Effects of Oven Drying Temperature and Drying Time on Rough Rice Moisture Content Determination

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ABSTRACT

THE effects of oven drying temperature and drying time on whole-kernel, long-grain rough rice moisture content determination were investigated for different moisture content levels ranging from approximately 9 to 22% (w.b.). The results showed that a simplified oven method can be used for rapid moisture measurement with accuracy comparable to that of a standard Association of Official Analytical Chemists (AOAC) method. An equation was developed that relates the apparent moisture content determined using a given drying time and temperature to the moisture content determined by the standard AOAC method.

INTRODUCTION

Accurate measurement of rough rice moisture content is important during harvesting, drying, storage and processing operations. It is often necessary to specify and use a standard moisture content for seed certification and storage, as well as for marketing and milling contracts.

Grain moisture content (% wet basis) is defined as the ratio of the weight of water that can be removed without changing the grain chemical structure to the initial weight of the grain. The basic reference methods for moisture content determination such as the Karl Fischer technique (Hart and Neustadt, 1957) and the method outlined by the International Organization for Standardization (ISO) (1978) have been used to standardize simplified oven methods that are then regarded as practical working methods. Reference methods are time consuming and tedious but were formulated to obtain accurate moisture values for calibration purposes. It is assumed in the use of reference methods that complete drying of material is achieved without any loss or decomposition of organic material. Practical methods developed on the basis of calibration against reference methods are used to reliably determine grain moisture content in a reasonable time and are corrected for any possible decomposition occurring during a test.

There are several practical air-oven procedures that have been standardized to determine moisture content of grains (Hart et al., 1959; United States Department of Agriculture (USDA), 1971; Association of Official Analytical Chemists (AOAC), 1980; American Society of Agricultural Engineers (ASAE), 1982). These methods are based on drying whole or ground grain in an oven over a fixed period of time. The drying temperature and time are usually specified for a particular type of grain on the basis of moisture content comparison with a reference method. ASAE Standard S352.1 (ASAE, 1982), which was adopted in 1972 based on the recommendations of Hart et al. (1959), emphasizes the use of whole-grain samples primarily due to simplicity and avoiding possible moisture loss during grinding. Various procedures for measuring moisture content of grains are listed in Table 1 for relative comparison.

Moisture content determinations made with different oven methods and different grains may not be the same due to the empirical nature of the methods. Oven exposure time depends upon the type of grain and the method used (Hart et al., 1959; Warner and Browne, 1963; Young et al., 1982; Bowden, 1984). Hart et al. (1959) showed that drying flaxseed in a moisture content range of 7.6 to 8.2% wet basis (w.b.), wheat at 12.0 to 12.3% and corn at 10.5 to 11.4% to a constant weight at

TABLE 1. PROCEDURES FOR MEASURING MOISTURE CONTENT OF GRAINS.

Method	Details
Reference methods	
International Organization for Standardization (1978)	Recommendation ISO R711, vacuum oven (10-20 mm Hg), 50°C, 3-4 g ground sample in presence of phosphoruspentoxide to constant weight.
Karl Fischer (Hart and Neustadt, 1957)	Extraction with dry methanol and water determined by titration.
Standard methods	
International Organization for Standardization (1979)	Recommendation ISO R712, air oven, 130-133°C, 2 h, 5 g ground sample.
Association of Official Analytical Chemists (1980)	(a) Vacuum oven (≤ 25 mm Hg), 98-100°C, 5 h, 2 g ground sample through a 20 mesh screen.
	(b) Air oven, 130 ±3°C, 1 h, 2 g ground sample.
United States Department of Agriculture (1971)	(a) Air oven one-stage (for samples containing 16% or less moisture content, 13% for rough rice), 129-131°C, 1 h, 2-3 g ground sample through a 20 mesh screen.
	(b) Air oven two-stage, unground sample reduced to 16% (13% for rough rice) or less moisture content in first stage. Moisture content determined as in first-stage procedure.
American Society of Agricultural Engineers (1982)	Standard: ASAE S352.1, air oven, temperature and time specified for various grains for unground samples weighing a minimum of 15 g.*

*Drying time and temperature are not specified for rough rice.

