TECHNICAL REPORT
66-34-FD

AD

INVESTIGATION OF DRYING PROCEDURES FOR COMPACTED FOODS

by

L. F. Ginette

FMC Corporation
Santa Clara, California

Contract No. DA-19-129-AMC-228 (N)

May 1966

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

U.S. ARMY MATERIEL COMMAND

Food Division
FD-46

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FOREWORD

Physical requirements for special food packets designed for combat soldiers who must carry their entire supply of food during extended periods impose severe restrictions on both weight and volume of the food components. Additional requirements stress the need for a variety of relatively high caloric products which remain stable over prolonged periods and retain sufficient acceptability when eaten without preparation to assure complete consumption. In general, a number of cooked food items dehydrated by freeze-drying or other suitable procedures fulfill all of the above requirements except that relating to volume. On the basis of a growing body of experimental evidence, it appears feasible to increase the density of dried foods by compression into rectangular blocks which have the added advantage of favoring protective packaging and efficient packing. In order to avoid undue fragmentation through compression of dry, brittle food, it has been found practical to increase the moisture content to 8 - 20 percent prior to compression. This plasticizing treatment is generally effective in minimizing fragmentation and, in a number of cases, even provides for restoration during hydration of the component parts of the compressed mass to their initial size and shape. On the other hand, experience has taught that foods, in the cited moisture range are quite susceptible to deterioration during storage.

This investigation was undertaken to identify one or more efficient drying procedures to restore compressed bars of high moisture content to a moisture level compatible with the required storage life. The scope of this contract reflects the assumption that compressed bars of all compositions can be dried with commercial air drying equipment without significant deterioration of physical, chemical or organoleptic properties.

Most of the numerical data accompanying this report are based on the statistical analysis or summary of a substantial number of primary observations which are recorded in a separate volume as 121 tables, 132 graphs, and 54 photographs revealing the appearance of the dried bars. This second volume is not scheduled for reproduction.

This investigation was performed in the Central Engineering Laboratories of the FMC Corporation in Santa Clara, California through funds allocated to the project titled: Combat Feeding Systems. Mr. L. F. Ginnette served as Official Investigator. He was assisted by R. W. Farrier, S. W. Sierra, J. S. Lennon, J. Davis and M. H. Nosvati.

Project Officer and Alternate Project Officer for the U. S. Army Natick Laboratories were respectively, Dr. Maxwell Brockmann and Mr. Justin Tuomy of the Animal Products Branch, Food Division.

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ABSTRACT

Compressed food bars representing protein, carbohydrate and fat in all proportions likely to be encountered with natural products and adjusted to 15 - 25 percent moisture were dried in a forced draft air drier under controlled conditions to a residual moisture content below 5 percent. Rates of drying were studied in relation to wet and dry bulb temperatures of the air flow, composition of bars, shape of bars and pressure of compression. Observations were performed to identify the effect of the drying regimen on surface texture, density, migration of fat and soluble components, and organoleptic properties. Conditions for a practical air drying process were defined.

I. INTRODUCTION

This is the final report of the work initiated under U.S. Army Natick Laboratories Contract DA-19-129-AMC-228 (N).

The primary objective of the research program was to determine optimal, commercially practicable conditions for finish drying (to less than 5% moisture) of eleven specified, partially dried, compacted foods.

The foods were:

1. Non-fat milk solids
2. Dried apples
3. Freeze-dried spinach
4. Freeze-dried peas
5. Freeze-dried shrimp
6. Freeze-dried beef
7. A bacon-rice-egg white mixture
8. Potato flakes
9. A flour-dried-egg mixture
10. A flour-dried-egg mixture containing 25% fat
11. A flour-dried-egg mixture containing 50% fat

Certain specifications with regard to these foods were laid down in the Statement of Work.

Summarized briefly, these were:

1. Moisture content before drying 15-25% D.B.
2. Moisture content after drying 5% or less, D.B.
3. Combined surface area of compacted piece - $>1.2\ cm.^2$

Certain observations to be made on the foods were also specified. These were:

1. Description of surface before and after drying
2. Analysis for moisture, fat and protein before drying
3. Assessment of organoleptic qualities before and after drying
4. Determination of moisture content during and after drying
5. Determination of moisture distribution during and after drying
6. Examination for loss of fat and fat migration
7. Examination for migration of soluble components

The research program was to lead to:

1. an evaluation of physical and chemical factors which have a major effect on the drying rate of bars.

2. an evaluation of the major physical and chemical and organoleptic changes resulting from drying.
3. determination of an optimal, commercially practicable air-drying procedure for compacted foods.

The program was thus very broad in scope, possessing both "engineering" and "food technology" aspects. For convenience in organizing the discussion, these two aspects are treated more or less separately in this report.

The discussion and condensed data will be found in Volume I. The entire raw data is assembled in Volume II.

II. SUMMARY AND CONCLUSIONS

The work reported herein was divided in several phases, as follows:

A. Foods were acquired and preconditioned to an initial moisture content in the specified range.

B. A forced-circulation air dryer was modified and adapted for the drying study.

C. Preliminary compaction and drying tests were made on all foods to establish reasonable conditions for more detailed study.

D. A set of drying rate determinations was made for each food. Specifically, conditions were as follows:

1. Air dry-bulb temperatures - 150°, 160°, 180°F.
2. Air absolute humidities - 0.02, 0.04 lb H_2O/lb air.
3. Piece shapes
    a. Disk, 2.25 in. dia, 0.5 in thick.
    b. Bar, 1 x 2 x 1/2 in.
4. Compaction pressures- three levels for each food.

E. A number of physical, chemical and organoleptic evaluations were made on each food, before and after drying. These included surface description, measurement of density and porosity, moisture content and distribution, soluble solids migration, fat content and migration, organoleptic acceptability.

F. Major conclusions resulting from the work were:

1. All of the foods could be formed into reasonably cohesive disks and bars, by compression, at moisture contents somewhere between 15 and 25%.

2. All of the compacted foods could in some way be air-dried to a moisture content of 5% or less, although some foods (especially the bacon-rice-egg) dried very slowly.

3. The foods fell into three categories with respect to organoleptic changes due to drying. They were:

    a. Group 1 (improved by drying).
    Apples, 25% fat combination, flour-egg white.

    b. Group 2 (unchanged by drying).
    Bacon combination, spinach, milk, 50% fat combination.

    c. Group 3 (harmed by drying).
    Shrimp, potatoes, beef, peas.

4. Moisture content was not uniform after drying; The region near the center of the disks and bars was noticeably more moist than the exterior.

5. Soluble solids did not migrate during drying.

6. The recommended environmental conditions for a commercially feasible air-drying process for compressed food bars may be summarized as follows:

Type of Dryer	Tray - Tunnel
Air Temperature	150°F, Approximately
Tray Loading	1.25 lb/ft^2 "
Air Velocity	250 ft/min. "
Piece Size	1/2 in. cubes "

7. Conditions for preparation of suitable compressed food bars are as follows:

Food	Compression Psi	Moisture Content
75% Wheat Flour, 25% Egg White	1000	20%
50% Wheat Flour, 25% Egg White, 25% Fat	1500	20%
25% Wheat Flour, 25% Egg White, 50% Fat	750	15%
45% Prefried Bacon, 35% Cooked Rice, 20% Egg White	1500	16%
Freeze-Dried Beef	2250	16%
Freeze-Dried Spinach	750	15%
Freeze-Dried Peas	1500	18%
Potato Flakes	3000	24%
Air Dried Apples	3000	15%
Non-Fat Milk Solids	500	15%
Freeze-Dried Shrimp	1500	16%

The conditions given in the preceding table are adequate to produce bars of sufficient mechanical strength at the listed moisture contents. It is possible that at higher moisture contents lower pressures might be used.

(In some cases (see text) organoleptic properties of the bars were harmed by compression at higher pressures; in other cases they were improved.)

8. Several factors had major effects on the drying rate of the bars. Air dry-bulb temperature, bar dimensions, and porosity had effects in the expected direction, i.e., high temperature, reduced size and high porosity all tended to increase the drying rate. In general, the effects of these variables appeared to be independent of the bars' material.

Apart from the effects of the above variables, each bar material had its characteristic drying rate, which was probably related to the different hygroscopicities of the various materials.

9. The effects of environmental factors and bar properties on drying rate strongly suggest that resistance to diffusion of vapor within the bar is the rate-limiting factor. A simplified theoretical treatment based on this principle correctly predicted the effects of air temperature, bar shape, and porosity, and also correctly predicted the shape of the drying curves.

III. EXPERIMENTAL

A. Selection and Preparation of Foods.

1. Food Samples

A list of the ingredients for the eleven specified foods - type or variety information, condition as purchased, and sources - are listed in Table 1*.

All were purchased dried, except peas and spinach, which were freeze-dried in the FMC pilot freeze-dryer in the following manner:

Prior to freeze-drying, the peas and spinach were cooked in boiling water for five minutes. The cooked foods were evenly spread on trays and frozen at -10° F. The trays were then loaded into the freeze-dryer. The pressure was rapidly brought to 100 microns Hg, absolute, and heating plate temperatures were set at 130°F. To insure thorough drying, 24 hour drying cycles were used. The vacuum was then broken with nitrogen gas, trays removed, and product immediately packaged. The dried foods were put into a large double-walled polyethylene bag (4 mils per wall thickness) under a steady bleed of nitrogen gas into the inner bag bottom. Each bag was then sealed and stored for at least one week to induce moisture equalization. Then the food was filled into cans, the cans were evacuated, flushed with nitrogen and sealed.

Myverol 1800 was selected as the fat because of its high melting temperature (154 - 158°F.) which would be compatible with at least one of the oven dry bulb temperatures.

2. Pre-conditioning

As purchased, none of the foods met the specified 15 - 25 (% Dry Basis) moisture content before drying. To aid in selecting a particular moisture content for each food within the specified range, preliminary compression and drying experiments were performed at different levels of moisture in the food. Where possible, moisture contents near the low end of the range (15%) were selected.

The food samples were pre-conditioned to the selected moisture levels by exposure to controlled-humidity atmospheres in vacuum desiccators. Humidity was controlled by means of saturated salt solutions or concentrated sulfuric acid. (Figure 1) By this method, it was possible to change the moisture content of the foods in a relatively short time. Furthermore, the moisture in the pre-conditioned food was uniformly distributed throughout the product. The data pertaining to the pre-conditioning of the foods is noted in Table 2. Additional specific information on some of the foods is listed below.

*Tables with arabic numbers are found in Appendix ; tables with roman numbers are found in the text.

Wheat flour 75% - egg white 25%

The specified proportion of flour and egg white were thoroughly mixed together before pre-conditioning.

Wheat flour 50% - fat 25% - egg white 25% - wheat flour 25% fat 50% - egg white 25%

Before pre-conditioning, the specified proportion of flour and egg white were thoroughly mixed together. The fat was added to the pre-conditioned food just before compression.

Pre-fried bacon 45% - pre-cooked rice 35% - egg white 20%

The rice and egg white were combined together, mixed, and pre-conditioned. The bacon was added to the pre-conditioned rice-egg white just before compression.

Freeze-dried beef

The beef steaks were passed through a table-model vegetable cutter before pre-conditioning.

Freeze-dried shrimp

Before pre-conditioning, the shrimp were broken in thirds to aid moisture sorption and compressibility.

3. Formation of Bars

In making the compacted foods, the standard Carver Laboratory Hydraulic Press (Model B) with a supplementary low-range pressure gage was used.

Two die shapes were utilized in forming the foods: (1) a cylindrical die furnished with the Carver press as a standard accessory (24.7 sq. cm. flat surface area), and (2) a one-inch by two-inch rectangular die set made up to conform to the sample size specifications as listed in the Statement of Work (12.9 sq. cm. flat surface area).

A considerable amount of preliminary compression work was done in order to establish the compression procedures and range for each food. Experience gained from the compression studies of Lampi (3) was drawn on during this time.

During the experimentation associated with bar formation, it was necessary to define cohesiveness - how well the compacted food stuck together. Thus far, cohesiveness has been evaluated subjectively according to appearance and handling properties. The following scale was set up for grading purposes: Excellent - no fragmentation or sloughing off of compacted material; Good - small degree of fragmentation or sloughing off of compacted material; Fair - moderate degree of fragmentation or sloughing off of compacted material; Poor - large degree of fragmentation of compacted material. A grade of less than good was not considered sufficiently cohesive to withstand normal handling without breakage or erosion.

