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An evaluation of a microwave technique for moisture content determination in snap beans

Daniel John Barber

To the Graduate Council:

I am submitting herewith a thesis written by Daniel John Barber entitled "An evaluation of a microwave technique for moisture content determination in snap beans." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering.

Luther R. Wilhelm, Major Professor

We have read this thesis and recommend its acceptance:

Kermit Duckett, Hugh O. Jaynes, John R. Mount

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Daniel John Barber entitled "An Evaluation of a Microwave Technique for Moisture Content Determination in Snap Beans." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

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recommend its acceptance:

Hugh D. Jaynes

John R Mount

Kermit E. Duncan

Accepted for the Council:

L Evans Roth

Vice Chancellor

Graduate Studies and Research

AN EVALUATION OF A MICROWAVE TECHNIQUE FOR

MOISTURE CONTENT DETERMINATION IN

SNAP BEANS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Daniel John Barber

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ABSTRACT

A study was conducted to compare a microwave oven procedure to the convection oven method for moisture determination of snap beans. Emphasis was on correlating microwave measurements with convection oven drying results. Drying parameters considered were sample preparation, microwave drying time, and number of samples per microwave load.

A dehumidifier was used to obtain a range of initial moisture values. The majority of the pods were pureed in a food processor for the microwave treatment combination procedure. The preliminary results for the convection oven revealed that whole or puree sample preparation had little effect on indicated moisture contents for the ranges tested. Whole sample preparation was selected as the reference moisture technique and was used to evaluate the microwave procedure.

Microwave oven preliminary results indicated that time intervals and number of samples had a major effect upon the indicated moisture content. The time intervals (8, 10, 12, and 18 minutes) and the number of samples per load (2, 3, and 4) were evaluated for the treatment combinations to determine percent moisture.

For determination of moisture in snap beans using the microwave oven at the No. 6 power setting, the indicated moisture contents given by drying three (10 gram) samples for 12 minutes were significantly different than convection dried samples at the 99% level of probability. Even though they were statistically diffeernt, the moisture contents had the best linear relationship with the convection moisture contents. A convection percent moisture prediction equation was established. Thus, the time reduction from 24 hours to 12 minutes offered by the microwave procedure has potential for moisture determination in snap beans.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

I. IMPORTANCE OF MOISTURE DETERMINATION

Water is the principal constituent of most raw foods and a structuralizing constituent of processed foods. Thus, "moisture content" is an important parameter in the study of food. The magnitude of the "moisture content" of foodstuff or raw foods depends on the method used for moisture determination.

The snap bean (Phaseolus vulgaris) is one of several high moisture level vegetables that are economically important to the commerical processor. In 1980, snap bean annual consumption was 6.59 pounds per capita. The United States has roughly 223 million citizens; thus, domestic consumption was about 1,469,570,000 pounds (Anonymous, 1982). Much research has been conducted on snap beans. Moisture content is usually an important factor of interest to the researcher and processors. Water activity and moisture content are major factors affecting the progress of microbiological and chemical spoilage reactions in foods (DeMan, 1980).

Water activity (a_w) is defined as the partial pressure of water in food (p) over the vapor pressure of water (p_o) at the same temperature; $a_w = p/p_o$. When the amount of moisture exceeds the amount of solids in a material, water activity is close to or equal to 1.0. At lower moisture contents, the activity of water is lower than 1.0.

Bacterial growth is virtually impossible below a water activity of 0.90 while most yeasts and molds are inhibited between 0.80 and 0.88 (DeMan, 1980).

While the quality of harvested fruits and vegetables is dependent on the conditions of growth and on postharvest treatments, a harvested fruit or vegetable contains a variety of oxidizable substrates and the molecular machinery required to perform oxidative reactions. The major process of concern is respiration and its mechanism is essentially the same in fruits, vegetables, and animal life (Desrosier and Desrosier, 1977).

Freshly harvested beans are alive. Living tissues respire and the energy is released in the form of heat. The amount of heat released varies with the commodity, increases as the temperature of the commodity increases, and influences microbial and mold growth rates.

Beans toughen after harvest and these changes occur at the cellular level. Cell wall metabolism is obviously related to tissue toughening (Desrosier and Desrosier, 1977 and Sterling, 1975).

Presently, the food industry has no single standard for vegetable moisture determination. Many different methods have been proposed, but none have been accepted as a standard. If there were a "quick" method for moisture determination, valuable time could be saved at the food processing plants. Thus, a "quick" standard method for vegetable moisture determination is needed.

II. OBJECTIVE

The objective of this study was to compare a microwave oven procedure to the convection oven method for moisture determination. Snap beans were used as the test product. The convection oven method was used as the reference. Emphasis was on correlating microwave measurements with convection oven drying results. Drying factors considered were sample preparation, microwave drying time, and number of samples per microwave load. The objective was to be positively or negatively satisfied based on the analyses of the experiment.

CHAPTER II

LITERATURE REVIEW

I. STANDARD METHODS FOR MOISTURE DETERMINATIONS

The "vacuum oven method" to determine moisture in vegetables is an unofficial standard because it is currently used as a reference for the calibration of other methods, as suggested by Makower _et al._ (1946). Other methods used for determining moisture content are: (1) mechanical convection oven, (2) electrical, (3), toluene distillation, (4) Fisher volumetric, (5) nuclear magnetic resonance, (6) dichromate oxidation, and (7) infrared radiation (AOAC, 1980 and Gould, 1977).

The Association of Official Analytical Chemists (AOAC) and the American Society of Agricultural Engineers (ASAE) have moisture determination procedures for several agricultural products. Examples of some procedures are listed below:

1. Cereal grains and seeds - vacuum oven method.
   Two grams well mixed sample heated at "98 - 100° C to constant weight (ca 5 hr) in partial vacuum having pressure equivalent to 25 mm Hg (3.3 kPa)" (AOAC method 14.002, AOAC, 1980).
2. Cereal grains and seeds - convection oven method.
   Use 15 gram unground sample or 100 gram sample for high moisture content seeds (over 25 percent). Oven temperature

and heating period are dependent on the grain or seed and are found in a table (ASAE S352, ASAE, 1982a).

3. Cheese - vacuum oven method.
   Two to three grams of prepared sample dried to constant weight (ca 4 hr) at 100° C under pressure 100 mm of Hg (AOAC method 16.217, AOAC, 1980).

4. Dried fruits - vacuum oven method.
   Five to ten grams of prepared sample dried for "6 hours at 70 $\pm$ 1° C under pressure 100 mm Hg (13.3 kPa)" (AOAC method 22.013, AOAC, 1980).

5. Meat and meat products - convection oven method.
   "Two grams dry material sample dried at 100 - 102° C for 16 - 18 hours in air oven (mechanical convection preferred)" (AOAC method 24.003, AOAC, 1980 and ASAE S353, ASAE, 1982b).

6. Forages - convection oven method.
   Twenty-five gram prepared sample dried at 103° C for 24 hours (ASAE S358.1, ASAE, 1982c).

II. BASIC PRINCIPLES OF MICROWAVE

Microwaves are electromagnetic waves similar to radio and television waves. All electromagnetic waves are characterized by wavelength and frequency. The FCC has designated two frequencies for microwave power generation in commercial and industrial applications. They are 2450 and 915 megahertz with respective wave lengths of 12.2 cm and 33 cm (Schiffmann, 1976). Other frequencies for comparison are U.S. AM broadcast stations - from 535 to 1605 kilohertz, International AM broadcasting - from 5.95 to 26.1 megahertz; U.S. FM broadcast stations - from 88.1 to 107.9 megahertz; and U.S. television broadcast stations - from 55.0 to 88.0 megahertz, 174.0 to 216.0 megahertz, and 470.0 to 890.0 megahertz (Buchsbaum, 1978) see Figure 1.

Microwaves have characteristics similar to light waves and transmit energy through space. Microwaves and light waves travel in straight lines. Both waves can be generated, reflected, transmitted, and absorbed. The basic difference between them is in the materials that reflect, transmit, and absorb them (Pieper et al., 1977).

Microwave power is generated in a special vacuum tube. Two types of tubes, Klystrons and Magnetrons, may be used to generate microwaves. The Klystron tube is an expensive higher powered unit which requires water cooling. The Magnetron tube is a lower powered generating tube which is air cooled. The latter tube has proven to be a very economical method of generating microwave energy (Davenport et al., 1979).

