each variety (Table 4.18). The prediction lines are not parallel, however, and therefore a comparison of their means could not be made using the Bonferroni (Dunn) T-test procedure (SAS, 1985) (Figures 4.6 and 4.7). Sesenteño and Chi-

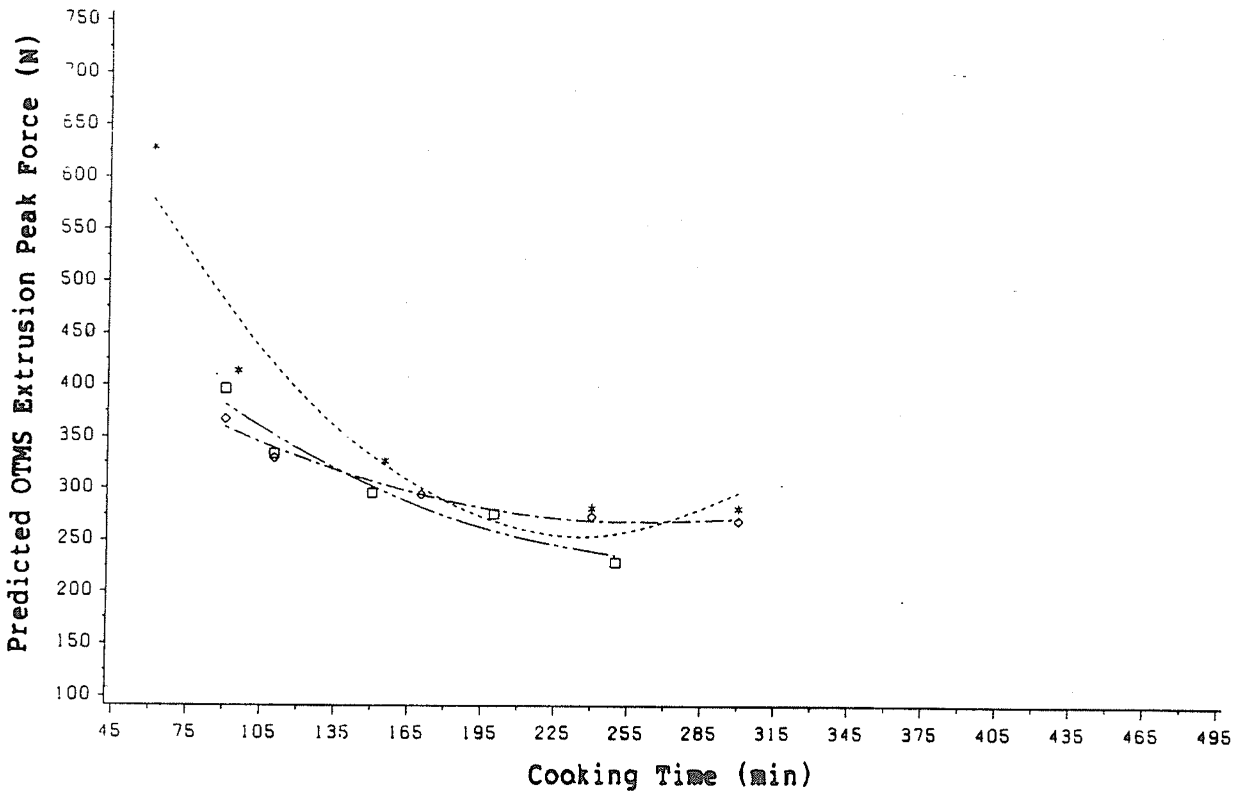

Figure 4.4: Predicted OTMS extrusion cell peak force (N) as a function of cooking time (min) for fresh samples of Chichicaste, Sesenteño, and Tamazulapa black beans.

---- Chichicaste
◇ -—◇ Sesenteño
□--—□ Tamazulapa

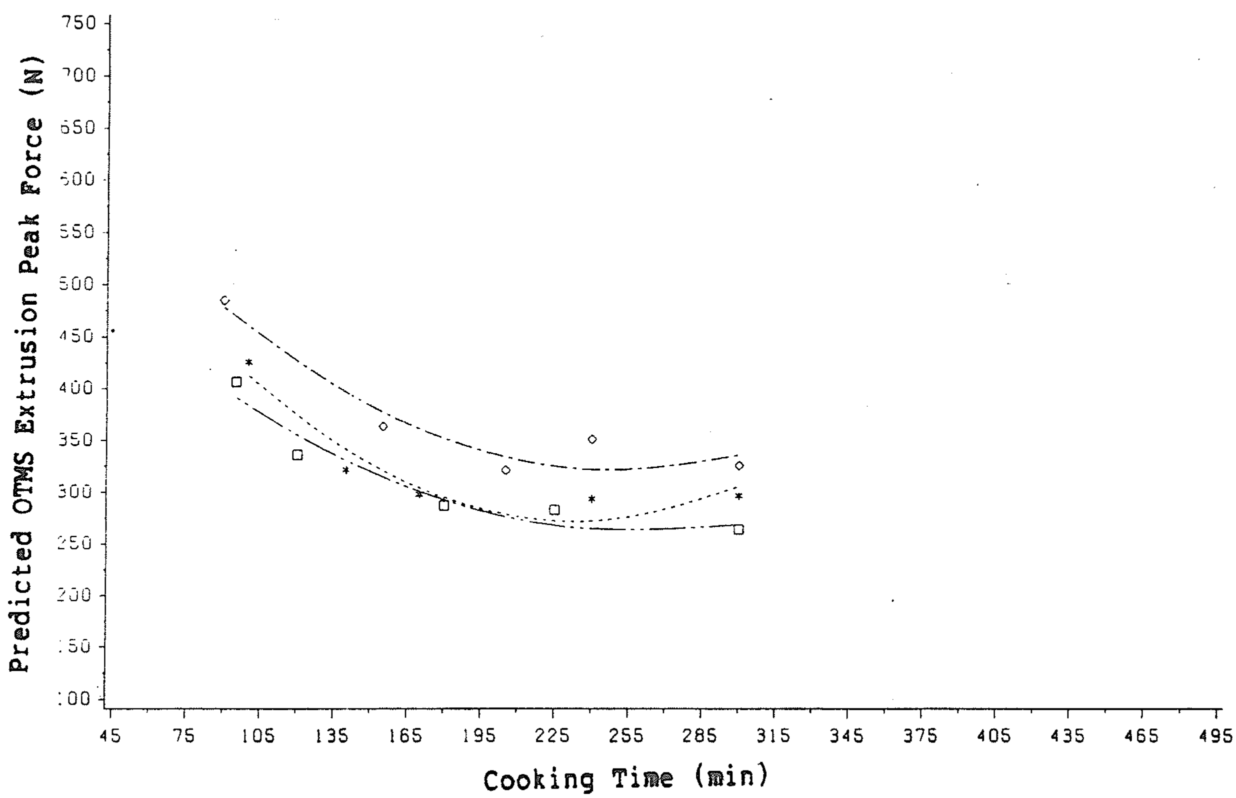

Figure 4.5: Predicted OTMS extrusion cell peak force (N) as a function of cooking time (min) for fresh Criollo A, Criollo B and Itzapa black beans.

---- Criollo A
◇ -—◇ Criollo B
□--—□ Itzapa

TABLE 4.18

Relationship between mean peak force as measured by the OTMS extrusion cell and mean cooking time acceptability score for each line of fresh samples of Guatemalan black beans.

Bean line	Equation	R^2
Chichicaste	Y† = 9.46406321 + 0.01263313 PF‡	0.600626
Criollo A	Y = 12.78225431 - 0.02796781 PF	0.439631
Criollo B	Y = 9.25221998 - 0.01395324 PF	0.263179
Itzapa	Y = 9.33087674 - 0.01942429 PF	0.476426
Sesenteño	Y = 12.33476764 - 0.02272186 PF	0.402688
Tamazulapa	Y = 8.82010824 - 0.01378704 PF	0.262449

† Y = Mean acceptability score.

‡ PF = Peak force in newtons.

chicaste did not need to soften as much as the other bean lines to become acceptable. According to their prediction lines they became acceptable at about 290 N. Criollo A and Criollo B became acceptable at a softer texture of approximately 240-250 N. Tamazulapa beans needed to be softened to at least 210 N to become acceptable while Itzapa beans became acceptable when force values were 180 N or less.

It is interesting to note that the two bean lines that did not need to soften as much as the others to be acceptable had the two lowest seedcoat thickness measurements (6.6 and 6.7 mg/cm^2, respectively). The Tamazulapa and Itzapa samples with high seedcoat thickness values of 8.0 and 8.1 mg/cm^2, respectively, had to be cooked to the lowest force meas-

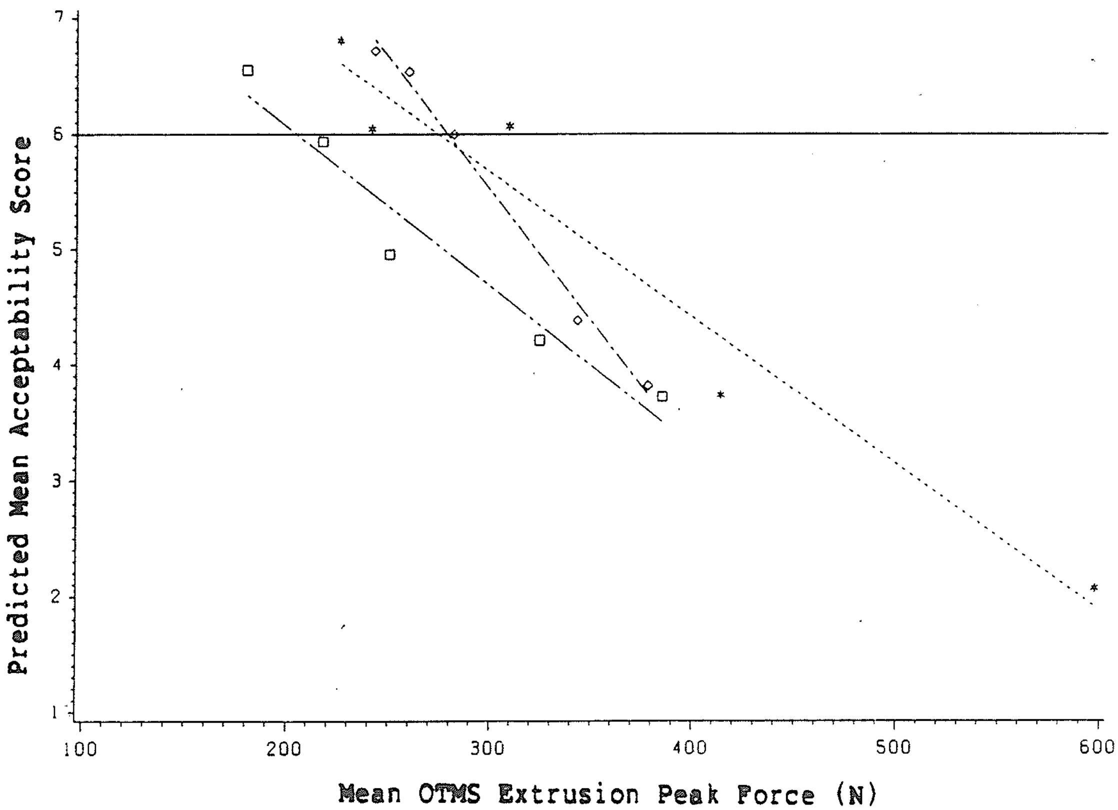

Figure 4.6: Predicted acceptability score as a function of OTMS extrusion cell peak force (N) (Cooking time acceptability) for fresh Chichicaste, Sesenteño, and Tamazulapa black beans.
---- Chichicaste
◇ -—◇ Sesenteño
□--—□ Tamazulapa

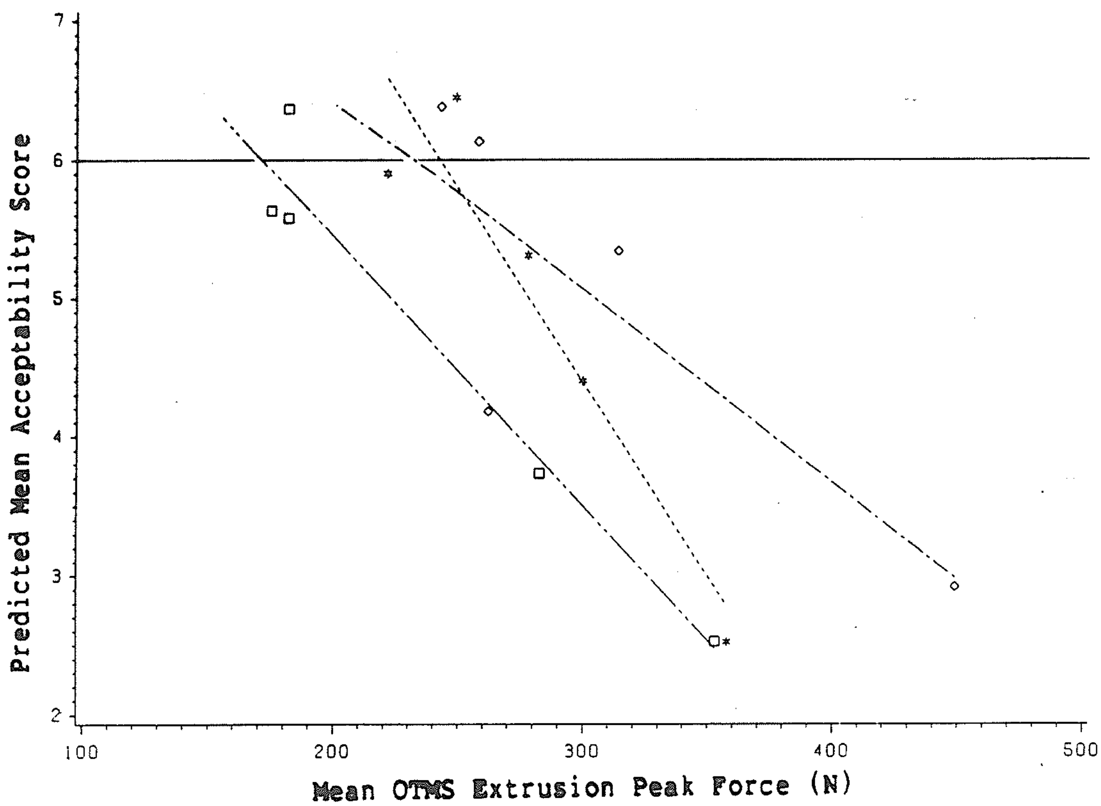

Figure 4.7: Predicted acceptability score as a function of OTMS extrusion cell peak force (N) (Cooking time acceptability) for fresh Criollo A, Criollo B and Itzapa black beans.

---- Criollo A
◇ -—◇ Criollo B
□--—□ Itzapa

urements of all 6 bean lines. An explanation for this occurrence may be related to the role the seedcoat has on OTMS peak force. Beans with thick seedcoats required excess cooking time to soften the seedcoat enough that the whole bean was considered acceptable. This longer cooking time caused the cotyledons to be softer (perhaps overcooked) and was expressed as a low peak force measurement. Beans with a thin seedcoat, on the other hand did not need a longer cooking time, beyond that which is required to soften the cotyledons, to soften the seedcoat. Thus, bean lines with thin seedcoats became acceptable at a relatively higher peak force value.

Seedcoat percent and seedcoat thickness had high negative correlations with OTMS peak force value and L/B ratio had a high positive correlation with the OTMS peak force value for the acceptably cooked stage (Table 4.19). Beans with higher L/B ratios were longer and had thinner seedcoats than the more round beans. Beans with thinner seedcoats needed less cooking to become acceptable and were thus harder at this point than beans with thicker seedcoats.

Texture profile panel scores were highly correlated to OTMS peak force values (Table 4.20). Hardness had the highest correlation (0.85) of all the texture characteristics with peak force. Particle size had the second highest correlation (0.84), followed by chewiness and particle size. The data for these texture characteristics has already been presented in Tables 4.8 - 4.11 (pages 114-117). The highest correlations for hardness and particle size with OTMS peak force may be due to the fact that hardness and particle size focus on the texture of the cotyledon, as does the OTMS, while seedcoat toughness and chewiness evaluate seedcoat texture.

TABLE 4.19

Pearson correlation coefficients for physical properties and mean OTMS extrusion cell peak force values (at acceptably cooked points) for 6 lines of fresh samples of Guatemalan black beans.

	Variable				
Variable	100 Bean Weight	L/B Ratio	Seedcoat Percent	Seedcoat Thickness	OTMS Peak Force
100 Bean Weight	1.00	0.07	0.13	0.26	-0.31
L/B Ratio		1.00	0.69	-0.83*	0.84*
Seedcoat Percent			1.00	0.85*	-0.79**
Seedcoat Thickness				1.00	-0.74**
OTMS Peak Force					1.00

* $p<0.05$

** $p<0.10$

TABLE 4.20

Pearson correlation coefficients for Texture Profile Analysis (TPA) panel mean scores and mean OTMS extrusion cell peak force values over all cooking stages for 6 lines of fresh samples of Guatemalan black beans.

	Texture Attribute			
	Hardness	Particle Size	Seedcoat Toughness	Chewiness
OTMS Peak Force	0.85*	0.84*	0.81*	0.82*

* $p<0.001$.

4.4 STORAGE STUDY

4.4.1 Physical Tests

4.4.1.1 Seed Weight

The 100-bean weight for the 6 bean lines under the two storage conditions ranged from Tamazulapa (low temperature - low humidity [LT]) of 20.08 g to 29.23 for Itzapa (high temperature - high humidity [HT]) (Table 4.21). Seed weights of the stored samples were almost identical to those of the fresh samples (Table 4.1, page 94). Thus, the ranking of the stored samples with regard to 100-bean weight was the same as for the fresh samples. The Itzapa samples were the largest grained followed in decreasing order by Criollo B, Criollo A, Chichicaste, Sesenteño and Tamazulapa. As reported with the freshly-harvested beans, bush type beans had lower 100-bean weights than the vine samples.

TABLE 4.21

Physical properties of 6 lines of stored samples of Guatemalan black beans.