Compression characteristics of the pre-conditioned foods are noted in Table 3. The compression conditions listed in Table 3 were used for the formation of the compacted disks and bars in the main body of the drying tests. Additional pertinent specific information on some of the foods is as follows:

<u>Wheat flour 75% - egg white 25% - wheat flour 50% - egg white 25% - wheat flour 25% - fat 50% - egg white 25% - non-fat milk solids</u>

The first bars made were characterized by a noticeable decrease in density from top to bottom, and less than excellent cohesiveness on the lower edge of the disks. These defects were due to the nature of the food (granular, high density) and the way it was compressed (stationary female die, mobile upper male die). A satisfactory bar was achieved by two compressions, inverting the die between compressions.

(Dual compression resulted in satisfactory bars only when two specific pressures were used. Deviation from the exact combination of pressures produced the same effect as one compression.)

<u>Pre-conditioned non-fat milk solids and wheat flour 75% - egg white 25%</u>

These were also compacted at three different dual compression levels each.

<u>Pre-fried bacon 45% - pre-cooked rice 35% - egg white 20%</u>

Pre-fried bacon was taken from the can and passed through a table model vegetable cutter and then placed in 0° F. freezer. Just before compression, weighted amounts of rice - egg white and frozen bacon were passed through the vegetable cutter to ensure thorough mixing.

<u>Freeze-dried beef</u>

The food was compressed in a chilled die.

Potato

An attempt was made at forming, either by molding or compression a compacted disk out of the potato granules specified in the Statement of Work. At moisture contents between 15 - 25 grams of water per 100 grams of dry substance, no cohesive disk could be formed by compression. Molding was tried without success. Potato flakes were used as a substitute.

Air-dried apples

Pre-conditioned apples were passed through a Hobart grinder (orifices 6 mm in diameter) then compressed in a chilled die.

The foods were compressed the day before they were to be dried. Moisture changes between compression and drying were minimized by holding the bars in a closed container.

B. Evaluation and Analytical Procedures

The following procedures were followed in the examination of the compacted foods. Where appropriate, identical test procedures were used before and after drying.

1. Moisture loss

Moisture loss during drying was determined by periodic rapid weighings using a Mettler K-7, top-weighing balance, with a scale graduation of 0.1 grams.

2. Densities

Densities were determined by making volume measurements in the Beckman Air Comparison Pycnometer, Model 930, on a known weight of material.

Two modes of Pycnometer operation were used: (a) standard operation mode (one to two atmosphere operation), and (b) inert gas purge (one to two atmosphere operation). The standard operation mode was used to make volume measurements on all of the foods except the air-dried apples, for which the inert gas (helium) purge was required. (Apparently, the air-dried apples belong to the group termed "surface active material".)

3. Linear measurements

Measurements of thickness, diameter, length and width were made by using vernier calipers. ("Thickness" is the dimension in the direction parallel to die motion.)

4. Surface descriptions

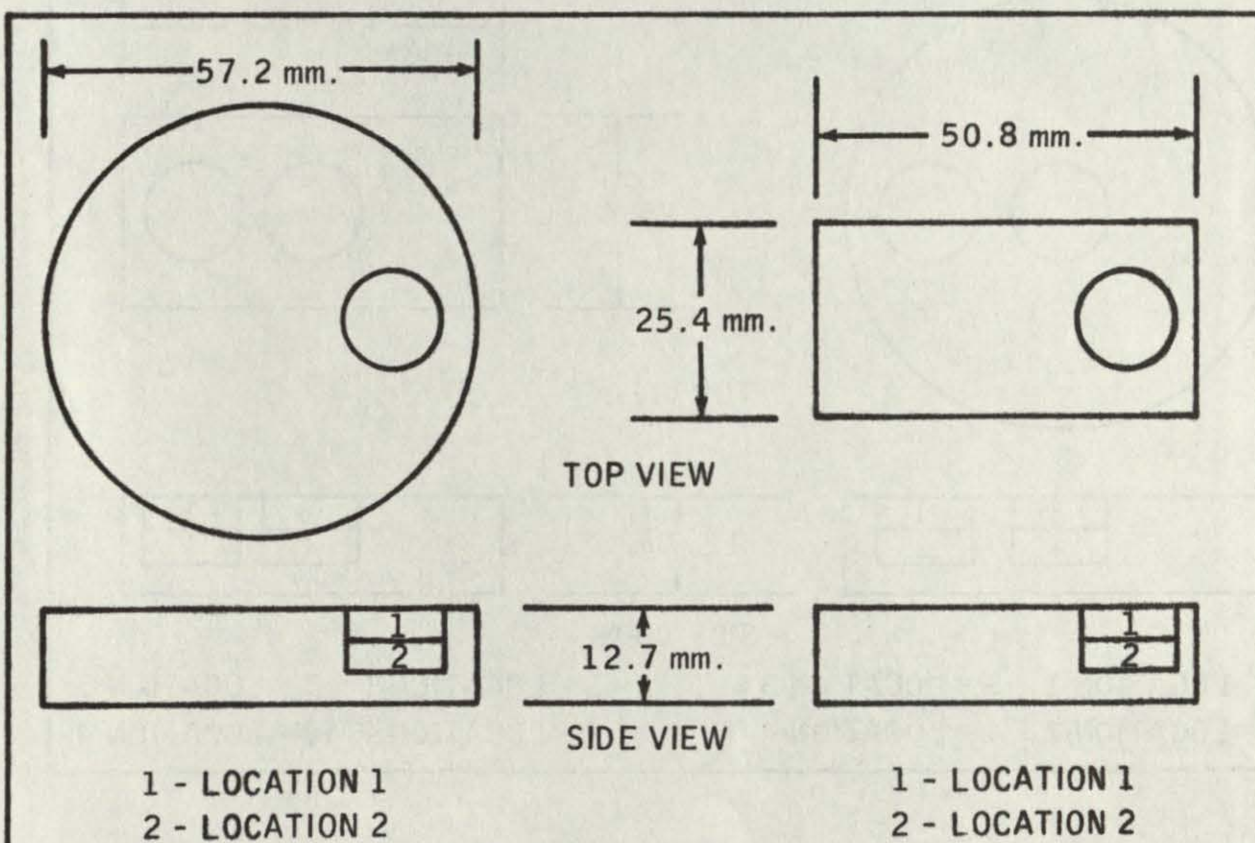
Photographs were taken to aid in making surface descriptions. The pictures were taken with a Nikon F 35 mm camera using AGFA IFF film having an ASA of 25.

For pictures of individual disks and bars (to show texture changes), a one to two magnification was obtained using an extension tube. A 200-watt spot with a snoot was used as a light source.

The same Nikon camera mentioned above, but without the extension tube, was used to take group pictures (to show color changes). Two 200-watt lamps were used as a light source.

5. Soluble solids

Samples for soluble solids determinations were taken and coded as follows:

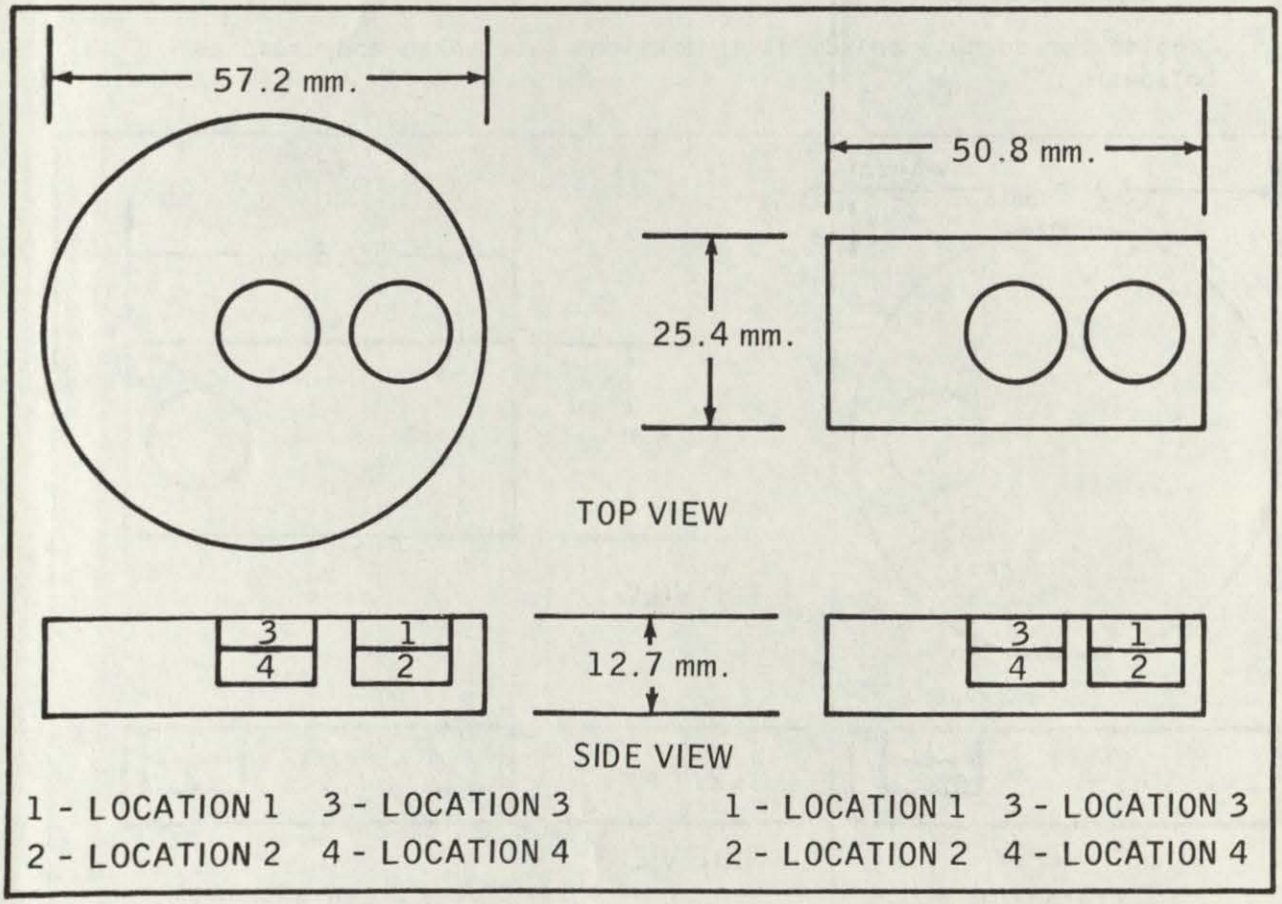


The samples were dried at 212° F. for an hour in previously dried and weighed aluminum dishes containing No. 2 Whatman Filter Paper. After cooling and weighing, the samples were washed with 800 ml of warm (120° F.) water in 100 ml aliquots. After drying again at 212° F. for an hour, the samples were cooled, weighed, and the total soluble solids were calculated from the weight loss.

6. Moisture contents

Moisture contents were determined using the vacuum oven method (16 hours, 70° C. and approximately 29" Hg).

Samples for moisture distribution were taken and coded as follows:



7. Crude fat analyses were performed using a Soxhlet extraction apparatus with petroleum ether as a solvent. The extraction was carried out for seven hours at a solvent condensation rate of 3 - 4 drops per second. The extracted fat was dried, cooled and weighed.

The results for the eleven foods are noted in Table 4 on a moisture free basis.

8. Protein analyses were performed according to the AOAC method for total protein as follows: a weighed fat-free, moisture free sample plus 18 grams of sodium sulfate (anhydrous) and one gram of copper sulfate were digested with 30 ml of H_2SO_4 for about two hours in a 800 ml Kjeldahl flask. After cooling, 200 ml of water was added along with enough NaOH to make the solution strongly alkaline. It was then distilled with a standard boric acid solution for about 30 minutes. This distillate was then titrated with 0.1 N HCl and calculated for total protein using the following formula:

$$\frac{\text{ml of HCl} \times \text{N of HCl} \times 0.017032 \times 100}{\text{weight of sample}} = \%NH_3 \times 5.14 = \%\ \text{protein}$$

The results for the eleven foods are noted in Table 4.

9. Organoleptic Evaluation

Two types of ballots were used to evaluate the foods. One ballot contained the hedonic scale* and the second a ranking column.

The hedonic scale was used to get some idea of the relative acceptability of the compressed, pre-conditioned foods before drying. The means of the hedonic ratings for each food are noted in Table 5.

