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Evaluation of Uncertainty of the Rice Moisture Measurement by the Drying Method

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Abstract: The uncertainty in the rice moisture content measured by the drying method, which is the highest standard in rice moisture content measurements, was evaluated. Based on the results, it was possible to assign a numerical index to the precision of the measurement obtained by the drying method. Further, since it is now possible to assign uncertainty for rice to calibrate rice moisture meters, this has for establishing traceability of the rice moisture meters in International System Units (SI).

Keywords: uncertainty, drying method, rice moisture.

1. INTRODUCTION

In recent times, there has been an increasing need to establish the traceability of measurements for most measurements. When the traceability of the measurement is established, it is necessary that measurement uncertainties are evaluated at every level of calibration.

In this study, we evaluated the uncertainty in the rice moisture content measured by the drying method, which is the highest standard in rice moisture content measurements. Evaluation of the uncertainty in the measurement of the rice moisture content based on the "Guide to the Expression of Uncertainty in Measurement" (GUM) [1] is complex because the rice samples are crushed when the moisture is measured. Thus, repeatability cannot be strictly evaluated.

Earlier, the uncertainty in the cereal moisture content measured by the drying method was evaluated [2]. However, in our opinion, the results of this evaluation did not present the data required to calculate standard uncertainties, and several sources of uncertainties were not accounted for.

We used analysis of variance (ANOVA) to evaluate the uncertainty in the rice moisture content measured by the drying method. The procedure used to measure the rice moisture content is defined in ISO 712: 1998 "Cereals and cereal products—Determination of moisture content—Routine reference method" [3]. However, the specifications of the grinders are not provided in detail in this document. Thus, the grinders used in this study were in accordance with the specifications of the Japanese standard [4].

2. EVALUATION OF UNCERTAINTY IN THE RICE MOISTURE CONTENT

2.1. Measurement Procedure Used in the Drying Method

In this study, rice moisture contents were measured in accordance with the procedure described in ISO 712. However, this document does not describe the specifications of the grinder in detail. Therefore, we used the grinder described in the "Standard Measurement Policy," [4] which is a notification from the Ministry of Agriculture, Japan. This grinder had the following specifications.

The diameter of the rollers is 25 mm.
Press a knurling tool against the surface of rollers at a depth of 0.5 mm with 9 knurls per cm.
Plate the rollers with chrome after quench.
The rotation ratio of the rollers is 1:2.
The distance between the rollers is 0.5 mm.

The procedure used to evaluate the rice moisture content measured by the drying method is as follows:

1. Prepare samples having adjusted moisture contents.
2. Grind the samples.
3. Measure the constant weight of the weighing can that is to be used. Weigh it only once.
4. Transfer the crushed samples into the weighing can and weigh them. Weigh them only once. With regard to the samples, take two samples belonging to the same lot.
5. Dry the two samples in the cans.
6. Weigh the samples after drying. Weigh them only once.
7. Calculate the moisture content.

We used this procedure to evaluate the uncertainty in the rice moisture content measured by the drying method. Polished rice that is made in Japan was used in these measurements.

2.2. Sources of Uncertainties in the Drying Method

The sources of uncertainties in the drying method are as follows:

1. Moisture dispersion caused by the temperature distribution in the dryer
2. Moisture dispersion caused by deviation between the samples
3. Moisture dispersion caused by the repeatability of the drying process
4. Moisture dispersion caused by the repeatability of the crushed samples
5. Moisture dispersion caused by the reproducibility of the grinders
6. Moisture dispersion caused by mass measurements

In this study, the values of the abovementioned dispersions were calculated, and the sources of uncertainties other than those arising from the abovementioned six sources were ignored because their effects were considered to be small.

