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Journal of FOOD PROCESS ENGINEERING

Edited by
D. R. HELDMAN

FOOD & NUTRITION PRESS, INC.
WESTPORT, CONNECTICUT 06880
USA

VOLUME 3, NUMBER 1 QUARTERLY

JOURNAL OF FOOD PROCESS ENGINEERING

All articles for publication and inquiries regarding publication should be sent to Prof. D. R. Heldman, Michigan State University, Department of Food Science and Human Nutrition, East Lansing, Michigan 48824 USA.

All subscriptions and inquiries regarding subscriptions should be sent to Food & Nutrition Press, Inc., 265 Post Road West, Westport, Connecticut USA.

One volume of four issues will be published annually. The price for Volume 3 is $50.00 which includes postage to U.S., Canada, and Mexico. Subscriptions to other countries are $60.00 per year via surface mail, and $67.00 per year via airmail.

Subscriptions for individuals for their own personal use are $30.00 for Volume 3 which includes postage to U.S., Canada, and Mexico. Personal subscriptions to other countries are $40.00 per year via surface mail, and $47.00 per year via airmail. Subscriptions for individuals should be sent direct to the publisher and marked for personal use.

The *Journal of Food Process Engineering* (USPS 456-490) is published quarterly by Food & Nutrition Press, Inc. — Office of Publication is 265 Post Road West, Westport, Connecticut 06880 USA.

Second class postage paid at Westport, Ct. 06880.

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FOOD & NUTRITION PRESS, INC.
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Food & Nutrition Press, Inc.
Westport, Connecticut USA

ISSN 0145-8876

Printed in the United States of America

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JULY 1980

July 6—9: SECOND INTERNATIONAL SYMPOSIUM ON DRYING. McGill University, Montreal Canada. Contact A. S. Mujumdar, Program Chairman Drying 80, Department of Chemical Engineering, McGill University, 3480 University Street, Montreal, Quebec, Canada.

July 28—August 1: FOOD RHEOLOGY: PRINCIPLES AND PRACTICES. MIT, Cambridge, Massachusetts. Contact Director of Summer Session, Room E19—356, Massachusetts Institute of Technology, Cambridge, Massachusetts 02130.

AUGUST 1980

August 26—28: INTERNATIONAL SYMPOSIUM ON FOOD TECHNOLOGY IN DEVELOPING COUNTRIES. University Pertanian, Malaysia. Kuala Lumpur, Malaysia. Contact Chairman, Food Technology in Developing Countries, Department of Food Science and Technology, Serdang, Selangor, Malaysia.

SEPTEMBER 1980

September 19—24: THIRTEENTH INTERNATIONAL TRADE FAIR OF THE FOOD INDUSTRY. Munich Fair Grounds, Munich, Germany. Contact Gerald G. Kallman Associates, 30 Journal Square, Jersey City, New Jersey 07306.

September 26: FOOD DEHYDRATION SYMPOSIUM. Kansas State University. Contact D. Y. C. Fung. Dept. of Animal Sciences and Industry. Kansas State University. Manhatten, Kansas 66506.

September 29—October 1: ASAE NATIONAL ENERGY SYMPOSIUM. Radisson Muehlebach Hotel, Kansas City, Missouri. Contact B. L. Clary, Agricultural Engineering Department, Oklahoma State University, Stillwater, Oklahoma 74074.

OCTOBER 1980

October 6—8: INTERNATIONAL SYMPOSIUM ON ENERGY AND FOOD INDUSTRY. Madrid, Spain. Contact A. Bonastre, Secretary General, Commission Internationale Des Industries Agricoles et Alimentaires, 24, Rue de Teheran, 75008, Paris, France.

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October 21—24. NATIONAL FROZEN FOOD CONVENTION. MGM Grand Hotel, Las Vegas, Nevada. Contact K. E. Mulderig, National Frozen Food Association, Inc., Suite 100, 1700 Old Meadow Road, McClean, Virginia 22102.

October 26—31: INTERNATIONAL MEETING ON RADIATION PROCESSING. Miyako Hotel, Tokyo, Japan. Contact Y. Orita, Secretary General, Third International Meeting on Radiation Processing, P. O. Box 6, Kuragano, Takasaki, 37—12, Japan.

EDITORIAL

As we begin the publication of Volume 3 of the *Journal of Food Process Engineering*, we are pleased to announce the addition of several professional colleagues to the Editorial Board for the Journal. These additions to the Editorial Board not only represent recognition of a somewhat broader scope of subject matter being published in the Journal, but a recognition of the contributions that these individuals have made to their professions. We are pleased that these individuals have agreed to join our Editorial Board and contribute to the future of the *Journal of Food Process Engineering.*

The new Editorial Board members include Dr. Solke Bruin, Professor of Food Engineering at the Agricultural University in Wageningen, the Netherlands. Dr. Bruin has been active in heat and mass transfer research related to food processing for several years and has established himself as a leader in food engineering research. Dr. J. T. Clayton, Professor and Head of the Food Engineering Department at University of Massachusetts is a new member of the Editorial Board. Dr. Clayton has been active in the development of an undergraduate food engineering curriculum at University of Massachusetts and in the planning of the First and Second International Congresses on Engineering and Food. Another new member of the Editorial Board is Dr. G. A. Hohner, Associate Director of Frozen Food Research and Development at the Quaker Oats Company. We feel that Dr. Hohner will provide additional industry perspective for the Editorial Board. Dr. D. B. Lund, Professor of Food Engineering in the Department of Food Science at University of Wisconsin is the fourth new member of the Editorial Board. Dr. Lund has established an excellent reputation as educator and researcher with particular emphasis on the applications of reaction dynamics to food processing. We are pleased to welcome Dr. R. P. Singh to the Editorial Board for the Journal. Dr. Singh is Associate Professor of Food Engineering at the University of California at Davis. Dr. Singh has been active in several areas of Food Engineering research with particular emphasis on energy conservation in food processing.

Without these new members of the Editorial Board for the *Journal of Food Process Engineering* as well as the continuing members, the quality of research being published in the Journal could not be established and maintained. These Editorial Board members have an active role in the publication process and often contribute directly to the Journal through research manuscripts or reviews. Their role becomes increasingly important as the activities of the Journal continue to expand.

THE HEAT OF COMBUSTION OF DRIED CITRUS PULP

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Received for Publication June 22, 1979
Accepted for Publication September 28, 1979

ABSTRACT

The heat of combustion of dried citrus pulp has been found to be 4150 ± 118 *cal/g or* 7470 ± 212 *Btu/lb. Dried citrus pulp has been compared with Bunker "c" fuel as a source of energy and found to be more valuable as a livestock feed.*

INTRODUCTION

Heat of combustion denotes the heat liberated by the combustion of all carbon and hydrogen with oxygen to form carbon dioxide and water, including the heat liberated by the oxidation of other elements such as sulfur, nitrogen, etc. which may be present in the substance. It is commonly expressed either in calories per gram (cal/g) or British thermal units per pound (Btu/lb). One cal/g is equivalent to 1.8 Btu/lb. When 1 lb of combustible is completely combusted, the heat released is called the heat of combustion or the heat value of the combustible.

A search of the literature has revealed little published information on the high heat value of dried citrus pulp as described by Kesterson and Braddock (1976). Ammerman *et al.* (1961) and Baird *et al.* (1974) determined the digestible energy values for dried citrus pulp as a feed for steers and swine, but did not determine the high heat values. Warner (1939) has suggested the use of dried orange culls as a fuel for heating citrus orchards in California.

The purpose of this paper is to give data on the heat of combustion as higher heating values for dried citrus pulp; as well as, to compare dried citrus pulp with Bunker "c" fuel as a source of energy.

MATERIALS AND METHODS

Experimental Samples

Thirty-seven (37) samples of commercially dried citrus pulp, citrus pellets, citrus meal and citrus dust were collected from six commercial processors representing all segments of the citrus processing industry for two different processing seasons. In addition, two experimental samples of dried pectin pomace were prepared from limes in the Agricultural Research and Education Center pilot plant feed mill located at Lake Alfred.

Method of Analysis

Heats of combustion were determined with a Parr oxygen bomb calorimeter (serial no. 2048) utilizing standard oxygen calorimetry and combustion methods. The carlorimeter was calibrated with benzoic acid and a W-factor (energy equivalent) of 1358 ± 10 cal/°F was obtained. Randomized samples of the dried citrus products were ground in a laboratory Wiley Mill (model 475 A) to pass a 20-mesh screen. Moisture content of the pulverized samples was determined on a 20 g sample in a vacuum oven at 60°C for 16 h. Water additions were made to 5 g of the pulverized sample in a glass covered weighing bottle to give a moisture content of 30%. The samples were thoroughly mixed and allowed to equilibrate overnight. Approximately 1 g of the pulverized sample adjusted to 30% moisture content was formed into a pellet, accurately weighed, and the heat of combustion determined under 30 atmospheres of oxygen. High heat values were reported on a bone dry basis (0% moisture).

RESULTS AND DISCUSSION

High Heat Values Versus Moisture Content

Homogeneous carbonaceous materials have a constant amount of combustion energy per unit of mass. However, moisture content can influence the burning of carbonaceous materials and complete combustion must be obtained to release maximum energy. Therefore, duplicate determinations were made on dried citrus pulp accurately adjusted to 8%, 15%, 25% and 35% moisture content to determine the optimum moisture level at which combustion was complete. Moisture levels at 25% or greater resulted in uniformly high heat values for dried citrus pulp graphically shown in Fig. 1. Standard calorimetric practice recommends a moisture content of 20 to 40% to facilitate the ease of weighing, handling and forming pellets. When it is necessary to handle bone dry material, weigh the sample, add moisture and then make the pellet. High heat values obtained in this study was collected at a moisture content of 30% and converted to a bone dry basis.

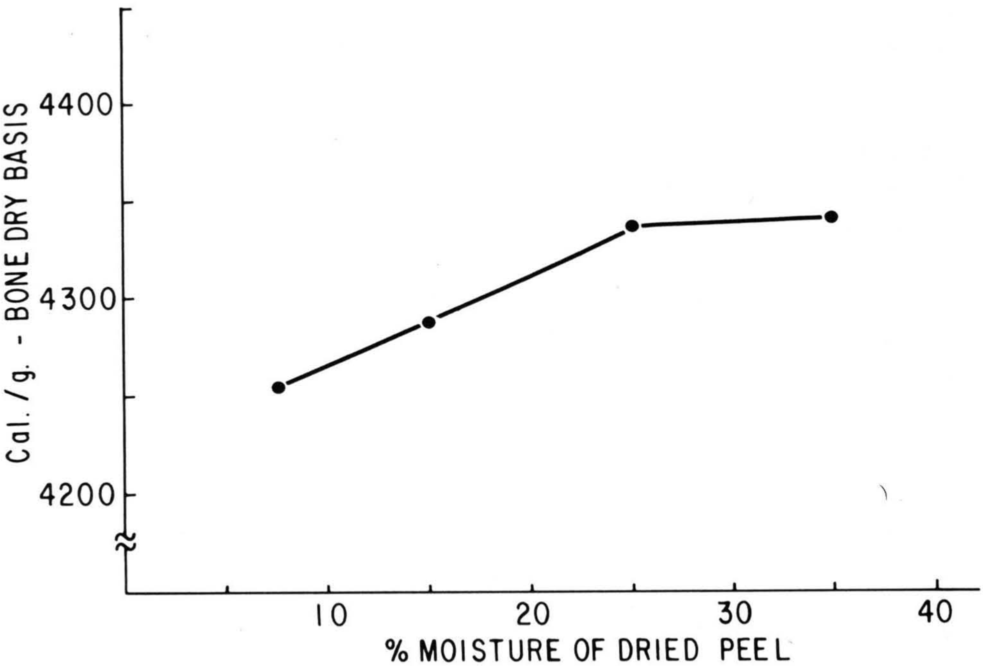

FIG. 1. HIGH HEAT VALUES OF DRIED CITRUS PEEL PRODUCTS AS RELATED TO MOISTURE CONTENT

High Heat Values of Dried Citrus Peel Products

The high heat values for dried citrus pulp, citrus pellets, citrus meal, citrus dust and pectin pomace are shown in Table 1. These data show that dried citrus feed products have fairly uniform overall high heat values, as follows: 4150 ± 118 cal/g or 7470 ± 212 Btu/lb with a variation among products of less than 3%. Reproducibility of the heats of combustion for individual samples was greater than 99%. Dried pectin pomace had considerably lower high heat values. Although only two samples were evaluated, the possibility of using high heat values as a method to determine the degree to which citrus products such as peel, juice sacs, etc. have been leached or washed is suggested.

Fuel Value of Dried Citrus Pulp

The fuel value of bone dry citrus pulp based on Bunker "c" fuel (153,600 Btu/gal at 45 cents/gal) at a combustion efficiency of 80% compared to the commodity value ($150/T) is as follows:

Table 1. High heat values of dried citrus peel products (bone dry basis)

SAMPLE NO.	DRIED CITRUS PULP		CITRUS PELLETS		CITRUS MEAL		CITRUS DUST		PECTIN POMACE	
	CAL./g	BTU/LB.	CAL./g	BTU/LB.	CAL./g	BTU/LB	CAL./g	BTU/LB.	CAL./g	BTU/LB.
1	4345	7821	4183	7529	4247	7645	4222	7600	2854	5137
2	4215	7587	4250	7651	4172	7510	4186	7535	2644	4759
3	4148	7466	4201	7561	3870	6966	4237	7627		
4	4107	7392	4088	7358	4182	7528	4209	7576		
5	4107	7392	4309	7756	3937	7087	3813	6863		
6	4351	7832	4142	7456	4071	7328	4232	7618		
7	4164	7495	4071	7328	4030	7254	4147	7465		
8	4129	7432	4036	7265						
9	4207	7573	4042	7276						
10	4199	7558	4138	7448						
11	4349	7828	4089	7360						
12	4136	7445								
SX	94	169	88	158	138	248	152	273		
$S\bar{X}$	27	49	26	48	52	94	57	103		
Avg	4205	7568	4141	7453	4073	7331	4149	7469	2749	4948
	OVERALL AVERAGE (37 SAMPLES) = 4150 ± 118 CAL./g AND 7470 ± 212 BTU/LB.									

Wt. bone dried pulp	100 lb
Fuel value	\$2.74
Commodity value	\$7.50
Therms energy	\$7.47

Many costs are involved in producing energy but only the high heat value for dried citrus pulp was considered here. The high heat value was chosen to make the comparison since waste heat evaporators commonly used by the Florida Citrus Industry can utilize the water of combustion. Since dried citrus pulp burns more efficiently at a moisture content of 25% or greater, less energy is required to dry the peel as a fuel than as a feed. However, the data show that dried citrus peel products are of greater value as a commodity, i.e. livestock feed than as a fuel source.

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BAIRD, D. M., ALLISON, J. R. and HEATON, E. K. 1974. The energy value for and influence of citrus pulp in finishing diets for swine. J. Anim. Sci. *38*, 545-553.

