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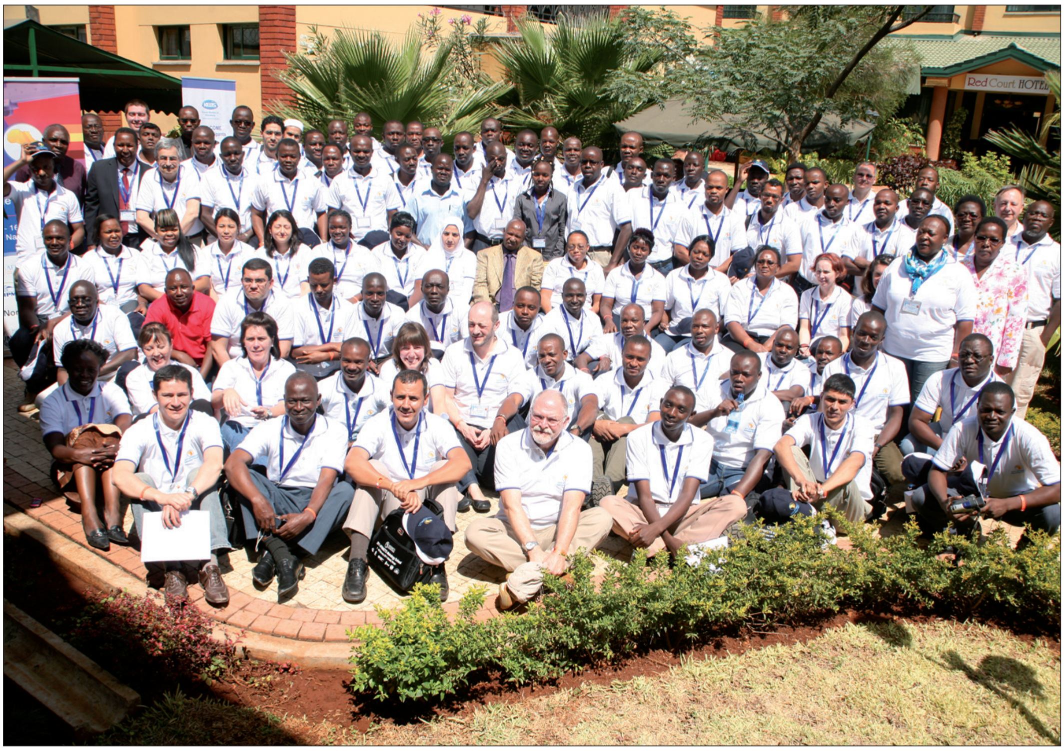

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MOISTURE MEASUREMENT

Rice moisture measurement in Thailand

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1 Introduction

Thailand has rice growing areas covering around 108 000 km^2, classified as seasonal (around 92 000 km^2) and off-seasonal (around 16 000 km^2), which can produce about 30 million metric tonnes per year. Therefore, rough (or "paddy") rice is an economically very important crop which generates high income earnings for Thailand. Rice farming generates an income for farmers (about 4 million households or about 16 million people out of Thailand's population of approximately 66 million earn their living from rice farming).

In general, trading of rough rice is based on weight but in Thailand the buyer will measure the moisture content in the rough grain to determine the price of the product. If the moisture content is above the set limit for safe storage, the buyer will reduce the weight of the product to compensate for the drying cost and weight loss after the drying.

Generally speaking, if the moisture content of the rough rice does not exceed 15 % based on wet weight or wet basis and the impurities do not exceed 2 % of the product weight, the farmer can receive full payment without weight reduction. But if the moisture content exceeds 15 %, the weight of product is reduced by 15 kg per 1 000 kg for every percent exceeding the set limit (15 %). In this case if the rice moisture meters have a 1 % error, this will cause a loss or gain of about 4 USD per metric tonne. Thus the accuracy of rice moisture measurement contributes to fair trade and to the confidence of stakeholders in rough rice transactions.

For these reasons the CBWM (Central Bureau of Weights and Measures) plays an important role and puts considerable effort into setting up the legal metrology control system on rice moisture meters in Thailand.