2.3. Model Equation of the Rice Moisture Content Measured by the Drying Method

The model equation of the rice moisture content measured by the drying method is expressed as follows:

$$M = \frac{m_0 - m_1}{m_0 - m_c} \times 100 + \varepsilon_T + \varepsilon_{SAM} + \varepsilon_{RD} + \varepsilon_{RC} + \varepsilon_G \tag{1}$$

where

M: The moisture content of the lot of the sample. (%)

m_0: The mass of the sample before drying + the mass of the weighing can. (g)

m_1: The mass of the sample after drying + the mass of the weighing can. (g)

m_c: The mass of the weighing can. (g)

ε_T: Moisture dispersion caused by the temperature distribution in the dryer. (%)

ε_{SAM}: Moisture dispersion caused by deviation between the samples. (%)

ε_{RD}: Moisture dispersion caused by the repeatability of the drying process. (%)

ε_{RC}: Moisture dispersion caused by the repeatability of the crushed samples. (%)

ε_G: Moisture dispersion caused by the reproducibility of the grinders. (%)

The law of propagation of uncertainty is applied to equation (1), and the results are as follows:

$$u_c^2(M) = \left[\frac{100(m_1 - m_c)}{(m_0 - m_c)^2}\right]^2 u_{m0}^2 + \left[-\frac{100}{m_0 - m_c}\right]^2 u_{m1}^2 + \left[\frac{100(m_0 - m_1)}{(m_0 - m_c)^2}\right]^2 u_{mc}^2 + u_T^2 + u_{SAM}^2 + u_{RD}^2 + u_{RC}^2 + u_G^2 \tag{2}$$

where

$u_c(M)$: Combined standard uncertainty of the rice moisture content measured by the drying method. (%)

u_{m0}: Standard uncertainty of the combined mass of the rice sample before drying and the weighing can. (g)

u_{m1}: Standard uncertainty of the combined mass of the rice sample after drying and the weighing can. (g)

u_{mc}: Standard uncertainty of the mass of the weighing can. (g)

u_T: Standard uncertainty caused by the temperature distribution in the dryer. (%)

u_{SAM}: Standard uncertainty caused by deviation between the samples. (%)

u_{RD}: Standard uncertainty caused by the repeatability of the drying process. (%)

u_{RC}: Standard uncertainty caused by the repeatability of the crushed samples. (%)

u_G: Standard uncertainty caused by the reproducibility of the grinders. (%)

In this study, uncertainty was evaluated based on equation (2).

2.4. Evaluating Several Standard Uncertainties

1) Standard uncertainty caused by the temperature distribution in the dryer, the deviation between the samples, the repeatability of the drying process, and the repeatability of the crushed samples.

We conducted an experiment to evaluate the moisture dispersion caused by the temperature distribution in the dryer, the deviation between the samples, the repeatability of the drying process, and the repeatability of the crushed samples.

The interior of the dryer was divided into 25 regions. We measured the moisture contents of 25 samples that belonged to the same lot but were distributed across different regions. This measurement was repeated twice.

The locations in the dryer and the number of repetitions are defined as i (i = 1,2, ・・・,25) and j (j = 1,2), respectively. In this study, equation (1) is expressed as follows:

$$M = \mu + (\varepsilon_T)_i + (\varepsilon_{SAM} + \varepsilon_{RD} + \varepsilon_{RC})_{ij} + \varepsilon_G \tag{3}$$

where μ is the true rice moisture content.

ε_T is varied and depends on the location in the dryer based on equation (3). The values of ε_{SAM}, ε_{RD}, and ε_{RC} vary in all measurement data. ε_G has only one deviation since only one grinder was used in this experiment. Therefore, by applying ANOVA to these measurement results, the deviation derived from locations in the dryer can be divided from the three other variations derived from the samples, the repeatability of the drying process, and the repeatability of grinding.

The measurement and ANOVA results are shown in Tables 1 and 2, respectively.

σ_P and σ_{e1} were obtained as follows using the ANOVA results shown in Table 2.

$$\hat{\sigma}_P = 0.01752(\%) \tag{4}$$

$$\hat{\sigma}_{e1} = 0.02581(\%) \tag{5}$$

Table 1. Measurement results (moisture variation attributable to uneven dryer temperature)

Location	Repetition	
	n_1	n_2
P1	13.97	13.99
P2	13.89	13.98
P3	13.96	13.98
P4	13.89	13.92
P5	13.99	13.95
P6	13.97	13.98
P7	13.94	13.94
P8	13.97	13.96
P9	13.96	13.99
P10	13.91	13.97
P11	13.90	13.92
P12	13.98	13.99
P13	13.95	13.98
P14	13.98	13.93
P15	13.96	13.99
P16	13.97	13.98
P17	13.89	13.94
P18	13.97	13.97
P19	13.94	13.96
P20	13.90	13.96
P21	13.96	13.93
P22	13.99	13.97
P23	13.88	13.92
P24	13.92	13.97
P25	13.97	13.95