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COMPUTER SIMULATION OF VITAMIN DEGRADATION IN A DRY MODEL FOOD SYSTEM DURING STORAGE[1]

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Received for Publication December 11, 1979
Accepted for Publication January 23, 1980

ABSTRACT

During storage of dry foods, oxidative mechanisms can result in nutrient degradation. Accurate prediction of the vitamin content for dry foods during storage is essential to provide the processor with the assurance of meeting label claims. Since appropriate shelf-life tests for measurement of vitamin degradation represents an alternative worth considering.

A mathematical model of the relationship between the rate constant of ascorbic acid oxidation and water activity was established. Computer simulation to predict product moisture content and ascorbic acid degradation in a dry model food product was developed by considering the simultaneous influence of water activity and temperature on rate constants which change with storage time due to varying storage environments.

The computer simulation predicts product moisture content and vitamin degradation in good agreement with the experimental data. The simulation will account for the influence of storage temperature and relative humidity as well as characteristics of the food product and package material.

INTRODUCTION

During storage, dry foods can deteriorate due to oxidative mechanisms resulting in nutrient degradation, off-flavor development and odor changes of the food products. Accurate prediction of the vitamin content in dry foods during storage is essential to provide the processor with the assurance of meeting label claims.

Shelf-life tests for measurement of vitamin degradation in foods are time consuming and costly. Computer simulation of vitamin destruction in dehydrated foods represents an alternative approach to shelf-life testing.

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[1] Michigan Agricultural Experiment Station Journal Article No. 7932.

The development of an acceptable computer simulation requires the incorporation of experimental kinetic data to describe the vitamin degradation as a function of water activity and temperature along with appropriate moisture and oxygen transport coefficients for the product package materials.

Computer simulations to predict storage stability of various food products have been developed in the recent years. Karel (1972) presented an approach to predict the storage life of foods based on information gained by experimentally determination of the properties of foods, the kinetics of food deterioration, and the package properties. Mizrahi *et al.* (1970) developed simulation of browning in freeze-dehydrated cabbage stored in packages with films having different permeabilities to water. The computer program used kinetics data for the browning reaction, moisture content of product, and mass transfer characteristics of package films. Simon *et al.* (1971) presented a computer prediction model describing the oxidative deterioration of freeze-dried shrimp. Organoleptic deterioration was correlated with absorption of oxygen and with loss of carotenoid pigment.

Kwolek and Bookwalter (1971) presented a mathematic model to predict storage stability as a function of time, temperature, and the kinetics parameter for product quality. The model was applied to data published by Bookwalter *et al.* (1968), for flavor and peroxide values of food products.

Labuza *et al.* (1972) developed a mathematical model to predict the moisture gain by dehydrated tea and milk based on a linear isotherm equation. Quast *et al.* (1972) developed a mathematical model for oxidation of potato chips. The rate of oxygen uptake for potato chips was determined as a function of oxygen partial pressure, equilibrium relative humidity, and extent of oxidation. Quast and Karel (1972) developed the computer simulation for potato chips which deteriorate by two mechanisms simultaneously; by oxidation due to atmospheric oxygen and by changes in texture due to moisture adsorption. Later, Quast and Karel (1973) used the computer simulation to calculate optimum permeabilities that allow deterioration due to these two interacting mechanisms. The influence of package film gage, bulk density of the product, initial oxygen concentration and initial relative humidity were studied using the computer simulation.

Further developments have been concerned with nutritional stability in foods. Heldman (1974) described a basic computer simulation for storage conditions that influence vitamin stability. Singh and Heldman (1975) presented a simulation of ascorbic acid degradation in a liquid infant formula. The oxygen uptake by the liquid food under the influence of light intensity and the effective depth of light penetration into the food product was investigated. Lee (1976) developed a computer simulation to predict ascorbic acid degradation in canned tomato juice during storage. The effect of pH, copper, and storage temperature were the parameters used in the mathematical model.

Labuza and Tannenbaum (1972) discussed the kinetics of ascorbic acid destruction as a function of temperature, water activity, and product composition based on previously published data. Vojnovich and Pfeifer (1970) investigated wheat flour and corn soya flour, Jensen (1969) studied seaweed and Karel and Nickerson (1964) reported data on orange juice powder. Wanninger (1972) presented a mathematical model to predict ascorbic acid stability during storage and considered temperature, product water content and oxygen concentration as parameters in the model as applied to the data published by Vojnovich and Pfeifer (1970). Lee and Labuza (1975) studied the rate of ascorbic acid destruction as a function of both water activity and moisture content with respect to sorption hysteresis and the extent of ascorbic acid deterioration in the intermediate moisture range. Kirk *et al.* (1977) determined the kinetics of total and reduced ascorbic acid destruction with and without vitamin A and riboflavin present, and as a function of water activity, moisture content, oxygen, and storage temperature.

The objectives of this investigation were: 1) to examine the rate of moisture uptake as a function of storage relative humidity and water vapor permeability through the package film and 2) to develop a computer-aided prediction of vitamin degradation in dry foods during storage.

THEORETICAL CONSIDERATIONS

For the purpose of this study, ascorbic acid concentration was used as the quality index. The oxidation of ascorbic acid under aerobic conditions will occur as follows:

$$\text{Ascorbic acid} \xrightarrow{\text{oxygen}} \text{Degradation products} \quad (1)$$

The degradation of ascorbic acid can be described by a first order function, so the reaction rate can be expressed as:

$$dC/dt = -kC \quad (2)$$

where:

C = concentration of ascorbic acid

t = time

k = first order rate constant

By integration and substituting the initial conditions $C = C_o$ and $t = t_o$ Equation (2) becomes:

$$C = C_o \exp(-kt) \quad (3)$$

The Influence of Water Activity

Factors influencing the vitamin degradation rates in a packaged dry food are oxygen and moisture. Assuming oxygen concentration is a non-limiting factor, then k is a function of water activity inside the package (a^i) and illustrated by:

$$k = f(a^i) \quad (4)$$

Based on the data provided experimentally by Kirk *et al.* (1977), the relationship between the rate constant (k) and a^i for a given temperature was a linear function:

$$k = K1\ a^i + K2 \quad (5)$$

Where:

K1, K2 = constants

The Influence of Temperature

The influence of temperature on the rate constant at a given water activity can be described by the general form of the Arrhenius Equation:

$$k = k_o \exp(-\Delta E/RT) \quad (6)$$

where:

k_o = Arrhenius constant, time^{-1}

ΔE = activation energy, cal/mole

R = gas constant, 1.987 cal/mole °K

T = absolute temperature, °K

The activation energy was determined experimentally by Kirk *et al.* (1977). By measurement of the rate constant (k) for different water activities at several temperatures, the relationship of k with a^i [Eq. (5)] was established for each temperature using least squares fitting analysis.

The Influence of Package Film

The changes in water activity inside the package due to increasing moisture content of the food product are controlled by the rate of moisture transfer (dM/dt) through the package film:

$$dM/dt = \frac{K\,A\,p}{x\,w_s}\,(a^o - a^i) \tag{7}$$

where:

dM/dt = the rate of moisture transfer, $\frac{g\ H_2O}{g\ \text{solid-hour}}$

K = film transfer coefficient, $\frac{g\ H_2O - cm}{m^2 - mm\ Hg - hr}$

A = surface area of package film, m^2

p = absolute pressure of outside air, mm Hg

a^o = water activity outside the package

x = film thickness, cm

w_s = weight of solid product in the package, g solid

Then, water activity inside the package can be calculated by the BET Equation for sorption isotherms:

$$a^i/M\,(1-a^i) = 1/w_m\,c + (c-1)\ a^i/w_m c \tag{8}$$

The BET constants (w_m and c) were measured by Bach (1974) using the Palnitkar and Heldman method (1971).

The Computer Simulation

The computer simulation flow sheet for the program used to predict the ascorbic acid concentration history at a given temperature and outside water activity is shown in Fig. 1. By minor modification, the simulation could be applied to different relationships of rate constants with

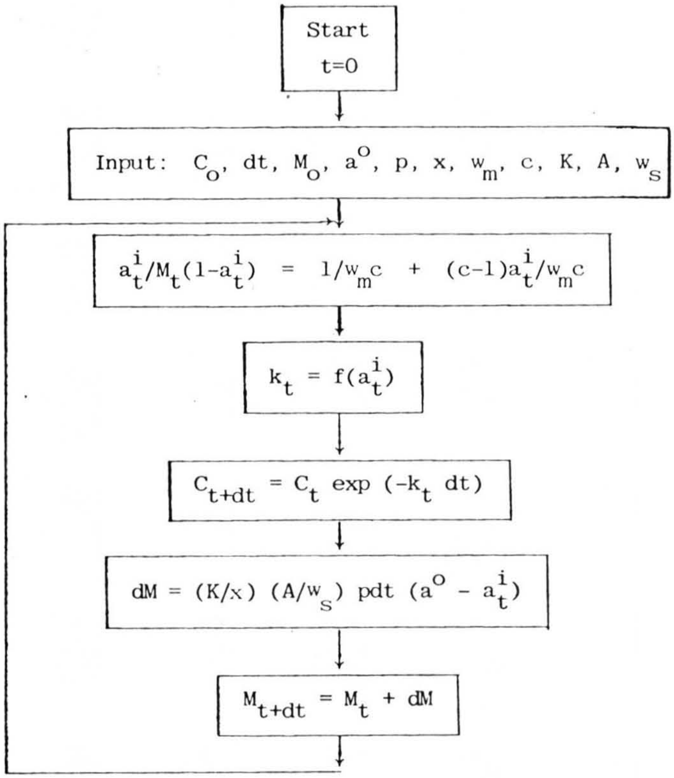

FIG. 1. THE COMPUTER SIMULATION FLOW SHEET AT A CONSTANT TEMPERATURE.

water activity according to changes in temperature and changes in the moisture transfer coefficient for the package film.

EXPERIMENTAL CONSIDERATIONS

Materials

The dry model food system used in this study had a composition as shown on Table 1. The measurement of the moisture transfer coefficient for the package film was carried out with anhydrous calcium chloride as desiccant in 8 mech granulars and free of 30 mesh fines as suggested by ASTM Standard E96 (1975).

The relationship between the rate constant (k) and the water activity (a^i) was determined using measurements of vitamin degradation is a sam-

Table 1. Composition of model food system

Component	Percent
Protein	10.2
Fat	1.0
Carbohydrate	76.6
Reducing Sugar	5.1
Sucrose	5.1
Salt	2.0

ple stored in a 303 × 414 can. A 10 g sample was placed in the can to establish a condition where oxygen was a non-limiting factor. To verify the computer simulation results, 3/4 oz breakfast cereal boxes with wax paper liners were used.

Procedures

The anhydrous calcium chloride, used for measurement of the moisture transfer coefficients, was reactivated before use by heating at 200° C for one hour. The desiccant (50 g) was then placed in the wax paper liners and measurements were conducted with and without paperboard boxes.

The rate constant (k) versus water activity (a^i) relationship was measured after the dry model food system had been equilibrated to water activities of 0.1, 0.24, 0.4, 0.5, and 0.65 in a chamber using conditioned air from an Aminco-Aire System. The water activities were selected from equilibrium moisture content isotherms for the product as measured at 10, 20, 30 and 37°C using the method described by Palnitkar and Heldman (1971). After equilibration, the dry model food system was placed in the cans and stored in cubicles with controlled temperature and relative humidity. More details about these procedures are presented by Kirk *et al.* (1977).

Experiments used to verify the computer simulation were conducted at 30°C with 10, 40 and 85% relative humidity. Each 3/4 oz cereal box contained 15 g of dry model food system placed in the heat-sealed wax paper liner. The dry model food system had been prepared using procedures described by Kirk *et al.* (1977) and were not equilibrated before being placed in the containers. The dry product contained USP reduced ascorbic acid at concentrations equivalent to 25% RDA per 100 g of dry model food system on a dry weight basis added to the product prior to freeze-drying.

All moisture content determinations were conducted as described by Kirk *et al.* (1977). The 2 g samples of product were dried to a constant weight in a vacuum oven at a vacuum of greater than $4.6 \times 10^3 \, N/m^z$ and at the same temperature as used for the storage experiments. A cold trap and dry air at a rate of 15-20 ml/min was used to aid in removal of moisture.

Ascorbic acid determinations were conducted using semi-automated O-phenylenediamine microfluorometric procedures described by Kirk and Ting (1975).

RESULTS AND DISCUSSIONS

A. Measurement of Moisture Transfer Coefficient

The experimental moisture transfer coefficients at various relative humidities for wax paper, with and without paperboard boxes are presented in Table 2. These data indicate that the paperboard box does not have a significant influence on the moisture transfer. This observation might be attributed to the type of seal for the paperboard box, which does not maintain a different environment inside the box when compared to the outside storage environment. Based on the experimental results, the average of moisture transfer coefficient used in the simulation was:

$$0.00174 \, gH_2O \cdot cm/m^2 \cdot 24 \, hr \cdot mmHg$$

or:

$$7.25 \times 10^{-5} \, gH_2O \cdot cm/m^2 \cdot hr \cdot mmHg$$

Table 2. Moisture transfer coefficient (K) at various relative humidities for wax paper with and without paperboard boxes.

Waxed paper	RH, %	K, $\frac{g \, H_2O\text{-cm}}{m^2\text{-24 hr-mm-Hg}}$
Without paperboard box	10	0.00168
	40	0.00174
	85	0.00184
With paperboard box	10	0.00162
	40	0.00171
	85	0.00182

B. Moisture Transfer to the Product

1. Influence of Relative Humidity. The results of the computer prediction and experimental data for moisture content of the dry model food systems stored at 10, 40 and 85% RH and 30° C are presented in Fig. 2. The predicted moisture contents are in good agreement with the experimental data. At 40% RH, the predicted equilibrium moisture content was higher than the experimental values, but the mean deviation was only 3.2%. At 85% RH, a longer time was required to reach the equilibrium condition. Although the experiment was limited to 17 weeks, the prediction curve was in close agreement with the experimentally determined data. The BET constants used in the simulation were obtained from the moisture adsorption isotherm curve measured by Bach (1974) for the range of 10% to 50% RH. At 85% RH, the BET constants were found by extrapolating the curve and this step may have influenced agreement predicted and experimental results.

2. Influence of Container. Film thickness and the moisture transfer coefficient (K) of the container influenced the transfer of moisture to the product. An increase in the film thickness reduced moisture transfer into the package (Fig. 3) and the increase in product moisture content was reduced. Increases in the moisture transfer coefficient resulted in greater moisture transfer rates into the package (Fig. 4) and the product achieved the equilibrium moisture condition more rapidly.

3. Influence of Temperature. The influence of temperature on the moisture content of the dry model food system is illustrated in Fig. 5. At lower temperatures, the product adsorbed water at a slower rate. In addition, the product equilibrated to a higher moisture content at the lower temperature.

C. Vitamin Retention During Storage

Results from laboratory experiments indicate that the relationship of rate constant (k) and water activity (a^i) at 30° C gave the following function:

$$k = (1.073 + 7.765\, a^i) \times 10^{-2}$$

This relationship appeared to be acceptable over the range of water activities from 0.1 to 0.65 (Purwadaria 1977).

The computer prediction of ascorbic acid retention in food products during storage at 40% RH and 30° C is in good agreement with the experimental data as illustrated in Fig. 6. Although agreement was not as good at 10% and 85% RH, the simulation seems sufficiently accurate for prediction of vitamin retention.