		2005/2006	2006/2007	2007/2008	2008/2009
Rice growing area (million m^2)	Seasonal rough rice	92.4	92.1	91.8	91.7
	Off-seasonal rough rice	15.8	16.1	15.9	18.1
Rough rice production (million metric T)	Seasonal rough rice	22.8	23.31	23.2	23.0
	Off-seasonal rough rice	6.8	8.79	8.4	8.3
Average unit price of rough rice *($/T)	Seasonal rough rice	196.0	254.9	290.7	300.9
	Off-seasonal rough rice	187.8	368.6	292.9	

Source: Department of Internal Trade, *1 USD = 33 Baht (approx.)

Table 1: Rice growing area, rough rice production and average unit price of rough rice

a. For verification and inspection of rice moisture meters against a rice standard

		MPE Verification (%)	MPE Inspection (%)
Rice moisture meters	Moisture content does not exceed 16 %	0.8	1.0
	Moisture content Exceeds 16 %	0.05 × MC	0.06 × MC

b. For verification and inspection of rice moisture meters against a standard rice moisture meter

	MPE Verification (%)	MPE Inspection (%)
Rice moisture meters	0.8	1.0

Table 2: Maximum Permissible Error (MPE)

2 Acquisition and development

In 2001 the CBWM set up a legal metrology project on rice moisture meters and received training support from the PTB. During 2002–2005 the CBWM also collaborated with the APLMF to survey rice moisture meters used in Thailand and sent representatives to participate in the training course on traceability of rice moisture meters held in the Philippines, Vietnam and Thailand.

Subsequently, the CBWM has set up a traceability system, standards used for calibration, and verification and inspection of rice moisture meters. The CBWM now has ministerial approval and is therefore able to enforce the regulation on rice moisture meters.

2.1 Legislation

In 2004 the CBWM issued ministerial regulation no. 2 B.E. 2547 based on OIML R 59:1984 *Moisture meters for cereal grains and oilseeds*. Rice moisture meters used for commercial transactions shall be verified by weights and measures officers and the validity period of verification is 2 years. During this period, officers can inspect rice moisture meters to be used in the marketplaces to determine whether their accuracy still complies with the prescribed MPE.

2.2 Traceability system

Based on OIML R 59, the rice moisture content is determined by using the air oven method according to ISO 712:1998 *Cereals and cereal products - Determination of moisture content - Routine reference method*. The reference standard rice moisture meter is calibrated by comparison with the rice standard according to ISO 7700-1:1984 *Food products - Checking the performance of moisture meters in use - Part 1: Moisture meters for cereals*. The working standard rice moisture meter is calibrated by comparison with the rice standard or reference standard rice moisture meter. Finally, the rice moisture meter is verified or inspected by comparison with the rice standard or working standard rice moisture meter (see Figure 1).

The MPE is the maximum difference between the meter reading and the nominal value of the working standard.