The low rating for the milk was due to the fact that there was a separation of the components of the milk (Figure 2). The lower layer consisted of a very wispy material while the topmost layer was just the oppositive, very viscous. (The mean ratings for flavor and odor of milk that had been neither pre-conditioned nor compressed were 6.3 and 5.6 respectively.)

For the organoleptic evaluation of the foods before and after drying, the ranking column was used. A sample ballot is illustrated in Figure 3. The results of the taste panel were evaluated statistically according to the methods of Kramer and Twigg (2).

In carrying out the ranking test, the bars were evaluated in the morning and the disks in the afternoon. At each sitting, a set of six coded samples was presented to each judge. The set represented three compression levels, sampled before and after drying.

* 9-point hedonic scale

The procedures for preparation of the eleven foods for tasting are noted below. The first three compacted food materials in the list were incorporated into recipes before testing to simulate their anticipated use (4). (The recipes for the dried and undried samples were adjusted to correct for the difference in moisture content of the foods.)

a. Wheat flour 75% - egg white 25%

Recipe for griddlecakes:	Dried bar material (gm)	Undried bar material (gm)
Wheat flour - egg white	45	52
Milk (fluid)	93	85
Shortening (melted)	5	5
Baking powder	1	1

The granular ingredients were sifted together. The milk and melted shortening were combined with the other ingredients and stirred 50 times. The batter was baked on a greased skillet.

b. Wheat flour 50% - fat 25% - egg white 25%

Recipe for plain cake:	Dried bar material (gm)	Undried bar material (gm)
Wheat flour - fat - egg white	58<	60<
Milk (fluid)	32	30
Sugar (granulated)	30	30
Baking powder	1	1

The granular ingredients were sifted together and the milk was added. The batter was stirred 150 times, poured into a pan and baked at 350° F. for 20 minutes in a preheated oven.

c. Wheat flour 25% - fat 50% - egg white 25%

Receipe for plain cake:	Dried bar material (gm)	Undried bar material (gm)
Wheat flour - fat - egg white	50	51
Milk (fluid)	22	22
Sugar (granulated)	37	37
Baking powder	1	1

The granular ingredients were sifted together and the milk was added. The batter was stirred 150 times, poured into a pan and baked at 350° F. for 20 minutes in a preheated oven.

d. Prefried bacon 45% - precooked rice 35% - egg white 20%

Recipe for casserole:
The bar materials were rehydrated in a slight excess of water, poured into a pan and baked at 350° F. for 20 minutes.

e. Freeze dried beef

The ground beef steak was rehydrated in a slight excess of water, poured into a pan and baked for 20 minutes at 350°F.

f. Freeze-dried spinach

The bar material was rehydrated in a slight excess of boiling water.

g. Freeze-dried peas.

The peas were rehydrated by cooking in boiling water for two minutes.

h. Potato flakes

Hot (160° F.) water was used to rehydrate the ground dried and undried material to the same moisture level (7.7%).

i. Air-dried apples

The bar material was placed in a Waring Blendor, and sufficient tap (70° F.) water was added to rehydrate the material to the same level (80%). The Blendor was turned on low speed for 30 seconds.

j. Non-fat milk solids

Forty-five grams of dried and forty-six grams of undried bar material was made up to a pint with tap water (70° F.) and placed in a refrigerator for two hours before serving.

k. Freeze-dried shrimp

The pieces of shrimp were rehydrated in warm (120° F.) water for one hour, drained and placed in the refrigerator to cool for two hours.

C. Dryer, Test Section, and Preliminary Runs

A Blue Line Horizontal Convection Oven, Model POM 136C, was modified for air-drying of the compressed foods. An overall view of the oven is shown in Figure 4, upper. Modifications included construction and installation of the test section, which can be seen through the left-hand window, and installation of the wet-bulb control and recording system. The modified drying oven is discussed below.

1. Temperature control and measurement

a. Dry bulb

The oven was originally supplied with a saturable-reactor-type dry-bulb controller. No modification was made to this controller. Dry-bulb temperatures are measured by means of a mercury-in-glass thermometer inserted through a port in the oven at top center.

b. Wet bulb

A wet-bulb recording and control apparatus was installed for this project. Most of the components are visible in the photograph, Figure 4, upper.

Wet-bulb temperature is regulated by injecting steam into the oven through a port just above the blower, to insure that steam is thoroughly mixed with the recirculating air stream. Steam flow is controlled by means of a Fisher type GG diaphragm valve, which is operated by a Foxboro two-mode circular chart recorder-controller. The thermal bulb of the recorder-controller is encased in a porous-sleeve water box located in the recirculation duct, below the test section. The deionized water supply reservoir for the water box is visible in Figure 4, above the oven.

Wet-bulb values appearing in data sheets are based on mercury-in-glass thermometer wet-bulb measurements made at the oven vent.

2. Air circulation

Air is recirculated within the oven by means of a blower located downstream from the test section. Air flow through the test section is horizontal, and from the right as one faces the test section. Air velocity can be varied by means of a hand-operated damper at the blower inlet (not visible in Figure 4). Maximum air velocity is about 250 fpm in the test section.

3. Test section

The test section consists of a vertical column of six removable weighing shelves located as shown in Figure 4, upper. A close-up of one shelf is shown in Figure 4, lower. (Three test disks of freeze-dried shrimp are shown on the shelf in the photograph; the shelf can accommodate up to nine disks or bars.) Drying air passes horizontally above and below the test objects, from right to left.

Also visible in Figure 4, lower, are shelves which accommodate two rows of dummy objects upstream from the weighing shelves. The dummies are the same size and shape as the test objects. The purpose of the dummies is to reduce "leading edge" effects so that the air flow pattern around the objects in the test section will be more representative of a large dryer.

Uniformity of air flow across the column of weighing shelves is improved by the static screen at far right. This screen consists of a perforated metal sheet of 40% open area. Perforations are 1/8 inch in diameter on 3/16 inch staggered centers.

4. Dryer uniformity trials

The uniformity of temperature and heat transfer within the test section was verified by measuring the rate of heating and final temperature of a disk of tin, provided with a central thermocouple. Specifications of the tin disk were as follows:

Thickness - 1.34 cm
Diameter - 5.75 cm
Weight - 246 g.

Results of the final uniformity trials (after installation of the dummy objects and static screen) are given in the following table.

HEATING CURVES, TIN TEST DISK, OVEN SET POINT, 160° F.

Time,	Disk Temperature					
Minutes	Shelf 1	Shelf 2	Shelf 3	Shelf 4	Shelf 5	Shelf 6
0	75	75	75	75	75	75
1	90	90	89	87	87	86
2	103	103	100	97	97	94
3	113	112	110	105	105	102
4	122	121	117	113	113	109
5	129	127	124	119	119	115
6	135	133	129	125	125	120
7	139	137	134	129	130	124
8	144	141	138	134	133	128
Final	158	158	157	157	157	157

There appears to be a tendency for heat transfer to be somewhat better on the upper weighing shelves than on the lower, but air temperature appears to be quite uniform. The small variation in heat transfer rate (±25%) is probably without effect on the drying rate. The average overall coefficient of heat transfer to the test disk was 3.7 BTU/hr-ft^2 °F.

5. Preliminary Drying

To assist in planning for the main body of the drying tests, preliminary drying experiments were conducted on all of the foods. After several initial runs, the following combinations of dry and wet bulb temperatures, corresponding with absolute humidity levels of 0.020 and 0.040 pounds of water per pound of dry air, were selected for the main tests.

Dry bulb temperatures	150	160	180
Wet-bulb temperature - 1	92	94	97
Wet-bulb temperature - 2	106	107	109

An upper limit of 0.040 absolute humidity was chosen to represent an ambient air temperature higher than would be expected anywhere in this country. The lower limit was chosen as representing a more reasonable level.

IV. DISCUSSION OF RESULTS

(Raw data collected on the eleven foods is compiled in Volume II.)

In the following section, the results are summarized and discussed, first according to the physical, chemical and organoleptic evaluations, and then with reference to drying characteristics.

A. Organoleptic, Physical and Chemical Evaluation

Of the data gained from the various evaluation procedures, that of the taste panels proved to give the most information about effects of drying on the compacted disks and bars. Nevertheless, some factors found in the physical and chemical evaluations amplified the conclusions of the organoleptic evaluation. In the following table are listed the shapes, compression levels and drying conditions recommended for each food on the basis of the overall evaluation.

Bar Composition	Press and Dwell (psi/sec)	Dry Bulb Tempera- ture (°F)	Absolute Humidity Level (lb H_2O/ lb dry air)	Shape
Potato Flakes	3000/60	150	-*	-**
Air-Dried Apples	3000/60	160	-	-
Freeze-Dried Shrimp	1500/60	160	0.02	Bars
Flour-Dry Egg White Combination	1000/30, die inverted, 1500/30	150	-	-
Non-Fat Milk Solids	500/30, die inverted, 500/30	150	0.04	-
25% Fat Combination	1500/30	150	-	-
50% Fat Combination	750/30	160	0.02	Bars
Freeze-Dried Spinach	750/60	150	-	Bars
Freeze-Dried Beef	2250/60	150	0.04	Bars
Bacon Combination	1500/60	180	-	Disks
Freeze-Dried Peas	1500/60	150	0.04	Bars

* 0.02 or 0.04 Level   ** Disks or Bars

1. Organoleptic Evaluation

Results of statistical analyses of rank sums are given along with the data in Table 1 through 11 of the Appendix, Volume II. Significance levels are indicated, where appropriate. These rank sums were converted to rank means for use in the discussion of the organoleptic data. The tables (6 - 14) containing the rank means are found in the Appendix of Volume I.

The effects of drying varied with each food,as shown by the following table of rank totals:

Rank Totals*

Food	Dried	Undried
Potatoes	1652	1876
Apples	2021	1759
Shrimp	1370	1646
Flour-Egg White	3013	1767
Milk	1461	1563
25% Fat Combination	2008	1646
50% Fat Combination	1841	1813
Spinach	1723	1805
Beef	1447	1829
Bacon Combination	1640	1636
Peas	1865	2545

* Number of Panelists Vary With Food.

With some foods, drying resulted in improved scores. (Apples, 25% fat combination and flour-egg white). For others, drying did not seem to have much effect (50% fat combination, spinach, bacon combination, and milk). For still others, drying lowered the taste panel scores (shrimp, potatoes, beef and peas).

In the following discussion, the foods are grouped according to the above categories.

Group I: Apples, 25% Fat Combination, Flour-Egg White

The dried samples were preferred over the undried samples, regardless of shape or compression, with one exception. Of the flour-egg white bars compressed at the lowest level (500 psi, die inverted, 1000 psi), those dried at 160°F/94°F were ranked significantly inferior to the other samples, causing the mean rank of the dried samples to be slightly lower than that of the undried samples:

Rank Means*of Flour-Egg White Bars

	500psi/1000psi**	750psi/1250psi	1000psi/1500psi
Dried	3.4	3.5	4.2
Undried	3.5	3.4	3.1

* Rank Columns: 1-6 (Best).

** 30 Second Compression, Die Inverted, 30 Second Compression.

Relative Preference (In Dried Samples)
In general, disks scored higher than bars and both disks and bars formed at high pressures scored better than those formed at lower pressures (Table 6). Now, disks dried more slowly than bars, and high-compression food dried more slowly than low-compression foods. This preference for high-compression and for disks over bars is therefore consistent with the preference for dried over undried.

No preference was shown for either humidity level, (Table 8). Practically no difference was produced by changing dry-bulb temperature (Table 7), although there was a very slight preference for foods dried at lower temperatures, which required longer drying times.

In short, within this group of foods, drying improved scores generally, and conditions which necessitated long drying times gave the most improvement.

Group II: 50% Fat Combination, Spinach, Bacon Combination, Milk

Mean scores for dried vs. undried samples are shown in Table 9. The panel found a slight preference on the average for undried over dried.

Relative Preference
Consistent with the above finding, the panel also preferred bars over disks and low-compression over high-compression samples (Tables 10 & 11). Further, they slightly preferred samples dried at low humidity and showed a stronger preference for foods dried at the lowest temperature.

In short, in this intermediate group we see the beginning of a reversal of all the trends shown in Group I, but no indication of gross reduction in organoleptic acceptability due to drying.

Group III: Shrimp, Potatoes, Beef, Peas

In this group the undried samples were generally given higher scores than the dried samples.

