Mechanical property and quality aspects of rice dried in industrial dryers

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Revised: 27 August 2017 / Accepted: 4 September 2017 / Published online: 21 September 2017
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Abstract The influence of drying methods on selected mechanical properties and qualities of MR219 rice variety has been investigated. The results showed significant effects of drying methods on bending strength and head rice yields while the average bending strength of paddy were 28.6–31.8 MPa. The effect of drying methods on apparent modulus of elasticity of rice was not significant (204.5–222.4 MPa). The fracture energy of rice varied significantly under control drying but not with industrial drying methods. Higher temperature in drying by IBD contributed in making the grains tougher, where the effect

of FBD temperature was positive toward the development of fracture energy inside rice kernel. IBD at temperature above 40 °C resulted in lower bending strength in rice kernels which affected head rice yield. Two stage paddy drying practices with FBD using temperature of 115–125 °C as first stage is still acceptable, and inclined bed dryer either as single stage or as second stage after FBD should be operated at temperature of <40 °C to maintain head rice yield. The whiteness and milling recovery of rice achieved from different drying methods were comparable.

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Keywords Industrial paddy drying · Inclined bed drying (IBD) · Fluidized bed drying (FBD) · Mechanical properties · Rice quality

Introduction

The evaluation on impacts of industrial drying methods on mechanical properties can be constructive for the rice industry in selecting suitable drying practice for producing quality rice. Mechanical properties are important and need to be identified and then be quantified in designing of agricultural processing machinery (Bhat and Riar 2016; Champagne et al. 2004). The importance of understanding mechanical properties and their influence on rice quality have been emphasized by several researchers (Mujumdar and Law 2010; Siebenmorgen and Qin 2005). For instance, a relevant contribution to produce quality rice is given by increase bending strength (35.7 MPa) in rice kernels from fixed bed drying using temperature of 40–60 °C (Talab et al. 2012). The hardness and stiffness of rice kernels from sound fluidized bed drying are higher than that of conventional drying ones that results high head rice yield and

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low fissures (cracks) in rice kernels (Tuyen et al. 2009). Formation of fissures in grain and subsequent breakage denote mechanical failures of rice kernels. Previous researchers (Cnossen et al. 2001; Fan et al. 2000; Corrêa et al. 2007; Buggenhout et al. 2014) have been investigated the fissure formation phenomenon in rice kernels under different drying conditions. They have noticed that fissures decline the structure and hardness of kernels and consequently reduce head rice yield.

Accordingly, the measurement of the mechanical properties of rice kernels is of great importance to identify the relation to milling quality of rice with respect to drying methods. The assessment of tensile strength and bending strength are two indicators that are well related to HRY (head rice yield) compare to compressive strength (Lu and Siebenmorgen 1995). However, it is difficult to set up tensile test since it requires a complicated preparation of specimen due to the irregular shape of rice kernels. In contrast, bending test is simple and maximum bending force has been proven to hold a good correlation with HRY (Buggenhout et al. 2014). Therefore, the three-point bending test is chosen as a method to accomplish the test at room temperature in the laboratory after collecting samples from different industrial drying operations in this study. In previous studies, physical properties, mechanical properties and quality aspects of rice (Itagi and Singh 2015; Bhat and Riar 2016; Shruti et al. 2016) have been reported based on laboratory scale drying experimental data. Therefore, little information are available on various industrial drying methods and their impact on rice qualities. Moreover, investigation on the effects of various drying temperature on the mechanical properties of Malaysia rice variety 'MR219' is not found in the literature. This rice variety found to be largely grown and dried in BERNAS others industrial paddy processing complexes in Malaysia. Thus, the aim of this work is to find the influences of industrial drying methods on selected mechanical properties such as bending strength, Young's modulus of elasticity and fracture energy and corresponding rice quality in terms of head rice yield, whiteness and milling recovery of MR219.

Materials and methods

Paddy drying methods

The drying methods applied in this study shown in drying layout Fig. 1. The details of the drying operations have been reported somewhere else (Sarker et al. 2013, 2014, 2015). Control paddy samples were dried using ambient air (26–32 °C at RH 60–75%, air velocity

0.05–1.5 m/s) while paddy was spread at 1–2 cm bed thickness on plastic mat under shed.

Sample collection for determining mechanical properties and qualities of rice

After completion of drying operation, five to seven kilograms of dried paddy were collected from different layers of the drying bed (i.e. top, middle and bottom) from FBD and IBD, and mixed to represent the uniform paddy sample of each drying method. Finally, about 500 g of each sample from different drying methods was collected in plastic bags and then stored in refrigerator at 5–7 °C for 3–4 weeks.

Determining mechanical properties of rice

The selected mechanical properties, namely, bending strength, apparent Young's modulus of elasticity and fracture energy of 100 individual sound rice kernels were determined by the three-point bending test described by previous investigators (Siebenmorgen and Qin 2005; ASAE 2009; Zhang et al. 2005; Tuyen et al. 2009; Talab et al. 2012) using a test device in the laboratory of Process and Food Engineering Department of Universiti Putra Malaysia. This test device was attached to the Universal Texture Analyzer (Stable Micro systems, TA.XT, UK).