Bean line	100-bean weight† (g)	Dimensions (cm)‡ Length	Breadth	Thickness	L/B ratio‡	Seedcoat percent†	Seedcoat thickness‡ (mg/cm^2)	Water absorption percent†* 4 hr+	24 hr
Chichicaste									
LT	24.96±1.04	1.135±0.067	0.673±0.028	0.485±0.026	1.69	8.86±0.26	6.6	90.8±1.9	102.0±3.3
HT	25.39±0.98	1.113±0.050	0.665±0.029	0.485±0.025	1.67	10.82±0.36	8.5	89.1±3.2	96.1±1.8
Criollo A									
LT	25.89±0.61	1.130±0.055	0.713±0.036	0.496±0.024	1.58	10.02±0.19	7.7	8.2±2.2	91.6±5.0
HT	25.98±0.61	1.139±0.048	0.179±0.039	0.493±0.034	1.58	9.96±0.12	7.6	1.9±0.5	89.8±6.3
Criollo B									
LT	25.94±0.97	1.065±0.060	0.686±0.035	0.487±0.031	1.55	9.91±0.18	8.4	7.2±4.8	93.1±2.3
HT	26.03±0.53	1.077±0.044	0.695±0.030	0.498±0.022	1.55	10.00±0.21	8.3	7.4±1.0	89.9±1.7
Itzapa									
LT	29.06±0.50	1.144±0.048	0.769±0.041	0.487±0.028	1.49	9.70±0.05	8.1	6.4±2.4	96.3±1.8
HT	29.23±0.55	1.149±0.053	0.752±0.036	0.491±0.027	1.53	9.90±0.23	8.3	10.1±0.8	95.2±2.7
Sesenteno									
LT	22.34±0.99	1.084±0.055	0.650±0.031	0.469±0.022	1.69	9.18±0.24	6.7	92.8±11.6	103.9±2.7
HT	23.08±0.86	1.086±0.059	0.658±0.035	0.487±0.024	1.65	9.27±0.07	6.9	85.5±5.0	102.6±4.3
Tamazulapa									
LT	20.08±0.35	0.939±0.044	0.655±0.030	0.470±0.021	1.43	9.99±0.63	8.0	85.0±2.1	103.1±3.2
HT	21.27±0.27	0.937±0.044	0.646±0.034	0.455±0.027	1.45	11.00±0.11	9.5	88.9±2.1	95.5±1.1

† Means and standard deviations based on 4 determinations.

‡ Means and standard deviations based on determinations from 30 beans.

* Both LT and HT based on an original water content of 13-14%. HT values were adjusted from 16-17% to 13-14%.

** LT = low temperature-low humidity conditions; HT = high temperature-high humidity conditions.

For all bean lines the samples from the HT storage treatment had higher 100-bean weights than the LT sample of the same bean line. This is due to the fact that the water content of the HT storage samples had been adjusted to 16-17% and had approximately 2-4% more water than the LT stored samples (13-14%) at the beginning of the study.

4.4.1.2 Seed Dimensions

Mean measurements for length, breadth, and thickness for the 6 lines of beans under the two storage conditions are presented in Table 4.21. These dimensions and the corresponding L/B ratio, i.e., shape were very similar to those of the fresh samples.

4.4.1.3 Seed Size Distribution

The distribution of seed sizes of the LT and HT stored was assumed to be the same as that of the fresh beans (Figure 4.1, page 97) and therefore, direct measurements on the LT and HT beans were not made.

4.4.1.4 Percent Seedcoat

The percent seedcoat values for the two storage treatments of the 6 bean lines are given in Table 4.21. Percent seedcoat values ranged from 8.86% for Chichicaste LT to 11.00% for Tamazulapa HT. For all bean lines except Criollo A, the percent seedcoat values for the HT samples were higher than the percent seedcoat values for the LT samples. These increases ranged from only 0.09% (Criollo B and Sesenteño) to as much as 1.96% (Chichicaste). The Criollo A HT seedcoat percent value was 0.06% lower than the Criollo A LT value. While the differences between the LT and HT percent seedcoat values were slight for most bean lines, the higher levels for Chichicaste HT and Tamazulapa HT were notable. The reason for this increase in seedcoat percentage is not known but may indicate the presence of a hardening defect.

4.4.1.5 Seedcoat Thickness

Seedcoat thickness (mg/cm^2) for the 6 bean lines stored under LT and HT conditions is given in Table 4.21. Thickness values ranged from 6.6 mg/cm^2 for Chichicaste LT to 9.5 mg/cm^2 for Tamazulapa HT. Chichicaste LT and Seseneño LT had similar values for seedcoat thickness (6.6 and 6.7 mg/cm^2, respectively). Criollo A LT's seedcoat thickness value was higher at 7.7 mg/cm^2. Tamazulapa LT and Itzapa LT had the highest values of the LT samples for seedcoat thickness. Among the HT stored bean lines, Seseneño HT had the lowest seedcoat thickness value (6.9 mg/cm^2). Criollo A HT had a higher value of 7.6 mg/cm^2. The HT samples of Chichicaste, Criollo B and Itzapa had similar thickness values of 8.5, 8.3 and 8.3 mg/cm^2, respectively. The Tamazulapa HT seedcoat thickness value was the highest at 9.5 mg/cm^2. For four of the 6 bean lines the difference between the seedcoat thickness values for their LT and HT samples were small. The differences between the LT and HT samples of Criollo A, Criollo B, Itzapa and Seseneño were from 0.1 to 0.2 mg/cm^2 with the HT value being the higher in the cases of Itzapa and Seseneño. The seedcoat thickness values differed between the two storage treatments by 1.9 and 1.5 mg/cm^2 for the Chichicaste and Tamazulapa samples, respectively. In both cases the HT treated beans had thicker seedcoats than the LT treated ones. Such thickening of the seedcoat may be an indication of a hardening defect in these lines.

4.4.1.6 Water Absorption

The percentages of water absorbed after 4 and 24 h of soaking are listed in Table 4.21 for both LT and HT stored bean lines. The water absorption percentages reported for the HT treated beans had been adjusted to account for the fact that their water content was 16-17%, 3-4% higher than that of the LT beans. Criollo A, Criollo B and Itzapa, the three bean lines from the Chimaltenango region, had lower levels of water absorption at both the 4 and 24 h soaking times for both storage treatments than the other three bean lines from the Jutiapa region. Chichicaste LT, Sesenteño LT and Tamazulapa LT had water absorption levels of 85.0% to 92.8% at 4 h while Criollo A LT, Criollo B LT and Itzapa LT had values of 6.4% to 8.2%. After 24 h of soaking the water absorption percentages of Criollo A LT, Criollo B LT and Itzapa LT had risen to 91.6%, 93.1% and 96.3%, respectively, which were still lower than the 102.0%, 103.9% and 103.1% absorbed by Chichicaste LT, Sesenteño LT and Tamazulapa LT, respectively. While the groupings of both LT and HT bean lines with respect to water absorption was the same, the actual percentages obtained for each storage treatment were not always the same for the same bean line. At 4 h soaking, the water absorption percentages for 4 of the 6 HT bean lines were higher than those of LT treatment. Water absorption percentages were slightly lower for Criollo A HT (5.1%) and Sesenteño HT (91.5%) than their corresponding LT samples (8.2% and 92.8%, respectively). After 24 h soaking, only the Tamazulapa HT had a lower water absorption percentage (101.5%) than its corresponding LT sample (103.1%).

Several authors have noted than beans stored at high humidities tended to have higher water absorption levels or faster rates of absorption that beans stored at low humidity levels or fresh beans (Burr et al., 1968; Sefa Dedeh et al., 1978, 1979; Quenzer et al., 1978; Jackson and Varriano-Marston, 1981; Plhak et al., unpublished). Black beans stored under high temperature and high humidity (HH) conditions (7 mo at 30°C and 80% RH [16% water content]) had higher initial rates and final water absorptions than beans stored under low temperature-low humidity (LL) conditions (7 mo at 15°C and 35% RH [8% water content]) (Plhak et al., unpublished). The initial rate of water absorption was lowered when the water content of the high temperature-high humidity beans was lowered from 16% to 8% before soaking. This lowered rate, however, was still not as low as that of the low temperature-low humidity beans (Plhak et al., unpublished). The water absorption levels in the HT stored beans were, in most cases, similar or lower for their corresponding LT beans and it seems apparent that there was an effect of higher initial water content on water absorption.

This study found that for both LT and HT bean samples, the bean lines with thinner seedcoats tended to have higher water absorption values at 4 h. This same pattern was reported by Sefa-Dedeh and Stanley (1979a) and was also noted with the freshly-harvested bean samples. As with the freshly-harvested bean samples, the Tamazulapa samples were the exception to this tendency. The thickening of seedcoat and increase in seedcoat percentage in the Chichicaste HT and Tamazulapa HT samples may account for the difference between the water absorption values for Chichicaste LT and HT at 24 h and for the lower water absorption level in Tamazulapa HT as compared to Tamazulapa LT at 24 h but it does not explain the higher water absorption percentage at 4 h for both HT samples.

4.4.2 Instrumental Tests

4.4.2.1 Raw Bean Hardness

Raw bean peak force values were highest for the bean lines with the largest seed sizes (Criollo A and Itzapa) and lowest for the bean lines with the smallest seed sizes (Chichicaste and Tamazulapa) (Table 4.22). Peak forces for the HT samples were lower or similar to those for the LT beans. The softer raw bean texture of the HT beans could be attributed to their higher moisture content. The range of raw bean peak forces for the LT beans was from 85.470 N (Tamazulapa LT) to 141.010 N (Criollo A LT). HT raw bean hardness forces varied from 67.080 N (Tamazulapa HT) to 132.650 N (Itzapa HT). The effect of hardening on raw bean hardness was not clear.

4.4.2.2 Cooked Bean Hardness

Peak force as measured by the OTMS was quadratically related to cooking time for bean lines under both storage regimes (Table 4.23). For both LT and HT treatments, Criollo A and Criollo B did not soften as much as the other lines. Itzapa, Sesenteño and Tamazulapa were the softest cooking beans under both storage treatments (Figures 4.8 and 4.11). There appears to be greater differences in the softening of the LT bean samples as compared to the HT as can be seen by the spread of curves. The HT samples only softened to a range of 250 to 350 N while the LT

TABLE 4.22

Mean raw bean peak force values as measured by the wedge apparatus for 6 lines of stored samples of Guatemalan black beans.

Bean lines		Raw bean peak force† (N)
Chichicaste		
	LT	94.760±14.36
	HT	85.720±11.85
Criollo A		
	LT	141.010±34.96
	HT	131.820±23.56
Criollo B		
	LT	100.690±15.01
	HT	99.350±17.28
Itzapa		
	LT	131.440±22.58
	HT	132.650±16.92
Sesenteño		
	LT	85.480±14.74
	HT	87.510±13.81
Tamazulapa		
	LT	85.470±16.70
	HT	67.080±11.17

† Mean and standard deviation based on minimum of 29 determinations.

TABLE 4.23

Relationship between cooking time and mean peak force as measured by the OTMS extrusion cell for each of the 6 lines of stored samples of Guatemalan black beans.

Bean line	Equation	R^2
Chichicaste	Y = 676.53 + 100.36 ST - 4.47 CT + 0.01 CT^2	0.75
Criollo A	Y = 572.82 + 12.71 ST - 2.17 CT + 0.00 CT^2	0.69
Criollo B	Y = 709.09 + 22.65 ST - 2.87 CT + 0.00 CT^2	0.79
Itzapa	Y = 572.96 + 10.30 ST - 2.46 CT + 0.00 CT^2	0.71
Sesenteño	Y = 474.21 + 27.14 ST - 2.01 CT + 0.00 CT^2	0.82
Tamazulapa	Y = 397.19 + 80.75 ST - 2.49 CT + 0.00 CT^2	0.79

† Y = Peak force in newtons.

‡ CT = cooking time in minutes.

samples had minimum peak force values of 150 to 325 N. Only Chichicaste HT and Tamazulapa HT were significantly harder than their LT samples (Figure 4.12). There was no significant difference between the LT and HT samples for any of the other bean lines although at all cooking times the HT sample had the higher reading.

The greater hardness of the cooked Chichicaste HT and Tamazulapa HT samples, when compared to their respective LT samples, may be related to their higher percent seedcoat and seedcoat thickness values. The presence of the seedcoat contributes to the peak force measurement as can be seen after long cooking times when the cotyledons are easily extruded from the cell, leaving empty seedcoats to be compressed by the column.

At the longer cooking times peak force values are shown to increase as the proportion of empty seedcoats to cooked cotyledons increase. The effect of the seedcoat on peak force can be seen throughout the cooking period as beans with higher seedcoat thicknesses (Chichicaste HT and Tamazulapa HT) tended to have higher peak force readings. The Chichicaste and Tamazulapa bean lines were shown to have hardened over the storage period while there was no significant hardening affecting the other lines.

Studies by Sefa-Dedeh et al. (1978, 1979) and Jackson and Varriano-Marston (1981) have shown that cooking time within a treatment depends strongly on the total moisture content of the beans. Reducing the water content of high temperature-high humidity (HH) stored beans from 16% to 8% did not reduce bean hardness after cooking (Plhak et al., unpublished). Beans stored for 7 mo under high temperature-high humidity (30°C and 80% RH [16% water content]) required 3.5 h of cooking to provide a puncture force equal to that of beans stored under low temperature-low humidity (15°C and 35% RH [8% water content]) and cooked for 1 h (Plhak et al., unpublished).

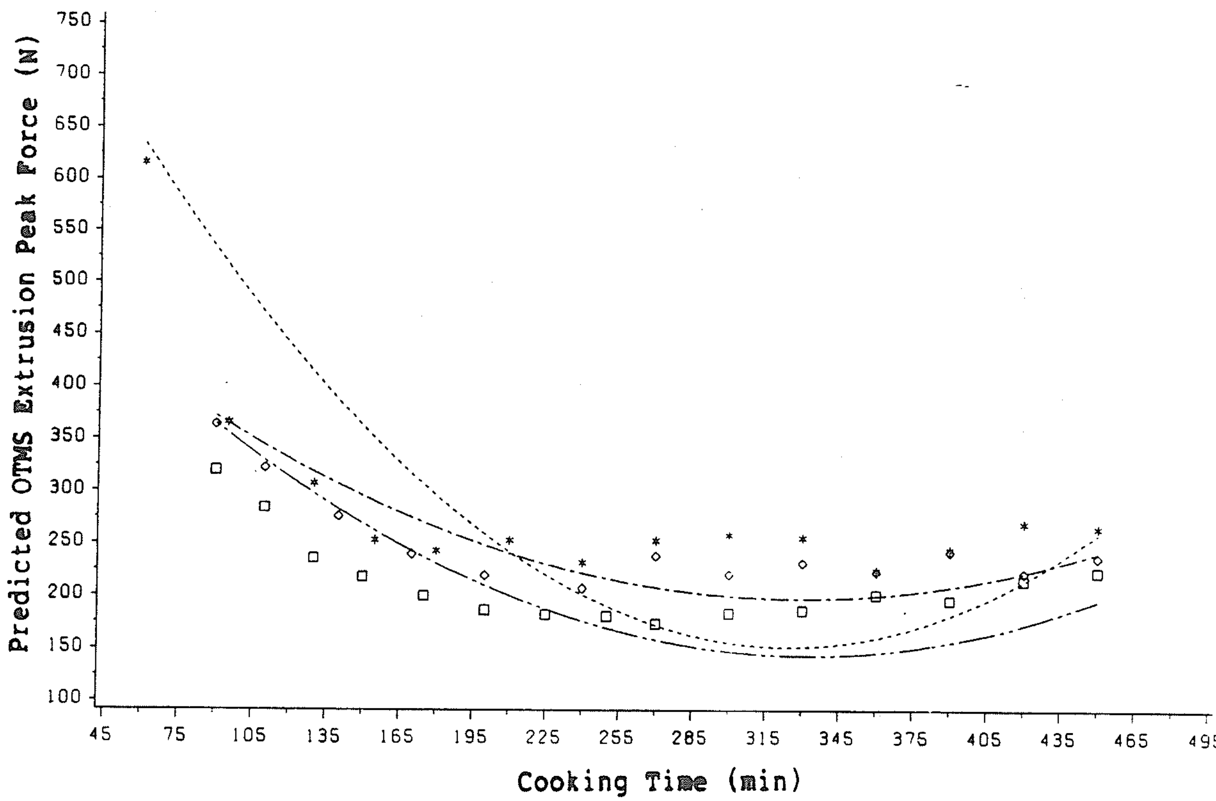

Figure 4.8: Predicted OTMS extrusion cell peak force (N) as a function of cooking time (min) for low temperature-low humidity stored samples of Chichicaste, Sesenteño, and Tamazulapa black beans.

---- Chichicaste
◇ -—◇ Sesenteño
□--—□ Tamazulapa

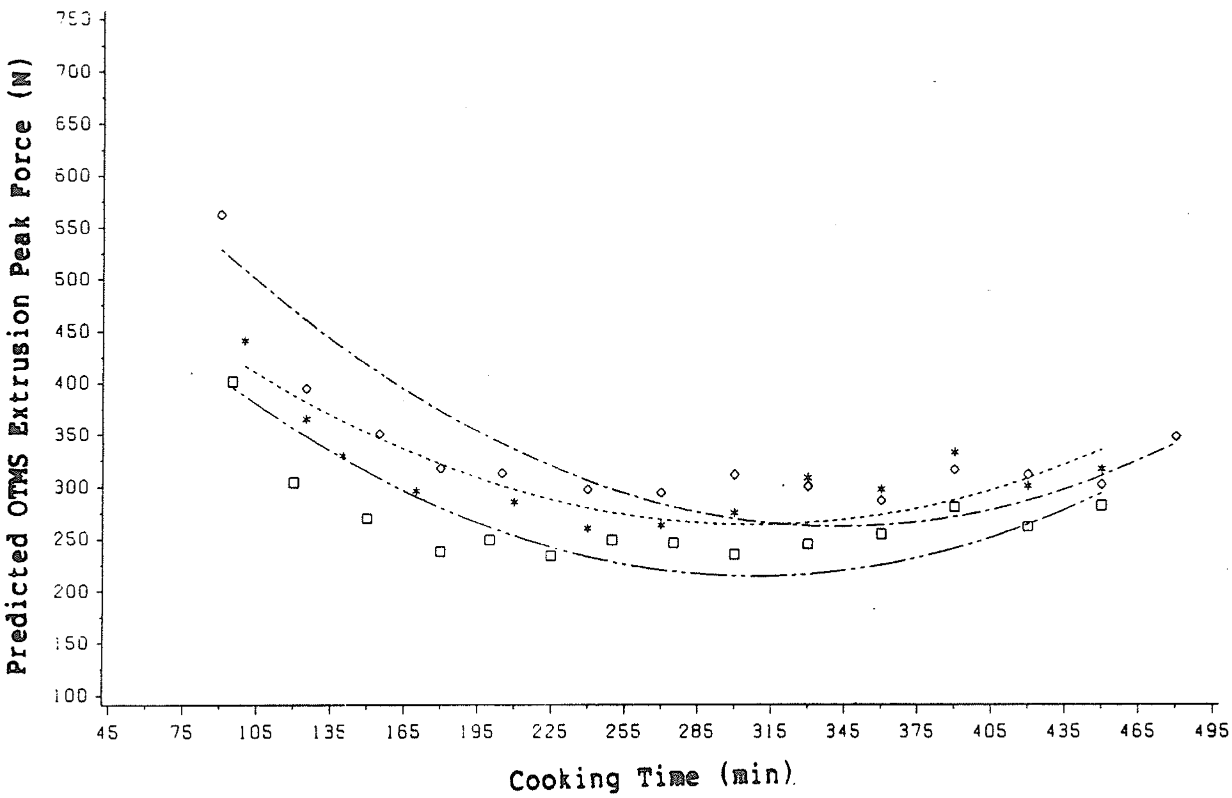

Figure 4.9: Predicted OTMS extrusion cell peak force (N) as a function of cooking time (min) for low temperature-low humidity stored samples of Criollo A, Criollo B, and Itzapa black beans.

