THERMAL EXPANSION AND MOISTURE CONTRACTION
AS RELATED TO BLANCHING OF
SPANISH PEANUTS

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PREFACE

This study was concerned with the coefficients of thermal expansion and moisture contraction of Spanish peanuts. The primary objectives were to determine the coefficients of cubical thermal expansion for Spanish peanut kernels and skins as a function of moisture and to determine the coefficient of moisture contraction for peanut kernels.

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LIST OF SYMBOLS

A = Cross-sectional area of a capillary tube, mm^2

a_g = Coefficient of cubical thermal expansion for Pyrex glass, cm^3/cm^3 °C

a_h = Coefficient of cubical thermal expansion for mercury, cm^3/cm^3 °C

a_k = Coefficient of cubical thermal expansion for peanut kernels, cm^3/cm^3 °C

a_m = Cubical coefficient of moisture contraction, cm^3/cm^3 % moisture

a_{m3} = Cubical coefficient of moisture contraction calculated as three times the linear coefficient, cm^3/cm^3 % moisture

a_s = Coefficient of cubical thermal expansion for peanut skins, cm^3/cm^3 °C

a_x = Coefficient of cubical thermal expansion for a sample, cm^3/cm^3 °C

B = Blanching percentage, %

B_T = Bulk modulus of elasticity, pascals

C = Emergent stem correction factor

D = Peanut kernel diameter, cm

E = Modulus of elasticity, pascals

H = Mercury column height, mm

H_b = Mercury column height at water bath level, mm

K = Constant for mercury placed in Pyrex

K_T = Isothermal compressibility, 1/pascals

L = Peanut kernel length, cm

L_m = Length of material, cm

Ln = Natural logarithm
L_s = Distance from the stem mark to the mercury meniscus at room temperature, mm
M = Moisture content, % dry basis
p = Pressure, pascals
T = Temperature, °C
T_{abs} = Absolute temperature, °C
T_f = Final temperature, °C
T_i = Initial temperature, °C
T_r = Temperature of liquid in emergent stem, °C
V = Volume of a peanut kernel, cm^3
V_g = Internal volume of the dilatometer bulb below the stem mark, mm^3
V_h = Volume of the mercury contained in the dilatometer bulb below the stem mark, mm^3
V_m = Volume of a peanut kernel at moisture, M, cm^3
V_{mt} = Total volume of mercury contained in the dilatometer, mm^3
V_p = Volume of the peanut sample at room temperature, mm^3
α = Linear coefficient of moisture contraction, cm/cm %
$(\alpha = x)$ = Statistical level of significance, x = probability of a Type I error
α_D = Linear coefficient of moisture contraction for kernel diameters, cm/cm %
α_L = Linear coefficient of moisture contraction for kernel lengths, cm/cm %
α_t = Linear coefficient of thermal expansion, cm/cm °C

β_0 = Prediction regression coefficient for the intercept

β_1 = Prediction regression coefficient

β_2 = Prediction regression coefficient

β_3 = Prediction regression coefficient

ΔL = Change in length of a material, cm

ΔM = Change in dry base moisture content, %

$\frac{\Delta x}{\Delta t}$ = Slope of the line depicting dilatometer column height versus temperature, mm/°C

ρ = Density, g/cm^3

σ = Stress on a material, pascals

CHAPTER I

INTRODUCTION

The Problem

Peanuts are a very important source of protein and oil for use in human food. In the processing of peanuts for peanut butter as well as other products, it is desirable to remove the red skin (testa) from around the peanut kernel. Removal of the skin, through a process known as blanching, eliminates a source of bitter flavor which may otherwise be imparted into the peanut products.

There are many different blanching processes (23). Generally, blanching processes require the use of chemicals, water spray, heat, or a combination thereof to first loosen skins before passing the peanuts through a peanut blancher. Shackelford (17) heated kernels to moderate temperatures prior to blanching and found that blanching percentage depended on heating temperature, initial moisture and final moisture content of the kernels. Since blanching percentage is a relative index of the degree of looseness of the peanut skin about its kernel it was believed that differences in thermal expansion between the kernel and its skin may be partly responsible for this skin loosening effect.

Large moisture gradients were found to increase stress cracking and checking of the outer surface of hygroscopic materials such as shelled corn and macaroni more than did large thermal gradients (6) (7). Since the percentage of moisture lost during heating prior to blanching was known to affect blanching percentages, the hygroscopic or moisture contraction of the kernels during drying was believed to also affect the looseness of the skin around the peanut kernel.

Thus, the problem was to determine if the apparent skin loosening effect caused by heating and drying could be partially explained on the basis of thermal expansion differences between the skin and the kernel and by the moisture contraction of the peanut kernel and skin. If the effects of temperature and moisture on skin loosening were better understood, it may be possible to optimize combinations of heating, drying, and cooling to produce higher blanching percentages. Reductions in heating temperature during drying would be beneficial in extending peanut storage life and lessening peanut quality deterioration.

Objectives

The objectives of this study were:

1. To experimentally determine the coefficient of cubical thermal expansion for Spanish peanut kernels and skins as a function of moisture content over the temperature range of 25 to 90°C.

2. To experimentally determine the coefficient of moisture contraction for Spanish peanut kernels at 40°C as a function of drying air relative humidity.

3. To relate the coefficients of cubical thermal expansion and moisture contraction to the blanching characteristics of peanut kernels.

CHAPTER II

LITERATURE REVIEW

The coefficients of cubical thermal expansion and the coefficients of moisture contraction are important physical properties having a direct application to the process of peanut blanching. In the peanut blanching process (removal of the skins from the kernel), the peanuts are commonly heated and dried to loosen the skin. The purpose of blanching is to remove the skin from the kernel to eliminate a source of bitter flavor which otherwise would be imparted to the peanut product. After the skins are removed, the hearts which also have a bitter flavor, are removed from peanuts used in peanut butter production.

Blanching Methods

Woodruff (23) reported five different methods of blanching: dry, water, spin, alkali, and hydrogen peroxide blanching. In dry blanching peanuts are heated to 138°C for about 25 minutes to remove at least three percent of the kernel moisture, cooled, and passed through a blancher which gently rubs the peanuts between brushes or ribbed rubber belting. The skins are rubbed off the kernel and the hearts are removed by screening the cotyledons. For certain peanut products such as salted nuts where whole kernels are desirable, a whole nut blancher with resilient rubber rolls is used to reduce splitting and scratching of the kernels.

The water blanching process involves slitting the skin longitudinally on opposite sides of a kernel and passing the kernels through a hot water spray to loosen the skins. Then the peanuts are transferred on a knobbed conveyor under an oscillating canvas-covered pad to rub off the skins. Kernels are dried at 49°C for about six hours to reduce the moisture content from approximately 12 to 6 percent. Although the water blanching process is more expensive than dry blanching, it extends the shelf-life of the peanuts longer than that of unblanched peanuts (23). The quality of water blanched peanuts decreases considerably if drying occurs too rapidly.

Spin blanching consists of slitting the skins and quickly drying the kernels at temperatures slightly lower than roasting temperatures. The kernels are then fed into a spin blancher which spins the kernels and unwraps the skins.

In the alkali method, peanuts are immersed in a one percent solution of sodium hydroxide followed by one percent hydrochloric acid. The peanuts are rinsed with water to remove the loose skins and are dried. This method was intended primarily for home use.

In hydrogen peroxide blanching, Takeuchi, et al. (21) immersed peanuts in a hydrogen peroxide solution for 30 to 60 seconds. The skins were observed to swell and loosen from the kernel. The hydrogen peroxide decomposes into water and oxygen by a biochemical reaction with catalase in the peanuts. Oxygen generated between the skin and the kernel loosens the skin which is removed by a peanut blancher either before or after drying.

A new method of blanching involves subjecting peanuts to a spray of liquid nitrogen at a temperature of -196°C for two minutes (16). The peanuts were immediately passed through a whole nut blancher to remove the skins. The process was very effective in removing nearly all of the skins, but it also caused the kernels to break into many small bits and pieces.

The most widely used commercial blanching methods generally require the peanuts to be heated, dried, and cooled to loosen the skins before passing the peanuts through a nut blancher. To investigate possible physical or mechanical effects of heating and cooling on the kernel and its skin it was desirable to know the thermal expansion coefficients for peanut kernels and skins.

Thermal Expansion

It is a well known fact that changes in the temperature of a material cause that material to expand or contract. The change in length, ΔL, of a material due to temperature changes can be expressed:

$$\Delta L = \alpha_t L_m (T_f - T_i) \qquad [1]$$

where:

α_t = coefficient of linear thermal expansion, cm/cm °C

L_m = length of the material at temperature T_i, cm

T_f = final temperature, °C

T_i = initial temperature, °C

The change in length of a material per unit length for a one degree change in temperature is known as the linear coefficient of thermal expansion and is denoted as α_t.

The coefficient of cubical or volumetric thermal expansion represents the change in volume per unit volume for a one degree change in temperature and is denoted as a_x. For an isotropic solid material Parker, et al. (14) stated that the coefficient of cubical thermal expansion, a_x, was related to the coefficient of linear thermal expansion by:

$$a_x = 3\alpha_t \qquad [2]$$

Parker, et al. (14) reported that since the density of fluids usually changes as the temperature or pressure of the fluid changes, the fluid volume can be written as a function of density, pressure and temperature:

$$f(\rho, p, T) = 0 \qquad [3]$$

The total derivative can be used to relate the change in density to the change in pressure and temperature:

$$d\rho = \left(\frac{\partial\rho}{\partial p}\right)_T dp + \left(\frac{\partial\rho}{\partial T}\right)_p dT \qquad [4]$$

Dividing by density gives the fractional change in density:

$$\frac{d\rho}{\rho} = \frac{1}{\rho}\left(\frac{\partial\rho}{\partial p}\right)_T dp + \frac{1}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_p dT \qquad [5]$$

The fractional change in density which would occur at constant temperature for a small pressure change dp is known as the isothermal compressibility, K_T.

$$K_T = \frac{1}{\rho}\left(\frac{\partial\rho}{\partial p}\right)_T \qquad [6]$$

The reciprocal of isothermal compressibility is the bulk modulus of elasticity, B_T, for which published values exist for many materials.

$$B_T = \frac{1}{K_T} = \rho\left(\frac{\partial p}{\partial\rho}\right)_T \qquad [7]$$

The fractional change in density which would occur at a constant pressure for a small temperature change dT is known as the coefficient of cubical thermal expansion, a_x.

$$a_x = -\frac{1}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_p \qquad [8]$$

For an ideal gas, a_x is simply equal to the reciprocal of absolute temperature, T_{abs} (14).

$$a_x = \frac{1}{T_{abs}} \qquad [9]$$

For a given change in both pressure and temperature, the fractional change in density of a fluid is a function of its bulk modulus of elasticity and its coefficient of cubical thermal expansion.

The coefficient of thermal expansion is one of the essential physical properties needed to perform a thermal stress analysis on peanut kernels and skins. Gatewood (8) reported that if all fibers of a material were free to expand and contract, no stresses were produced by a change in temperature. But, in a continuous or constrained body, expansion and contraction usually could not occur freely and thermal stresses were produced.

Thermal stress is dependent on the modulus of elasticity, E, of a material. The modulus of elasticity may be written:

$$E = \frac{\sigma}{\Delta L/L_m} \qquad [10]$$

where: σ = uniform stress on a material, pascals

ΔL = change in length of the material due to stress, cm

L_m = initial length of the material, cm

Eliminating $\Delta L/L_m$ from equations [1] and [10] and rearranging yields:

$$\sigma = -\alpha_t E(T_f - T_i) \qquad [11]$$

Coefficients of thermal expansion and the modulus of elasticity are two physical properties necessary for a complete thermal stress analysis of peanut kernels. Before performing any thermal stress analysis it was deemed necessary to first determine the magnitude of the coefficients which would predict peanut kernel volume changes due to thermal expansion and moisture contraction.

A method for determining the coefficient of cubical thermal expansion was described in Standard Method of Test for Coefficient of Cubical Thermal Expansion of Plastics, ASTM Designation D864-52 (18). The testing apparatus, known as a dilatometer, basically consisted of a long Pyrex capillary tube with one end fused to a Pyrex bulb containing the test specimen. The bulb was filled with a confining fluid such as mercury. By slowly heating the bulb containing mercury and the test specimen, the expansion of the specimen was calculated by measuring the rise in the column of mercury in the constant cross-section capillary tube for a given temperature increase.

Ekstrom, et al. (7) determined the coefficient of cubical thermal expansion for corn kernels. Dilatometers were used to determine the cubical coefficient over the temperature range of 18 to 74°C as a function of kernel moisture content. Values obtained ranged from 18.5×10^{-5}/°C at 5 percent moisture to 32.8×10^{-5}/°C at 20 percent wet base moisture content. Since a transition point at 43°C was found, coefficient values above 43°C were larger than those below 43°C.

Magne and Wakeham (11) reported that the mean coefficient of cubical thermal expansion for peanut oil was 76.4×10^{-5}/°C over the temperature range of 30 to 200°C.

CRC Handbook of Chemistry and Physics (5) revealed that the coefficient of cubical thermal expansion for water increased exponentially with temperatures from 25.7×10^{-5}/°C at 25°C to 69.6×10^{-5}/°C at 90°C.

Arora, et al. (1) determined the coefficient for cubical thermal expansion for rice at 12 percent wet base moisture content over the temperature range of 30 to 70°C. For rice kernels above and below the transition temperature, 53°C, the coefficient was calculated to be 33.6×10^{-5}/°C and 24.0×10^{-5}/°C, respectively.

Prasad, et al. (15) and Mannapperuma (12) determined the coefficient of cubical thermal expansion for brown rice over the temperature range of 30 to 70°C. Values obtained ranged from $2.4 \times 10^{-5}/°C$ to $175.0 \times 10^{-5}/°C$ at dry base moisture contents of 2.2 and 29.2 percent, respectively. A transition temperature was not found, therefore a single coefficient was valid over the entire temperature range of 30 to 70°C.

Moisture Contraction

As previously stated blanching processes usually require a certain amount of drying to accompany heating of the peanuts. Since it was not known to what extent moisture loss affects the size or volume of a Spanish peanut kernel, the cubical coefficient of moisture contraction was determined. The cubical coefficient was defined as the change in volume per unit volume for a removal of one dry base percentage point of moisture.

Steele and Brown (20) determined the dimensional changes in freshly dug Virginia and Florigiant peanuts due to drying. The peanuts were dried with air from a controlled environment chamber at 30°C and 75 percent relative humidity for 16 days. The kernels were optically profiled for length and for diameters perpendicular and parallel to the cotyledon interface after exposure periods of 0, 1, 2, 4, 8 and 16 days. Based on an average of eight kernels for each exposure period, a plot of the dimensions of the kernels was found to decrease almost linearly with a decrease in percent dry base moisture content.

Effects of slow or rapid drying are believed to be influenced by the method of moisture retention within a biological material. Mohsenin (13) reported that moisture is retained in biological materials by two different methods, molecular adsorption and capillary absorption.

Barkas, et al. (2) stated that molecular adsorption occurs by the attraction of water molecules to specific points in the molecular structure of a material. When the distance between the water molecule and the gel material of a cell wall becomes very small (approximately 10^{-7}cm) the force of attraction is great enough to draw the water into the micellar spaces of the cell wall. This process, which occurs at very low moisture contents, is known as "adsorption compression." "Adsorption compression" causes a net decrease in the volume of the gel-water aggregate. With a further moisture increase, the attraction for the water molecule diminishes; and the volume increase due to added moisture is approximately equal to the volume of the water added.

Mohsenin (13) stated that at much higher moisture contents very few polar sites remain available for holding water molecules. Thus, water is held by the formation of chains of water molecules called "water bridges" which span between water molecules that have been absorbed in the material. If a tensile stress within the elastic limit of the material was applied, the "water bridges" would be ruptured. Upon removal of the stress, the water bridges would reform without any indication of plastic deformation.

The second method of moisture retention is by capillary absorption. Capillary absorption occurs when voids in a cellular material are large enough to hold water in a liquid form by forces of surface tension. The size of the capillary radius which will retain water is a function of surface tension, molecular weight, density of the liquid, the gas constant, absolute temperature, and relative humidity of the air. In general, the size of the capillary radius which will retain water becomes larger as relative humidity increases.

It is not known exactly how much moisture is held in hygroscopic materials by capillary absorption or by molecular adsorption. Hall and Rodriquez-Arias (9) concluded that for shelled corn in moisture equilibrium with 5 to 90 percent relative humidity air, moisture retention was primarily due to multimolecular adsorption.

Rapid drying of peanut kernels leads to large differences in moisture content between the outer surface and the center core. Van Arsdel, et al. (22) reported that large differences in moisture content within a material cause shrinkage effects that depend on the rate of drying. For example, if a highly shrinking material is dried so slowly that the moisture gradient is small, internal stresses are minimized and the material shrinks down fully to a solid core. Conversely, if the material is dried quickly and the outer surface becomes much drier than the center, the outer surface is subjected to sufficient tension to permanently set the surface in nearly its original dimensions. When the center finally dries, the internal stresses pull the material apart and consequently the dried material contains numerous cracks and holes in its structure.

The bulk density of a dried material is affected by fast or slow drying conditions. Van Arsdel, et al. (22) reported that dehydrated 0.95 cm potato cubes which were dried at 65°C and 7 percent relative humidity for 3 3/4 hours to 11 percent dry base moisture had a bulk density approximately one-half that of an equal weight of potato cubes which were dried to the same moisture content with nearly saturated air for 15 hours. Thus, a decrease in drying rate reduced the volume of potato cubes.

CHAPTER III

EQUIPMENT AND INSTRUMENTATION

Thermal Expansion

Dilatometers

Three dilatometers were constructed similar to provisions set forth in Standard Method of Test for the Coefficient of Cubical Thermal Expansion of Plastics, ASTM Designation D864-52 (18). Each dilatometer consisted of a one meter long precision diameter Pyrex capillary tube fused to the end of a 14 mm ID x 12.5 cm Pyrex tube. The open end of the 14 mm ID tube consisted of a ground glass joint which was fitted with a removable stopcock as shown in Figure 1. The removable stopcock feature enabled the dilatometers to be filled with samples, sealed and reused without the use of glass blowing equipment. A one meter measuring stick was attached to each capillary tube to facilitate measuring the mercury column height.

Mercury Filling Apparatus

A Welch vacuum pump capable of obtaining a 0.1 micron vacuum was used to evacuate the air from the dilatometers prior to filling with mercury. A tygon tube connected the stopcock to a reservoir of mercury as shown in Figure 2. A 500 ml vacuum flask was installed between the upper end of the dilatometer capillary tube and the vacuum pump as a

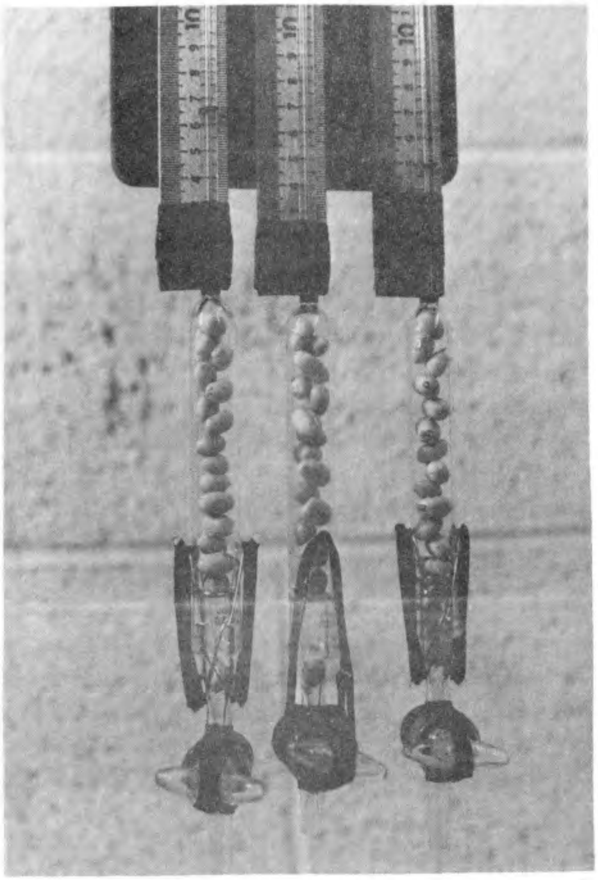

Figure 1. Dilatometers with Removable Stopcocks Filled with Peanut Kernels

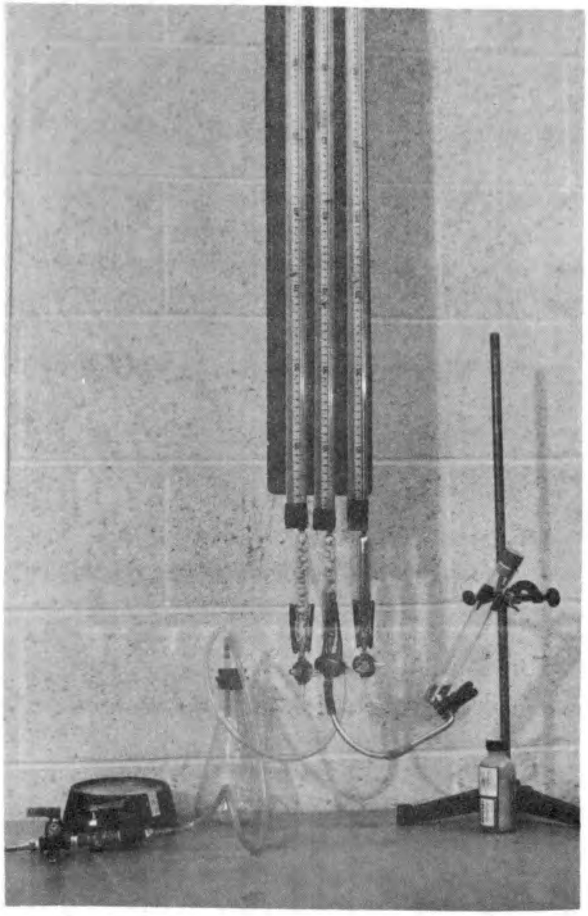

Figure 2. Mercury Filling Apparatus

mercury trap. Vacuums were monitored with a vacuum gauge and a mercury manometer. For all dilatometry tests new Bethlehem Instrument continuous vacuum triple distilled mercury was used.

Water Bath

The water bath for heating the dilatometer bulbs consisted of a 4000 ml Pyrex beaker filled with tap water as shown in Figure 3. The use of water in a temperature bath was recommended by ASTM D864-52 (18) for the temperature range of 10 to 90°C. The beaker was heated and magnetically stirred with a Cole Parmer hot plate. The hot plate was equipped with a temperature probe which was used to control the heating rate. The temperature near the center of the water bath was measured with a thermister probe and a Thermistemp temperature controller to within ±0.1°C. The water bath temperature was also monitored with a mercury thermometer.

Helium-Air Comparison Pycnometer

A Micromeritics Model 1302 helium-air comparison pycnometer as shown in Figure 4 was used to determine the initial volumes (± 0.1 cm^3) of peanut samples at room temperature. A Welch vacuum pump was employed to remove air from the test sample and from the pycnometer chamber. A helium cylinder and pressure regulator provided the desired 3.4×10^4 to 5.5×10^4 pascals (5 to 8 psig) helium pressure needed to operate the pycnometer.