Bending strength

Bending strength was determined using the following equation (ASAE 2009; Kamst et al. 1999).

$$\sigma = \frac{FLC}{4I} \quad (1)$$

where, σ is bending strength (Pa), F is peak bending force (N), L is distance between the two supports (m), C is distance from the neutral axis to the outer layer of the rice kernel (m) and it can be calculated by $C = D/2$. I is the moment of inertia (m^4) can be calculated as: $I = 0.049 B^3 D^3$. Where, B is the major diameter of the ellipse (width of the rice kernel) and D is the minor diameter of the ellipse (thickness of the rice kernel).

Apparent modulus of elasticity

The following equation was used to calculate apparent modulus of elasticity (ASAE 2009).

$$E = \frac{FL^3}{48I\delta} \quad (2)$$

where, E is apparent modulus of elasticity (Pa) and δ is deformation (m).

Fig. 1 (Drying layout) Drying methods with major process steps (A, B and C are the main drying methods followed in the plant site while No. 1 is control drying and No. 2–6 process lines were undertaken for the present study as practically found during observation)

Fracture energy

Fracture energy of sample was calculated by using the following equations (ASAE 2009).

$$G = \frac{\int F d\delta}{A} \quad (3)$$

where, G is fracture energy (J/m^2), $\int F d\delta$ is energy under the area of the force–deformation curve, which can be obtained by any software of integration capability, A is the area of fracture surface (m^2).

Rice milling quality evaluation

Two rice samples from each drying line were used for their quality determination. All the quality analysis were performed at Food Analysis Laboratory of UPM-BERNAS under Faculty of Food Science and Technology, Universiti Putra Malaysia. Each sample of 125 gm of dried and cleaned paddy was dehusked with a Testing Husker (THU-35A, Satake Engineering Co., Ltd. Japan) while the bran was removed with a Satake Testing Mill (TM 05C) running for 45 s for each amount of dehusked brown rice. Head rice was separated by the Satake Test Grain Grader (TRG 05B) using a 5.2-mm S-type identical cylinder. Whiteness was measured using a Satake whiteness tester with four replications, because, milled rice sample was taken twice from each sample of HRY determination. Percentage of milling recovery was calculated as the weight of total milled rice

including head rice and broken rice divided by weight of dried paddy sample multiplied by 100.

Statistical analysis

The statistical analysis was carried out by using single factor experiment in completely randomized design (CRD). The only factor was drying. Each drying method was replicated twice. The statistical software package SAS 9.2 version was used to calculate the mean values, standard error mean (SEM) and analysis of variance of obtained values on rice qualities such as head rice yield, whiteness and milling recovery and all mechanical properties. Meanwhile, Duncan's Multiple Range Test analysis was employed to determine the differences in rice qualities and mechanical properties among the drying methods at $P \leq 0.05$.

Results and discussions

Bending strength

The mean values of bending strength shown in Fig. 2 indicated the differences in bending strengths of rice kernel among the drying methods. The average bending strength was ranged from 28.6 to 31.8 MPa. Analysis of variance (ANOVA) revealed that the industrial drying methods were significantly (at $P \leq 0.05$) effective in

Fig. 2 Effect of industrial drying methods on bending strength. (IBD inclined bed dryer, LT lower temperature (35–39 °C); HT higher temperature (40–44 °C), FBD fluidized bed dryer, Cond. conditioner)

developing the bending strength of rice kernel. Talab et al. (2012) reported similar results during thin layer drying of paddy using temperature of 40–60 °C. They added that bending strength in kernel increased (35.7 MPa) with decreasing the grain moisture content (up to 10%). Even though there was no statistical significant difference in bending strength among two stage FBD followed by IBD and control drying but slightly higher magnitude of bending strength was achieved by the paddy as shown in drying layout Fig. 1.

These results were consistent with findings of Tuyen et al. (2009). These authors reported that the hardness and stiffness of sound fluidized bed dried rice kernels were higher than that of conventionally dried ones. Perhaps, higher temperature applied during FBD might contribute to develop mechanical strength inside the kernel through partial gelatinization of the starch on the surface of the kernels, thus, the milling quality was enhanced (Ti-rawanichakul et al. 2004). Similar observation was reported by Jaiboon et al. (2011) that the degree of gelatinization in rice increased with the increase in the drying temperature. The gelatinization of starch makes the surface become dense, and some of the surface cracks can become fused and disappear during this process. Table 1 indicates that comparatively lower final moisture of the slow (drying time is 16.5 h) dried rice might result in yielding higher HRY in the case of single stage drying that is reported detailed in somewhere else (Sarker et al. 2015). On the other hand, the use of higher drying air temperature (40–44 °C) in IBD-HT single stage method resulted in rapid drying by 11.5 h that caused higher moisture gradient

in grain bed, thus, fissure developed inside kernel. Consequently, reduced head rice yield was obtained.