---- Criollo A
◇ -—◇ Criollo B
□--—□ Itzapa

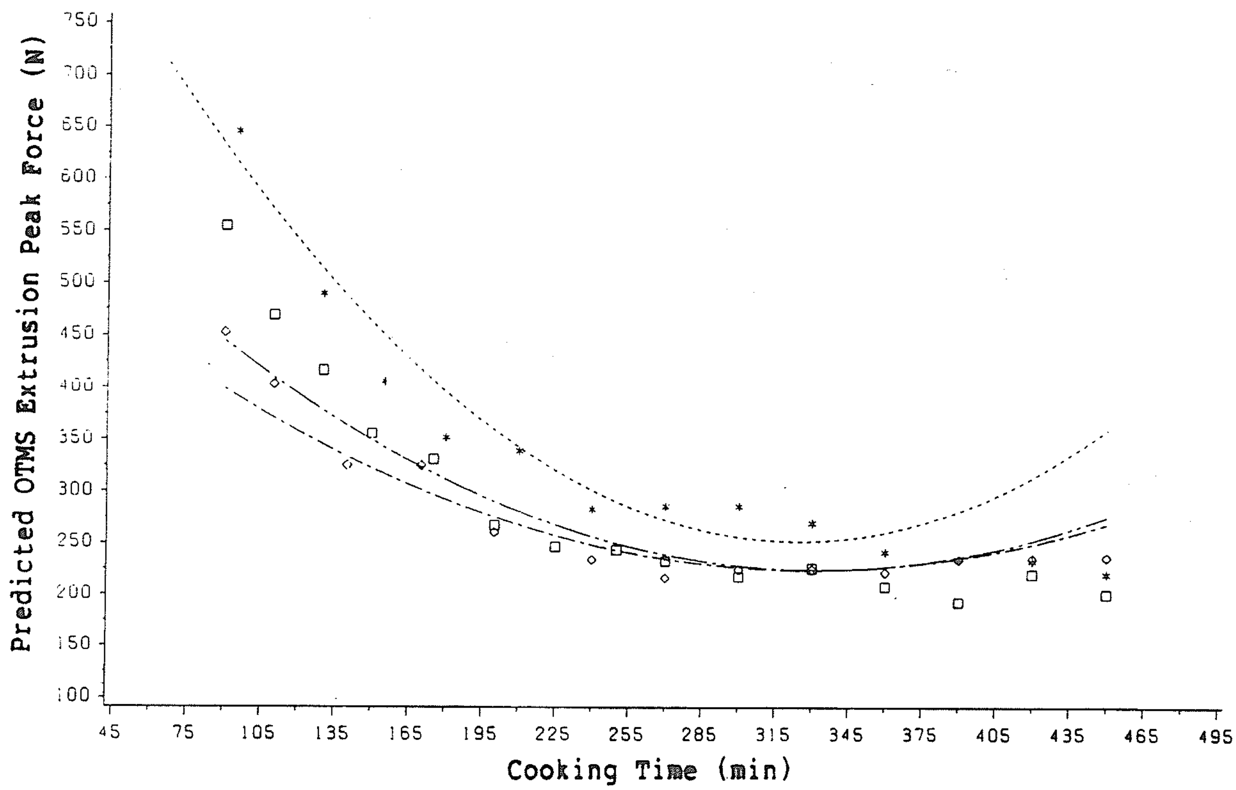

Figure 4.10: Predicted OTMS extrusion cell peak force (N) as a function of cooking time (min) for high temperature-high humidity stored samples of Chichicaste, Sesenteño, and Tamazulapa black beans.

---- Chichicaste
◇ -—◇ Sesenteño
□--—□ Tamazulapa

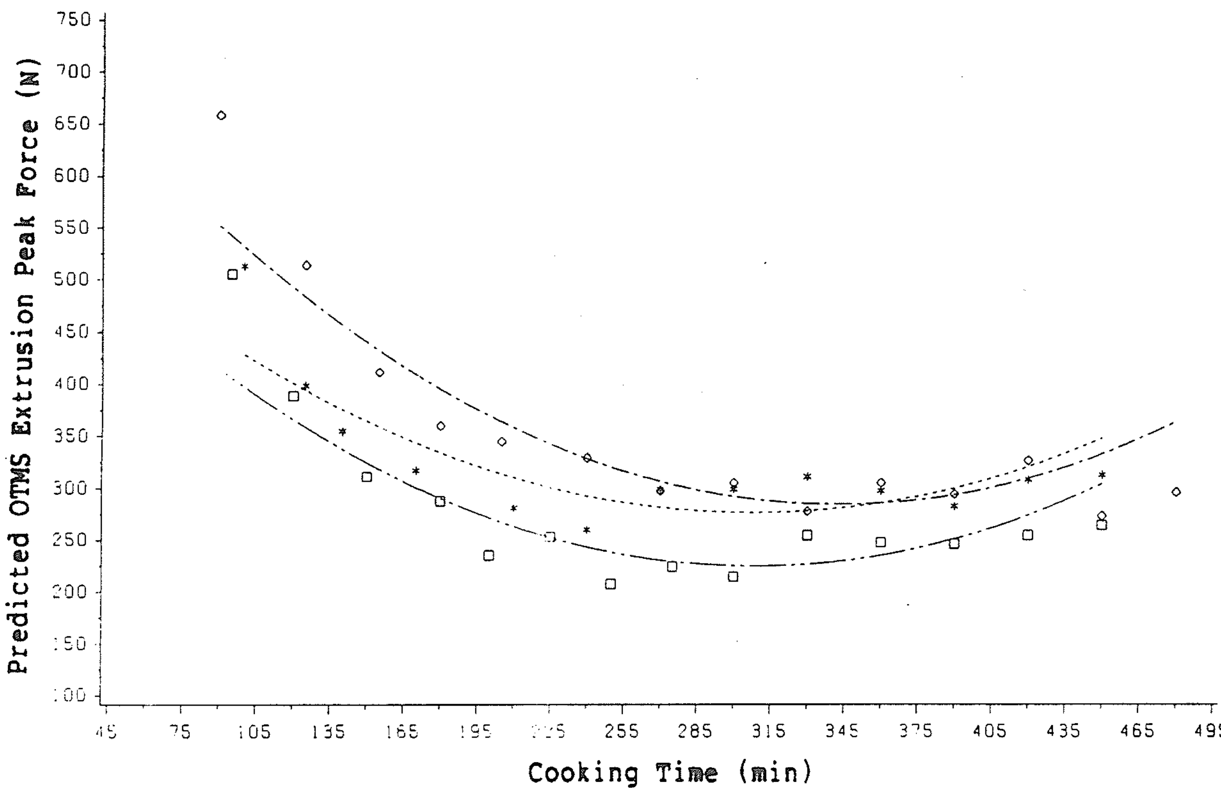

Figure 4.11: Predicted OTMS extrusion cell peak force (N) as a function of cooking time (min) for high temperature-high humidity stored samples of Criollo A, Criollo B, and Itzapa black beans.

---- Criollo A

◇ -—◇ Criollo B

□--—□ Itzapa

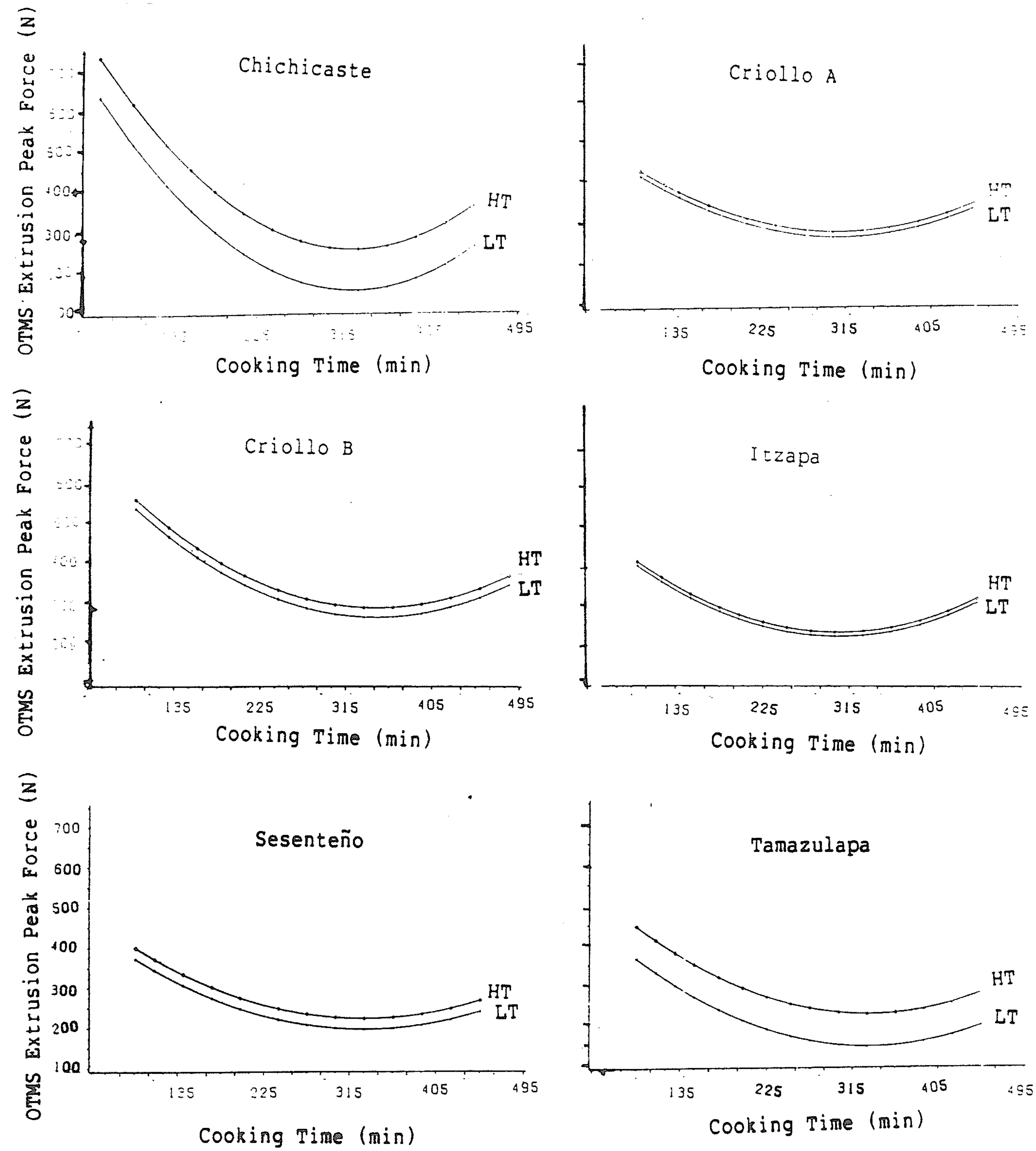

Figure 4.12: Predicted OTMS extrusion cell peak force (N) as a function of cooking time (min) for each of 6 lines of low temperature-low humidity and high temperature-high humidity stored samples of Guatemalan black beans.

4.4.3 Sensory Analysis

4.4.3.1 Cooking Time Determination

To facilitate the evaluation of the cooked texture of LT and HT stored beans by the in-house acceptability and TPA panels it was necessary to determine cooking times for each bean line under each storage condition to cook to an acceptable and equivalent degree of doneness (Table 4.24). For five of the 6 bean lines the time chosen for the LT sample was equal to or lower than that used for the freshly-harvested sample of the same line. The times chosen for the HT samples were greater than those for the LT samples for all bean lines except Criollo A where it remained the same.

The cooking times required by the stored samples to reach an acceptably cooked texture were chosen to correspond to the texture of the freshly-harvested sample of the same line and were based on OTMS peak force readings. A large sample of beans were cooked (400 g in 2000 mL of water) and 60 g samples were withdrawn for evaluation every 15 minutes. Two OTMS peak force determinations were made at each cooking time sampled. A force-time curve was drawn for each bean line under each storage treatment. The cooking time chosen to provide an acceptably cooked sample was the time that corresponded to the lowest force value on the curve or where the curve levelled off. In many cases the OTMS peak force value of the stored samples at this time was very similar to that of the acceptably cooked freshly-harvested samples.

TABLE 4.24

Cooking times and corresponding mean OTMS extrusion cell peak force values for 6 lines of freshly-harvested and stored samples of Guatemalan black beans cooked to their acceptably-cooked stage.

	Cooking time (in minutes) (OTMS peak force [in newtons])		
Bean line	Freshly-harvested	LT	HT
Chichicaste	155 (309)†	130 (290)	240 (277)
Criollo A	240 (221)	240 (264)	240 (268)
Criollo B	240 (258)	240 (264)	270 (299)
Itzapa	180 (182)	225 (229)	250 (233)
Sesenteño	170 (282)	140 (230)	200 (292)
Tamazulapa	200 (217)	150 (268)	300 (258)

† OTMS measurement is average of two readings from sample given to in-house acceptability panel.

4.4.3.2 In-house Comparative Acceptability Panel

The distribution of acceptability scores among the in-house comparative acceptability panel members for the low temperature storage (LT) samples and for the high temperature storage (HT) samples are shown in Appendix Q.

The comparative acceptability panel was carried out to determine if differences existed among the bean lines when a direct comparison was made among the bean lines which had undergone the same storage treatment, and had been cooked to their acceptably-cooked point, that is, under the assumption of equal doneness (Table 4.25).

For the LT stored samples, mean acceptability scores ranged from 5.07 (Sesenteño LT) to 6.27 (Criollo A LT). The absolute values of acceptability scores for HT samples were lower and ranged from 4.94 (Sesenteño HT) to 6.09 (Tamazulapa HT). Acceptability scores were the lowest for Chichicaste and Sesenteño under both storage regimes.

The difference in the absolute acceptability scores for the Chichicaste LT and HT and Sesenteño LT and HT samples were quite similar. The most acceptable LT sample, Criollo A LT, became the third most acceptable through an acceptability score reduction of 0.70. Itzapa HT's score was 0.30 less than its LT acceptability score yet it held its rank of second most acceptable. The acceptability score for Criollo B HT was 0.40 lower than for its LT sample, consequently its ranking was reduced from third to fourth most acceptable. Tamazulapa HT, on the other hand, received an acceptability score 0.70 above its LT score which place it as the most acceptable of all HT samples.

The texture of the Itzapa, Chichicaste and Sesenteño beans did not seem to deteriorate under high temperature and high humidity storage. The Criollo A HT and Criollo B HT appeared to have experienced some deterioration in texture that resulted in reducing their acceptability. The cooked texture of the Tamazulapa sample appeared to have improved through HT storage, but it really may have not changed while the other bean lines deteriorated more severely in relation to it.

4.4.3.3 Texture Profile Analysis Panel

The Texture Profile Analysis (TPA) panel mean scores for hardness, particle size, toughness of seedcoat and chewiness for the 6 bean lines under 2 storage regimes are given in Table 4.26. Although cooking times were chosen for both the LT and HT samples to provide equivalent degrees of doneness, scores for all four texture profile characteristics for the HT samples were higher for almost all bean lines. The fact that the cooking times for the HT beans to become acceptably cooked were longer than the LT samples for most lines (the same time for both LT and HT Criollo A) is a clear indication that hardening did occur in the HT treated samples.

With LT and HT treatment results combined, samples cooked to an acceptable degree of doneness had hardness scores that ranged from 6.2 (Criollo B LT) to 10.48 (Criollo B HT). Hardness scores for LT beans ranged from 6.21 (Criollo B LT) to 8.89 (Sesenteño LT). HT bean hardness scores ranged from 7.34 (Itzapa HT) to 10.48 (Criollo B HT). Particle size scores for LT and HT beans ranged from 6.50 (Itzapa LT) to 10.83 (Criollo B). Scores for particle size of LT beans were from 6.50

TABLE 4.25

Comparisons of comparative acceptability panel mean acceptability scores for samples of Guatemalan black beans stored under low temperature-low humidity and high temperature-high humidity conditions.

	Storage Condition			
	Low temperature-low humidity		High temperature-high humidity	
Bean line	Rank	Mean Score	Rank	Mean Score
Chichicaste	5	5.17†‡ab*	5	5.11ab
Criollo A	1	6.27b	3	5.51ab
Criollo B	3	5.60ab	4	5.20ab
Itzapa	2	6.07ab	2	5.77ab
Sesenteño	6	5.07a	6	4.94a
Tamazulapa	4	5.30ab	1	6.09a

† Each line was cooked to reach similar peak force for both storage conditions.

‡ For texture acceptability: 1=extremely unacceptable and 8=extremely acceptable.

* In each column, means with the same letter are not significantly different ($p<0.05$) as determined using the Bonferroni (Dunn) T-test procedure.

TABLE 4.26

Texture Profile Analysis (TPA) mean scores† for hardness, particle size, seedcoat toughness and chewiness for 6 lines of stored samples of Guatemalan black beans cooked to their acceptably cooked point.

Bean line and storage treatment (Cooking time)		Texture Attribute		
	Hardness	Particle	Seedcoat	Chewiness
Chichicaste				
(130) LT	8.37a‡	9.47a	11.37a	5.97a
(240) HT	9.09a	9.56a	11.69a	5.84a
Criollo A				
(240) LT	6.22a	7.08a	11.23a	5.30a
(240) HT	9.03b	8.56a	12.49a	5.82a
Criollo B				
(240) LT	6.21a	7.31a	11.76a	5.44a
(270) HT	10.48b	10.83b	13.43a	6.70a
Itzapa				
(225) LT	6.35a	6.50a	10.78a	5.51a
(250) HT	7.34a	8.07a	11.70a	5.70a
Sesenteño				
(140) LT	8.89a	9.51a	13.75a	6.29a
(200) HT	9.22a	9.47a	12.66a	6.43a
Tamazulapa				
(150) LT	8.05a	8.80a	10.26a	5.25a
(300) HT	9.18a	9.98a	12.51a	5.86a

† Mean of 3 replications.

‡ Within each bean line and Texture Profile Analysis characteristic, mean TPA scores followed by the same letter are not significantly different ($p<0.05$) as determined using the Bonferroni (Dunn) T-test procedure.

(Itzapa LT) to 9.51 (Sesenteño LT) while HT bean scores had a range of 8.07 (Itzapa HT) to 10.83 (Criollo B HT). Seedcoat toughness scores ranged from 10.26 (Tamazulapa LT) to 13.75 (Sesenteño LT) over both LT and HT samples. Among the HT samples with acceptable texture, scores for toughness of seedcoat varied from 11.69 (Chichicaste HT) to 13.43 (Criollo B HT). Over both LT and HT samples, chewiness scores for acceptably cooked samples varied from 5.25 (Tamazulapa LT) to 6.70 (Criollo B HT). Among LT beans, Tamazulapa LT had the lowest score (5.25) and Sesenteño LT had the highest (6.29). Chewiness scores ranged from 5.70 (Itzapa HT) to 6.70 (Criollo HT) for the HT beans.

In a study by dos Santos Garruti and dos Santos Garruti (1983) on common Phaseolus vulgaris L. beans, storage at 25°C and 65-70% RH produced beans which were harder and more chewy as determined by a trained profile analysis panel. Morris et al. (1956), using a standard cooking time for each variety, found a significant deterioration in texture and flavour in beans which had been stored for 6 months at 77°F (25°C) at moisture contents above 13%. In this study the TPA panel results support these findings as almost all attribute scores for the HT samples were higher than those for the corresponding LT sample.