Table 2. ANOVA results (moisture variation attributable to uneven dryer temperature)

Sources	S	f	V	$E(V)$
Location	0.03071200	24	0.00127967	$\sigma_e^2 + 2\sigma_P^2$
Error	0.01665000	25	0.00066600	σ_e^2
Total	0.04736200	49		

where σ_P, σ_{e1}, $\hat{\sigma}_P$, and $\hat{\sigma}_{e1}$ are as follows:

σ_P : Expectation of the standard deviation of the variation caused by the temperature distribution in the dryer.

σ_{e1} : Expectation of the standard deviation of the variation caused by the deviation between the samples, repeatability of the drying process, and repeatability of the crushed samples.

$\hat{\sigma}_P$: Estimated value of the standard deviation of the variation caused by the temperature distribution in the dryer.

$\hat{\sigma}_{e1}$: Estimated value of the standard deviation of the variation caused by the deviation between the samples, repeatability of the drying process, and repeatability of the crushed samples

The rice moisture content is defined as the mean value of the results obtained from two locations. Therefore, the uncertainty in the rice moisture content derived from different locations in the dryer is estimated as follows:

$$u_T = \frac{0.01752}{\sqrt{2}} = 0.01239(\%) \tag{6}$$

Similarly, the uncertainty derived from the deviation caused by the samples, repeatability of the drying process, and repeatability of grinding is expressed as follows:

$$u_R = \frac{0.02581}{\sqrt{2}} = 0.01825(\%) \tag{7}$$

where u_R represents the combined uncertainties caused by the deviation due to the samples, repeatability of the drying process, and repeatability of grinding.

Table 3. Measurement results (moisture variation attributable to reproducibility between grinders)

No.	Moisture (%)	Average (%)
21	13.906	
	13.912	13.91
16	13.783	
	13.789	13.79
20	13.820	
	13.827	13.82
17	13.977	
	13.973	13.98
22	13.911	
	13.907	13.91
14	13.895	
	13.907	13.90
11	13.951	
	13.903	13.93
12	13.895	
	13.867	13.88
18	13.788	
	13.810	13.80
15	13.780	
	13.806	13.79
13	13.947	
	13.918	13.93
23	14.011	
	13.925	13.97
19	13.816	
	13.860	13.84

2) Standard uncertainty caused by the reproducibility of the grinders.

These are the moisture content dispersions estimated when the same type of grinder is used to crush the same samples. We conducted an experiment to evaluate the moisture dispersion resulting from the reproducibility between the grinders.

We prepared 13 grinders. In each grinder, one sample belonging to the same lot was crushed, and the procedure was repeated.

The grinders and the number of repetitions are defined as i (i = 1,2, ・・・,25) and j (j = 1,2), respectively. In this study, equation (1) is expressed as follows.

$$M = \mu + \left(\varepsilon_T + \varepsilon_{SAM} + \varepsilon_{RD} + \varepsilon_{RC}\right)_{ij} + \left(\varepsilon_G\right)_i \quad (8)$$

Therefore, by applying ANOVA to these measurement results, the deviation caused by the reproducibility of the grinders is divided from that caused by other sources of uncertainty. The measurement and ANOVA results are shown in Tables 3 and 4, respectively.

Table 4. ANOVA results (moisture variation attributable to reproducibility between grinders)

Sources	S	f	V	$E(V)$
Reproducibility of the grinders	0.10355988	12	0.00862999	$\sigma_{e2}^2 + 2\sigma_G^2$
Error	0.00735825	13	0.00056602	σ_{e2}^2
Total	0.11091813	25		

σ_G was obtained as follows by using the ANOVA results shown in Table 4.

$$\hat{\sigma}_G = 0.06350(\%) \quad (9)$$

where σ_G, σ_{e2}, and $\hat{\sigma}_P$ are as follows:

σ_G : Expectation of the standard deviation of the variation caused by the reproducibility of the grinders.

