COMPARISON OF MICROWAVE AND OVEN DRYING TECHNIQUES FOR MOISTURE DETERMINATION OF THREE DIFFERENT SIZES OF PADDY (*Oryza sativa* L.) VARIETIES

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Abstract
The standard method for grain moisture measurement is considered as conventional air oven drying technique. The standard conventional air oven method requires a longer period of time to determine the moisture content (m.c). Although electric moisture meters are popular in rice industries, it has to be calibrated frequently with the oven dry method. Therefore, alternative but fast and reliable method is required, especially, for the grain marketing industries. Three different sizes of paddy (Oryza sativa L.) samples (Bg300-intermediate bold, Bg358-short round and At405-long slender) were used for this study. Five different moisture levels (12-20% wet basis) were prepared by adding known amount water. Correlation between the microwave oven and hot air oven moisture values were evaluated using Pearson, Spearman and Kendall statistical techniques. The linear regression relationship was also established between hot air oven and microwave oven moisture determination method. According to the data, except 870 W of absorbed MW power setting level, the other two MW power setting (265 W and 550 W) showed a significant statistical correlation (R>0.55, P<0.01)between the air oven and MW oven m.c. values of three paddy samples. However, MW settings of 550 W for 7 min of absorbed power indicated the significantly higher regression coefficient of determination (R^2=0.94, P<0.01) with air oven m.c values. From the study, it was revealed that the domestic microwave oven can successfully use to determine the moisture content of different paddy varieties as an alternative method to the conventional air oven drying method.

Key words: microwave, paddy, moisture, hot air oven, power

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1. INTRODUCTION

Moisture content (m.c) is the most important factor that affects the storage, processing and marketing of rice (Kraszewski *et al.*, 1998; Nelson *et al.*, 1998; Ismail and Alyahya, 2003). Most of the physical, chemical, mechanical and thermal properties of rice are affected due to m.c which is later determined the quality of the raw rice (paddy). Due to frequent fluctuation of relative humidity (r.h) than the temperature in the tropics, m.c of the stored paddy and rice should be checked on a periodic time scale. Rice m.c is independent from the quantity or shape of the materials (Trabelsi *et al.*, 1999) but it is most suitable parameter for harvesting, storage, processing, transport and price determination in the market (Kraszewski *et al.*, 1998; Lawrence *et al.*, 1998; Trabelsi and Nelson, 2004). At the time of paddy harvest, m.c was about 20% (wet basis), but harvested paddy must be dried to a 12% m.c (w.b) for safe storage (Cao *et al.*, 2004). If paddy is harvested at higher m.c > 20% (w.b), it may cause mechanical damage to the paddy kernels during the mechanical harvesting process. As a result of that grains can be infected by fungi and insects. If the m.c of storage rice/paddy is higher than the storage environment, then microorganisms and insects can spoil the cereal grains making them unsuitable for human and animal consumption. Rice is unique among other cereal grains because it is consumed primarily as whole grains. Therefore, high breakage of rice grains during milling caused significant loss to the rice quality and their market value. Nonuniform moisture distribution is often found in rice storage; therefore, sampling and moisture determination is an important operation to control postharvest

loss of grains (Kraszewski *et al*., 1998; Digman *et al*., 2012).
The standard method for grain moisture measurement is considered as conventional air oven drying technique (Sharma and Hanna, 1989; Kaasova *et al*., 2002). Several standard temperature-time combinations that are being used for these ovens such as 100-102 °C for 16-18 hours, 100-110 °C for 14 hours and 130°C for 2 hours (Bouraoui *et al*., 1993; Miah *et al*., 2002). The standard conventional air oven method requires a longer period of time to determine the m.c (Nelson *et al*., 1998). Although electric moisture meters are popular in rice industries, it has to be calibrated frequently with the oven dry method. Therefore, alternative but fast and reliable method is required, especially, for the grain marketing industries (Trabelsi and Nelson, 2004; Trabelsi *et al*., 2009; Digman *et al*., 2012). It has been found that direct relationship exists between the m.c and dielectric properties of grain moisture content (Kraszewski *et al*., 1998; Calay *et al*., 1995).
Microwave heating (MW) applications have been well known for a long time, and have many potential applications such as grain moisture determination, drying, disinfestation, heating, blanching, extraction, cooking etc.(Sale, 1976; Venkatesh and Raghavan, 2004).Microwave oven considerably saves time, utilizes less space, and requires approximately 25% less energy than the conventional air oven (Chandrasekaran *et al*., 2013). Although the initial cost of an MW oven is higher than the conventional air oven, however, operational cost is low compared to the air oven method. Therefore, the domestic microwave oven has enormous potential use to determine the m.c of many cereals within a short period of time under low cost. Therefore, objective of this study is to compare the effectiveness of conventional air oven drying method and a domestic microwave oven method to determine the moisture content of rice.