Morris et al. (1956) reported that storage of beans with moisture contents less than 10% for 2 years maintained cooking quality almost as well as storing them at -10°F (-23°C). In the present study TPA hardness and particle size scores for LT beans (8% water content) were the only attribute scores that were similar to those of acceptably cooked freshly-harvested beans.

Texture profile attributes of hardness, particle size and chewiness were shown to be significantly correlated to acceptability score (Table 4.27). The relatively high rating of the Criollo A LT, Itzapa LT and Criollo B LT among the LT samples for acceptability may be related to the relatively low hardness, low chewiness and small particle size as perceived by the TPA panel. Criollo A LT, Criollo B LT, and Itzapa LT and Tamazulapa LT had the lowest chewiness scores. Such differences between these four bean lines, with respect to these characteristics, and Chichicaste and Sesenteño were not noted in the HT samples. The relatively low acceptability rating for Chichicaste and Sesenteño under both storage treatments may be due, in the comparison of the LT samples, to their relatively high hardness and particle size scores.

For all bean lines, except Tamazulapa, the mean acceptability scores was lower for the HT than the LT beans (Table 4.25). While the actual mean acceptability scores for Chichicaste HT and Sesenteño HT were very similar to their respective samples, differences between the acceptability scores for the LT and HT samples of the other bean lines were as much as 0.70. The mean acceptability score for the Criollo A, Criollo B and Itzapa dropped 0.70, 0.40, and 0.30, respectively, from the LT to the HT storage sample. These reductions in acceptability could be related to increased hardness, particle size and chewiness as determined by the TPA panel. While Chichicaste HT and Sesenteño HT samples experienced increases in hardness, particle size and chewiness, it was not to such a large degree. The increased acceptability of the Tamazulapa sample from the LT to the HT can not be explained as above since the same textural changes were noted by the TPA panel with the opposite result with respect to the acceptability score. This indicates that another

TABLE 4.27

Pearson correlation coefficients for Texture Profile Analysis (TPA) mean scores and comparative acceptability panel acceptability mean scores for 6 lines of stored samples of Guatemalan black beans.

	Variable				
Variable	Hardness	Particle Size	Seedcoat Toughness	Chewiness	Accept-ability
Hardness	1.00	0.94****	0.67*	0.82***	-0.60*
Particle Size		1.00	0.60*	0.82***	-0.61*
Seedcoat Toughness			1.00	0.74**	-0.37
Chewiness				1.00	-0.73**

**** $p<0.0001$
*** $p<0.001$
** $p<0.01$
* $p<0.05$.

factor, or combinations of factors, besides the four attributes measured by the TPA panel, is affecting acceptability. OTMS peak force values did not seem to correspond to acceptability score rankings.

4.5 RELATIONSHIPS BETWEEN PHYSICAL, INSTRUMENTAL AND SENSORY TESTS AND ACCEPTABILITY

Correlations between physical, instrumental and sensory test results with acceptability for all bean lines and storage treatments are given in Table 4.28. Percent seedcoat and seedcoat thickness were significantly correlated to mean acceptability score (-0.55, p=0.050; -0.63, p=0.025, respectively). Both 4 h and 24 h water absorption percentages were significantly correlated to acceptability score (-0.58, p=0.040 and -0.73, p=0.009, respectively).

Several authors have noted that water absorption was well correlated to cooked bean texture but the rate of water absorption was not related (Burr et al., 1968; Sefa-Dedeh et al., 1978, 1979; Quenzer et al., 1978; Jackson and Varriano-Marston, 1981; Plhak et al., unpublished).

Raw bean hardness (peak force) was significantly correlated to acceptability score (0.59, p=0.036). Mean TPA scores for hardness, particle size and chewiness were correlated to mean acceptability score (0.59, p=0.037; -0.80, p=0.003; and -0.75, p=0.006, respectively).

Correlation coefficients of 0.77 and 0.87 were reported between sensory texture and puncture force for black beans cooked at 100°C and 121°C, respectively (Silva et al., 1981a). A correlation coefficient of

TABLE 4.28

Correlations between physical, instrumental and sensory test results for 6 lines of fresh and stored samples of Guatemalan black beans.

	MS	MP	THICK	M4	M24	MC	MA	MH	MPS	MTC	MCH	MPF
(MS) Mean Seed Weight	1.0000	-0.1151 P=.376	0.1739 P=.315	-0.7460 P=.007	-0.4182 P=.115	0.7592 P=.005	0.4767 P=.082	0.9313 P=.000	-0.6121 P=.030	-0.3049 P=.195	-0.3146 P=.188	-0.5990 P=.034
(MP) Mean Percent Seedcoat		1.0000	0.8967 P=.000	-0.0885 P=.404	-0.4968 P=.072	-0.0908 P=.402	-0.5489 P=.050	-0.0471 P=.449	-0.3990 P=.127	-0.2360 P=.256	-0.5795 P=.040	-0.5120 P=.085
(Thick) Mean Seedcoat Thickness			1.0000	-0.3058 P=.195	-0.6240 P=.027	0.0038 P=.496	-0.6298 P=.025	0.1754 P=.314	-0.4849 P=.078	-0.3947 P=.129	-0.6749 P=.016	-0.8863 P=.014
(M4) Mean 4 h Water Absorption				1.0000	0.8469 P=.001	-0.8201 P=.002	-0.5787 P=.040	-0.8089 P=.002	0.5181 P=.063	0.0443 P=.452	0.3249 P=.180	0.3668 P=.149
(M24) Mean 24 h Water Absorption					1.0000	-0.5376 P=.054	-0.7279 P=.009	-0.5076 P=.067	0.4437 P=.089	-0.0121 P=.487	0.3998 P=.128	0.3600 P=.153
(MC) Mean Raw Bean Hardness						1.0000	0.5900 P=.036	0.9002 P=.000	-0.6473 P=.022	-0.1366 P=.368	-0.3914 F=.132	-0.4055 P=.123
(MA) Mean Acceptability Score							1.0000	0.5870 P=.037	-0.7958 P=.003	-0.3483 P=.162	-0.7472 F=.006	-0.7152 P=.010
(MH) Mean Hardness (TPA)†								1.0000	-0.7012 P=.012	-0.4053 P=.123	-0.4293 F=.108	-0.6203 P=.028
(MPS) Mean Particle Size (TPA)									1.0000	0.6167 P=.029	0.7863 P=.003	0.8143 P=.002
(MTC) Mean Seedcoat Toughness (TPA)										1.0000	0.6161 P=.029	0.7110 P=.011
(MCH) Mean Chewiness (TPA)											1.0000	0.8145 P=.002
(MPF) Mean Peak Force OTMS Extrusion												1.0000

† TPA = Texture Profile Analysis panel results.

0.93 was found by Aguilera and Steinsaper (1985) for the relationship between sensory evaluation and puncture force of black beans.

When one examines the differences in physical hardness and the ability of the panelists to recognize these, it becomes apparent that, in general, panelists' ability to differentiate between samples is affected by the actual physical hardness of the samples, i.e., whether the samples are relatively hard or soft. Panelists were able to differentiate between samples that were different by as little as 10 newtons when the physical hardness was relatively high.

Some relationship appears to exist between the sensory rating of hardness by trained panelists and the physical hardness of raw or cooked values determined by the OTMS, however, more investigation is required. The inherent variability of the sample used may have had an adverse effect in the development of a strong relationship between the two variables, since panelists were assessing hardness using a small sample of beans while the OTMS was making a reading on a much larger sample. Panelists would have been able to sense the greater variability in the sample than would the OTMS. Perhaps a longer period of training or a different method of training the panelists would have reduced the variability in their ratings and the lack of correlation between the two methods.

4.6 SUMMARY

4.6.1 Physical Tests

4.6.1.1 Seed Weight, Seed Dimensions and Seed Size Distribution

The bush bean samples studied (Chichicaste, Criollo B, Sesenteño and Tamazulapa) tended to have lower seed weights and a larger proportion of small beans than the vine samples (Criollo A and Itzapa) and thus were considered to be smaller beans. Beans grown in the Chimaltenango region (Criollo A, Criollo B and Itzapa) tended to have a higher proportion of large-sized beans. Shape, as indicated by L/B ratio, did not seem to be related to bean type or growing location.

4.6.1.2 Percent Seedcoat and Seedcoat Thickness

Samples from the Chimaltenango region (Criollo A, Criollo B and Itzapa) as well as the Tamazulapa sample had similar and higher values for percent seedcoat than the Chichicaste and Sesenteño samples grown in Jutiapa. Higher percent seedcoat values were noted in the HT treated Chichicaste and Tamazulapa samples and appeared to be a function of the hardening process. This increase in seedcoat percentage might account for the extra time required to cook these samples to an acceptable degree of doneness as compared to their respective LT samples.

The increase in seedcoat percentage noted in the HT treated beans may, however, be representing a loss of cotyledon material rather than an increase in amount of seedcoat. The cotyledon would be metabolized faster due to the higher metabolic rate of the HT beans while the seedcoat amount would be left relatively unchanged.

Seedcoat thickness values did not seem to be related to bean type or growing location. Greater seedcoat thicknesses were noted in the HT stored Chichicaste and Tamazulapa samples as compared to their corresponding LT samples. This thickening was accompanied by increases in percent seedcoat and may indicate a hardening defect.

4.6.1.3 Water Absorption

Bean samples from the Chimaltenango region (Criollo A, Criollo B and Itzapa) had lower water absorption levels than the Chichicaste, Sesenteño and Tamazulapa samples from Jutiapa. Water absorption percentages were lower for vine than bush beans. A 4 h soaking period facilitated a grouping of bean lines with respect to water absorption percent that was not as evident after 24 h soaking. Water absorption levels in HT stored samples were lower than the LT samples once adjusted for initial water content. The hardened beans seemed to absorb slightly less water.

4.6.2 Sensory Analysis

4.6.2.1 In-house Acceptability Panel

The different bean lines were shown to cook and become acceptable at different rates. The Sesenteño and Tamazulapa samples (both bush beans), became more acceptable at shorter cooking times than the other bean lines. A most acceptably cooked point was chosen, based on panel results and corresponded to 90% cooked for the Chichicaste, Itzapa and Sesenteño samples and to 100% cooked for the Criollo A, Criollo B and Tamazulapa samples. Cooking times that corresponded to these acceptably cooked points were used to prepare samples of equivalent degree of doneness for further instrumental and sensory testing.

After reviewing OTMS peak force values, TPA scores and in-house comparative acceptability panel scores for these cooked samples it was concluded that all samples should have been cooked to their 100% cooked point. Bean lines were compared for overall acceptability by the in-house panel. Those bean lines in which the acceptability cooked point corresponded to only 90% had lower acceptability scores than those cooked to their 100% cooked point. TPA scores and OTMS peak force values for the 90% cooked samples were higher than those cooked to 100%. It was evident that not all samples were cooked to the same degree. The samples that had been cooked to their 90% cooked stage seemed to be undercooked in relation to those samples cooked to their 100% cooked stage. It was concluded that the best method to determine acceptably cooked cooking times would be to use the predictive equations obtained in this study using an acceptability score of 6.

Relative acceptability scores, as shown by the storage data, seem to be related to hardness, particle size and chewiness as determined by the TPA panel. Cooked samples with relatively high TPA scores for these characteristics tended to have relatively low acceptability scores. The Tamazulapa sample was the exception, however, which indicates that a factor, or combination of factors, other than the four TPA characteristics evaluated, influenced acceptability.

4.6.2.2 Texture Profile Analysis Panel

Fresh bean samples with acceptable texture had TPA hardness scores of 8.8 or less. Particle size scores for acceptable beans were 8.9 or less. Acceptably cooked samples had seedcoat toughness scores of 11.6 or less while acceptable chewiness scores were 5.3 or less. All TPA attributes were highly correlated with each other and with mean acceptability score for fresh beans.

Even though the cooking times for the HT beans were longer than or the same as (Criollo A) their corresponding LT sample, the scores for almost all attributes were higher for the HT samples than the LT samples. This indicated that hardening defects did occur in the HT treated samples but only hardness and particle size scores for the LT samples were low enough to be within the range for acceptably cooked texture seen with the freshly-harvested samples.

4.6.3 Instrumental Tests

4.6.3.1 Raw Bean Hardness

The lowest raw bean peak forces corresponded to samples which were composed of the smallest beans (Sesenteño and Tamazulapa). Larger beans had higher raw bean peak forces. HT treated beans tended to have lower raw bean peak forces than their corresponding LT samples likely due to their higher water content.

4.6.3.2 Cooked Bean Hardness

As cooking times increased, peak force values tended to decrease initially and then remain the same and/or slightly increase as cooking continued. Different bean lines softened at different rates. The Chichicaste beans did not soften as much as the other lines. Itzapa beans cooked to the softest texture of the 6 lines. There were no significant differences in the softness of the remaining lines. The acceptably cooked points of the 6 bean lines corresponded to samples within a softness range of 250 to 300 N. Beans stored under HT conditions did not soften as much during cooking as did LT treated beans. Only the Chichicaste HT and Tamazulapa HT samples were significantly harder than their respective LT sample. Both these HT samples were shown to have higher seedcoat thickness and seedcoat percent values than their LT samples.

TPA scores were highly correlated with OTMS peak force values for cooked bean texture. The physical characteristics of seedcoat percent and seedcoat thickness were also highly correlated with these OTMS values.

Chapter V

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

1. Different lines of Guatemalan black beans require different cooking times to reach the same acceptable degree of doneness. These cooking times can be determined using large untrained consumer-type panels or by small trained panels evaluating percentage of cooked beans.

2. As cooking time increased, cooked bean texture hardness, particle size, seedcoat toughness and chewiness decreased according to Texture Profile Analysis (TPA) panel results.

3. Acceptably cooked beans had hardness and particle size scores of less than 7.6 and 7.2, respectively, on a 15 cm line scale with 30 intervals. The mean seedcoat toughness score that corresponded to an acceptably cooked samples was 10.9 or less. The critical mean chewiness score, assessed by a chew count was 4.9. Significant correlations were present between acceptability score, as determined by a comparative acceptability panel, and mean hardness (0.59, p=0.037), mean particle size (-0.79, p=0.003), and mean chewiness (-0.75, p=0.006).

4. OTMS peak force values in the range of 200 to 300 newtons indicated acceptable softness for the bean lines tested. There was a significant correlation (-0.71, p=0.010) shown between acceptability score and peak force.

5. High temperature - high humidity storage resulted in longer cooking times to soften beans. Even when adequately softened these beans exhibited texture changes.

6. Mean acceptability score was significantly correlated with such physical factors as percent seedcoat (0.55, p=0.050), seedcoat thickness (0.63, p=0.025), 4 h water absorption (-0.58, p=0.040), 24 h water absorption (-0.74, p=0.009) and raw bean hardness (0.59, p=0.036).

5.2 RECOMMENDATIONS FOR FURTHER RESEARCH

1. Bean researchers must realize that different bean lines react differently to cooking and to storage. Consequently, care must be taken in choosing bean lines for research projects and for extrapolating results from one bean line to another.

2. The separate contribution of seedcoat and cotyledon to the softening rates should be researched further.

3. The methods developed and used in this study would be of use in evaluating the effectiveness of pre-cooking treatments used to reduce cooking time for hardened beans.

4. Results of the Texture Profile Analysis panel and the in-house acceptability panels indicate that a factor or combination of factors other than hardness, particle size, seedcoat toughness or chewiness affect acceptability. Such factors may include colour or flavour and should be investigated.

5. Studies should be carried out to determine how closely an in-house Guatemalan panel approximates average Guatemalan consumers in acceptability rating. It would also be interesting to investigate how the different cultural groups in Guatemala evaluate acceptability.

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Appendix A

QUESTIONNAIRE USED FOR PANEL SELECTION - ENGLISH AND SPANISH VERSIONS.

I. GENERAL DATA

Name:____ Sex:________

Occupation:_____________________________Address:_____________________

II.____

Please answer the following questions sincerely.

1. Are you interested in participating in a training program for the sensory analysis judges?

   Yes________ No________

2. Do you smoke?

   Yes________ No________

3. Do you eat chili with your meals?

   Yes________ No________

4. Do you have problems detecting odours?

   Yes________ No________

5. Do you have problems detecting flavours?

   Yes________ No________

6. What flavour do you prefer?

	Yes	No
Sweet		
Salty		
Sour		
Bitter		

7. What are you favourite foods?

a.________________ b.________________

c.________________ d.________________

e.________________ f.________________

g.________________ h.________________

i.________________ j.________________

8. What foods do you not like?

a.________________ b.________________

c.________________ d.________________

e.________________ f.________________

g.________________ h.________________

i.________________ j.________________

9. Do you suffer from frequent colds or respiratory illnesses?

Yes________ No________

10. Do you use a dental plate or false teeth?

Yes________ No________

11. If you are selected to receive training, what time is convenient for you?

From________ To________ (a.m.)

From________ To________ (p.m.)

I. DATOS GENERALES

Nombre: ______________________ ______________ Sexo: __________

Ocupación: ____ ______________ Dirección: ___ ______________

II

Favor de responder las siguientes preguntas con la mayor sincerida

1. Tiene interés en participar en un adiestramiento para la formación de jueces de análisis sensorial.

   Sí ______ No ______

2. ¿Fuma usted?

   Sí ______ No ______

3. ¿Come chile con las comidas?

   Sí ______ No ______

4. ¿Tiene problemas para detectar olores?

   Sí ______ No ______

5. ¿Tiene problemas para detectar sabores?

   Sí ______ No ______

6. ¿Qué sabor prefiere?

	Sí	No
Dulce	______	______
Salado	______	______
Acido	______	______
Amargo	______	______

7. ¿Cuáles son sus alimentos favoritos?

a. ______________________ b. ______________________

c. ______________________ d. ______________________

e. ______________________ f. ______________________

g. ______________________ h. ______________________

i. ______________________ j. ______________________

8. ¿Qué alimentos no le gustan?

a. ______________________ b. ______________________

c. ______________________ d. ______________________

e. ______________________ f. ______________________

g. ______________________ h. ______________________

i. ______________________ j. ______________________

9. ¿Padece con frecuencia de catarros ó enfermedades respiratorias?

Sí ______ No ______

10. ¿Usa placa ó puente dental?

Sí ______ No ______

11. En caso de ser seleccionado para recibir adiestramiento, qué hora es para usted conveniente.

De ______ A ______ (En la mañana)

De ______ A ______ (En la tarde)

Appendix B

PROCEDURES AND BALLOTS USED IN TESTS CARRIED OUT FOR SCREENING PANELISTS - ENGLISH AND SPANISH VERSIONS.

Test #1 - Recognition Test for the Four Basic Tastes (Jellinek, 1985)

Nine aqueous solutions of sucrose, sodium chloride, citric acid and caffeine were prepared and presented in a randomized order to panelists for identification. One litre of each sample was prepared for 30 panelists following the method of Jellinek (1985). A sample of distilled water was included as a tenth sample.

Basic Taste	Test Solution
Sweet	0.40 g/100 mL sucrose
"	0.80 g/100 mL sucrose
Salty	0.08 g/100 mL sodium chloride
"	0.15 g/100 mL sodium chloide
Sour	0.02 g/100 mL citric acid monohydrate
"	0.03 g/100 mL citric acid monohydrate
"	0.04 g/100 mL citric acid monohydrate
Bitter	0.02 g/100 mL caffeine
"	0.03 g/100 mL caffeine

Thirty mL samples were poured into cups coded with letters. Panelists were asked to swish the samples around in their mouths and then expectorate into spit cups. After ballots were completed, a discussion was held relating to the taste areas of the tongue and palate (Jellinek, 1985).