σ_{e2} : Expectation of the standard deviation of the variation caused by the temperature distribution in the dryer, deviation between the samples, repeatability of the drying process, and repeatability of crushed samples.

$\hat{\sigma}_P$: Estimated value of the standard deviation of the variation caused by the reproducibility of the grinders.

As a result, only one grinder was used in the actual measurement. Therefore, the uncertainty in the rice moisture content caused by the reproducibility of the grinders is estimated as follows:

$$u_G = \hat{\sigma}_G = 0.06350(\%) \quad (10)$$

3) Standard uncertainty of mass measurements

a) Repeatability of mass measurements of the weighing can: u_{CAN}

In order to evaluate the repeatability of mass measurements of the weighing can, the mass of five weighing cans was measured five times. Table 5 shows the measurement results.

The results indicate that most of the measurement data included a mean value of ±0.0001 g. Therefore, rectangular distribution of the possible values of the mass of the weighing can with a half-width of 0.00001 g was assumed.

$$u_{CAN} = \frac{0.0001}{\sqrt{3}} = 0.0000577 \ (\text{g}) \quad (11)$$

Table 5. Measurement results (repeatability of mass measurements of the weighing can)

Weighing can (No.)	Mass of the weighing can				
	1	2	3	4	5
25	11.2966	11.2966	11.2966	11.2966	11.2966
26	11.0373	11.0374	11.0374	11.0373	11.0373
28	10.7781	10.7780	10.7779	10.7780	10.7780
27	11.0427	11.0427	11.0426	11.0426	11.0427
39	10.7202	10.7202	10.7201	10.7201	10.7200

b) Uncertainty in the calibration of the weighing machine: u_S

Uncertainty in the calibration of the weighing machine is evaluated from the calibration certificate of the weighing machine. However, we could not obtain a weighing machine with a corresponding calibration certificate. Therefore, as a typical case, let the expanded uncertainty in the calibration of the weighing machine be 0.00005 g (k = 2).

$$u_S = \frac{0.00005}{2} = 0.000025 \ (\text{g}) \quad (12)$$

Table 6. Measurement results (repeatability of mass measurements of one weighing can and its sample)

No.	Mass (Can + Samples) (g)
1	16.7741
2	16.7743
3	16.7741
4	16.7742
5	16.7742
6	16.7743
7	16.7743
8	16.7742
9	16.7744
10	16.7744
S.D.	0.0001080

c) Repeatability of the mass of a weighing can and the sample: u_{mr}

When the mass of the weighing can containing the sample was measured repeatedly, the measurement result showed some dispersion.

In order to evaluate this uncertainty, the mass of one weighing can and its sample was measured 10 times. The results are shown in Table 6.

In this result, the standard deviation of the repeatability of the mass of a weighing can and its sample was 0.0001080 g. In actual measurement, the weighing can and its sample were weighed once. Therefore,

$$u_{mr} = 0.0001080 \text{ (g)} \tag{13}$$

d) With regard to u_{mc}, u_{m0}, and u_{m1}

u_{mc} expresses the standard uncertainty of the mass of the weighing can. Therefore, u_{mc} was obtained by combining the uncertainty of the repeatability of the mass measurements of the weighing can with the uncertainty in the calibration of the weighing machine.

The u_{mc} result is as follows:

$$u_{mc} = \sqrt{u_{CAN}^2 + u_S^2} = \sqrt{0.0000577^2 + 0.000025^2} = 0.0000629 \text{ (g)} \tag{14}$$

u_{m0} expresses the standard uncertainty of the combined mass of the rice sample before drying and the weighing can, and u_{m1} represents the standard uncertainty of the combined mass of the rice sample after drying and the weighing can. Therefore, both uncertainties were obtained by combining the uncertainty of the repeatability of the mass of a weighing can and the sample with the uncertainty in the calibration of the weighing machine.

The u_{m0} and u_{m1} results are as follows:

$$u_{m0} = u_{m1} = \sqrt{u_S^2 + u_{mr}^2} = \sqrt{0.000025^2 + 0.0001080^2} = 0.0001109 \text{ (g)} \tag{15}$$

2.5. Result of the Evaluation of Uncertainties

Table 7 shows the measurements of the moisture content of a lot of Japanese polished rice. The measurements were taken using the drying method. Table 8 shows the uncertainty budget.