2. MATERIALS AND METHODS

2.1. Paddy samples preparation

The paddy or rough rice (*O. sativa* L.) varieties Bg300, Bg358 and At405 (Table 1) were obtained from the Research and Development Institute, Sri Lanka. Paddy samples were collected at the harvest maturity and sun dried up to about 12% wet basis (w.b) of moisture content (m.c).

Table 1. Paddy varieties according to their grain type and maturity

Paddy variety	Grain type	Common rice name	Maturity stage (days)
Bg300	Intermediate bold	*Nadu*	90
Bg358	Short round	*Samba*	105
At405	Long slender	*Basmati*	120

Experiments were conducted for the combinations of five different moisture levels which were 12%, 14%, 16%, 18%, and 20% (w.b.). Initial m.c of the samples was 11.6±0.7% (w.b) determined by the air oven drying method. Based on the initial moisture value, different levels of moisture samples (predicted moisture) were prepared by adding the required amount of distilled water. Each sample was placed in an airtight glass bottle and stored at 4°C for 4 weeks to attain equilibrium predicted moisture levels. During the storage period, bottles were regularly shaken to facilitate the even distribution of moisture throughout the paddy samples.

2.2. Moisture determination by hot air oven

Moisture content (m.c) of the paddy samples was determined by hot air oven method. The samples were grounded using a laboratory mill (Fred Stein LaboratoriesM-2, USA) and 5 g of each ground sample was used to determine moisture content. Three ground paddy samples were weighed into moisture cans and then the samples were heated in a forced air oven (SIBATA SPF-600, Japan) at 130°C for 2 hours (Miah *et al*., 2002). Wet basis moisture content (w.b %) was measured using following equation:

$$\text{Moisture content (wb \%)} = \frac{\text{weight of moisture (g)}}{\text{weight of sample paddy (g)}} \times 100$$

2.3. Calibration of microwave oven

A domestic MW oven (Toshiba ER-SS25) was used to determine the moisture. The oven has a capacity of 25l with a rotating circular glass shelf of diameter 315 mm. According to the instruction of the manufacturer, power consumption and power output of the MW oven were 1450 W and 900 W, respectively. At 100% MW output power is equal to 900W of heat energy emits by the MW frequency of 2450 MHz. MW oven was calibrated to obtain the absorbed power output levels. A deionized water sample of 200 ml in a 250 ml glass beaker was heated in the microwave oven for 120 s. The temperature rise was measured using a T-type thermocouples and data logger (TC08-PicoTech, UK). A piece of an asbestos sheet was placed on the rotating glass shelf during the heating period to prevent the MW shattering and damage to the magnetron. Maximum MW power output for a given sample was determined prior to the experiment. The output absorbed MW power was calculated ($Q/t = m\ c_p\ \Delta T$) by dividing the energy absorbed by water and beaker by the time. The mean values for the absorbed MW powers corresponding to power settings of 300 W, 500 W and 800 W were observed as 265±5, 550±6, and 870±15 W, respectively.