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respective oven temperatures in ranges of 100 to 130°C, 100 to 110°C, and 94 to 105°C resulted in small but significantly different moisture contents. Such differences could further increase over wider ranges of grain moisture contents. This is supported by Bowden (1984), who compared three routine oven methods for moisture content determination of wheat and barley. He concluded that the variation of moisture content within the replicates increased with moisture content level. Other differences in methods were reported by Matthews (1962), who observed discrepancies of up to 0.3% w.b. when using a 130°C-16 h method for whole grain and up to 0.5% w.b. for a 130°C-1 h ground sample method. Random errors in grain moisture content determinations replicated two or three times may range from 0.2 to 0.5% w.b. depending upon the sample location within an oven and/or the use of different ovens (Warner and Browne, 1963).

Drying whole grain in a forced-convection air-oven according to ASAE Standard S352.1 (ASAE, 1982) is the most widely used method of moisture content determination and yields highly reproducible results under selected conditions of time and temperature. The disadvantage of this method is a long drying time requirement. Therefore a rapid moisture content determination method using high-temperature, short-time guidelines would be valuable in time savings if proven accurate.

Though air-oven procedures have been standardized for moisture determination of several common whole grains, there exists no such standard for rough rice. Noomhorm and Verma (1982) have compared rough rice moisture content determinations using the 130°C-16 h whole-grain method based on the work of Matthews (1962). They used the AOAC (1980) method as a standard, incorporating two-stage drying over the moisture content range of approximately 10-19% w.b. They concluded that the whole-grain oven method gave significantly higher moisture contents compared to the AOAC method. Thus, there is a need to develop a standard oven procedure for whole-grain rough rice moisture content determination that would be accurate, rapid and easy to use.

OBJECTIVES

The objectives of this study were:

1. to determine the effects of oven drying temperature and time on the moisture content determination of unground (whole-grain), long-grain rough rice in the 9 to 22% w.b. moisture content range
2. to develop a standard recommendation of drying temperature and time for general use in determining rough rice moisture content, patterned after the procedure outlined in ASAE standard S352.1 (ASAE, 1982).

MATERIALS AND METHODS

Overall Procedure

This study began as a laboratory exercise to explore the overall effects of oven drying temperatures and times in determining the moisture content of unground, long-grain rough rice. As such, a preliminary study was conducted in which the moisture content of samples varying in moisture content from approximately 10 to 19% w.b. was determined using an air convection oven held at 130°C in one set of tests and at 200°C in a subsequent test. Drying times for the 130°C setting were 1, 6 and 20 h; for the 200°C setting, only a 1 h time was used.

The results of this determination revealed a trend that indicated a possible relationship between the moisture contents attained with the various drying temperature/time combinations. This, coupled with the fact that a standard whole-grain air-oven procedure did not exist for rough rice, prompted a comprehensive study of this subject.

The comprehensive study was conducted in the following phases:

1. Eight lots of rice taken from the same, single source were dried to moisture contents ranging from 9 to 22% w.b.
2. The variability in moisture content determination attributed to sample location in the oven used in this study was determined.
3. The moisture content of the eight lots of rice was determined by various standard moisture content determination procedures to establish the actual moisture content of each lot.
4. The moisture content of samples taken from each of the eight moisture content lots was determined by oven drying samples at selected temperatures and times.
5. A relationship between the apparent moisture content determined at each drying temperature/time combination and the moisture content determined by a standard procedure was established.

Experimental Procedure

Long-grain rough rice (Tebonnet variety) was combine harvested at the Rice Research and Extension Center, Stuttgart, AR, at an approximate moisture content of 25% w.b. Immediately after combining, the rice was cleaned in an A. T. Farrel* Model 2B cleaner to remove immature kernels and foreign material. The clean rice was placed in plastic bags and stored at 1°C for about 2 months prior to testing.

Rice was conditioned to eight moisture content levels ranging from 9.2 to 22.3% w.b. Each lot was dried to the appropriate moisture content level by placing rice on trays constructed of light wooden frames with metal screen bottoms and exposing the rice to room conditions averaging 26°C and 60% RH. It was necessary to dry two batches of rice to lower moisture contents in an air oven set at 40°C. Samples were then sealed in polyethelene bags and stored at 1°C for several days until testing.

The drying oven was a Blue M Model OV-490A-2 having two heaters each with a rating of 16.4 amps at 120 volts and employing forced-air circulation and temperature control within ±1°C. Only two shelves located near the oven center were used to minimize errors due to temperature variations within the oven. The temperature of air in the vicinity of the sample containers was monitored using a precision mercury bulb thermometer. The sample containers had a diameter of 50 mm, a depth of 40 mm and were constructed of light gage sheet metal.

Prior to a given moisture content determination, the oven was preheated to a desired temperature using

*Mention of a commercial name does not imply endorsement by the University of Arkansas.