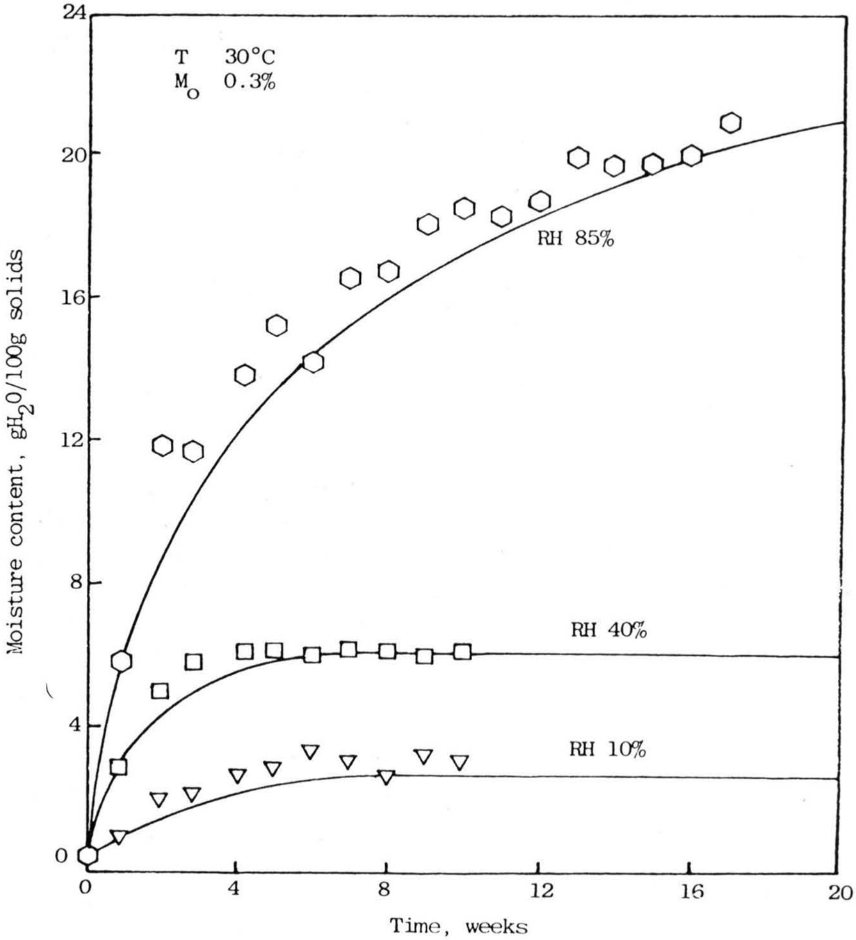

FIG. 2. COMPUTER PREDICTION AND EXPERIMENTAL DATA FOR MOISTURE CONTENT OF THE DRY MODEL FOOD SYSTEM DURING STORAGE AT 30°C AND VARIOUS RELATIVE HUMIDITIES WITH FILM THICKNESS OF 0.009 CM AND MOISTURE TRANSFER COEFFICIENT OF 7.25×10^{-5}

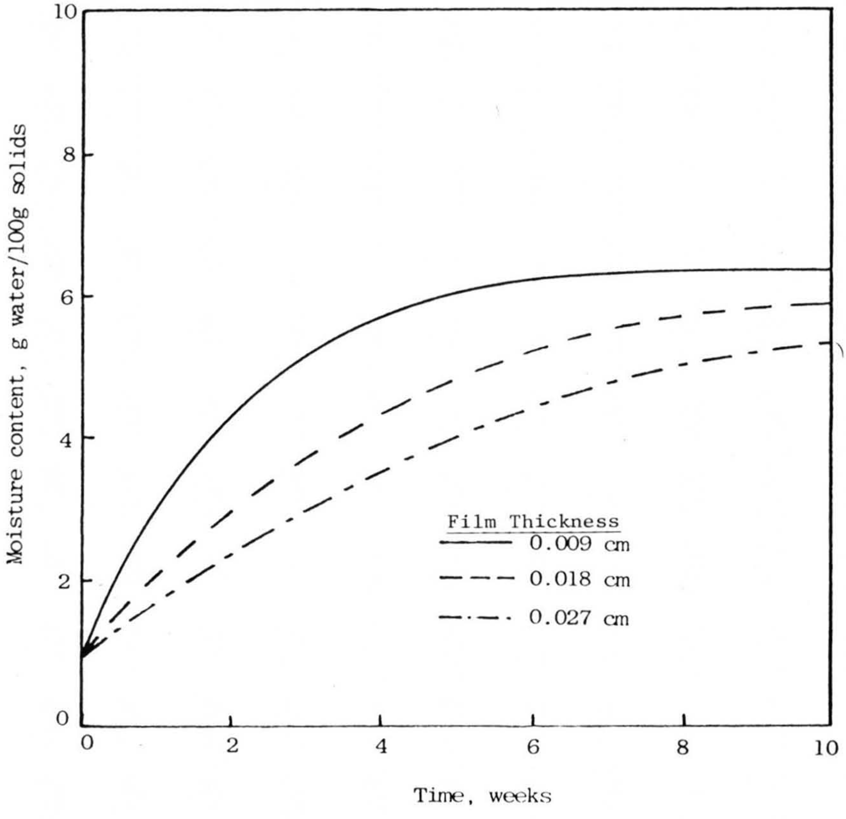

FIG. 3. COMPUTER PREDICTION OF DRY MODEL FOOD MOISTURE CONTENT DURING STORAGE WITH VARIOUS PACKAGE FILMS AT STORAGE TEMPERATURES OF 30°C, RELATIVE HUMIDITY OF 40% AND MOISTURE TRANSFER COEFFICIENT OF 7.25×10^{-5}

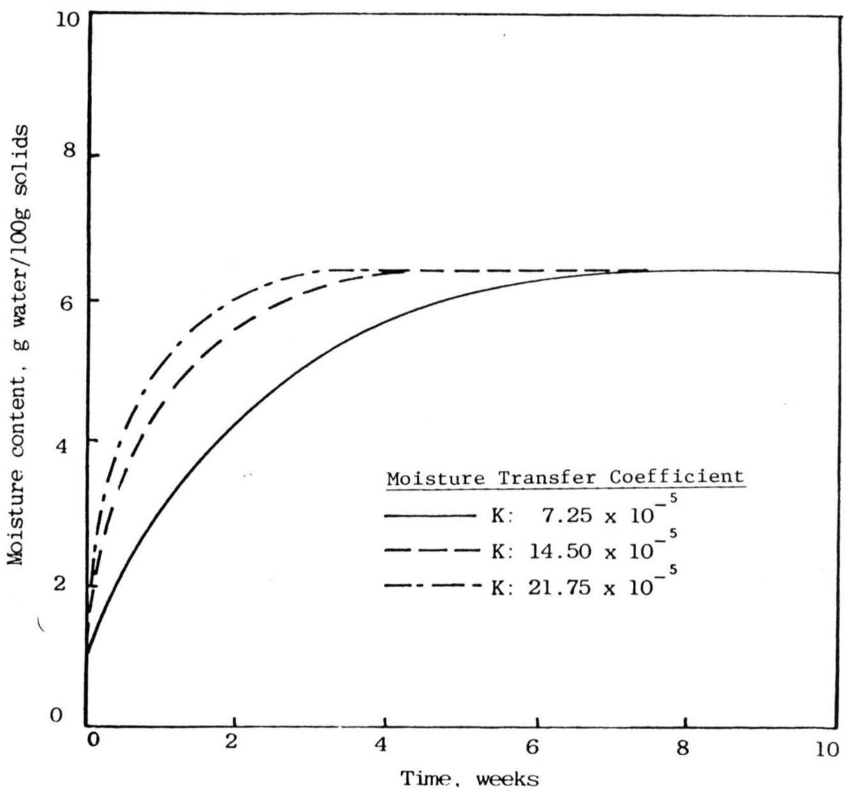

FIG. 4. COMPUTER PREDICTION OF DRY MODEL FOOD MOISTURE CONTENT DURING STORAGE USING VARIOUS MOISTURE TRANSFER COEFFICIENTS WITH STORAGE TEMPERATURE OF 30°C, RELATIVE HUMIDITY OF 40% AND FILM THICKNESS OF 0.009 CM

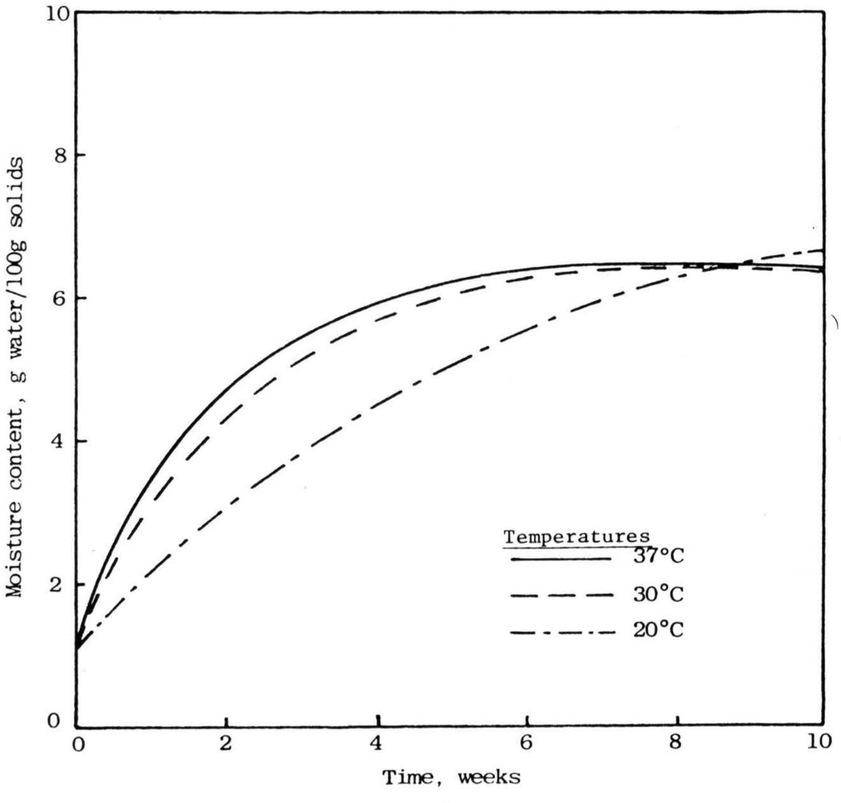

FIG. 5. COMPUTER PREDICTION OF DRY MODEL FOOD MOISTURE CONTENT DURING STORAGE AT VARIOUS TEMPERATURES WITH 40% RELATIVE HUMIDITY

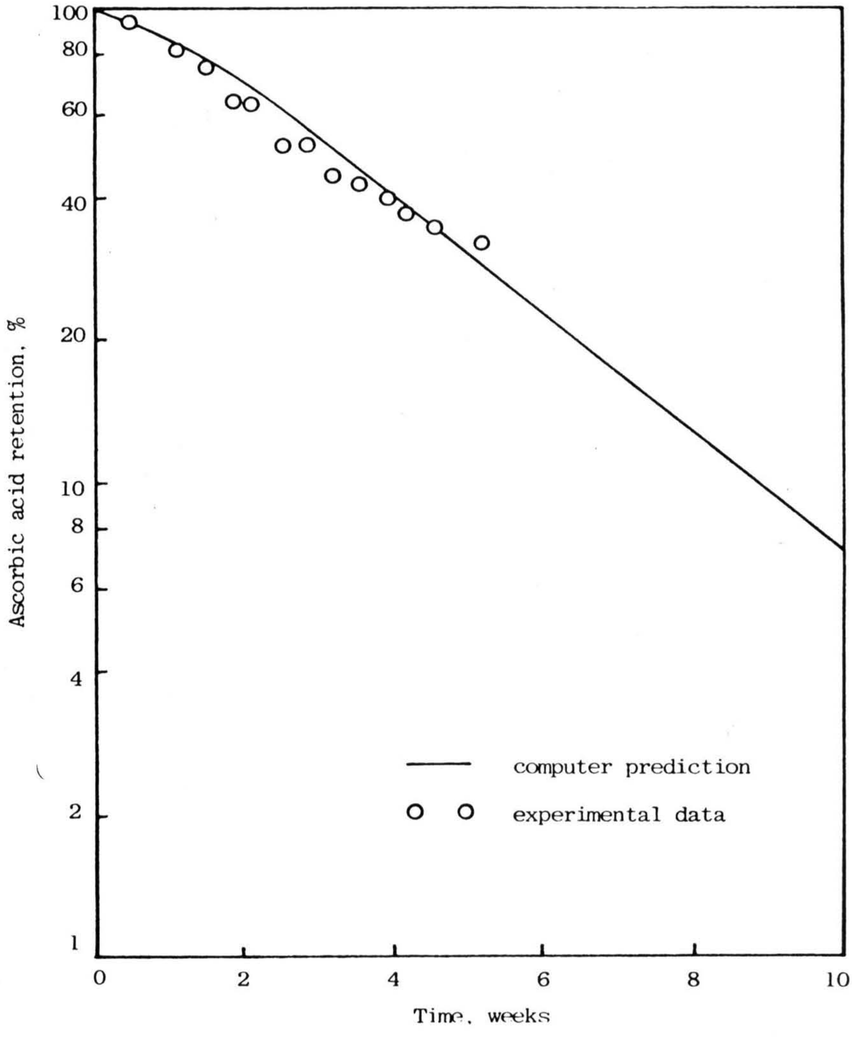

FIG. 6. COMPUTER PREDICTION AND EXPERIMENTAL DATA FOR ASCORBIC ACID RETENTION IN THE MODEL FOOD SYSTEM DURING STORAGE AT 40% RH AND 30°C WITH INITIAL MOISTURE CONTENT OF 1%, FILM THICKNESS OF 0.009 CM AND MOISTURE TRANSFER COEFFICIENT OF 7.25×10^{-5}

D. Computer Simulation of Vitamin Degradation

The computer simulation developed in this investigation is based on (1) a first order kinetics reaction between ascorbic acid and oxygen and (2) the assumption that oxygen is not a limiting factor in the reaction. Thus, the simulation can be used to predict the vitamin degradation in dry foods during storage with reasonable accuracy when these assumptions are met.

The output from the computer simulation is in the form of product moisture content and vitamin retention in the product as a function of time. The simulation can be used to evaluate package film materials, the characteristics of food product and the storage environments. An illustration of the computer predictions with varying RH (Fig. 7), varying initial moisture content (Fig. 8), varying package film (Fig. 9), varying moisture transfer coefficient (Fig. 10), and varying product mass per unit of package surface area (Fig. 11) illustrates the value of the prediction approach.

The results indicate that the computer simulation can be used successfully in predicting vitamin degradation in a dry model food system during storage. The simulation accounts for the influence of storage temperature and relative humidity as well as characteristics of the product package. The prediction of vitamin concentrations at any time during storage of a dry model food system using the developed computer simulation should be valuable in the evaluation of package materials and storage environments for dry food products.

CONCLUSIONS

(1) The relationship between moisture content of a dry food and storage time can be predicted from knowledge of storage temperature and relative humidity as well as package film thickness and moisture transfer coefficient for the product container.