Relative Preference of Dried Samples
Rank means for foods in this group are shown in Tables 12 and 13. In general, these foods showed a fairly strong reversal of the trends exhibited by the foods in Group I. There was a preference for low-compression foods, foods dried at low-humidity, for bars over disks, and an increase in the degree of preference for foods dried at low temperature.

With foods in this group, then, there was a consistent preference for foods dried under conditions that led to short drying times at a given temperature, and, superimposed on this, a preference for foods dried at low temperatures.

Conclusions from Organoleptic Evaluation

The following table lists the best conditions, among those tested, for drying the eleven foods.

Bar Composition	Press and Dwell (psi/sec)	Dry Bulb Tempera- ture (°F)	Absolute Humidity Level (lb H_2O/ lb dry air)[2]	Shape
Potato Flakes	3000/60	150, 180	-*	-**
Air-Dried Apples	3000/60	160	-	-
Freeze-Dried Shrimp	1500/60	160	0.02	Bars
Flour-Dry Egg White Combination	1000/30, die inverted, 1500/30	150	-	-
Non-Fat Milk Solids	500/30, die inverted, 500/30	150	0.04	-
25% Fat Combination	1500/30	150	-	-
50% Fat Combination	750/30	160	0.02	Bars
Freeze-Dried Spinach	750/60	150	-	Bars
Freeze-Dried Beef	2250/60	150	0.04	Bars
Bacon Combination	1500/60	180	-	Disks
Freeze-Dried Peas	1500/60	150	0.04	Bars

* 0.02 or 0.04 Level ** Disks or Bars

2. Physical Characteristics

The physical characteristics of the dried and undried compacted, pre-conditioned foods are outlined in Tables 12 through 33, Volume II Appendix, except where noted in the text below.

a. Cohesiveness and Strength

No change in the cohesiveness of the compacted foods resulted from drying, except for the 25% fat and 50% fat combination foods. At 150° drying temperatures (below the melting point of the fat) cohesiveness declined somewhat. Loss of moisture caused the edges to be easily eroded away. Temperatures above the melting point of the fat prevented the loss of cohesiveness from occurring during drying as the fat completely permeated the compacted foods.

Drying significantly affected the overall strength of some disks and bars:

Flour, Egg White - Disks and bars dried at 180°F/97°F were damaged by "normal" handling.

Spinach and Apples- The disks and bars increased tremendously in overall strength during drying.

b. Dimensions

Drying caused four types of dimensional changes to occur, viz.

1. Increase in thickness, shrinkage in diameter (disks), length and width (bars) - potatoes, shrimp, bacon combination and peas.
2. Increase in all dimensions - apples.
3. Decrease in all dimensions - milk.
4. No change in thickness, shrinkage in diameter (disks), length and width (bars) - flour-egg white, 25% fat and 50% fat combination, spinach and beef.

c. Density

Samples for density determination were taken from both discs and bars, before and after drying. For the first three foods tested - apples, potatoes and shrimp - pycnometer runs were made on samples from all eighteen lots. The results obtained on these foods showed that all drying treatment produced the same change in density. Thereafter, only randomly selected samples of each food were run.

A table of the average true density values for each food is given below in gm/cc:

Food	Undried	Dried
Potatoes	1.47	1.50
Shrimp	1.34	1.32
Bacon Combination	1.25	1.26
Peas	1.40	1.42
Apples	1.41	1.12
Milk	1.44	1.48
Flour-Egg White	1.32	1.45
25% Fat Combination	1.29	1.22
50% Fat Combination	1.21	1.19
Spinach	1.40	1.47
Beef	1.25	1.27

Apples were the only food that showed a significant change in true density upon drying.

d. Fat Migration

Significant migration of fat occurred only in the 25% and 50% fat combination foods. Drying temperatures above the melting point of the fat (154°F) resulted in disks and bars that were completely permeated with fat.

e. Fat Losses

The amount of fat lost by the 25% fat combination on drying was negligible. Calculated on a per cent wet basis, the amount of fat lost was less than 0.01 at the most, and this occurred at the 180°F dry bulb temperatures.

The 50% fat combination food lost more fat than the 25% combination. Fat losses by the former are noted in the following table. (Wet basis percentages).

(F°) Drying Conditions	DISKS 500 psi	750 psi	1000 psi	BARS 500 psi	750 psi	1000 psi
150/92	0	0	0	0	0	0
150/106	0	0	0	0	0	0
160/94	0	0.01	0.01	<0.01	<0.01	<0.01
160/107	0	0.01	0.03	<0.01	<0.01	0.03
180/97	0.02	0.02	0.06	0.10	<0.01	0.08
180/109	0.06	0.02	0.08	0.70	0.10	0.09

Even at the 180°F dry bulb temperatures the amount of fat lost was not really large. However, the fat lost created a somewhat messy situation in the dryer.

3. Soluble Solids

Comparisons of percent soluble solids (dry basis) of the compacted pre-conditioned foods are found in Tables 34 through 55, Volume II Appendix. The percent soluble solids was determined at all drying temperatures for the first three foods, potatoes, apples and shrimp. As expected, (because of the low initial moisture content of the foods), there was no significant migration of solids within the disks and bars.

Thereafter, the percent soluble solids was determined first for the compacted foods dried under the most-and least-severe drying conditions. These consistently failed to yield evidence of a significant migration of solids. The remaining samples were not run.

The shrimp disks and bars were made up of rather large pieces of shrimp. Consequently, the non-uniform nature of the samples may have prevented detection of any significant migration of solids.

Results for the 50% fat combination were somewhat lower in value than the 25% fat combination as expected, due to the higher fat content of the former. The higher fat content might also have interfered with the analysis, particularly at the 180°F dry bulb temperature.

The results for the bacon combination samples dried at 180°F/97°F appear to be somewhat lower than at 150°F/106°F or for the undried samples. The complete saturation of the disks and bars with the fat from the bacon at the 180°F dry bulb temperatures was probably the reason for the lower values.

There appears to be no significant transfer of solids within pieces of either shape which can be attributed to the effect of drying.

4. Moisture Content

In tables 56 through 121, Volume II Appendix, are noted the comparisons of moisture contents (% dry basis) of the compacted foods at various stages of drying. The uniformity of the moisture distribution after drying varied with each food:

Potatoes: The moisture distribution data for 150°F/106°F and 160°F/107°F, two relatively mild drying conditions, displayed the most uniformity after drying. The same data for 180°F/97°F, the most severe drying condition, showed the least uniformity after drying.

Apples: The moisture distribution data displayed relative uniformity.

Shrimp: Relative uniformity with exceptions, due probably to the heterogeneous nature of the disks and bars.

Flour, Egg White: Relative uniformity with the exception of the disks and bars dried at 180°F/97°F, the most severe drying condition.

Milk: Disks dried at 150°F/92°F, and 160°F/107°F, and bars dried at 150°F/92°F, 160°F/94°F, and 180°F/109°F displayed relative uniformity in moisture content.

25% and 50% Fat Combination and Bacon Combination: The moisture distribution data obtained after drying showed non-uniformity for all drying conditions , due to the poor moisture vapor transfer within the bar (a consequence of the high fat content, and low porosity).

Spinach: Relatively uniform.

Beef: The moisture content of the bars after drying was relatively uniform except for Location 4, the center of the bar. Moisture distribution data for the disks, on the other hand, indicated much less uniformity in moisture content.

Peas: With the exception of the samples dried at the 180°F dry bulb temperatures where the moisture loss occurred quite rapidly, all of the disks and bars dried to a uniform moisture content.

5. Surface Description

a. Surface Color

Group pictures showing the disks and bars dried under the most and least severe drying conditions are presented in Figures 1 through 20, Volume II, Appendix.

The color of disks and bars of the following foods was not affected by the drying conditions: peas, shrimp, flour-egg white, milk and spinach. The color of the other six foods was affected by the drying conditions in the following manner:

Potatoes: The 150°F/106°F drying conditions appear to have little or no effect on the color of the disks and bars. The 180°F/97°F drying conditions, on the other hand, produced a light brown color. Actually, this brown color developed from the inside out; the interior of all the disks and bars dried at 180°F/97°F were a light to dark brown color. The same was true for the 180°F/109°F drying conditions. At the lower drying temperatures, there was only a faint development of this brown color. The 2250 psi/60 sec compression level, which produced the slowest drying, appeared to aggravate the development of the brown color for those samples dried at 180°F/97°F.

Apples: There was a slight development of brown color upon drying, particularly noticeable in the disks dried at 180°F/97°F. Compression did not appear to have any effect on the color development.

25% and 50% Fat Combination: The group pictures show the effect of the drying temperatures on the fat; the darker color of the disks and bars at 180°F/97°F indicates that the fat melted during drying. Compression did not appear to have any effect on the color development over drying.

Bacon Combination and Beef: Drying caused deepening of the brown color on the surface of the disks and bars, particularly at the highest (180°F) dry bulb temperatures. Compression did not appear to have any effect on the color developed during drying.

The color of all of the foods was the same on all surfaces, for both shapes.

b. Surface Texture

Close-up shots of individual disks and bars dried under the same conditions mentioned above are shown in Figures 21 through 54, Volume II, Appendix. For the first three foods all compression levels are shown. For the remaining eight foods only the lowest compression level is shown, as no differences attributable to compression were detected.

The differences between the dried and undried pieces were categorized into three groups, according to the nature of the observed effect.

1. Appearance of Cracks: milk

2. Roughening: flour-egg white, 25% and 50% fat combination, bacon combination and potatoes.

3. No Effect: spinach, beef and peas.

The effects were especially noticeable at the more severe drying conditions.

Only two of the eleven foods - potatoes and apples - showed any effect due to compression. For both, increased pressure resulted in smoother disks and bars.

The top and bottom views of the disks and bars are differentiated as to whether their respective surfaces are flat or rounded. With the exception of the potatoes, neither top nor bottom surfaces of any foods showed changes due to drying.

For the potatoes, the top views of the disks show more change due to drying than the bottom views. This was due to greater effect of compression on the top surface than the bottom surface.

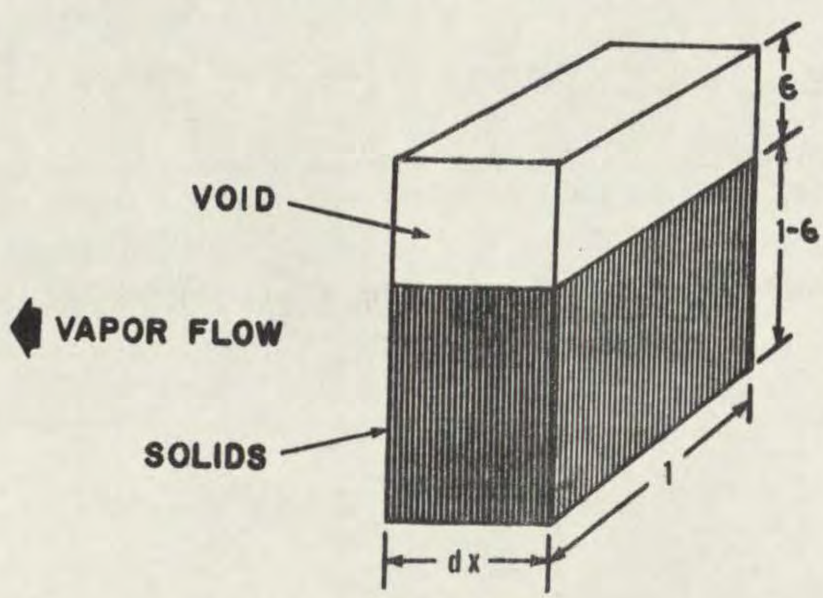
The top surfaces of the potato disks dried at 150°F/160°F were rougher than those dried at 180°F/97°F. Lower temperature resulted in a longer drying time, more expansion and a rougher surface than the higher temperatures.

B. Drying Rate Theory, Compressed Food Bars

1. Mechanism

The bars consist of pieces or granules of food containing a relatively small amount of moisture. In all cases the moisture content is within the hygroscopic range, so free liquid is absent. Further, the compressed bars contain 10 - 40 percent of void space, as measured by the air-comparison pycnometer. It therefore seems reasonable that migration of moisture from the interior of the bar to the surface is accomplished in the vapor phase. If so, the drying rate may be controlled by the resistance to diffusion of vapor through relatively stagnant atmospheric gases in the void spaces inside the bars. An approximate drying rate equation applicable to such a situation is derived in the following text.