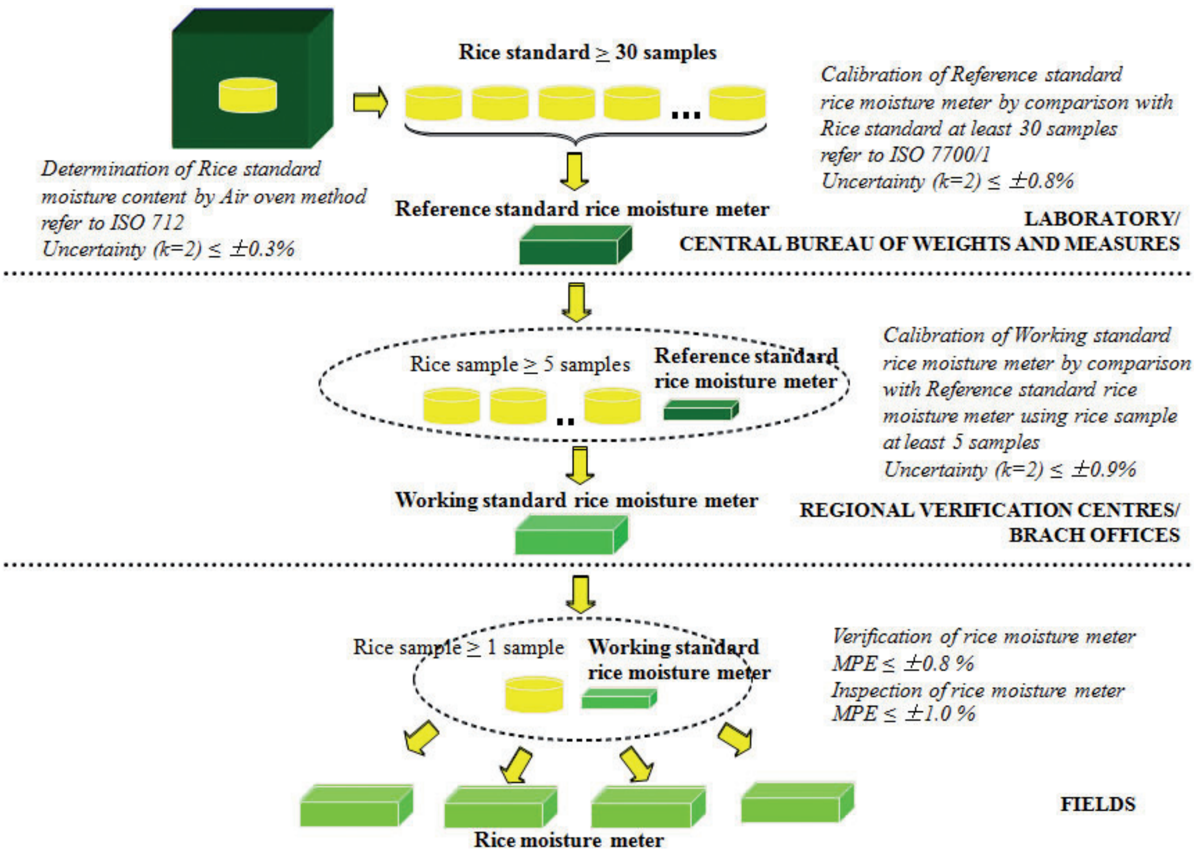

Figure 1: Traceability system of rice moisture meters

2.3 Standards

The CBWM has set the standards and classified them into 3 levels of accuracy as follows:

(1) Rice standard used for calibrating the reference standard rice moisture meter with an uncertainty (k = 2) of less than or equal to ± 0.3 %.
(2) Reference standard rice moisture meter used for calibrating the working standard rice moisture meter with an uncertainty (k = 2) of less than or equal to ± 0.8 %.
(3) Working standard rice moisture meter used for the verification and inspection of rice moisture meters with an uncertainty (k = 2) of less than or equal to ± 0.9 %.

2.3.1 Rice standard

2.3.1.1 Preparation of rice standard

Rough rice samples are collected during the harvest season in the high moisture range of about 26 %–28 %, approximately 10 kg per sample. Each sample is cleaned using winnower and hand sieves and then divided into several portions, approximately 1 kg per portion. The moisture content of each portion is decreased to obtain several moisture values in the measuring range of the rice moisture meter for calibration, verification and inspection by 2 methods:

(1) drying under laboratory conditions; and
(2) drying in the oven at 30 °C or 60 °C which is required when the moisture content is lower than 16 %.

Finally, the sample is put on a rolling machine until its moisture content is homogeneous and the temperature of the sample is stabilized in the laboratory.

2.3.1.2 Determination of the moisture content of the rice standard using ISO 712

For a sample with a moisture content less than or equal to 15 %, take a sample of 5 g ± 1 g as a test sample. Grind the test sample until the size of the particles obtained is no greater than 1.8 mm, using an electric mill which does not absorb moisture, which does not generate heat, and which is not in contact with the outside air during the grinding process, by very short successive grinding actions.

Rapidly pour the ground sample into the drying can and close the lid. Weigh (m_0) using a weighing instrument of class II with maximum capacity 220 g and resolution 0.1 mg. Spread the sample evenly over the base of the drying can and open the lid before drying in the oven at 130 °C for 2 h, using a fan forced oven which has a temperature stability and uniformity ≤ ± 0.5 °C. After the drying time has elapsed, close the lid in the oven, take the drying can out of the oven, and leave in the desiccators for about 45 min to cool down to laboratory temperature before weighing (m_1). Laboratory conditions: t = 25 °C ± 1 °C and h = 50 % ± 10 %. Carry out two determinations on the same sample.

For a sample with a moisture content greater than 15 %, take a sample of slightly greater than 5 g as a test sample and weigh (m_2) in the drying can with the lid on. Dry the test sample in the oven at 130 °C for about 10 min and then cool down to laboratory temperature for 2 h before weighing (m_3). Proceed in the same way as for the sample with a moisture content less than or equal to 15 %.