TABLE 2. APPARENT MOISTURE CONTENT (%, w.b.) OF ROUGH RICE SAMPLES FOR DIFFERENT DRYING TEMPERATURES AND TIMES.

	Oven drying temperature and time			
	130°C			200°C
Moisture level	1 h	6 h	20 h	1h
1	6.35	8.96	10.00	–
2	7.30	9.96	11.00	11.92
3	8.10	10.80	11.92	12.20
4	9.24	11.84	13.12	13.76
5	10.56	13.08	14.20	14.84
6	11.80	14.48	15.64	15.96
7	13.00	15.76	15.64	15.96
8	14.10	16.80	18.16	18.36
9	15.16	18.04	19.20	19.80
Slope*	1.041	1.022	1.000	1.033
Intercept*	3.418	0.880	0.000	−1.004
R^2	0.9944	0.994	1.0000	0.9943
MSE†	0.235	0.257	0.0	0.058

*Values were determined by linear regression of moisture contents in each method to those attained at 130°C and 20 h.

†Mean square error.

forced-air circulation with the oven side vents open. Test portions of whole rough rice weighing 25 g were obtained from large lots of rice using a Boerner divider. All moisture content determinations were duplicated. Samples were randomly placed in the oven and were periodically removed, immediately weighed and returned to the oven within a total time of about 3 to 5 min. All mass measurements were made to the nearest 0.01 g on a top-loading open pan balance. The locations of sample containers on the oven shelves as well as the locations of the oven shelves were routinely changed during the course of the experiment to reduce the unwanted effect of sample location in determining moisture content.

Determination of Variability Due To Sample Location

The variation in moisture content as affected by sample location within the oven was determined by selecting 18 samples from the lowest moisture content lot and randomly placing them in the oven, nine on each shelf. Using the procedure for weighing as outlined above, the apparent moisture content of the samples was determined at 4 and 20 h using an oven temperature of 130°C. 'Apparent' moisture contents were computed based on the sample weights at selected drying times for the corresponding oven temperature.

Standard Moisture Content Determination Procedure

The methods used to determine the actual moisture content of the eight moisture content lots of rice were the vacuum oven and air oven standard methods recommended by AOAC (1980) and outlined in Table 1. A two-stage procedure was used whenever sample moisture contents exceeded 13% w.b. (USDA, 1971). Variations of these methods as to oven temperature, oven drying time and whole samples versus ground samples were also used and are listed in Table 4.

Drying Time and Temperature Test Procedure

Duplicate samples from each of the eight lots were dried in the air oven using the sampling and weighing procedure described above. The samples were placed in the oven and subsequently weighed at 1, 2, 4, 8, 20 and 72 h from the start of drying. The oven temperatures used were 110, 130, 150 and 170°C. Apparent moisture content for each drying temperature/time combination was calculated based on the mass removed by drying as determined by the sample masses at each weighing.

RESULTS AND DISCUSSION

Exploratory Analysis

The data from the exploratory tests of the effect of drying temperature and time on moisture content determination are shown in Table 2. It was observed that a moisture content value determined by a given drying temperature and time at a given moisture content level was different from the moisture content value determined by another drying temperature and time by a consistent amount over the range of moisture content levels. This observance led to an analysis in which each set of moisture content values determined at a given drying temperature and time was regressed against the

TABLE 3. APPARENT MOISTURE CONTENT (% w.b.) OF ROUGH RICE SAMPLES FOR DIFFERENT LOCATIONS AND DRYING PERIODS AT 130°C.

Drying period, h	Upper shelf			Lower shelf		
	Left	Center	Right	Left	Center	Right
	8.88	8.92	8.96	8.84	8.88	8.84
4	9.00	8.84	9.20	8.88	8.88	9.08
	8.92	8.92	8.96	8.88	8.84	8.92
Column mean (standard deviation)	8.93 (0.061)	8.89 (0.046)	9.04 (0.138)	8.87 (0.023)	8.87 (0.023)	8.95 (0.122)
Shelf mean (standard deviation)		8.96 (0.10)			8.89 (0.07)	
	10.44	10.40	10.44	10.44	10.40	10.40
20	10.52	10.40	10.56	10.44	10.40	10.56
	10.44	10.40	10.40	10.44	10.40	10.40
Column mean (standard deviation)	10.47 (0.046)	10.40 (0.0)	10.47 (0.083)	10.44 (0.0)	10.40 (0.0)	10.45 (0.092)
Shelf mean (standard deviation)		10.44 (0.06)			10.43 (0.05)	

TABLE 4. APPARENT MOISTURE CONTENTS (%, w.b.) OF ROUGH RICE AT VARIOUS MOISTURE CONTENT LEVELS DETERMINED BY DIFFERENT MEASUREMENT METHODS.