(2) Ascorbic acid degradation in a dry model food system can be predicted using a computer simulation with initial moisture content, storage temperature and relative humidity, package film thickness and moisture transfer coefficient for the product container as input parameters.

(3) The computer simulation of ascorbic acid degradation illustrates that nutrient degradation rate increases with increased relative humidity of storage, increased initial moisture content, reduced package film thickness, increased moisture transfer coefficient and decreased ratio of product mass to package surface area.

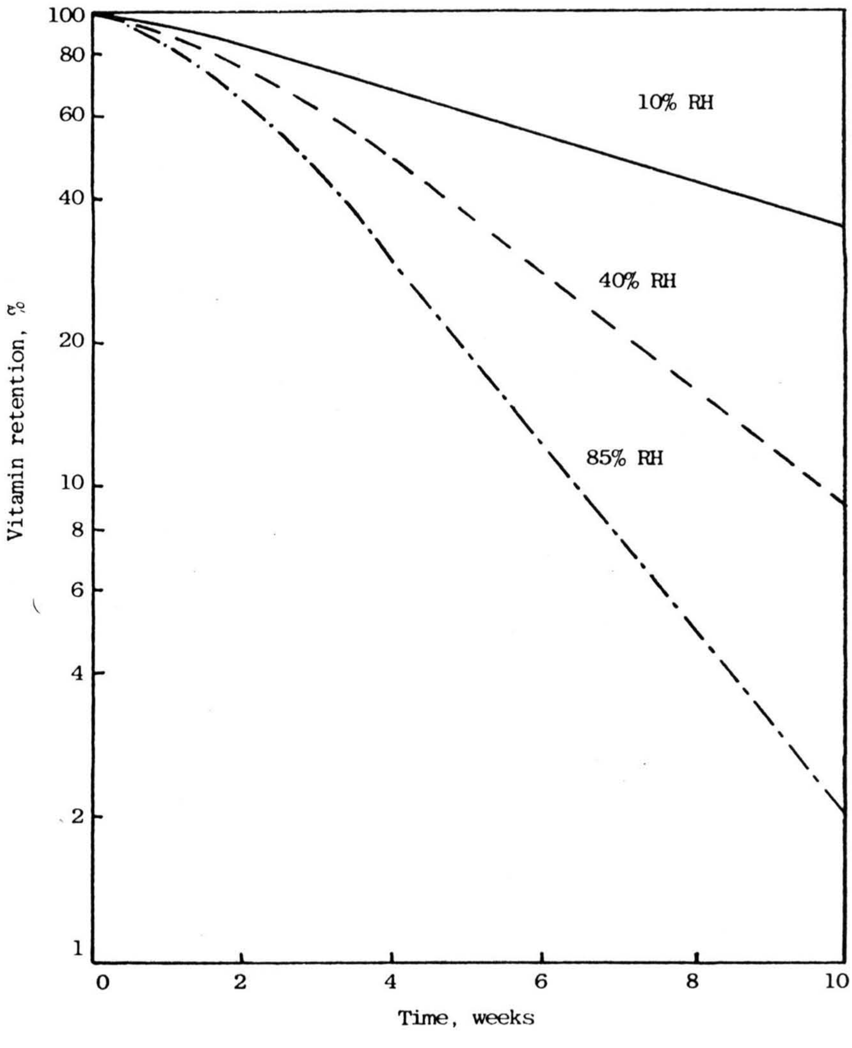

FIG. 7. COMPUTER PREDICTION OF VITAMIN RETENTION IN A FOOD PRODUCT DURING STORAGE AT VARIOUS RELATIVE HUMIDITIES WITH TEMPERATURE OF 30°C, INITIAL MOISTURE CONTENT OF 1%, FILM THICKNESS OF 0.009 CM AND MOISTURE TRANSFER COEFFICIENT OF 7.25×10^{-5}

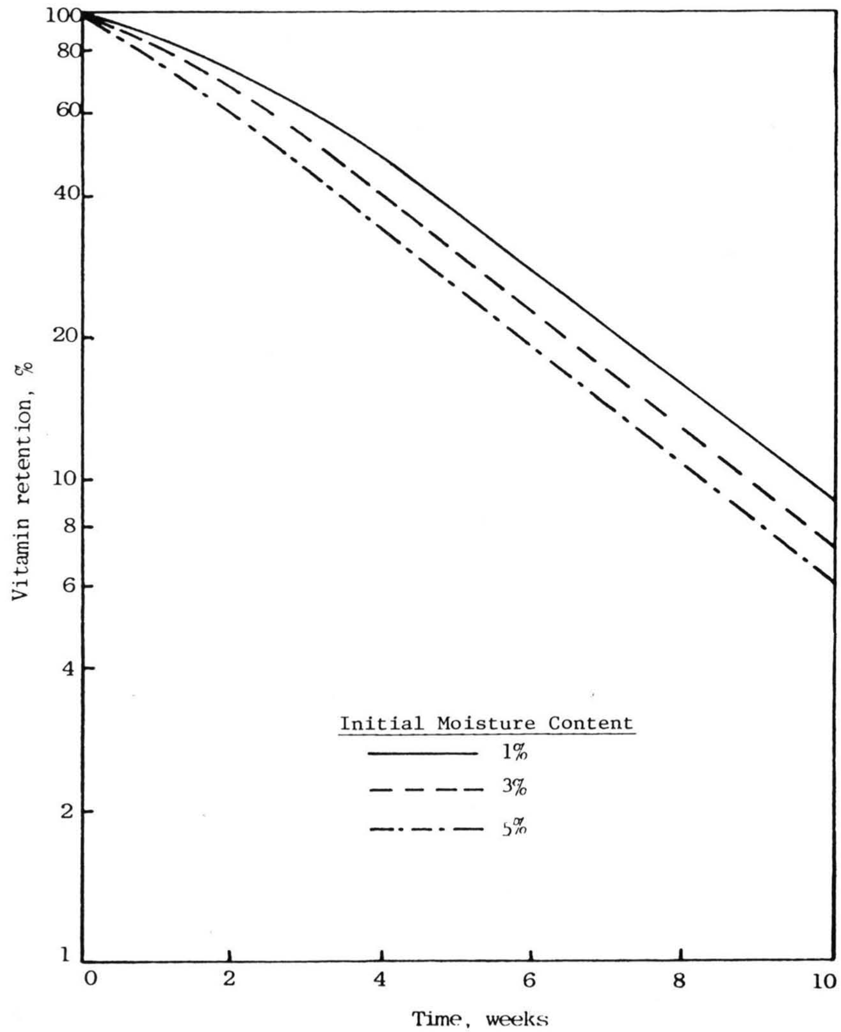

FIG. 8. COMPUTER PREDICTION OF VITAMIN RETENTION IN A FOOD PRODUCT DURING STORAGE AT VARIOUS INITIAL MOISTURE CONTENTS WITH STORAGE TEMPERATURE OF 30°C, RELATIVE HUMIDITY OF 40%, FILM THICKNESS OF 0.009 CM AND MOISTURE TRANSFER COEFFICIENT OF 7.25×10^{-5}

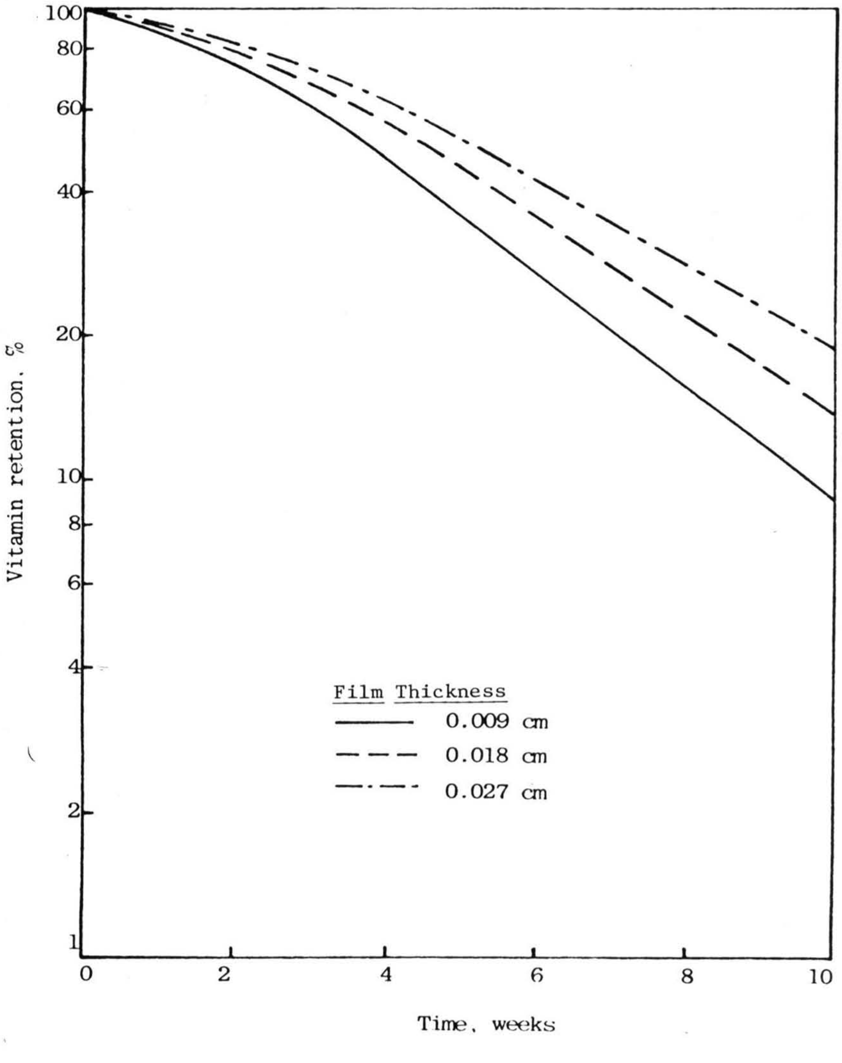

FIG. 9. COMPUTER PREDICTION OF VITAMIN RETENTION IN A FOOD PRODUCT DURING STORAGE WITH VARIOUS PACKAGING FILMS, STORAGE TEMPERATURE OF 30°C, RELATIVE HUMIDITY OF 40%, INITIAL MOISTURE CONTENT OF 1% AND MOISTURE TRANSFER COEFFICIENT OF 7.25×10^{-5}

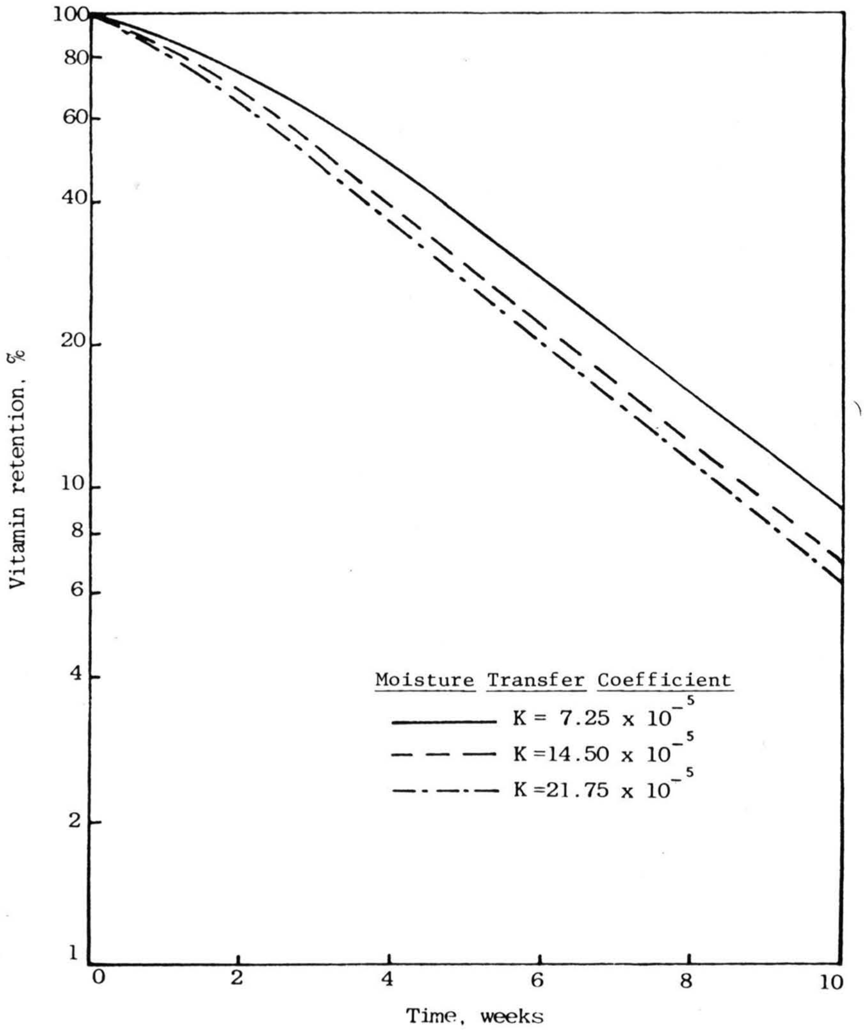

FIG. 10. COMPUTER PREDICTION OF VITAMIN RETENTION IN A FOOD PRODUCT DURING STORAGE AT VARIOUS MOISTURE TRANSFER COEFFICIENTS WITH STORAGE TEMPERATURE OF 30°C, RELATIVE HUMIDITY OF 40%, INITIAL MOISTURE CONTENT OF 1% AND FILM THICKNESS OF 0.009 CM

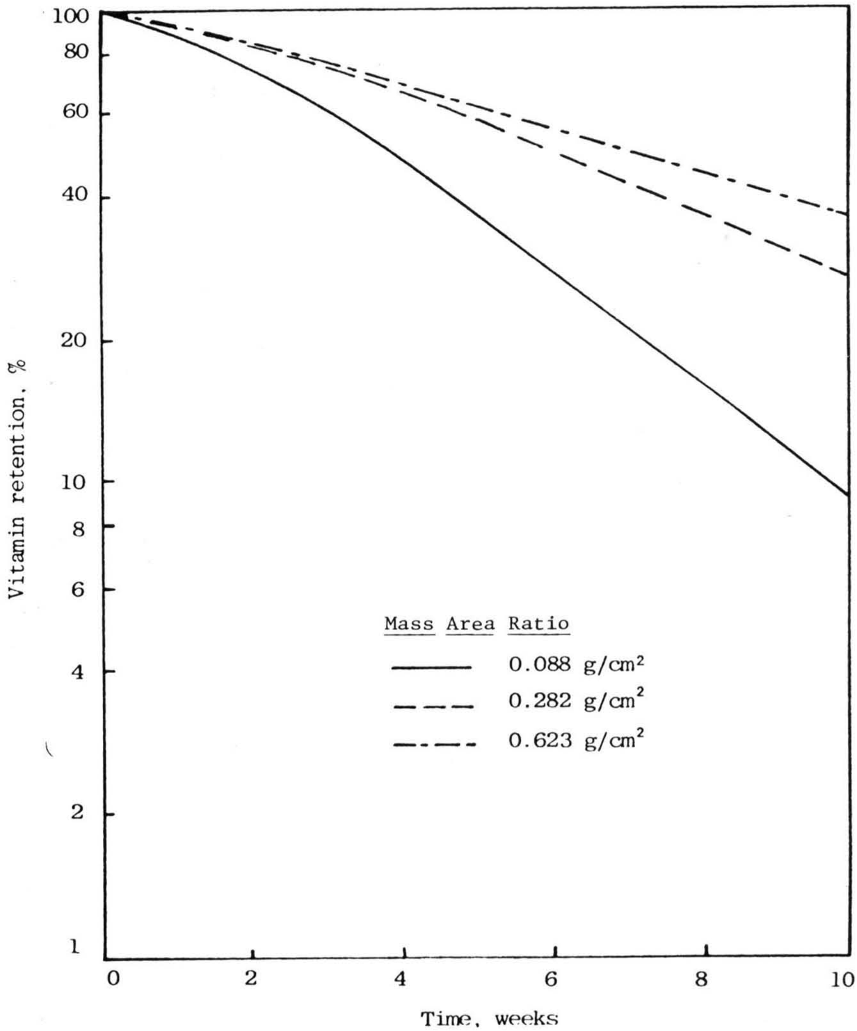

FIG. 11. COMPUTER PREDICTION OF VITAMIN RETENTION IN A FOOD PRODUCT DURING STORAGE AT VARIOUS PRODUCT MASS PER UNIT PACKAGING SURFACE AREA RATIOS, WITH STORAGE TEMPERATURE OF 30°C, RELATIVE HUMIDITY OF 40%, FILM THICKNESS OF 0.009 CM, MOISTURE TRANSFER COEFFICIENT OF 7.25×10^{-5} AND INITIAL MOISTURE CONTENT OF 1%