Recognition Test for Four Basic Tastes

Name:____ Date:_______________

You have received aqueous solutions containing low concentrations of sucrose (sweet), sodium chloride (salty), citric acid (sour) and caffeine (bitter).

Your task is to recognize the basic taste of each sample solution (sweet, salty, sour or bitter).

When the sample taste like water (in concentrations below your threshold) mark with a zero (0). If your recognition of the taste is questionable, write a question mark (?). Retasting is allowed. When you recognize the taste please write it down.

Sample codes	Taste quality
A	_______________
B	_______________
C	_______________
D	_______________
E	_______________
F	_______________
G	_______________
H	_______________
I	_______________
J	_______________

(Jellinek, 1985).

PRUEBA PARA EL RECONOCIMIENTO DE LOS CUATRO SABORES BASICOS

Nombre:______________________________ Fecha:______________

Usted está recibiendo soluciones acuosas conteniendo bajas concentraciones de sucrosa (dulce), cloruro de sodio (sal), ácido cítrico (ácido) y cafeína (amargo).

Su tarea es reconocer el sabor básicos de cada muestra (dulce, salado, ácido, ó amargo).

Cuando el sabor de la muestra es como agua, (en concentraciones bajas para su umbral) marcar con cero (0). Si usted reconoce algún sabor y no está seguro, entonces escriba un signo de interrogación (?). Puede volver a probar la muestra si es necesario para tomar su decisión. Cuando reconozca el sabor por favor escriba el nombre.

Código de Muestra	Sabor Encontrado
A	______________
B	______________
C	______________
D	______________
E	______________
F	______________
G	______________
H	______________
I	______________
J	______________

Gracias.

Test #2 - Odour Recognition

Each panelist was given ten different odourants placed in separate coded foil-covered test tubes with screw tops. All odourants had been purchased at the supermarket.

Basic Odour	Odourant
orange	orange extract
vanilla	vanilla flavoured extract
cloves	ground cloves
anise	anise essence
olive oil	olive oil
cinnamon	ground cinnamon
coconut	coconut essence
lemon	lemon extract
oregano	ground oregano
almond	almond essence

Panelists were instructed to screw off the lids and to take 3 sniffs. Panelists were asked to refrain from looking at the samples inside the tubes.

Before testing, panelists were given a brief talk on the anatomy of the nose, its physiology and the smelling technique. The difference between normal breathing and sniffing was demonstrated.

The results were classified as being correct, being a correction description or incorrect (Jellinek, 1985).

Odour Recognition Test

Name:______________________________ Date:__________

You will receive 10 samples in tubes.

Try to recognize the odour and write your answer in the right-hand column (Odour recognition).

When you ae not able to recognize the odour, attempt a description and write it in the middle column (odour description).

Even when you can recognize the odour, describe it as well. This is important for later tests.

Code	Odour description	Odour recognition
______	______________________	______________________
______	______________________	______________________
______	______________________	______________________
______	______________________	______________________
______	______________________	______________________
______	______________________	______________________
______	______________________	______________________
______	______________________	______________________
______	______________________	______________________
______	______________________	______________________

(Jellinek, 1985).

PRUEBA PARA EL RECONOCIMIENTO DE OLOR

Nombre: ______________________ Fecha: ______________

Usted estará recibiendo 10 muestras en tubos. Trate de reconocer el olor y escribir su resultado en la columna de la derecha (olor reconocido). Cuando no se sienta competente para reconocer el olor, intente hacer una descripción y escribala en la columna de el centro (descripción del olor).

Aun cuando usted pueda reconocer el olor, describalo. Esto es importante para las próximas pruebas.

Muestra No	Descripción del olor	Olor Reconocido

Comentarios:

Test #3 - Flavour Recognition Test

Twelve coloured fruit-flavoured samples were presented to the panelists in a randomized fashion. For some samples, artificial colour had been added to a fruit-flavoured drink made from a powdered mix. For other samples, artificial flavour had been added to coloured distilled water. Panelists were asked to identify the flavour while disregarding the colour.

Flavour	Colour
grape	purple
strawberry	red
strawberry	yellow
mandarin orange	orange
mandarin orange	red
pineapple	green
pineapple	yellow
lemon	green
lemon	red
raspberry	red

(Malcolmson, 1985).

Flavour Recognition

You will receive 10 coded flavoured drinks. Test the samples in the order they are listed on the ballot. Write the name of the flavour that you perceive on the appropriate line.

Sample Code	Identified flavour	Comments:
________	____________________	
________	____________________	
________	____________________	
________	____________________	
________	____________________	
________	____________________	
________	____________________	
________	____________________	
________	____________________	
________	____________________	

RECONOCIMIENTO DE SABOR

Nombre:______________________________________ Fecha:______________

Usted estará recibiendo 10 muestras codificadas de bebidas con sabor. Pruebe las muestras en el orden en que se encuentran listadas en la ficha. Escriba el nombre del sabor que usted percibe en la linea apropiada.

Codigo de Muestra	Sabor Identificado	Comentarios:
________	__________________	
________	__________________	
________	__________________	
________	__________________	
________	__________________	
________	__________________	
________	__________________	
________	__________________	
________	__________________	
________	__________________	

Gracias.

Test #4 - Texture (Hardness) Rating Scale

Panelists were given 9 food samples to rank in order of hardness. Panelists were told to bite down once with their molar teeth on the sample and to evaluate the force required to penetrate the sample. Panelists were given a demonstration of this technique.

Sample	Specifications
cream cheese	(Parma) 1/2" cube
capas cheese	(Queso de capas) (La Predera) 1/2" cube
cheddar cheese	(Parma) 1/2" cube
olives	(Yoguy) one whole without pimento
wiener	(Toledo - Salchicha Versalles) 1/2" slice
peanut	(Roland - natural, fresh) one whole
hard candy	(Brachs peppermint lozenges) one whole
carrot	(bulk - fresh) 1/2" cube
almond	(bulk - fresh) one whole

(Bourne et al., 1975).

Texture (Hardness) Rating Scale

Rank these 9 samples for hardness. The softest sample is ranked first (1), the second softest is ranked second (2), etc., the hardest sample is ranked ninth (9). Write the sample names on the appropriate lines.

1. ______________________________

2. ______________________________

3. ______________________________

4. ______________________________

5. ______________________________

6. ______________________________

7. ______________________________

8. ______________________________

9. ______________________________

Comments:

ESCALA DE RANGOS PARA TEXTURA (DUREZA)

Nombre: ____________________________________ Fecha: ______________

Esta es una prueba de rangos para evaluar la dureza de las muestras. La muestra menos dura ó sea la más suave estará en el 1er rango, la segunda menos dura será la 2a., etc. La muestra más díficil será la 9a. Escriba el nombre de la muestra en al rango y linea que usted considere apropiada.

1. __________________________
2. __________________________
3. __________________________
4. __________________________
5. __________________________
6. __________________________
7. __________________________
8. __________________________
9. __________________________

Comentarios:

Gracias.

Test #5 - Physiology of Aroma Perception

The session began with a discussion of the physiology of aroma perception. In order to demonstrate this phenomenon, panelists were given a cup containing cinnamon sugar. They were asked not to look at or smell the sample. Panelists were then instructed to block their noses and to take a spoonful of the sample into their mouths and chew it with their mouths open. They were told to analyze the aroma (flavour) they perceived. Panelists were then instructed to quickly close their mouths, open their noses and exhale. They were asked to analyze the perceived aroma.

In a second exercise, panelists werre asked to identify samples of grapefruit juice and pear nectar by sniffing alone. Panelists were then asked to identify samples of grapefruit juice and peach nectar by slurping. The slurping technique was demonstrated.

Sample	Brand
Grapefruit juice (unsweetened)	Juice Bowl
Pear nectar	Kern's
Peach nectar	Kern's

The third exercise involved presenting 2 samples (red wine and unsweetened black coffee) that could not be differentiated with eyes and nose closed. Panelists worked in groups of two with one blindfolded panelist being given the sample by the other. The blindfolded panelist was told to close his/her nose and then take the sample in the mouth and swirl it with the mouth open. The panelist was instructed not to swallow the sample but to expectorate into a expectoration cup. Before opening the nose the panelist was asked to identify the sample (Jellinek, 1985).

AROMA RECOGNITION BY SNIFFING

Name:______________________________ Date:______________

You will receive 2 samples in cups. Try to recognize the aroma by sniffing and write your response in the column on the right (recognized aroma). When you don't feel able to identify the aroma, try to describe it in the centre column (aroma description). Even when you can recognize the aroma, describe it.

Please do not taste the samples.

Thank you

Sample number	Aroma description by SNIFFING	Recognized aroma by SNIFFING
______	____________	____________
	____________	
______	____________	____________
	____________	

AROMA RECOGNITION BY SLURPING

Name:____ Date:_________________

You will receive 2 samples in cups. Try to recognize the aroma by slurping and write your response in the column on the right (recognized aroma). When you don't feel able to identify the aroma, try to describe it in the centre column (aroma description). Even when you can recognize the aroma, describe it.

Thank you

Sample number	Aroma description by SLURPING	Recognized aroma by SLURPING
________	____________________	____________________
	____________________	
________	____________________	____________________
	____________________	

PRUEBA PARA EL RECONOCIMIENTO DE AROMA
POR MEDIO DE HUSMEAR

Nombre:___________________________________ Fecha:____________________

Usted estará recibiendo 2 muestras en vasos. Trate de reconocer el aroma por medio de husmear y escribir su resultado en la columna de la derecha (aroma reconocido). Cuando no se sienta competente para reconocer el aroma, intente hacer una descripción del tipo del aroma y escribala en la columna del centro (descripción del aroma). Aun cuando usted pueda reconocer el aroma, describalo.

POR FAVOR NO PRUEBE LA MUESTRA EN LA BOCA.

Gracias

Muestra No.	Descripción de aroma por medio de HUSMEAR	Aroma Reconocido por por medio de HUSMEAR
________	________________________	________________________
	________________________	
________	________________________	________________________
	________________________	

PRUEBA PARA EL RECONOCIMIENTO DE AROMA
POR MEDIO DE SORBER

Nombre:________________________________ Fecha:____________________

Usted estará recibiendo 2 muestras en vasos. Trate de reconocer el aroma por medio de husmear y escribir su resultado en la columna de la derecha (aroma reconocido). Cuando no se sienta competente para reconocer el aroma, intente hacer una descripción del tipo del aroma y escribala en la columna del centro (descripción del aroma). Aun cuando usted pueda reconocer el aroma, describalo.

Gracias

Muestra No.	Descripción de aroma por medio de SORBER	Aroma Reconocido por por medio de SORBER
________	____________________	____________________
	____________________	
________	____________________	____________________
	____________________	

Appendix C

% COOKED BALLOT USED IN GUATEMALA - SPANISH VERSION.

LA TEXTURA DE FRIJOL NEGRO - % COCIDO

Número de panelista: _______ Fecha: ______________

Nombre: ____

LAS INSTRUCCIONES:

Evalue 10 frijoles al azar de cada muestra y escriba en la balota la cantidad de los frijoles que Ud. crea estan "cocidos" ó "crudos".

EL METODO:

1. Ponga 1 frijol entre las muelas (dientes de atrás) y muérda en el centro de él.
2. Presione el mismo frijol en el paladar de la boca con su lengua.
3. Considere: (Por favor, recuerde que NO estamos evaluando la cáscara)

```
DURA------------------------------------------►CRUDO
                              Granulosos ó
          ┌------------►con grumos duros,---►CRUDO
          |             ásperos ó arenosos
SUAVE-----|
          |             Fino, suave,
          └------------►como puré,---------►COCIDO
                        homogeneo
```

4. Colocar un mínimo de 3 de los frijoles restantes dentro de su boca. Circule el número del código de la muestra de frijol que usted más prefiere solamente para textura.

Código de Muestra	Cantidad de los frijoles COCIDOS	Cantidad de los frijoles CRUDOS

OBSERVACIONES:

GRACIAS.

Appendix D

TEXTURE PROFILE ANALYSIS BALLOT USED IN GUATEMALA - SPANISH VERSION.

EVALUACION DE TEXTURE DE FRIJOLES

Número de panelista:________________ Fecha:________________

Nombre:____

Evaluar la muestra de acuerdo a los siquientes parámetros. Primero, evalúe el estandar de la muestra para establecer un punto de referencia, y luego evaluar las muestras codificadas y marcar la intensidad relativa de las muestras de frijol codificadas en cada escala.

Fase Inicial de Morder

DUREZA

Queso Crema ———————————————— Almendra

Fase Masticatoria

TAMANO DE PARTICULA

Fino, blando Mantequilla ———————————————— Grueso Mani

PERCEPCION DE CASCARA

Suave ———————————————— Duro

MASTICACION

Código de Muestra	No. de Masticadas

COMENTARIOS:

GRACIAS.

Appendix E

DEFINITIONS USED FOR THE FOUR CHARACTERISTICS EVALUATED BY THE GUATEMALAN TEXTURE ANALYSIS PANEL - SPANISH VERSION.

DEFINICIONES PARA LA EVALUACION DE TEXTURA

DUREZA:

Morder en el centro de la muestra de frijoles (2), una vez, con los molares, y evaluando la fuerza requirida para penetrar en la muestra.

TAMAÑO DE PARTICULA:

Masticar la muestra de frijoles (2) con los molares, de 2 a 3 masticadas, y frotar el cotiledón entre la lengua y el paladar y evaluar el tamaño de las partículas.

PERCEPCION DE CASCARA:

Mordiendo el frijol, separar la cáscara del cotiledón entre la molar y fuera del cotiledón, frotando entre la lengua y el paladar. Evaluar la fuerza requerida para morder a través de la cáscara de un frijol con los dientes de enfrente.

MASTICACION:

Coloque una muestra de frijoles (2) en su boca, y mastique de una forma constante (1 masticada por segundo), contando el número de masticadas hasta que la muestra esté lista para ser tragada.

Appendix F

IN-HOUSE ACCEPTABILITY BALLOT USED IN GUATEMALA - SPANISH VERSION.

Nombre: ______________________________ Fecha: ______________________________

Muestra: Frijoles negros cocidos

Pruebe cada una de las siguientes muestras de frijoles. Chequee la categoría a la que corresponde la mejor descripción de su evaluación de la textura cocida en base a su gusto de cómo come los frijoles parados en casa. Pruebe escribir una razón ó una observación si a usted no le gusta la textura de una muestra.

Código de muestra	La textura es extremadamente aceptable	La textura es muy aceptable	La textura es moderadamente aceptable	La textura es un poco aceptable	La textura es un poco inaceptable	La textura es moderadamente inaceptable	La textura es muy inaceptable	La textura es extremadamente inaceptable

OBSERVACIONES: ______________________________

Appendix G

DISTRIBUTIONS OF ACCEPTABILITY SCORES AMONG THE PANELISTS OF THE IN-HOUSE COOKING TIME ACCEPTABILITY PANEL FOR EACH OF THE 6 LINES OF FRESH GUATEMALAN BLACK BEAN SAMPLES COOKED TO 5 DIFFERENT COOKING STAGES.

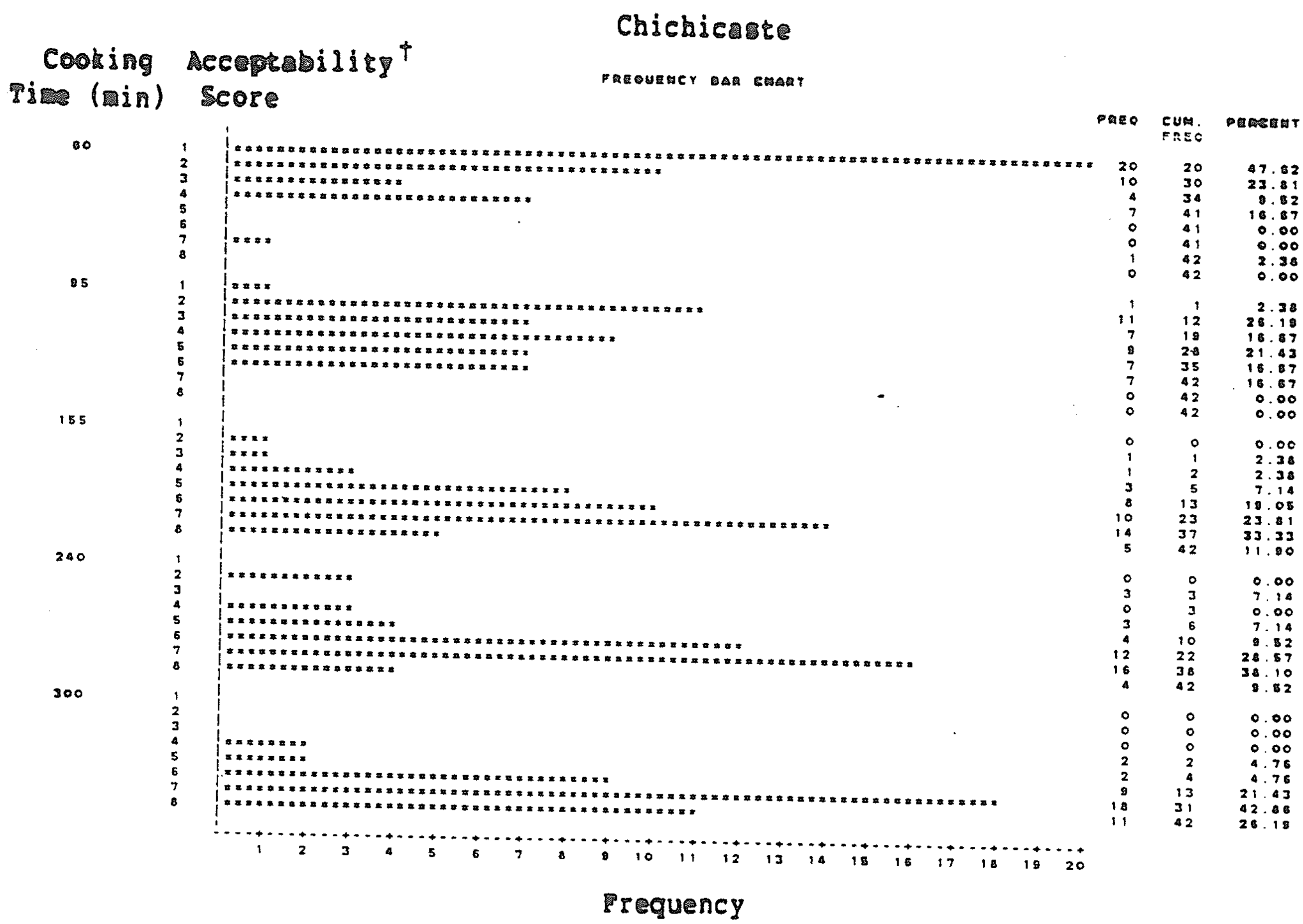
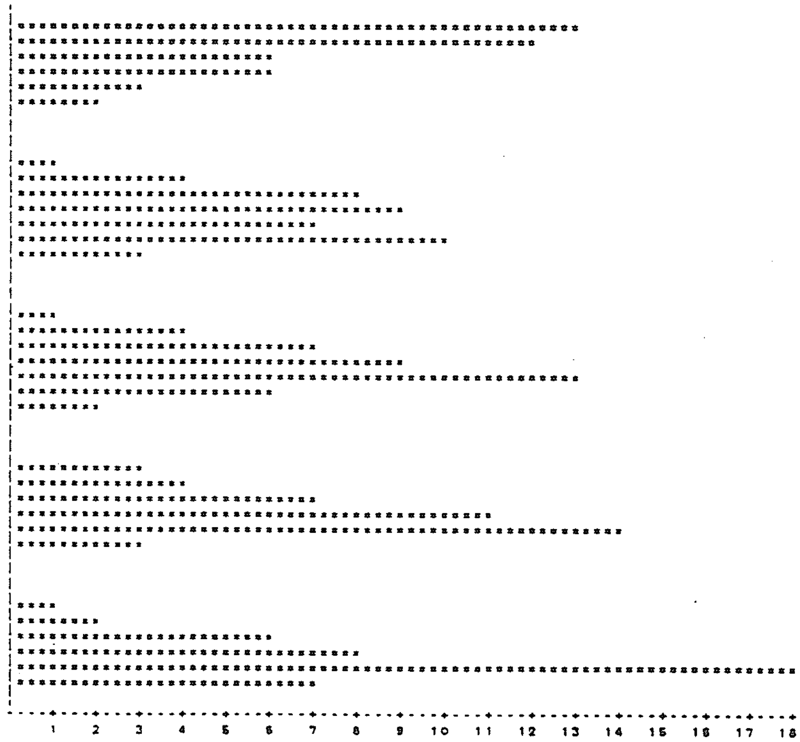


Figure G.1: Distribution of acceptability scores among the panelists of an in-house cooking time acceptability panel for the fresh Chichicaste sample cooked to 5 different cooking stages.