	Measurement method						
	Air oven				Vacuum oven		
Moisture level	130°C-1h ground	130°C-20h ground	130°C-20h whole	70°C-20h ground	70°C-20h whole	100°C-5h ground	100°C-20h whole
1	9.18	10.51	10.00	8.79	7.01	8.99	7.23
2	10.67	11.97	11.46	10.28	8.44	10.48	8.68
3	12.82	13.93	13.69	12.55	10.69	12.75	10.90
4	14.40	15.79	15.26	13.98	12.20	14.21	12.52
5	15.60	16.98	16.53	15.27	13.86	15.49	14.13
6	18.40	19.66	19.10	17.96	16.27	18.18	16.57
7	19.99	21.21	20.55	19.57	17.97	19.76	18.21
8	22.27	23.41	22.79	21.92	20.24	22.13	20.50
Slope*	1.000	1.010	1.026	1.003	0.986	1.003	0.983
Intercept*	0.000	−1.428	−1.171	0.339	2.271	0.135	2.057
R^2	1.0000	0.9999	0.9998	0.9999	0.9999	0.9993	0.9986
MSE†	0.0	0.011	0.011	0.004	0.024	0.004	0.024

*Values were determined by linear regression of moisture contents in each method to those attained at 130°C and 1 h in an air oven.
†Mean square error.

set of moisture contents determined at 130°C and 20 h. The results of this analysis are shown at the bottom of Table 2. The high values of the coefficient of determination and low values of the mean square error for each regression indicated a strong correlation between the values determined by each method and that at 130°C and 20 h. An F-test (Neter and Wasserman, 1974) was used to show that the slope values for the regression lines were equal (alpha=0.05).

This strong correlation indicated that a rapid moisture content determination based on a very high drying temperature and short time (e.g., 200°C and 1 h) might be used to estimate the moisture content attained at 130°C and 20 h. However, since moisture content depended upon oven drying temperature and time, it was necessary to identify a standard oven procedure for estimating the actual moisture content of rough rice. Accordingly, a hypothesis was postulated and investigated that a relationship between standard and apparent moisture contents existed.

Sample Location Effects

Table 3 gives the apparent moisture content determinations of whole-grain rough rice samples made at different locations on the two shelves after drying for 4 and 20 h in an oven set at 130°C. The standard deviation of moisture content on both the upper and lower shelves for each drying time was less than 0.1% w.b. However, individual moisture contents showed a deviation from the associated shelf/drying period mean of up to 0.24% w.b. It was observed that an increase in the drying time from 4 to 20 h resulted in lower standard deviations in mean moisture contents.

Moisture Content Determination by Standard Methods

Table 4 shows the rough rice moisture contents determined by different measurement methods at various moisture content levels. In this part of the study, the AOAC air oven method (130°C, 1 h, ground sample) was selected as standard and compared with other moisture content measurement methods. This standard method gave slightly higher moisture contents than the vacuum oven method (100°C, 5 h). Drying of whole-grain rough rice at 130°C for 20 h over-estimated the moisture contents in comparison to those attained with the standard method over the moisture content range of 9 to 22% w.b.

A comparison of the results of each method was made using a regression analysis in which each set of moisture content values obtained with a given method was regressed against the moisture contents obtained with the accepted standard method. The results of this analysis are shown in Table 4. As in the exploratory analysis, the moisture contents determined by a standard method could be predicted accurately (see Table 4 for coefficients of determination and mean square error values for each case) based on the moisture contents attained with the other methods. These results further verified the hypothesis that apparent moisture contents determined by different oven methods over a wide range of moisture levels are linearly related to standard moisture contents.

Development of Drying Temperature and Time Relationship

Figs. 1 to 4 show the relationship between the standard (AOAC method; air oven, 130°C, 1 h, ground sample) and apparent moisture contents based on the drying of whole rough rice samples for selected times at 110, 130, 150 and 170°C, over a moisture content range of about 9 to 22% w.b. These relationships were represented by the following equation:

$$M_{stan} = a_o + a_1 M_{app} \quad \ldots\ldots\ldots [1]$$

M_{stan} = standard moisture content, % w.b.
M_{app} = apparent moisture content, % w.b.
a_o, a_1 = regression coefficients.