The method by which the energy leaves the Magnetron tube and enters the microwave oven depends on the interaction of an external magnetic field with the electric field generated between the Magnetron's cathode and anode, in a cylindrical configuration. The cylindrical cathode emits electrons which are attracted by the surrounding cylindrical anode. The direction of the external magnetic field is perpendicular to the electric field. In the Magnetron tube, because of the interaction of the electric and magnetic field, the electrons rotate in a spoke-like

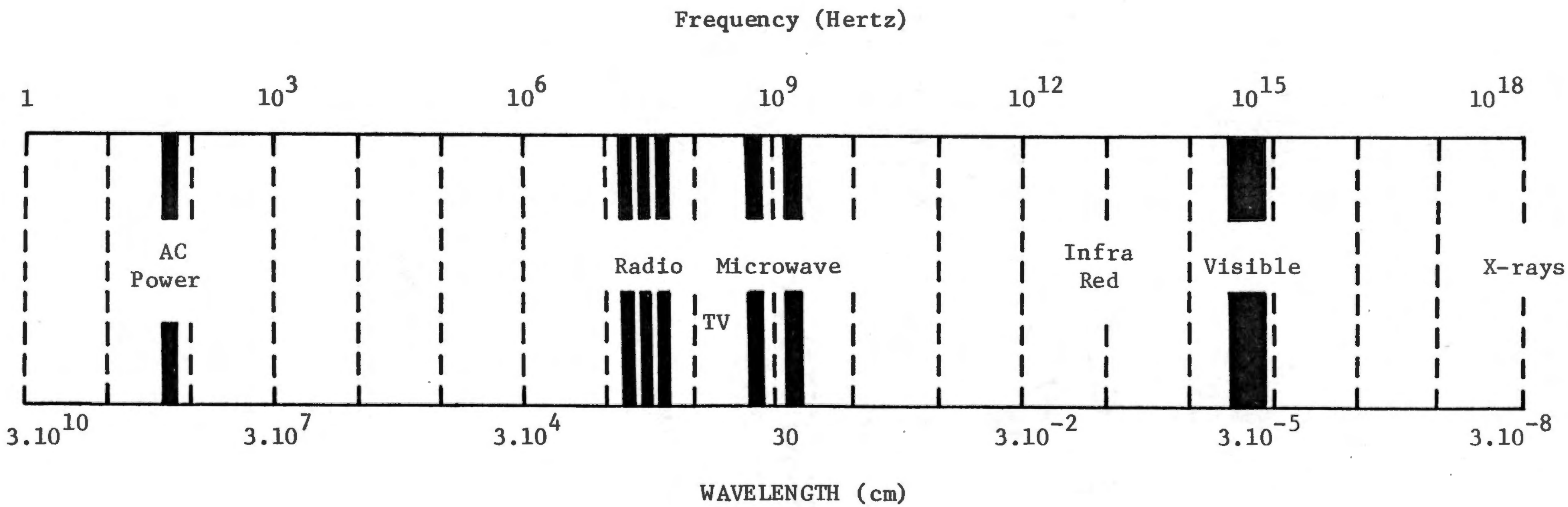

Figure 1. The electromagnetic spectrum. Band widths are not to scale, but only represent the location in the spectrum.

pattern. The rotating field takes the place of the stream of electrons. The field's modulation by the microwave signal depends on the geometry of cathode and anode, a circular waveguide structure and the design of the anode itself. A practical Magnetron anode consists of an even number of segments which give rise to modes of oscillation. The voltage applied between the cathode and anode determines the mode in operation. Some Magnetron designs contain resonating cavities between anode segments which make the Magnetron an essentially single frequency device. A conversion efficiency of 80% from D.C. into microwaves is typical of many Magnetron tubes (Buchsbaum, 1978). The microwaves exit the Magnetron and travel down a waveguide, which functions to deliver them to the cavity. The cavity is usually made of stainless steel and serves to both confine the microwaves and reflect them toward the food product. Food is placed inside the cavity for heating. A mode stirrer, which resembles a slowly revolving fan, serves to distribute the microwaves more uniformly throughout the cavity to prevent hot and cold spots during heating. The basic components of a microwave oven are shown in Figure 2 (Schiffmann, 1976).

The electromagnetic field within the microwave oven changes direction millions of times per second. The molecules of samples being treated attempt to shift their position to align themselves with the ever changing electromagnetic field polarity. Heat produced throughout the sample being treated is by the intermolecular friction between the millions of molecules oscillating about their axes. Thus, a material heated by microwave energy is more or less uniformly heat throughout, instead of being heated from the inside out, a common misconception (Pieper et al., 1977).

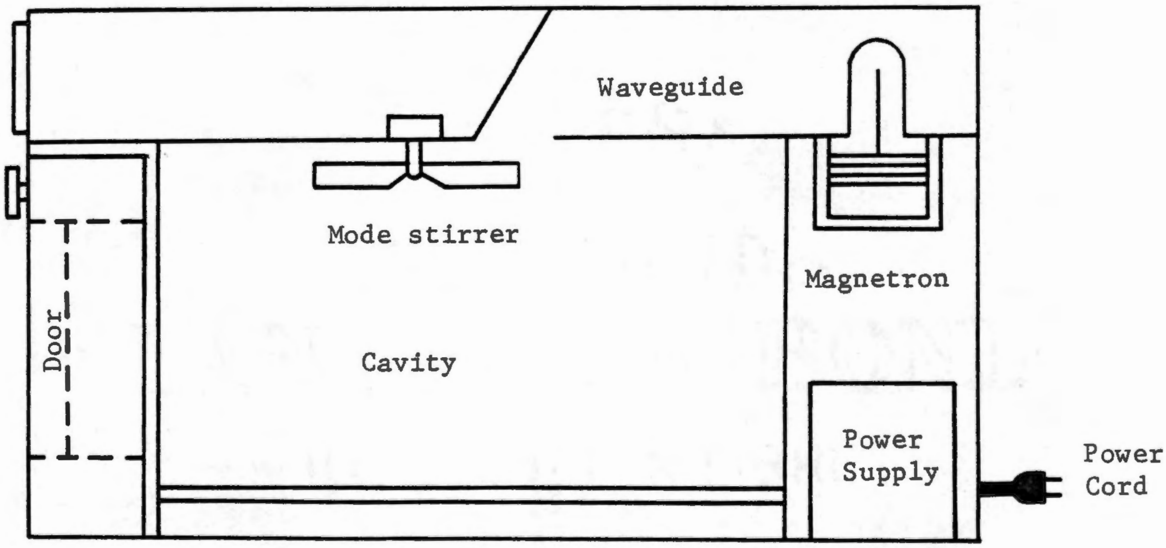

Figure 2. Basic components of a microwave oven.

III. APPLICATIONS OF MICROWAVE ENERGY TO MOISTURE MEASUREMENTS FOR FOOD PRODUCTS

Moisture content is an important property commonly used to determine the correct harvest date of grains and certain food crops. One standard method of determining moisture content in corn is by drying at "98 - 100° C to constant weight (ca 5 hr) in partial vacuum having pressure equivalent to 25 mm Hg" in a vacuum oven (AOAC method 14.002, AOAC, 1980). ASAE S352 is another method for measuring moisture content in corn (drying 72 hours at 103 ± 1° C in a convection oven) (ASAE, 1982a).

Becwar et al. (1977) compared microwave heating with the vacuum oven method and got comparable results for several varieties of sweet corn. Becwar used an Amana "Radarange" microwave oven. The heating time for a 10 gram sample, prepared in a blender for uniform consistency, was 3 minutes. After initial tests showed that whole kernels splattered, the study concluded significant variations occurred with whole kernels. With the blended samples, they found only a ± 1% difference between the two methods. Using a t-test, they found no significant difference at the 95% probability level.

Davenport et al. (1979) also noted the splattering and popping problem with whole kernels. They concluded the microwave oven gave lower moisture levels for whole corn, with the exception of deformed corn (crushed by a hammer), and oats than the convection oven. The best results were obtained using a 20 gram crushed corn sampled dried for 25 minutes in a home microwave oven.

Click and Baker (1980) compared microwave during with the convection oven for alfalfa, ear corn, soybeans, shelled corn, and potato chips. They found no significant difference between the methods for alfalfa; significant differences for ear corn due to ear burning, for shelled corn of meal consistency, and for potato chips; and concluded further experimentation was needed for soybeans. Click et al. (1982) obtained favorable results for moisture levels when comparing the microwave oven and convection still-air oven drying methods for shelled corn, wheat, barley, oats, forages, and soils. Whole kernel corn was dried in the microwave without the problems noted by Davenport et al. (1979) and Becwar et al. (1977). They concluded that, if the procedures outlined in the paper were strictly followed, the results from the microwave oven should be equivalent to the results from the convection still-air oven method.