† 8-point scale with 1= extremely unacceptable and 8= extremely acceptable.

Criollo A

FREQUENCY BAR CHART



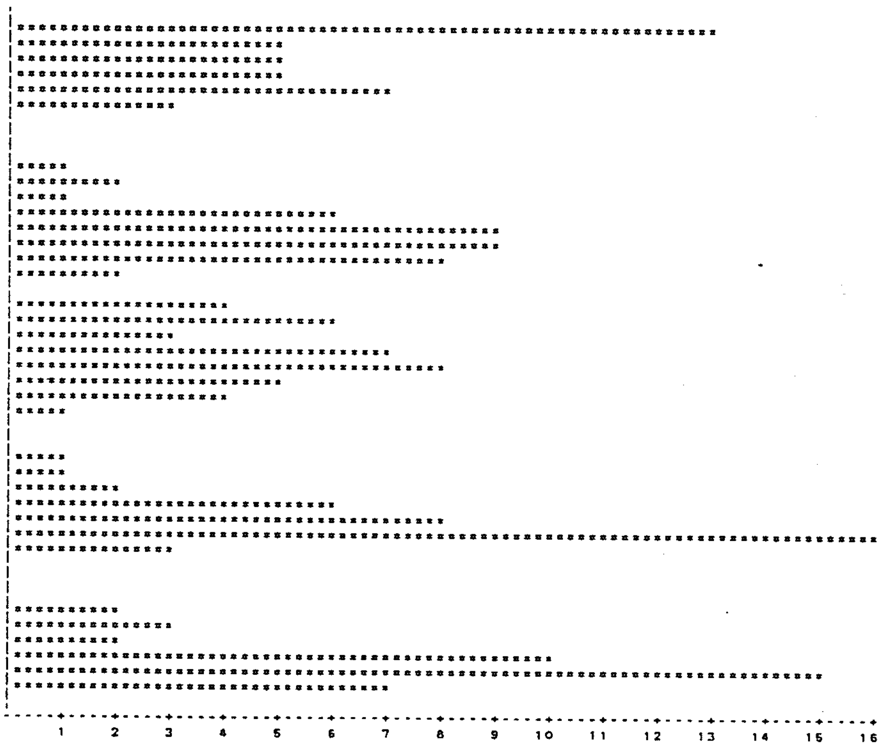
Cooking Time (min)	Acceptability[†] Score	FREQ	CUM. FREQ	PERCENT
100	1	13	13	30.95
	2	12	25	28.57
	3	6	31	14.29
	4	6	37	14.29
	5	3	40	7 14
	6	2	42	4.76
	7	0	42	0.00
	8	0	42	0.00
140	1	1	1	2.38
	2	4	5	9.52
	3	8	13	19.05
	4	9	22	21 43
	5	7	29	16.67
	6	10	39	23.81
	7	3	42	7.14
	8	0	42	0.00
170	1	0	0	0.00
	2	1	1	2.38
	3	4	5	9.52
	4	7	12	16.67
	5	9	21	21.43
	6	13	34	30.95
	7	6	40	14.29
	8	2	42	4.76
240	1	0	0	0.00
	2	0	0	0.00
	3	3	3	7.14
	4	4	7	9.52
	5	7	14	16.67
	6	11	25	26.19
	7	14	39	33.33
	8	3	42	7.14
300	1	0	0	0.00
	2	0	0	0.00
	3	1	1	2.38
	4	2	3	4.76
	5	6	9	14.29
	6	8	17	19.05
	7	18	35	42.86
	8	7	42	16.67

Figure G.2: Distribution of acceptability scores among the panelists of an in-house cooking time acceptability panel for the fresh Criollo A sample cooked to 5 different cooking stages.

[†] 8-point scale with 1= extremely unacceptable and 8= extremely acceptable.

Criollo B

FREQUENCY BAR CHART



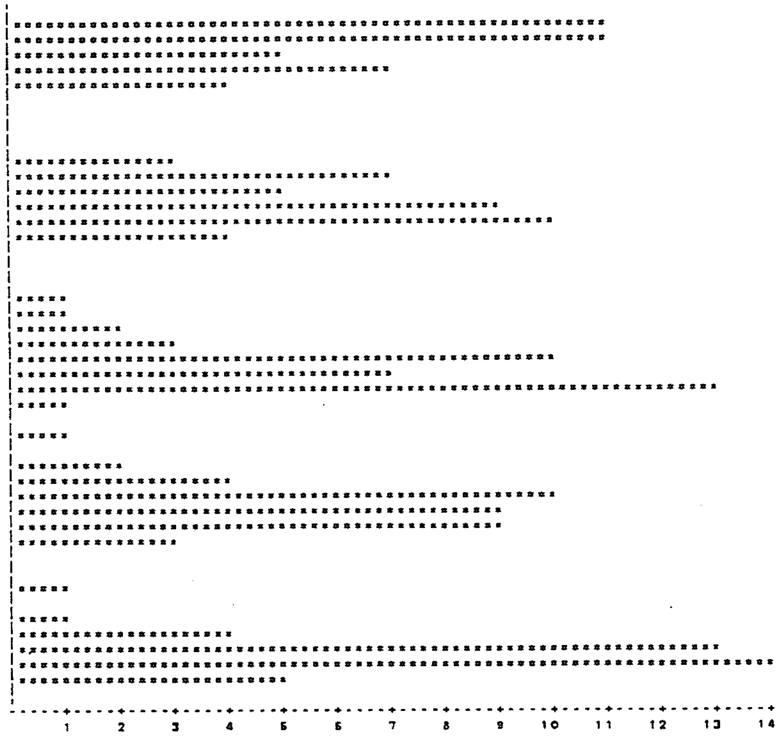
Cooking Time (min)	Acceptability † Score	FREQ	CUM. FREQ	PERCENT
90	1	13	13	34.21
	2	5	18	13.16
	3	5	23	13.16
	4	5	28	13.16
	5	7	35	18.42
	6	3	38	7.89
	7	0	38	0.00
	8	0	38	0.00
155	1	1	1	2.63
	2	2	3	5.26
	3	1	4	2.63
	4	6	10	15.79
	5	9	19	23.68
	6	9	28	23.68
	7	8	36	21.05
	8	2	38	5.26
205	1	4	4	10.53
	2	6	10	15.79
	3	3	13	7.89
	4	7	20	18.42
	5	8	28	21.05
	6	5	33	13.16
	7	4	37	10.53
	8	1	38	2.63
240	1	0	0	0.00
	2	1	1	2.70
	3	1	2	2.70
	4	2	4	5.41
	5	6	10	16.22
	6	8	18	21.62
	7	16	34	43.24
	8	3	37	8.11
300	1	0	0	0.00
	2	0	0	0.00
	3	2	2	5.13
	4	3	5	7.69
	5	2	7	5.13
	6	10	17	25.64
	7	15	32	38.46
	8	7	39	17.95

Figure G.3: Distribution of acceptability scores among the panelists of an in-house cooking time acceptability panel for the fresh Criollo B sample cooked to 5 different cooking stages.

† 8-point scale with 1= extremely unacceptable and 8= extremely acceptable.

Itzapa

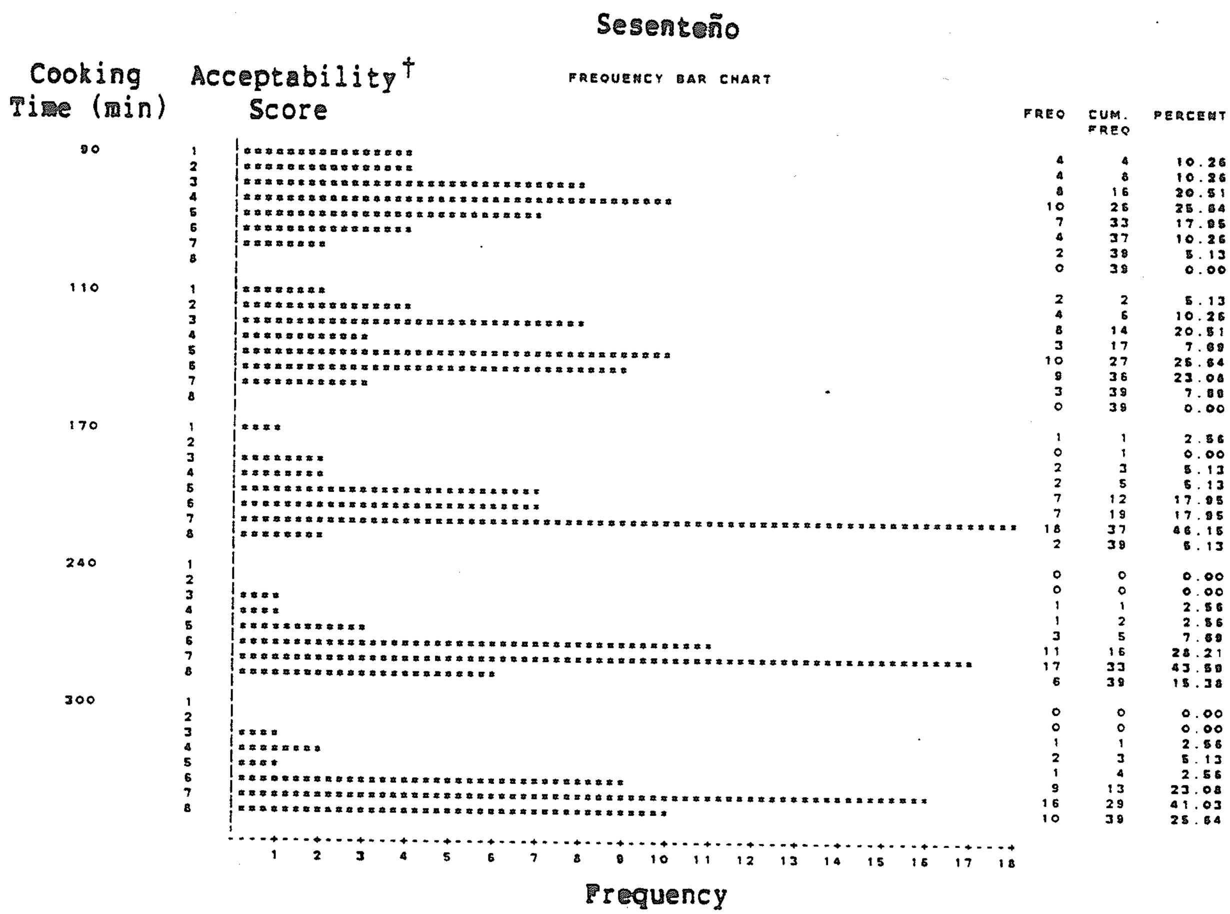
FREQUENCY BAR CHART



Cooking Time (min)	Acceptability[†] Score	FREQ	CUM. FREQ	PERCENT
95	1	11	11	28.95
	2	11	22	28.95
	3	5	27	13.16
	4	7	34	18.42
	5	4	38	10.53
	6	0	38	0.00
	7	0	38	0.00
	8	0	38	0.00
120	1	3	3	7.89
	2	7	10	18.42
	3	5	15	13.16
	4	9	24	23.68
	5	10	34	26.32
	6	4	38	10.53
	7	0	38	0.00
	8	0	38	0.00
180	1	1	1	2.63
	2	1	2	2.63
	3	2	4	5.26
	4	3	7	7.89
	5	10	17	26.32
	6	7	24	18.42
	7	13	37	34.21
	8	1	38	2.63
225	1	1	1	2.63
	2	0	1	0.00
	3	2	3	5.26
	4	4	7	10.53
	5	10	17	26.32
	6	9	26	23.68
	7	9	35	23.68
	8	3	38	7.89
300	1	0	0	0.00
	2	1	1	2.63
	3	0	1	0.00
	4	1	2	2.63
	5	4	6	10.53
	6	13	19	34.21
	7	14	33	36.84
	8	5	38	13.16

Figure G.4: Distribution of acceptability scores among the panelists of an in-house cooking time acceptability panel for the fresh Criollo B sample cooked to 5 different cooking stages.

† 8-point scale with 1= extremely unacceptable and 8= extremely acceptable.



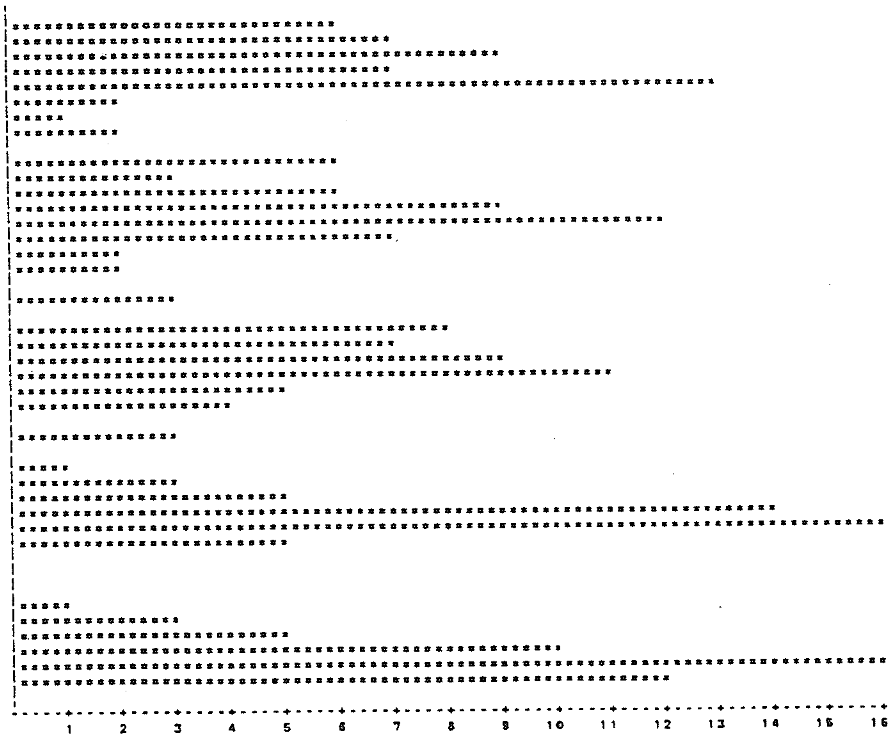
Cooking Time (min)	Acceptability Score	FREQ	CUM. FREQ	PERCENT
90	1	4	4	10.26
	2	4	8	10.26
	3	8	16	20.51
	4	10	26	25.64
	5	7	33	17.95
	6	4	37	10.26
	7	2	39	5.13
	8	0	39	0.00
110	1	2	2	5.13
	2	4	6	10.26
	3	8	14	20.51
	4	3	17	7.69
	5	10	27	25.64
	6	9	36	23.08
	7	3	39	7.69
	8	0	39	0.00
170	1	1	1	2.56
	2	0	1	0.00
	3	2	3	5.13
	4	2	5	5.13
	5	7	12	17.95
	6	7	19	17.95
	7	18	37	46.15
	8	2	39	5.13
240	1	0	0	0.00
	2	0	0	0.00
	3	1	1	2.56
	4	1	2	2.56
	5	3	5	7.69
	6	11	16	28.21
	7	17	33	43.59
	8	6	39	15.38
300	1	0	0	0.00
	2	0	0	0.00
	3	1	1	2.56
	4	2	3	5.13
	5	1	4	2.56
	6	9	13	23.08
	7	16	29	41.03
	8	10	39	25.64

Figure G.5: Distribution of acceptability scores among the panelists of an in-house cooking time acceptability panel for the fresh Sesenteño sample cooked to 5 different cooking stages.

† 8-point scale with 1= extremely unacceptable and 8= extremely acceptable.

Tamazulapa

FREQUENCY BAR CHART



Cooking Time (min)	Acceptability† Score	FREQ	CUM. FREQ	PERCENT
90	1	6	6	12.77
	2	7	13	14.89
	3	9	22	19.15
	4	7	29	14.89
	5	13	42	27.66
	6	2	44	4.26
	7	1	45	2.13
	8	2	47	4.26
110	1	6	6	12.77
	2	3	9	6.38
	3	6	15	12.77
	4	9	24	19.15
	5	12	36	25.53
	6	7	43	14.89
	7	2	45	4.26
	8	2	47	4.26
150	1	3	3	6.38
	2	0	3	0.00
	3	8	11	17.02
	4	7	18	14.89
	5	9	27	19.15
	6	11	38	23.40
	7	5	43	10.64
	8	4	47	8.51
200	1	3	3	6.38
	2	0	3	0.00
	3	1	4	2.13
	4	3	7	6.38
	5	5	12	10.64
	6	14	26	29.79
	7	16	42	34.04
	8	5	47	10.64
250	1	0	0	0.00
	2	0	0	0.00
	3	1	1	2.13
	4	3	4	6.38
	5	5	9	10.64
	6	10	19	21.28
	7	16	35	34.04
	8	12	47	25.53

Figure G.6: Distribution of acceptability scores among the panelists of an in-house cooking time acceptability panel for the fresh Tamazulapa sample cooked to 5 different cooking stages.

† 8-point scale with 1= extremely unacceptable and 8= extremely acceptable.

Appendix H

ONE-WAY ANALYSIS OF VARIANCE (ANOVA) FOR THE EFFECT OF COOKING TIME (IN MINUTES) ON ACCEPTABILITY SCORE OF FRESH BLACK BEANS.