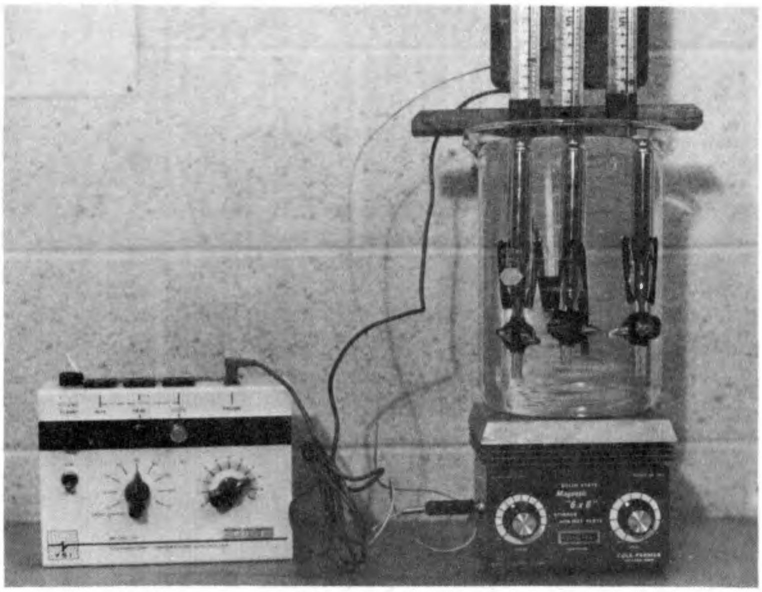

Figure 3. Water Bath, Hot Plate, and Temperature Measuring Apparatus

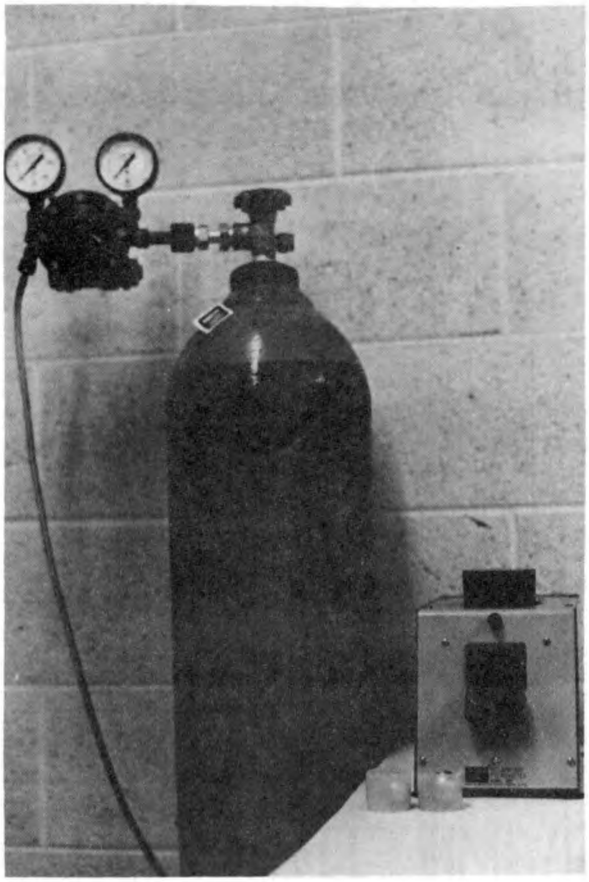

Figure 4. Helium-Air Comparison Pycnometer and Helium Cylinder with Pressure Regulator

Moisture Contraction

Environmental Chamber

An environmental chamber used to dry peanut kernels was constructed from clear plexiglas plastic. The chamber dimensions were 12 cm in width, 7 cm in height and 40 cm in length as shown in Figure 5. To attain nearly uniform air flow conditions across the center of the chamber, an inlet and outlet perforated transition chamber was placed in the chamber next to the air inlet and outlet. The top, bottom, and walls were constructed of plexiglas 0.32 cm thick. The ends were made of plexiglas 1.27 cm thick.

The inlet air temperature and relative humidity conditions were controlled with an Aminco-Aire precision temperature-humidity air supply unit which continuously circulated air through a 0.4 m^3 insulated chamber. A Dayton Model 2C781 centrifugal fan was used to draw air out of the large circulation chamber through a 3.8 cm ID flexible tube and into the environmental chamber. A Honeywell Brown Electronic 0-200°F thermocouple potentiometer was used to monitor the temperature in the environmental chamber as shown in Figure 6.

Microprojector

A Wilder Model A microprojector equipped with a 20 X magnifying lens was used to measure the dimensional changes of peanut kernels during drying as shown in Figure 7. The image of a kernel was magnified 20 times and projected onto a grid surface. Dimensional changes as small as 0.025 mm were detected.

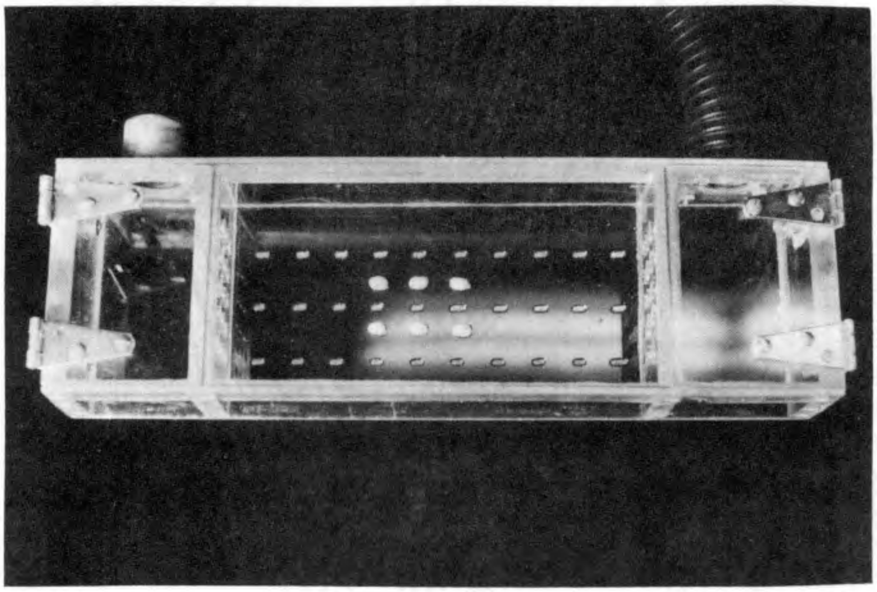

Figure 5. Plexiglas Environmental Chamber for Drying Peanut Kernels

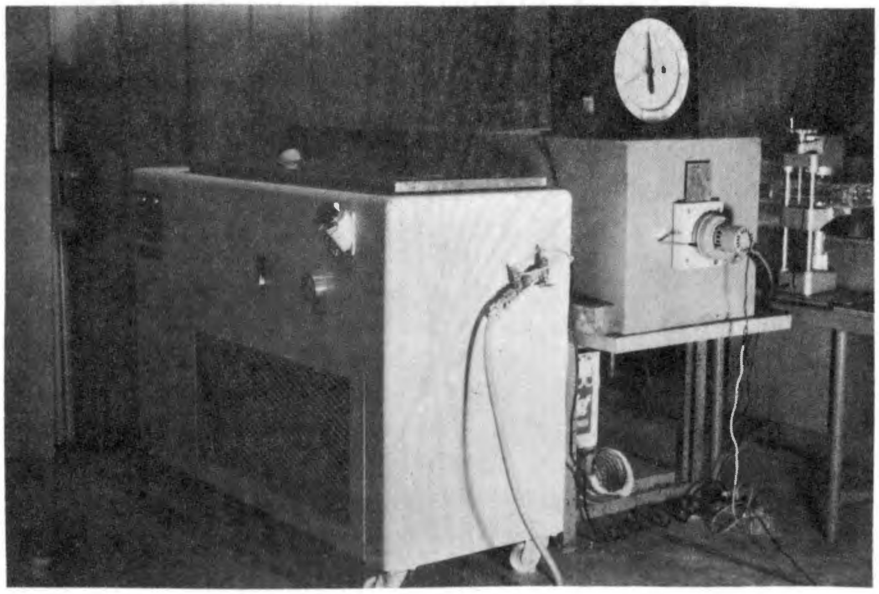

Figure 6. Air Supply Unit, Circulation Chamber (on Table), Centrifugal Fan, and Thermocouple Potentiometer

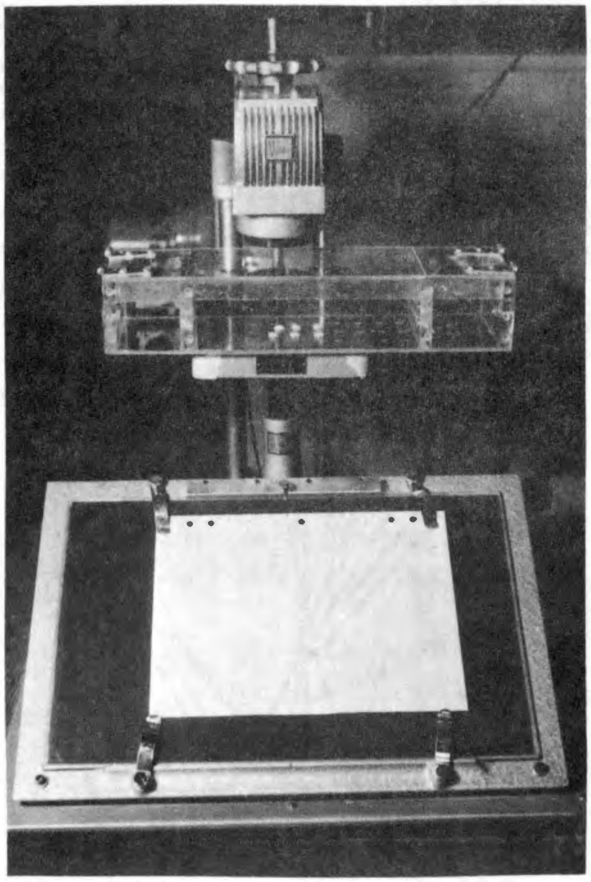

Figure 7. Wilder Microprojector with 20 x Lens and Environmental Chamber

CHAPTER IV

EXPERIMENTAL MATERIAL AND PROCEDURE

Thermal Expansion

Peanut Kernels and Skins

Peanut kernels used for the determination of the coefficient of cubical thermal expansion were purchased from a commercial sheller at approximately eight percent moisture content.[1] Spanish peanuts were manually sorted and only those whole kernels large enough to be retained by an "Official USDA 15/64 inch" grading seive were used. At least one week prior to testing, a sample of approximately 1500 grams was hygroscopically conditioned to the desired moisture content in a controlled humidity and temperature chamber. The sample was sealed in an air-tight bag and allowed to equilibrate for a minimum of 48 hours at 4°C and stored at that temperature. The sample was removed from cold storage 12 to 18 hours before testing so that the sample would be at room temperature prior to its volume determination.

Peanut skins were obtained by manually sorting loose skins from shelled kernels. Preliminary investigations indicated that skins received in this manner were more nearly intact and contained less foreign material than those obtained from a blanching process. The skins were

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[1] All moisture contents used in this dissertation are expressed as percent dry basis unless otherwise stated.

initially at 14 percent moisture content which was much higher than that of the kernels. Karon and Hillery (10) reported that for Runner peanut kernels and skins in moisture equilibrium, the skins will typically contain a percentage of moisture approximately twice that of the kernels. The skins were hygroscopically conditioned as needed to attain desired moisture contents. The skins were given 48 hours to equilibrate and were stored in air-tight containers at 4°C until 12 to 18 hours before testing.

Preparation of Dilatometer Samples

Three samples of sixteen peanuts were randomly selected from one 1500 gram sample. The kernels were then individually skinned. Each sample was weighed on an analytical balance to the nearest 0.0001 gram. The volume of each sample was determined by a Micromeritics helium-air comparison pycnometer to the nearest 0.1 cm^3. The temperature of the sample at the time of the volume determination became the reference temperature for that sample throughout all further testing. Reference temperatures ranged from 23°C to 28°C.

Skin sample size was limited by the size of the dilatometers as shown in Figure 8. Preliminary testing revealed that sample sizes greater than four grams resulted in skin compaction which later caused difficulty in attaining a complete mercury filling in the dilatometers. Skin samples of approximately one to three grams were weighed and measured for volume.

Filling the Dilatometers

Mercury was utilized as the confining liquid for the dilatometers.

Figure 8. Dilatometers Filled with Peanut Skins (Dilatometer on the Right also Contains Mercury.)

Bekkedahl (4) reported that the confining liquid should meet several requirements: (a) the fluid should exist as a liquid over the entire range of temperature measurements; (b) the liquid must have a sufficiently low vapor pressure to prevent evaporation loss during heating; (c) its viscosity must not become overly high at lower temperatures; (d) it must have minimal swelling effects on the specimen; and (e) the cubical thermal expansion coefficient must be accurately known over the entire temperature range to be tested. Confining liquids such as water, acetone and various alcohols have been used for dilatometry measurements, however, Bekkedahl (4) strongly recommended the use of mercury in all dilatometry determinations which do not require measurements below the mercury freezing point of -39°C.

The samples of pre-measured volumes and weights were placed inside the dilatometer bulbs. High vacuum stopcock grease was applied to all ground glass joints and the removable stopcock was securely fastened into the dilatometer bulb by means of wire and heavy rubber bands. With proper procedure a vacuum tight seal was easily obtained. With the three dilatometers suspended in a vertical position the mercury filling apparatus was connected to the lower end of the stopcock as shown in Figure 2. A vacuum was drawn from the upper end of the capillary tube to evacuate air from the dilatometer and sample. The stopcock was slowly opened to allow mercury to completely fill the dilatometer bulb and part of the capillary tube. The mercury column level in the capillary tube was noted and the vacuum on top of the column was released. A negligible drop in the mercury column when the vacuum was released indicated that the dilatometer had been successfully sealed, evacuated, and filled with mercury. Next the mercury level was lowered to 20 cm above the stem mark by draining mercury from the stopcock. The stem mark which divided the dilatometer into the bulb below and the capillary above also indicated the height of the dilatometer in relation to the water bath level as shown in Figure 9.

All three dilatometers were filled with samples at the same moisture content. Moisture contents were determined by oven drying representative samples at 105°C for 24 hours. Six moisture contents ranging from 0.5 to 15.7 percent for the kernels were tested. Five moisture contents ranging from 2.4 to 29.0 percent were used for the skins. Skin moisture contents covered a higher range of moisture than kernels because skins in equilibrium with kernels are normally at much higher moisture contents than the kernels.

Mercury Column Height

Each dilatometer was adjusted to an initial level of approximately 20 cm above the stem mark at room temperature after the vacuum on top of the column was released. Assuming the center of mass of the sample was approximately four cm below the stem mark, then 24 cm of mercury plus one atmosphere (76 cm) or approximately 1.332×10^5 pascals (19.3 psia) was initially exerted on the sample. Upon heating the sample to 90°C, thermal expansion of the sample and mercury caused the mercury column to rise by 10 to 40 cm depending on the sample tested. Assuming the maximum 40 cm rise occurred, then a hydrostatic pressure of 64 cm of mercury plus one atmosphere or a total pressure of 1.867×10^5 pascals (27.1 psia) was exerted on the sample. Thus, for each degree rise in temperature and corresponding column height the sample was subjected to a slightly higher pressure. Based on ASTM Designation D864-52 (18) it was

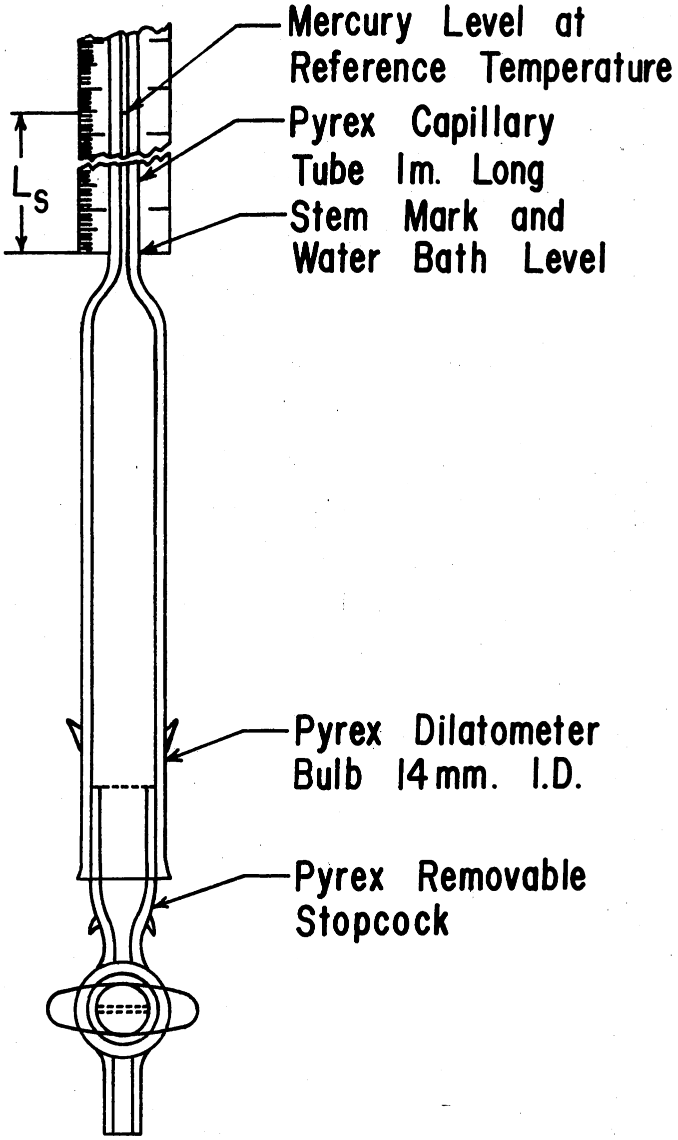

Figure 9. Illustration of Dilatometer with Stem Mark and Removable Stopcock

assumed that the pressure difference created by the increased capillary column height would have a negligible effect on the values of the coefficients of cubical thermal expansion.

Heating the Dilatometers

A 4000 ml Pyrex beaker was filled with water 12 to 18 hours prior to heating to allow the water temperature to equilibrate with the room air temperature. The three dilatometers were submerged to their stem marks in the water bath which was vigorously mixed with a magnetic stirrer. Mercury column readings to the nearest 0.1 cm were periodically taken for each dilatometer. After the readings remained constant for 30 minutes the dilatometer sample, mercury and water bath were assumed to all be at an equilibrium temperature. The water bath was slowly heated at a rate not to exceed 0.5°C per minute. Temperature near the center of the water bath was measured with a thermister probe to the nearest 0.1°C and a mercury thermometer to the nearest 0.5°C. Due to the slow heating rate and relatively small diameter of the dilatometer bulbs it was assumed that dilatometer sample temperatures were essentially the same as the water bath temperatures.

Water bath temperatures and mercury column heights were recorded at 5 to 10 minute intervals until 90°C was reached. At that time the heat was turned off but the magnetic stirrer was left running. One minute readings were taken until the mercury columns reached a maximum level and then decreased. The maximum level usually occurred within three minutes after heating was stopped. The increase in mercury column height while water bath temperature remained constant generally never exceeded 0.2 cm.

Dilatometers were heated from room temperature 25°C ± 3°C to 90°C. Three heatings were performed on each sample and between each heating the dilatometers and water bath were allowed to cool overnight by free convection.

After the final heating and cooling, the mercury and sample were carefully collected from each dilatometer and weighed together on an analytical balance to the nearest 0.0001 gram. The mercury weight was determined by subtracting the original sample weight from the total weight of the sample and mercury. The total volume of mercury contained in the dilatometer, V_{mt}, was determined by dividing the total weight of the mercury by the density of mercury at the room reference temperature (the temperature of the sample at the time of its volume determination).

Emergent Stem Correction

Water bath temperatures and mercury column heights measured to the nearest 0.1 cm were recorded for each dilatometer. An emergent stem correction factor was added to each mercury column reading to compensate for the difference in temperature between the mercury contained in the capillary tube and that in the dilatometer bulb. Thus, actual mercury column readings would be lower than those obtained if the entire capillary tube and dilatometer bulb were submerged and heated in the water bath. Bekkedahl (4) used the correction factor, C:

$$C = K(T - T_r)(H - H_b) \qquad [12]$$

where: K = 0.00017 if mercury is used in Pyrex glass

T = measured temperature of water bath, °C

T_r = temperature of the liquid in the emergent stem, °C which is essentially the same as room temperature

H = the mercury column height, mm

H_b = the mercury column height at the level of the bath, mm

After applying the correction factor to peanut kernels and skins the observed mercury column heights increased by 0.5 cm or less.

Calculation of Capillary Cross-Sectional Area

The cross-sectional area of the capillary tube for each dilatometer was experimentally determined by filling each dilatometer and capillary tube with new triple distilled mercury to an approximate 50 cm height. The mercury and dilatometers were essentially at the room air temperature (±0.5°C). The vacuum above the mercury columns was released and readings were taken of the column heights for each dilatometer to the nearest 0.05 cm. Excess droplets of mercury from the bottom of the stopcock were removed and the dilatometers were individually drained to an approximate five cm height. Exact column height readings were again recorded and the collected mercury was weighed on an analytical balance to the nearest 0.0001 grams. The weight of the mercury divided by the known density of mercury at the measured room temperature yielded the volume of mercury contained in each capillary tube. This volume was divided by the difference in column height to obtain the average cross-sectional area of each capillary tube. Three replications of capillary cross-sectional area were performed for each dilatometer. The mean cross-sectional areas were calculated to be 1.146, 1.154, 1.262 mm^2 for dilatometers 1, 2, 3 respectively.

It was assumed that the calculated cross-sectional areas were uniform over entire capillary tube length. In preliminary investigations where the dilatometers were filled only with mercury, mercury heights in all three dilatometer capillaries increased linearly with temperature. Since mercury expands at the same rate over the entire 25 to 90°C temperature range, it is apparent that if capillary cross-sectional areas were not essentially uniform then mercury column heights could not increase linearly with temperature.

Calculation of the Coefficient of Cubical Thermal Expansion

The coefficient of cubical thermal expansion was calculated from a formula similar to that used in ASTM Designation D864-52 (18).

$$A\frac{\Delta x}{\Delta t} = a_x V_p + a_h V_h - a_g V_g \qquad [13]$$

where: a_x = the coefficient of cubical thermal expansion, 1/°C for the sample

a_g = the coefficient of cubical thermal expansion for Pyrex glass, 1.0×10^{-5}/°C

a_h = the coefficient of cubical thermal expansion for the mercury, 18.2×10^{-5}/°C

A = cross-sectional area of the capillary tube, mm^2

$\frac{\Delta x}{\Delta t}$ = slope of the line depicting the change in mercury column height, per unit change in temperature of the water bath, mm/°C

V_p = the volume of the peanut sample at the room temperature, mm^3

V_g = the internal volume of the dilatometer bulb below the stem mark, mm^3

$V_g = V_h + V_p$

V_h = the volume of the mercury contained in the dilatometer bulb below the stem mark, mm^3

$V_h = V_{mt} - L_s \times A$

V_{mt} = the total volume of mercury contained in the dilatometer, V_{mt} was determined by dividing the total weight of the mercury by the density of mercury at the room reference temperature, mm^3

L_s = distance from the stem mark to the mercury meniscus when the dilatometer and water bath were at the room reference temperature, mm

The room reference temperature referred to the temperature measured when the peanut sample was placed in the helium-air comparison pycnometer for its volume determination.