Therefore, the moisture content in this lot of rice is represented as follows:

$$M = 13.96 \text{ (\%)} \pm 0.13 \text{ (\%)} \ (k = 2) \tag{16}$$

3. CONCLUSION

In this study, the uncertainties in the rice moisture content measured by the drying method were evaluated, and one of the essential requirements of the International System of Units (SI) for establishing the traceability of the rice moisture meters was satisfied. The uncertainty in the rice moisture content obtained by the drying method was approximately ±0.1%.

Table 7. Measurement data

Source	Value
The mass of sample A before drying + the mass of weighing can A	15.8234 g
The mass of sample B before drying + the mass of weighing can B	15.9631 g
The mass of weighing can A	10.8135 g
The mass of weighing can B	11.2915 g
The mass of sample A after drying + the mass of weighing can A	15.1234 g
The mass of sample B after drying + the mass of weighing can B	15.3112 g
The moisture content in sample A	13.97 %
The moisture content in sample B	13.95 %
Mean value of the samples	13.96 %

We tried to compare this result with that of a previous study [3]. However, this attempt was unsuccessful because the previous study did not provide details of the methods used for the evaluation of several standard uncertainties, particularly Type B evaluation and the treatment of the correlations between the sources of uncertainties.

The first major source of uncertainty was the deviation between grinders. The uncertainty caused by the deviation between different types of grinders could be the first new and major source of uncertainty when several types of grinders are used. In this study, only one type of grinder was employed. In the future, it will be necessary to evaluate the uncertainty caused by the deviation between different types of grinders

On the other hand, the uncertainty in the mass measurements was sufficiently smaller than the expanded uncertainty. It can be stated that the expanded uncertainty will not be affected by the uncertainty in the mass measurements when a weighing machine with a resolution of 0.1 mg is used.

The uncertainty caused by the different types of dryers could not be evaluated in this study. Several dryers are required to evaluate this uncertainty. However, comparisons among several testing laboratories would be more suitable for evaluating this uncertainty than measurements using several types of dryers in the same testing laboratory.

Similarly, the uncertainty caused by different types of grinders can be evaluated if grinders from several testing laboratories are compared. The procedures of uncertainty evaluation in one testing laboratory were shown in this study. Therefore, the E_n number defined in ISO Guide 43-1 [5] and its expanded method used in the BIPM key comparison [6] can be applied for comparing the measurements of rice moisture content between several testing laboratories.

However, there are some problems in comparing rice moisture content measurements between several testing laboratories since (1) rice moisture measurements are breaking test and (2) rice moisture content drastically changes with time. These problems should be resolved in the near future.

Table 8 Uncertainty budget

Symbol	Source	Standard Uncertainty	Sensitivity Coefficient	Standard Uncertainty(%)
u_T	Uncertainty caused by the temperature distribution in the dryer.	0.01239 (%)	1	0.01239
u_R	Uncertainty caused by the deviation between the samples, the repeatability of the drying process, and the repeatability of the crushed samples.	0.01825 (%)	1	0.01825
u_G	Uncertainty caused by the reproducibility of the grinders.	0.06350 (%)	1	0.06350
u_{m0}	Uncertainty of the combined mass of the rice sample before drying and the weighing can.	0.0001109 (g)	17.1715 (%/g)	0.001904
u_S	Uncertainty in the calibration of the weighing machine.	0.000025 (g)		
u_{mr}	Uncertainty of the weighing can and samples.	0.0001080 (g)		
u_{m1}	Uncertainty of the combined mass of the rice sample after drying and the weighing can.	0.0001109 (g)	-19.9605 (%/g)	0.002214
u_S	Uncertainty in the calibration of the weighing machine.	0.000025 (g)		
u_{mr}	Uncertainty of the weighing can and samples.	0.0001080 (g)		
u_{mc}	Uncertainty of the weighing can.	0.0000629 (g)	2.78894 (%/g)	0.0001754
u_S	Uncertainty in the calibration of the weighing machine.	0.000025 (g)		
u_{CAN}	Uncertainty of the weighing can.	0.0000577 (g)		
		Combined Standard Uncertainty (%)		0.06729
		Expanded Uncertainty (%) (k =2)		0.13

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