Chichicaste

Source of variation	df	MS	F	Pr>F
Cooktime	1	531.56	214.75***	0.0001
Error	208	2.47		
Total	209			

Criollo A

Source of variation	df	MS	F	Pr>F
Cooktime	1	334.34	146.94***	0.0001
Error	208	2.27		
Total	209			

Criollo B

Source of variation	df	MS	F	Pr>F
Cooktime	1	228.97	74.22***	0.0001
Error	188	3.08		
Total	189			

Itzapa

Source of variation	df	MS	F	Pr>F
Cooktime	1	326.70	140.52***	0.0001
Error	188	2.32		
Total	189			

Sesenteño

Source of variation	df	MS	F	Pr>F
Cooktime	1	235.01	106.54***	0.0001
Error	193	2.21		
Total	194			

Appendix H (continued)...

Tamazulapa

Source of variation	df	MS	F	Pr>F
Cooktime	1	256.51	88.14***	0.0001
Error	233	2.91		
Total	234			

Appendix I

ANALYSIS OF COVARIANCE (ANCOVA) FOR THE EFFECT OF COOKING TIME ON TEXTURE PROFILE ANALYSIS (TPA) HARDNESS SCORE FOR FRESH BLACK BEANS.

Chichicaste

Source of variation	df	MS	F	Pr>F
Cooktime	1	3036.32	167.86***	0.0001
Rep	2	63.72	3.52*	0.0329
Error	109	18.09		
Total	112			

Criollo A

Source of variation	df	MS	F	Pr>F
Cooktime	1	2777.29	151.31***	0.0001
Rep	2	6.69	0.36	0.6952
Error	121	18.35		
Total	124			

Criollo B

Source of variation	df	MS	F	Pr>F
Cooktime	1	2332.53	154.97***	0.0001
Rep	2	95.69	6.36*	0.0024
Error	121	15.05		
Total	124			

Itzapa

Source of variation	df	MS	F	Pr>F
Cooktime	1	2055.88	113.00***	0.0001
Rep	2	10.58	0.58	0.5609
Error	96	18.19		
Total	99			

Appendix I (continued)...

Sesenteño

Source of variation	df	MS	F	Pr>F
Cooktime	1	1980.68	146.47***	0.0001
Rep	2	9.01	0.67	0.5155
Error	111	13.52		
Total	114			

Tamazulapa

Source of variation	df	MS	F	Pr>F
Cooktime	1	1133.91	85.18***	0.0001
Rep	2	77.66	5.83*	0.0041
Error	91	13.31		
Total	94			

Appendix J

ANALYSIS OF COVARIANCE (ANCOVA) FOR THE EFFECT OF COOKING TIME ON TEXTURE PROFILE ANALYSIS (TPA) PARTICLE SIZE SCORE FOR FRESH BLACK BEANS.

Chichicaste

Source of variation	df	MS	F	Pr>F
Cooktime	1	3581.58	171.79***	0.0001
Rep	2	33.11	1.59	0.2090
Error	109	20.85		
Total	209			

Criollo A

Source of variation	df	MS	F	Pr>F
Cooktime	1	3371.25	191.39***	0.0001
Rep	2	53.35	3.03	0.0520
Error	121	17.61		
Total	124			

Criollo B

Source of variation	df	MS	F	Pr>F
Cooktime	1	3094.16	200.94***	0.0001
Rep	2	0.99	0.06	0.9407
Error	121	15.40		
Total	124			

Itzapa

Source of variation	df	MS	F	Pr>F
Cooktime	1	2230.81	101.58***	0.0001
Rep	2	40.13	1.83	0.1663
Error	96	21.96		
Total	99			

Appendix J (continued)...

Sesenteño

Source of variation	df	MS	F	Pr>F
Cooktime	1	1908.70	125.93***	0.0001
Rep	2	2.27	0.15	0.8609
Error	111	15.16		
Total	114			

Tamazulapa

Source of variation	df	MS	F	Pr>F
Cooktime	1	1304.84	80.66***	0.0001
Rep	2	69.80	4.32*	0.0162
Error	91	16.18		
Total	94			

Appendix K

ANALYSIS OF COVARIANCE (ANCOVA) FOR THE EFFECT OF COOKING TIME ON TEXTURE PROFILE ANALYSIS (TPA) SEEDCOAT TOUGHNESS SCORE FOR FRESH BLACK BEANS.

Source of variation	df	MS	F	Pr>F
Chichicaste				
Cooktime	1	3723.21	131.15***	0.0001
Rep	2	35.02	1.23	0.2952
Error	109	28.39		
Total	112			
Criollo A				
Cooktime	1	3609.16	150.08***	0.0001
Rep	2	100.21	4.17*	0.0179
Error	116	24.05		
Total	119			
Criollo B				
Cooktime	1	3635.75	122.19***	0.0001
Rep	2	27.35	0.92	0.4016
Error	116	29.75		
Total	119			
Itzapa				
Cooktime	1	2442.03	65.00***	0.0001
Rep	2	33.25	0.89	0.4160
Error	96	37.57		
Total	99			

Appendix K (continued)...

Sesenteño

Source of variation	df	MS	F	Pr>F
Cooktime	1	3548.11	150.40***	0.0001
Rep	2	0.77	0.03	0.9698
Error	111	23.59		
Total	114			

Tamazulapa

Source of variation	df	MS	F	Pr>F
Cooktime	1	2352.98	148.46***	0.0001
Rep	2	183.02	11.55***	0.0001
Error	91	15.85		
Total	94			

Appendix L

ANALYSIS OF COVARIANCE (ANCOVA) FOR THE EFFECT OF COOKING TIME ON TEXTURE PROFILE ANALYSIS (TPA) CHEWINESS SCORE FOR FRESH BLACK BEANS.

Chichicaste

Source of variation	df	MS	F	Pr>F
Cooktime	1	863.62	74.37***	0.0001
Rep	2	10.75	0.93	0.3993
Error	109	11.61		
Total	112			

Criollo A

Source of variation	df	MS	F	Pr>F
Cooktime	1	556.96	85.67***	0.0001
Rep	2	21.27	3.27*	0.0413
Error	121	6.50		
Total	124			

Criollo B

Source of variation	df	MS	F	Pr>F
Cooktime	1	573.45	103.76***	0.0001
Rep	2	16.69	2.84	0.0624
Error	121	5.53		
Total	124			

Itzapa

Source of variation	df	MS	F	Pr>F
Cooktime	1	361.62	67.77***	0.0001
Rep	2	19.52	1.83	0.1661
Error	96	5.34		
Total	99			

Appendix L (continued)...

Sesenteño

Source of variation	df	MS	F	Pr>F
Cooktime	1	286.86	101.21***	0.0001
Rep	2	6.95	2.46	0.0905
Error	111	2.83		
Total	114			

Tamazulapa

Source of variation	df	MS	F	Pr>F
Cooktime	1	224.74	75.61***	0.0001
Rep	2	18.75	6.31*	0.0027
Error	91	2.97		
Total	94			

Appendix M

PREDICTION LINES FOR THE RELATIONSHIP BETWEEN EACH OF THE 4 TEXTURE PROFILE ANALYSIS (TPA) CHARACTERISTICS

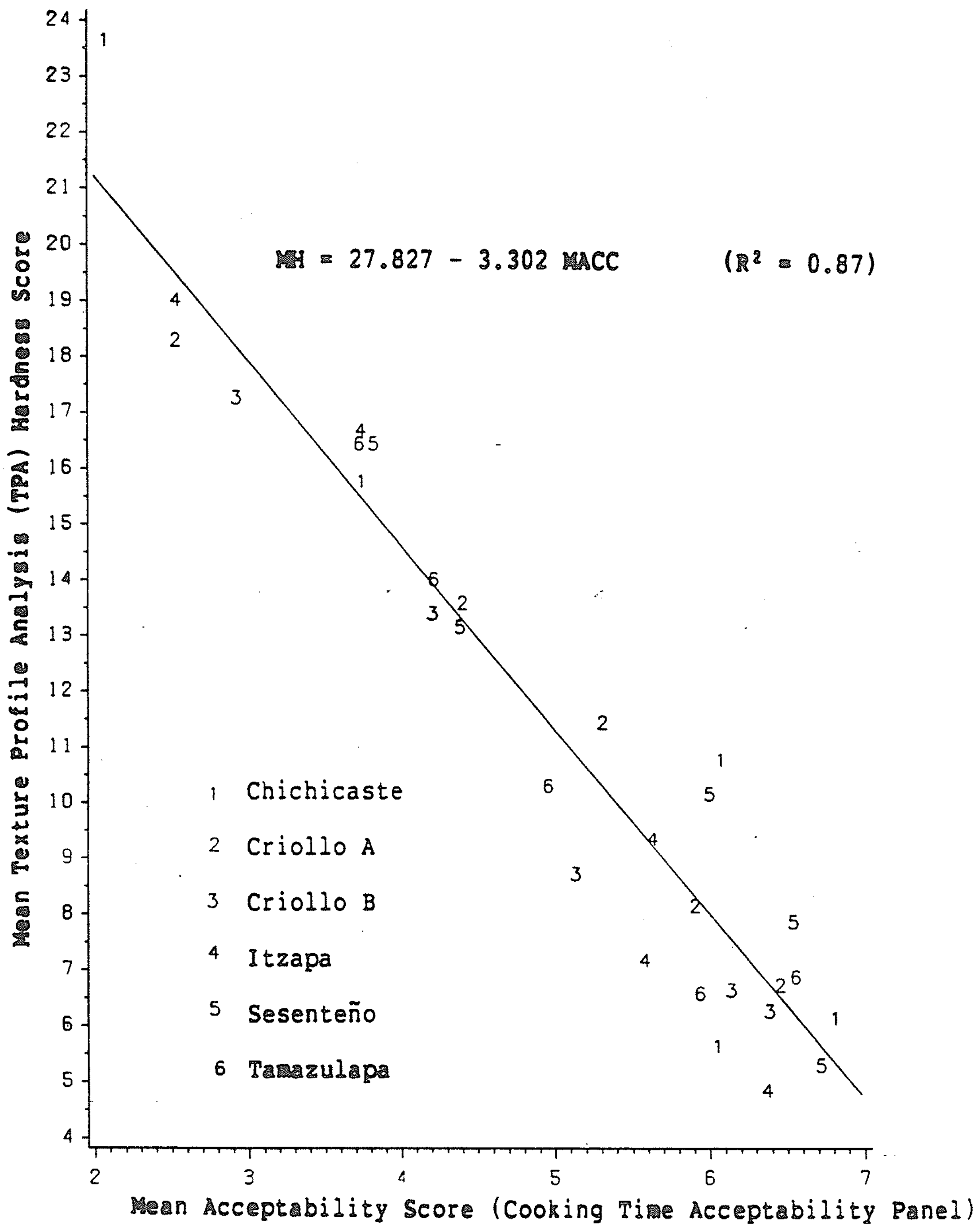


Figure M.1: Prediction line for the relationship between texture profile analysis (TPA) mean hardness score and comparative acceptability panel mean acceptability score.

where MH = mean texture profile analysis (TPA) hardness score
MACC = mean acceptability score (cooking time acceptability panel)

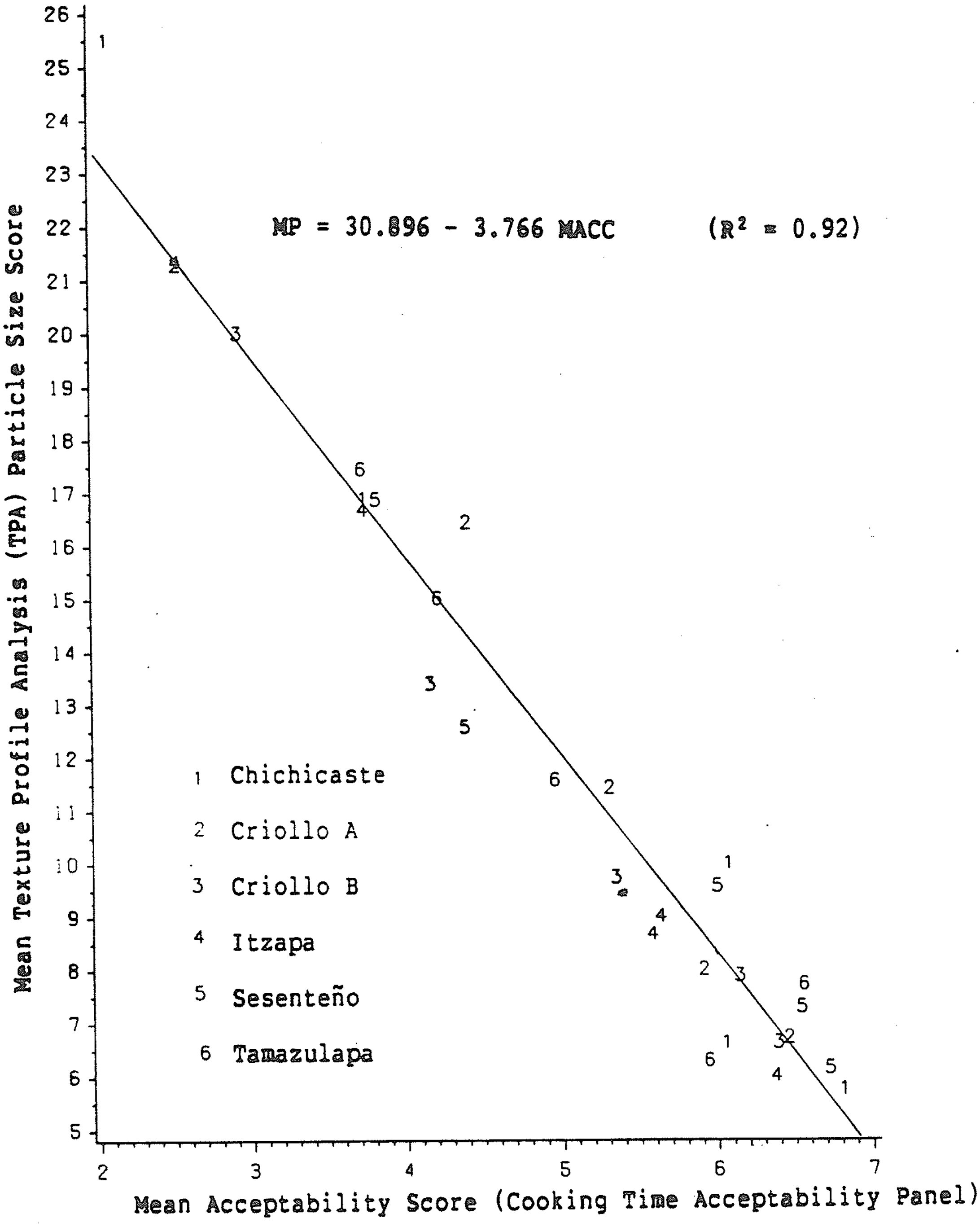


Figure M.2: Prediction line for the relationship between texture profile analysis (TPA) mean particle size score and comparative acceptability panel mean acceptability score.

where MP = mean texture profile analysis (TPA) particle size score
MACC = mean acceptability score (cooking time acceptability panel)

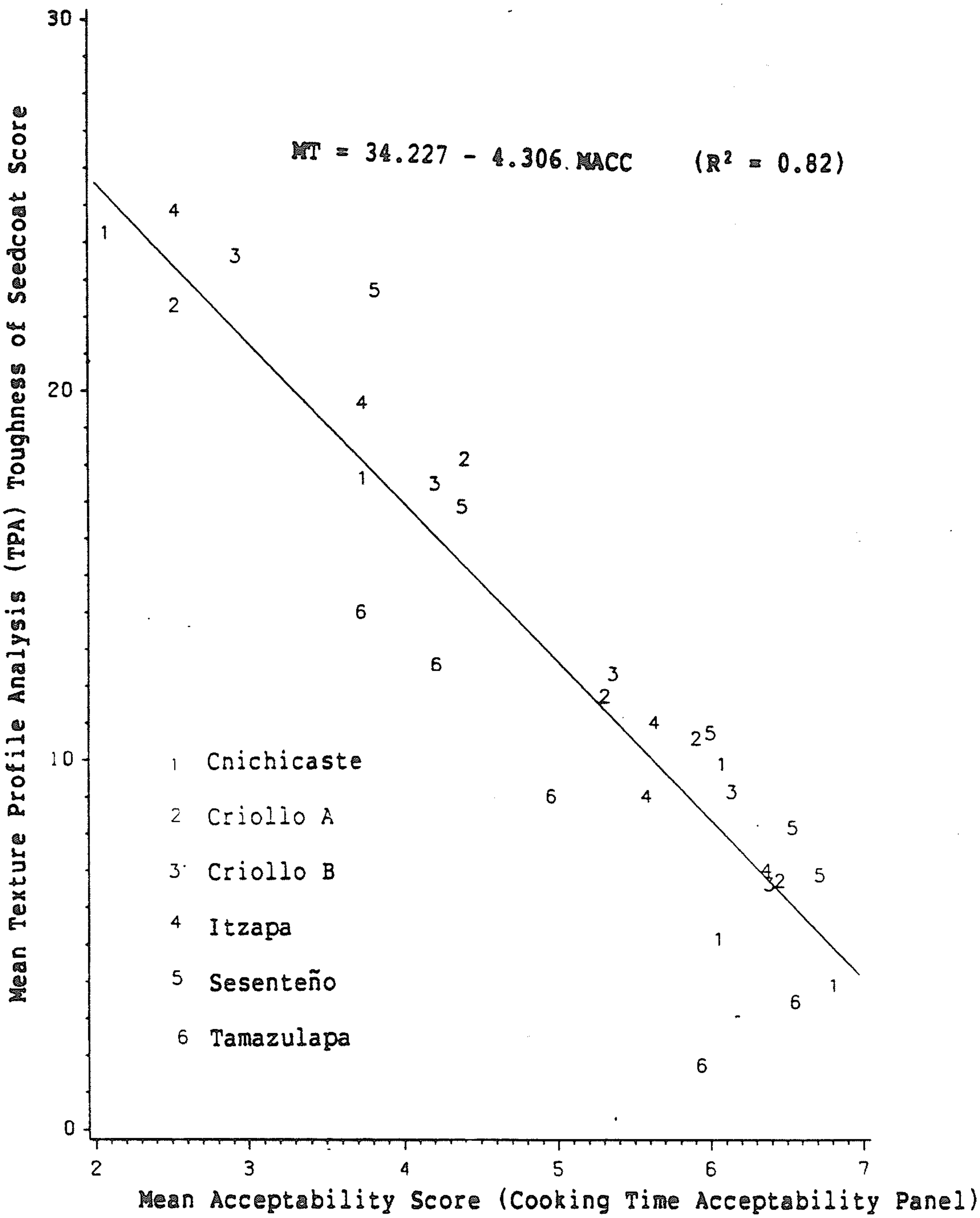


Figure M.3: Prediction line for the relationship between texture profile analysis (TPA) mean seedcoat toughness score and comparative acceptability panel mean acceptability score.

where MT = mean texture profile analysis (TPA) seedcoat toughness score
MACC = mean acceptability score (cooking time acceptability panel)