Solving equation [13] for a_x yields:

$$a_x = \left[A\frac{\Delta x}{\Delta t} + a_g V_g - a_h V_h\right] / V_p \qquad [14]$$

A Fortran program shown in Table XVIII in Appendix C was utilized to readily solve for a_x. Sample calculations for a_x are shown in Appendix A.

Calibration of the Dilatometers

The three dilatometers were calibrated with materials of known cubical thermal expansion coefficients. The materials used were new triple distilled mercury and Pyrex beads. The dilatometers were heated and cooled three times. For the mercury determinations, a_x ranged from 17.46×10^{-5}/°C to 18.93×10^{-5}/°C as shown in Table XVIII in Appendix C. The mean value of a_x was 18.56×10^{-5}/°C. Compared to the published a_x value of mercury of 18.2×10^{-5}/°C, the absolute error ranged from

0.10 x 10^{-5}/°C to 0.74 x 10^{-5}/°C (18). The mean absolute error was 0.52 x 10^{-5}/°C. A plot of mercury column height versus temperature indicated that there was a negligible hysteresis effect between the first and successive heatings. Thus, when the dilatometers were filled only with mercury, due to its liquid state there were no initial stresses on the mercury to cause a hysteresis effect.

Next, each dilatometer was tested with five Pyrex beads. The beads were each approximately 0.8 cm in diameter and 2.5 cm long. Pyrex was used because it was known to have a very small coefficient of cubical thermal expansion, 1.0 x 10^{-5}/°C, and was a substance that would not react with mercury (18).

Values of a_x for Pyrex ranged from 1.12 x 10^{-5}/°C to 1.77 x 10^{-5}/°C as shown in Table XVIII in Appendix C. The mean value of a_x was 1.45 x 10^{-5}/°C. Absolute error ranged from 0.12 x 10^{-5}/°C to 0.77 x 10^{-5}/°C. The mean absolute error was 0.45 x 10^{-5}/°C which compares closely to 0.52 x 10^{-5}/°C found for mercury alone.

Experimental Design for Thermal Expansion Coefficients

A randomized complete block experimental design was used to determine if moisture had a significant effect on the coefficient of cubical thermal expansion. Each of the three dilatometers represented one complete block. Within each block there were six moisture levels, 0.5, 4.2, 6.7, 10.0, 13.5 and 15.7 percent for the kernels. Five moisture levels, 2.4, 7.6, 14.3, 18.8 and 29.0 percent were used for the skins. Within each level of moisture there were three heatings of the dilatometers.

Moisture Contraction

The moisture contraction coefficient, a_m, was defined as the change in volume per unit volume for a one percentage point reduction in moisture content ($cm^3/cm^3\%$). To determine the coefficient, peanut kernels were individually dried in a clear plexiglas chamber under controlled temperature and humidity conditions. The length and diameter dimensions of the kernels were periodically measured by optically projecting and magnifying the image of the kernel with a microprojector. Periodic weighings of individual kernels were used to calculate the moisture content at the times when dimensional measurements were taken.

Preparation of Kernels

To determine the coefficient of moisture contraction due to drying, naturally moist Spanish peanut kernels were freshly dug from the Oklahoma State University Agronomy Farm near Perkins, Oklahoma. Kernel moistures varied from 15 to 107 percent with an average of 45 percent. Due to the high moisture contents and short storage life, the peanuts were stored at 4°C and were replaced with freshly dug peanuts approximately every two weeks. The effect of peanut digging dates on the coefficient of moisture contraction was not investigated. The pods were hand shelled and the skins were carefully removed from the kernel immediately prior to testing. Apical and basal kernels were tested separately to determine if a difference in the coefficient of moisture contraction for apical and basal kernels existed.

Environmental Chamber Temperature and Humidities

The coefficient of moisture contraction for Spanish peanut kernels was determined as a function of drying rate. To find the effect of drying rate, the drying air was maintained at four different relative humidities (20, 42, 70 and 80 percent). Temperature of the drying air was held constant at 40°C for all relative humidities so that any thermal expansion effects would be eliminated. The air supply unit was set at the conditions as shown in Table I.

TABLE I

AIR SUPPLY UNIT SETTINGS NEEDED TO ATTAIN THE DESIRED PEANUT ENVIRONMENTAL CHAMBER CONDITIONS

Air Supply Unit Settings			Peanut Environmental Chamber Conditions	
Water Temperature °C	Dry Bulb Temperature °C	Relative Humidity%	Dry Bulb Temperature °C	Relative Humidity%
6	48	13	40	20
22	48	27	40	42
32	48	45	40	70
35	48	54	40	80

The dry bulb temperature of the drying air near the center of the environmental chamber was monitored with a thermocouple and a Honeywell Brown Electronik Potentiometer. Due to relatively high air velocities, drying air temperatures were fairly uniform (±1°C) over the entire environmental chamber. The relative humidity of the air in the circulation chamber was determined from a graph supplied with the air supply unit. To use the graph it was necessary to know the water temperature in the air supply unit and the dry bulb temperature in the circulation chamber. The dry bulb temperature and relative humidity of air in the circulation chamber defined a state point on a psychrometric chart which was used to calculate the new relative humidity at the 40°C temperature that existed in the environmental chamber. The new calculated relative humidity was then assumed to be essentially equal to the actual relative humidity in the environmental chamber.

The relative humidity in the circulation chamber was periodically measured with an Opancol Quicktest humidity probe (±5% relative humidity). Due to the ability of the air supply unit to consistently maintain dry bulb and water temperatures within ±0.5°C, the air supply unit was capable of controlling relative humidity more precisely than measurements of relative humidity could be performed. Thus, calculated relative humidities were always within the accuracy of the humidity probe.

Drying air from the circulation chamber was passed continuously over the kernels in the environmental chamber at a velocity of approximately 15 m/min (50 ft/min). It was assumed that with air velocities as high as 15 m/min passing over a thin layer of fully exposed kernels, a negligible increase in drying rate would occur if higher air velocities were used. Only six kernels were placed in the environmental chamber at one time since it was not readily possible to trace the optical images and maintain accurate weighings of more than six kernels during one drying.

Calibration of the Microprojector

The microprojector was calibrated using a flat metal disc which was measured optically and then with a Brown and Sharpe 0-25 mm micrometer. Five measurements were made with each method. For the microprojector the diameters were 12.002, 12.000, 12.000, 12.000 and 12.000 mm. For the micrometer the diameters were 12.000, 12.002, 12.002, 11.997 and 12.006 mm. The average values obtained by the two methods varied by less than 0.01 percent. In all measurements with the microprojector care was taken to obtain a sharp image by turning the focus adjustment knob in a clockwise direction only.

Determination of Dimensional Changes

A Wilder microprojector was utilized to measure the length and diameter dimensions of a peanut kernel. The image of a kernel was magnified twenty times and projected onto a centimeter grid surface from which changes in dimensions were measured.

The total of six kernels, three apical and three basal usually obtained from six different pods, were placed in the plexiglas environmental chamber at one time. Cotyledons were laid face down in the plexiglas chamber. Length and a diameter dimension parallel to the cotyledon interface were measured optically from the cotyledons. The whole kernels were turned with the cotyledon interface in a vertical plane. This enabled length and a diameter dimension perpendicular to the cotyledon interface to be measured. Length and diameter dimensions were optically measured to the nearest 0.025 mm.

Preliminary testing revealed that as a kernel dried, the bottom kernel surface would distort slightly causing the kernel to change its orientation each time it was viewed on the microprojector. Consequently, the germ was removed from the cotyledons and the bottom of the cotyledons was thinly shaved with a razor blade to remove the minimal amount needed to produce a flat surface. The whole kernels were placed with the cotyledon interface in a vertical plane and a thin slice approximately one mm in thickness was removed from the bottom surface. The flat surface eliminated the problem of keeping the kernel properly orientated. It was assumed that the removal of a thin slice did not significantly alter the way the kernel responded.

The kernels were individually weighed after they were sliced. The six kernels were placed in the environmental chamber and the projected image of the kernels was magnified twenty times. The image was traced onto 18 x 25 cm graph paper. For the 20, 42, and 70 percent relative humidity treatments, the images of the kernels were traced initially before drying, and then at 0.5, 1.0, 2.0, 4.0 and 24 hours from the start of drying. Immediately after each tracing, the kernels were individually removed and weighed on an analytical balance to the nearest 0.0001 gram. The kernels were out of the chamber for approximately two minutes for each weighing. It was assumed that this periodic removal from the chamber would not significantly affect the total drying time. After the 24 hour measurements, the kernels were oven dried for 24 hours at 105°C so that moisture contents could be calculated. After oven drying, the kernels were weighed and the projected images were traced so that the oven dry lengths and diameters would be known.

The length and diameter dimensions were measured from the tracing of individual kernels and plotted against the corresponding moisture contents. A least squares regression analysis was performed for each kernel to determine the slope of the lines depicting kernel lengths and diameters versus moisture content.

Experimental Design for Moisture Contraction Coefficients

The linear moisture contraction coefficients, α_L and α_D, were the dependent variables used in the experimental design. The coefficients α_L and α_D were determined by dividing the slope of the lines depicting length and diameter kernel dimensions versus moisture by oven dry lengths and diameters, respectively (cm/cm%).

Whole kernels and cotyledons were tested separately. Relative humidity was set to one of four levels (20, 42, 70 and 80 percent) to be investigated as main effects. Six kernels (three apical and three basal) were placed in the environmental chamber at one time. Each of the three apical or basal kernels was called a triplicate. After testing, the kernels were removed and the relative humidity was changed to a new level. Two replications of the experiment were performed for both whole kernels and for cotyledons. A total of 48 whole kernels and 48 cotyledons were measured. Table II illustrates the experimental design.

TABLE II

EXPERIMENTAL DESIGN FOR THE LINEAR COEFFICIENTS OF MOISTURE CONTRACTION, α_L AND α_D

Relative Humidity	Whole Kernels							Cotyledons						
	Type	Rep-1			Rep-2			Type	Rep-1			Rep-2		
		Triplicate			Triplicate				Triplicate			Triplicate		
		1	2	3	1	2	3		1	2	3	1	2	3
20%	Apical							Apical						
	Basal							Basal						
42%	Apical							Apical						
	Basal							Basal						
70%	Apical							Apical						
	Basal							Basal						
80%	Apical							Apical						
	Basal							Basal						

CHAPTER V

RESULTS AND DISCUSSION

Thermal Expansion

Dilatometer Column Height Versus Temperature

A plot of mercury column height versus temperature indicated a linear relationship between the variables. A Statistical Analysis System, SAS, least squares regression program was used to determine the slope of the straight line which best fitted the data points (3). Correlation coefficients ranged from 0.97 to 0.99 but in 96 out of 99 determinations the correlation coefficients were larger than 0.99. Dilatometry literature review, ASTM Designation D864-52 (18) and Ekstrom, et al. (7) indicated that a transition point often occurs at a certain temperature. Above the transition temperature the slope was greater than below the transition temperature. For the peanut kernels and skins a transition temperature was not found. Thus, one slope was calculated for the entire temperature range from 25 to 90°C. Typical plots of mercury column height versus temperature are shown in Figures 10 and 11 for the kernels and skins respectively.

Hysteresis Effect of Heatings

Before the first heating each dilatometer was adjusted to an initial level of approximately 20 cm above the stem mark after the vacuum

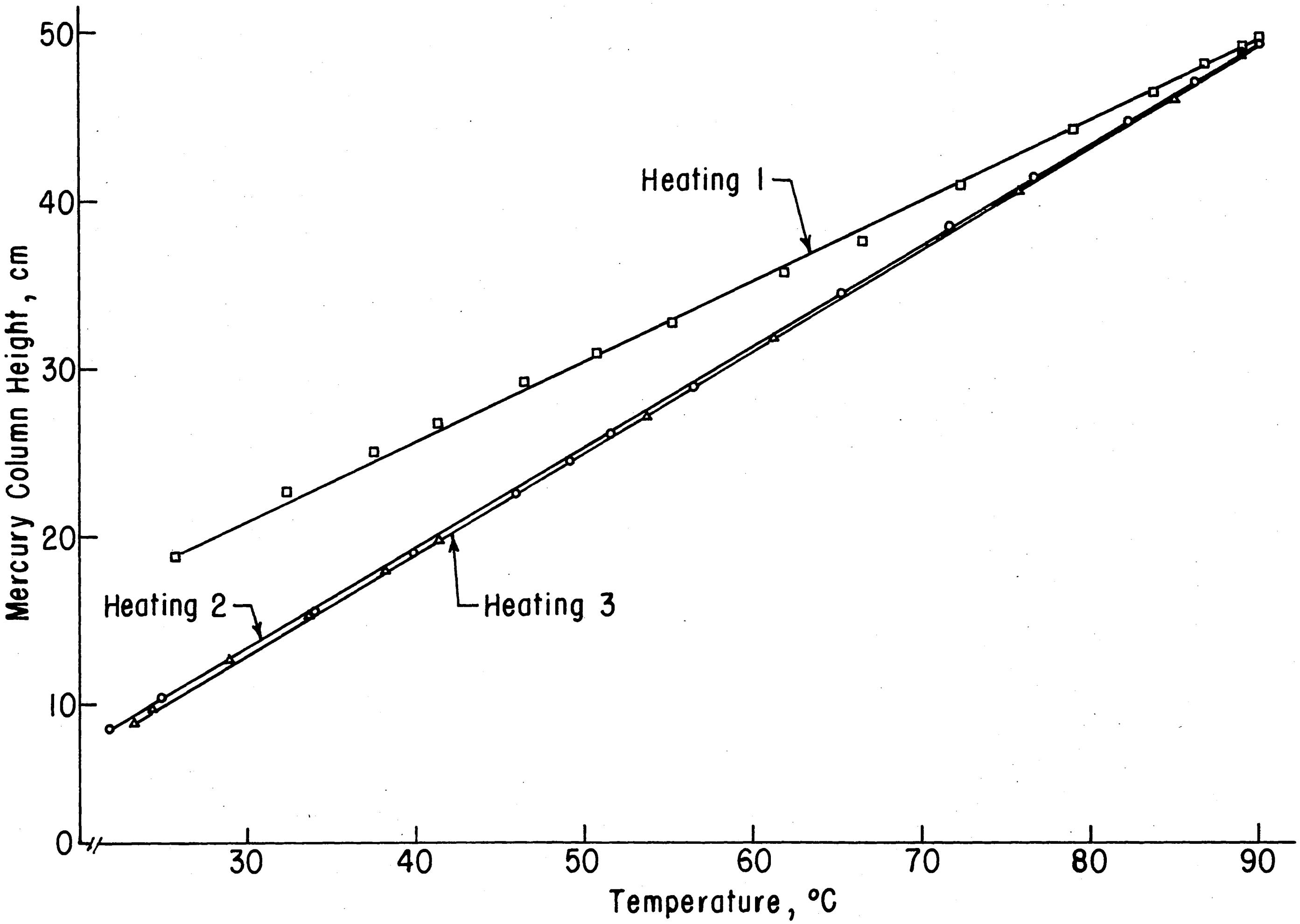

Figure 10. Response of Dilatometer 1 to Heating for 10.0 Percent Moisture Spanish Peanut Kernels

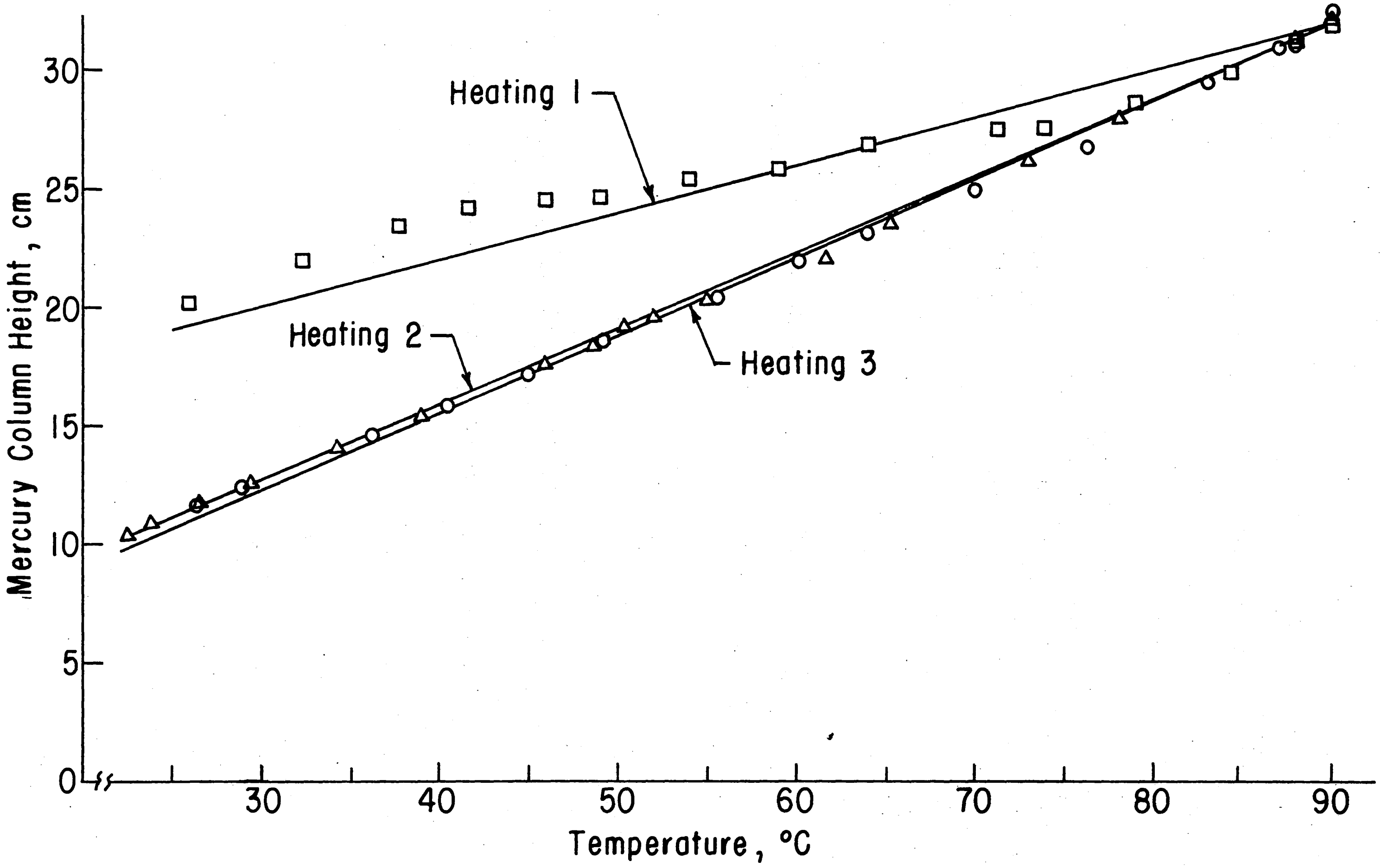

Figure 11. Response of Dilatometer 1 to Heating for 14.3 Percent Moisture Spanish Peanut Skins

was released. After the first heating to 90°C and cooling to room temperature, the height of the mercury column generally dropped below its level prior to the first heating. After the second and subsequent heating and cooling cycles, a smaller, negligible hysteresis effect was observed as shown in Figure 10. A similar finding was reported by Ekstrom, et al. (7) for shelled corn. ASTM Designation D864-52 (18) stated that coefficient values obtained from the first heating may greatly differ from values obtained from subsequent heatings. This difference was attributed to stresses within the test sample which were released at the temperatures reached during the first heating.

A large hysteresis was more noticeable for peanut skins than for kernels after the first heating. For several skin samples the hysteresis was so large that the mercury column decreased during the first heating as illustrated in Figure 11. Thus, a negative coefficient of cubical thermal expansion was calculated for the first heating (See Table XVIII in Appendix C). The most feasible explanation is that the vacuum drawn upon filling the dilatometers left minute void spaces in the sample which were not completely filled with mercury. Upon heating, the thermal expansion of the skins and the reduced viscosity of the mercury slowly allowed the mercury to completely fill these void spaces. This created an apparent decrease in mercury column height. Due to the nature and necessary size of the skin sample the large hysteresis effect could not be eliminated completely.

The size of the skin samples ranged from 0.94 to 3.1 grams. Preliminary tests indicated that if a skin sample size much larger than four grams was used the sample was so tightly packed into the dilatometers that it was nearly impossible to obtain a complete vacuum and to fully fill void spaces with mercury. Smaller samples would reduce the accuracy of the computed coefficient. It was also believed that hygroscopic samples of peanut kernels or skins should not be subjected to a high vacuum for a prolonged period of time to maintain a constant moisture. Thus, peanut kernel and skin samples were exposed to a vacuum for no longer than one to two minutes during the dilatometer filling with mercury.

Recommendations given by ASTM Designation D864-52 (18) stated that coefficients obtained for the first heating should be disregarded because coefficients which were nearly equal and obtained from second and subsequent heatings were more likely to be correct. Coefficients calculated from different heatings but for the same sample and dilatometer were considered to be statistically dependent on the previous heating. Therefore, the coefficients calculated for the second and third heating were averaged to yield one coefficient for each dilatometer at each moisture level.

Statistical Analysis

A randomized complete block experimental design was used to determine if moisture had a significant effect on the coefficients of cubical thermal expansion. The coefficients used were an average of the two values obtained from the second and third heatings. Each of the three dilatometers represented one complete block. Within each block there were six moisture levels: 0.5, 4.2, 6.7, 10.0, 13.5 and 15.7 percent for the kernels. For the skins five moisture levels, 2.4, 7.6, 14.3, 18.8 and 29.0 percent were used. The kernels and skins were analyzed separately.

An analysis of variance indicated that moisture had a significant effect ($\alpha = 0.05$) on the coefficients of cubical thermal expansion as shown in Table VI in Appendix B. However, dilatometers did not have a significant effect ($\alpha = 0.05$) on a_x for peanut kernels or skins.

A regression analysis was performed to determine the equation which would best describe the relationship between the coefficient, a_x, and moisture content. Table III summarizes six models fitted for peanut kernels and skins. Also shown are the regression coefficients, correlation coefficients, calculated F-test values used in testing for lack of fit of the model, and the standard deviations of a_x about the regression line.

The model $a_x = \beta_0 + \beta_1(\text{Ln } M)$ was selected to best fit the data for the kernels and skins. It was desired to select a model with a relatively high correlation coefficient. But it should be noted that correlation coefficients can not be compared between models which have had a logarithmic transformation of the dependent variable and those which have not been transformed. Thus, an F value for the ratio of the mean square due to lack of fit divided by the mean square due to pure error was calculated. Analyses of Variance, Tables VII through XII, Appendix B, were used to test for the lack of fit for each regression model.