Verma et al. (1981) and Noomhorn and Verma (1981) concluded that microwave oven methods, using four samples per load with the proper power level and time, agreed closely with the ASAE and AOAC methods for sorghum grass, wheat, and rough rice. However, the accuracy of the microwave oven was lower for soybeans.

Pieper et al. (1977) compared microwave drying with the existing AOAC methods and got comparable results when analyzing cheese. The time for a 10 gram sample, prepared according to AOAC 16.216, was 2.25 minutes. A specially designed microwave unit was used to develop a microwave technique for a rapid determination of moisture in cheese.

The unit was equipped with an internal balance, a recirculating water system, and a variable power control for adjusting microwave intensity.

Jaynes (1974) accomplished milk pasteurization using microwaves as the energy source in a continuous heating apparatus with two-stage regeneration. Phosphatase tests and bacterial plate counts were used to measure the adequacy of pasteurization. The treatments (72° C for 15 seconds) were compared to those of controls treated 62.8° C for 30 minutes. A taste panel compared the microwave pasteurized milk and the control and found no significant difference.

Perrin *et al.* (1980) compared microwave drying with the vacuum and convection drying ovens and found the microwave results to give significantly lower moisture levels. Two samples per test were used for the different ovens. The microwave oven (Amana "Radarange") indicated lower moisture levels for fresh snap beans than for frozen beans. Also, they concluded that a 10 gram pureed sample with an oven power setting of No. 6 gave the best results without excessive burning of the sample.

CHAPTER III

PROCEDURE

I. GENERAL INFORMATION

Early Galatin Snap Beans were obtained from the University of Tennessee, Knoxville Plant Science Farm. The beans were hand-picked and stored in a refrigerator until test preparation time. The majority of the pods selected for testing were number 5 sieve size.

The Statistical Analysis System (SAS) package (Ray, 1982) available at the University of Tennessee Computer Center was used for the comparison analyses of the microwave and convection ovens.

II. EQUIPMENT AND MATERIALS

Research was carried out during the 1982 growing season. The snap beans were planted, sprayed, and weeded until harvest time. The beans were hand-harvested, refrigerated, and later prepared for moisture determination tests.

Tests were conducted using the following equipment and materials:

1. Oven, Precision Scientific Company convection oven. Catalog Number 1244, 230 volts, 18.0 amps, and 4100 watts. Forced air convection with $1.36m^2$ shelf space.
2. 390T Home Food Dehydrator, Nutri-flow, Portland, OR. Model Number NSI, 115 volts A.C., 7.29 amps, and 60 Hz.

3. Amana Touchmatic II Radarange Microwave Oven, Amana Refrigeration Inc., Amana, IA. Model Number RR-10A, 2450MHz, 120 volts, and 750 watts maximum power output (modified to 60% of normal power output).
4. Food Processor, Faberware Inc., Bronx, NY. Model Number 286.
5. Balance, Metler E200, Metler Instrument Corporation, Hightstown, NJ.
6. Refrigerator.
7. Imposion-Proof Vacuum Desiccator.
8. Glass petri dishes, 100 x 10 mm.
9. Aluminum cans with lids, 5.5 x 9 cm.
10. Desiccant.

III. TEST PLAN

The convection drying parameter of interest was the method of sample preparation while the parameters for the microwave oven were drying time and number of samples per load. A total of 24 runs were tested with the initial moisture contents varied to obtain a range of moisture values.

Differences among treatment combinations were partitioned as follows: (1) twelve treatment combinations associated with the microwave oven were partitioned by considering the combinations to represent a 3 x 4 factorial arrangment having 3 levels of load (2, 3, and 4 samples per load) and 4 levels of time (8, 10, 12, and 18 minutes) and (2) two treatment combinations in the convection oven were compared for sample preparation method (whole pods versus puree). Figure 3 shows the 14 treatment combinations.

The considered factors in the microwave oven treatments were the number of samples per load and time intervals for the 12 time-load combinations. Time intervals were divided into continuous and interrupted groups. The continuous group consisted of the 8, 10, and 12 minute intervals while the interrupted group was the 18 minute interval. The 18 minute interval was broken down into a continuous 8 minute interval followed by two cycles of a 3 minute pause with the microwave door open and 2 minute heating interval.

For each run conducted, the convection oven was the standard (reference) for comparison and was operated at the same conditions: 100° C $\pm$ 1° C for 24 hours (a modification of AOAC and ASAE methods for grains). Cans were removed and weighed after the 24 hour drying period. The assumption was made that the weight lost by each sample at the time of weighing was the moisture removed from the beans. Wilhelm (1979) had verified this assumption in previous tests. Moisture content was calculated on the wet basis.

The microwave oven was operated at a fixed power setting (No. 6). The 12 different time-load combinations were used for each of the 24 runs. The samples were removed and weighed after the designated heating time. Moisture content was computed under the same assumption as for the convection oven.

Convection Oven		Microwave Oven			
Whole[a]	Puree[a]	Puree[a]			
(24 Hr)	(24 Hr)	Time 1 (8 min.)	Time 2 (10 min.)	Time 3 (12 min.)	Time 4[b] (18 min.)
2 Samples per load	2 Samples per load	2 Samples per load	2 Samples per load	2 Samples per load	2 Sample per load
		3 Samples per load	3 Samples per load	3 Samples per load	3 Samples per load
		4 Samples per load	4 Samples per load	4 Samples per load	4 Samples per load

[a]Represents the sample preparation method.

[b]Time 4 represents the interrupted time interval.

Figure 3. The fourteen treatment combinations for convection and microwave oven test plan representing one of twenty-four replications. Other replications had the same time-load combinations.

IV. MICROWAVE OVEN CALIBRATION

Before any drying runs were conducted, a paper map model of the microwave oven bottom was constructed to locate the hot spots in the oven and to keep the same petri dish positions for the duration of the tests. Two geometric patterns were drawn for each of the 2, 3, and 4 sample locations. The center point of the model was located by the intersection of the diagonal lines running from corner to corner. The hot spots were determined by recording temperature differences for 100 gram water samples for 1, 2, and 3 minute time intervals in all locations of each geometric pattern. The 2, 3, and 4 sample location patterns showing the greatest temperature differences were considered to contain hot spots and were rejected as possible patterns. See Figures 4, 5, and 6. The dimensions of the paper map model were 14-3/8 by 13-1/2 inches with the larger dimension representing the width of the microwave oven.

The microwave oven was checked for power ouput at the No.6 setting using the three different geometric patterns. One hundred gram samples of water placed in polystrene cups were used in each of the three distinct patterns. Timed heating intervals of 3, 3.5, and 4 minutes were utilized to obtain the temperature changes for the 2, 3, and 4 samples per load, respectively. A temperature recorder was employed to acquire the individual initial and final sample temperatures after the specified heating period. The average of three replications for each pattern were calculated to determine the total energy output.