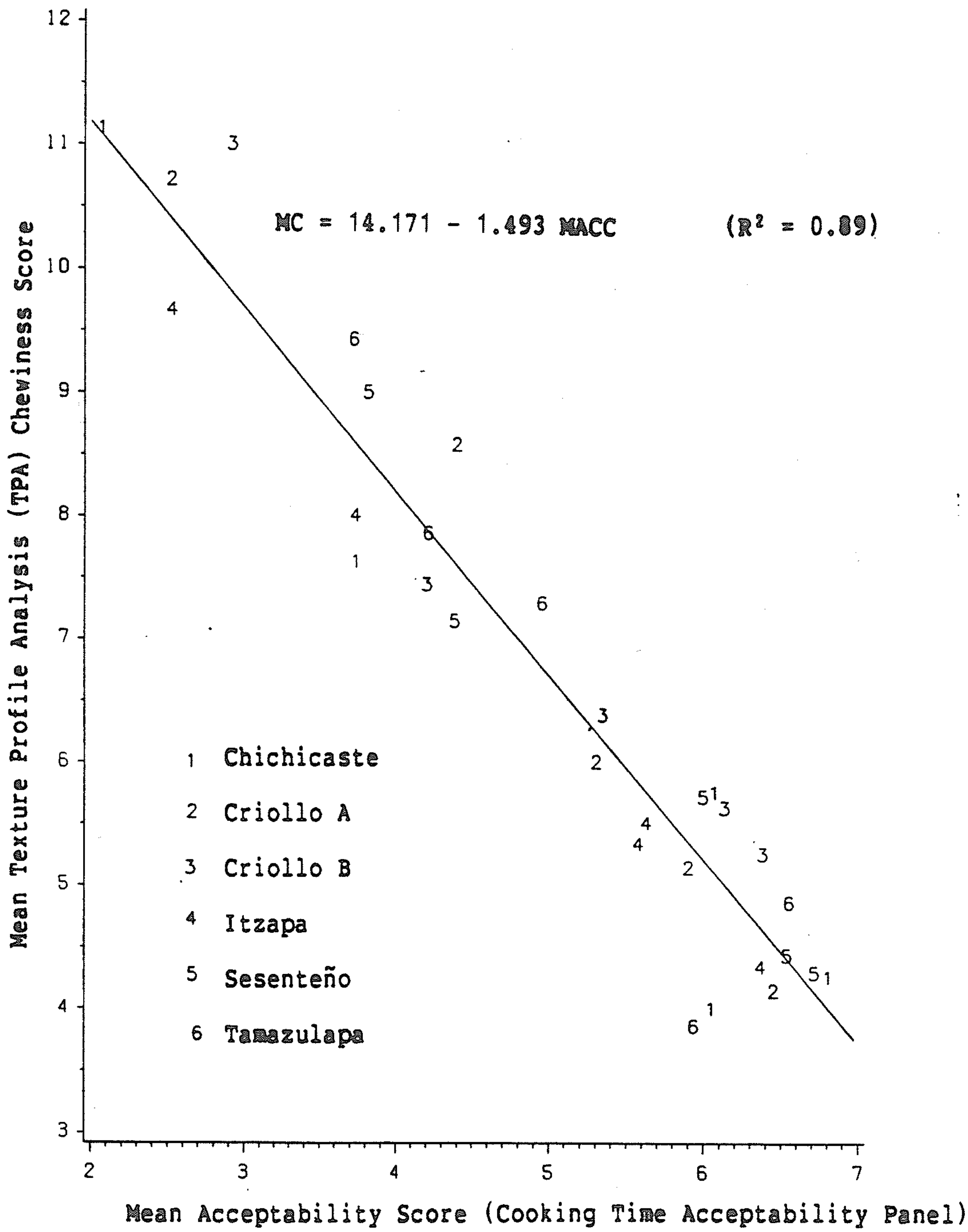


Figure M.4: Prediction line for the relationship between texture profile analysis (TPA) mean chewiness score and comparative acceptability panel mean acceptability score.

where MC = mean texture profile analysis (TPA) chewiness score
MACC = mean acceptability score (cooking time acceptability panel)

Appendix N

ONE-WAY ANALYSIS OF VARIANCE FOR THE EFFECT OF VARIETY ON ACCEPTABILITY SCORE OF FRESH BLACK BEANS.

Source of variation	df	MS	F	Pr>F
Variety	5	10.45	4.20**	0.0012
Error	210	2.49		
Corrected total	215			

Appendix O

DISTRIBUTION OF ACCEPTABILITY SCORES AMONG THE PANELISTS OF AN IN-HOUSE COMPARATIVE ACCEPTABILITY PANEL FOR 6 LINES OF FRESH GUATEMALAN BLACK BEAN SAMPLES COOKED TO THEIR INDIVIDUAL ACCEPTABLY COOKED POINT.

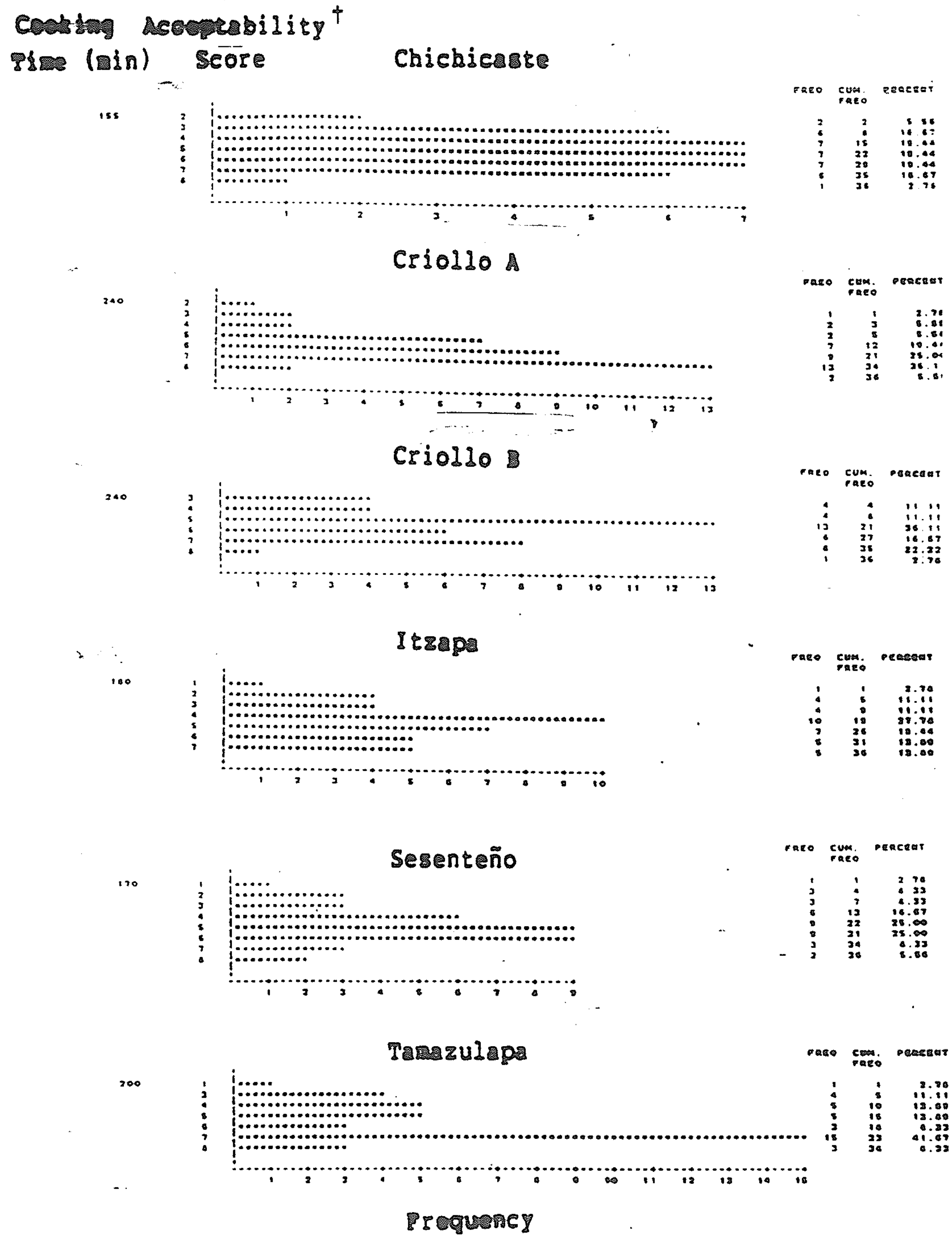


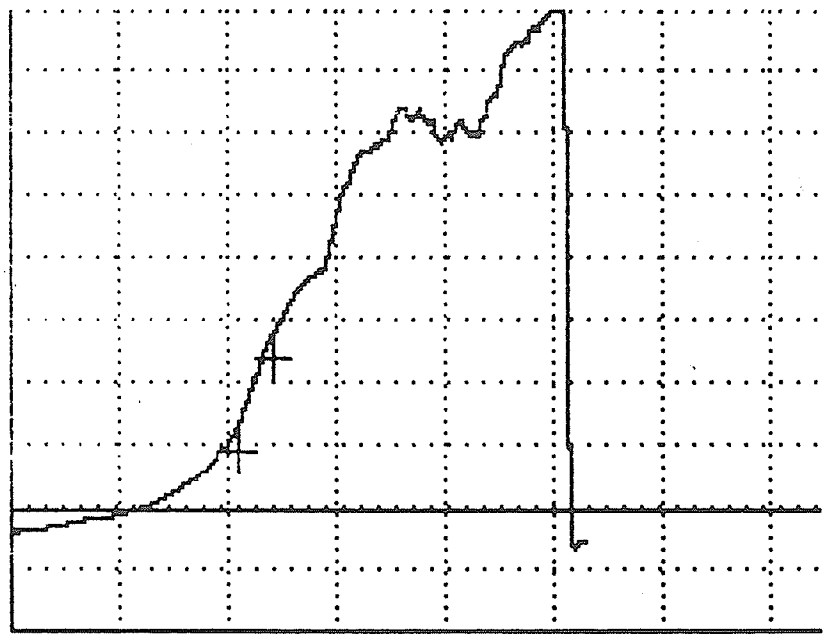
Figure O.1: Distribution of acceptability scores among the panelists of an in-house comparative acceptability panel for 6 lines of fresh samples of Guatemalan black beans cooked to their individual acceptably-cooked point.

† 8-point scale with 1= extremely unacceptable and 8= extremely acceptable.

Appendix P

SAMPLE OTMS DATA CURVE FROM APPLE IIE COMPUTER.

DATA ANALYSIS AND GRAPH FOR 673B
11 APRIL 1986



MOVING AVERAGE CONSTANT USED: 1

DATE OF TEST: 860411

ELAPSED TESTTIME (S)	=	53.595
XHEAD SPEED (CM/M)	=	6.600
PEAK FORCE (N)	=	89.428
TIME TO PEAK (S)	=	50.981
DEF. TO PEAK (MM)	=	56.080
FIRMNESS 1 (N/MM)	=	4.641
ENERGY TO PEAK (J)	=	4190.587
COMPRES.ENERGY (J)	=	4576.660
TENSILE ENERGY (J)	=	-113.074
TOTAL ENERGY (J)	=	4689.734

Appendix Q

DISTRIBUTION OF ACCEPTABILITY SCORES AMONG THE PANELISTS OF AN IN-HOUSE COMPARATIVE ACCEPTABILITY PANEL FOR 6 LINES OF STORED GUATEMALAN BLACK BEAN SAMPLES COOKED TO THEIR INDIVIDUAL ACCEPTABLY COOKED POINT.

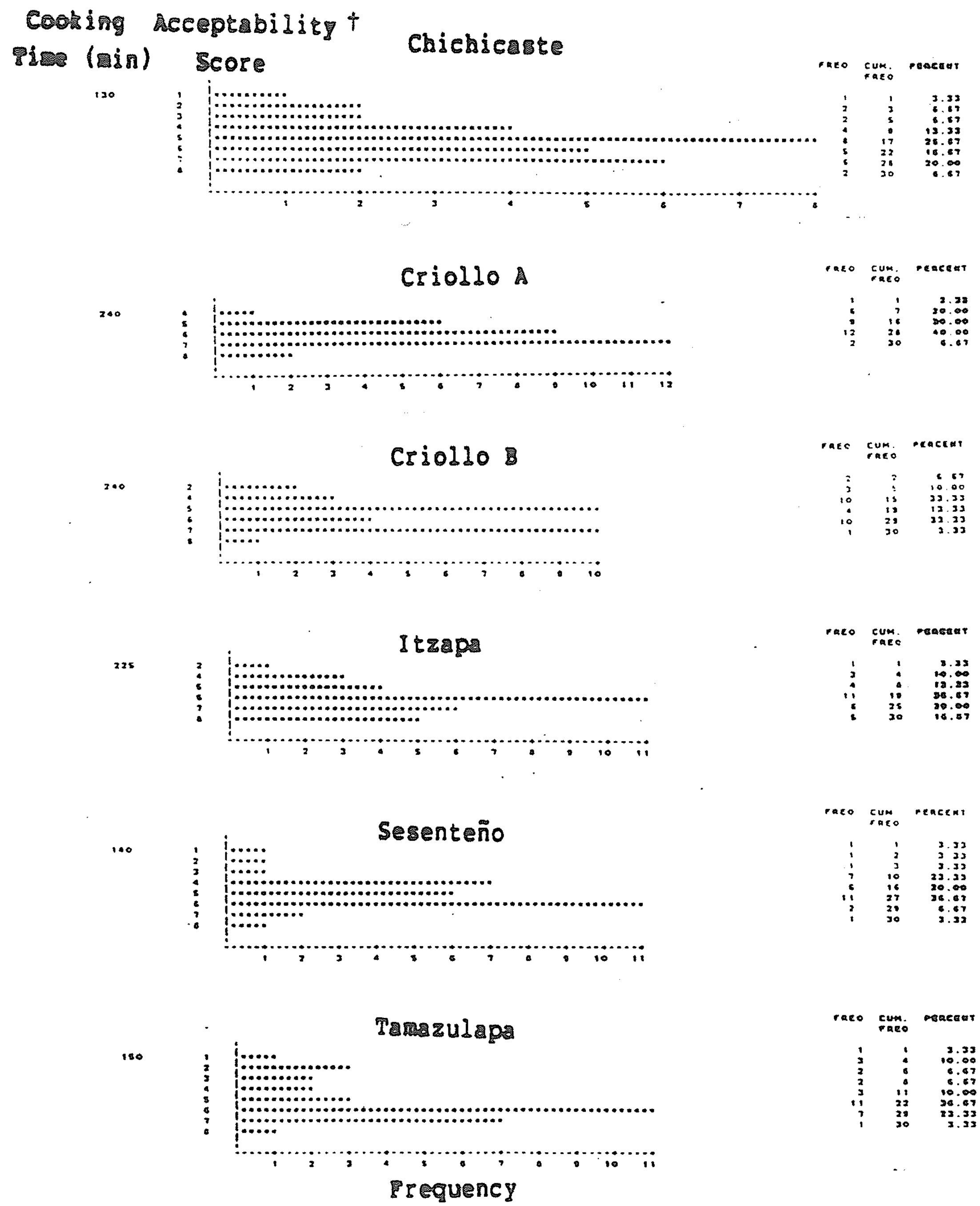


Figure Q.1: Distribution of acceptability scores among panelists of an in-house comparative acceptability panel for 6 lines of low temperature-low humidity stored samples of Guatemalan black beans.

† 8-point scale with 1= extremely unacceptable and 8= extremely acceptable.

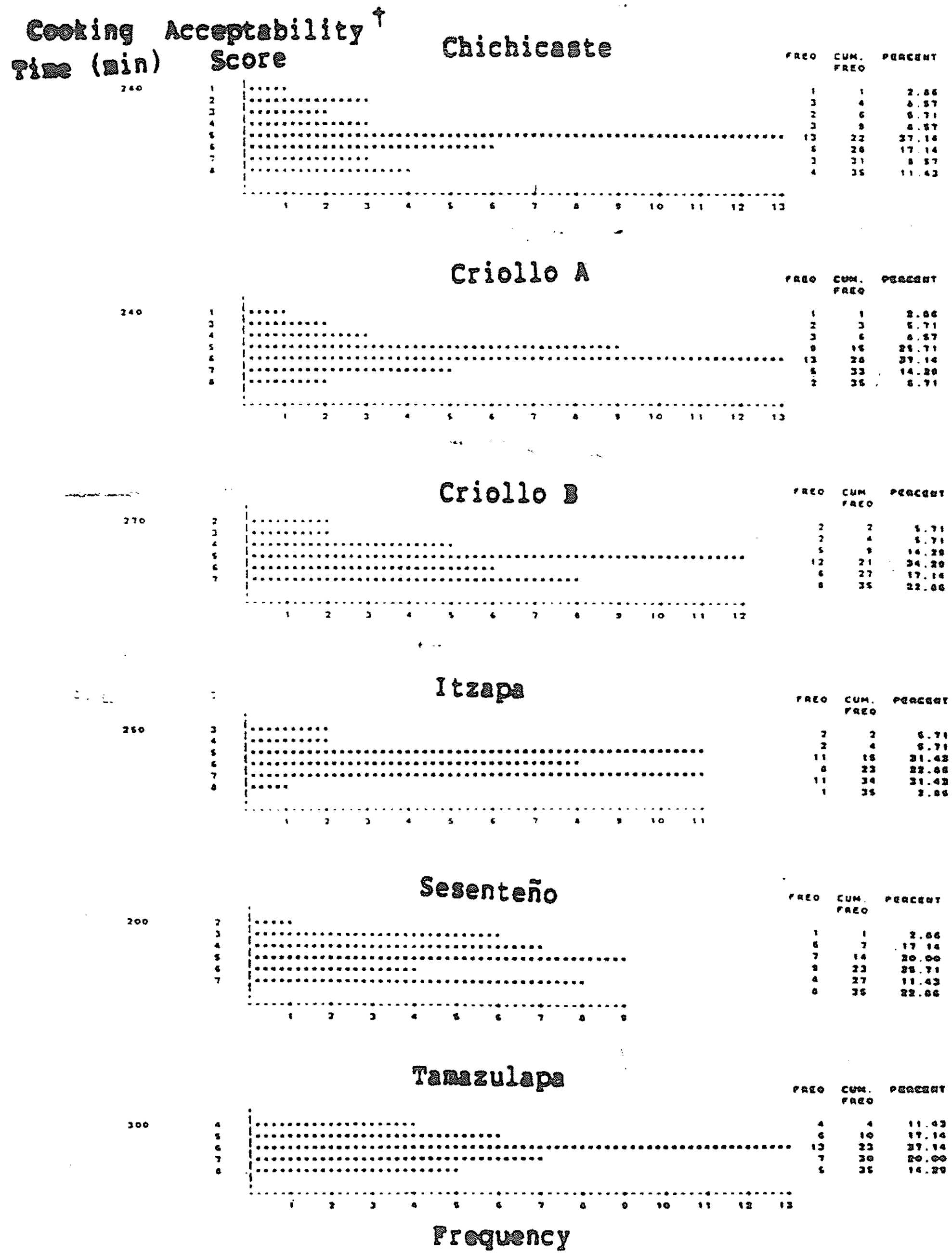


Figure Q.2: Distribution of acceptability scores among panelists of an in-house comparative acceptability panel for 6 lines of high temperature-high humidity stored samples of Guatemalan black beans.

† 8-point scale with 1= extremely unacceptable and 8= extremely acceptable.