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BREAKAGE OF RICE DURING MILLING — EFFECT OF KERNEL DEFECTS AND GRAIN DIMENSION[1]

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Received for Publication December 12, 1979
Accepted for Publication March 5, 1980

ABSTRACT

Ten lots of paddy having varying dimensions and contents of cracked and immature grains were milled using laboratory McGill equipment. Grain breakage seemed to originate almost entirely from kernel defects, for it rarely exceeded the content of defective grains. In short and round varieties, a good part of the highly defective (HD = multiple-cracked and immature) grains but few of those with a single transverse crack (STC) broke during shelling, and the remaining HD grains seemed to break during pearling. In medium and slender varieties, most HD and a good part of STC grains broke during shelling, any remaining HD (but not STC) grains appeared to break during pearling. Breakage during pearling increased (within the above limits) with increasing degree and pressure of milling. Improved shelling gave substantial advantage for undermilled rice, but only a moderate advantage for highly milled rice.

INTRODUCTION

The existing literature on the factors responsible for breakage of rice grains during milling was critically reviewed in a recent paper (Bhattacharya 1979). Based on gaps in information revealed therein, a comprehensive study of the relationship of various types of kernel defects, grain shape and size, moisture content, age and type of milling equipment — individually and in their interaction — to rice breakage during milling has been initiated in this laboratory. The first part of this study is reported here.

MATERIALS AND METHODS

Paddy

Paddy was procured from the University of Agricultural Sciences Exper-

[1] This is paper number 2 in a series: Breakage of Rice During Milling.

Journal of Food Process Engineering 3 (1979) 29—42.

iment Station at Mandya. Some of the lots were harvested under personal supervision at an early or medium stage (referred to as early and medium harvest, respectively) to avoid excessive grain cracking. Others were harvested on the farm under customary practice, usually at a late stage (referred to as late harvest). The lots were dried, cleaned, fumigated and then stored in the laboratory in closed metal containers. They were milled at an approximate age of one year after harvest. Parts of one early-harvested lot (Adt 27), with very few cracked grains, were deliberately damaged by: (a) soaking in water for a few hours followed by drying in shade, and (b) soaking in water for 3 days followed by drying in a through-flow dryer at 60°C. Moisture of the samples was determined by drying about 5 g at 105°C for 24 h and adding a correction factor of 1% to the percentage weight loss (Indudhara Swamy *et al.* 1971).

Milling

Milling was with McGill laboratory equipment. Paddy (2—5 Kg) was shelled with a McGill sample sheller under two conditions. In one, the sheller was so set that approximately 50% of the grains were shelled in one pass (designated "light" shelling), while in the other about 90—95% of the grains were shelled in each pass (designated "full" shelling). In either case, the resulting mixture was separated using a Schule laboratory paddy separator (only one or two channels being used) or, when the paddy was too little, a Carter dockage tester with riddle 000. The unshelled paddy was then reshelled under identical conditions, and the process repeated until practically all the grains had been shelled.

The brown rice was pooled, and broken grains (less than 3/4-size kernels) in it were separated using a laboratory Schule trieur. The percentage of breakage by weight was calculated, after which the broken grains were discarded.

The whole-grain brown rice was mixed well, a small portion (using a sample divider) was set aside for defective-kernel analysis, and the balance was divided into several 110-g sublots. Each sublot was milled (pearled) with a modified McGill miller No. 1 using different weights and for different times to different degrees of milling (d.m.) (Bhattacharya and Sowbhagya 1972). Generally results of only three d.m. — designated low, medium and high, and representing approximately 3, 5 and 8% d.m. respectively — are presented here in consideration of space.

After milling, the rice and bran fractions were sieved with an 18-mesh screen, the tops being combined, and broken grains (less than 3/4-size kernels) were separated using a laboratory sizing device. The percentage breakage by weight so determined in rice milled from whole brown rice was recalculated to the original mixture of whole plus broken brown rice.

Defective-Kernel Analysis

Contents of various types of cracked and immature grains were determined in representative samples of paddy (manually shelled) and machine-shelled whole brown rice, in duplicate, using a microbiological colony counter as described earlier (Indudhara Swamy and Bhattacharya 1979). The contents thus determined in the whole brown rice were recalculated to the original mixture of whole plus broken brown rice. The following types of whole kernels were distinguished:

(a) sound grains,
(b) STC = kernels with a single transverse crack,
(c) MTC = kernels with multiple transverse cracks,
(d) LC = kernels with longitudinal (usually with one or more transverse) cracks, and
(e) Im = immature grains.

The last three types have also been referred to in aggregate as highly defective (HD) grains, i.e. HD = MTC + LC + Im. Similarly the sum total of all whole kernels other than sound have been referred to as total defective (TD) grains, i.e. TD = HD + STC.

Size and Shape

Length (L) and breadth (B) of milled rice were determined by arranging randomly selected 10 unbroken sound kernels end-to-end and edge-to-edge respectively, in duplicate, and measuring (Adair *et al.* 1966). Kernel weight (w) of milled rice was determined by counting and weighing 100 grains in duplicate.

RESULTS AND DISCUSSION

The various samples, their harvest stage, treatment if any, grain dimensions and moisture contents are shown in Table 1. Since the moisture contents of the samples were not appreciably different, this factor may be assumed not to have influenced the results significantly.

Breakage during Shelling

A comparison of the counts of the various types of whole kernels in the samples before and after shelling gave a clear indication of which of these broke during this step. Full details of these results in a few selected varieties are shown in Table 2. Results of all the varieties in a more abbreviated form are reproduced in Table 3. The extent of breakage is shown in Table 3 and can also be judged from the last column of Table 2. These results show the following:

Table 1. Description of experimental paddy samples

Sl. No.	Designation	Variety	Harvest	Treatment	Moisture Content, % Wet Basis	Length,[1] mm	L/B[1]
1	Adt (a)	Adt 27	Early	—	12.9	4.0	1.7
2	Adt (b)			Soaking damaged[2]	11.3		
3	Adt (c)			Drying damaged[3]	12.8		
4	T 65	Taichung 65	Late	—	12.3	4.8	1.7
5	Co 25	Co 25	Late	—	12.8	4.9	2.0
6	RC	Ratnachudi	Medium	—	11.6	5.6	2.5
7	BS (eh)	Bangara Sanna	Early	—	12.3	5.6	2.8
8	BS (lh)	Bangara Sanna	Late	—	11.5		
9	VS	Vankasannam	Medium	—	12.1	5.7	3.4
10	SR 26 B	SR 26 B	Early	—	12.7	7.7	3.5

[1] Of whole-grain milled rice
[2] Paddy (No. 1) soaked in water for 4 h and dried in shade
[3] Paddy (No. 1) soaked in water for 3 days and then dried at 60° C

Table 2. Change in the content of defective whole kernels upon shelling of paddy

Sl. No.[1]	Sample[1]	Shelling[2]	Type of Whole Grains[3] in Sample, % by Weight					
			Sound	STC	MTC	LC	Im	Total
2	Adt (b)	—	47.2	35.6	13.2	3.1	0.9	100.0
		Light	49.0	32.7	9.9	1.3	1.0	93.9
		Full	51.7	33.3	2.2	0.5	0.5	88.2
3	Adt (c)	—	11.2	19.4	4.4	61.7	3.3	100.0
		Light	9.8	14.2	4.8	45.8	2.2	76.8
		Full	11.2	12.2	2.7	37.2	1.5	64.8
4	T 65	—	10.0	17.2	14.6	55.5	2.7	100.0
		Light	11.7	16.9	11.7	12.7	1.5	54.5
		Full	9.8	15.1	7.3	7.9	1.0	41.1
7	BS (eh)	—	91.9	4.3	1.3	0.0	2.5	100.0
		Light	90.5	2.5	0.0	0.0	1.4	94.7
		Full	90.0	0.6	0.0	0.0	1.6	92.2
8	BS (lh)	—	42.2	21.7	27.9	3.6	4.6	100.0
		Light	43.3	4.0	0.7	0.0	1.0	49.0
		Full	41.2	2.3	0.2	0.0	0.3	44.0
9	VS	—	66.0	13.3	14.4	0.5	5.8	100.0
		Light	64.0	4.2	3.6	0.0	2.2	74.0
		Full	63.8	4.4	0.6	0.0	0.6	69.4
10	SR 26 B	—	49.1	21.9	8.2	0.0	20.8	100.0
		Light	46.6	3.8	2.7	0.0	6.2	59.3
		Full	37.0	2.0	0.6	0.0	0.9	40.5

[1] Same as in Table 1

[2] The first row under each sample shows its grain analysis before shelling (determined after manual dehusking). Light and full shelling represent, respectively, about 50% and 90-95% of paddy grains shelled in one pass

[3] STC = Grains with a single transverse crack
MTC = multiple transverse cracks
LC = longitudinal ± transverse cracks
Im = Immature grains

Table 3. Relation between kernel defects and grain breakage during milling of paddy

Sample[1]	Shelling[2]	Defective Whole Grains in Sample[3], %		d.m.,[4] %	Breakage,[5] % by Weight		Calculated % by Weight of Grains Broken[3,6]		
		HD	TD				HD	STC	Sound
1. Adt (a)	—	4.5	7.9						
	Full	—	—	0	1.8		40	0	0
				H	5.1	(3.3)	100	18	0
2. Adt (b)	—	17.2	52.8						
	Light	12.2	44.9	0	6.1		36	0	0
				L	8.4	(2.3)	49	0	0
				M	12.5	(6.4)	73	0	0
				H	15.6	(9.5)	91	0	0
	Full	3.2	36.5	0	11.8		69	0	0
				L	14.4	(2.6)	84	0	0
				M	16.5	(4.7)	96	0	0
				H	18.5	(6.7)	100	4	0
3. Adt (c)	—	69.4	88.8						
	Light	52.8	67.0	0	23.2		33	0	0
				L	74.7	(51.5)	100	27	0
				M	77.2	(54.0)	100	42	0
				H	79.5	(56.3)	100	52	0
	Full	41.4	53.6	0	35.2		51	0	0
				L	68.0	(32.8)	98	0	0
				M	77.8	(42.6)	100	43	0
				H	80.7	(45.5)	100	53	0

(continued)

4. T 65	—	72.8	90.0						
	Light	25.9	42.8	0	45.5		63	0	0
				L	68.2	(22.7)	94	0	0
				M	71.3	(25.8)	98	0	0
	Full	16.2	31.3	0	58.9		81	0	0
				L	72.1	(13.2)	99	0	0
				M	74.2	(15.3)	100	8	0
5. Co 25	—	47.4	70.6						
	Light	20.9	31.5	0	41.4		87	0	0
				M	55.2	(13.8)	100	31	0
	Full	5.5	16.6	0	53.8		100	28	0
				H	61.2	(7.4)	100	60	0
6. RC	—	23.0	43.2						
	Light	5.0	16.0	0	26.3		100	16	0
				H	32.4	(6.1)	100	46	0
	Full	1.5	9.7	0	35.5		100	62	0
				H	38.4	(2.9)	100	76	0
7. BS (eh)	—	3.8	8.1						
	Full	1.6	2.2	0	7.8		100	93	0
				H	8.4	(0.6)	100	100	0
8. BS (lh)	—	36.1	57.8						
	Light	1.7	5.7	0	51.0		100	69	0
				L	52.4	(1.4)	100	75	0
				M	52.7	(1.7)	100	76	0
				H	53.4	(2.4)	100	80	0
	Full	0.5	2.8	0	56.0		100	92	0
				L	56.1	(0.1)	100	92	0
				M	56.3	(0.3)	100	93	0
				H	56.5	(0.5)	100	94	0

(continued)

Table 3. Relation between kernel defects and grain breakage during milling of paddy (cont.)

Sample[1]	Shelling[2]	Defective Whole Grains in Sample[3], %		d.m.,[4] %	Breakage,[5] % by Weight		Calculated % by Weight of Grains Broken[3,6]		
		HD	TD				HD	STC	Sound
9. VS	—	20.7	34.0						
	Light	5.8	10.0	0	26.0		100	40	0
				L	27.2	(1.2)	100	49	0
				M	29.1	(3.1)	100	63	0
				H	31.2	(5.2)	100	79	0
	Full	1.2	5.6	0	30.6		100	74	0
				L	31.0	(0.4)	100	77	0
				M	31.8	(1.2)	100	84	0
				H	32.2	(1.6)	100	86	0
10. SR 26 B	—	29.0	50.9						
	Light	8.9	12.7	0	40.7		100	53	0
				L	46.1	(5.4)	100	78	0
				M	45.5	(4.8)	100	75	0
				H	60.3	(19.6)	100	100	19
	Full	1.5	3.5	0	59.5		100	100	18
				L	61.6	(2.1)	100	100	22
				M	62.1	(2.6)	100	100	23
				H	70.1	(10.6)	100	100	39

[1] See Table 1
[2] The dash (—) is this column refers to original paddy
[3] HD = Highly defective grains (= grains with multiple and longitudinal cracks + immature grains)
TD = Total defective grains (= HD + STC)
STC = Grains with a single transverse crack
[4] 0 = Zero (i.e., unmilled brown rice after shelling)
L, M, H = Low, medium and high degree of milling, respectively
[5] Data in parenthesis refer to breakage occurring during the pearling step
[6] The total breakage is first calculated as a % of HD grains (up to a maximum of 100%), any excess breakage is calculated as a % of STC grains, and further excess as a % of sound grains

(1) Extent of breakage during shelling in any sample was closely related to the contents of its defective kernels. The more the defective kernels, the more was the breakage, and vice versa (Table 2).
(2) In any sample, more rice broke and more of the defective kernels disappeared during full shelling than during light shelling.
(3) In terms of magnitude, the order of disappearance during shelling (i.e. breakage) of the various whole kernels was: LC, MTC, Im, STC, sound.
(4) Within the above general picture, precisely which type of grains broke and how much were a function of the grain length and shape. In short and round varieties (Adt 27, Taichung 65), not all the HD grains broke and STC grains broke but little — the proportions being lesser in Adt 27, the shorter of the two varieties. In medium and slender varieties, on the other hand, most of the HD whole grains disappeared during shelling, and also a large part of the STC grains especially during full shelling. In SR 26B, an exceptionally long and slender variety, the proportions were still more, and even some of the sound whole kernels disappeared during shelling. Co 25 and RC, in keeping with their dimensions, gave an intermediate picture (Table 3).