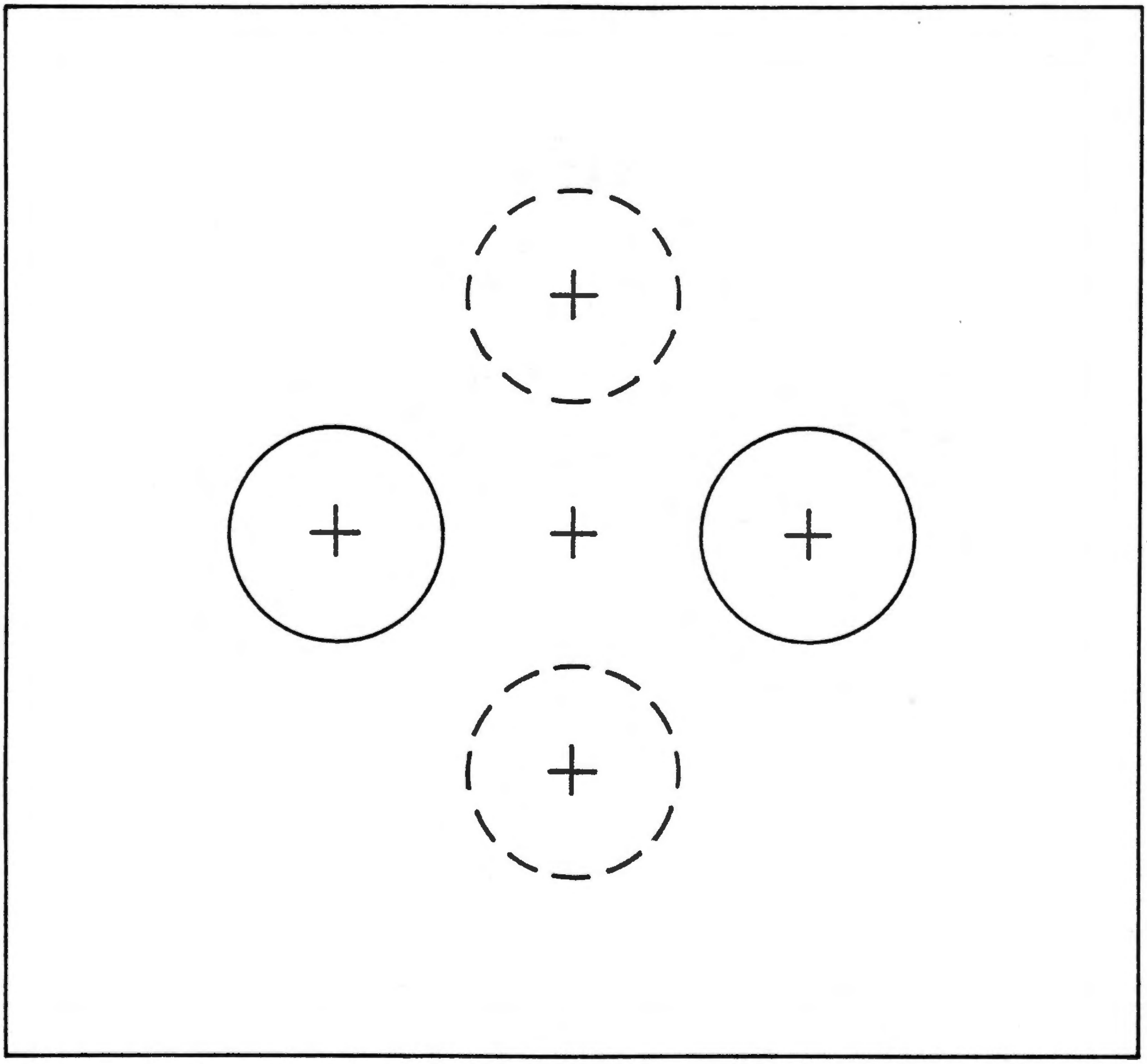

Figure 4. Two sample geometric design pattern with the dashed line circles indicating the rejected pattern. Samples were positioned around a 3" radius from the center.

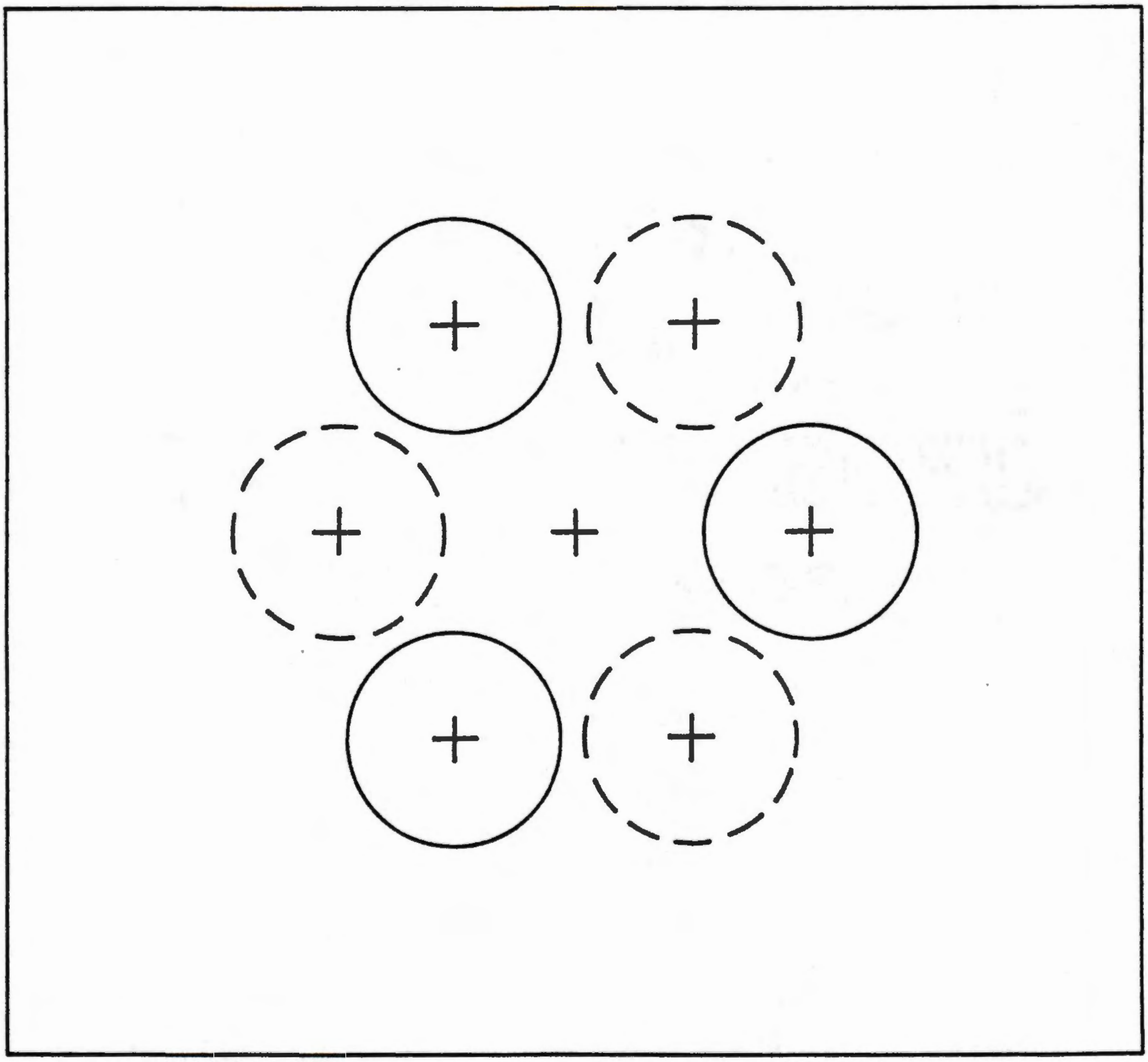

Figure 5. Three sample geometric design pattern with the dashed line circles indicating the rejected pattern. Samples were positioned around a 3" radius from the center.