Since the calculated F value of 1.50 for kernels for the $a_k = \beta_0 + \beta_1(\text{Ln } M)$ model was smaller than the tabled $F_{4,12\ (0.05)}$ value of 3.26 it was concluded that there was not sufficient evidence to reject the model at the $\alpha = 0.05$ significance level.

TABLE III

SUMMARY OF MODELS FITTED FOR CUBICAL THERMAL EXPANSION COEFFICIENT VERSUS MOISTURE CONTENT

Models for Kernels	R^2	Std Dev	$F = \frac{MSL}{MSE}$	F-test df
$a_k = 52.2637 + 0.5961\ M$	0.714	2.101	13.646^*	4,12
$a_k = 49.9030 + 1.5577\ M - 0.058223\ M^2$	0.847	1.588	3.019	3,12
$a_k = 48.7777 + 2.7330\ M - 0.253566\ M^2 + 0.008150\ M^3$	0.886	1.416	1.805	2,12
$a_k = 52.1921 + 2.9710\ \mathrm{Ln}\ M$	0.869	1.422	1.501	4,12
$\mathrm{Ln}\ a_k = 3.9557 + 0.0107\ M$	0.710	$0.038^@$	7.997^*	4,12
$\mathrm{Ln}\ a_k = 3.9533 + 0.0539\ \mathrm{Ln}\ M$	0.883	0.024	1.415	4,12

Models for Skins	R^2	Std Dev	$F = \frac{MSL}{MSE}$	F-test df
$a_s = 29.5873 + 0.9797\ M$	0.654	7.044	3.865^*	3,10
$a_s = 21.1880 + 2.6162\ M - 0.051920\ M^2$	0.785	5.776	1.702	2,10
$a_s = 19.2373 + 3.3770\ M - 0.113567\ M^2 + 0.001309\ M^3$	0.788	5.997	3.247	1,10
$a_s = 16.7527 + 11.3749\ \mathrm{Ln}\ M$	0.791	5.479	1.022	3,10

TABLE III (Continued)

Models for Skins	R^2	Std Dev	$F = \frac{MSL}{MSE}$	F-test df
$\ln a_s = 3.3807 + 0.0249\ M$	0.647	0.182[@]	6.850[*]	3,10
$\ln a_s = 3.0316 + 0.2986 \ln M$	0.835	0.124	1.414	3,10

[*] Indicates statistical significance at $\alpha = 0.05$ level, therefore the model should be rejected due to lack of fit.

All regression coefficients were multiplied by 10^5.

a_k, a_s denotes the coefficients of cubical thermal expansion for peanut kernels and skins respectively.

M denotes the moisture content in the percent dry base.

[@] Standard deviations for equations which have had a logarithmic transformation on the dependent variable can not be compared to equations which have not had a logarithmic transformation on the dependent variable.

For the skins the semi-logarithmic model has a calculated F value of 1.02. Since this F value was smaller than the $F_{3,10\ (0.05)}$ value of 3.71 it was concluded that there was not sufficient evidence to reject the model at the $\alpha = 0.05$ significance level.

The linear model $a_x = \beta_0 + \beta_1(M)$ for both kernels and skins was rejected due to lack of fit as shown in Table III. The semi-logarithmic model $a_x = \beta_0 + \beta_1(\text{Ln } M)$ was selected over the log-log model for simplicity and because a semi-logarithmic plot indicated that the data could be adequately fitted by a straight line as shown in Figures 12 and 13. The semi-logarithmic model was selected over the quadratic and cubic models because its standard deviation about the regression line was usually less than that of the quadratic or cubic models.

Discussion of Thermal Expansion Coefficients

The predicted coefficient of cubical thermal expansion, a_k for kernels, was found to range from 50.0 x 10^{-5}/°C to 60.5 x 10^{-5}/°C at moisture contents of 0.5 and 15.7 percent respectively.[1] The cubical thermal expansion for peanut oil was reported by Magne and Wakeham (11) to be 76.4 x 10^{-5}/°C over the temperature range of 30 to 200°C. It was reported by Stansbury, et al. (19) that the oil content of samples of dry Spanish peanuts ranged from 45 to 55 percent by weight and that the average oil content was approximately 50 percent. Assuming that approximately 50 percent of the peanut kernel volume is composed of oil which has a relatively high cubical thermal expansion coefficient,

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[1] All coefficients of linear and cubical expansion or contraction were written times 10^{-5} to remain consistent throughout this dissertation and with literature review.

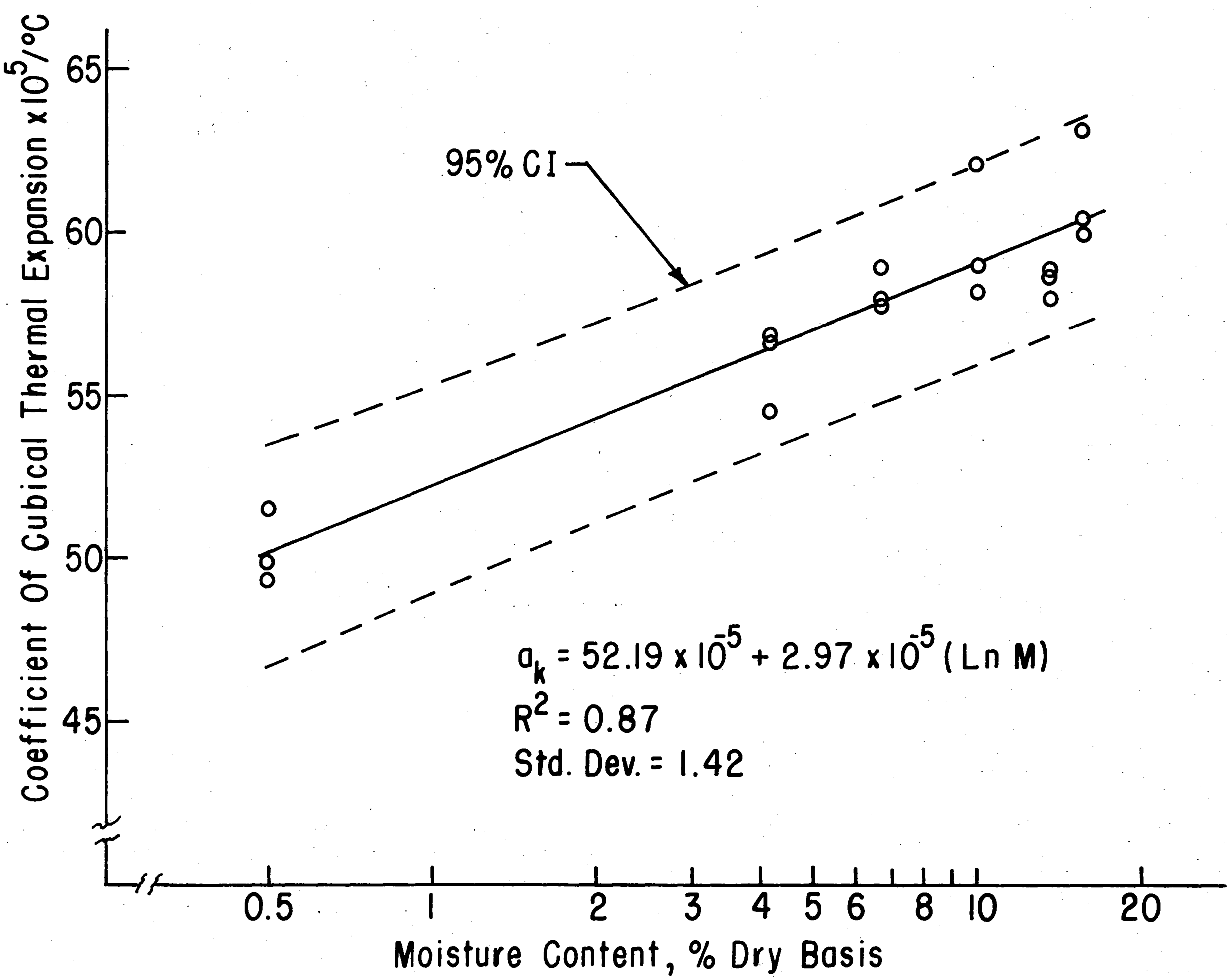


Figure 12. Predicted Line, Data Points, and 95 Percent Confidence Interval for a Future Individual Observation for Kernels

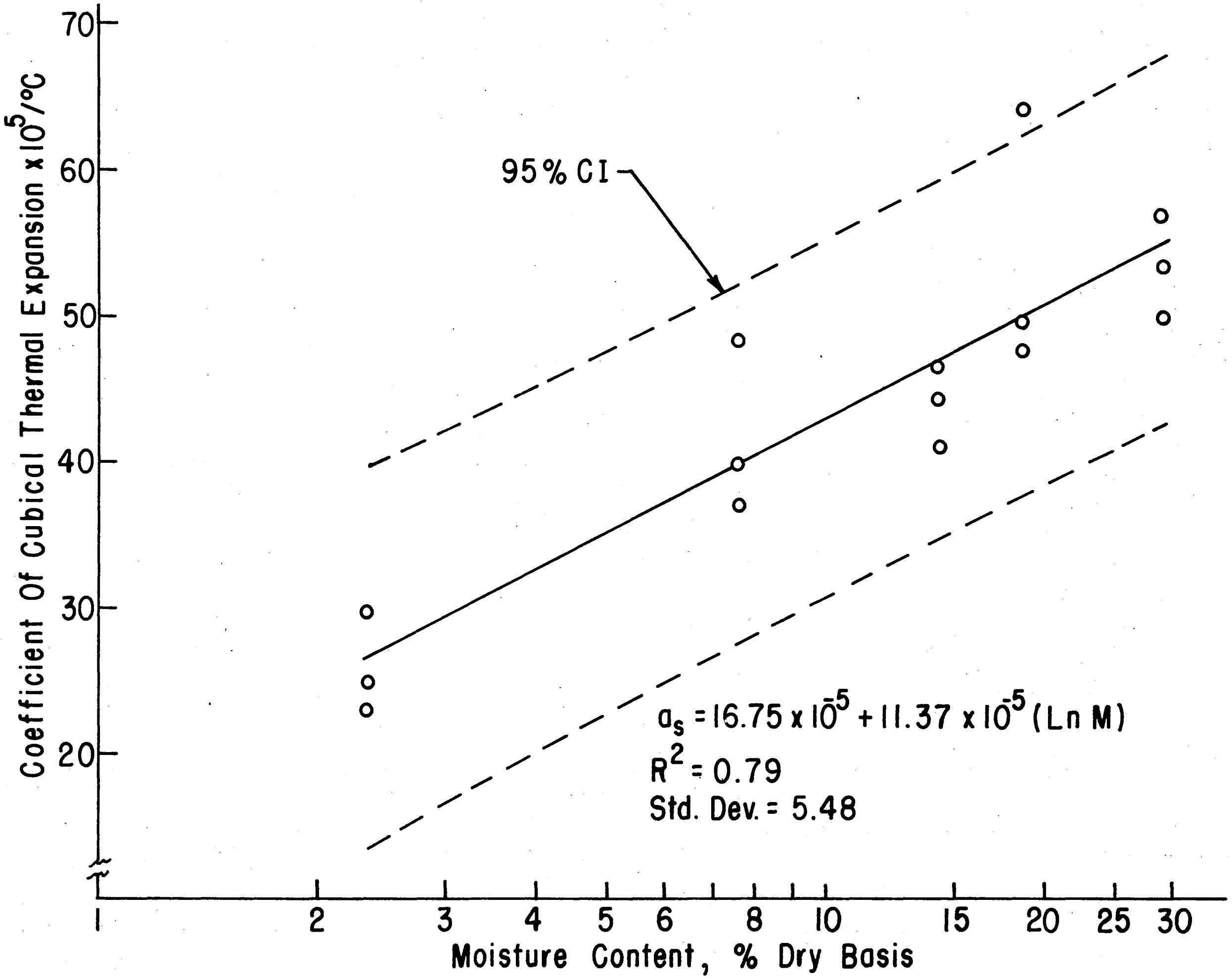
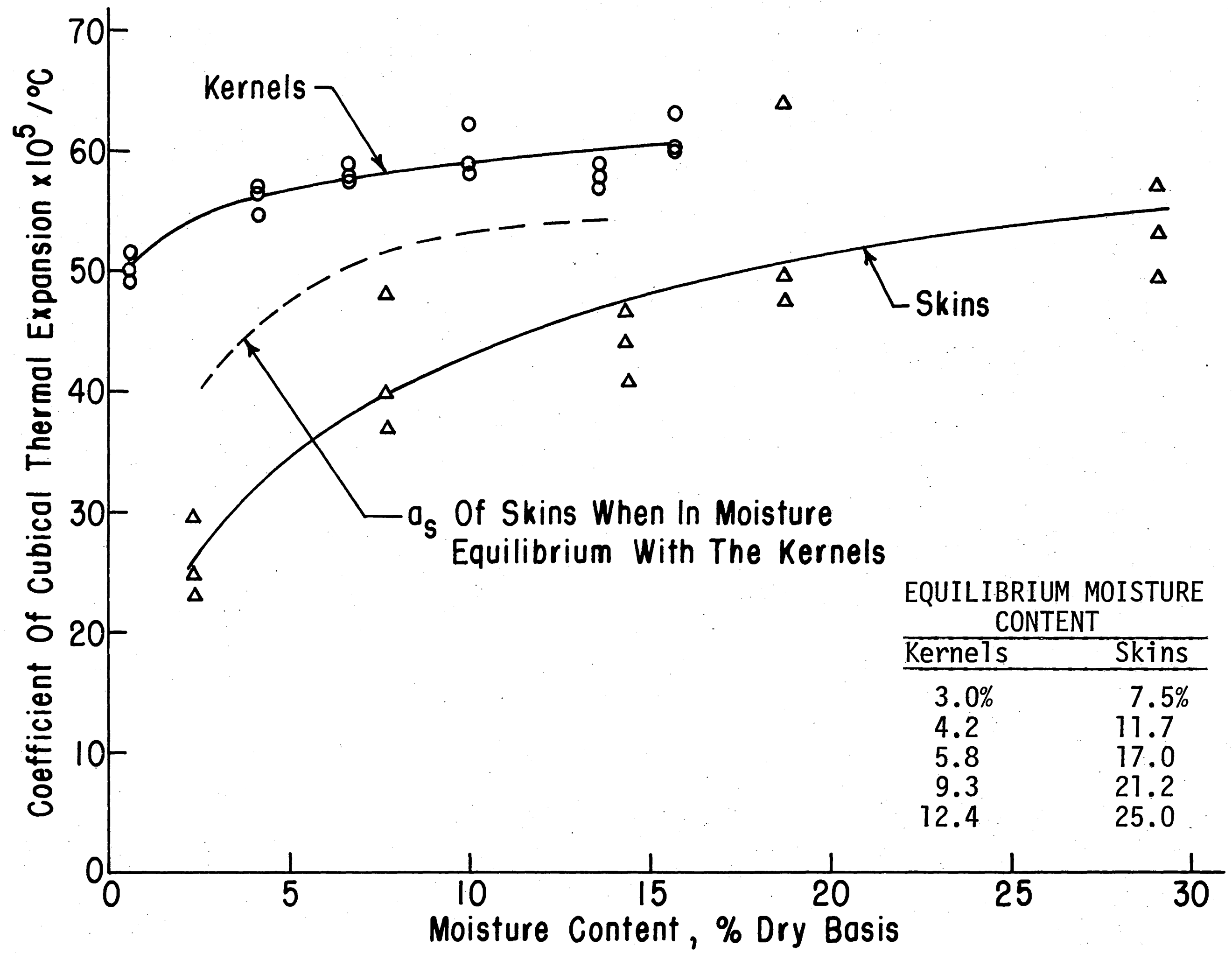


Figure 13. Predicted Line, Data Points, and 95 Percent Confidence Interval for a Future Individual Observation for Skins

76.4 x 10^{-5}/°C, it would appear logical that peanuts and possibly other oilseed grains would have cubical thermal expansion coefficients larger than those of grains containing relatively low amounts of oil. It was found that Spanish peanut kernels did have higher cubical thermal expansion coefficients over all moisture ranges than did shelled corn or rice. Ekstrom, et al. (7) reported the maximum value for corn was 32.8 x 10^{-5}/°C at 20 percent wet basis moisture content. Arora, et al. (1) determined the maximum value for rice at 12 percent wet base moisture to be 33.6 x 10^{-5}/°C. Thus, commodities such as shelled corn and rice which contain relatively low percentages of oil also have relatively low coefficients of cubical thermal expansion.

In one exploratory test peanut kernels were partially defatted by pressing at 1000 psi for three minutes. The sample weight was reduced by approximately 30 percent due to the oil removed. Assuming that the sample originally contained 50 percent oil by weight, then after pressing the sample contained approximately 28 percent oil by weight. Three dilatometers determinations yielded an average a_k of 35.2 x 10^{-5}/°C for 7.4 percent moisture peanut kernels. The predicted value of a_k for 7.4 percent kernels which were not partially defatted was 58.5 x 10^{-5}/°C as shown in Figure 12. Apparently a higher oil content produces a larger coefficient of cubical thermal expansion.

The predicted coefficient of cubical thermal expansion for the peanut skins ranged from 26.5 x 10^{-5}/°C to 54.5 x 10^{-5}/°C at 2.4 and 29.0 percent moisture contents respectively as shown in Figure 13. Figure 14 shows that for peanut kernels and skins at the same moisture content, a_k for the kernels is considerably larger than that of the skins. However, Karon and Hillery (10) reported that Runner peanut



EQUILIBRIUM MOISTURE CONTENT

Kernels	Skins
3.0%	7.5%
4.2	11.7
5.8	17.0
9.3	21.2
12.4	25.0

Figure 14. Comparison of the Coefficient of Cubical Thermal Expansion for Spanish Peanut Kernels and Skins

skins at 25°C which were in moisture equilibrium with kernels at 25°C contained wet base moisture percentages 2 to 2.5 times higher than that of the kernels. The dashed line in Figure 14 indicates the approximate value of a_s for the skins when the skins are initially in moisture equilibrium with the kernels. In an actual peanut drying situation the skins would quickly lose moisture and therfore no longer be in moisture equilibrium with the kernels. As the skins deviate further from moisture equilibrium with the kernels, the dashed line in Figure 14 continues to shift downward approaching the solid line for the predicted values of a_s for the skins. As drying occurs a_s decreases due to moisture loss and due to a downward shift in the skin moisture equilibrium curve. Figure 14 also shows that a_s decreases more than a_k. As drying continues there would be a greater tendency for the kernels to expand more than the skins causing an increased stress on the skins. But when cooling occurs, the kernel would also contract more than the skins and possibly cause the skin to fit loosely around the kernel. It appears likely that differences in coefficients of cubical thermal expansion could aid in rupturing and loosening the skin around a peanut kernel.

Moisture Contraction

Length and Diameter Changes

Images of whole peanut kernels and cotyledons were periodically magnified and projected onto 18 x 25 cm graph paper as the peanuts were dried. Figures 18 and 19 in Appendix D show a typical projected area for a whole kernel and a cotyledon respectively. The projected areas did not contract uniformly as drying occurred. It is believed that the edges of the peanut kernels may have contracted nonuniformly which led to large variations in dimensional measurements. Length dimensions were taken from the projected areas at a point which was believed to be the maximum length but still representative of the average length shrinkage for that kernel. Diameters were measured perpendicular to the length dimension at the maximum diameter which was still representative of the average diameter shrinkage. Length and diameter dimensions were recorded for every drying interval and plotted against moisture content. Figure 15 shows typical plots of length and diameter versus moisture for whole kernels and cotyledons. Steele and Brown (20) found the lengths and diameters of Virginia and Florigiant peanut kernels decreased linearly with moisture loss. Spanish peanut kernel dimensions were also found to decrease linearly with moisture loss. A least squares regression analysis was performed to determine the slopes of the lines which best fitted individual kernel length and diameter dimensions versus moisture content.

The slopes of length and diameter versus moisture content were denoted as $\Delta L/\Delta M$ and $\Delta D/\Delta M$, respectively and were calculated only from the change in dimensions which occurred during the 0 to 24 hour drying period. For the whole kernels, $\Delta D/\Delta M$ represented the change in perpendicular diameter per unit change in moisture. For the cotyledons $\Delta D/\Delta M$ indicated the change in parallel diameter per unit change in moisture. The values of $\Delta L/\Delta M$ and $\Delta D/\Delta M$ which were calculated from a least squares regression analysis are listed in Tables XIX and XX in Appendix D under the names Lslope and Dslope respectively.

The slopes $\Delta L/\Delta M$ represented an absolute change in dimension per unit change in moisture. Since it was believed that the size of a kernel might affect the magnitude of expansion or contraction, $\Delta L/\Delta M$ and

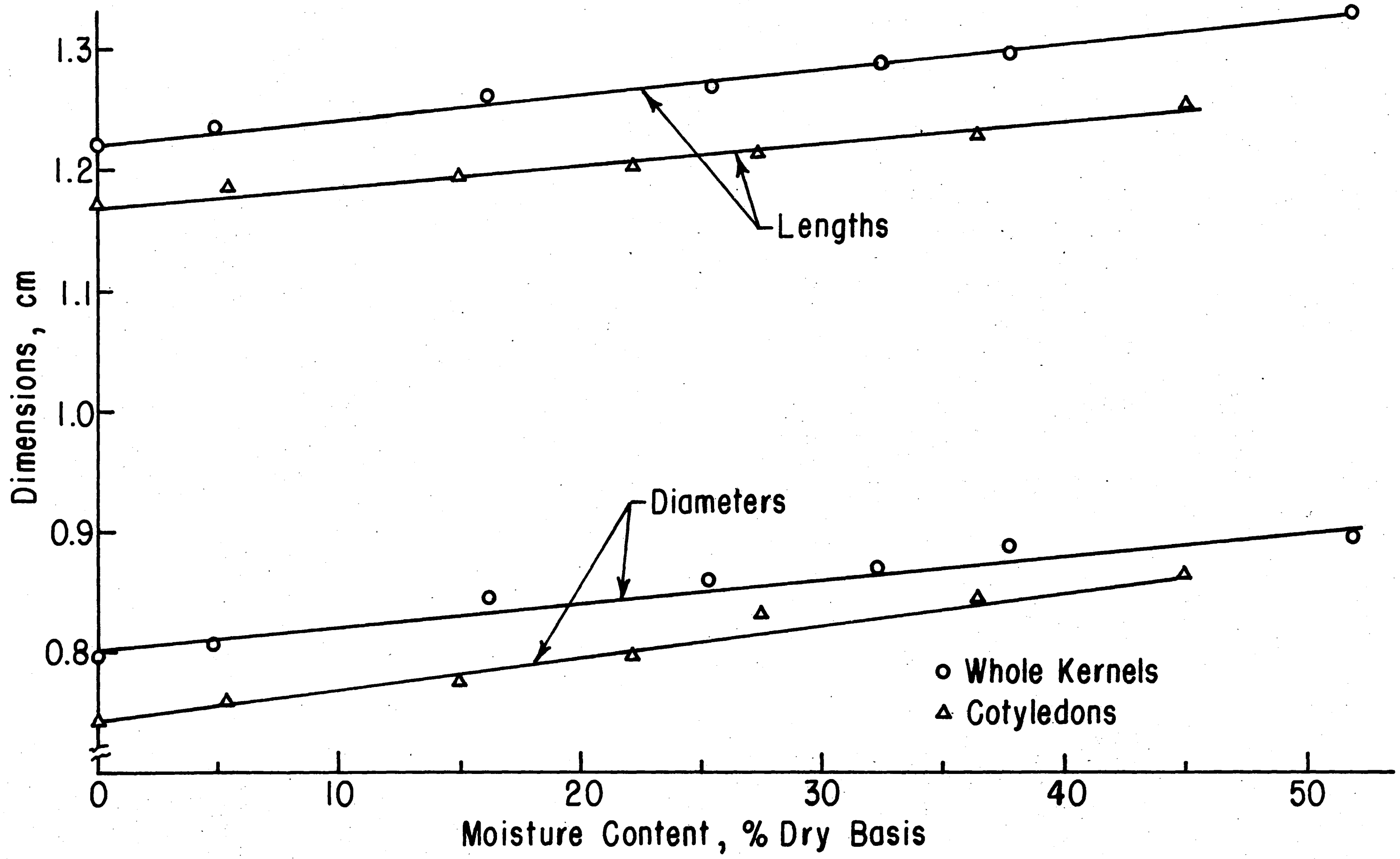


Figure 15. Typical Plots of Length and Diameter Versus Moisture for Whole Kernels and Cotyledons Dried at 40°C and 42 Percent Relative Humidity

$\Delta D/\Delta M$ were divided by their respective oven-dry lengths. Thus, the relative change in length and diameter dimensions were denoted by $\Delta L/L\ \Delta M$ and $\Delta D/D\ \Delta M$ (cm/cm %). The terms $\Delta L/L\ \Delta M$ and $\Delta D/D\ \Delta M$ are linear moisture contraction coefficients and were denoted as α_L, and α_D, respectively. Values of α_L and α_D for individual kernels are shown in Tables XIX and XX in Appendix D under the names AlphaL and AlphaD, respectively.