2.3.1.3 Evaluation of the measurement uncertainty of the rice standard

The moisture content, w, less than or equal to 15 % is obtained from:

$$w = \left(1 - \frac{m_1}{m_0}\right) \cdot 100\%$$

Then the uncertainty of the moisture content less than or equal to 15 % is to be estimated as:

$$u^2(w) = \left(\frac{100 \cdot m_1}{m_0^2}\right)^2 \cdot u_{m_0}{}^2 + \left(-\frac{100}{m_0}\right)^2 \cdot u_{m_1}{}^2 + u_R{}^2 + u_C{}^2 + u_L{}^2$$

The moisture content, w, greater than 15 % is obtained from:

$$w = \left(1 - \frac{m_1 \cdot m_3}{m_0 \cdot m_2}\right) \cdot 100\%$$

Then the uncertainty of the moisture content greater than 15 % is to be estimated as:

$$u^2(w) = \left(\frac{100 \cdot m_1 \cdot m_3}{m_0^2 \cdot m_2}\right)^2 \cdot u_{m_0}{}^2 + \left(-\frac{100 \cdot m_3}{m_0 \cdot m_2}\right)^2 \cdot u_{m_1}{}^2 +$$

$$+ \left(\frac{100 \cdot m_1 \cdot m_3}{m_0 \cdot m_2^2}\right)^2 \cdot u_{m_2}{}^2 + \left(-\frac{100 \cdot m_1}{m_0 \cdot m_2}\right)^2 \cdot u_{m_3}{}^2 + u_R{}^2 + u_C{}^2 + u_L{}^2$$

where:

w is the moisture content, as a percentage of the mass of the rice standard
m_0 is the mass of the rice standard
m_1 is the mass of the rice standard after drying
m_2 is the mass of the rice standard taken before pre-conditioning

m_3 is the mass of the pre-conditioned rice standard

u_{m0} is the uncertainty due to the weighing mass of the rice standard

u_{m1} is the uncertainty due to the weighing mass of the rice standard after drying

u_{m2} is the uncertainty due to the weighing mass of the rice standard taken before pre-conditioning

u_{m3} is the uncertainty due to the weighing mass of the pre-conditioning rice standard

u_R is the uncertainty due to the repeatability of the moisture measurement

u_C is the uncertainty due to the capability of the oven to dry the rice standard

u_L is the uncertainty due to the moisture loss while the rice standard is exposed to the air before weighing

The uncertainty due to the weighing mass u_{m0}, u_{m1}, u_{m2}, u_{m3} was considered from weighing the mass of the rice standard by using a weighing instrument under laboratory conditions as specified in 2.3.1.2. The repeatability of the weighing instrument was determined experimentally from weighing the mass of the rice standard in the drying can, evaluated as a type A standard uncertainty with a normal distribution from the standard deviation of the weighing equal to 0.07 mg. The linearity of the weighing instrument was ± 0.11 mg obtained from the calibration certificate, evaluated as a type B standard uncertainty with a rectangular distribution for weighing the empty drying can and the drying can with the rice standard equal to:

$\frac{0.11}{\sqrt{3}}$ = 0.06 mg. The standard uncertainty of weighing the mass of the rice standard was evaluated as being equal to:

$$u_{m_0}, u_{m_1}, u_{m_2}, u_{m_3} = \sqrt{(0.07)^2 + 2 \cdot (0.06)^2} \text{ mg} = 0.11 \text{ mg}$$

The uncertainty due to the repeatability of the moisture measurement u_R was considered from the limited difference value between two moisture determinations on the same sample, and shall not exceed 0.15 g of moisture per 100 g for a sample with a moisture content of ≤ 15 % or shall not exceed 0.20 g of moisture per 100 g for a sample with a moisture content > 15 % as specified in ISO 7700-1:1984, evaluated as a type B standard uncertainty with a rectangular distribution equal to:

$$u_{R,\,mc\le 15\%} = \frac{0.15\ \%}{2 \cdot \sqrt{3}} = 0.043\ \% \quad or \quad u_{R,\,mc>15\%} = \frac{0.20\ \%}{2 \cdot \sqrt{3}} = 0.058\ \%$$