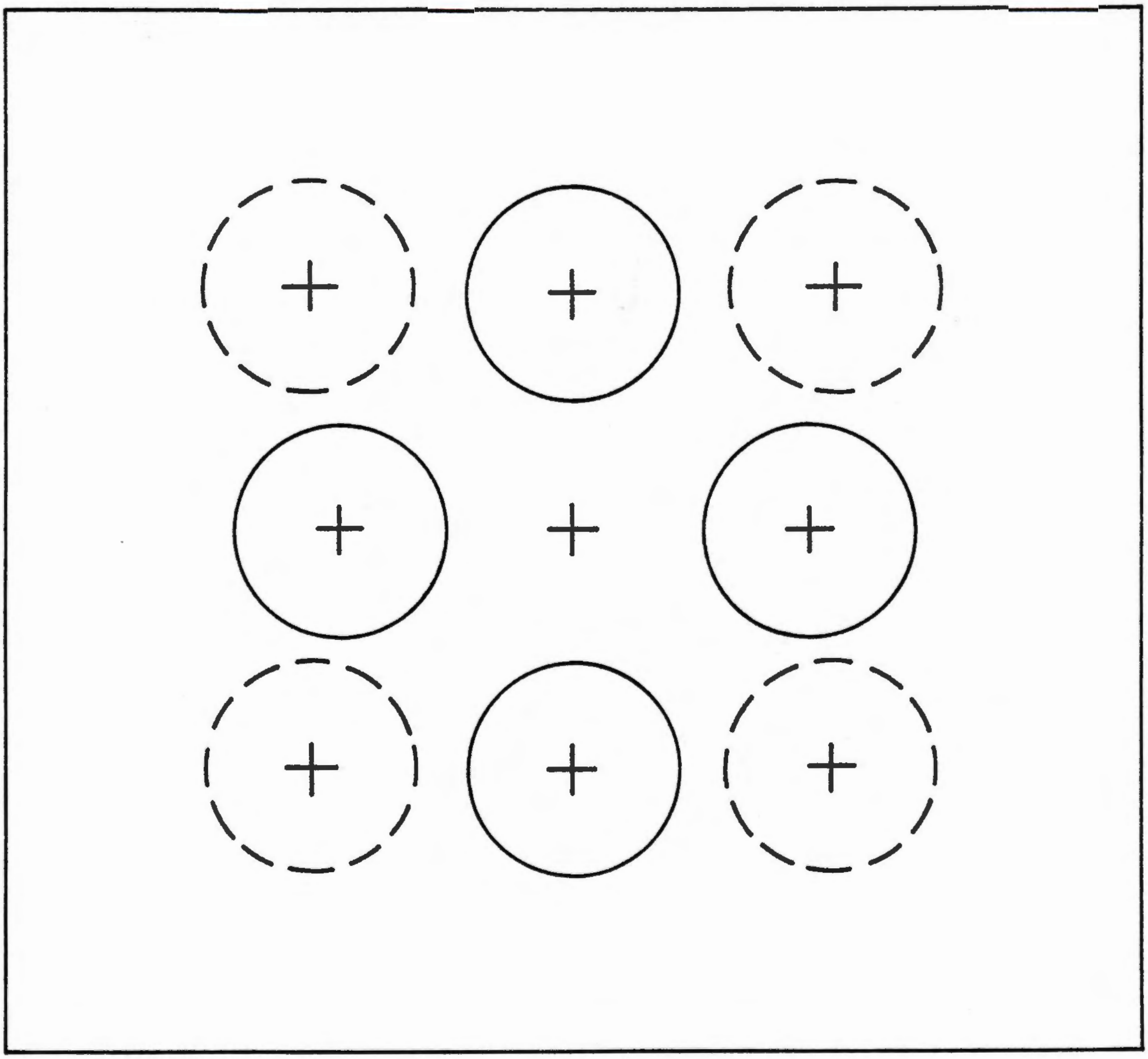

Figure 6. Four sample geometric design pattern with the dashed line circles indicating the rejected pattern. Samples were positioned around a 4.5" radius along the diagonal axis from the center and a 3" radius along the horizontal and vertical axes.

The power output of the oven for each pattern could be calculated from the load temperature rise, the mass of the load, and the time duration of the test (see Figure 7).

Variation among replications was small. However, variation by sample position within the oven was great - up to 25%. This position significance emphasized the importance of careful sample placement in microwave drying studies.

V. TEST SAMPLE PREPARATION

After harvesting, beans were placed in the refrigerator until the preparation operation began. At the time of preparation, the beans were removed from the refrigerator and placed in the dehumidifier. The dehumidifier was set at various temperatures and time intervals (hours) to obtain a range of initial moisture content. Pods were removed from the dehumidifier and prepared for the convection and microwave ovens.

The majority of the pods were pureed in the food processor until a homogeneous mixture was obtained (about 30 - 35 minutes depending on the initial moisture content). If the puree preparation was hot, it was placed in the refrigerator to cool. The homogeneous mixture was used for 13 of the 14 treatment combinations. Whole pods were used for the remaining treatment.

Five beans were placed into each of two preweighed aluminum cans for the whole sample preparation to be dried in the convection oven. Pods were broken into thirds to fit inside the cans. The

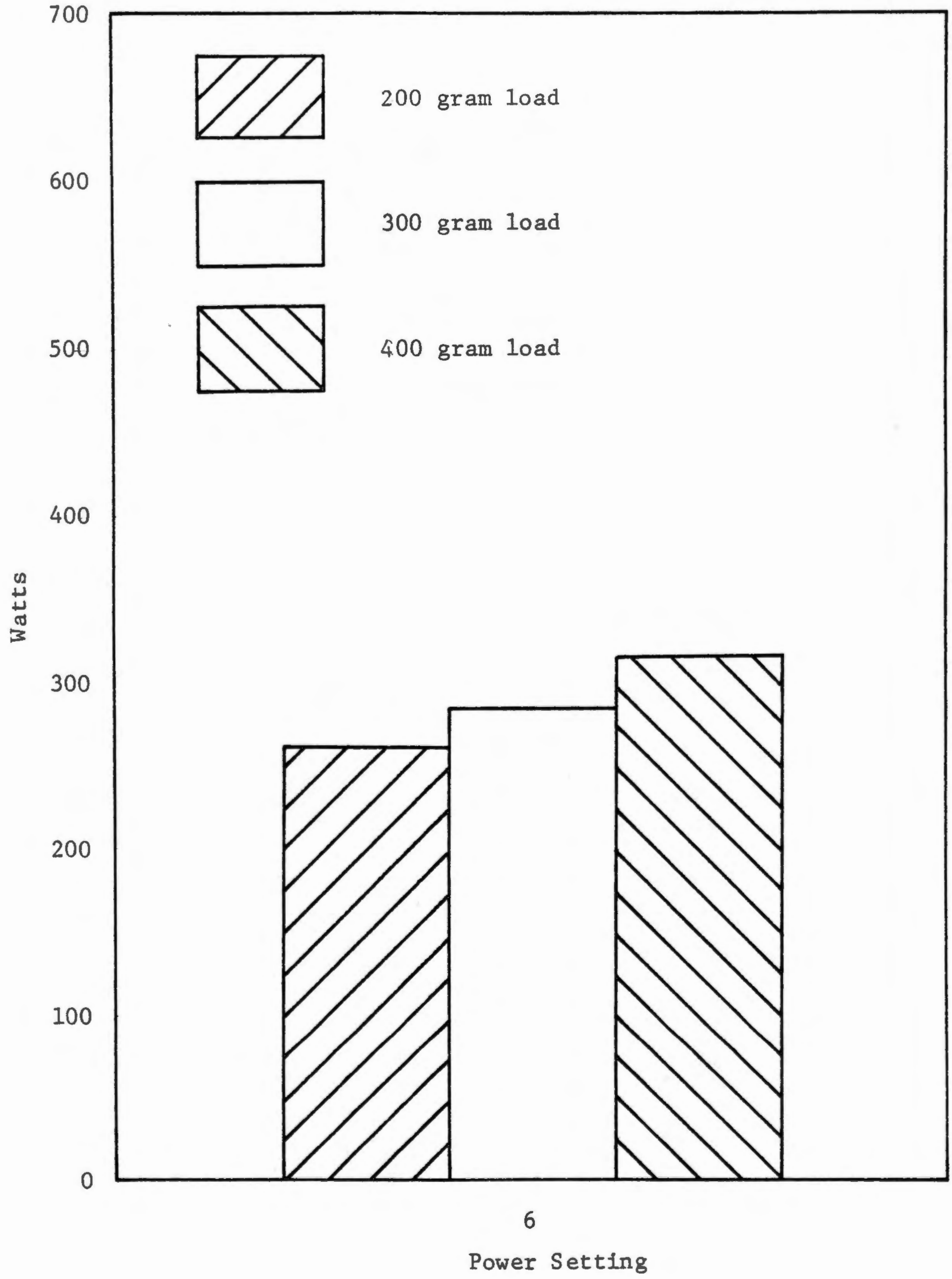

Figure 7. Average microwave power output for the 200, 300, and 400 gram water samples utilizing heating intervals of 3, 3.5, and 4 minutes, respectively.

gross weight varied from 50 to 64 grams. Also, puree samples were placed into two preweighed aluminum cans in amounts approximately equal to the gross weight of the whole samples. Both preparations (4 samples) were loaded into the oven. Cans were removed and weighed after the 24 hour drying period. Moisture content was then determined.

For each microwave oven run, 36 samples of approximately 10 grams each were used. The puree samples were placed into preweighed pyrex petri dishes and weighed. The dishes were then placed, without the lids, on the geometric pattern for the appropriate treatment combination. After the specified time interval, the glass plate in the bottom of the microwave was pulled half-way out of the microwave to allow some cooling (about 5 minutes). Petri dishes were removed and weighed after the heating time interval from which moisture content was determined. Also, the puree mixture was again blended to ensure the best homogeneous state before each time-load combination.

CHAPTER IV

RESULTS AND DISCUSSION

The analyses of the results were divided into five phases to evaluate the correlation between the convection and microwave ovens. In the first phase, the sample preparation method for determining convection oven moisture content was analyzed. Microwave continuous versus interrupted time interval procedures were evaluated in the second phase. In the third phase, slope correlations between the two ovens were obtained. In the fourth phase, a predicted convection moisture content equation was determined using the 9 continuous time-load microwave combination moisture contents. In the final phase, only the microwave combination of 12 minutes and 3 samples per load was used to predict the convection oven moisture content equation.

I. PHASE ONE: (WHOLE VS. PUREE: CONVECTION SAMPLES)

The moisture content of whole and pureed samples was determined in the convection oven. A statistical evaluation of the results is shown in Table 1.