Young's modulus of elasticity

The average value of apparent Young's modulus of elasticity of rice kernel from different drying methods was ranged from 204.5 to 222.4 MPa. This increased value of Young's modulus of elasticity did not vary significantly (at $P \leq 0.05$) with respect to the drying methods. These results are supported by the findings of Talab et al. (2012) while they dried paddy (MR219) using air temperature from 40 to 60 °C. Nonetheless, a significant enhancement in apparent modulus of elasticity was achieved by decreasing the grain moisture content during drying process at 60 °C (Zhang et al. 2005; Talab et al. 2012). It is clearly perceived that the effect of drying method (while paddy dried with higher and lower temperature) on apparent modulus of elasticity was not so prominent. Because, modulus of elasticity measures the load deformation behavior of a material. Thus, the results indicated that altered drying temperature of different industrial drying methods did not affect grain deformation due to load applied for breaking the grains while this effect was inconclusive.

Fracture energy

The effect of drying on fracture energy in rice kernel noticed significant ($P \leq 0.05$) differences with industrial drying methods compared to control drying. The mean value of fracture energy as function of drying methods are plotted in Fig. 3. Fracture energy of rice kernel during industrial drying was slightly higher than that dried by ambient air drying. However, fracture energy among the industrial drying methods did not vary significantly as viewed in Fig. 3 while all the drying methods got 'a' or 'ab' letters. Fracture energy is an indicator of grains tougher which indicates that the higher the fracture energy, the more difficult it is to break the material. From this point of view, it can be said that the heaped paddy dried with higher temperature of 40–44 °C in second stage drying by inclined bed dryer resulted in making the grains tough as shown by higher fracture energy up to 625 J/m² while the effect of fluidized bed drying temperature was positive toward the development of fracture energy inside rice kernel. Similar case also noticed to bending strength development inside the kernel, higher temperature applied during fluidized bed drying contributed to make kernel harder which is supported by the other investigation (Ti-rawanichakul et al. 2004; Tuyen et al. 2009). They stated that partial gelatinization of the starch on the surface of the

Table 1 Milling results obtained from different industrial drying methods

Drying method	Drying time (h)		Moisture content (%wb)		% Head rice yield	% Whiteness	% Milling recovery
	For first stage	For second stage	Initial	Final			
Control	16 in 2 days (single stage drying)		23.5	13.5	*56.89 ± 0.53 ^a	37.98 ± 0.51 ^a	70.18 ± 0.10 ^a
IBD-LT	16.5 (single stage drying)		23.5	13.6	53.47 ± 1.07 ^{ab}	38.36 ± 1.47 ^a	70.72 ± 0.29 ^a
IBD-HT	11.5 (single stage drying)		23.5	11.5	47.80 ± 0.33 ^c	37.95 ± 0.33 ^a	68.70 ± 1.66 ^a
FBD + Cond. + IBD-LT	1.92 min	14.4	23.5	12.9	51.76 ± 0.54 ^{bc}	40.15 ± 0.05 ^a	70.66 ± 0.06 ^a
FBD + Cond. + IBD-HT	1.92 min	12.5	23.5	13.3	49.88 ± 0.04 ^{bc}	39.28 ± 0.45 ^a	67.19 ± 0.13 ^a
			By first stage to 18–19	In second stage			
FBD + Cond. + Heap + IBD	1.92 min	7.5	23.5	12.1	48.01 ± 2.78 ^c	40.2 ± 0.10 ^a	68.96 ± 1.17 ^a
			By first stage to 18–19	In second stage			

IBD inclined bed dryer, LT low temperature (36–39 °C), HT high temperature (40–44 °C), FBD fluidized bed dryer, Cond. conditioner

* Mean values ± standard error mean (SEM)

^{a–d} The test values: same letters for the different quality attributes in each column mean that the values are not significantly different ($p > 0.05$)

Fig. 3 Effect of industrial drying methods on fracture energy (IBD inclined bed dryer, LT lower temperature (35–39 °C), HT higher temperature (40–44 °C), FBD fluidized bed dryer, Cond. conditioner)

kernels occurred during drying at higher temperatures thus fracture energy increased in dried rice kernels and the milling quality of rice was well maintained. Moreover, mechanical properties were found to be positively correlated with the head rice yield (Mohapatra and Bal 2012).

Conclusion

The mechanical properties of dried rice kernel determined from different drying methods provided an evident relation to produce quality rice in terms of head rice yield, whiteness and milling recovery. The highest values of bending strength and fracture energy were achieved by the grains dried at high temperature (115–120 °C) in FBD followed by heaping (for 10–20 h) and IBD. Thus, it made the grains slightly stronger and tougher, which was found positive toward the development of bending strength and fracture energy inside grains to improve rice qualities. On the other hand, inclined bed paddy drying at temperature above 40 °C resulted in lower bending strength in rice kernels which affected head rice yield. Finally, this work suggests either two stage paddy drying practices with FBD using temperature of 115–125 °C as first stage followed by IBD using temperature <40 °C at second stage or single stage IBD using temperature <40 °C for their industrial implementation.

Acknowledgements The authors acknowledge BERNAS, Malaysia, for the financial support, as well as for allowing to carry out the study at their paddy processing complexes. Our heartiest gratitude also goes to the Food Analysis Laboratory of UPM-BERNAS for facilitating the milling test.

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