Statistical Analysis

An analysis of variance was performed on the two dependent variables α_L and α_D separately for whole kernels and for the cotyledons as shown in Tables XIII through XVI in Appendix B. F-tests were performed for kernel types (apical or basal), relative humidities, and humidity by type interaction.

F-tests indicated that no significant difference ($\alpha = 0.05$) was found between apical or basal kernel types for α_L and α_D in either Spanish whole kernels or cotyledons. For Virginia peanuts Steele and Brown (20) observed that basal kernels were usually larger than apical kernels and that the average percentage of dimensional change with moisture was larger for basal than apical kernels. It was not reported whether the difference in dimensional changes with moisture between apical and basal Virginia kernels was statistically significant.

Based on the F-tests in Tables XIV and XVI in Appendix B, relative humidity did not significantly affect α_D for whole kernels or cotyledons. Relative humidity did significantly affect α_L for whole kernels and cotyledons as shown in Tables XIII and XV in Appendix B. Therefore, a least significant difference test (LSD) was performed on the means of α_L. For whole kernels an LSD of 0.00882 was needed for a significant difference ($\alpha = 0.05$) to exist between relative humidities. The vertical line in Table IV indicated that no significant difference existed between 20 and 42 percent and between 70 and 80 percent relative humidities for α_L. For cotyledons an LSD of 0.00556 was needed. Thus, no significant difference existed between 20 and 42 percent and between 70 and 80 percent relative humidities for α_L. Since no significant difference was found between 20 and 42 percent or 70 and 80 percent relative humidities, the α_L values were averaged together to give one value for the 20 to 42 percent range and another value for the 70 to 80 percent range for the whole kernels and cotyledons.

TABLE IV

LEAST SIGNIFICANT DIFFERENCES FOR MEANS OF α_L AND α_D

	Whole Kernels		Cotyledons	
Relative Humidity (%)	α_L	α_D	α_L	α_D
20	0.00202	0.00208	0.00138	0.00292
42	0.00211	0.00196	0.00121	0.00413
70	0.00306	0.00241	0.00305	0.00453
80	0.00332	0.00272	0.00315	0.00423

Note: The least significant difference ($\alpha = 0.05$) for α_L of whole kernels and for cotyledons was 0.00882 and 0.00556 respectively. The F-test for effect of humidity on α_D was not significant. Therefore, the least significant difference was not calculated for α_D.

For the whole kernels, the humidity by type interaction term was found to significantly affect α_L. A plot of α_L versus relative humidity for each kernel showed an interaction to exist only between the 20 and 42 percent relative humidities which were later averaged together.

Cotyledon Displacement

Woodward and Hutchinson (24) reported that splitting of peanut kernels increases as drying rate increases. Virginia, Runner and Spanish whole green peanut kernels with their skins removed were dried at 24°C at relative humidities of 12, 40, 60 and 80 percent to approximately 12 percent moisture content. After drying, the opposing displacement between cotyledons at the end opposite the germ was measured. For Virginia and Runner peanuts the average displacement was approximately 0.14, 0.11, and 0.04 cm at relative humidities of 12 to 40, 60, and 80 percent respectively. Thus, rapid drying at low relative humidities caused the peanut kernels to spread further apart at the end opposite the germ.

In measuring the whole kernel diameters, some cotyledons would occasionally spread slightly apart after some initial drying and volume shrinkage occurred. Since periodic weighings of the peanuts required relocation of the sample, it was not possible to make accurate measurements of cotyledon displacement. Kernels were visually checked to see that cotyledons were always intact before kernel dimensions were recorded. Readings were taken such that dimensional changes could be assumed due only to moisture contraction.

Coefficient of Moisture Contraction

The cubical coefficient of moisture contraction was computed from the linear coefficients by calculating the change in volume per unit volume which would occur for a one percent loss in moisture. Two methods were used to calculate a cubical coefficient of moisture contraction once the linear coefficient was known. The simplest method was to multiply the average linear coefficient of moisture contraction by three. For small values of α and an isotropic solid this is adequate. The other method involved approximating the volume of a peanut kernel as a prolate spheroid, an ellipse rotated about its major axis.

In the first method, the coefficients of cubical moisture contraction were found by calculating the average of α_L and α_D and multiplying by three. Cubical coefficient values for individual kernels are shown in Tables XIX and XX in Appendix D under the name Alpha3 which will be referred to as a_{m3}. For the whole kernels, values of a_{m3} averaged over 20 to 42 percent and 70 to 80 percent relative humidities were 613 x 10^{-5} cm^3/cm^3 % and 865 x 10^{-5} cm^3/cm^3 %, respectively. Values of α_L and α_D were averaged over the relative humidities which were not shown to be significantly different. For the cotyledons, values of a_{m3} averaged over 20 to 42 percent and 70 to 80 percent relative humidities were 698 x 10^{-5} cm^3/cm^3 % and 1122 x 10^{-5} cm^3/cm^3 %, respectively.

The coefficient of cubical moisture contraction for brown rice kernels was calculated by Prasad, et al. (15) by averaging the linear moisture contraction coefficients for length, width, and thickness and multiplying by three. By this method rice kernels were assumed to be an isotropic solid and the cubical coefficient was assumed to be equal to three times the linear contraction coefficient. The coefficient of cubical moisture contraction for brown rice was found to be 1215×10^{-5} cm^3/cm^3 % for kernels dried at 25°C from 23.5 to 5.5 percent moisture.

The second method of calculating the coefficient of cubical moisture contraction was to approximate the volume of a peanut kernel at various moisture contents with a prolate spheroid. The volume, V, of a prolate spheroid, an ellipse rotated about its major axis, can be written:

$$V = \frac{4\pi}{3} \frac{L}{2}\left(\frac{D}{2}\right)^2 \qquad [15]$$

where L/2 and D/2 are the half-lengths of the major and minor axes, respectively. The volume, V_m, of the kernel at some moisture content, M, was calculated by:

$$V_m = \frac{4\pi}{3}\left(\frac{L}{2} + \alpha_L \frac{L}{2} M\right)\left(\frac{D}{2} + \alpha_D \frac{D}{2} M\right)^2 \qquad [16]$$

The cubical coefficient of moisture contraction, a_m, for a ΔM change in moisture content was defined as:

$$a_m = \frac{V_m - V_{m-1}}{V_m \, \Delta M} \qquad [17]$$

where: V_m = the volume calculated at the moisture M
V_{m-1} = the volume calculated at the moisture $M - \Delta M$
ΔM = an arbitrarily chosen 1% change in moisture content

For whole kernels a_m was calculated for a one percent moisture change of ΔM. For drying conditions of 40°C and relative humidities ranging from 20 to 42 percent, an α_L value of 0.00206 was calculated by averaging over the 20 and 42 percent humidities. Values of α_L and α_D were averaged over the relative humidities which were not shown to be significantly different. For slower drying conditions with 40°C and relative humidities of 70 to 80 percent, an average α_L of 0.00319 was used. The value of α_D, 0.00230, was obtained by averaging over all relative humidities for the whole kernels.

For the cotyledons the average values 0.00113, 0.00310, and 0.00395 were calculated for α_L at 20 to 42 percent, α_L at 70 to 80 percent, and α_D at 20 to 80 percent relative humidities, respectively.

The length, L, of 1.033 cm was obtained by averaging all of the oven-dry lengths for all whole kernels and cotyledons over all relative humidities. The diameters, D, of 0.827 and 0.674 were obtained by averaging the oven-dry diameters over all relative humidities for the whole kernels and cotyledons respectively. Table XVIII in Appendix D shows the oven-dry lengths and diameters for individual whole kernels. Table XIX in Appendix D lists the oven-dry lengths and diameters for individual cotyledons.

A Fortran computer program shown in Table XXI in Appendix D was used to calculate a_m from 1 to 90 percent moisture content by increments, ΔM, of one percent for two drying rates for the whole kernels and cotyledons. For the whole kernels dried at 40°C and 20 to 42 percent relative humidity, a_m ranged from 660×10^{-5} to 550×10^{-5} cm^3/cm^3 % for moistures ranging from 1 to 90 percent respectively as shown in Figure 16. For the 70 to 80 percent relative humidity range, values of a_m ranged from 771×10^{-5} to 625×10^{-5} cm^3/cm^3 %.

Figure 16 indicates that for cotyledons dried at 40°C and relative humidities within the 20 to 42 percent range, a_m varies from 889×10^{-5} to 685×10^{-5} cm^3/cm^3 % at moistures of 1 to 90 percent respectively. Cotyledons dried more slowly with 70 to 80 percent relative humidities produced a_m values of 1080×10^{-5} to 825×10^{-5} cm^3/cm^3 %.

Prolate Spheroid Assumption

In the calculation of a_m it was assumed that the volume of a peanut

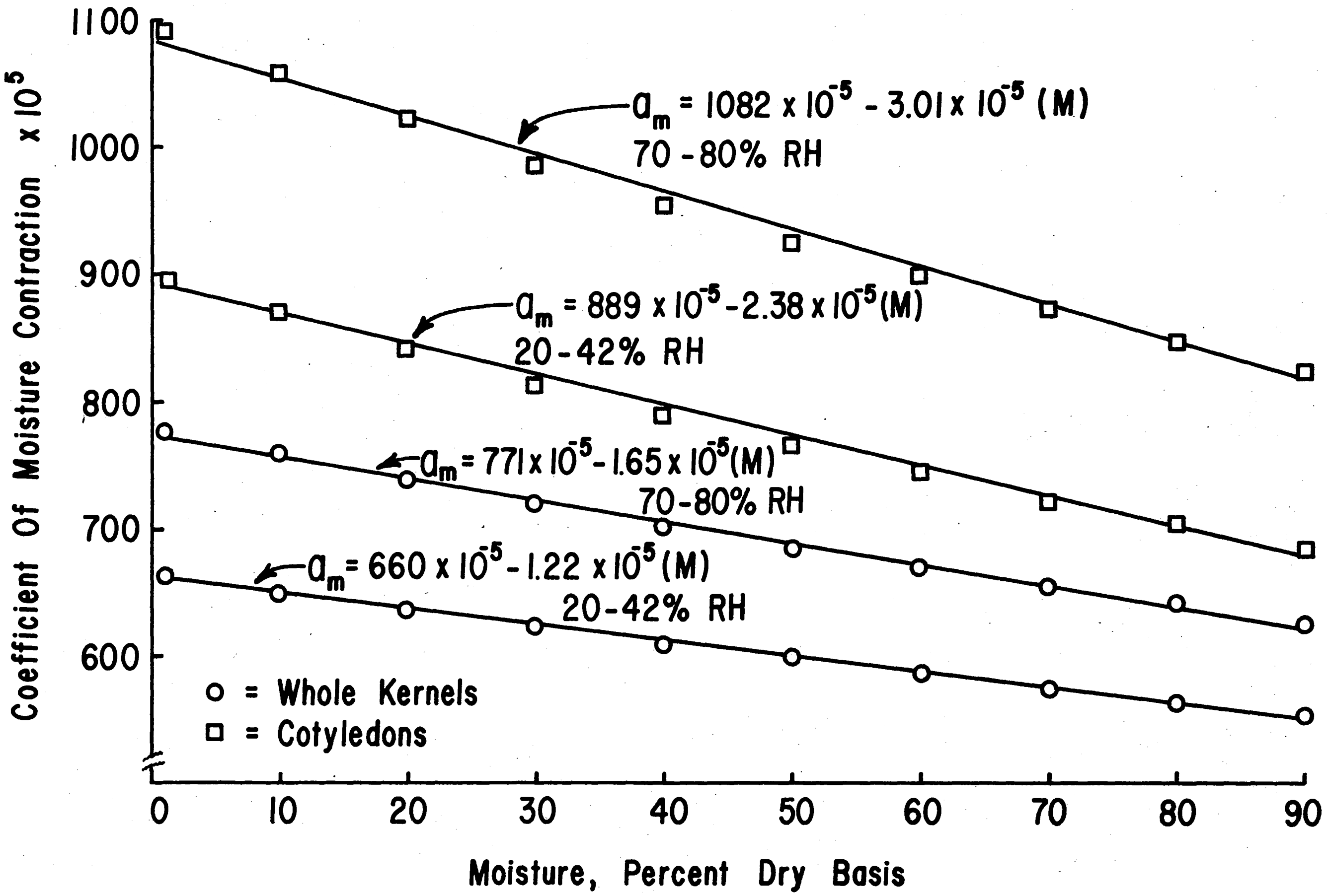


Figure 16. Cubical Coefficients of Moisture Contraction and Predicted Lines as a Function of Moisture Content and Relative Humidity

kernel could be approximated by a prolate spheroid. To test the validity of this assumption, the length and diameters of 30 whole peanut kernels at 6.5 percent moisture content were measured with the microprojector. The volumes of the 30 peanuts were also measured three times with a Micromeretics helium-air comparison pycnometer. The average peanut volume determined by the pycnometer was 0.44 cm^3. The average volume of a prolate spheroid, calculated from the maximum peanut diameters and lengths, was 0.58 cm^3. The prolate spheroid assumption tended to overestimate the volume because the maximum length and diameter dimensions were used in the calculations. Also, any air spaces between the cotyledons halves of the whole kernels would cause prolate spheroid volumes to be larger than volumes determined by the pycnometer method which would not account for such air spaces.

Discussion of Moisture Contraction Coefficients

Values of a_{m3} for whole kernels and cotyledons in the 20 to 42 percent relative humidity ranges were within the range of values calculated for a_m. In the 70 to 80 percent relative humidity range, a_{m3} values for whole kernels and cotyledons were slightly larger than those of a_m as shown in Table V.

Table V indicates that coefficient values for whole kernels were smaller than those for cotyledons. A possible explanation is that the microprojected images of cotyledon dimensions were obtained from the outermost peanut edges. But for the whole kernels, the maximum dimensions were projected from a convex surface of the side of the peanut. During drying, it is possible that outermost edges of the cotyledons would shrink more than whole kernels which were fully intact. Thus, because of the geometrical shape of the cotyledons, they could be expected to contract more than whole kernels.

TABLE V

COMPARISON OF CUBICAL COEFFICIENTS OF MOISTURE CONTRACTION a_{m3} AND a_m*

Relative Humidity Range (%)	Whole Kernels		Cotyledons	
	a_{m3}	a_m	a_{m3}	a_m
20 - 42	613	550 - 660	698	685 - 889
70 - 80	865	625 - 711	1122	825 - 1080

*Values of a_{m3} and a_m are expressed times 10^5.

The relative humidity range used for drying peanuts with 40°C air affected the cubical coefficients of moisture contraction as shown in Table V. Drying peanuts at 40°C for 24 hours produced average moisture contents of 4.8 and 10.5 percent for the relative humidity ranges of 20 to 42 percent and 70 to 80 percent respectively. It is theorized that drying rate affects the final volume. Van Arsdel, et al. (22) stated that if a highly shrinking material was dried quickly and the outer surface became much drier than the center, the outer surface was subjected to sufficient tension to permanently set the surface in nearly its original dimensions. When the center finally dried and contracted, the internal stresses pulled the material apart and the dried material contained many cracks and holes. Conversely, if the material was dried slowly with a small moisture gradient from outer surface to the center core, internal stresses were minimized and the material contracted fully to a solid core.

As previously noted, Van Arsdel, et al. (22) found that dehydrated potato cubes which were dried rapidly to 11 percent moisture had a bulk density approximately one-half that of an equal weight of potato cubes which were dried slowly to the same moisture content. Thus, slowly dried potato cubes contracted approximately twice as much as those dried rapidly.

Blanching Characteristics

Most peanut blanching processes use some type of heating and drying of the peanuts to loosen the skin from around the kernel. It was hypothesized that the loosening effect may be the result of thermal expansion of the skin and kernels during heating, due to moisture contraction of the peanuts during drying, and thermal contraction of the peanuts during cooling.

Shackelford (17) determined blanching percentages for Spanish peanut kernels dried at 71, 82, and 93°C. Initial moistures ranged from 6 to 10 percent wet base. Final moistures ranged from 4 to 7 percent wet base as shown in Table XXIII in Appendix E. In general, as the amount of moisture removed during drying increased, the blanching percentage increased. Blanching percentages were defined as 100 times the weight ratio of those kernels with skins completely removed by one pass through the blancher to the total weight of the peanuts blanched.

In the process of heating and drying prior to peanut blanching, the kernels undergo a continuous series of volume changes. First, heating would expand the kernel volume, and next drying would contract the volume. Upon cooling, the volume would further decrease. It was assumed that heating, drying, and cooling occur in three separate steps; though in actual practice, heat and mass transfer would occur simultaneously. Thus initial heating would be accompanied by some moisture loss; and some moisture would also be lost during cooling. In order to determine if blanching percentage was related to the changing kernel volume which occurred due to heating, drying, and cooling, the changes in volume were calculated using the equations for cubical thermal expansion and moisture contraction of whole kernels.

$$a_k = 52.19 \times 10^{-5} + 2.97 \times 10^{-5}(\text{Ln } M) \qquad [20]$$

$$a_m = 660.89 \times 10^{-5} - 1.23 \times 10^{-5}(M) \qquad [21]$$

Equation 20 was determined for 0.5 to 15.7 percent moisture content Spanish peanut kernels heated from 25 to 90°C. It was assumed that the equation could be extrapolated to 93°C and would also apply for cooling. Equation 21 was determined by a least squares regression on the data shown in Figure 16 for whole kernels dried at 40°C and 20 to 42 percent relative humidities. It was assumed that equation 21 could be applied to peanut kernels in Shackelford's (17) data which were dried at higher temperatures and lower relative humidities.

Sample calculations are shown in Table XXII in Appendix E for determining the change in kernel volume after heating, drying, and cooling of whole Spanish peanuts. A Statistical Analysis System computer program was used to perform all the coefficient calculations and to compute the final volume of a peanut kernel. The kernel was assumed to have an initial volume of 1.0 cm^3 at its initial moisture content and at 25°C. The calculated kernel volumes after heating, drying, and cooling are shown in Table XXIII in Appendix E along with heating temperatures, initial and final moistures, and the corresponding blanching percentages which were determined by Shackelford (17).

A plot of the final kernel volumes versus percent blanched is shown in Figure 17. A regression analysis was performed to determine if a predicted straight line would fit the data significantly better than a straight line through the mean of percents blanched. A t-test indicated the slope of the prediction line was significantly different than zero at the $\alpha = 0.05$ level. The prediction equation given in Figure 17 is not intended for use in predicting blanching percentages, but only to show that a significant correlation between percent blanched and final volume exists. Thus, Figure 17 indicates that blanching percentage increases as final kernel volume after heating, drying, and cooling decreases. There is one cluster of data points in Figure 17 for each level of difference between initial and final wet base moisture contents. For example, at a final kernel volume of 0.955 cm^3 a six percent wet base moisture difference between initial and final moistures occurred. At 0.992 cm^3 a moisture difference of only one percent existed. Thus, the difference between initial and final peanut moisture content greatly affected the final kernel volume. Figure 17 indicates that final kernel volume for peanuts heated to 93°C was only slightly smaller than that for kernels heated to 71°C. Moisture loss during drying apparently has a much greater effect on final kernel volume than heating temperature.