The uncertainty due to the capability of the oven to dry the rice standard u_C was considered after drying the maximum number of samples that the oven will accommodate at a temperature of 130 °C ± 3 °C, then heating the same test samples for 2 h and then for a further 1 h. The results did not differ by more than 0.15 g of moisture per 100 g of sample as specified in ISO 712:1998, evaluated as a type B standard uncertainty with a rectangular distribution equal to:

$$u_C = \frac{0.15\ \%}{2 \cdot \sqrt{3}} = 0.043\ \%$$

The uncertainty due to the moisture loss during the time the rice standard was exposed to the air before weighing u_L was considered for the sample that was ground according to the conditions specified in ISO 712:1998, exposed to the air at t = 25 °C ± 1 °C and h = 50 % ± 10 %, in the period of grinding operation less than 20 s as in Table 3, evaluated as a type B standard uncertainty with a rectangular distribution equal to:

$$u_L = \frac{0.036\ \%}{2 \cdot \sqrt{3}} = 0.0104\ \%$$

2.3.2 Reference standard rice moisture meter

2.3.2.1 Calibration of the reference standard rice moisture meter

Adjust the temperature of the rice standards and the reference standard rice moisture meter until stabilized at the laboratory temperature. Simultaneously measure the moisture content of the rice standards and of the reference standard rice moisture meter by the routine reference method.

No.	Time during which the ground sample was exposed to the air							
	0 s		10 s		20 s		30 s	
	Weight g	Moisture loss %	Weight g	Moisture loss %	Weight g	Moisture loss %	Weight g	Moisture loss %
1	5.2740	0.000	5.2734	-0.011	5.2721	-0.036	5.2716	-0.046
2	5.0757	0.000	5.0747	-0.020	5.0741	-0.032	5.0732	-0.049
3	5.2221	0.000	5.2209	-0.023	5.2203	-0.034	5.2194	-0.052

* The moisture content of the sample in the experiment is approximately 15 %.

Table 3: Moisture loss for the ground sample exposed to the air at t = 25 °C ± 1 °C and h = 50 % ± 10 %

		Sample with moisture content less than or equal to 15 %			Sample with moisture content greater than 15 %		
Quantity X_i	Probability distribution	Standard uncertainty $u(x_i)$	Sensitivity coefficient c_i	Uncertainty contribution $u_i(y)$	Standard uncertainty $u(x_i)$	Sensitivity coefficient c_i	Uncertainty contribution $u_i(y)$
m_0	normal	0.00011 g	17.00000 %·g^{-1}	0.00187 %	0.00011 g	14.99967 %·g^{-1}	0.00165 %
m_1	normal	0.00011 g	-20.00000 %·g^{-1}	-0.00220 %	0.00011 g	-17.64667 %·g^{-1}	-0.00194 %
m_2	normal				0.00011 g	12.49972 %·g^{-1}	0.00138 %
m_3	normal				0.00011 g	-14.16667 %·g^{-1}	-0.00156 %
u_R	rectangular	0.04300 %	1	0.04300 %	0.05800 %	1	0.05800 %
u_C	rectangular	0.04300 %	1	0.04300 %	0.04300 %	1	0.04300 %
u_L	rectangular	0.01040 %	1	0.01040 %	0.01040 %	1	0.01040 %
Combined uncertainty				0.06176 %			0.07302 %
Expanded uncertainty (k = 2)				**0.12352 %**			**0.14604 %**

Table 4: Uncertainty budget for determining the moisture content of the rice standard according to ISO 712

2.3.2.2 Evaluation of the measurement uncertainty of the reference standard rice moisture meter

The error of the reference standard rice moisture meter reading is obtained from:

$$E_P = \bar{e} = \frac{\sum_{i=1}^{k}\sum_{j=1}^{n}(MR_{Pij} - w_i)}{kn}$$

Then the uncertainty for the reference rice moisture meter reading is to be estimated as:

$$u^2(E_P) = u(\bar{e})^2 + u_{dP}{}^2 - u_w{}^2$$

where:

- E_P is the error of the reference standard rice moisture meter reading
- $\bar{e}$ is the average error of the reference standard rice moisture meter reading from the routine reference method
- MR_{Pij} is the reference standard rice moisture meter reading obtained from j–n repeated measurements of the rice standard i–k
- w_i is the moisture value of the rice standard i–k obtained by the routine reference method
- $u(\bar{e})$ is the uncertainty due to the variance of the reference standard rice moisture meter reading error
- u_{dP} is the uncertainty due to the limited resolution of the reference standard rice moisture meter
- u_w is the uncertainty of the rice standard