2.4. Moisture determination by microwave method

Samples were taken out of the refrigerator and brought to room temperature before moisture determined by the MW oven drying. A sample of 5 g was weighed into a 50 ml beaker and was placed on center of the asbestos sheet which was placed on the rotating glass shelf of the microwave oven (Verma and Noomhorm, 1983). The asbestos was used to protect the magnetron and supply the adequate heat from the MW oven, especially when the samples reached low moisture levels during drying. The samples were heated at 265 W, 550 W and 870 W of absorbed MW power output settings at 20, 7 and 4 min respectively. The weight of each paddy sample was determined after MW drying and then the sample was discarded. The beaker was initially heated in the MW oven for 2 min before using. Microwave power setting levels were selected based on the previous studies conducted elsewhere in the world for the moisture determination of cereals (Sharma and Hanna, 1989; Bouraoui *et al.*, 1993; Walde *et al.*, 2002). The weight loss after each MW drying was expressed as an apparent m.c. of the paddy samples. All readings were taken in triplicates. The measurement was stopped if the sample was burnt in any situation. The same beaker was used throughout all the experiments after dry cleaning.

2.5. Data analysis

One-way analysis of variance (ANOVA) was performed for the data obtained from standard air oven m.c and apparent MW oven m.c. Fisher's least significant difference test (LSD) was used for mean comparisons at $P<0.05$. Parametric Pearson "R" correlation coefficient and non-parametric Spearman and Kendall ranking correlation techniques were used to determining the correlation coefficient of moisture contents between the air oven and microwave oven. General linear model (GLM) was mainly used to establish the relationship between the variables tested under the comparison (Ismail and Alyahya, 2003). PROC GLM (SAS 9.1) procedure was used to establish a linear model for the determination of moisture by microwave method. The regression coefficient of determination of R^2, F value, fit standard error and P (=0.05) values were used to provide the goodness of fit of the data to the straight line.

3. RESULTS

3.1. Moisture determination

Initial m.c of the paddy samples was 11.6±0.14% (w.b.). The apparent m.c (±SD) obtained after different MW power-time setting levels and air oven drying for each predicted m.c (Table 2). Air oven method was used as a standard moisture determination method. Compared to the air oven, moisture determination of three different absorbed MW power-time settings was not uniform.
The results show that there was no statistical difference (P>0.05) of moisture contents between air oven drying and MW oven drying methods at 550 W of absorbed MW power output. Average m.c of paddy samples drying at 870 W was significantly higher (P<0.05) than that of m.c obtained by air oven method.

Some paddy samples were exploded in the process of heating/drying at 870 W due to the vapor pressure rising rapidly inside the paddy seed. Microwave drying at 275 W absorbed MW power showed the lowest apparent moisture contents at all 5 predicted moisture levels compared to the other two MW drying methods. Therefore, MW drying at 550 W showed more or less similar moisture values (P>0.05) compared to the moisture values of air oven drying for all three paddy varieties.

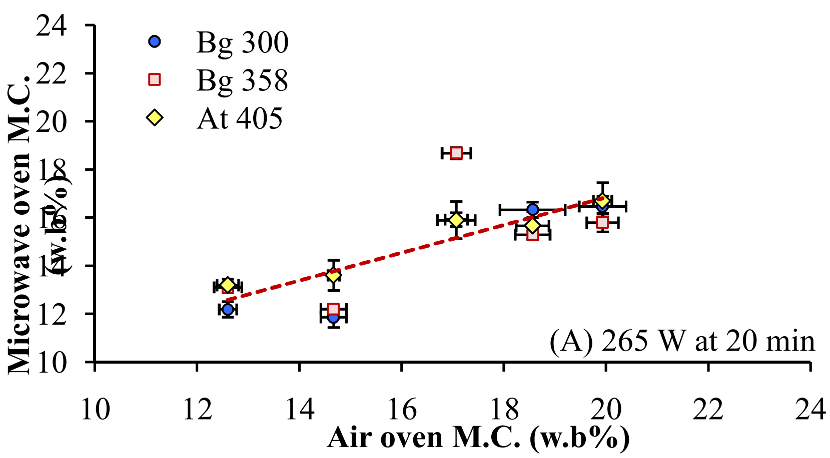
3.2. Correlation between air oven and microwave oven method