It should be noted that predicted peanut kernel volume changes due to heating from some initial temperature, T_i, to a final temperature,

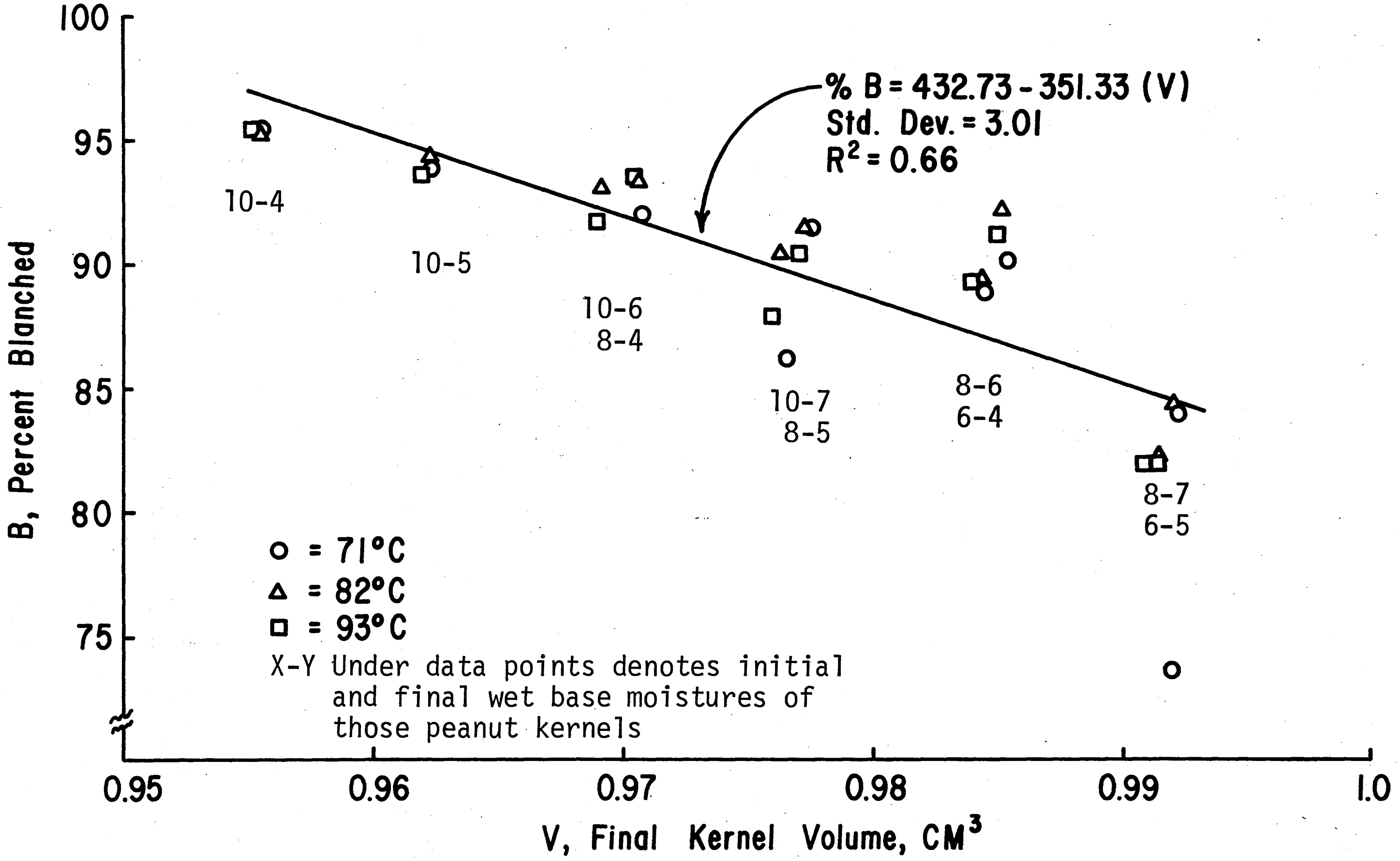


Figure 17. Plot of Percent Blanched Versus Final Peanut Kernel Volume After Heating, Drying, and Cooling (Assumes an Initial Volume of 1.0 cm^3 at 25°C and at Initial Kernel Moistures) (17)

T_f, were not equal to the predicted volume decrease which would occur due to cooling from T_f to T_i. Two factors are believed responsible for unequal volume changes: (1) heating and cooling are done at two different moisture contents; (2) the kernel volume which is multiplied by a_k varies continuously with heating, drying, and cooling.

Sample calculations in Table XXII in Appendix E predict volume changes for a peanut kernel heated from 25 to 82°C, dried from 8.7 to 4.2 percent moisture, and cooled from 82 to 25°C. Assuming an initial volume of 1.0 cm^3, the kernel increased by 0.0334 cm^3 due to heating. After drying, the kernel decreased by a smaller amount, 0.0323 cm^3, due to cooling. The volume reduction by cooling alone was less than the volume increase by heating because a_k decreased due to moisture loss during drying. Generally, if appreciable moisture is lost during heating and drying, then the volume increase due to heating will be greater than the volume reduction due to cooling to the original temperature.

The temperature to which peanuts are cooled affects the final kernel volume. Shackelford (17) determined that blanching percentages of Spanish peanuts (with standardized initial moistures of eight percent dried to a standardized final wet base moisture of five percent) increased as the cooling temperature decreased from 32 to 18°C. If the kernel referred to in Table XXII in Appendix E was cooled only to 32°C instead of 25°C, a_k for cooling would be equal to 0.02821. Multiplying 0.02821 by the volume after drying, 1.0030 cm^3, yields a volume reduction of 0.02829 cm^3. The new final volume would be 0.9747 cm^3. Figure 17 indicates that a blanching percentage of approximately 90 percent is obtained with a final volume of 0.9747 cm^3. For kernels cooled to 25°C with a final kernel volume of 0.9707 cm^3, a blanching percentage of approximately 92 percent would be attained. Thus, blanching percentage can be predicted to increase as peanuts are cooled to lower temperatures.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

The coefficients of cubical thermal expansion were experimentally determined for Spanish peanut kernels and for peanut skins over the temperature range of 25 to 90°C. The linear coefficients of moisture contraction during drying were determined for Spanish peanut cotyledons and whole kernels at 40°C. The cubical coefficients of moisture contraction were calculated from the linear coefficients. The combination of thermal expansion and moisture contraction cubical coefficients were used to predict kernel volume change during the heating, drying, and cooling phases which occur prior to peanut blanching. A correlation was found to exist between kernel volume change and peanut blanching percentages.

Conclusions

The coefficient of cubical thermal expansion is greater for Spanish peanut kernels than for skins at equivalent moisture contents. The coefficients were found to increase exponentially with an increase in moisture content. The following semi-logarithmic models were selected to adequately fit the data:

for kernels $a_k = 52.19 \times 10^{-5} + 2.97 \times 10^{-5}(\text{Ln } M)$

$$0.5\% \leq M \leq 15.7\%$$

for skins $a_s = 16.75 \times 10^{-5} + 11.37 \times 10^{-5}(\mathrm{Ln}\ M)$

$2.4\% \leq M \leq 29.0\%$

Relatively high oil contents in peanut kernels are believed to cause the coefficient of cubical thermal expansion for peanut kernels to be greater than that of shelled corn, rice, or peanut skins at approximately the same moisture contents.

Since peanut skins have a smaller coefficient of cubical thermal expansion than kernels, an increase in temperature should cause greater stresses in the skin than in the kernel.

The linear coefficients of moisture contraction varied considerably among kernels treated alike. No significant difference ($\alpha = 0.05$) in the linear coefficients was found between apical or basal kernel types. For the linear coefficients for length dimensions, a significant difference was found between the 42 and 70 percent relative humidities.

Cubical coefficients of moisture contraction were calculated by two different methods. In the first method the average of α_L and α_D was multiplied by three. Values of cubical coefficients for whole kernels were 613×10^{-5} and 865×10^{-5} cm^3/cm^3 % for the 20 to 42 percent and 70 to 80 percent relative humidity ranges, respectively. Cubical coefficients for cotyledons obtained in this manner were 698×10^{-5} and 1122×10^{-5} cm^3/cm^3 % for the 20 to 42 percent and the 70 to 80 percent relative humidities, respectively.

Cubical coefficients of moisture contraction calculated from the prolate spheroid assumption were approximately the same magnitude as those obtained by multiplying linear coefficients by three. For whole kernels dried at 40°C and 20 to 42 percent relative humidities, a_m varied from 660×10^{-5} to 550×10^{-5} cm^3/cm^3 % for moistures ranging from 1 to 90 percent. For the 70 to 80 percent relative humidity range, a_m varied with moisture from 771 x 10^{-5} to 625 x 10^{-5} cm^3/cm^3 %. Values of a_m for cotyledons were 889 x 10^{-5} to 685 x 10^{-5} cm^3/cm^3 % for the 20 to 42 percent relative humidities and 1080 x 10^{-5} to 825 x 10^{-5} cm^3/cm^3 % for the 70 to 80 percent relative humidities.

Cubical coefficients of moisture contraction for whole kernels were smaller than those of cotyledons. It is believed that exposed cotyledon edges, from which optical measurements were taken, contracted slightly more than at other locations in a whole kernel.

The magnitude of cubical thermal expansion compared to cubical moisture contraction is important. Peanut kernels were found to expand in the range of 50 x 10^{-5} to 60.5 x 10^{-5} cm^3/cm^3 °C. Cubical coefficients of moisture contraction for whole kernels varied greatly but were in the range of 550 x 10^{-5} to 865 x 10^{-5} cm^3/cm^3 % depending on moisture content, relative humidity, and method of coefficient computation. Thus, the volume of a whole peanut kernel can be predicted to decrease approximately ten times more for a one percent moisture reduction than for a one degree C temperature reduction.

Heating, drying, and cooling conditions used by Shackelford (17) to loosen peanut skins prior to blanching were simulated and the volume change of peanut kernel was calculated from the coefficients of thermal expansion and moisture contraction. Blanching percentages as determined by Shackelford (17) were found to increase as the peanut kernel volume decreased.

Recommendations for Future Research

The coefficient of moisture contraction for peanut skins needs to be determined. This knowledge could be used to further correlate blanching percentages with temperature and moisture conditions prior to blanching.

It would be useful to measure the coefficient of moisture contraction for whole peanuts dried at higher temperatures and lower relative humidities. Such conditions would be nearer to drying conditions presently used in dry blanching processes.

Experimental measurements of volume contraction for peanut kernels exposed to cryogenic temperatures would be helpful in studying and improving cryogenic blanching techniques. Such knowledge would greatly extend the temperature range of known coefficients of cubical thermal expansion for Spanish peanuts.

There are several other physical properties such as the modulus of elasticity, ultimate tensile stress, and Poisson's ratio which need to be determined for peanut kernels and if possible for skins. With knowledge of such properties, finite element techniques could be used to predict stresses on skins and kernels due to temperature and moisture gradients.

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APPENDIXES

APPENDIX A

SAMPLE CALCULATION OF THE COEFFICIENT OF CUBICAL THERMAL EXPANSION

APPENDIX A

SAMPLE CALCULATION OF THE COEFFICIENT OF CUBICAL THERMAL EXPANSION

Dilatometer 1, Heating 2, 0.5% Moisture Kernels

$A = 1.146\ \mathrm{mm}^2$

$\Delta x/\Delta t = 5.1451\ \mathrm{mm/°C}$

$L_s = 188\ \mathrm{mm}$

$V_p = 7785.2\ \mathrm{mm}^3$

$V_{mt} = 11533.3\ \mathrm{mm}^3$

$a_g = 1.0 \times 10^{-5}/°\mathrm{C}$

$a_h = 18.2 \times 10^{-5}/°\mathrm{C}$

$V_h = V_{mt} - L_s \times A = 11533.3\ \mathrm{mm}^3 - 188\ \mathrm{mm} \times 1.146\ \mathrm{mm}^2$

$V_h = 11317.8\ \mathrm{mm}^3$

$V_g = V_h + V_p = 11317.8\ \mathrm{mm}^3 + 7785.2\ \mathrm{mm}^3 = 19103.1\ \mathrm{mm}^3$

$a_x = \left[A\frac{\Delta x}{\Delta t} + a_g V_g - a_h V_h\right] / V_p$

$$a_x = \Big[(1.146\ \mathrm{mm}^2)(5.1451\ \mathrm{mm/°C}) + (1.0 \times 10^{-5}/°\mathrm{C})(19103.1\ \mathrm{mm}^3) - (18.2 \times 10^{-5}/°\mathrm{C})(11317.8\ \mathrm{mm}^3)\Big] / 7785.2\ \mathrm{mm}^3$$

$a_x = 51.732 \times 10^{-5}/°\mathrm{C}$

APPENDIX B

ANALYSES OF VARIANCE

TABLE VI

ANALYSIS OF VARIANCE FOR THE EFFECT OF MOISTURE ON THE THERMAL EXPANSION COEFFICIENT

Kernels

Source	df	SS	MS	F
TOTAL	17	247.216		
Dilatometers	2	3.822	1.911	1.07
Moistures	5	225.646	45.129	25.43**
Error (Dil x M)	10	17.748	1.775	

Skins

Source	df	SS	MS	F
TOTAL	14	1865.728		
Dilatometers	2	0.506	0.253	0.007
Moistures	4	1567.022	391.755	10.510**
Error (Dil x M)	8	298.200	37.275	

** Indicates statistical significance at $\alpha = 0.01$

TABLE VII

ANALYSIS OF VARIANCE FOR THE MODEL $a_X = \beta_0 + \beta_1(M)$

Kernels

Source	df	SS	MS	F
TOTAL	17	247.216		
Regression	1	176.602	176.602	40.015**
Error	16	70.614	4.413	
Lack of Fit	4	49.044	24.522	13.646[1.]
Pure Error	12	21.570	1.797	

1. An F value greater than $F_{4,12}$ (0.05) of 3.36 indicated that unless a 1 in 20 chance of sampling error occurred there was sufficient evidence to reject the linear model due to lack of fit.

Skins

Source	df	SS	MS	F
TOTAL	14	1865.728		
Regression	1	1220.617	1220.617	24.597**
Error	13	645.111	49.624	
Lack of Fit	3	346.406	115.468	3.865[2.]
Pure Error	10	298.705	29.871	

2. An F value greater than $F_{3,10}$ (0.05) of 3.71 indicated that unless a 1 in 20 chance of sampling error occurred there was sufficient evidence to reject the linear model due to lack of fit.

**Indicates significance at $\alpha = 0.01$

TABLE VIII

ANALYSIS OF VARIANCE FOR THE MODEL $a_x = \beta_0 + \beta_1(M) + \beta_2(M)^2$

Kernels

Source	df	SS	MS	F
TOTAL	17	247.216		
Regression	2	209.371	104.685	41.493**
Error	15	37.845	2.523	
Lack of Fit	3	16.275	5.425	3.019[1]
Pure Error	12	21.570	1.797	

1. An F value smaller than $F_{3,12}$ (0.05) of 3.49 indicated that unless a 1 in 20 chance of sampling error occurred there was not sufficient evidence to reject the quadratic model due to lack of fit.

Skins

Source	df	SS	MS	F
TOTAL	14	1865.728		
Regression	2	1465.369	732.685	21.971**
Error	12	400.359	33.363	
Lack of Fit	2	101.654	50.827	1.702[2]
Pure Error	10	298.705	29.871	

2. An F value smaller than $F_{2,10}$ (0.05) of 4.10 indicated that unless a 1 in 20 chance of sampling error occurred there was not sufficient evidence to reject the quadratic model due to lack of fit.

**Indicates significance at $\alpha = 0.01$

TABLE IX

ANALYSIS OF VARIANCE FOR THE MODEL $a_x = \beta_0 + \beta_1(M) + \beta_2(M)^2 + \beta_3(M)^3$

Kernels

Source	df	SS	MS	F
TOTAL	17	247.216		
Regression	3	219.160	73.053	73.053**
Error	14	28.056	2.004	
Lack of Fit	2	6.486	3.243	1.805[1.]
Pure Error	12	21.570	1.797	

1. An F value smaller than $F_{2,12}$ (0.05) of 3.85 indicated that unless a 1 in 20 chance of sampling error occurred there was not sufficient evidence to reject the cubic model due to lack of fit.

Skins

Source	df	SS	MS	F
TOTAL	14	1865.728		
Regression	3	1470.036	490.012	13.622**
Error	11	395.692	35.972	
Lack of Fit	1	96.987	96.987	3.247[2.]
Pure Error	10	298.705	29.871	

2. An F value smaller than $F_{1,10}$ (0.05) of 4.76 indicated that unless a 1 in 20 chance of sampling error occurred there was not sufficient evidence to reject the cubic model due to lack of fit.

**Indicates significance at $\alpha = 0.01$

TABLE X

ANALYSIS OF VARIANCE FOR THE MODEL
$a_x = \beta_0 + \beta_1(\text{Ln } M)$

Kernels

Source	df	SS	MS	F
TOTAL	17	247.216		
Regression	1	214.859	214.859	106.244**
Error	16	32.357	2.022	
Lack of Fit	4	10.787	2.697	1.501[1]
Pure Error	12	21.570	1.797	

1. An F value smaller than $F_{4,12}$ (0.05) of 3.26 indicated that unless a 1 in 20 chance of sampling error occurred there was not sufficient evidence to reject the semi-logarithmic model due to lack of fit.

Skins

Source	df	SS	MS	F
TOTAL	14	1865.728		
Regression	1	1475.433	1475.433	49.144**
Error	13	390.295	30.023	
Lack of Fit	3	91.590	30.530	1.022[2]
Pure Error	10	298.705	29.871	

2. An F value smaller than $F_{3,10}$ (0.05) of 3.71 indicated that unless a 1 in 20 chance of sampling error occurred there was not sufficient evidence to reject the semi-logarithmic model due to lack of fit.

** Indicates significance at $\alpha = 0.01$

TABLE XI

ANALYSIS OF VARIANCE FOR THE MODEL $\text{Ln } a_x = \beta_0 + \beta_1(M)$

Kernels

Source	df	SS	MS	F
TOTAL	17	0.080159		
Regression	1	0.056886	0.056886	39.108**
Error	16	0.023273	0.001454	
Lack of Fit	4	0.016921	0.004230	7.997[1.]
Pure Error	12	0.006352	0.000529	

1. An F value larger than $F_{4,12}$ (0.05) of 3.26 indicated that unless a 1 in 20 chance of sampling error occurred there was sufficient evidence to reject the semi-logarithmic model due to lack of fit.

Skins

Source	df	SS	MS	F
TOTAL	14	1.217674		
Regression	1	0.787367	0.787367	23.787**
Error	13	0.430307	0.033100	
Lack of Fit	3	0.289460	0.096486	6.850[2.]
Pure Error	10	0.140847	0.014085	

2. An F value larger than $F_{3,10}$ (0.05) of 3.71 indicated that unless a 1 in 20 chance of sampling error occurred there was sufficient evidence to reject the semi-logarithmic model due to lack of fit.

**Indicates significance at $\alpha = 0.01$

TABLE XII

ANALYSIS OF VARIANCE FOR THE MODEL
$\text{Ln } a_x = \beta_0 + \beta_1(\text{Ln } M)$

Kernels

Source	df	SS	MS	F
TOTAL	17	0.080159	-	
Regression	1	0.070812	0.070812	121.216**
Error	16	0.009347	0.000584	
Lack of Fit	4	0.002995	0.000748	1.415[1]
Pure Error	12	0.006352	0.000529	

1. An F value smaller than $F_{4,12}$ (0.05) of 3.26 indicated that unless a 1 in 20 chance of sampling error occurred there was not sufficient evidence to reject the log-log model due to lack of fit.

Skins

Source	df	SS	MS	F
TOTAL	14	1.217674		
Regression	1	1.017081	1.017081	65.915**
Error	13	0.200593	0.015430	
Lack of Fit	3	0.059746	0.019915	1.414[2]
Pure Error	10	0.140847	0.014085	

2. An F value smaller than $F_{3,10}$ (0.05) of 3.71 indicated that unless a 1 in 20 chance of sampling error occurred there was not sufficient evidence to reject the log-log model due to lack of fit.

**Indicates significance at $\alpha = 0.01$

TABLE XIII

ANALYSIS OF VARIANCE FOR EFFECT OF RELATIVE HUMIDITY AND TYPE (APICAL OR BASAL) ON α_L FOR WHOLE KERNELS

Source	df	SS	MS	F
TOTAL	47	2684.134		
Rep	1	5.224	5.224	
Hum	3	1577.366	525.788	11.422*
Error A (Rep x Hum)	3	138.102	46.034	
Type	1	21.871	21.871	0.495
Error B (Rep x Type)	1	44.220	44.220	
Hum x Type	3	44.428	14.809	13.259*
Error C (Rep x Hum x Type)	3	3.350	1.117	
Residual (Trip (Rep Hum Type))	32	849.572	26.549	

* Indicates significance at $\alpha = 0.05$

TABLE XIV

ANALYSIS OF VARIANCE FOR EFFECT OF RELATIVE HUMIDITY AND TYPE (APICAL OR BASAL) ON α_D FOR WHOLE KERNELS

Source	df	SS	MS	F
TOTAL	47	1684.042		
Rep	1	1.043	1.043	
Hum	3	420.575	140.192	2.544
Error A (Rep x Hum)	3	165.288	55.096	
Type	1	0.180	0.180	0.001
Error B (Rep x Type)	1	167.968	167.968	
Hum x Type	3	127.740	127.740	0.014
Error C (Rep x Hum x Type)	3	39.261	39.261	
Residual (Trip (Rep Hum Type))	32	761.986	23.812	

TABLE XV

ANALYSIS OF VARIANCE FOR EFFECT OF RELATIVE HUMIDITY AND TYPE (APICAL OR BASAL) ON α_L FOR COTYLEDONS

Source	df	SS	MS	F
TOTAL	47	6115.809		
Rep	1	1.879	1.879	
Hum	3	4695.533	1565.177	85.341**
Error A (Rep x Hum)	3	55.021	18.340	
Type	1	98.758	98.758	7.354
Error B (Rep x Type)	1	13.428	13.428	
Hum x Type	3	153.798	51.266	1.302
Error C (Rep x Hum x Type)	3	118.140	39.380	
Residual (Trip (Rep Hum Type))	32	979.251	30.602	

**Indicates significance at $\alpha = 0.01$

TABLE XVI

ANALYSIS OF VARIANCE FOR EFFECT OF RELATIVE HUMIDITY AND TYPE (APICAL OR BASAL) ON α_D FOR COTYLEDONS

Source	df	SS	MS	F
TOTAL	47	5922.288		
Rep	1	539.105	539.105	
Hum	3	1824.995	608.332	2.074
Error A (Rep x Hum)	3	879.833	293.277	
Type	1	125.518	125.518	5.954
Error B (Rep x Type)	1	21.079	21.079	
Type x Hum	3	99.112	33.037	0.171
Error C (Rep x Hum x Type)	3	578.383	192.794	
Residual (Trip (Rep Hum Type))	32	1854.261	57.945	

TABLE XVII

ANALYSIS OF VARIANCE FOR BLANCHING PERCENT AS A LINEAR FUNCTION OF FINAL KERNEL VOLUME

Source	df	SS	MS	F
TOTAL	29	745.548		
Regression	1	492.107	492.107	54.367**
Error	28	253.441	9.051	

**Indicates significance at $\alpha = 0.01$

Calculated t-test values for the regression coefficients of the predicted model, B = 432.732 - 351.327 (V), indicated that both regression coefficients were significantly different than zero at the $\alpha = 0.01$ level.

