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Correlation between head rice yield and specific mechanical property differences between dorsal side and ventral side of rice kernels

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ABSTRACT

Three-point bending tests on both ventral and dorsal sides of brown rice kernels were conducted to determine relationship between head rice yield and mechanical properties. Kernel breaking force on ventral side was lower than that on dorsal side. The same result was also revealed in the breaking strength and the elastics modulus. Frequency distribution of the kernel-to-kernel breaking force of ventral side was significantly different from that of the dorsal side. The breaking force difference between the ventral side and the dorsal side increased with increase in the average breaking force. It was found that rice milling quality index not only was related linearly with the breaking force on both the ventral and the dorsal sides, but also related to the breaking strength difference between the two sides. The head rice yield increased with the increase in the break force difference between the ventral side and the dorsal side.

1. Introduction

Rice is the most important crop in China, an annual yield of 200 million tons, which is 1/3 of national cereal crop production and alone supplies a half of the Chinese food demand. The main problem of rice production is the huge amount of loss from broken rice during the postharvest processes. Both the quality and market value of the broken rice are greatly reduced. Rice breakage is closely related to the rice fissure. The rice fissure may result from any one postharvest processing stage, which starts from the late maturing stage in the field, to the ensuing stages of rice harvesting, drying, storage and milling processes. Once fissure initiates in the rice kernel in each of these stages, this fissure will more likely grow in the next stage. And fissure will finally cause rice breakage in the milling process. An increased rice broken rate will lead to a reduced head rice yield. Thus rice producers regard head rice yield as one of their primary objectives, monitoring and controlling fissure initiation and growth is generally an important concern. A decrease in rice breakage means a decrease in loss. Therefore it is very important to propose a quickly and effectively evaluating way in which the rice mechanical properties can be related to rice breakage potentials.

It is found that mechanical property of rice kernel is related to rice milling quality. The average bending force to break rough rice was significantly related to head rice yield. But the head rice yield cannot be correctly quantified by average maximum compressive force to crush/break brown rice (Lu and Siebenmorgen, 1995). A strong linear relationship between head rice yield and the percentages of strong kernels of brown rice samples, defined as kernels that sustained a 20 N force in bending, was found (Siebenmorgen and Qin, 2005). The breaking strength and breaking energy of the fissured brown rice kernels decreased with longer drying duration (Zhang et al., 2005). The drying treatment and the post-drying durations also affected the breaking force distribution (Siebenmorgen et al., 2005). Tensile strength of rice kernel was found to be significantly lower than the compressive strength (Kamst et al., 1999, 2002; Bamrungwong et al., 1988).

Fissure tended to initiate on the ventral side of rice when it was under absorption or desorption condition, and the initiated fissure would grow from ventral side to dorsal side (Jia et al., 2002a; Satoshi et al., 1992; Xiao and Ma, 2007). Thus fissure growing greatly reduces the breaking strength of fissured rice. The researches have verified that the fissure initiation is concerned with the tensile strength of rice grain. When the tensile stress exceeds the tensile strength, fissure (crack) is caused in the rice kernels (Kunze and Choudhury, 1972; Sarker and Kunze, 1996; Lan and Kunze, 1996). But the tensile strength in the rice could not been measured, “The stress pattern in a rice kernel during drying is a very complex, physically unobservable phenomenon. It is currently impossible to directly determine the internal stress distribution in individual kernels caused by temperature and moisture content changes (Jia et al., 2002a).” Many researchers have used the finite element

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simulation method to research the stress distribution in the individual kernel (Sarker and Kunze, 1996; Lan and Kunze, 1996; Jia et al., 2002a,b). In spite of these findings, our understanding on the mechanism of the fissure initiation and growth processes is still very limited.