The parameters obtained from linear regression of each temperature/time combination are given in Table 5. The slopes of the relationships in Figs. 1 to 4 appeared to be independent of the oven drying temperatures and times. The intercepts, however, were linearly related to

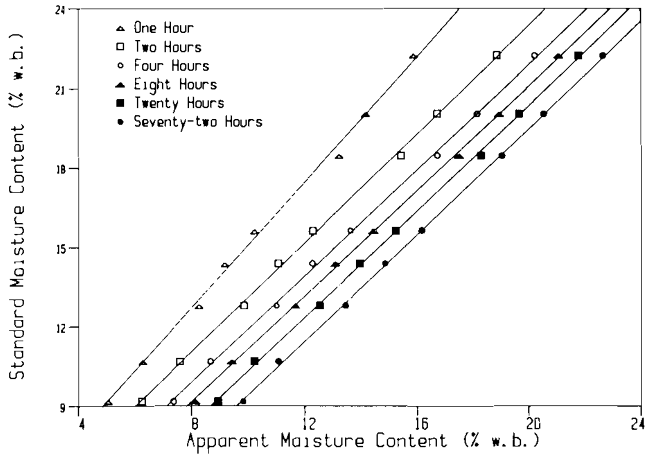

Fig. 1—Effects of drying time at 110°C on apparent moisture content.

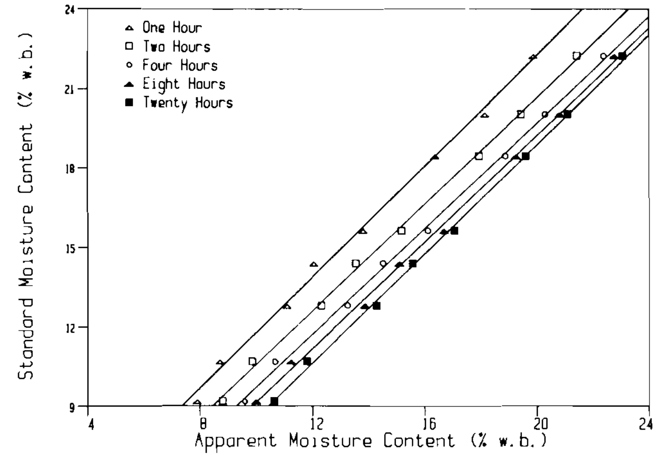

Fig. 3—Effects of drying time at 150°C on apparent moisture content.

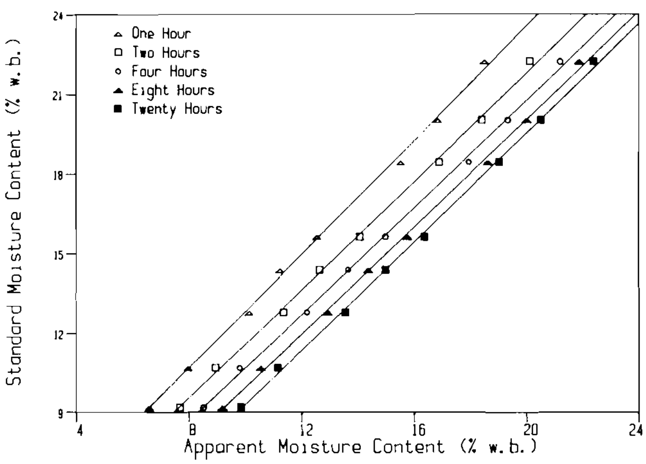

Fig. 2—Effects of drying time at 130°C on apparent moisture content.

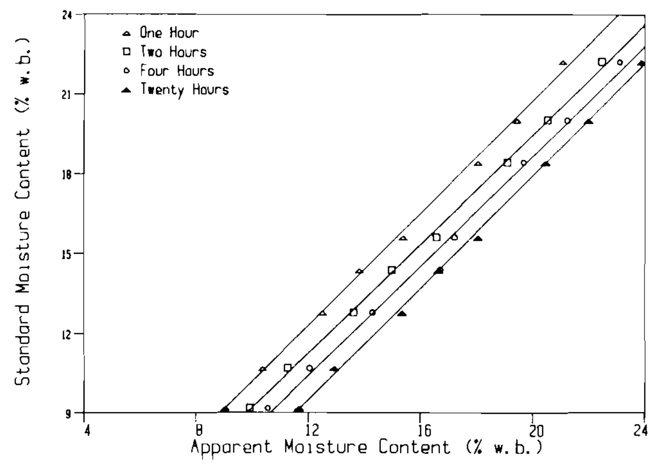

Fig. 4—Effects of drying time at 170°C on apparent moisture content.

the logarithm of drying times as shown in Fig. 5. The following equation form was used to describe this relationship:

$$a_o = b_o + b_1 (\ln t) \quad \ldots\ldots [2]$$

where:

a_o = intercept in equation [1]
b_o, b_1 = regression coefficients
t = drying time, h.