The uncertainty due to the variance of the reference standard rice moisture meter reading error $u(\bar{e})$ was considered from the standard deviation of the error of the reference standard rice moisture meter reading using the routine reference method, evaluated as a type A standard uncertainty with a normal distribution. For example, if we use the standard deviation value s = 0.36748 % from the data in Figure 2, the uncertainty will be equal to:

$$u(\bar{e}) = 0.36748\ \%$$

The uncertainty due to the limited resolution of the reference standard rice moisture meter u_{dP} was considered from the reading resolution of the meter, d = 0.1 %, evaluated as a type B standard uncertainty with a rectangular distribution equal to:

$$u_{dP} = \frac{0.1\ \%}{2\cdot\sqrt{3}} = 0.02887\ \%$$

The uncertainty of the rice standard u_w was considered from the expanded uncertainty (coverage factor k = 2) of the moisture measurement of the rice standard by the routine reference method, evaluated as a type B standard uncertainty with a normal distribution equal to:

$$u_w = \frac{0.15\ \%}{2} = 0{,}075\ \%$$

2.3.3 Working standard rice moisture meter

2.3.3.1 Calibration of the working standard rice moisture meter

Adjust the temperature of the rice standards, reference standard rice moisture meter and working standard rice moisture meter until stabilized at the laboratory temperature. Measure the moisture content of the rice standards using the reference standard rice moisture meter and working standard rice moisture meter continuously.

2.3.3.2 Evaluation of the measurement uncertainty of the working standard rice moisture meter

The error of the working standard rice moisture meter reading is obtained from:

$$E_S = \bar{e} = \frac{\sum_{i=1}^{k}\sum_{j=1}^{n}(MR_{Sij} - MR_{Pij})}{kn}$$

Then the uncertainty of the working standard rice moisture meter reading is to be estimated as:

$$u^2(E_S) = u(\bar{e})^2 + u_{dS}{}^2 - u_P{}^2 - u_{RP}{}^2 - u_{dP}{}^2$$

where:

- E_S is the error of the working standard rice moisture meter reading
- $\bar{e}$ is the average error of the working standard rice moisture meter reading from the reference standard rice moisture meter reading
- MR_{Sij} is the working standard moisture meter reading obtained from *j–n* repeated measurements of the rice standard *i–k*
- MR_{Pij} is the average of the reference standard rice moisture meter reading obtained from *j–n* repeated measurements of the rice standard *i–k*
- $u(\bar{e})$ is the uncertainty due to the variance of the working standard rice moisture meter reading error
- u_{dS} is the uncertainty due to the limited resolution of the working standard rice moisture meter
- u_p is the uncertainty of the reference standard rice moisture meter
- u_{RP} is the uncertainty due to the repeatability of the reference standard rice moisture meter obtained from *j–n* repeated measurements
- u_{dP} is the uncertainty due to the limited resolution of the reference standard rice moisture meter

The uncertainty due to the variance of the working standard rice moisture meter reading error $u(\bar{e})$ was considered from the standard deviation of the error of the working standard rice moisture meter reading from the average of the reference standard rice moisture meter reading, evaluated as a type A standard uncertainty with a normal distribution. For example, if the reference and working standard rice moisture meters to be used have the same calibration curve, the standard deviation should therefore not exceed 0.2 %. The uncertainty will be equal to:

$u(\bar{e}) = 0.2$ %

The uncertainty due to the limited resolution of the working standard rice moisture meter u_{dS} was considered from the reading resolution of the meter, $d = 0.1$ %, evaluated as a type B standard uncertainty with a rectangular distribution equal to:

$$u_{dS} = \frac{0.1\ \%}{2 \cdot \sqrt{3}} = 0.02887\ \%$$

The uncertainty of the reference standard rice moisture meter u_p was considered from the expanded uncertainty (coverage factor $k = 2$) of the reference standard rice moisture meter calibration, evaluated as a type B standard uncertainty with a normal distribution equal to:

$$u_P = \frac{0.75\ \%}{2} = 0.375\ \%$$

The uncertainty due to the repeatability of the reference standard rice moisture meter reading u_{RP} was considered from the maximum standard deviation of the reference standard rice moisture meter reading repeated measurement 10 times the rice standard *i–k*, assumed to be equal to 0.1 %, evaluated as a type A standard uncertainty with a normal distribution equal to:

$$u_{RP} = \frac{0.1\ \%}{\sqrt{10}} = 0.03162\ \%$$

The uncertainty due to the limited resolution of the reference standard rice moisture meter u_{dP} was considered from the reading resolution of the meter, $d = 0.1$ %, evaluated as a type B standard uncertainty with a rectangular distribution equal to:

$$u_{dP} = \frac{0.1\ \%}{2 \cdot \sqrt{3}} = 0.02887\ \%$$

Quantity X_i	Value x_i	Standard uncertainty $U(x_i)$	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(y)$
$\bar{e}$	0 %	0.36748 %	normal	1	0.36748 %
u_{dP}	0 %	0.02887 %	rectangular	1	0.02887 %
u_W	0 %	0.07500 %	normal	1	0.07500 %
E_P	0 %				0.37 616 %

Expanded uncertainty (U) = $k \times u$ (E_P) % = 2 × 0.37616 % = 0.75233 %

Table 5: Uncertainty budget of the reference standard rice moisture meter calibration

Quantity X_i	Value x_i	Standard uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(y)$
$\bar{e}$	0 %	0.20000 %	normal	1	0.20000 %
u_{dS}	0 %	0.02887 %	rectangular	1	0.02887 %
u_P	0 %	0.37500 %	normal	1	0.37346 %
u_{RP}	0 %	0.03162 %	normal	1	0.03162 %
u_{dP}	0 %	0.02887 %	rectangular	1	0.02887 %
E_S	0 %				0.42678 %

Expanded uncertainty (U) = $k \times u$ (E_S) % = 2 × 0.42678 % = 0.85356 %

Table 6: Uncertainty budget of the working standard rice moisture meter calibration

2.4 CBWM collaborates with manufacturers in developing rice moisture meters

CBWM organized a meeting among manufacturers and dealers to inform them about the regulation, and which direction they should follow when developing rice moisture meters in Thailand.

CBWM and manufacturers jointly developed the rice moisture meters calibration curve by using various domestic rice varieties as samples, in particular those varieties that are of the greatest economic importance such as Khao-Dawk-Mali-105. The result of this collaboration was the “Thai rice calibration curve”, which is more suitable and more accurate than before. The accuracy of the calibration curve also aligns with the MPE specified by Ministerial Regulation No. 2 (see Figures 2 and 3).

3 Benefits

After the implementation of Ministerial Regulation No. 2, the CBWM set up the legal metrology control system on rice moisture meters, complying with international standards, and took on responsibility for the verification and inspection of rice moisture meters. Meanwhile, farmers and stakeholders in rough rice transactions can increasingly access rice moisture meters to be verified and inspected by weight and measure officers. Those rice moisture meters that fail in the process of the inspection are prohibited for use until repaired and re-verified (see Figure 4).

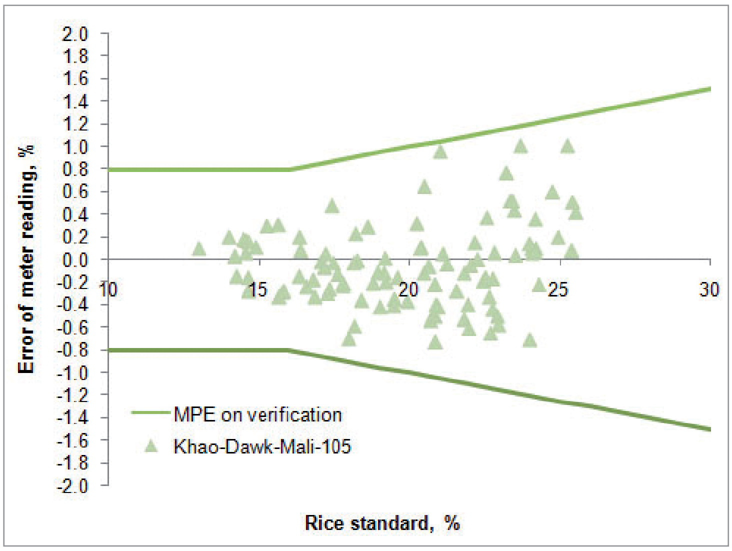

Figure 2: Checking the calibration curve of Capacitance type rice moisture meter (model: PM 410), by rice standard; rough rice type, Khao-Dawk-Mali-105 variety, low part of the North-eastern Region of Thailand and crop year 2008/2009