APPENDIX C

COMPUTER PROGRAM AND THERMAL EXPANSION DATA

TABLE XVIII

COMPUTER PROGRAM AND DATA USED TO CALCULATE COEFFICIENTS OF CUBICAL THERMAL EXPANSION

```
C      CUBICAL COEFF OF THERMAL EXPANSION OF PEANUTS KERNELS OR SKINS
C      READ VARS AS  A MM2,DXDT MM/C,STEML MM, VP MM3, VMERC MM3
C      TYPE:  1=KERNELS  2=SKINS  3=MERCURY  4=PYREX
       REAL MOIST
       KK=1
       WRITE (6,20)
 10    FORMAT(2F10.6,3F10.3,I2,2I1,F5.1)
 20    FORMAT(1H0,'  TYPE  MOIST %DB  DIL  HEATING  ',2X,'COL AREA MM2',
      1 2X,'DX/DT MM/C  STEM LEN MM   VOL PNT MM3   VOL MERC MM3',3X,
      2 1X,'ALPHA /C')
 21    FORMAT(1H1,'  TYPE  MOIST %DB  DIL  HEATING  ',2X,'COL AREA MM2',
      1 2X,'DX/DT MM/C  STEM LEN MM   VOL PNT MM3   VOL MERC MM3',3X,
      2 1X,'ALPHA /C')
 30    FORMAT(1H ,4X,I1,6X,F4.1,6X,I1,6X,I1,9X,F5.3,9X,F6.4,7X,F5.0,
      1 7X,F7.1,9X,F7.1,1X,2PE14.3)
  1    READ(5,10)A,DXDT,STEML,VP,VMERC,ITYPE,IDIL,IHEAT,MOIST
       IF(A .EQ. 0.0) GO TO 40
       IF(KK .EQ. 19 .OR. KK .EQ. 73) WRITE (6,21)
       AG=0.000010
       AM=0.000182
       VSTEM=A*STEML
       VO=VMERC-VSTEM+VP
       AP=(A*DXDT-(VO-VP)*AM + AG*VO)/VP
       DBMST=(MOIST*100.)/(100.-MOIST)
       WRITE(6,30)ITYPE,DBMST,IDIL,IHEAT,A,DXDT,STEML,VP,VMERC,AP
       KK=KK+1
       GO TO 1
 40    CONTINUE
       STOP
       END
```

TABLE XVIII (Continued)

TYPE	MOIST %DB	DIL	HEATING	COL AREA MM2	DX/DT MM/C	STEM LEN MM	VOL PNT MM3	VOL MERC MM3	ALPHA /C
1	0.5	1	1	1.146	5.1517	190.	7785.2	11533.3	51.835E-05
1	0.5	1	2	1.146	5.1451	188.	7785.2	11533.3	51.732E-05
1	0.5	1	3	1.146	5.1191	186.	7785.2	11533.3	51.345E-05
1	0.5	2	1	1.154	4.9469	193.	7660.7	11989.1	49.101E-05
1	0.5	2	2	1.154	4.9669	191.	7660.7	11989.1	49.397E-05
1	0.5	2	3	1.154	4.9541	189.	7660.7	11989.1	49.199E-05
1	0.5	3	1	1.262	4.4573	193.	7617.2	11215.3	50.073E-05
1	0.5	3	2	1.262	4.4515	193.	7617.2	11215.3	49.977E-05
1	0.5	3	3	1.262	4.4373	193.	7617.2	11215.3	49.741E-05
1	4.2	1	1	1.146	5.4041	190.	8273.5	11238.1	52.944E-05
1	4.2	1	2	1.146	5.6769	170.	8273.5	11238.1	56.675E-05
1	4.2	1	3	1.146	5.6538	167.	8273.5	11238.1	56.348E-05
1	4.2	2	1	1.154	5.2856	191.	7816.3	11676.2	53.828E-05
1	4.2	2	2	1.154	5.4938	173.	7816.3	11676.2	56.856E-05
1	4.2	2	3	1.154	5.4745	171.	7816.3	11676.2	56.566E-05
1	4.2	3	1	1.262	4.7932	192.	8498.5	10486.9	51.444E-05
1	4.2	3	2	1.262	5.0135	173.	8498.5	10486.9	54.666E-05
1	4.2	3	3	1.262	4.9948	172.	8498.5	10486.9	54.386E-05
1	6.7	1	1	1.146	4.9829	201.	7725.4	11792.9	49.174E-05
1	6.7	1	2	1.146	5.5423	199.	7725.4	11792.9	57.467E-05
1	6.7	1	3	1.146	5.7469	176.	7725.4	11792.9	60.444E-05
1	6.7	2	1	1.154	4.9829	202.	7950.2	11587.5	48.764E-05
1	6.7	2	2	1.154	5.5172	180.	7950.2	11587.5	56.464E-05
1	6.7	2	3	1.154	5.7268	149.	7950.2	11587.5	59.429E-05
1	6.7	3	1	1.262	4.6664	202.	8525.8	10387.6	49.631E-05
1	6.7	3	2	1.262	5.1167	206.	8525.8	10387.6	56.306E-05
1	6.7	3	3	1.262	5.3072	177.	8525.8	10387.6	59.052E-05
1	10.0	1	1	1.146	4.7381	188.	8678.2	11119.8	41.957E-05
1	10.0	1	2	1.146	6.0218	107.	8678.2	11119.8	58.725E-05
1	10.0	1	3	1.146	6.0385	107.	8678.2	11119.8	58.945E-05
1	10.0	2	1	1.154	4.8703	190.	8607.9	11311.1	44.129E-05
1	10.0	2	2	1.154	5.9385	123.	8607.9	11311.1	58.295E-05
1	10.0	2	3	1.154	5.9351	123.	8607.9	11311.1	58.250E-05
1	10.0	3	1	1.262	4.1018	190.	8194.4	10493.2	42.649E-05
1	10.0	3	2	1.262	5.3875	113.	8194.4	10493.2	62.246E-05
1	10.0	3	3	1.262	5.3769	112.	8194.4	10493.2	62.080E-05
1	13.5	1	1	1.146	5.2253	167.	8551.2	11153.1	48.979E-05
1	13.5	1	2	1.146	5.9671	121.	8551.2	11153.1	58.814E-05
1	13.5	1	3	1.146	5.9521	121.	8551.2	11153.1	58.613E-05
1	13.5	2	1	1.154	5.0188	165.	8696.3	11063.4	46.094E-05
1	13.5	2	2	1.154	6.0039	105.	8696.3	11063.4	59.030E-05
1	13.5	2	3	1.154	5.9715	107.	8696.3	11063.4	58.604E-05
1	13.5	3	1	1.262	4.6878	160.	9091.8	10125.2	47.297E-05
1	13.5	3	2	1.262	5.4673	112.	9091.8	10125.2	58.002E-05
1	13.5	3	3	1.262	5.4612	111.	9091.8	10125.2	57.915E-05
1	15.7	1	1	1.146	5.7737	167.	8702.6	10638.2	56.382E-05
1	15.7	1	2	1.146	6.2796	131.	8702.6	10638.2	62.964E-05
1	15.7	1	3	1.146	6.3030	130.	8702.6	10638.2	63.270E-05
1	15.7	2	1	1.154	5.5790	170.	8898.4	10695.5	53.056E-05
1	15.7	2	2	1.154	6.1408	130.	8898.4	10695.5	60.254E-05
1	15.7	2	3	1.154	6.1749	130.	8898.4	10695.5	60.696E-05
1	15.7	3	1	1.262	4.7220	172.	8523.6	10453.8	50.255E-05
1	15.7	3	2	1.262	5.3779	129.	8523.6	10453.8	59.858E-05
1	15.7	3	3	1.262	5.3911	129.	8523.6	10453.8	60.054E-05

TABLE XVIII (Continued)

TYPE	MOIST %DB	DIL	HEATING	COL AREA MM2	DX/DT MM/C	STEM LEN MM	VOL PNT MM3	VOL MERC MM3	ALPHA /C
2	2.4	1	1	1.146	2.7552	198.	554.4	18656.7	-12.484E-06
2	2.4	1	2	1.146	2.9076	189.	554.4	18656.7	29.934E-05
2	2.4	1	3	1.146	2.9034	190.	554.4	18656.7	29.102E-05
2	2.4	2	1	1.154	2.7205	198.	623.5	18614.5	-26.788E-06
2	2.4	2	2	1.154	2.8592	188.	623.5	18614.5	22.674E-05
2	2.4	2	3	1.154	2.8624	188.	623.5	18614.5	23.266E-05
2	2.4	3	1	1.262	2.4002	199.	619.7	17890.9	19.517E-07
2	2.4	3	2	1.262	2.5242	191.	619.7	17890.9	25.167E-05
2	2.4	3	3	1.262	2.5210	191.	619.7	17890.9	24.515E-05
2	7.6	1	1	1.146	2.5847	195.	738.4	18270.6	-18.236E-05
2	7.6	1	2	1.146	2.9473	170.	738.4	18270.6	37.372E-05
2	7.6	1	3	1.146	2.9418	166.	738.4	18270.6	36.412E-05
2	7.6	2	1	1.154	2.5449	193.	501.9	18342.3	-34.814E-05
2	7.6	2	2	1.154	2.9110	168.	501.9	18342.3	48.373E-05
2	7.6	2	3	1.154	2.9084	168.	501.9	18342.3	47.775E-05
2	7.6	3	1	1.262	2.2032	197.	708.6	17487.9	-25.068E-05
2	7.6	3	2	1.262	2.5707	171.	708.6	17487.9	39.586E-05
2	7.6	3	3	1.262	2.5749	170.	708.6	17487.9	40.303E-05
2	14.3	1	1	1.146	1.6533	200.	1899.9	16552.4	-47.050E-05
2	14.3	1	2	1.146	3.1782	114.	1899.9	16552.4	44.038E-05
2	14.3	1	3	1.146	3.2602	113.	1899.9	16552.4	48.974E-05
2	14.3	2	1	1.154	1.5915	198.	1806.7	16726.8	-54.411E-05
2	14.3	2	2	1.154	3.1149	107.	1806.7	16726.8	41.893E-05
2	14.3	2	3	1.154	3.1893	104.	1806.7	16726.8	46.613E-05
2	14.3	3	1	1.262	1.5094	198.	1890.9	16411.5	-45.271E-05
2	14.3	3	2	1.262	2.7924	123.	1890.9	16411.5	39.496E-05
2	14.3	3	3	1.262	2.8368	120.	1890.9	16411.5	42.425E-05
2	18.8	1	1	1.146	2.1514	185.	814.5	18415.6	-80.708E-05
2	18.8	1	2	1.146	3.0653	134.	814.5	18415.6	46.643E-05
2	18.8	1	3	1.146	3.0793	129.	814.5	18415.6	48.492E-05
2	18.8	2	1	1.154	1.9672	189.	964.8	18293.2	-85.937E-05
2	18.8	2	2	1.154	3.0832	117.	964.8	18293.2	46.067E-05
2	18.8	2	3	1.154	3.1461	111.	964.8	18293.2	53.467E-05
2	18.8	3	1	1.262	1.6334	187.	953.3	17251.1	-89.763E-05
2	18.8	3	2	1.262	2.7951	122.	953.3	17251.1	62.545E-05
2	18.8	3	3	1.262	2.8229	119.	953.3	17251.1	66.157E-05
2	29.0	1	1	1.146	3.2508	76.	1312.3	17877.3	51.743E-05
2	29.0	1	2	1.146	3.2772	83.	1312.3	17877.3	54.123E-05
2	29.0	1	3	1.146	3.3425	86.	1312.3	17877.3	59.871E-05
2	29.0	2	1	1.154	3.2948	55.	1617.4	17762.2	47.866E-05
2	29.0	2	2	1.154	3.3351	61.	1617.4	17762.2	50.815E-05
2	29.0	2	3	1.154	3.4065	65.	1617.4	17762.2	55.959E-05
2	29.0	3	1	1.262	2.7107	198.	2000.2	16579.2	31.610E-05
2	29.0	3	2	1.262	2.9773	180.	2000.2	16579.2	48.235E-05
2	29.0	3	3	1.262	3.0215	179.	2000.2	16579.2	51.013E-05

TABLE XVIII (Continued)

TYPE	MOIST %DB	DIL	HEATING	COL AREA MM2	DX/DT MM/C	STEM LEN MM	VOL PNT MM3	VOL MERC MM3	ALPHA /C
3	0.0	1	1	1.146	2.9577	199.	8000.0	11596.9	18.926E-05
3	0.0	1	2	1.146	2.9425	199.	8000.0	11596.9	18.708E-05
3	0.0	1	3	1.146	2.9577	201.	8000.0	11596.9	18.931E-05
3	0.0	2	1	1.154	2.9217	198.	8000.0	11668.4	18.550E-05
3	0.0	2	2	1.154	2.9292	196.	8000.0	11668.4	18.653E-05
3	0.0	2	3	1.154	2.9363	197.	8000.0	11668.4	18.758E-05
3	0.0	3	1	1.262	2.5082	198.	8000.0	10997.1	17.460E-05
3	0.0	3	2	1.262	2.5618	198.	8000.0	10997.1	18.306E-05
3	0.0	3	3	1.262	2.5881	198.	8000.0	10997.1	18.721E-05
4	0.0	1	1	1.146	1.7473	198.	8092.4	11771.6	12.066E-06
4	0.0	1	2	1.146	1.7623	199.	8092.4	11771.6	14.214E-06
4	0.0	1	3	1.146	1.7617	199.	8092.4	11771.6	14.130E-06
4	0.0	2	1	1.154	1.7305	198.	7995.5	11781.3	11.240E-06
4	0.0	2	2	1.154	1.7542	198.	7995.5	11781.3	14.661E-06
4	0.0	2	3	1.154	1.7539	198.	7995.5	11781.3	14.617E-06
4	0.0	3	1	1.262	1.5069	199.	8111.1	11086.6	14.686E-06
4	0.0	3	2	1.262	1.5255	198.	8111.1	11086.6	17.553E-06
4	0.0	3	2	1.262	1.5268	198.	8111.1	11086.6	17.755E-06

APPENDIX D

MOISTURE CONTRACTION DATA

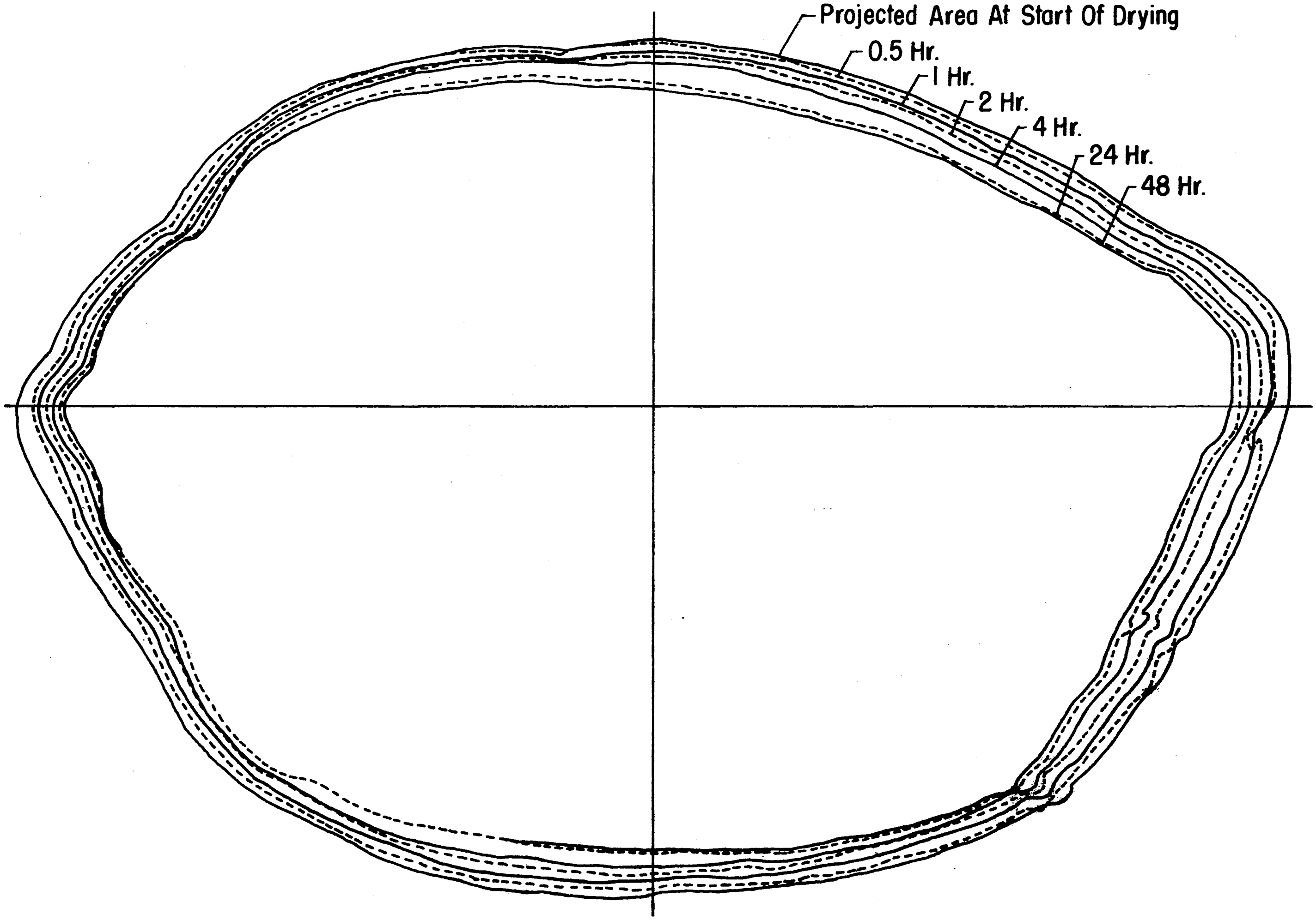

Figure 18. Moisture Contraction of a Typical Whole Peanut Kernel Dried at 40°C and 42 Percent Relative Humidity for Consecutive Drying Intervals of 0, 0.5, 1, 2, 4, 24, and 48 Hours

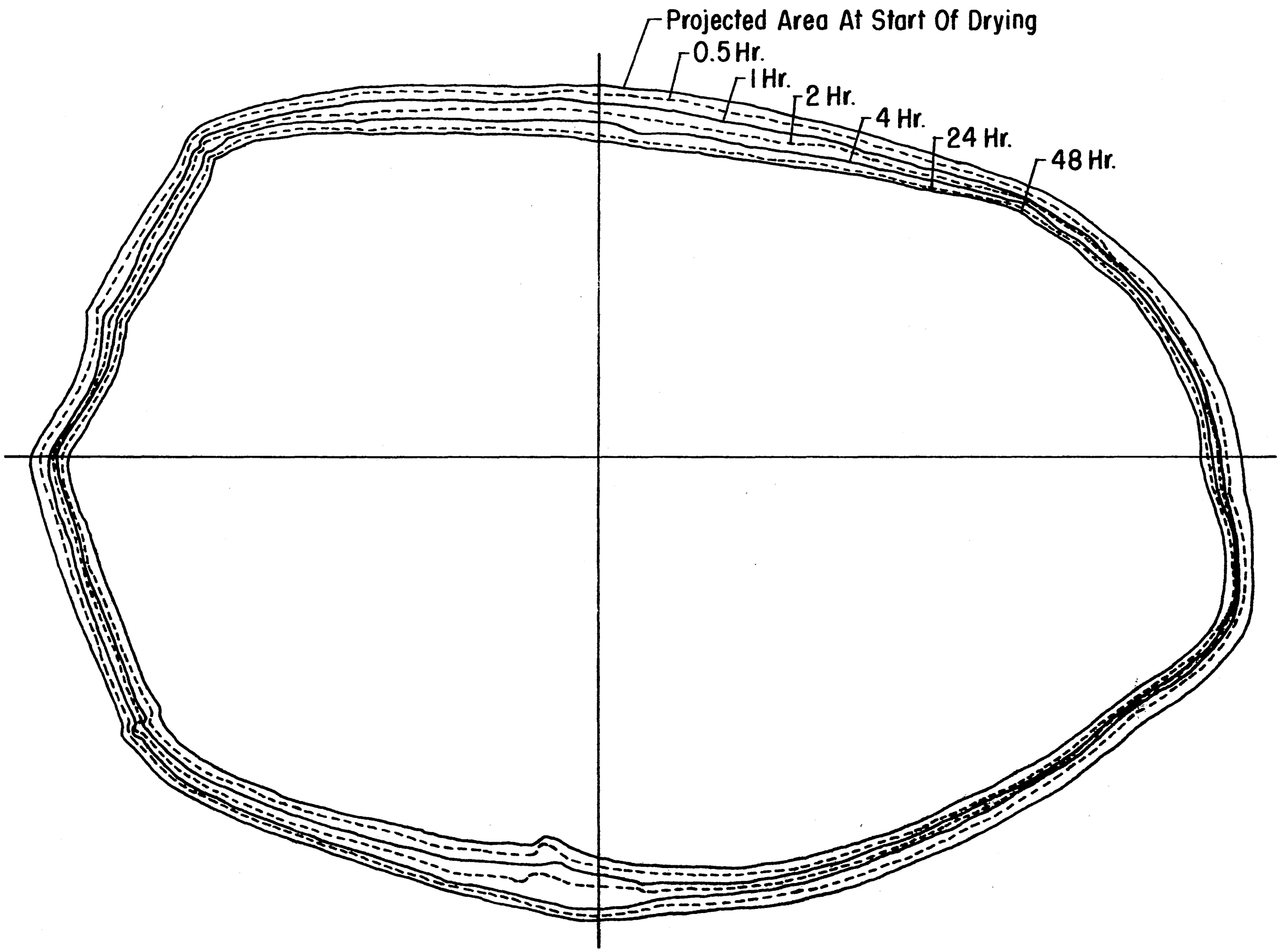

Figure 19. Moisture Contraction of a Typical Cotyledon Dried at 40°C and 42 Percent Relative Humidity for Consecutive Drying Intervals of 0, 0.5, 1, 2, 4, 24, and 48 Hours