Table 6 gives the parameters of equation [2] for each temperature. The slopes were similar. However, the intercepts of the relationships represented by equation [2] were related to the oven drying temperature in the following manner and as illustrated in Fig. 6:

$$b_o = c_o + c_1 T \quad \ldots\ldots [3]$$

where:

c_o, c_1 = regression coefficients
T = drying temperature, °C.

Using linear regression, the values of c_o and c_1 were found to be 10.33 and -0.0625, respectively.

Equations [1] to [3] were combined using mean slopes of relationships shown in Figs. 1 to 5 to give:

$$M_{stan} = 10.33 - 0.0625\,T - 0.999 \ln t + 1.021\,M_{app}. \quad \ldots\ldots [4]$$

TABLE 5. REGRESSION COEFFICIENTS OF EQUATION [1].

Time, h	Temperature, °C							
	110		130		150		170	
	a_0	a_1	a_0	a_1	a_0	a_1	a_0	a_1
1	*	*	2.1117	1.0723	1.2826	1.0477	−0.3925	1.0574
2	2.8659	1.0243	1.3686	1.0212	0.4873	1.0087	−1.0807	1.0280
4	1.9229	0.9990	1.3596	0.9407	−0.2874	0.9996	−2.0336	1.0356
8	1.2321	0.9931	−0.1362	1.0094	−0.9374	1.0089	−3.2457	1.0597
20	0.2845	1.0038	−0.9434	1.0247	−1.8213	1.0362	*	*
72	−0.6486	1.0070	*	*	*	*	*	*
Average slope		1.0054		1.0137		1.0202		1.0452

*Data was not collected at the extreme temperature/time combinations.

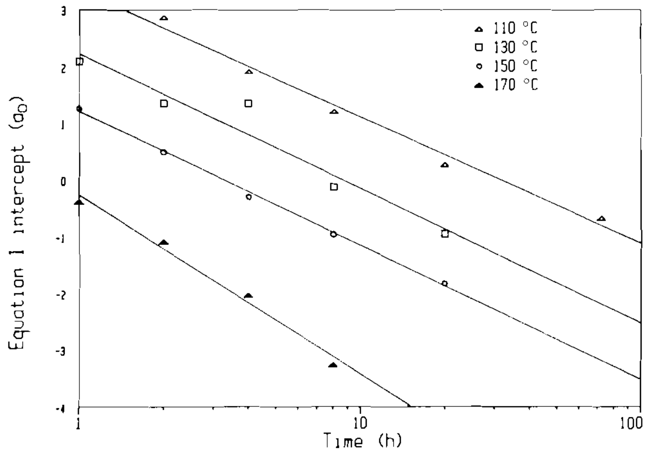

Fig. 5—Relationship between equation [1] intercept (a_0) and time.

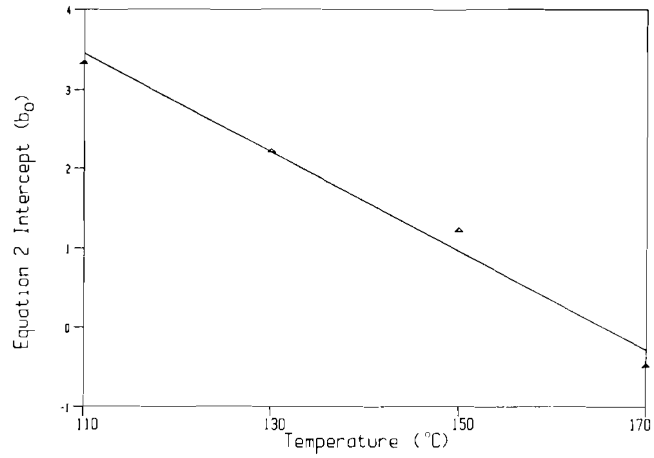

Fig. 6—Relationship between equation [2] intercept (b_0) and temperature.

Equation [4] was developed on the basis of the preceding least squares analysis, which yields a functional relationship among the experimental variables.

Based on these exploratory calculations and observations, a general relationship was subsequently developed through regression of the data shown in Figs. 1 to 4 based on the form of equation [4] as follows:

$$M_{stan} = 9.15 - 0.053\,T - 1.028 \ln t + 1.016\, M_{app} \quad [5]$$

The coefficient of determination and standard error of estimate for equation [5] were 0.992 and 0.390, respectively.