2. Derivation of the Drying Rate Equation



The above sketch indicates an element of an infinite slab undergoing drying. The element has unit area normal to the direction of moisture movement, and thickness dx. The element contains moisture, solids, and void space. It is assumed that movement of moisture occurs only by diffusion of vapor in the voids and only in a direction normal to the element, as indicated by the arrow. The moisture in the solids is assumed to be in equilibrium with the vapor in the adjacent voids. The vapor diffuses at a rate given by the following equation (originally proposed in a slightly modified form by Krischen in 1938):

$$G = x - \left(\frac{1}{K}\right)\left(\frac{MDP}{RT}\right)\varepsilon\left(\frac{1}{1-y}\right)\frac{\partial y}{\partial x} \qquad (1)$$

where G = vapor mass velocity, lb/hr-ft^2

D = diffusivity of water vapor in air, ft^2/hr

ε = void fraction

K = a diffusion resistance factor, dimensionless

P = absolute pressure, atmospheres

R = gas constant, ft^3-atm/lb-mole $^{-\circ}$K

x = distance in direction of vapor movement

T = absolute dry bulb temperature, °K

y = mol fraction vapor in atmosphere

The relation between the vapor and moisture gradients is given by (2).

$$\frac{\partial y}{\partial x} = \frac{dy}{dc}\frac{\partial c}{\partial x} \qquad (2)$$

where c is the moisture content dry basis, $\frac{dy}{dc}$ is the slope of the (de)sorption isotherm.
Therefore, by combining the equations (1) and (2),

$$G = -\frac{1}{K}\left(\frac{MDP}{RT}\right)\varepsilon\left(\frac{1}{1-y}\right)\left(\frac{dy}{dc}\right)\frac{\partial c}{\partial x} \qquad (3)$$

The mass of vapor diffusing out of the element in time $d\Theta$ is given by (4).

$$\left[G_{(x+dx)} - G_{(x)}\right] d\Theta = -\frac{1}{K}\frac{MDP}{RT}\varepsilon\frac{\partial}{\partial x}\left[\frac{1}{1-y}\frac{dy}{dc}\frac{\partial c}{\partial x}\right] dx d\Theta \qquad (4)$$

This must be equal to the mass of moisture given up by the solids, which is $\rho_s \frac{\partial c}{\partial \Theta} dx d\Theta$, where ρ_s is the weight of solids per unit volume.

By equating these last two expressions, and cancelling the like terms,

$$\frac{\partial}{\partial x}\left[\frac{1}{1-y}\frac{dy}{dc}\frac{\partial c}{o x}\right] = \left[\frac{K\rho_s RT}{\varepsilon MDP}\right]\frac{\partial c}{\partial \Theta} \qquad (5)$$

If the assumption is made that the material in the bar is everywhere locally in equilibrium with the atmosphere inside the bar, some useful substitutions can be made in equation (5):

Let H_R = the relative humidity in equilibrium with moisture content c.

$$\text{Then } 1-y = 1-H_R\left(\frac{P^*}{P}\right) \qquad (6)$$

P^* = Vapor pressure of water at the temperature in the bar.

P = The total pressure of gas in the bar.

$$\text{and } \frac{dy}{dc} = \left(\frac{P^*}{P}\right)\frac{dH_R}{dc} \qquad (7)$$

$$\text{so } \frac{1}{1-y} = \frac{P^*}{P-H_R P^*}\left(\frac{dH_R}{dc}\right) \qquad (8)$$

When the moisture content of the material is fairly low and /or the temperature is low, the quantity $P^*/(P-H_R P^*)$ can be approximated by P^*/P. In such a case, equation (5) becomes (9).

$$\frac{\partial}{\partial x}\left[\frac{dH_R}{dc}\left(\frac{\partial c}{\partial x}\right)\right] = \left[\frac{K\rho_s RT}{\epsilon MDP^*}\right]\frac{\partial c}{\partial \theta} \qquad (9)$$

For the special case in which the slope of the isotherm is constant, equation (9) becomes identical in form to the equation for the transient heat conduction in a slab. The solution of (9) can then be represented in the following form:

$$(c/co) = f\left[\frac{K\rho_s RT\ X^2}{\epsilon MD(dH/dc)\ P^*\ \theta}\right] \qquad (10)$$

X = the half-thickness of the slab
θ = the drying time
C_o = the original concentration of moisture

Conclusions that can be drawn from equation (10) are that the fraction of the initial moisture content at a given time should be;

1. inversely proportional to vapor pressure of water at the dry-bulb temperature,
2. proportional to the square of the half-thickness,
3. inversely related to the porosity,
4. inversely related to hygroscopicity,
5. substantially higher in the center of the piece than near the edges.

Another practical conclusion relates to the expected shape of the curves of moisture content vs. time. As shown in Carslaw and Jaeger[1] and elsewhere, the moisture content of the pieces should in the early stages of drying, be a linear function of the square root of the drying time.

Further, the slope of the curve will be proportional to the square root of the diffusion parameter of equation (9).

It is shown in the following discussion of the drying rate studies that these conclusions are valid and should be useful in extending the data to fit situations not covered in the present very limited study.

(Parenthetically, it should be noted that numerical solutions of equation (9) can be readily obtained. Digital computer programs of sufficient flexibility already exist for such equations. Unfortunately the appropriate data (i.e. the isotherms) are not usually available.)

In reporting the raw drying data, plots of moisture content vs. the square root of the drying time were used (Vol. II, Figs. 55 to 187), since this was expected to lead to nearly straight-line relationships. However, these plots showed a pronounced "warming up" effect, so the curves do not appear to have the shape that would be predicted by the preceding derivation. This "warming time", during which the temperature of the piece is well below the the temperature of the air in the dryer, is appreciable. (Fig. 5 shows a time-temperature curve for an apple disk, for example.) If the drying curves for disks are adjusted by assuming no significant loss of weight during the first seven minutes, the curves do have the correct shape. This is shown in Fig. 6 , in which representative sets of data have been plotted against the square root of the adjusted drying time. In each case, the first seven minutes were discounted, and the time scale for each run was adjusted by a constant factor in order to superimpose all the curves. The scale factors used for the individual runs are listed below. (In figure 6 , abscissa equals (net drying time) ÷ (factor).)

Food	Temperature	
	150	180
Spinach	21.7	13.8
Peas	29.2	21.8
Milk	16.6	11.2
Apple	34.0	20.3
Bacon, Rice, Egg	57.5	50.8

The line drawn through the data points represents the analytical solution of the partial differential equation for one-dimensional diffusion (at constant diffusivity) in an infinite slab. This seems to provide a very good means of correlating the data, undoubtedly good enough for all practical purposes. By this method it should be possible to calculate a characteristic drying rate parameter for each food on the basis of a few runs, and then make fairly accurate predictions of the effects of nearly all the environmental variables.

C. Drying Rates - Observations of Disks and Bars

Drying curves for all the foods are shown in Figures 55 to 187*. In all cases the moisture content has been plotted against the square root of this drying time (expressed in minutes). After an initial warm-up period, nearly all food produced drying curves which had a substantially linear portion.

All foods but two - those containing 25 and 50 percent fat - showed "normal" drying behaviour at all temperatures. The two "fatty" foods showed anomalous behaviour at temperatures above the melting point of the fat, but normal behaviour at lower temperature.

1. Effect of Dry-bulb Temperature and Piece Shape

The effects of dry-bulb temperature and piece shape are typified by the results shown in Table I, which are for eight of the foods at the lowest compression level and wet-bulb temperature.

TABLE I

Time to Reach 1/3 of Original Moisture Content, Minutes

Air Temp.	Shape	NFMS	Spin	EW-F	Shrimp	Peas	Apple	Meat	Potato
		Food							
180	Bar	45	41	50	61	112	114	161	142
	Disc	56	74	79	81	174	137	151	174
160	Bar	67	76	72	148	187	231	174	174
	Disc	96	132	123	137	262	289	182	346
150	Bar	100	90	112	144	246	320	219	361
	Disc	110	182	149	196	299	441	400	484

The sharp dependence of drying rate on dry-bulb temperature and piece shape is readily apparent in Table I. The drying rate appears to be roughly proportional to the vapor pressure of water at the dry-bulb temperature. This effect is demonstrated in Table II in which are listed the products of the drying times for Table I and the vapor pressure of water, expressed in atmospheres.

* Appendix, Part II.

TABLE II

(Time to Reach 1/3 of Original Moisture) X (Vapor Pressure)

Food

Air Temp.	Shape	NFMS	Spin	EW-F	Shrimp	Peas	Apple	Meat	Potato	MEAN
180	Bar	23.0	21.0	25.6	31.2	57.3	58.4	82.4	72.7	48.3
180	Disc	28.7	37.9	40.4	41.5	89.1	70.1	77.3	89.1	
160	Bar	21.6	24.5	23.2	47.7	60.2	74.4	56.0	56.0	49.2
160	Disc	30.9	42.5	39.6	44.1	84.4	93.0	58.6	111.4	
150	Bar	25.3	22.8	28.3	36.4	62.2	80.9	55.4	91.3	52.5
150	Disc	27.8	46.0	37.7	49.6	75.6	111.6	101.2	112.4	

In general, bars dried faster than discs. Drying times for discs were 38% longer than drying time for bars on the average. This difference in rate is approximately in proportion to the square of the "equivalent thickness", (or volume to surface ratio) a result that would be expected in a diffusion controlled process occurring in a slab-like object. Application of the "equivalent half-thickness" rule is illustrated in Table III-A, where the times from Table II-A have been divided by the square of the appropriate equivalent half-thickness (given in inches)

TABLE III

(Time) X (Vapor Pressure) ÷ (Equivalent Half-Thickness^2)

Food

Air Temp.	Shape	NFMS	Spin	EW-F	Shrimp	Peas	Apple	Meat	Potatoe	MEAN
180	Bar	1120	1023	1247	1519	2791	2844	4013	3540	2262
180	Disc	959	1266	1349	1386	2976	2341	2582	2976	1979
160	Bar	1052	1193	1130	2323	2932	3623	2727	2727	2213
160	Disc	1032	1420	1323	1473	2819	3106	1957	3720	2106
150	Bar	1232	1110	1378	1773	3029	3940	2698	4446	2450
	Disc	928	1536	1259	1657	2525	3727	3380	4088	2387
MEAN		1053	1258	1281	1688	2845	3263	2892	3582	

Mean for all Bars - 2308

Mean for all Discs - 2157

The extent to which the temperature and shape factors used above can account for variation in the drying rate are quantitatively shown by an Analysis of Variance of the Data in Table III, viz:

Analysis of Variance, Data of Table III

Source of Variation	D/F.	Sum of Squares	Mean Square	F
Total	47	50962603		
Between Foods	7	43428933		
Within Foods	40	7533670		
Residual Temp. (T)	2	841581	420790	2.33
Residual Shape (S)	1	273760	273760	1.52
TXS	2	107937	53968	1
Pooled Interactions with foods	35	6310393	180296	

Standard error = 425
C.U. = 19%

The residual (unaccounted for) effects of temperature and shape are not significant above the 10% level. Therefore, the temperature and shape factors used above seem adequate to account for the effects of those two variables within the (rather sizeable) experimental standard error of 19%.

To summarize, then, it may be said that the drying rate is roughly proportional to the vapor pressure of water at the dry-bulb temperature and inversely proportional to the equivalent half-thickness of the piece.

2. Differences Between Foods - Effect of Porosity

Tables I to III show that the drying rates of individual foods vary considerably. This is no doubt due in part to differences in the intrinsic water-binding properties of the foods (i.e., the isotherms). To some extent, however, the differences between foods seem to be related to porosity (fraction of void space).

In Table IV, below, the mean time factors from Table III are listed along with the porosity as calculated from air-pycnometer measurements made on the pieces discs and bars before drying.

TABLE IV

Food	$\frac{\text{Time} \times \text{V.P.}}{(\text{Thickness})^2}$	Porosity
NFMS	1053	.35
Spin	1258	.38
EW-F	1281	.33
Shrimp	1688	.35
Peas	2845	.35
Meat	2892	.18
Apple	3263	.32
Potato	3582	.35
B,R-EW	(Very Long)	.13

There appears to be a perceptible tendency for the more porous foods to dry more rapidly. For the data in the above table the effect is not statistically significant, probably because the porosity effects tend to be masked by the intrinsic difference in water-binding by the different foods.