Breakage during Pearling

Extent of grain breakage occurring during the pearling step (over and above that during shelling) is shown in parentheses under the column "breakage" in Table 3. These results reveal the following:

(1) The greater the quantity of defective kernels that escaped unhurt during shelling and came into the brown rice (shown against "light shelling" and "full shelling" under each sample), the greater was the breakage during pearling. Thus, more grains broke in lightly-shelled as compared to fully-shelled brown rice, and in round as compared to medium-slender varieties. In fact, in fully-shelled slender varieties (barring SR 26B) very little additional breakage occurred during pearling. These facts showed that: (a) grain breakage during pearling too was related to defective grains, and (b) the advantage of improved shelling tended to be partly nullified during pearling.
(2) In contrast to the situation during shelling, when a greater proportion of defective grains broke in medium-slender than in round varieties, there was no such striking difference between different grain types during pearling. In all cases, the extent of final breakage was nearly equal to the content of residual HD kernels in the samples.

Although there was no direct evidence during pearling, unlike during shelling, of precisely which kernels broke in this step, the above results strongly suggest that nearly all the residual HD whole kernels in a sample broke during pearling, but few if any of the STC or sound kernels did so, irrespective of the grain type. The only exception to the above generalization was the unusually long variety, SR 26B, in which the breakage, as during shelling, clearly exceeded even the residual TD grain count. Evidently, even some sound kernels broke here at high d.m.

(3) Extent of breakage increased with increasing degree of milling (d.m.). However, as is evident in the samples giving high absolute figures of breakage (Adt 27 [c], Taichung 65, Co 25), most of the breakage occurred even on initial low milling after which the figure increased slightly. In other words, it appeared as if the grains that were prone to break, broke rather easily and quickly. This supported the earlier hypothesis that it is mostly the highly defective kernels that actually broke during pearling. For, if breakage was a consequence of the stress of milling *per se* irrespective of kernel defects, breakage should have increased linearly with time and d.m.

(4) For achieving equal d.m., breakage increased with increasing pressure applied during pearling, as is shown in some typical data in Table 4. In other words, gentle milling for longer time gave less breakage than hard milling for less time. This is a well-known principle noted also by earlier workers (Raghavendra Rao *et al.* 1967). However, it is important to note that even when milled under high pressure, the breakage did not exceed the TD count. In other words, grain breakage was still presumably confined to defective kernels, though apparently some STC grains broke here at high d.m.

Total Breakage

The values of total breakage (shelling and pearling) are shown in Table 3. Comparing these data with the defective-kernel counts in the original paddy (first row under each sample), and viewing in the light of the results observed separately during shelling and pearling, the following observations seem to emerge:

(1) Breakage was preeminently related to the content of defective kernels in the sample being milled. Whatever the grain type and quality and whatever the milling condition, the total breakage never exceeded the total count of defective kernels (except in SR 26B).

(2) Comparing light vs full shelling, the initial advantage in grain breakage in the former got progressively reduced as the d.m. increased.

Table 4. Effect of pressure during milling on rice breakage

Load, lb	RC[1]		SR 26 B[2]	
	d.m., %	Breakage, %	d.m., %	Breakage, %
1	2.2	27.8	3.0	61.6
	3.1	27.8	5.7	62.1
	5.1	28.4	6.7	62.7
	—	—	7.2	65.3
2	5.1	28.9	6.4	63.8
4	2.1	29.7	5.0	63.8
	4.5	30.4	6.2	65.7
	8.1	32.4	7.5	68.0
	—	—	8.0	70.1
6	8.1	37.0	8.2	74.7

[1] Light-shelled
[2] Full-shelled

(3) Within the overall limits of defective-grain count, breakage increased with increasing d.m. as expected.

(4) In round varieties, total breakage tended to equal or slightly exceed the HD grains count (at high d.m.), except in highly damaged Adt 27 where the value was a little more. In medium and slender varieties, breakage was more and approached the TD grains count; in SR 26B variety, however, the breakage far exceeded the TD count at high d.m.

These above relations are brought out well by calculating the breakage values sequentially in terms of the various types of kernels as shown in the right hand side of Table 3. In this calculation, breakage is first attributed to HD grains; any excess breakage is then attributed to STC grains; and further excess finally to sound grains.

It is true that these figures are only calculated values and do not necessarily imply that it is precisely these grains that broke and to the extent indicated. It is also possible that grain breakage may be partly a statistical phenomenon, whereby a less or not damaged grain may occasionally break in preference to a more damaged one. Nevertheless, in view of: (a) the clear indication about the relation of breakage to various kernel defects noted in the results under shelling and pearling, and (b) a clear pattern emerging in the table among so many varieties despite wide variation in size, shape and kernel defect, it can be assumed that the calculated values shown in the table do give a reasonable approximation — at least an impressionistic picture — of the actual state of affairs. This way of presentation has the additional advantage that the results of diverse varieties with diverse grain condition are thereby reduced to a common denominator, so that different mill systems and samples can be directly compared.

Bhattacharya (1969) in an earlier study with six varieties, using McGill sheller ("full" shelling) and miller, noted that: (a) total breakage closely corresponded to the total count of defective grains, and (b) most of the breakage occurred during shelling itself, there being very little addition during pearling. All the six varieties used in the study were medium in length and medium or slender in shape, and hence these results are in accord with the present findings. Matthews *et al.* (1970), on the other hand, found that the final breakage (using the McGill equipment) in U.S. long-grain rice was 2-3 times the content of cracked kernels as determined by X-ray photography of intact paddy. Whether their method could detect all the cracks in paddy is a matter of consideration.

Direct Milling of Paddy

All the paddy samples were also directly milled in the McGill miller No. 1 up to approximately equivalent degrees of milling. The resulting grain breakage values (not shown) were quite similar to those obtained after shelling and milling (slightly less than after light shelling and pearling in round varieties, equal to or slightly more than after full shelling and pearling in slender varieties). It would, therefore, seem that using, for instance, the Engelberg huller for direct milling of paddy — a practice universally condemned — may not be much worse than using it only as a pearler.

CONCLUSIONS

Broadly speaking it can be concluded that, under the milling system used, rice grains did not break merely because they were being milled. The ultimate cause of rice breakage lay in the kernel, and it is the defective grain that mostly broke. What precise proportion of these defective grains broke, however, was a function of the grain size and shape, milling system and degree of milling.

In round and short varieties, a good part of the highly defective grains broke during shelling, and the remaining portions of these grains broke during pearling at high degrees of milling. Grains with a single transverse crack, however, broke only slightly during shelling and little, if at all, further during pearling. Total breakage at high d.m. therefore tended to equal or slightly exceed the HD count.

In medium and slender grains, on the other hand, most of the HD grains and also a substantial part of the STC grains broke during shelling (i.e. full shelling), but breakage during pearling here again was confined by and large to the small amount of HD whole grains that remained. As a result, total breakage at high d.m. here approached the TD count. In exceptionally long and slender grains, some sound grains also broke, during shelling as well as pearling, and the total breakage exceeded the TD count.

Comparing the results of (a) T 65 and Co 25, and (b) RC, BS and VS, it would appear that both grain length and grain shape are important. Results of SR 26B show that stress increases so much with increasing grain length, that even sound grains — otherwise so resistant — are liable to fail in exceptionally long (and slender) varieties.

A lower proportion of the grains broke than described above at lower d.m. However, for equal d.m., more of the defective grains failed under high-pressure than under gentle and gradual pearling.

A better shelling system ("light" shelling in the present studies) gave substantial advantage at low d.m. but the advantage got narrowed as the d.m. increased. Also, due to the specific effect of the shelling and pearling steps on the different defective kernels in different grain types (shelling generally affected the HD kernels in round varieties, but HD as well as STC kernels in slender varieties; pearling generally affected HD kernels alone in either), better shelling gave a greater advantage in medium and slender varieties and when the defective kernels consisted substantially of STC kernels.

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BREAKAGE OF RICE DURING MILLING — COMPARISON AMONG DIFFERENT SHELLERS[1]

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Received for Publication December 12, 1979
Accepted for Publication March 5, 1980

ABSTRACT

A medium-long, semislender variety of paddy was shelled using four types of shellers (rubber roll, centrifugal, disc under-runner, McGill) followed by pearling with a McGill miller. Grain breakage during shelling was the least in the rubber roll. But the less the breakage during shelling, the more it was during pearling. As a result, the rubber roll gave considerable advantage after low and medium degrees of milling, but only a marginal advantage at high milling. Total rice breakage was equal to or less than the content of defective grains in the original paddy depending on the sheller.

INTRODUCTION

Based on a recent critical review of the factors responsible for breakage of rice during milling (Bhattacharya 1979), a comprehensive study on the subject has been initiated in this laboratory. Development of different types of cracks in rice and the visual appearance of such cracked and immature rice grains in transmitted light (Indudhara Swamy and Bhattacharya 1979a) and the effect of these defects on rice breakage in interaction with grain size and shape (Indudhara Swamy and Bhattacharya 1979b) were described in the first two papers of this series. Effect of different types of shellers has been studied here.

It is generally known that the rubber-roller sheller gives a better performance than other types. However, this aspect has been generally tested so far in mill-scale studies up to low or medium degrees of milling (d.m.), but results cannot necessarily be extrapolated to high d.m. It has been shown in the previous work (Indudhara Swamy and Bhattacharya 1979b) that the advantage accrued out of a better shelling system (simulated by using the McGill sheller such that only about 50% of paddy was shelled in one pass) was progressively nullified during the subsequent pearling step as the d.m.

[1] This is paper number 3 in a series: Breakage of Rice During Milling.

increased. Besides, it would be of interest to evaluate the breakage results in terms of the content of defective kernels in the paddy being milled. These aspects have been studied here.

MATERIALS AND METHODS

The paddy, Bangara Sanna variety, was purchased from the market and stored in the laboratory after fumigation for about one year. It was a medium long (5.6 mm, milled rice) and semislender (length/breadth ratio 2.8) variety. Its moisture content was 12.1% (wet basis).

Defective grains in the original paddy (after manual dehusking) as well as in the respective shelled brown rice were analysed in transmitted light as described earlier (Indudhara Swamy and Bhattacharya 1979a). As before, whole grains were classified as: (a) sound, (b) with a single transverse crack (STC), (c) with multiple transverse cracks (MTC), (d) with longitudinal (± transverse) cracks (LC), and (e) immature grains (Im). Categories (c) to (e) have also been referred to in aggregate as highly defective (HD) grains, and HD + STC grains as total defective (TD) grains.

Milling

The following four types of shellers were used:
(a) rubber-roller sheller,
(b) under-runner emery disc sheller,
(c) centrifugal sheller, and
(d) McGill sample sheller.

The first three units were small commercial models. The particular rubber-roll sheller used (Rajalakshmi) was not the best of its type and gave a somewhat greater grain breakage than usual for this class.

A modified McGill miller No. 1 was used for pearling of the shelled brown rice. The general procedure for milling and separation of broken grains was as in the previous paper (Indudhara Swamy and Bhattacharya 1979b). All shelling was "semilight" (about 70% by weight paddy shelled in each pass).

As already described in the above paper, the breakage data were also calculated serially as progressive percentages of HD, STC and sound grains (see Table 2). This calculation helped to roughly visualize at a glance which grains generally broke at each stage.

RESULTS AND DISCUSSION

Defective-kernel analysis in the grains before and after shelling (Table 1),

Table 1. Content of various whole kernels in sample before and after shelling

Shelling	Whole Kernels, % by Weight					
	Total	Sound	Defective[2]			
			STC	MTC	LC	Im
—[1]	100.0	64.8	16.4	13.2	3.1	2.5
Rubber roll	85.1	59.1	16.9	6.0	0.4	2.7
Centrifugal	73.2	57.3	9.8	3.7	0.0	2.4
Disc	69.8	59.5	6.9	1.9	0.0	1.5
McGill	66.7	62.5	3.3	0.6	0.0	0.3

[1] This row shows the kernel analysis in the original paddy as tested after manual dehusking
[2] For definition, see Materials and Methods

as well as the breakage occuring during shelling (Tables 1 and 2) clearly showed the following:

(1) Breakage in the different shellers was in the following order: rubber roll < centrifugal ⩽ disc ⩽ McGill.
(2) In the rubber roll, LC and MTC (i.e., HD but excluding Im) grains broke appreciably. But, STC and sound grains did not break.
(3) In the remaining shellers, HD grains broke drastically and also a large part of the STC grains. But sound grains remained unaffected.

The results of breakage occuring during the pearling step (shown in parentheses under the column "Breakage" in Table 2), and a comparison of these data with the residual contents of defective kernels in the respective shelled brown rice (columns 2 and 3) show the following:

(1) Breakage increased in each case with increasing degree of milling (d.m.), as expected.
(2) The more the defective whole grains were spared during shelling, i.e. the less the breakage upon shelling, the more was the breakage during pearling. In other words, the advantage accrued out of a good shelling system was partially (though not fully) nullified during pearling.
(3) The quantum of breakage (at high d.m.) was a little more than the residual content of HD grains in the respective brown rice. Apparently, all or most of the residual HD grains broke during pearling, but only a small proportion of the STC grains and none of the sound grains did so. For instance, in the McGill-shelled sample, where very few HD whole grains were left, there was negligible addition to breakage during pearling even up to high d.m.

Table 2. Grain breakage obtained with different shellers and at different degrees of milling

Sheller	Defective Kernels, %		d.m.[1]	Breakage[2], % by Weight	Calculated % by Weight of Grains[3] Broken		
	HD	TD			HD	STC	Sound
—[4]	18.8	35.2					
Rubber roll	9.1	26.0	0	14.9	79	0	0
			L	23.0 (8.1)	100	26	0
			M	26.6 (11.7)	100	48	0
			H	31.4 (16.5)	100	77	0
Centrifugal	6.1	15.9	0	26.8	100	49	0
			L	30.1 (3.3)	100	69	0
			M	33.5 (6.7)	100	90	0
			H	36.3 (9.5)	100	100	2
Disc	3.4	10.3	0	30.2	100	70	0
			L	31.9 (1.7)	100	80	0
			M	33.4 (3.2)	100	89	0
			H	35.6 (5.4)	100	100	1
McGill	0.9	4.2	0	33.3	100	88	0
			L	33.5 (0.2)	100	90	0
			M	33.9 (0.6)	100	92	0
			H	35.0 (1.7)	100	99	0

[1] 0 = Zero
L, M, H = low, medium and high degrees of milling (d.m.), representing approximately 3,5 and 8% d.m., respectively
[2] Figures in parentheses represent breakage occuring during the pearling step
[3] See, for definition of symbols, Materials and Methods
[4] In the original paddy

Combining the above two sets of data, and as shown in the calculations in the right half of Table 2, the following can be said about the total breakage:

(1) Total breakage (at high d.m.) was somewhat less than the original-sample TD grains content when using the rubber-roller sheller.
(2) Total breakage more or less equaled the original TD content in all the other shellers.
(3) There was no appreciable difference in performance among the three shellers other than the rubber roll.
(4) The rubber roll gave considerable advantage at low and medium d.m., but only a marginal advantage at high d.m. over the other shellers. However, it must be remembered that the above state-

ment applies to when a metal roller is used as a pearler, and may not necessarily apply with other types of pearlers.