Relative Effects of Time and Temperature

Though equation [5] was adequate for general use, the interactions and relative contributions of experimental variables on estimated moisture contents were further investigated by considering the following model:

$$M_{stan} = b_o + b_1 M_{app} + b_2(T \cdot \ln t) + b_3 T + b_4 \ln t + b_5(M_{app} \cdot \ln t) + b_6(M_{app} \cdot T) \quad [6]$$

where: b_0, b_1, b_2, b_3, b_4, b_5, and b_6 are regression coefficients.

The pertinent results of a step-wise multiple regression analysis using equation [6] and the data of Fig. 1 through 4 are shown in Table 7 with the model variables listed in the order of their relative contributions. It was found that all of the model variables of equation [6] sufficiently improved the model to warrant inclusion in the model at a level of significance of 5%. The regression coefficients and standard error of estimates for the model variables were:

b_0 = 11.1906 $s(b_0)$ = 0.7877
b_1 = 0.9019 $s(b_1)$ = 0.0521
b_2 = 0.0014 $s(b_2)$ = 0.0012
b_3 = -0.0658 $s(b_3)$ = 0.0054
b_4 = -1.4123 $s(b_4)$ = 0.1779
b_5 = 0.0128 $s(b_5)$ = 0.0063
b_6 = 0.6830E-03 $s(b_6)$ = 0.3457E-03

The experimental variables and their interactions listed in equation [6] accounted for about 99.2% of the total variance and can be used to estimate the standard moisture content accurately. Among the single factors, ln t had the least effect in improving the model. The interactions, $M_{app} \cdot \ln t$ and $M_{app} \cdot T$, did not contribute greatly despite their being statistically significant. Therefore a simpler form of Equation [6] could be adopted without any perceptible loss of accuracy using only the most significant variable terms with the following regression coefficients:

$$M_{stan} = b_o + b_1 M_{app} + b_2 T \cdot \ln t + b_3 T + b_4 \ln t \quad [7]$$

where:

b_0 = 9.6578 $s(b_0)$ = 0.3631
b_1 = 1.0168 $s(b_1)$ = 0.0075
b_2 = 0.0022 $s(b_2)$ = 0.0012
b_3 = -0.0567 $s(b_3)$ = 0.0025
b_4 = -1.3224 $s(b_4)$ = 0.1631.

Equation [7] provides a simple means of adjusting apparent moisture content determinations for various oven drying temperatures and times to the moisture

TABLE 6. REGRESSION COEFFICIENTS OF EQUATION [2].

Temperature, °C	b_0	b_1
110	3.3548	−0.9726
130	2.2337	−1.0355
150	1.2220	−1.0323
170	−0.4742	−0.9568
Average slope		−0.9993

TABLE 7. RESULTS OF THE STEP-WISE MULTIPLE REGRESSION ANALYSIS.

Variables in model	R^2	Mean square error
M*	0.8926	1.410
M, T·ln t	0.9487	0.977
M, T·ln t, T	0.9885	0.464
M, T·ln t, T, ln t	0.9921	0.387
M, T·ln t, T, ln t, M·ln t	0.9922	0.385
M, T·ln t, T, ln t, M·ln t, M·T	0.9924	0.381

*'M' is the abbreviation of 'M_{app}'.

TABLE 8. ESTIMATED OVEN DRYING TIMES (h) FOR ROUGH RICE SAMPLES OF DIFFERENT MOISTURE LEVELS AT SELECTED OVEN TEMPERATURES.

Moisture level % w.b.	Oven drying temperature, °C			
	110	130	150	170
9.0	27.28	10.51	3.72	1.20
11.0	28.14	10.86	3.85	1.24
13.0	29.03	11.21	3.98	1.28
15.0	29.95	11.58	4.12	1.33
17.0	30.89	11.97	4.26	1.38
19.0	31.87	12.36	4.41	1.43
21.0	32.88	12.77	4.56	1.48
23.0	33.92	13.19	4.72	1.53
Average time	30.50	11.81	4.20	1.36
(Standard deviation)	(2.32)	(0.94)	(0.35)	(0.12)

TABLE 9. COMPARISON OF EXPERIMENTAL (NOOMHORM AND VERMA, 1982) AND PREDICTED (PRESENT STUDY) MOISTURE CONTENTS OF ROUGH RICE SAMPLES.