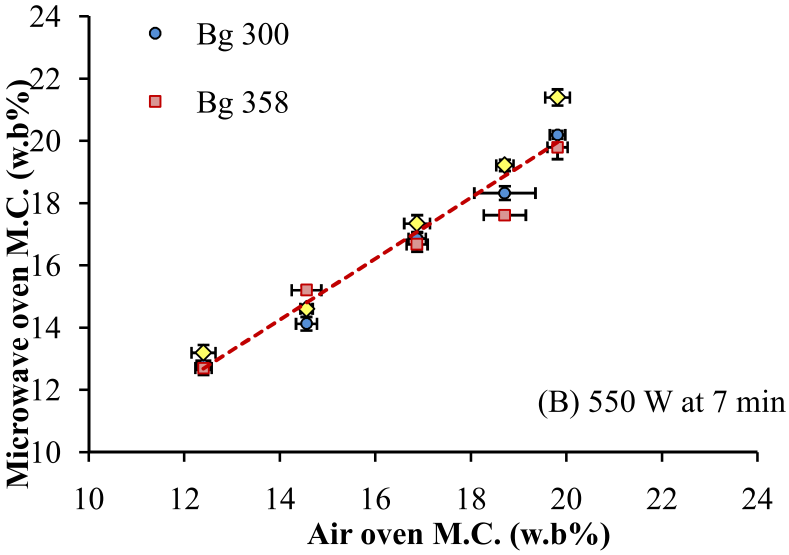
Apparent m.c values obtained from three absorbed MW power levels and air oven moisture data were chosen to establish the relationship between the microwave oven and air oven m.c determination methods (Figure 1).

Table 2. Mean (±standard deviation) of five apparent moisture contents of three paddy varieties determined by air oven and microwave oven drying methods

Standard mean (±SD) air oven m.c (w.b%)	Apparent mean (±SD) MW oven m.c (w.b%)		
	265 W for 20 min	550 W for 7 min	870 W for 4 min
12.60±0.14^{a*}	12.20±0.14^{a*}	12.33±0.12^{a*}	13.80±0.11^{b*}
14.67±0.31^{b}	12.87±0.22^{a}	14.13±0.22^{b}	16.47±0.22^{c}
17.07±0.08^{a}	16.93±0.22^{a}	16.87±0.18^{a}	18.84±0.21^{b}
18.56±0.64^{b}	15.33±0.08^{a}	18.33±0.12^{b}	20.27±0.16^{c}
19.93±0.16^{b}	16.47±0.22^{a}	20.47±0.29^{b}	21.87±0.29^{c}

*Mean (±SD) followed by the same simple superscript within a raw are not significantly different (P>0.05)





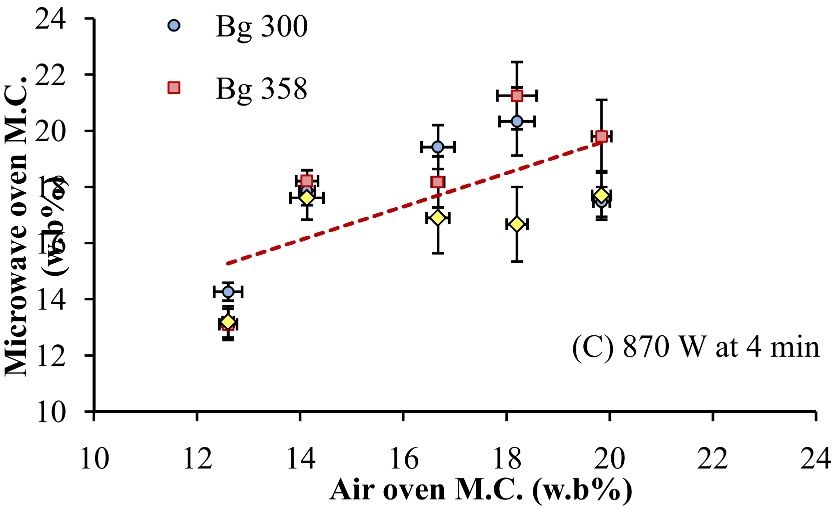


Fig.1. Apparent moisture contents (w.b%) relationship of three different sizes of paddy varieties determine by air oven and domestic microwave oven drying methods: (A) 265 W within 20 min drying, (B) 550 W within 7 min drying and (C) 870 W within 4 min of absorbed microwave drying.