TABLE XIX

DATA FOR SPANISH PEANUT KERNEL WHOLES

OBS	TYPE	RUN	HUM	IMOIST	LENGTH	LSLOPE	ALPHAL	DIAM	DSLOPE	ALPHAD	ALPHA3
1	A	1	20	39.46	1.1525	.002255	.00195662	.8875	.001855	.00209014	.0060701
2	A	2	20	36.47	1.1500	.002185	.00190000	.8325	.001265	.00151952	.0051293
3	A	3	20	35.56	1.1275	.002320	.00205765	.7675	.001655	.00215635	.0063210
4	A	4	20	34.63	0.9925	.002395	.00241310	.8175	.001990	.00243425	.0072710
5	A	5	20	46.58	1.1450	.002170	.00189520	.8200	.000925	.00112805	.0045349
6	A	6	20	38.13	1.0150	.002285	.00225123	.8250	.001430	.00173333	.0059768
7	B	1	20	35.71	0.9925	.002655	.00267506	.8050	.001610	.00200000	.0070126
8	B	2	20	40.32	1.0775	.001155	.00107193	.7400	.003040	.00410811	.0077701
9	B	3	20	37.14	0.9575	.002465	.00257441	.7900	.001945	.00246203	.0075547
10	B	4	20	35.82	1.0400	.001655	.00159135	.7700	.001580	.00205195	.0054649
11	B	5	20	37.95	0.9050	.001740	.00192265	.8300	.001275	.00153614	.0051882
12	B	6	20	39.96	1.0150	.001950	.00192118	.8475	.001520	.00179351	.0055720
13	A	1	42	28.41	1.1725	.002500	.00213220	.8075	.002045	.00253251	.0069971
14	A	2	42	42.69	1.1275	.001800	.00159645	.7825	.001295	.00165495	.0048771
15	A	3	42	38.74	1.2375	.002090	.00168889	.8225	.001205	.00146505	.0047309
16	A	4	42	51.85	1.2200	.002045	.00167623	.7975	.001865	.00233856	.0060222
17	A	5	42	48.22	0.9800	.002370	.00241837	.8150	.001910	.00234356	.0071429
18	A	6	42	51.93	1.1750	.002740	.00233191	.7500	.001965	.00262000	.0074279
19	B	1	42	37.28	1.0275	.002325	.00226277	.8750	.001540	.00176000	.0060342
20	B	2	42	35.86	1.0700	.001890	.00176636	.8525	.001670	.00195894	.0055879
21	B	3	42	43.59	0.8575	.002220	.00258892	.8625	.001315	.00152464	.0061703
22	B	4	42	51.67	0.9650	.002205	.00228497	.8125	.001720	.00211692	.0066028
23	B	5	42	49.29	0.9400	.002390	.00254255	.9000	.001695	.00188333	.0066388
24	B	6	42	46.53	1.0450	.002115	.00202392	.8600	.001205	.00140116	.0051376
25	A	1	70	32.63	1.1750	.003995	.00340000	.9050	.001460	.00161326	.0075199
26	A	2	70	35.27	1.0500	.002205	.00210000	.8450	.001470	.00173964	.0057595
27	A	3	70	35.08	1.1350	.004250	.00374449	.8275	.002075	.00250755	.0093781
28	A	4	70	50.97	0.8750	.002850	.00325714	.8275	.002620	.00316616	.0096350
29	A	5	70	57.85	1.1075	.002655	.00239729	.7400	.002040	.00275676	.0077311
30	A	6	70	45.17	1.1825	.002840	.00240169	.8325	.002105	.00252853	.0073953
31	B	1	70	38.67	1.0250	.003710	.00361951	.8725	.001800	.00206304	.0085238
32	B	2	70	37.15	1.0525	.003255	.00309264	.8950	.003255	.00363687	.0100943
33	B	3	70	34.41	0.8725	.003770	.00432092	.8875	.001980	.00223099	.0098279
34	B	4	70	55.79	1.0075	.002055	.00203970	.8875	.002105	.00237183	.0066173
35	B	5	70	48.90	1.0375	.002840	.00273735	.8875	.002045	.00230423	.0075624
36	B	6	70	55.43	0.9425	.003465	.00367639	.8800	.001820	.00206818	.0086169
37	A	1	80	44.33	0.9925	.002915	.00293703	.7475	.002065	.00276254	.0085494
38	A	2	80	40.01	0.9800	.003750	.00382653	.8650	.002240	.00258960	.0096242
39	A	3	80	42.99	1.1825	.003130	.00264693	.8025	.002080	.00259190	.0078583
40	A	4	80	50.75	1.1450	.003765	.00328821	.7975	.002430	.00304702	.0095028
41	A	5	80	47.01	1.0525	.003785	.00359620	.7850	.002385	.00303822	.0099516
42	A	6	80	54.39	1.1450	.004090	.00357205	.9175	.002690	.00293188	.0097559
43	B	1	80	39.51	0.7750	.002180	.00281290	.6875	.002035	.00296000	.0086594
44	B	2	80	45.33	0.8250	.003250	.00393939	.8850	.001850	.00209040	.0090447
45	B	3	80	46.15	0.9700	.003090	.00318557	.8175	.002265	.00277064	.0089343
46	B	4	80	52.18	0.9150	.003165	.00345902	.7850	.001780	.00226752	.0085898
47	B	5	80	44.62	0.8850	.002735	.00309040	.7900	.002220	.00281013	.0088508
48	B	6	80	46.86	0.9275	.003270	.00352561	.8425	.002380	.00282493	.0095258

TABLE XX

DATA FOR SPANISH PEANUT COTYLEDONS

OBS	TYPE	RUN	HUM	IMOIST	LENGTH	LSLOPE	ALPHAL	DIAM	DSLOPE	ALPHAD	ALPHA3
1	A	1	20	38.84	1.0350	.001315	.00127053	.7875	.001195	.00151746	.0041820
2	A	2	20	35.52	1.1400	.000795	.00069737	.7550	.000975	.00129139	.0029831
3	A	3	20	35.85	1.1300	.000510	.00045133	.7600	.000850	.00111842	.0023546
4	A	4	20	75.57	1.0650	.001900	.00178404	.5900	.002430	.00411864	.0088540
5	A	5	20	107.80	0.9300	.000665	.00071505	.4700	.002150	.00457447	.0079343
6	A	6	20	106.97	1.0475	.000290	.00027685	.4585	.002255	.00491821	.0077926
7	B	1	20	42.73	0.8900	.001875	.00210674	.7925	.001575	.00198738	.0061412
8	B	2	20	39.41	1.0425	.001180	.00113189	.7200	.001885	.00261806	.0056249
9	B	3	20	39.44	1.0850	.001340	.00123502	.6850	.001825	.00266423	.0058489
10	B	4	20	69.25	0.9600	.001185	.00123437	.5975	.002000	.00334728	.0068725
11	B	5	20	68.85	0.9625	.000575	.00059740	.5800	.002445	.00421552	.0072194
12	B	6	20	63.91	1.0575	.001010	.00095508	.6635	.001750	.00263753	.0053889
13	A	1	42	39.25	1.0140	.001720	.00169625	.7200	.002060	.00286111	.0068360
14	A	2	42	39.28	1.1440	.001150	.00100524	.6900	.002435	.00352899	.0068013
15	A	3	42	93.77	1.0940	.000640	.00058501	.4750	.002750	.00578947	.0095617
16	A	4	42	47.32	1.2025	.002030	.00168815	.6430	.003220	.00500776	.0100439
17	A	5	42	45.02	1.1700	.001745	.00149145	.7400	.003015	.00407432	.0083487
18	A	6	42	46.89	1.3055	.001425	.00109154	.7205	.002705	.00375434	.0072688
19	B	1	42	40.51	0.7425	.001855	.00249832	.6685	.002240	.00335079	.0087737
20	B	2	42	65.44	1.0235	.000465	.00045432	.5775	.002395	.00414719	.0069023
21	B	3	42	38.82	1.0735	.000660	.00061481	.6810	.003250	.00477239	.0080808
22	B	4	42	55.51	1.1150	.000945	.00084753	.6700	.002420	.00361194	.0066892
23	B	5	42	50.13	1.0375	.001485	.00143133	.6675	.002895	.00433708	.0086526
24	B	6	42	50.55	1.0800	.001265	.00117130	.6480	.002840	.00438272	.0083310
25	A	1	70	95.10	0.9400	.002245	.00238830	.6200	.003100	.00500000	.0110824
26	A	2	70	45.80	1.0590	.003340	.00315392	.7450	.003070	.00412081	.0109121
27	A	3	70	71.27	1.1785	.002995	.00254137	.6235	.003245	.00520449	.0116188
28	A	4	70	40.24	1.0995	.003780	.00343793	.7550	.003765	.00498675	.0126370
29	A	5	70	37.58	1.1100	.004235	.00381532	.7425	.003530	.00475421	.0128543
30	A	6	70	40.60	1.0250	.002875	.00280488	.7265	.003470	.00477632	.0113718
31	B	1	70	44.94	1.1115	.003555	.00319838	.7150	.002745	.00383916	.0105563
32	B	2	70	60.49	0.8300	.002595	.00312651	.6450	.002615	.00405426	.0107712
33	B	3	70	62.27	0.9345	.002695	.00288390	.5910	.003090	.00522843	.0121685
34	B	4	70	41.97	1.0520	.003590	.00341255	.7475	.002770	.00370569	.0106773
35	B	5	70	41.84	1.1200	.002995	.00267411	.7190	.003385	.00470793	.0110731
36	B	6	70	41.80	1.0955	.003440	.00314012	.8135	.003290	.00404425	.0107766
37	A	1	80	30.62	1.1425	.002350	.00205689	.6900	.004390	.00636232	.0126288
38	A	2	80	31.66	1.0600	.002935	.00276887	.6925	.003290	.00475090	.0112797
39	A	3	80	52.78	0.8675	.003595	.00414409	.6175	.001870	.00302834	.0107586
40	A	4	80	24.89	1.0800	.002135	.00197685	.6850	.003220	.00470073	.0100164
41	A	5	80	22.79	1.0800	.002905	.00268981	.6500	.003180	.00489231	.0113732
42	A	6	80	29.20	0.9500	.002595	.00273158	.6700	.002445	.00364925	.0095712
43	B	1	80	15.31	0.9500	.003170	.00333684	.6850	.001885	.00275182	.0091330
44	B	2	80	30.28	0.9000	.002955	.00328333	.7150	.002560	.00358042	.0102956
45	B	3	80	29.53	0.9775	.003520	.00360102	.7525	.002475	.00328904	.0103351
46	B	4	80	19.30	0.9225	.003390	.00367480	.6750	.002840	.00420741	.0118233
47	B	5	80	18.85	0.9225	.003360	.00364228	.6600	.003405	.00515909	.0132021
48	B	6	80	26.19	0.8150	.003175	.00389571	.6325	.002770	.00437945	.0124127

TABLE XXI

COMPUTER PROGRAM TO CALCULATE THE CUBICAL COEFFICIENT OF MOISTURE CONTRACTION ASSUMING A PROLATE SPHEROID VOLUME

```
C       PROGRAM TO CALCULATE COEFFICIENT OF MOISTURE CONTRACTION
C       ASSUMES A PROLATE SPHEROID SHAPE FOR PEANUT KERNELS
C       ALPHA IS CALCULATED FOR A 1 % CHANGE IN MOISTURE BUT WRITTEN
C       ONLY EVERY 10TH TIME
        DIMENSION ASL(5), VM(100),ALPHA(100),X(100),Y(100)
        REAL M
 11     FORMAT (F5.0,5X,F6.4,5X,F6.4,5X,F8.6)
 13     FORMAT(1H0,'ALPHA M = ',F12.9,' + ',F12.9,' % DB MOISTURE')
 14     FORMAT(1H0,'  M  ',3X,' V(J+1) ',3X,' V(J) ',7X,'ALPHA')
 15     FORMAT(6X,'R = ',F8.4)
 25     FORMAT(1H1,1X,'WHOLE KERNELS 20 TO 42 % RELATIVE HUMIDITY RANGE')
 26     FORMAT(1H0,1X,'WHOLE KERNELS 70 TO 80 % RELATIVE HUMIDITY RANGE')
 27     FORMAT(1H0,1X,'COTYLEDONS 20 TO 42 % RELATIVE HUMIDITY RANGE')
 28     FORMAT(1H0,1X,'COTYLEDONS 70 TO 80 % RELATIVE HUMIDITY RANGE')
        ASL(1)=0.0020644
        ASL(2)=0.0031945
        ASD=0.0022976
        AD=0.826666
        AL=1.03348975
        DO 30 KK=1,2
        DO 40 I=1,2
        IF(KK .EQ. 1 .AND. I .EQ. 1)WRITE(6,25)
        IF(KK .EQ. 1 .AND. I .EQ. 2)WRITE(6,26)
        IF(KK .EQ. 2 .AND. I .EQ. 1) WRITE(6,27)
        IF(KK .EQ. 2 .AND. I .EQ. 2) WRITE(6,28)
        M=1.0
        DELTM=M
        IC=1
        WRITE (6,14)
        VM(1)=(3.14159*4.*AL*AD *AD )/( 3.*8.)
        DO 20 J=1,90
        VM(J+1)=(3.14159*4.*((AL+ASL(I)*AL*M)/2.)*
       1(((AD+ASD *AD*M)/2.)**2.))/3.
        ALPHA(J) = (VM(J+1)-VM(J))/(VM(J+1)*DELTM)
        IF(J .EQ. 1) GO TO 22
        IF(IC .NE. 10) GO TO 21
 22     CONTINUE
        WRITE (6,11) M,VM(J+1),VM(J),ALPHA(J)
        IF (IC .EQ. 10) IC=0
 21     CONTINUE
        IC=IC+1
        M=M+DELTM
 20     CONTINUE
        N=89
        DO 45 J=1,N
        Y(J)=ALPHA(J)
 45     X(J)=J
        CALL LEAST(N,X,Y,A,B,R)
        WRITE(6,13)A,B
        WRITE(6,15)R
 40     CONTINUE
        ASL(1)=0.0011263
        ASL(2)=0.0030992
        ASD=0.0039542
        AD=0.67352075
 30     CONTINUE
        STOP
        END
```

```
      SUBROUTINE LEAST(N,X,Y,A,B,R)
      DIMENSION X(N), Y(N)
      SUMX=0.
      SUMY=0.
      SUMXY=0.
      SUMXSQ=0.
      SUMYSQ=0.
      DO 50 I=1,N
      SUMX=SUMX +X(I)
      SUMY=SUMY+Y(I)
      SUMXY=SUMXY+X(I)*Y(I)
      SUMXSQ=SUMXSQ+X(I)*X(I)
   50 SUMYSQ=SUMYSQ+Y(I)*Y(I)
      XBAR=SUMX/N
      YBAR=SUMY/N
      SQSUMX=SUMX**2
      SQSUMY=SUMY**2
      SMLXLY=SUMXY-SUMX*SUMY/N
      SMSQLX=SUMXSQ-SQSUMX/N
      SMSQLY=SUMYSQ-SQSUMY/N
      B=SMLXLY/SMSQLX
      A=YBAR-B*XBAR
      R=SMLXLY/SQRT(SMSQLX*SMSQLY)
      RETURN
      END
```

TABLE XXI (Continued)

```
WHOLE KERNELS 20 TO 42 % RELATIVE HUMIDITY RANGE

 M        V(J+1)      V(J)        ALPHA
 1.       0.3723      0.3698      0.006630
10.       0.3950      0.3924      0.006502
20.       0.4213      0.4186      0.006363
30.       0.4487      0.4459      0.006230
40.       0.4773      0.4744      0.006103
50.       0.5071      0.5041      0.005980
60.       0.5381      0.5349      0.005864
70.       0.5703      0.5670      0.005752
80.       0.6038      0.6004      0.005644
90.       0.6386      0.6351      0.005537

ALPHA M =  0.006608926 + -0.000012250 % DB MOISTURE
    R =  -0.9979
```

```
WHOLE KERNELS 70 TO 80 % RELATIVE HUMIDITY RANGE

 M        V(J+1)      V(J)        ALPHA
 1.       0.3727      0.3698      0.007748
10.       0.3993      0.3963      0.007569
20.       0.4304      0.4272      0.007378
30.       0.4630      0.4597      0.007197
40.       0.4972      0.4937      0.007025
50.       0.5331      0.5294      0.006860
60.       0.5706      0.5667      0.006704
70.       0.6097      0.6057      0.006555
80.       0.6507      0.6465      0.006413
90.       0.6934      0.6890      0.006275

ALPHA M =  0.007711120 + -0.000016515 % DB MOISTURE
    R =  -0.9982
```

```
COTYLEDONS 20 TO 42 % RELATIVE HUMIDITY RANGE

 M        V(J+1)      V(J)        ALPHA
 1.       0.2477      0.2455      0.008977
10.       0.2683      0.2659      0.008698
20.       0.2923      0.2898      0.008408
30.       0.3175      0.3150      0.008138
40.       0.3441      0.3414      0.007888
50.       0.3720      0.3691      0.007652
60.       0.4012      0.3982      0.007430
70.       0.4317      0.4286      0.007222
80.       0.4637      0.4604      0.007025
90.       0.4970      0.4936      0.006840

ALPHA M =  0.008893229 + -0.000023887 % DB MOISTURE
    R =  -0.9977
```

```
COTYLEDONS 70 TO 80 % RELATIVE HUMIDITY RANGE

 M        V(J+1)      V(J)        ALPHA
 1.       0.2482      0.2455      0.010926
10.       0.2735      0.2706      0.010575
20.       0.3036      0.3005      0.010212
30.       0.3357      0.3324      0.009872
40.       0.3701      0.3665      0.009557
50.       0.4067      0.4029      0.009257
60.       0.4456      0.4416      0.008978
70.       0.4870      0.4827      0.008716
80.       0.5308      0.5263      0.008468
90.       0.5772      0.5724      0.008234

ALPHA M =  0.010822855 + -0.000030119 % DB MOISTURE
    R =  -0.9979
```

APPENDIX E

SAMPLE CALCULATIONS AND COMPUTER PROGRAM FOR KERNEL VOLUME CHANGES DUE TO HEATING, DRYING, AND COOLING

TABLE XXII

SAMPLE CALCULATIONS FOR THE CHANGE IN PEANUT KERNEL VOLUME AFTER HEATING, DRYING, AND COOLING

Assume an initial kernel volume of 1.0 cm^3 at 8 percent wet basis (8.69% dry basis) and 25°C. Dry kernels at 82°C to 4 percent wet base final moisture (4.16% dry basis).

Calculate heating expansion coefficient:

$$a_k = 52.19 \times 10^{-5} + 2.97 \times 10^{-5}(\text{Ln } M)/°C$$

$$a_k = 52.19 \times 10^{-5} + 2.97 \times 10^{-5}(\text{Ln } 8.69)/°C \times (82 - 25°C)$$

$$a_k = 58.61 \times 10^{-5}/°C \times 57°C = 0.0334$$

Calculate moisture contraction coefficient:

$$a_m = 660.89 \times 10^{-5} - 1.23 \times 10^{-5}(M)/\%$$

$$a_m = 660.89 \times 10^{-5} - 1.23 \times 10^{-5}(8.69)/\% \times (8.69 - 4.16\ \%)$$

$$a_m = 650.20 \times 10^{-5}/\% \times 4.53\% = 0.0294$$

Calculate cooling contraction coefficient:

$$a_k = 52.19 \times 10^{-5} + 2.97 \times 10^{-5}(\text{Ln } 4.16)/°C \times (82 - 25°C)$$

$$a_k = 56.42 \times 10^{-5}/°C \times 57°C = 0.0322$$

	New Volume:
Volume after heating:	
$1.0\ cm^3 \times 0.0334 = 0.0334\ cm^3$	1.0334 cm^3
Volume after drying:	
$1.0334\ cm^3 \times 0.0294 = 0.0304$	1.0030 cm^3
Volume after cooling:	
$1.0030 \times 0.0322 = 0.0323$	0.9707 cm^3

TABLE XXIII

COMPUTER PROGRAM AND DATA TO CALCULATE KERNEL VOLUME CHANGES DUE TO HEATING, DRYING, AND COOLING

```
DATA KERNEL;
INPUT HT 1-3 IM 6-7 FM 10-11 BL 14-17 WH 20-23 AIRT 26-27 CT 30-31;
V=1.0;
I=(IM*100)/(100-IM);
F=(FM*100)/(100-FM);
DT=HT-AIRT;
DCT=HT-CT;
DM=I-F;
AH=(0.0005219209+0.0000297098*LOG(I))*DT;
VH=V+(V*AH);
AD=(0.0066089-0.000012251*I)*DM;
VD=VH-(VH*AD);
AC=(0.0005219209+0.0000297098*LOG(F))*DCT;
VC=VD-(VD*AC);
DROP V DT DM DCT;
DROP AIRT CT WH;
CARDS


  30 OBSERVATIONS IN DATA SET KERNEL        12  VARIABLES

PROC PRINT DATA=KERNEL;
TITLE 'VOLUME CHANGE OF KERNELS BY HEATING, DRYING, AND COOLING';
```

TABLE XXIII (Continued)

VOLUME CHANGE OF KERNELS BY HEATING, DRYING, AND COOLING

OBS	HT	IM	FM	BL	I	F	AH	VH	AD	VD	AC	VC
1	71	6	4	90.1	6.3830	4.16667	.0265416	1.02654	.0144741	1.01168	.0259587	.985421
2	71	6	5	83.9	6.3830	5.26316	.0265416	1.02654	.0073132	1.01903	.0262780	.992256
3	71	8	4	92.0	8.6957	4.16667	.0269642	1.02696	.0294491	0.99672	.0259587	.970847
4	71	8	5	91.4	8.6957	5.26316	.0269642	1.02696	.0223193	1.00404	.0262780	.977659
5	71	8	6	88.8	8.6957	6.38298	.0269642	1.02696	.0150379	1.01152	.0265416	.984673
6	71	8	7	73.5	8.6957	7.52688	.0269642	1.02696	.0075998	1.01916	.0267669	.991880
7	71	10	4	95.5	11.1111	4.16667	.0272992	1.02730	.0449498	0.98112	.0259587	.955654
8	71	10	5	93.9	11.1111	5.26316	.0272992	1.02730	.0378525	0.98841	.0262780	.962440
9	71	10	6	92.7	11.1111	6.38298	.0272992	1.02730	.0306042	0.99586	.0265416	.969428
10	71	10	7	86.1	11.1111	7.52688	.0272992	1.02730	.0231999	1.00347	.0267669	.976606
11	82	6	4	92.1	6.3830	4.16667	.0328885	1.03289	.0144741	1.01794	.0321663	.985195
12	82	6	5	84.3	6.3830	5.26316	.0328885	1.03289	.0073132	1.02533	.0325619	.991948
13	82	8	4	93.4	8.6957	4.16667	.0334121	1.03341	.0294491	1.00298	.0321663	.970717
14	82	8	5	91.5	8.6957	5.26316	.0334121	1.03341	.0223193	1.01035	.0325619	.977448
15	82	8	6	89.2	8.6957	6.38298	.0334121	1.03341	.0150379	1.01787	.0328885	.984396
16	82	8	7	82.2	8.6957	7.52688	.0334121	1.03341	.0075998	1.02556	.0331677	.991543
17	82	10	4	95.3	11.1111	4.16667	.0338272	1.03383	.0449498	0.98736	.0321663	.955597
18	82	10	5	94.4	11.1111	5.26316	.0338272	1.03383	.0378525	0.99469	.0325619	.962305
19	82	10	6	93.1	11.1111	6.38298	.0338272	1.03383	.0306042	1.00219	.0328885	.969227
20	82	10	7	90.4	11.1111	7.52688	.0338272	1.03383	.0231999	1.00984	.0331677	.976348
21	93	6	4	91.1	6.3830	4.16667	.0392355	1.03924	.0144741	1.02419	.0383738	.984891
22	93	6	5	82.0	6.3830	5.26316	.0392355	1.03924	.0073132	1.03164	.0388457	.991561
23	93	8	4	93.5	8.6957	4.16667	.0398601	1.03986	.0294491	1.00924	.0383738	.970509
24	93	8	5	90.3	8.6957	5.26316	.0398601	1.03986	.0223193	1.01665	.0388457	.977159
25	93	8	6	89.2	8.6957	6.38298	.0398601	1.03986	.0150379	1.02422	.0392355	.984037
26	93	8	7	81.9	8.6957	7.52688	.0398601	1.03986	.0075998	1.03196	.0395685	.991124
27	93	10	4	95.4	11.1111	4.16667	.0403553	1.04036	.0449498	0.99359	.0383738	.955464
28	93	10	5	93.7	11.1111	5.26316	.0403553	1.04036	.0378525	1.00098	.0388457	.962092
29	93	10	6	91.7	11.1111	6.38298	.0403553	1.04036	.0306042	1.00852	.0392355	.968947
30	93	10	7	87.8	11.1111	7.52688	.0403553	1.04036	.0231999	1.01622	.0395685	.976009

HT	Heating temperature, °C
IM	Initial moisture, % wet base
FM	Final moisture, % wet base
BL	Blanching percentage, %
I	Initial moisture, % dry base
F	Final moisture, % dry base
AH	Coefficient for heating, cm^3/cm^3
VH	Volume of a peanut kernel after heating (Assumes an initial volume of 1.0 cm^3 before heating), cm^3
AD	Coefficient for drying, cm^3/cm^3
VD	Volume of a peanut kernel after heating and drying, cm^3
AC	Coefficient for cooling, cm^3/cm^3
VC	Final volume of a peanut kernel after heating, drying, and cooling, cm^3

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