The method of sample preparation was not significant at the 99% level of probability. This result indicated that either whole or puree beans could be used for the drying tests. Therefore, in the later phases, cut (broken) whole beans were used for samples in the convection oven. Table 1 shows that the replications were

Table 1. Convection Drying Analyses for Whole vs. Puree Sample Preparation

Source	DF	Type I SS	F Value	PR>F
Replication	24	135.3802	48.11	0.0001
Preparation	1	0.0001	0.00	0.9707

Source	DF	Sum of Squares	Mean Square	F Value	PR>F	R-Square	C.V.
Model	25	135.3804	5.4152	46.19	0.0001	0.9796	0.3744
Error	24	2.8138	0.1172		STD DEV	CONVEN MEAN	
Corrected Total	49	138.1942			0.3424	91.4534	

significant; however, this result was expected since the moisture contents were varied initially to obtain a wide range of values.

It was noted that the lower the initial moisture content, the more charred (black) the samples appeared after the 24 hour drying period; all convection samples varied from dark brown to black in appearance.

II. PHASE TWO: (CONTINUOUS VS. INTERRUPTED MICROWAVE TIME INTERVALS)

Continuous (12 minute) and interrupted (18 minute) microwave time intervals for moisture content were evaluated by replications, load (number of samples), time, and the interaction between load and time. Both treatment combinations had a total of 12 minutes heating time. Phase two analysis results are given in Table 2.

Load was significant at the 99% level of probability while the time interval was not significant. However, the interaction between the load and time was significant at the 95% level of probability. During the 3 minute pause periods of the interrupted time interval with the door open, the samples possibly cooled, thus affecting the amount of energy necessary to reheat the samples to remove (evaporate) moisture from the puree samples (more moisture remained in the samples after the heating time). It was concluded that the procedures for the time treatment combinations were significantly different due to the load and time interaction between the continuous and interrupted time intervals. Consequently, the interrupted time moisture contents

Table 2. Continuous vs. Interrupted Time Intervals for Microwave Analyses

Source	DF	Type I SS	F Value	PR>F
Replication	24	466.4919	77.71	0.0001
Load	2	4.6537	17.83	0.0001
Time	1	0.0015	0.01	0.9379
Load x Time	2	1.1575	4.44	0.0373

Source	DF	Sum of Square	Mean Square	F Value	PR>R	R-Square	C.V.
Model	26	466.4919	18.1655	69.60	0.0001	0.9392	0.5699
Error	117	30.5366	0.2609		STD DEV	MWWBPERC MEAN[a]	
Corrected Total	143	502.8415			0.5108	89.6505	

[a]MWWBPERC MEAN represents the measured microwave moisture contents.

were removed from further analyses, thus reducing the microwave 3 x 4 factorial array to a 3 x 3 factorial arrangement of continuous load-time combinations (see Figure 3, page 16, and Figure 8).

It was noted that all microwave samples varied from a straw color to dark brown in physical appearance after the varying heating periods. Light brown and dark brown appearances are represented as slightly burned and burned, respectively.

The physical appearances for the heated 12 minute-load combinations (continuous time interval) were slightly burned to burned (92% of the samples), slightly burned to burned (24%), and slightly burned (8%) for 2, 3, and 4 samples per load, respectively. For the interrupted time interval, 40% of the load 2 samples were slightly burned, 12% of load 3, and 12% of load 4, respectively.

III. PHASE THREE: (LINEAR, QUADRATIC, AND CUBIC RELATIONSHIPS ESTABLISHED FOR THE MICROWAVE VERSUS CONVECTION OVEN MOISTURE CONTENTS)

The slopes of the relationship between the measured microwave and actual convection oven moisture contents were evaluated using a stepwise regression analysis for the different load-time combinations. The top five linear models (those with the highest R^2 values) are shown in Table 3. Once the linear models were determined, the non-linear (quadratic and cubic) models for load-time combinations were analyzed.

C O N V E C T I O N O V E N	MW[a] Time=8 min Load[b] = 2 (T8L2)	MW Time=10 min Load = 2 (T10L2)	MW Time=12 min Load = 2 (T12L2)
	MW Time=8 min Load = 3 (T8L3)	MW Time=10 min Load = 3 (T10L3)	MW Time=12 min Load = 3 (T12L3)
	MW Time=8 min Load = 4 (T8L4)	MW Time=10 min Load = 4 (T10L4)	MW Time=12 min Load = 4 (T12L4)

[a]MW represents the microwave oven.

[b]Load represents number of samples per load.

Figure 8. The 3 x 3 factorial arrangement of continuous time-load treatment combinations representing one of twenty-four replications. Other replications had the same time-load combinations.

Table 3. Top Five Microwave Linear Models

Rank	Combination	R^2
1	T12L3[a]	0.9428
2	T10L2	0.9391
3	T12L2	0.9354
4	T12L4	0.9339
5	T8L2	0.9151

[a]T and L represent the time interval in minutes and the number of samples per load, respectively.

No significant differences (P>0.99) were found between the linear and non-linear models for the T12L3, T10L2, T12L4, and T8L2 combinations. T and L represent time intervals in minutes and number of samples per load, respectively. However, while T12L2 was not significant at 95% level of probability for the cubic model, it was for the quadratic model. See Table 4 for non-linear results.

It was concluded that the measured microwave moisture contents had a linear relationship to the actual convection oven measurements and that the best linear model was the 12 minute and 3 samples per load combination (see Figure 5, page 19, and Table 3). The differences between the actual convection and the microwave moisture contents ranged from -0.82 to + 1.03% for the load-time combination (T12L3) model with a coefficient of determination of 0.9428.

Table 4. Non-Linear Microwave Models

Combination	Model	PR>F	R^2
T12L3[a]	Linear	0.0001	0.9428
	Quadratic	0.1802	0.9478
	Cubic	0.6810	0.9482
T10L2	Linear	0.0001	0.9301
	Quadratic	0.4648	0.9407
	Cubic	0.8200	0.9409
T12L2	Linear	0.0001	0.9354
	Quadratic	0.0383	0.9479
	Cubic	0.4732	0.9492
T12L4	Linear	0.0001	0.9339
	Quadratic	0.3860	0.9364
	Cubic	0.6683	0.9370
T8L2	Linear	0.0001	0.9151
	Quadratic	0.7195	0.9156
	Cubic	0.6575	0.9165

[a]T and L represent the time interval in minutes and the number of samples per load, respectively.

IV. PHASE FOUR: (CONVECTION PREDICTION EQUATION MODEL)

The calculated convection percent moisture (Mcoven) equation was analyzed using the microwave moisture contents (Mmoven) for the 9 continuous time-load combinations per replication. Total number of replications was 24. The model was based on the average of the 24 replications for the 9 time-load combinations. The purpose of the equation was to predict the moisture content for the convection oven from the measured microwave data.

The convection prediction model was restricted to the Mmoven, the time interval, the number of samples (load), and the interactions of Mmoven and time and of Mmoven and load. The time and load interaction was removed from the regression model analysis after determining the factor not to be significantly different at the 99% level of probability. Results of the analysis are shown in Table 5.

Significant differences ($P>0.99$) were found for time, load, and interactions of Mmoven and time and of Mmoven and load. However, the Mmoven was not significant at the 99% level of probability (see Type III (partial) Sum of Squares in Table 5). The prediction model for the convection percent moisture was found to be:

$$\begin{aligned} \text{Mcoven} = {} & 87.8706 + 0.0494\,(\text{Mmoven}) - 8.8054\,(\text{time}) + \\ & 7.9600\,(\text{load}) + 0.0965\,(\text{Mmoven})\,(\text{time}) - \\ & 0.0854\,(\text{Mmoven})\,(\text{load}) \quad \text{. . . . . Eq.1.} \end{aligned}$$

Table 6 shows the equation analysis.

Table 5. Convection Drying Model Analysis Using Microwave Moisture Contents from Load-Time Combinations

Source	DF	Type I SS	F Value	PR>F	DF	Type IIISS	F Value	PR>F
Mmoven[a]	1	553.67789	1575.09	0.0001	1	0.05749	0.16	0.68
Time	1	19.43131	55.28	0.0001	1	30.07769	85.56	0.0001
Load	1	15.52765	44.17	0.0001	1	6.42859	18.29	0.0001
Mmoven x Time	1	29.62981	84.29	0.0001	1	28.81820	81.98	0.0001
Mmoven x Load	1	5.90237	16.79	0.0001	1	5.90237	16.79	0.0001

Source	DF	Sum of Squares	Mean Square	F Value	PR>F	R-Square	C.V.
Model	5	624.16905	124.83381	355.12	0.0001	0.89424	0.6485
Error	210	73.81940	0.35152	Std. Dev.		Mcoven[b] Mean	
Corrected Total	215	697.98846		0.59289		91.41854	

[a]Mmoven represents the mean microwave oven moisture content.

[b]Mcoven represents the mean convection oven moisture content.