The present results are in broad agreement with the earlier study (Indudhara Swamy and Bhattacharya 1979b) with respect to (a) the relative advantage at different d.m. of an improved shelling system (simulated in the above work by using the McGill sheller to shell only 50% by weight of the grains in each pass) and (b) the breakage during shelling and pearling of medium-semislender grains.

It can be concluded that:

(1) It is by and large only the defective rice grains that break during milling. In other words, the cause of rice breakage lies primarily in the grain; the act of milling only manifests it.

(2) The advantage in reduced grain breakage accrued out of using a good shelling system, if followed by a metal-roller type pearler, is progressively reduced as the degree of milling increases. However, one likely advantage of rubber-roller shellers not studied here is in total milling yield. The considerably reduced grain breakage during shelling would undoubtedly mean reduced loss of small broken pieces during aspiration of the husk and would to that extent increase the total milled rice out-turn.

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LITERATURE ABSTRACTS

ABSTRACTS FROM THE JOURNAL OF FOOD SCIENCE

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MECHANICAL INTERPRETATION OF COMPRESSIVE STRESS-STRAIN RELATIONSHIPS OF SOLID FOODS. F. J. Calzada and M. Peleg. J. Food Sci. *43*, 1087–1092.

True compressive stress-strain relationships of various solid foods have been demonstrated in a three-dimensional display that has included the tests true strain histories. The shapes of the stress-strain curves and complementary relaxation and compressibility data indicated the existence of two antagonistic mechanisms which regulated the stress levels. These were internal fractures which tended to decrease the mechanical strength of the deformed specimens and structural compaction that had the tendency to increase it. It has also been demonstrated that the true stresses could be influenced by the specimen dimensions as well as by the strain rate.

SOME MATHEMATICAL ASPECTS OF MASTICATION AND ITS SIMULATION BY MACHINES. M. Peleg. J. Food Sci. *43*, 1093–1095.

If the deformation process of a specimen satisfies the condition: $H(t) = g(H_o) \cdot f(t)$ (Eq. 1), where H (t) is the deformed specimen length at time (t), $g(H_o)$ is a function of the initial length (H_o) only and f (t) a function of time only, then the true strain ϵ (t) and the strain rate ϵ (t) are: $\epsilon(t) = \ln f(t)$ (Eq. 2), and $\epsilon(t) = [d \ln f(t)]/dt$ (Eq. 3). These imply that the stress-strain (or force-time) relationship of a homogenous material is independent of the specimen length and is only determined by the rheological properties of the material and the selected function f (t). If the deformation histories produced in mastication satisfy the condition set by Eq (1) it would provide a partial mathematical explanation to why sensory textural-rheological properties are not affected by the specimen dimensions in contrast to instrumental parameters obtained by existing testing machines. The construction of machines that provide such straining histories is physically possible (they would not, however, be operated at a constant deformation rate), and therefore it is theoretically possible to obatin instrumental parameters that are dimension independent. The concept is demonstrated with some simplified rheological models and its possible application to food testing evaluated.

SHORT-CUT METHOD FOR THE CALCULATION OF STERILIZATION CONDITIONS YIELDING OPTIMUM QUALITY RETENTION FOR CONDUCTION-TYPE HEATING OF PACKAGED FOODS. H. A. C. Thijssen, P. J. A. M. Kerkhof and A. A. A. Liefkens. J. Food Sci. *43*, 1096–1101.

Based on analytical equations for the temperature distribution history in a container, the relation between the reductions of the concentrations of heat labile food components, including microorganisms, nutrients and sensory factors, and the kinetic parameters of the reactions causing these reductions, has been calculated numerically. For a constant temperature of the heating medium with time it is concluded that the loss of quality is almost minimal at one Fourier value of the heating time. This optimal Fourier value is a function of only the Biot number and the relationship between initial product temperature, cooling water temperature and retort temperature. At an infinite value of Biot and a cooling water temperature equal to the initial product temperature the optimum Fourier value amounts to 0.5. On the basis of this conclusion a short-cut calculation method is developed. The method is valid for Biot numbers larger than 10, initial homogeneous product temperatures equal to or larger than the temperature of the cooling medium and for the main container geometries including spheres, cylinders and rectangular bodies. The method does not require tedious interpolations of tables. The calculation of the optimum process conditions to obtain the desired sterility and the calculation of the retention of the quality factor of interest require only a few minutes on a pocket calculator. For routine calculations the procedure can conveniently be programmed.

ASYMMETRY IN FREEZE-DRYING. J. A. Zarkarian and C. J. King. J. Food Sci. *43*, 992—997.

This paper describes what is meant by asymmetric freeze-drying and reports experimental observations of the phenomenon. Current mathematical models of freeze-drying cannot account for asymmetry. This theoretical deficiency is corrected by the development and solution of a freeze-drying theory termed the asymmetrically retreating-ice-front (ARIF) model.

ACCELERATION OF LIMITED FREEZE-DRYING IN CONVENTIONAL DRYERS. J. A. Zarkarian and C. J. King. J. Food Sci. *43*, 998—1011.

Limited freeze-drying leaves a substantial, predetermined and uniform moisture content, such as is required for compression of the product. The process can be accomplished by modification of ordinary freeze-dryers. It is shown that the time required for limited freeze-drying can be reduced by as much as a factor of two through the use of programmed platen temperatures, starting with higher temperatures which are then reduced as srying proceeds. I-cm cubes of cooked beef can be dried to a uniform average moisture content of 10% in 7 hr in this way. The observed temperature histories and drying times agree well with the predictions of a quantitative model for asymmetric freeze-drying.

TEXTURAL PROPERTIES OF AMULOSE SPONGES. A. Torres Q., H. G. Schwartzberg, M. Peleg, R. Rufner. J. Food Sci. *43*, 1006—1009.

Sponges were prepared by freezing and thawing of amylose gels. The sponges had a characteristic "leafy" structure reminiscent of the fleshy part of some seafoods. The mechanical properties of the sponges were evaluated by uniaxial compression. It has been found that the true stress-strain relationship of the sponge could be described by $\sigma = E_1 \epsilon + E_2 \epsilon^n$, where σ and ϵ are the true stresses and strains. E_1, E_2 and n are constants. It has been suggested that the first component is the elastic contribution of the sponge and the second component is the contribution of structural compaction which becomes dominant at large deformation levels. The effects of consecutive compressive cycles as well as amylose concentration and freezing methods were also evaluated in terms of mechanical parameters. Explanation of the latter has been suggested in terms of the deformation mechanism of sponges.

CONTINUOUS DIFFUSION-EXTRACTION METHOD TO PRODUCE APPLE JUICE. C. R. Binkley and R. C. Wiley. J. Food Sci. *43*, 1019—1023.

The continuous stepless counter-current De Danski Sukkerfabrikker diffusion apparatus originally developed to recover sugar solids from sugar beets was studied as a physical procedure to recover apple juice. This procedure was compared with apple juice recovery using a Willmes press which is an example of a batch mechanical pressing operation. Crinkle-cut apple slices 3 mm in thickness were introduced into the diffuser and heated from 55-75°C. The cell sap containing soluble nutrients was diffused through the apple cell membrane and extracted by heated potable water flowing under the force of gravity. The diffusion-type juice soluble solids yields were 13.47% higher than those for the press-type juices and resulting extracted pomace was low in waste-soluble solids. Sensory comparisons between the pressed and diffusion juices showed preference for the pressed product.

LIQUID NITROGEN EXPOSURE AS AN ALTERNATIVE MEANS OF CHILLING POULTRY. A. S. Arafa and T. C. Chen. J. Food Sci. *43*, 1036—1037.

Chilling of broilers by liquid nitrogen exposure resulted in lower Warner-Bratzler shear values and longer sarcomere lengths, indicating more tender meat when compared with immersion chilled broilers. Liquid nitrogen chilling also resulted in higher cooking yields. Experienced panelists detected a highly significant ($P < 0.005$) difference between liquid nitrogen chilled and immersion chilled poultry meat with a preference for the liquid nitrogen chilled product. Significant correlations existed between objective and subjective methods for tenderness evaluation and between Warner-Bratzler shear values and sarcomere lengths. Liquid nitrogen chilling of poultry resulted in a product with a longer shelf-life when compared with that of immersion chilled broilers.

DEFINITION OF A PREDICTION MODEL FOR DETERMINATION OF THE EFFECT OF PROCESSING AND COMPOSITIONAL PARAMETERS ON THE TEXTURAL CHARACTERISTICS OF FABRICATED SHRIMP. H-M Soo, E. H. Sander and D. W. Kess. J. Food Sci. *43*, 1165—1171.

The designs of Scheffe [J. Royal Stat. Soc., Series B (1963) 25: 235], and of McLean and Anderson [Technometrics (1966) 8 (3): 447] were used to study the effect of processing (mixing times and temperatures) and compositional (shrimp, isolated soy protein, NaCl, and sodium tripolyphosphate) parameters on the textural changes of fabricated shrimp. Prediction equations were developed to investigate the effect of those parameters on textural changes of the cooked shrimp patties. There is not a significant interaction effect between the processing and compositional parameters. Mixing temperature has a greater effect on texture of cooked shrimp patties than does mixing time. The directional derivatives of the response surface and the contour plots were used to examine the compositional effects. Sodium tripolyphosphate (STP) causes the greatest change in response among components studied. The optimum level of NaCl for springiness is 2%, whereas the optimum level of STP is dependent upon the isolated soy protein (ISP) level. Springiness of cooked shrimp patties increases with increasing ISP and decreasing shrimp levels in the mixture. The calculated optimum processing and compositional parameters for fabricated shrimp texture were obtained by using a non-linear programming routine, and agree with the measured values. The designs and data analysis procedures can be used to develop accurate prediction models for the effect of processing and compositional parameters on textural characteristics of fabricated shrimp.

DEGRADATION KINETICS OF ASCORBIC ACID AT HIGH TEMPERATURE AND WATER ACTIVITY. B. M. Laing, D. L. Schluetter and T. P. Labuza. J. Food Sci. *43*, 1440—1443.

The kinetics of ascorbic acid degradation were studied in an intermediate moisture model food system as a function of water activity (0.69 - 0.90) and temperature (61 - 105°C). The disappearance of ascorbic acid in each case followed a zero order kinetic model. Rates of ascorbic acid degradation ranged from 1.5-10.5 mg/100 g solids/min, while the activation energy was in the range of 14-17 Kcal/mole. It is suggested that dissolved oxygen concentration was limiting above 92°C, resulting in a rate decrease between 92 and 105°C. Rates of ascorbic acid degradation were found to increase with increasing a_w, except at 105°C, where the opposite was observed. An equation derived from the integrated zero order rate law was used to predict ascorbic acid losses during an unsteady state heating process approximating a linear temperature rise, with good results. The same equation was much less accurate (predictions were 2 - 4 times larger), when used to predict ascorbic acid losses during extrusion processing, most likely due to the difficulty in obtaining an accurate temperature history of the extruded product.

COMPARISONS BETWEEN MODEL PREDICTIONS AND MEASURED VALUES FOR AVAILABLE LYSINE LOSSES IN A MODEL FOOD SYSTEM. J. C. Wolf, D. R. Thompson, and G. A. Reineccius. J. Food Sci. *43*, 1486—1490.

A mathematical model, developed to predict available-lysine losses in a model food system which had undergone an isothermal-nonstirred process, was tested under different process conditions. The model predictions were compared to measured available-lysine losses in both jacketed-mixer processing and extrusion processing. Statistical analysis using a paired t-test analysis indicated a significant correlation between predicted and actual results for the jacket-mixer process. In the extrusion experiment a statistically significant correlation (0.7) occurred when the predicted values were plotted against observed. However, variation due to product backmixing and inaccurate temperature measurement prevented a rigorous test of the model. The reaction order of available lysine loss in casein, single-cell protein and a soy protein isolate were determined at an elevated temperature. The casein and single-cell protein followed first-order reaction kinetics. The soy isolate initially follows first-order loss but after an approximate loss of 40-50% available lysine, the loss abruptly stops and a no-loss phase occurs.

ABSTRACTS FROM TRANSACTIONS OF THE ASAE

DEWATERING KELP FOR FUEL, FEED, AND FOOD USES: PROCESS DESCRIPTION AND MATEIAL BALANCES. Marcus R. Hart, Donald De Fremery, Cameron K. Lyon and George O. Kohler. Tran. ASAE *21* FE, 186—190, 196.

The Ocean Food and Energy Farm Project envisions using *Macrocystis pyrifera* (giant kelp), grown in vast ocean farms, as a source of a fermentable material for producing a substantial portion of our nation's fuel gas and as a source of animal feed and/or human food. However, the high ash content of kelp may be inhibitory or toxic to anaerobic fermentation and may limit the proportion of kelp in animal feeds. A process has been developed by the Western Regional Research Center which reduces the ash and water content of kelp and increases its caloric and bulk densities. In a typical example, kelp is treated with $CaCl_2$, heated, and pressed to remove 75 percent of the moisture and 65 percent of the ash initially present; 70 percent of the organic solids are retained for fermentation. Technical feasibility of the process has been demonstrated in pilot-plant testing using commercially available equipment.

DESIGN AND EVALUATION OF A SALT AGGLOMERATION SYSTEM. R. Paul Singh and Edward T. Huxel. Tran. ASAE *21* FE, 191—196.

A continuous system was designed to agglomerate micro-powdered salt (Na Cl) into a porous, open structured agglomerate of greater size than the original individual salt particles. The effect of design variables on the final size distribution, shape, surface characteristics, density, and strength of the agglomerated salt were studied. The operating variables studied were the amount of moisture added to the dry salt, the feed fate of dry salt to the system, and the rotational speed and length of the agglomerating drum. The operating variables were evaluated with respect to weight mean diameter and size distribution of the final agglomerated product, and moisture content of the moist agglomerates.

The weight mean diameter and size distribution were independent of the rotational speed, the length of the agglomerating drum, the retention time of the moist salt in the agglomerating drum, and the feed rate of the dry salt. The weight mean diameter and size distribution were dependent on the amount of water present in the moist agglomerates for the moisture ranges and material studied. The strength of the agglomerated salt particles were related to the amount of water added to the powdered salt.

PRETREATMENT OF FISH CULTURE WASTEWATER FOR NITRIFICATION. Kenneth M. Lomax and Fredrick W. Wheaton. Tran. ASAE *21* FE, 197—200.