Table 3. Parametric and non-parametric correlation coefficients between microwave oven and air oven moisture determination methods of the three paddy varieties

Absorbed microwave power	Method	R*	P**
265 W for 20 min.	Pearson	0.70	0.001
	Spearman	0.68	0.006
	Kendall	0.55	0.007
550 W for 7 min.	Pearson	0.92	0.001
	Spearman	0.68	0.002
	Kendall	0.56	0.007
870 W for 4 min.	Pearson	0.15	0.600
	Spearman	0.20	0.483
	Kendall	0.19	0.362

*Correlation coefficient;**Probability level

Table 4. Predicted linear moisture relationships of air oven and microwave oven drying moisture content (w.b%) of the three paddy varieties

Microwave power (W)	Microwave time (min.)	Linear equation*	Adjusted R^2	F value	Fit SE†	P**
265	20	Y= 0.87 + 1.06 X	0.54	20.25	1.77	0.001
550	7	Y= 0.28 + 0.97 X	0.94	255.72	0.64	0.001
870	4	Y= 3.01 + 0.76 X	0.36	10.75	2.09	0.01

*Y = standard air oven drying m.c (w.b%); X = microwave oven drying m.c (w.b%)
†Fit standard error; **Probability level

Three Pearson, Spearman, and Kendall correlations were used to evaluate the fitness of the relationship between air oven m.c and microwave oven m.c (Thattil *et al.*, 1999).The parametric Pearson correlation gave the highest R-value of 0.92 for air oven and 550 W of MW ovens drying and established a good linear relationship (Table 3). Non-parametric Spearman and Kendall rank correlations also showed the significantly high correlation ($R>0.55$, $P<0.01$) between air oven and MW oven drying methods. This indicates that the high degree of association (Spearman rank) and strength of dependence (Kendall rank) between two drying methods for moisture determination.

MW drying at 870 W of absorbed power (within 4 min) did not show any significant ($P>0.05$) relationship between the two drying methods. It also has the lowest Pearson, Spearman and Kendall correlations of R = 0.15, R = 0.2 and R = 0.19 respectively. Although at 265 W for 20 min exposure was absorbed comparatively high MW energy, Spearman and Kendall showed more or less similar rank correlations values ($R > 0.55$) to the 550 W MW power but showed comparatively lower Pearson linear correlation (R = 0.70) to the 550 W MW power level. Therefore, the MW oven drying at 550 W for 7 min was selected as the best moisture determination energy value alternative to the air oven drying method.

3.3. Moisture prediction

The apparent m.c content data obtained from the MW oven drying method (X) and air oven drying moisture values (Y) were fitted to a GLM. All three MW absorbed power setting levels of 265 W, 550 W and 870 W showed significant ($P<0.05$) positive relationship (Table 4). The highest positive coefficient of determination was observed between air oven and MW oven drying at 550 W of MW power exposure (adjusted $R^2 = 0.94$; $P<0.001$) for 7 min but the lowest coefficient of determination value was observed between MW oven drying at 870 W for 4 min MW energy exposure and air oven drying method.

The highest F value of 255.72 and smallest F value of 10.75 was obtained for the absorbed MW power levels of 550 W and 870 W respectively. Absorbed MW power level of 265 W at a longer power exposure time of 20 min also indicated the comparatively good linear regression fitting (adjusted $R^2 = 0.54$; F = 20.25; $P<0.001$) between MW oven exposure and air oven drying next to the 550 W of absorbed MW power level.