Table 6. Prediction Equation Analysis for Determining Convection Moisture Content

Parameter	Estimate	T for HO: Parameter = 0	PR> T	STD Error of Estimate
Intercept	87.8706	8.05	0.0001	10.9169
Mmoven[a]	0.0494	0.40	0.6863	0.1222
Time	-8.8054	-9.25	0.0001	0.9519
Load	7.9600	4.28	0.0001	1.8613
Mmoven x Time	0.09651	9.05	0.0001	0.0106
Mmoven x Load	-0.0854	-4.10	0.0001	0.0208

Prediction Equation:

Mcoven[b] = 87.8706 + 0.0494 (Mmoven) - 8.8054 (Time) + 7.9600 (Load) + 0.0965 (Mmoven x Time) -0.0854 (Mmoven x Load)

[a]Mmoven represents the microwave oven moisture content.

[b]Mcoven represents the convection oven moisture content.

The actual moisture content minus the predicted content (residual) for the convection oven were plotted against the predicted convection moisture content (predict) (see Figure 9). Negative slopes of the predicted moisture contents versus the residuals were observed for the different replications of microwave treatment combinations. (Notice the linear arrangements of points along lines at about 30° from the vertical axis.) It was concluded that the slopes were functions of the "fabricated" (bias) actual convection data. For each of the 24 runs, nine measured microwave moisture contents were compared to one convection moisture content (Figure 8, page 29). The scatter of data points reflected the different drying phenomena for the varying initial moisture contents. Higher variability was observed at lower moisture contents. Free and bound water are two forms of moisture available in all food stuffs. A good portion of the available moisture in the beans is bound. Bound water is that moisture which is held within a body by strong forces due to a variety of binding mechanisms. This bound water has different levels of tightness. The amount of bound water removed will vary with the temperature-time (hours) combinations in the dehumidifier (at preparation time) and with the samples themselves. At high moisture levels, more of the water is free and is removed rather uniformally. As the moisture content decreases, the ratio of bound water to free water increases; thus, contributing to more variability in results as the moisture content in the beans decreased.

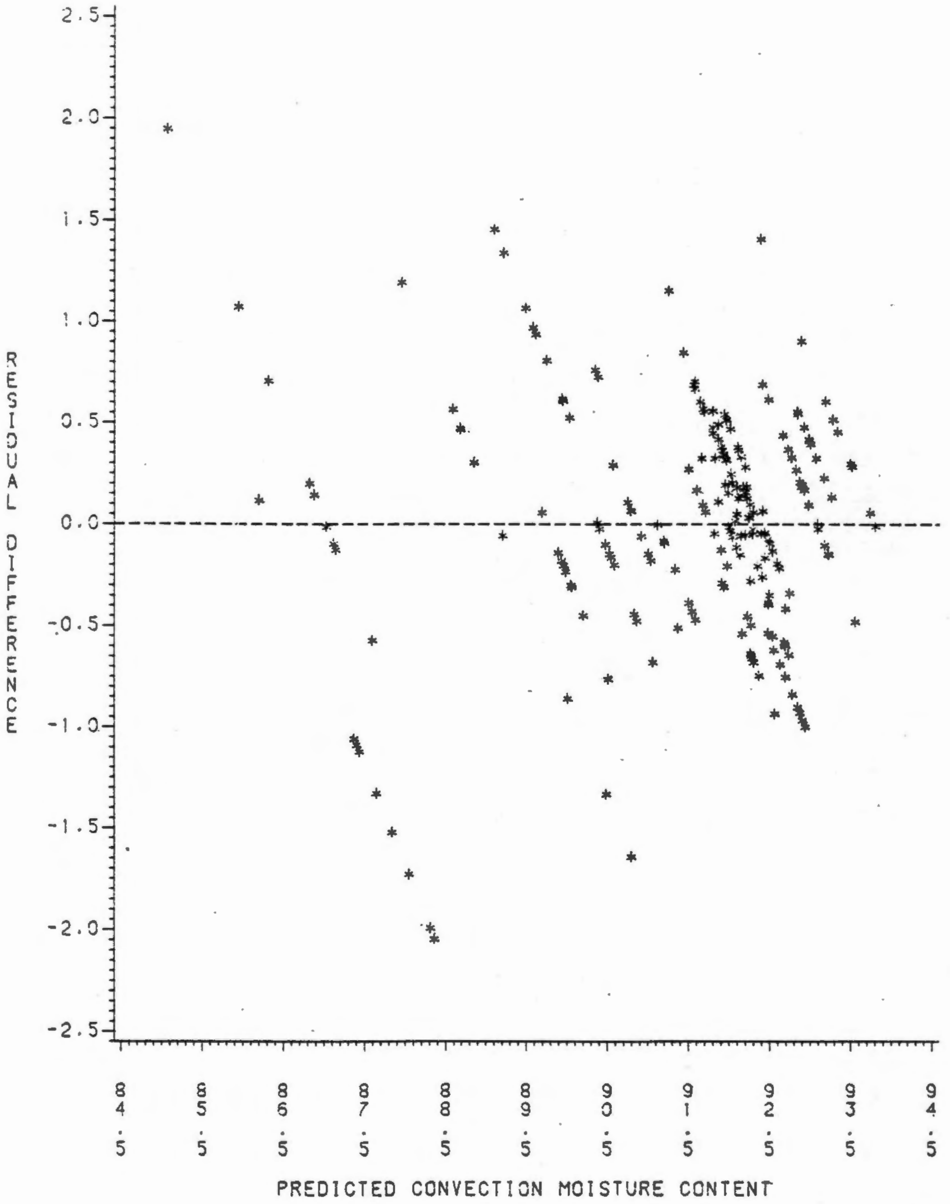

Figure 9. Actual minus predicted moisture contents for convection oven plotted against predicted convection oven moisture content using the microwave oven.

V. PHASE FIVE: (BEST MICROWAVE COMBINATIONS TO PREDICT CONVECTION MODEL)

Results from Phase Three concluded that T12L3 was the best time-load microwave combination for predicting the convection moisture content. T and L represented the time interval in minutes and number of samples per load, respectively. An equation based on the 12 minute time and 3 samples per load was established for predicting the convection moisture content.

The Mcoven equation (wet basis moisture content) included only the microwave moisture content (Mmoven, T12L3) as an independent parameter. Table 7 shows the final results. Moisture content as determined by the microwave heating was significantly lower ($P>0.99$) than that measured by the convection oven. Applying the intercept value and the linear coefficient generated by the analysis gave the prediction equation:

$$\text{Mcoven} = 1.2871 + 1.0048\,(\text{Mmoven}) \quad \text{.......... Eq. 2.}$$

The intercept (1.2871) may be related to the physical appearance differences between the charred convection samples (removal of sugar and other components) and the microwave samples when determining the measured moisture contents.

Residuals were calculated using Equation 2 with the data for the 24 replications of treatment T12L3. These are shown in Figure 10. The range of residuals was 1.038 to -0.828%. Mcoven represents the mean convection moisture content for the model. The range of variation

Table 7. Convection Prediction Analysis Using 12 Minute and 3 Sample Microwave Data

Source	DF	Type I SS	F Value	PR>F
Mmoven[a]	1	73.1209	362.86	0.0001

Source	DF	Sum of Squares	Mean Square	F Value	PR>F	R-Square	C.V.
Model	1	73.1209	73.1209	362.86	0.0001	0.9428	0.4910
Error	22	4.4332	0.2015		STD DEV	Mcoven MEAN	
Corrected Total	23	77.5542			0.4489	91.4185	

Parameter	Estimate	T for HO: Parameter	PR> T	STD Error of Estimate
Intercept	1.2871	0.27	0.7882	4.7324
Mmoven	1.0048	19.05	0.0001	0.0527

Prediction Equation: Mcoven[b] = 1.2871 + 1.0048 (Mmoven)

[a]Mmoven represents the microwave oven moisture content.

[b]Mcoven represents the convection oven moisture content.