3. Effect of Compression Level

Compression pressure has a definite effect on the drying rate of the bars. In 94 out of 132 cases, disc and bars compressed at higher pressures dried more slowly than those compressed at low pressures. The effect is undoubtedly related to differences in porosity. Unfortunately, we were not able to gather enough data to establish a quantitative relation between porosity and drying rate. Some porosity measurements were made on each food at each compression level. The results are shown in Table V.

TABLE V

Effect of Compression on Porosity

Food	Pressure	Porosity	Average
NFMS*	500/500	.354)	
	750/500	.373)	.324
	750/750	.246)	
SPIN*	500	.384)	
	750	.382)	.367
	1000	.335	
EW-F*	500	.333)	
	750	.282)	.296
	1000	.273)	
SHRIMP*	1000	.353)	
	2000	.288)	.299
	3000	.255)	
PEAS	1500	.354)	
	1750	.347)	.343
	2000	.328)	
APPLE	1000	.315)	
	2000	.303)	.293
	3000	.261)	
MEAT	2000	.180)	
	2250	.200)	.187
	2500	.1821)	
POTATO	1500	.362)	
	2250	.345)	.350
	3000	.344)	
BR-EW	1500	.129)	
	1750	.126)	.128
	2000	.129)	

* These four foods showed the strongest relation between porosity and compression level

4. Effect of Wet-bulb Temperature

In general, the changes in wet-bulb temperatures had little effect on drying rate. It appeared that all of the bars could be dried to 5% average moisture at the highest wet-bulb temperature used, which, at 150° dry-bulb, corresponded to a relative humidity of nearly 25%.

D. Recommended Drying Procedure

The physical, chemical and organoleptic evaluations indicated that the foods should be dried at moderate temperatures. For most foods it would probably be best to keep the drying time as short as possible at a given temperature. This can be done in a variety of ways as suggested by the theory and experimental evidence.

One obvious improvement would be to reduce the size of the pieces. A one-half inch cube, for example would have an equivalent half-thickness of 0.0835 inches, as compared to 0.143 inches for the 1x2x1/2 inch bars and 0.173 inches for the discs. Cubes would then be expected to dry in about 1/3 the time required for bars, and in about 1/4 the time required for discs.

Another improvement, suggested by the theory, would be to dry the food under vacuum. Even a modest reduction in pressure would produce a substantial increase in the drying rate (by increasing the diffusivity). A vacuum dryer for these foods would be more expensive than an air dryer, but only about half as expensive as a freeze dryer. Very low pressure would not be required. A barometric condenser or Nash pump would probably produce as low a pressure as would be needed (50 mm, for example). No mechanical vacuum pumps or refrigeration would be required.

If, however, cost considerations were to prohibit any drying method other than the cheapest, i.e., air drying, the following system is recommended:

Type of dryer: Counter-current tunnel

Air temperature: About 150 degrees F.

Tray loading: About 1.25 lb/ft^2

Air velocity: About 250 fpm

Piece size: 1/2 inch cubes

Under the conditions, the drying times should range from about 30 minutes for fast-drying foods such as milk solids to 120 minutes for slow-drying foods such as potato flakes.

E. Approximate Drying Cost

The cost of finish drying of compressed food bars, if carried out by the procedure recommended above, is not very great. The following cost formula for tray-type dryers is based on data published by Aries and Newton (Chemical Engineering Cost Estimation, McGraw - Hill, 1956, page 33).

$$\text{Installed cost} = 4500\ (\theta W)^{0.6}\ \text{dollars}$$

where θ = drying time, hours

W = feed rate, hundred of pounds/hr.

By way of example, a tray-tunnel dryer to process 1000 lb./hr. of material having a 2 hour drying time showed cost about $16,000. The annual amortization on such a unit, assuming a 2,400 hours of operation annually, and a five year amortization period, would amount to about 0.4¢/lb. of material. Such cost would be negligible.

V. LITERATURE CITED

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4. Lowe, Belle, Experimental Cookery, 4th edition. John Wiley and Sons, Inc, New York 1958

VI. APPENDIX

TABLE 1

DESCRIPTIONS OF FOOD SAMPLES
(AS PURCHASED)

Food Item	Type or Variety	Conditions as Purchased	Brand and/or Distributor
Precooked rice	Long grain white	Cooked, dried	General Foods, Inc.
Potato granules	White meat Idaho	Cooked, dried	R. T. French Co.
Potato flakes	Unknown	Cooked, dried	Pillsbury Company
Air-dried apples	Gravenstein	Dried	Towne House Safeway Stores, Inc.
Non-fat milk solids	--	Dried	Carnation Company
Dry egg white	--	Dried	Hirsch Bros. Co. San Francisco, Calif.
Prefried bacon	--	Prefried	Oscar Mayer & Co.
Freeze-dried peas	Unknown	Frozen	Flav-R-Pac No. Pacific Canners & Packers, Portland, Oregon; Dried, FMC
Freeze-dried spinach	Unknown	Frozen	Flav-R-Pac No. Pacific Canners & Packers, Portland, Oregon; Dried, FMC
Dry wheat flour	Unknown	Dried	Wondra, General Mills, Inc.
Freeze-dried shrimp	Medium Jumbo	Dried	Kraft Foods, Dist.
Fat (Myverol 1800)	Distilled Monoglycerides	Granular	Distillation Products Ind.
Freeze-dried beef steaks	--	Dried	Armour & Company

TABLE 2

PRECONDITIONING CHARACTERISTICS OF DRIED FOODS

Food	Amount (gm)	Moisture Content before Preconditioning (% Dry Basis)	Preconditioning Solution	Time (Hrs.)	Moisture Content after Preconditioning (% Dry Basis)
Dry wheat flour 75%, dry egg white 25%	200	10.18	sat. sol. KNO_3	30	21.59
Dry wheat flour 50%, dry egg white 25%	150	9.80	sat. sol. KNO_3	30	22.99
Dry wheat flour 25%, dry egg white 25%	150	9.03	sat. sol. KNO_3	54	29.13
Precooked rice 35%, dry egg white 20%	165	8.24	sat. sol. KNO_3	24	15.70
Freeze-dried beef	56	0.44	sat. sol. KNO_3	24	16.74
Freeze-dried spinach	100	1.19	sat. sol. NaCl	18	16.54
Freeze-dried peas	120	0.24	sat. sol. NaCl	39	16.58
Potato flakes	100	7.91	sat. sol. KNO_3	30	25.00
Air-dried apples	227	33.92	conc. H_2SO_4	20	14.35
Non-fat milk solids	155	3.34	sat. sol. KNO_3	32	15.59
Freeze-dried shrimp	90	1.58	sat. sol. NaCl	24	15.92

TABLE 3

COMPRESSION CHARACTERISTICS OF PRE-CONDITIONED FOODS

Food	Moisture Content (%-Dry Basis)	Amount (gms.)	Press and Dwell (psi/sec)	Dimensions before drying (mm)	Density before drying (gm/cc)	Cohesivenes
Dry wheat flour 75%, dry egg white 25%	20.09	35	750/30, die inverted, 1250/30	12.8 x 57.5	1.023	excellent
Dry wheat flour 50%, fat 25%, dry egg white 25%	17.24	35	1250/30, die inverted, 1750/30	11.7 x 57.4	1.156	excellent
Dry wheat flour 25%, fat 50%, dry egg white 25%	14.57	34	750/30, die inverted, 1000/30	12.1 x 57.4	1.086	excellent
Prefried bacon 45%, precooked rice 35%, dry egg white 20%	20.59	36	1750/60	12.8 x 58.2	1.039	good
Freeze-dried beef	16.74	31	2250/60	11.9 x 58.0	0.976	excellent
Freeze-dried spinach	16.54	27	750/60	12.0 x 57.8	0.857	excellent
Freeze-dried peas	16.58	29	1750/60	12.0 x 57.8	0.857	excellent
Potato flakes	25.49	31	1000/60	12.6 x 57.1	0.930	excellent
Air-dried apples	14.35	36	2000/60	12.5 x 57.3	1.117	excellent
Non-fat milk solids	15.59	36	750/30, die inverted, 750/30	13.1 x 57.3	1.066	excellent
Freeze-dried shrimp	16.18	30	1750/60	13.3 x 57.7	1.035	excellent

TABLE 4

FAT AND PROTEIN ANALYSIS OF DRIED FOODS

Food	% Fat[1]	% Total Protein[2]
Dry wheat flour 75%, dry egg white 25%	0.58	29.24
Dry wheat flour 50%, fat 25%, dry egg white 25%	29.04	37.54
Dry wheat flour 25%, fat 50%, dry egg white 25%	56.34	50.32
Precooked rice 35%, prefried bacon 45%, dry egg white 20%	26.40	40.27
Freeze-dried beef	24.93	93.76
Freeze-dried spinach	2.59	36.86
Freeze-dried peas	1.96	27.49
Potato flakes	0.24	8.14
Air-dried apples	0.69	1.34
Non-fat milk solids	0.56	32.74
Freeze-dried shrimp	3.46	89.82

[1] Moisture free
[2] Moisture and fat free

TABLE 5

ORGANOLEPTIC EVALUATION OF UNDRIED, COMPACTED PRE-CONDITIONED FOODS

Food	Mean of the Hedonic Ratings	
	Flavor	Odor
Dry wheat flour 75%, dry egg white 25%	6.4	6.9
Dry wheat flour 50%, fat 25%, dry egg white 25%	5.7	5.3
Dry wheat flour 25%, fat 50%, dry egg white 25%	7.1	5.9
Precooked rice 35%, prefried bacon 45%, dry egg white 20%	7.4	7.0
Freeze-dried beef	6.2	5.8
Freeze-dried spinach	6.1	6.2
Freeze-dried peas	7.0	5.9
Potato flakes	7.0	6.3
Air-dried apples	6.4	6.5
Non-fat milk solids	4.4	5.2
Freeze-dried shrimp	5.9	5.7

TABLE 6

Rank Means* of Compacted Dried Foods (Group 1) -

Compression Level X Shape

	Apples			25% Fat Combination			Flour-Egg White			
Shape	1000 psi	2000 psi	3000 psi	1000 psi	1250 psi	1500 psi	500 psi**	750 psi	1000 psi	Shape Mean
Disks	3.8	3.8	3.9	3.9	3.6	3.9	3.6	3.9	3.9	3.81
Bars	3.6	3.7	3.7	3.7	4.0	4.0	3.3	3.3	3.7	3.66
Mean	3.7	3.75	3.8	3.8	3.8	3.95	3.45	3.6	3.8	

* Rank Columns 1-6 (best)
** First Compression

Compression Means

Low........ 3.65
Medium..... 3.72
High....... 3.85

TABLE 7

Rank Means* of Dried Compacted Foods (Group 1)

Compression Level X Shape X Dry Bulb Temperature

Dry Bulb Temperature (°F)	Shape	Apples 1000psi	Apples 2000psi	Apples 3000psi	25% Fat Combination 1000psi	25% Fat Combination 1250psi	25% Fat Combination 1500psi	Flour-Egg White 500psi**	Flour-Egg White 750psi	Flour-Egg White 1000psi	Mean
150	Disk	4.0	4.0	3.6	4.0	3.9	4.1	3.5	3.7	4.2	3.89
160	Disk	3.9	4.2	4.0	3.8	3.2	3.8	3.4	3.9	4.2	3.82
180	Disk	3.6	3.0	3.9	3.9	3.6	3.9	3.9	4.1	3.1	3.67
150	Bar	3.3	3.4	3.6	3.2	3.7	4.3	3.4	3.5	4.8	3.69
160	Bar	3.8	3.7	4.0	4.0	4.1	3.4	3.3	3.3	3.8	3.71
180	Bar	3.5	3.9	3.5	3.7	4.4	4.2	3.5	3.6	3.9	3.80

* Rank Columns: 1-6 (Best) ** First Compression Temperature Means: 150 - 3.79, 160 - 3.76, 180 - 3.73

TABLE 8

Rank Means* of Dried Compacted Foods (Group 1)

Compression Level X Shape X Absolute Humidity Level

Absolute Humidity (lbH$_2$OVapor / lb dry air)	Shape	Apples 1000psi	Apples 2000psi	Apples 3000psi	25% Fat Combination 1000psi	25% Fat Combination 1250psi	25% Fat Combination 1500psi	Flour-Egg White 500psi**	Flour-Egg White 750psi	Flour-Egg White 1000psi	Mean
0.02	Disk	4.0	3.7	3.6	3.3	3.7	4.2	3.6	3.8	3.9	3.76
0.04	Disk	3.7	3.8	4.1	4.1	3.5	3.6	3.6	3.9	3.8	3.79
0.02	Bar	3.4	3.5	4.1	3.7	3.8	4.0	3.3	3.6	4.4	3.76
0.04	Bar	3.7	3.8	3.3	3.7	4.3	4.0	3.5	3.3	4.4	3.78