4. DISCUSSION

Generally, domestic MW ovens were not equipped with an airflow system. Therefore, in some instances, a quick charring of the sample was observed. This effect can be attributed to the emission of heat as radiation, which is a result of internal heat generation (Bouraoui *et al.*, 1993; Digman *et al.*, 2012). The results can be affected by non-uniform energy distribution during MW heating/drying. A good deal of trial and error is usually required to avoid common problems of uneven heating, under drying or scorching problem (Bouraoui *et al.*, 1993). The microwave oven operates at room temperature and atmospheric pressure. Therefore, large fluctuation of RH could have a significant effect on the sample moisture determination (Beary, 1988). These environmental effects are absent in a conventional air oven method because it is operated at fixed temperature conditions. High water content relates to MW absorption of power, stronger reflection, and shorter wavelengths, which is relates to various absorption mechanisms of energy dissipation in the microwaved material (Ryynänen *et al*., 2004; Trabelsi *et al*., 2009). Low microwave power was used with a longer drying time of food sample. This causes a higher consumption of energy by the sample (Wang *et al*., 2007). Therefore, MW drying at 265 W for 20 min MW energy absorption showed comparatively lower coefficient of determination (adjusted R^2 = 0.51) between two moisture determination methods compared to the 550 W MW drying. Grain physical and chemical characteristics may change rapidly when they heat for a longer period of time. Therefore, some amount of moisture may tightly entrap in the starchy kernels. Kaasova *et al*. (2002) found, when high moisture wheat grains were subjected to lengthy MW heating at low absorbed MW power (298 W) significantly changed the physical and chemical characteristics of wheat. Samples exposure to high absorbed MW power rapidly develops a high internal temperature within a short period of time and it became very difficult to control the temperature. This effect can be attributed to the uncontrollable final product temperature, which is a consequence of the availability of limited water during the final stages of drying. It causes a rapid increase in the material temperature leading to scorching of the sample (Zhang *et al*., 2006). This could be the reason that we observed a poor moisture correlation (Pearson R = 0.15; P=0.6) between air oven and microwave oven drying of paddy samples at 870 W within 4 min of MW energy exposure. Bouraoui *et al*. (1993) reported that a high MW power level (ca. 800 W) could cause overestimation of moisture content in some seed samples. This may probably due to the development of high vapor pressure and restriction of vapor flux flow from inside to outside of the seed. The other reason may relate to the sudden change of physico-chemical characteristics of starchy endosperm of the rice (Kaasova *et al*., 2001, Trabelsi *et al*., 2009). However, drying at 550 W of MW absorption power was highly controllable compared to the 265 W and 870 W of MW absorption levels. Therefore, at 550 W of MW absorption showed good moisture correlation data (Pearson R = 0.92; P=0.001) between air oven and microwave oven heating. If moisture data can be taken before any large temperature development within the samples, precision of the moisture value may not be significantly affected due to physico-chemical changes or sample scorching. This can be achieved by keeping the heat transfer at low level under control MW energy absorption. It was shown that the moisture content of rice decreased linearly with an increase in MW energy (power × time) consumption and was significantly influenced on the quality of rice (Zhao *et al*., 2007). According to Sharma and Hanna (1989), the moisture content of the soybean > 12% (w.b) can accurately be predicted using 1.5 min MW drying at 619 W of absorbed MW power without scorching the seed sample. They found that MW drying time and moisture content determined by the air oven has an exponential relationship. However, the moisture estimation is related to the development of final product temperature within the paddy sample and the amount of vapor diffusion from inside to outside of the paddy samples.

5. CONCLUSIONS

From the study, it was revealed that the domestic microwave oven can successfully use to determine the moisture content of different paddy varieties as an alternative method to the conventional air oven drying method. The rice processors can use the optimum microwave power-time combination in the routine moisture analyses replacing the time-consuming air oven technique. Therefore, it can be concluded that 550 W of absorbed MW power setting at 7 min is more significant (P<0.05) than any other tested microwave power absorption levels to determine the paddy moisture content between 12-20% (w.b).

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