Three pretreatment schemes were tested for effects on nitrification in a gravel filter. The different solids pretreatments had no statistically significant effect on nitrification as measured by ammonia concentrations, but did have a significant effect on clogging of the gravel filter. Foam fractionation eliminated clogging as measured by head loss. The system consisting of a settling basin with 20-min retention, a foam fractionation unit, and a gravel filter, proved best since it was the least complicated system which eliminated clogging during the test period. Measured water quality parameters are summarized and catfish waste production is presented.

FOOD LOSSES IN HARVEST AND HANDLING SYSTEMS FOR FRUITS AND VEGETABLES. M. O'Brien, R. B. Fridley and L. L. Claypool. Trans. ASAE *21* FE, 386—390.

When fruits and vegetables are mechanically harvested and handled they are damaged sufficiently to cause losses before and during processing. Impacts from drops on hard surfaces or on other fruits, or while on horizontal conveyors, or resulting from in-transit vibrations are main causes of damage. The magnitude of both quality and product losses are maturity and time-temperature dependent.

ENGINEERING CONSIDERATIONS IN THE AQUACULTURE OF MACROBRACHIUM ROSENBERGII IN SOUTH CAROLINA. Paul Zielinski, Walter E. Castro and Paul A. Sandifer. Trans. ASAE *21* FE, 391—394, 398.

A summary is presented of the progress to date on engineering experimentation involved with the culture of the fresh water prawn, *Macrobrachium rosenbergii.* This work is part of a Core Project on the culture of this species and includes the development of larval culture facilities, intensive culture systems, and grow-out ponds. Studies of required flow circulation in cylindrical and rectangular tanks have been conducted, as well as studies on methods of moving and aerating culture water. From the tank studies, a method of determining particle settlement in tanks of similar shape and for shrimp feed of different specific weight is discussed.

Based on the research conducted in South Carolina and funded by SC Sea Grant, some considerations in hatchery design and pond harvesting are presented. The advantages of engineered ponds over conventional ponds are discussed. A proposed method of water treatment for hatcheries and grow-out ponds is also presented. Behavioral elements of the animal as they relate to engineering design are discussed where appropriate.

AN ATTEMPTE TO MECHANIZE NUTRIENT RECOVERY FROM ANIMAL EXCRETA. Harry J. Eby and Wallace L. Dendy. Trans. ASAE *21* FE, 395—398.

A mechanized system was developed to determine the feasibility of using fly larvae to extract nutrients from animal wastes and of recovering the larvae for ultimate use as a feedstuff on a large scale. The system was not sufficiently efficient to justify further development at the present time. Environmental conditions conducive for growth of larvae in the batch incubator were not adequately maintained. Components of the system, however, should be useful in the technology for mass rearing of insects. The larvae screen separator satisfactorily attained a 90 percent separation efficiency.

ABSTRACTS FROM AICHE JOURNAL

DYNAMICS AND CONTROL OF THE ACTIVATED SLUDGE AND WASTEWATER PROCESS. U. Attir and M. M. Denn. AICHE J. *24* (4), 693—698.

The dynamics of the activated sludge process are governed under certain conditions by interactions between the reactor and settler through sludge recycle. Settler underloading can lead to extremely sluggish system response, indicating that effective sludge height regulation is an important control objective. This objective may be in conflict with the need to maintain small variations in reactor solids concentration. An effective compromise can be achieved by using ratio control on both sludge recycle and settler underflow. This control policy does not require sludge storage.

MEASUREMENT OF STRUCTURED MICROBILA POPULATION DYNAMICS BY FLOW MICROFLUOROMETRY. J. E. Bailey, J. Fazel-Madjlessi, D. N. McQuitty, L. Y. Lee and J. A. Oro. AICHE J. *24* (4), 570—577.

Commercial microbiological processes frequently contain dispersed microorganisms which are heterogeneous in their age, size, and composition. Relative protein and nucleic acid contents of individual bacteria in *Bacillus subtilis* submerged cultures have been measured experimentally using laser flow microfluorometry. Marginal and joint population composition density data and their complex patterns of evolution during batch growth provide an impetus and emerging basis for a new generation of potentially robust mathematical models of microbial systems.

COMBINED FORCES AND FREE CONVECTION IN A REVERSE OSMOSIS SYSTEM. C. Y. Chang and J. A. Guin. AICHE J. *24* (6), 1046—1054.

The influence of combined forced and free convection on the performance of a reverse osmosis sytem in a horizontal circular pipe is examined. The free convective motion, which is superimposed upon the main axial flow, is caused by buoyancy forces arising from the buildup of a dense solute boundary layer near the membrane surface. The three-dimensional convective diffusion problem is solved by dividing it into a perturbation part accounting for the buoyancy effects present for $Ra \neq 0$ and a nonperturbation part for the intrinsic convective flow pattern present even when $Ra = 0$.

An approximate solution to the nonperturbation equations is obtained from the literature, and the perturbation equations are solved using a stream function-vorticity scheme valid for high Schmidt numbers. The effects of rejection parameter, Rayleigh number, and pressure parameter on the Sherwood number and concentration polarization are studied. Correlations are developed for the asymptotic Sherwood number and the effective axial length at which free convection becomes significant. The numerical results are in reasonable agreement with limiting analytical solutions and with the experimental asymptotic Sherwood numbers measured by Derzansky and Gill (1974) and Hsieh *et al.* (1976).

A MODEL APPROACH TO DYNAMICS OF NONLINEAR PROCESSES. R. J. Fisher and M. M. Denn. AICHE J. *24* (3), 519—523.

Approximate process dynamics of certain nonlinear systems can be estimated by elementary quadratures using a modal approach. The transient response including quadratic nonlinearities is determined by the eigenvalues, eigenvectors, and adjoint eigenvectors of the linearized system equations. The only restriction is that the dominant eigenvalue of the linearized system must be widely separated from the next slowest mode. Several process models satisfy this requirement.

The method is illustrated by application to a fourth-order model of a fluidized bed. The dynamical response is in agreement with numerical solutions to the complete model equations, including estimates of finite regions of stability.

A SPARSE COMPUTATION SYSTEM FOR PROCESS DESIGN AND SIMULATION. PART 1. DATA STRUCTURES AND PROCESSING TECHNIQUES. T. D. Lin and R. S. H. Mah. AICHE J. *24* (5), 830—839.

As an alternative to tearing, symbolic permutation may be used to facilitate data processing rather than dimensional reduction in equation solving, permitting a reduction in computing effort without introducing any deleterious effects on the numerical convergence. Data structures and processing techniques suitable for this purpose have been successfully devised and tested. A program incorporating these techniques has been implemented on a CDC 6400 computer and used to solve irreducible systems of up to 551 linear and nonlinear equations.

PREDICTION OF THE SORPTIONAL EQUILIBRIUM RELATIONSHIP FOR THE FRYING OF FOODSTUFFS. E. Rotstien, and A. R. H. Cornish. AICHE J. *24* (6), 956—966.

After existing correlations were reviewed to predict the equilibrium of foodstuffs with moist air, it was found that they were not adequate. A new equilibrium expression is presented on the basis of equal chemical potentials in the external and internal phases.

The resulting equation can be used over most of the range of moisture contents of sugar based foodstuffs including the high moisture region; it also provides simple analytical expressions for the partial derivatives of moisture content with respect to temperature and to water vapor activity.

RELIABILITY OF OPTIMIZATION PROCEDURES FOR OBTAINING GLOBAL OPTIMUM. B. C. Wang and R. Luus. AICHE J. *24* (4), 619—626.

The importance of the starting point, the size of initial search region, and the search region reduction rate is examined with respect to the reliability of different direct search optimization procedures in being able to furnish the global optimum for non-unimodal systems. Although, in general, the reliability of an optimization procedure is problem dependent, it is nevertheless clear that reliability cannot be increased simply by selecting larger search regions or by reducing the rate of contraction of the search region. A more efficient means of increasing reliability is to embody a pseudo one-dimensional search in the optimization procedure to enable the search to leave a local optimum and proceed to a better optimum.

ABSTRACTS FROM ASHRAE TRANSACTIONS

PERFORMANCE OF VACUUM TUBE SOLAR COLLECTOR SYSTEMS. G. Engholm, and J. Herz. ASHRAE Trans., *84* (2), 419—434.

Vacuum tube solar collectors have minimal heat losses; therefore, their efficiency is relatively insensitive to ambient temperatures, wind conditions and insolation levels. Inlet temperature increases from 85°C (185°F) to 132°C (270°F), reducing average efficiency by only 13%. Thus, it is simpler to predict performance of vacuum tube collectors than coventional flat-plate collectors. A simple manual procedure is presented to predict the performance of vacuum tube collector systems. It is based on the results of many hourly computer simulations for various applications and of correlative test data.

CONTROLS FOR HEAT RELAIM WITH THERMAL STORAGE COUPLED WITH SOLAR HEATING. F. E. Filson, Jr. ASHRAE Trans., *84* (2), 381—386.

Heat relaim with thermal storage is dependent on a constant cooling load. When the cooling load varies, the quantity of rejected heat will vary directly with the cooling load. During the heating season it is desirable to store rejected heat at the highest temperature obtainable. The addition of solar cells to the basic system increases the ability to store water at temperatures above the condenser — leaving water temperatures from the refrigeration machine. This elevated temperature will increase the time/temperature ability of the storage system for long week-end shut down of the building utilizing this stored heat. When stored, tank water temperatures are reduced to approximately 85°F (29.4°C), too low to be effective for heating. This water is then used to false load the evaporator section of the refrigerant compressor thereby creating temperatures of 105°F leaving the condensers for use by the heating system for heating the building. During this cycle, any heat above 45°F (7.2°C) obtained from the solar system is usable in the evaporator section for false loading. During the heating system, when the stored water temperature in the storage tank drops to approximately 45°F

(7.2°C) and no further heat is available, the emergency boiler is energized, false loading the evaporator section, thereby, again, making available 105°F water for the heating system. Limit controls must be provided in the storage tank and in the chilled water return piping to the evaporator for satisfactory operation. The introduction of solar cells has the distinct advantage of increasing the stored tank water temperatures above 105°F (40.6°C) and increasing the time limit being imposed on a standard system limited to 105°F (40.6°C).

THE APPLICATION OF ASHRAE STANDARD 93-77 TO THE THERMAL PERFORMANCE TESTING OF AIR SOLAR COLLECTORS. S. A. Mumma, J. W. Yelloff and B. Wood. ASHRAE Trans., *84* (2), 410—418.

The Research and Service Foundation, College of Architecture, Arizona State Univ. has provided professional thermal performance testing of air solar collectors for the past several years. Recently, that work has been done in compliance with ASHRAE Standard 93-77. The standard has had a positive and dramatic impact upon unifying the testing procedures and more importantly upon the data presentation format. However, as with any new standard a few minor improvements could be made. The central thrust of this paper is to identify where and how the improvements should be made.

A GRAPHICAL APPROACH TO THE EFFICIENCY OF FLAT PLATE COLLECTORS. M. K. Selcuk. ASHRAE Trans., *84* (2), 395—409.

A nomogram is described which can be used to determine the thermal performance of flat-plate solar collectors. The use of this nomogram results in two performance factors: the net absorptance "a" and the net heat loss coefficient "b". These factors are used in the collector efficiency equation when it is expressed as:

$$\nu = \text{a-b} \quad \frac{t_1 - t_a}{H}$$

The nomogram takes into account the angle of incidence, collector slope, absorber plate design, the insulating materials and thicknesses and the optical properties of the absorbing surface and glazing materials and the flow factors. A case example is given to illustrate the use of the nomogram.

ABSTRACTS FROM INTERNATIONAL JOURNAL OF HEAT AND MASS TRANSFER

EFFICIENT NUMERICAL TECHNIQUE FOR ONE-DIMENSIONAL THERMAL PROBLEMS WITH PHASE CHANGE. L. E. Goodrich. Int. J. Heat Mass Transfer, *21*, 615—621.

A new numerical scheme for one-dimensional heat flow problems with phase change is presented. The technique, which continuously monitors the progression of the phase interface, is unusual for the high accuracy achieved without sacrifice to computing efficiency.

ERRATA

Journal of Food Process Engineering, **Volume 2, Number 4**

Page 338: The first line after Equation 1 should read as follows:
where: μ is viscosity in poise

Page 341: Figure 2 symbols within the illustration should be "p" instead of "cp".
The corrected illustration is reproduced below:

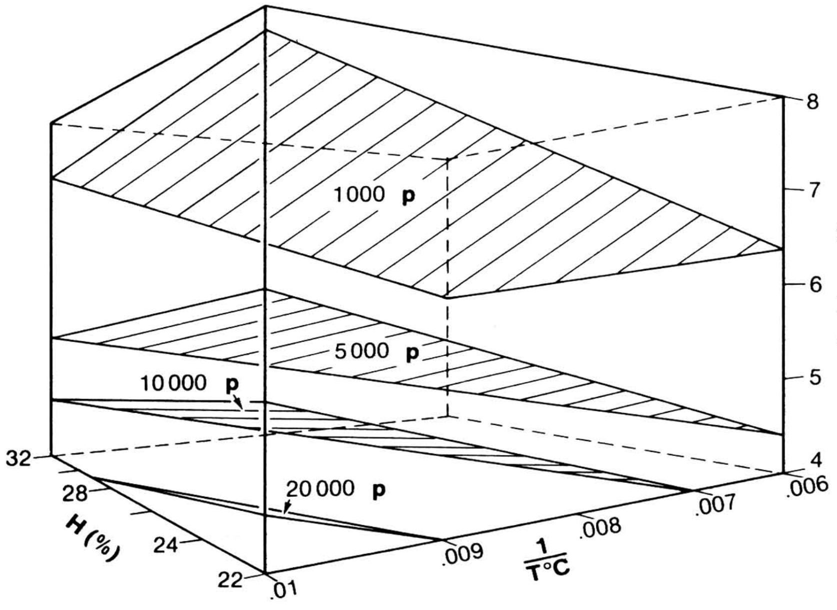

FIG. 2. RESPONSE SURFACES OF SOY DOUGH VISCOSITY

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Journal of Food Process Engineering

A. PUBLICATION NO. 4 5 6 4 9 0

2. DATE OF FILING Oct. 1, 1979

3. FREQUENCY OF ISSUE Quarterly

A. NO. OF ISSUES PUBLISHED ANNUALLY 4

B. ANNUAL SUBSCRIPTION PRICE $50.00

4. LOCATION OF KNOWN OFFICE OF PUBLICATION *(Street, City, County, State and ZIP Code) (Not printers)*
265 Post Road West, Westport, Fairfield, CT 06880

5. LOCATION OF THE HEADQUARTERS OR GENERAL BUSINESS OFFICES OF THE PUBLISHERS *(Not printers)*
265 Post Road West, Westport, Fairfield, CT 06880

6. NAMES AND COMPLETE ADDRESSES OF PUBLISHER, EDITOR, AND MANAGING EDITOR

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John J. O'Neil, 265 Post Road West, Westport, CT 06880

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Technomic Publishing Co.	265 Post Road West, Westport, CT 06880
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HASSON, E. P. and LATIES, G. G. 1976. Separation and characterization of potato lipid acylhydrolases. Plant Physiol. *57*, 142–147.

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