Moisture content, % w.b.		
Experimental		Predicted
130°C, 16 h	AOAC	Equation [7]
11.24	10.85	10.84
11.82	11.74	11.43
12.88	12.60	12.51
14.82	13.10	14.48
15.74	15.01	15.42
16.20	15.68	15.89
17.36	16.52	17.07
18.44	17.63	18.16
19.50	18.40	19.24

contents determined by the standard AOAC method. Equation [7] can be used to show that the oven drying time required at a given temperature to match the apparent and standard moisture contents would be influenced by the sample moisture level. Table 8 shows the oven drying times predicted by equation [7] assuming apparent and standard moisture contents to be the same for sample moisture levels ranging from 9 to 23% w.b. It is obvious that low moisture rough rice samples would require shorter drying times at any set oven temperature and vice versa. These findings indicated that, in order to attain the most accurate possible results, a common drying time cannot be specified over a wide range of moisture levels. This supports the view that a two-stage drying procedure is required to determine the moisture content of high moisture content grains (USDA, 1971).

Recommended Procedure

The dependence of average drying time (Table 8) on oven temperature in the range of moisture content levels used in this experiment was expressed by the following equation:

$$t = e^{(9.146 - 0.052T)}; \quad R^2 = 0.998. \quad \ldots\ldots\ldots\ldots [8]$$

Equation [8] gives estimates of drying time at different oven drying temperatures for apparent moisture content determination of whole rough rice samples relative to the standard AOAC method. This equation can thus be used to estimate the approximate drying time required for a desired oven temperature when the moisture content is unknown. Since equation [8] was developed using average drying times over a range of moisture content levels, the apparent moisture content determined after drying for the time period estimated by equation [8] should be used as an input to equation [7] for a more accurate determination of moisture content. This procedure accounts for the significant differences that could result due to varying sample moisture content levels. In summary, equation [8], or the values of Table 8, can be used as a first step in estimating an approximate drying time for a desired oven temperature. The apparent moisture content from the drying test is then used as an input to equation [7] to determine the moisture content that would have been attained with the standard AOAC method.

The results in Table 8 show that drying rice for about 11.5 h at a conventional oven drying temperature of 130°C can be adopted as a general standard oven procedure for rough rice moisture content determination, although the subsequent use of equation [7] to account for varying initial sample moisture contents is recommended. Alternately, a rapid moisture content determination procedure based on the use of equation [7] and higher oven temperatures also proved to be reliable. The results of this study support the hypothesis that apparent moisture contents determined at different drying temperatures and times with an oven procedure over a wide range of moisture levels are related to the actual moisture contents of rough rice samples.

Validation

The proposed approach was validated using the moisture content determination data of rough rice reported by Noomhorm and Verma (1982). They found that 130°C-16 h drying of rough rice resulted in significantly higher moisture contents compared to the standard AOAC method. Using equation [7], the moisture contents of rough rice samples were computed by entering the experimental moisture content values determined at 130°C and 16 h by Noomhorm and Verma as apparent moisture contents. Table 9 shows that the experimental AOAC (Noomhorm and Verma, 1982) and computed (present study) moisture contents were close, generally within 0.5% w.b. except for a few cases. A close examination of the experimental data of Noomhorm and Verma revealed that moisture content differences between the two methods varied up to 1.72% w.b., perhaps due to experimental discrepancies. This was contrary to the observations made in the present study, which showed a more consistent pattern in moisture difference values when comparing various methods of moisture measurement (Table 4).

SUMMARY AND CONCLUSIONS

A study of the effects of oven drying temperature and time on whole-grain rough rice moisture content determination showed that the moisture content determined by a standard AOAC method could be accurately estimated from the apparent moisture content determined by oven drying at various oven temperatures for various times at moisture contents ranging from approximately 9 to 22% w.b. More specifically, the following conclusions were drawn:

1. Oven procedures involving various oven drying temperatures and times resulted in consistent moisture content differences relative to a standard AOAC method in the moisture content range of approximately 9 to 22% w.b.

2. A relationship between standard (actual) and apparent moisture contents was developed to quantify the effects of oven drying temperatures and times. This relationship can be used as the basis for rapid moisture content determination using high-temperature, short-time (e.g., 200°C, 1 h) drying of rough rice in an oven.

3. Oven drying times for moisture content determination of whole-grain rough rice depended upon the sample moisture level. Low moisture samples required shorter drying times than high moisture samples required. A 11.5-h drying time at 130°C appears to be satisfactory for general use in the moisture content range of approximately 9 to 22% w.b. However, subsequent use of an expression relating apparent to standard moisture content is recommended to account for varying sample moisture contents.

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