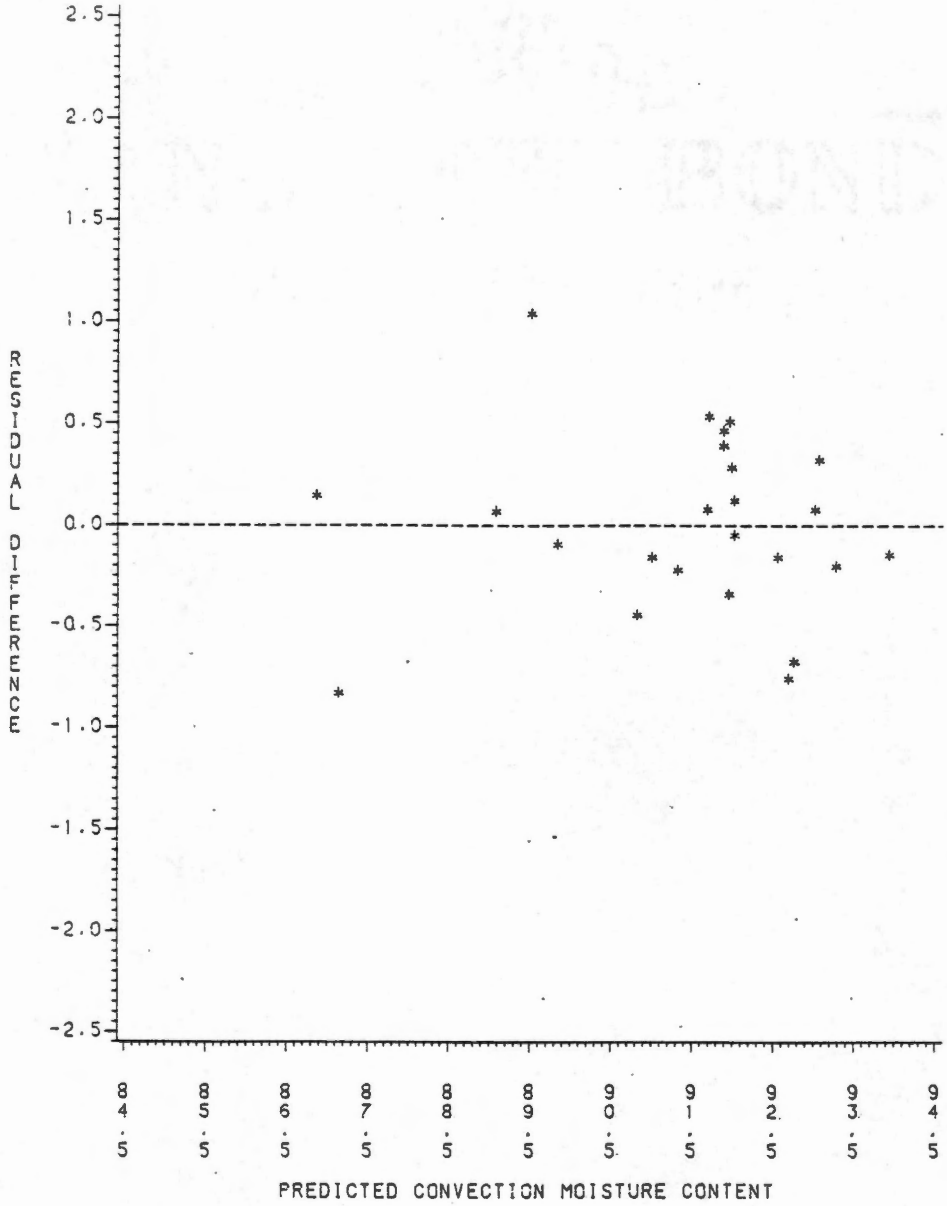

Figure 10. Residual difference for convection oven plotted against predicted moisture content using T12L3 microwave combination with the one variable model.

($\pm$ 0.94%) is not very large for a material containing, usually, greater than 90% moisture. Thus, the microwave procedure is acceptably precise (S.D.=0.45% HOH) for the purpose at hand. The matter of accuracy was not established since the moisture content by Microwave heating was always lower (intercept=1.29%). The matter of which method gave more accurate results is open to question, particularly since the samples dried in the convection oven were charred. Yet the results indicate the microwave results can be fit to a "standard" method by a simple, linear correspondence equation.

The possibility of using other microwave ovens is reasonable if one "calibrates" the oven to the same (close) power output as shown in Figure 7, page 22. Another problem that one should be conscious of is to avoid hot and cold spots for sample geometric locations.

From the researchers point of view, the use of microwave heating and Equation 2 would hasten chemical and nutritional analyses and for the food processors, it would shorten the holding period (storage before processing).

CHAPTER V

SUMMARY AND CONCLUSIONS

I. SUMMARY

Much research has been conducted on snap beans. Moisture content is usually an important factor of interest to the researcher and to processors. Presently, the food industry has no single standard for vegetable moisture determination. Many different methods have been proposed, but none have been accepted as a standard.

Some researchers have described the use of microwave energy for determining moisture content in food products. The proposal to use microwave energy as a "quick" method of moisture determination prompted a study to evaluate its potential for determining moisture content in snap beans. The study was conducted to compare a microwave oven procedure to the convection oven method for moisture determination. Emphasis was on correlating microwave measurements with convection oven drying results.

The moisture measurements were analyzed to evaluate the effect of the sample preparation method in the convection oven, the effect of continuous versus interrupted time intervals (microwave oven), the linear slope relationships between the different microwave treatment combinations and the convection oven, and the prediction equation for the moisture content, that would result from drying in a convection oven.

Puree samples were prepared in a food processor. The convection oven was operated at 100 $\pm$ 1° C with four (50 to 65 gram) samples. The Amana "Radarange" microwave oven was operated at the No. 6 power setting. Microwave sample size was 10 grams of puree beans. Time intervals 8, 10, 12, and 18 minutes and number of samples per load were 2, 3, and 4 for the microwave oven.

II. CONCLUSION

Convection Sample Preparation

The drying process required 24 hours at 100 $\pm$ 1° C in the convection oven. Of the parameters studied in this analysis, sample preparation was found to be non-significant. Whole-broken and puree samples gave the same indicated moisture contents. Either whole-broken or puree samples can be used.

Continuous vs. Interrupted Microwave Time Intervals

Of the parameters studied, three were found to be significant. Time and load interaction had a major effect upon the indicated moisture content. The larger the number of samples, the more moisture to be removed. During the pause periods of the interrupted time, the samples possibly cooled, thus affecting the amoung of energy necessary to reheat the samples and to remove moisture from the samples. The procedures gave different indicated moisture contents; thus, the interrupted time procedure was removed from further analyses.

Linear, Quadratic, and Cubic Relationships Established for the Measured Microwave Versus Convection Oven Moisture Contents

In this analysis, slope relationships were found to be linear between the measured moisture contents for the top five (those with the highest R^2 values) microwave and convection ovens. Quadratic and Cubic models were not significant at the 99% level of probability.

Convection Prediction Equation Model

Of the parameters analyzed, four were found to be significant. The time, load, and the interactions of the Mmoven-time and Mmoven-load had a major effect upon the indicated moisture content whereas the Mmoven itself did not. The prediction equation based on the average of the 24 replications for the 9 time-load microwave combinations was as follows:

$$\text{Mcoven} = 87.8706 + 0.0494\ (\text{Mmoven}) - 8.8054\ (\text{time}) + 7.9600\ (\text{load}) + 0.0951\ (\text{Mmoven})\ (\text{time}) - 0.0854\ (\text{Mmoven})\ (\text{load}) \quad \text{Eq.1.}$$

Any one of the 9 time-load microwave combination would predict the convection oven moisture content using the above equation.

Best Microwave Combination to Predict Convection Moisture Content

For the independent parameter studied in the final analysis, the Mmoven (T12L3 combination) was used. The microwave measurements were consistently lower than the actual convection oven measurements. The following equation was established to predict a moisture content by convection heating from microwave data (T12L3):

$$\text{Mcoven} = 1.2871 + 1.0048\ (\text{Mmoven}) \quad \text{Eq.2.}$$

The range of residuals was 1.038 to -0.828%. The microwave procedure was acceptably precise (S.D. = 0.45% HOH) for a material containing greater than 90% moisture.

Further testing is needed to verify the accuracy of Equation 2 for the convection moisture determination. The potential for microwave energy usage in determining moisture contents is high due to its ability to reduce drying times for food products.

III. RECOMMENDATIONS

The following recommendations should be considered for the different phases. In the first analysis, drying rate (phenomena) curves should be established to determine the bound water properties of snap beans. The convection drying period (24 hours) should be shortened and the temperature lowered in order to reduce the charring of samples. When charring occurs, sugars and other components are being removed as well as the moisture. In the second analysis, more testing is required to evaluate the interrupted time intervals in determining moisture contents. In the fourth analysis, bound water was removed at different energy levels at lower moisture contents. It is recommended that more replications at low moisture conditions be performed to improve the convection prediction equation. An alternative approach would be to use a definitive moisture method like the Karl Fischer titration as a standard to compare accuracies of methods that remove water by heating. In the final analysis, more tests should be performed using the 12 minute and 3 sample microwave combination to determine the accuracy of the convection prediction equation.

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