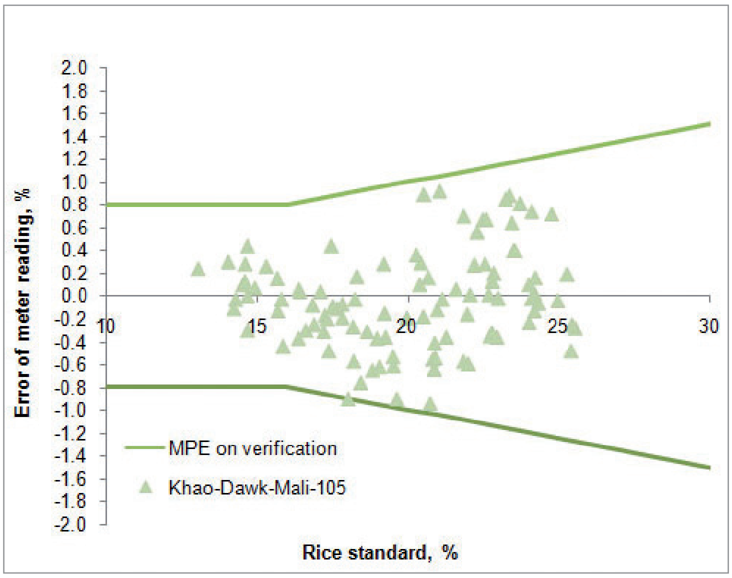

Figure 3: Checking the calibration curve of Capacitance type rice moisture meter (model: EE-KU 60th anniversary), by rice standard; rough rice type, Khao-Dawk-Mali-105 variety, low part of the North-eastern Region of Thailand and crop year 2008/2009

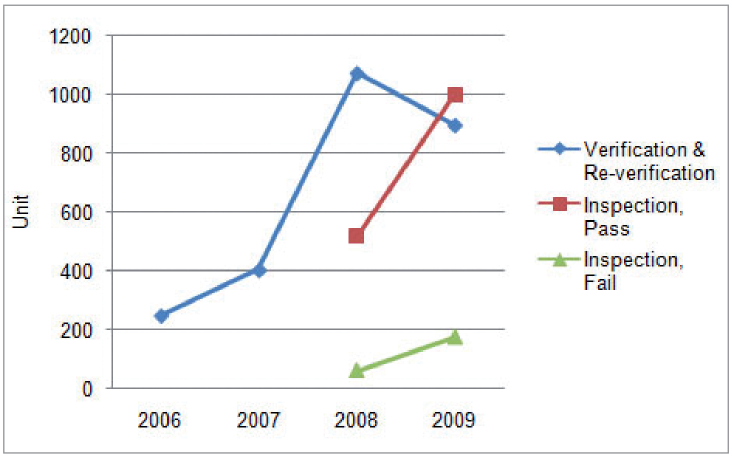

Figure 4: Statistics of verification and inspection of rice moisture meters

4 Results and expectations

From the statistics results it was found that the number of rice moisture meters is increasing, and that it is important to control the process of moisture measurement of rice standards and the calibration of rice moisture meters used as standards.

As seen in Table 4, the accuracy of the rice standard is suitable for use as a standard for verification and inspection of rice moisture meters due to its expanded uncertainty which is less than 1/3 of the MPE, but the expanded uncertainty of rice moisture meters used as standards will be more than 1/3 of the MPE.

However, practically, the use of rice moisture meters as standards is necessary for re-verification and inspection of rice moisture meters in those areas that are distant from the laboratory. Thus the calibration process and/or the capability of the rice moisture meters would need to be developed further in the future. ■

References

[1] OIML Recommendation R 59:1984 *Moisture meters for cereal grains and oilseeds*

[2] ISO 712:1998 *Cereals and cereal products - Determination of moisture content - Routine reference method*

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[4] APLMF *Guideline: Accuracy maintenance of moisture meters for cereal grains* (draft), 2002