* Rank Columns: 1-6 (Best) ** First Compression Humidity Means: Low - 3.76, High - 3.77

TABLE 9

Rank Means * of Compacted Foods (Group 2)

Compression Level X Shape

		50% Fat Combination			Spinach			Bacon Combination			Milk			
		500psi	750psi	1000psi	500psi	750psi	1000psi	1500psi	1750psi	2000psi	C1**	C2	C3	Mean
Disks	Dried	3.7	3.4	3.3	3.6	3.2	3.2	3.6	3.4	3.6	3.7	3.1	3.1	3.41
	Undried	3.7	3.7	3.2	3.6	3.9	3.6	3.3	3.4	3.3	3.7	3.6	3.7	3.56
Bars	Dried	3.6	4.0	3.3	3.4	3.8	3.4	3.2	3.6	3.4	3.5	3.4	3.4	3.50
	Undried	3.4	3.4	3.4	3.5	3.3	3.6	3.4	3.8	3.5	3.9	3.4	3.4	3.50

* C1 - 5000psi/500psi - C2 - 500psi/750psi - C3 - 750psi/750psi; 30 sec. compression, die inverted, 30 sec. compression

** Rank Columns: 1-6 (best)

Shape Means

Disks	3.45
Bars	3.50

Compression Means

Low	3.55
Medium	3.53
High	3.40

Mean for dried 3.46
Mean for undried 3.53

TABLE 10

Rank Means* of Dried Compacted Foods (Group 2)

Compression Level X Shape X Dry Bulb Temperature

Dry Bulb Temperature (°F)	Shape	50% Fat Combination			Spinach		Bacon Combination				Milk**		
		500psi	750psi	1000psi	500psi	750psi	1000psi	1500psi	1750psi	2000psi	C1	C2	C3
150	Disk	3.5	3.9	2.9	3.8	3.4	3.1	4.3	2.8	3.4	3.3	3.4	4.3
160	Disk	4.0	3.2	3.6	3.4	3.1	3.1	2.8	3.4	3.6	4.2	3.0	2.8
180	Disk	3.3	3.1	3.5	3.5	3.0	3.3	3.6	3.7	3.7	3.7	3.0	3.2
150	Bar	3.2	4.2	3.3	3.4	3.7	3.9	3.3	3.8	3.7	3.6	3.2	3.3
160	Bar	3.8	3.9	3.2	3.7	3.5	3.2	3.4	3.4	3.7	3.6	3.2	3.1
180	Bar	3.7	3.8	3.3	3.2	4.1	3.1	3.0	3.7	2.9	4.0	3.3	3.0

* Rank Column: 1 - 6 (Best)

** C1 - 500psi/500psi, C2 - 500psi/750psi, C3 - 750psi/750psi, 30 Sec Compression, Die Inverted, 30 Sec Compression.

Temperature Means: 150 - 3.53, 160 - 3.41, 180 - 3.40.

TABLE 11

Rank Means* of Dried Compacted Foods (Group 2)

Compression Level X Shape X Absolute Humidity Level

Absolute Humidity ($\frac{lb H_2O \text{ Vapor}}{lb \text{ dry air}}$)	Shape	50% Fat Combination 500psi	750psi	1000psi	Spinach 500psi	750psi	1000psi	Bacon Combination 1500psi	1750psi	2000psi	** Milk C1	C2	C3
0.02	Disk	3.6	4.0	3.4	3.5	3.2	3.4	3.5	3.3	3.8	3.6	3.2	2.8
0.04	Disk	3.6	2.8	3.2	3.6	3.2	3.4	3.6	3.5	3.4	3.9	3.1	3.4
0.02	Bar	3.8	3.9	3.1	3.5	3.9	3.4	3.6	3.7	3.0	3.6	3.6	3.2
0.04	Bar	3.3	4.0	3.4	3.4	3.5	3.4	2.9	3.6	3.8	3.5	3.3	3.6

* Rank Column: 1 - 6 (Best)

** C1 - 500psi/500psi, C2 - 500psi/750psi, C3 - 750psi/750psi; 30 Sec Compression, Die Inverted, 30 Sec Compression.

Humidity Means: Low - 3.48, High 3.43

TABLE 12

Rank Means* of Compacted Foods (Group 3)

Compression Level X Shape

	Shrimp			Potatoes			Beef			Peas		
Shape	1500psi	2000psi	2500psi	1500psi	2250psi	3000psi	2000psi	2250psi	2500psi	1500psi	1750psi	2000psi
Disks	3.6	2.9	2.6	3.4	3.1	3.4	2.7	3.4	3.0	2.7	3.1	3.0
Bars	4.0	3.4	2.4	3.1	3.5	3.3	2.9	3.6	3.0	3.2	3.0	3.0

* - Rank Columns: 1-6 (best)

Shape Means

Disks-3.07
Bars -3.20

Compression Means

Low 3.21
Middle......3.25
High........2.96

TABLE 13

Rank*Means of Dried Compacted Foods (Group 3)

Compression Level X Shape X Dry Bulb Temperature

Dry Bulb Temperature (°F)	Shape	Shrimp			Potatoes			Beef			Peas		
		1500	2000	2500	1000psi	2250psi	3000psi	2000	2250	2500	1500psi	1250psi	2000psi
150	Disk	3.7	3.3	2.6	3.2	3.1	3.8	2.6	3.3	3.4	3.0	3.1	3.0
160	Disk	3.9	2.7	2.4	3.3	2.8	3.1	2.9	3.8	2.9	2.6	2.9	2.7
180	Disk	3.3	2.9	2.9	3.5	3.0	3.6	3.0	3.3	2.7	2.5	3.2	2.9
150	Bar	4.0	3.2	2.4	3.1	3.3	3.5	2.9	4.1	3.5	3.4	3.4	3.2
160	Bar	4.0	3.4	3.0	3.0	3.7	2.9	2.9	3.3	2.9	3.4	2.5	2.7
180	Bar	4.1	3.5	1.9	3.2	3.5	3.4	2.6	3.3	2.7	2.7	3.0	2.9

* Rank Columns - 1-6 (best)

TABLE 14

Rank Means* of Compacted Foods (Group 3)

Compression Level X Shape X Absolute Humidity Level

Absolute Humidity $\left(\frac{\text{lb. } H_2O \text{ Vapor}}{\text{lb. Dry Air}}\right)$	Shape	Shrimp 1500	Shrimp 2000	Shrimp 2500	Potatoes 1500psi	Potatoes 2050psi	Potatoes 3000psi	Beef 2000	Beef 2250	Beef 2500	Peas 1500psi	Peas 1750psi	Peas 2000psi
0.02	Disk	4.2	3.1	2.5	3.5	2.7	3.5	2.7	3.6	3.2	2.6	3.1	3.0
0.04	Disk	3.1	2.8	2.8	3.2	3.4	3.3	2.7	3.3	2.8	2.8	3.0	3.0
0.02	Bars	4.3	3.3	2.4	3.0	3.6	3.4	2.7	3.3	3.3	3.1	3.1	2.8
0.04	Bars	3.7	3.4	2.5	3.1	3.5	3.1	3.2	3.8	2.7	3.3	2.8	3.1

* Rank Columns 6-1 (best)

Temperature Means

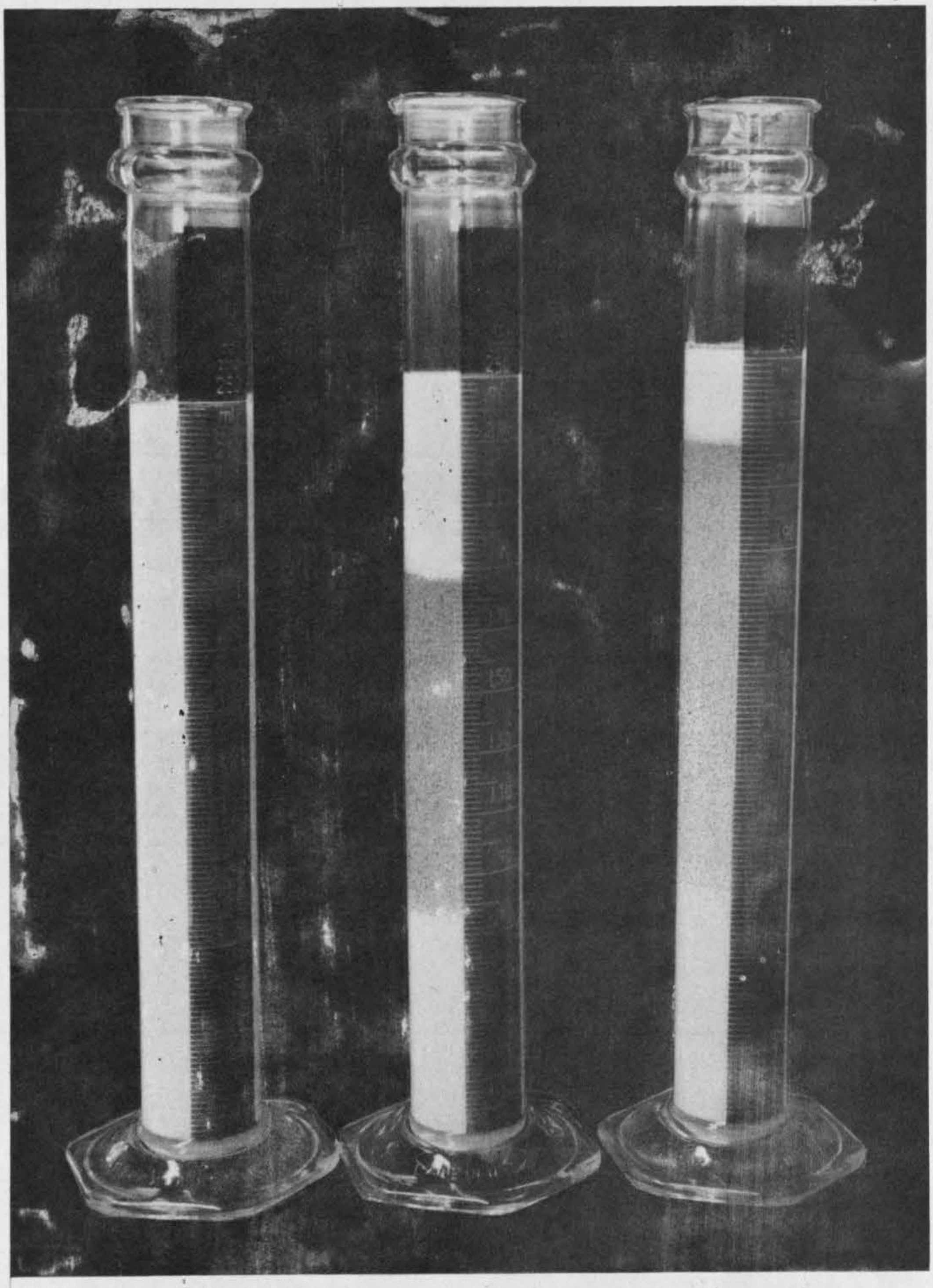
150..........3.25
160..........3.07
180..........3.07

Humidity Means

Low.......3.17
High......3.10

FIGURE 1

Vaccum desiccator containing a saturated solution of NaCl for pre-conditioning freeze-dried peas.



A B C

FIGURE 2

Rehydration characteristics of non-fat milk solids: (A) control, (B) preconditioned, (C) preconditioned and compressed.

Date: ____________ Product: ____________ Name: ____________

DIRECTIONS: Please indicate the order of your preference for these samples--from the best to the least. The one you like best should receive a high score of six; 2nd best, five; etc.

DO NOT RANK ANY OF THE SAMPLES THE SAME. IF IN DOUBT, DO THE BEST YOU CAN.

RANKING TABLE

6	5	4	3	2	1
Best to eat	2nd	3rd	4th	5th	6th

PLACE SAMPLE NUMBER IN APPROPRIATE COLUMN. NO TIES!!!!

FIGURE 3

Sample Taste Testing Ballot

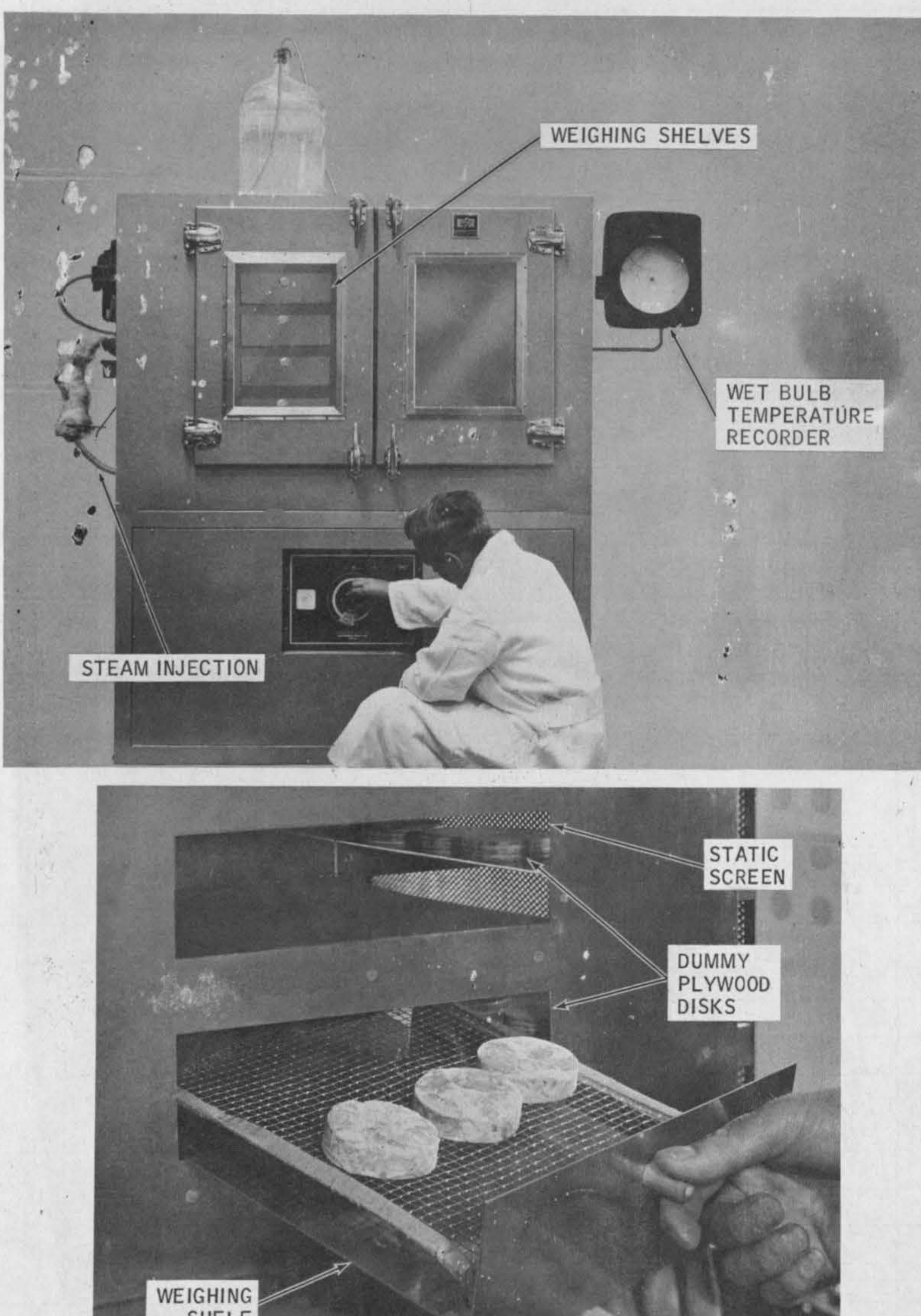
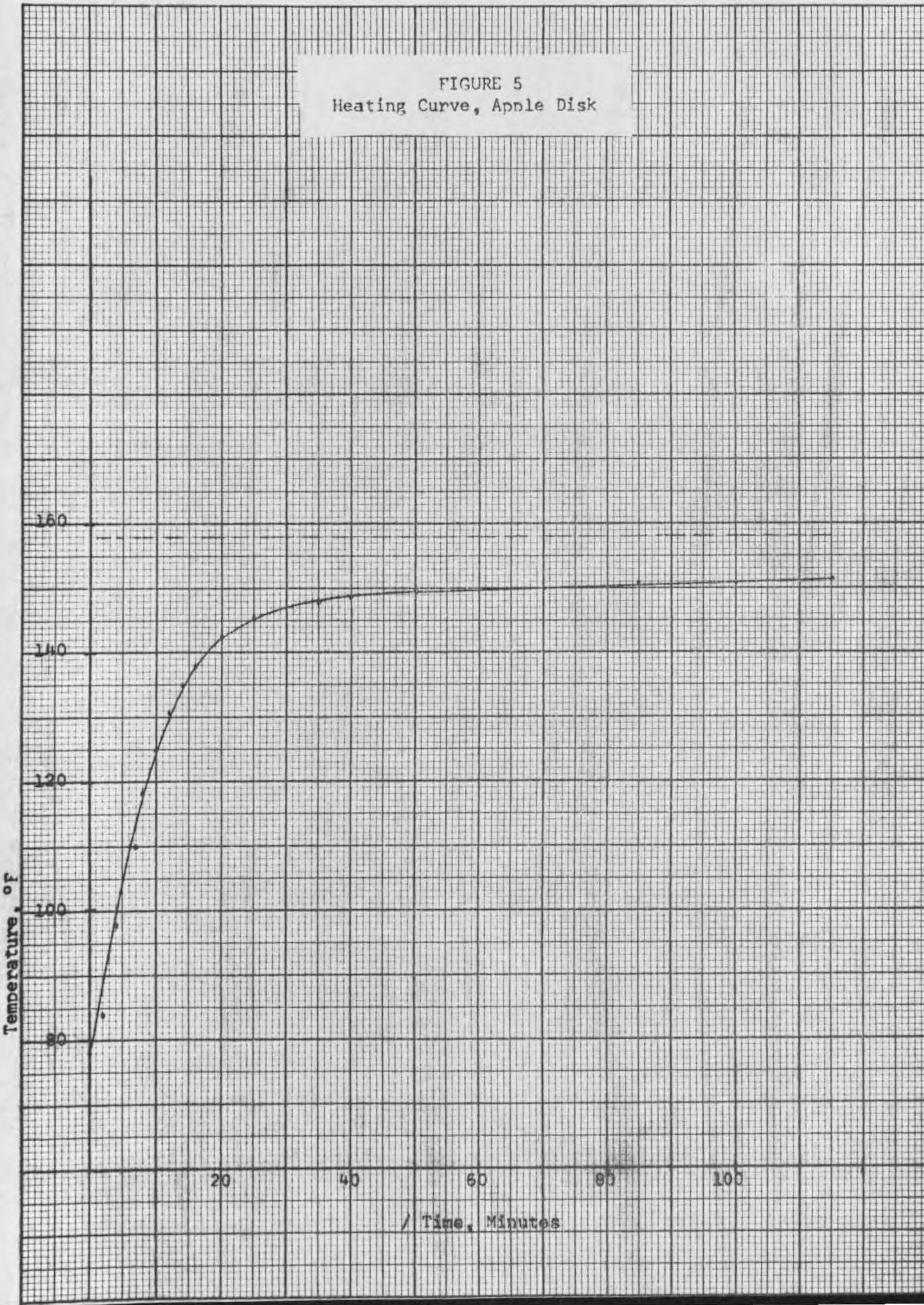


FIGURE 4
Blue M Electric Oven model POM-136C with portable test section.

FIGURE 5
Heating Curve, Apple Disk



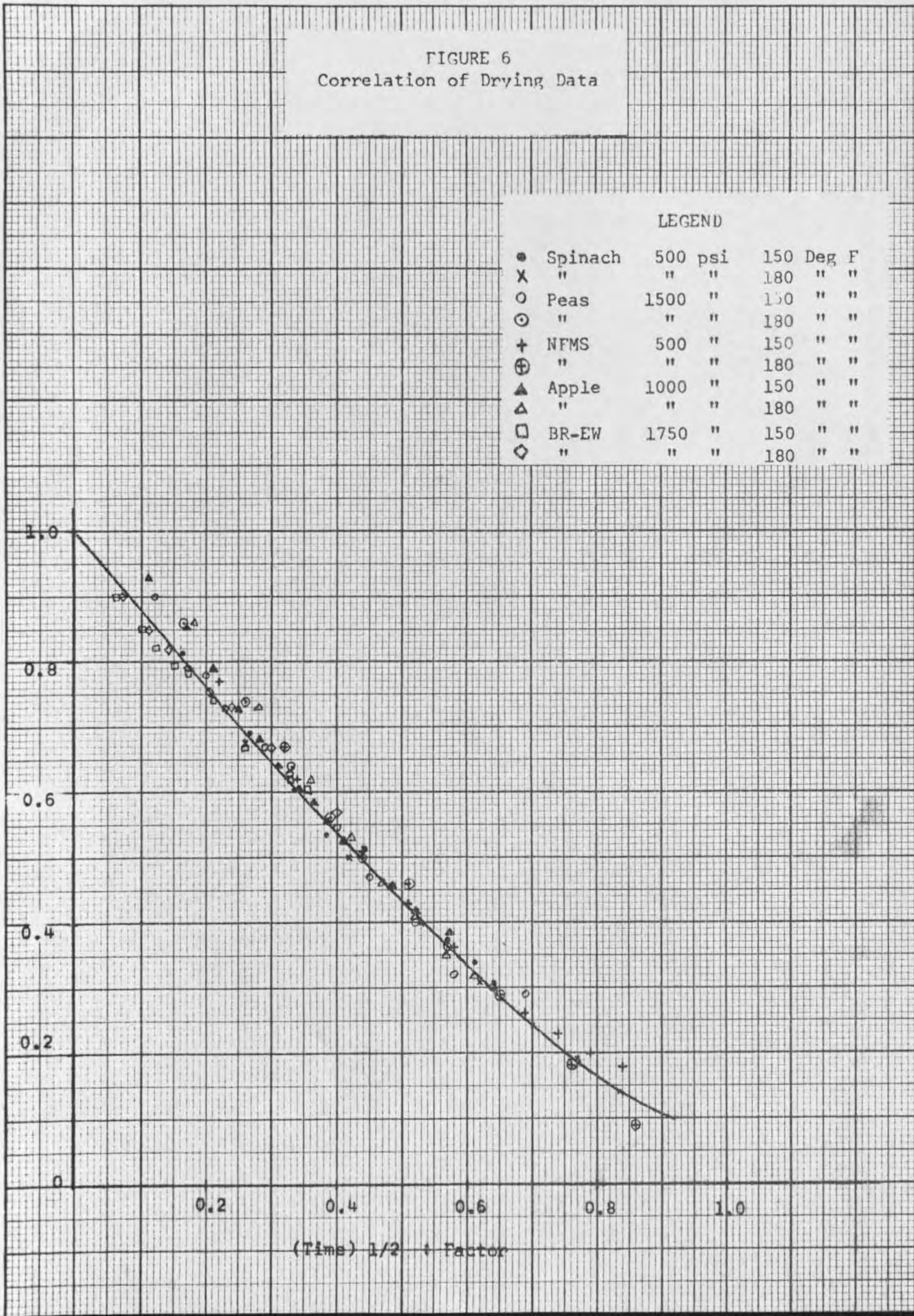


FIGURE 6
Correlation of Drying Data
LEGEND
Spinach 500 psi 150 Deg F
" " " 180 " "
Peas 1500 " 150 " "
" " " 180 " "
NFMS 500 " 150 " "
" " " 180 " "
Apple 1000 " 150 " "
" " " 180 " "
BR-EW 1750 " 150 " "
" " " 180 " "
1.0
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1.0
(Time) 1/2 ÷ Factor

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13. ABSTRACT

Compressed food bars representing protein, carbohydrate and fat in all proportions likely to be encountered with natural products and adjusted to 15 - 25 percent moisture were dried in a forced draft air drier under controlled conditions to a residual moisture content below 5 percent. Rates of drying were studied in relation to wet and dry bulb temperatures of the air flow, composition of bars, shape of bars and pressure of compression. Observations were performed to identify the effect of the drying regimen on surface texture, density, migration of fat and soluble components, and organoleptic properties. Conditions for a practical air drying process were defined.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Drying	8		6			
Compressed foods	2		9			
Foods bars	2		9			
Storage stability	4		7			
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