It has been verified that there always exists the texture and microstructure difference between the dorsal side and the ventral side (Li and Ding, 2010; Tamaki et al., 2007). The phenomenon of fissure (crack) initiation and growth also appeared on the ventral side of rice kernels. So we hypothesize that the structural strength of the ventral side is possibly lower than that of the dorsal side. The milling quality could be predicted by mechanical properties. Also the reason for fissure always initiation and growth from the ventral side of rice kernel can be easily understood. So we should pay more attention to avoiding reducing the mechanical properties on the ventral side at setting the drying and processing conditions. It is therefore necessary to investigate if the fissure initiation on the ventral side is related to the strength difference between the dorsal side and the ventral side of rice kernel, and if this difference also affects the milling quality.

2. Materials and methods

2.1. Experimental materials

Eight rice cultivars, Ningjing-3, Wuyujing-23, Huaidao-9, Yanjingdao, Wuyujing-3, Wuyongjing-7 and Ningjingdao were harvested in 2008 and 2009 from Haifeng State Farm, Jiangsu Province Yancheng City, Zhendao-8 was harvested in 2008 from Jiangpu farm of Nanjing Agricultural University. The harvested rice samples were immediately transported to laboratory, cleaned, dried in shade and stored at temperature of 4 °C for five months. Rice samples with uniform moisture content were obtained.

Moisture content of each dried rice samples was measured by drying three 10 g samples for 24 h in an oven preset at 130 °C before rice samples were used for the mechanical property measurement by a three-point bending test (Jindal and Siebenmorgen, 1987). All moisture contents are expressed on a wet basis unless otherwise noted.

2.2. Three-point bending testing methods

Three-point bending tests have been employed by many researchers to study the mechanical properties of rice kernels (Lu and Siebenmorgen, 1995; Nguyen and Kunze, 1984; Siebenmorgen and Qin, 2005). One of the most used critical parameters associated with three-point bending tests was peak breaking force. Three-point bending tests were conducted using a texture analyzer (TMS-PRO, Food Technology Corporation, USA), with a three-point bending test device, as shown in Fig. 1a. The distance between two supporting points was set at 3.4 mm for all the three-point bending tests. In order to test the breaking force of brown rice kernel on both the dorsal and the ventral sides, supporting point was cut into a shape of V-slot, so that brown rice kernel could be loaded steadily on the dorsal or the ventral sides, just as it was presented at right side of Fig. 1a. The deformation rate was set at 30 mm/min. The loading head had a flat end with a thickness of 1.2 mm and a length of 10 mm. The three-point breaking force of brown rice kernels was tested after paddy was manually dehulled. The dorsal side and the ventral side of brown rice are presented in Fig. 1b. In the experiments, 200 sound brown rice kernels were randomly picked for mechanical property measurement by loading on the dorsal side. Another 200 sound brown rice kernels were randomly picked for mechanical property measurement by loading on the ventral side. When kernels were loaded on the ventral side, the tested three-point breaking force was taken as the ventral side breaking force. When kernels were loaded on the dorsal side, the tested three-point breaking force was taken as the dorsal side breaking force.

2.3. Testing rice dimensions

In order to calculate mechanical properties of brown rice kernel, width and thickness of 50 brown rice kernels of each cultivar were measured using a dial micrometer. The arithmetic mean of width and thickness of 50 brown rice kernels were taken as rice kernel width and thickness, respectively.

2.4. Milling tests

Four 50 g subsamples from each cultivar were milled to determine brown rice yield, head rice yield and broken rice yield. The head rice yield and broken rice yield were tested according to National Standards of China GB/T21719-2008 (Chinese standard GB/T21719, 2008) and GB/T5503-2009 (Chinese standard GB/T5503, 2009). Each sample was dehulled using JLMJ dehulling and milling machine (Jiading Grains and Oils Inspection Instrumental Factory, Shanghai, China) and milled for 3 min using the same machine. Head rice was separated from broken rice kernels using a sieve.

2.5. Mechanical properties

From a breaking force–deformation curve measured during a three-point bending test, the peak breaking force (loading force at the break point where loading force significantly dropped), deformation at breakage, breaking strength (also known as flexural strength), apparent modulus of elasticity, and fracture energy were obtained. Those variables were used to calculate the mechanical

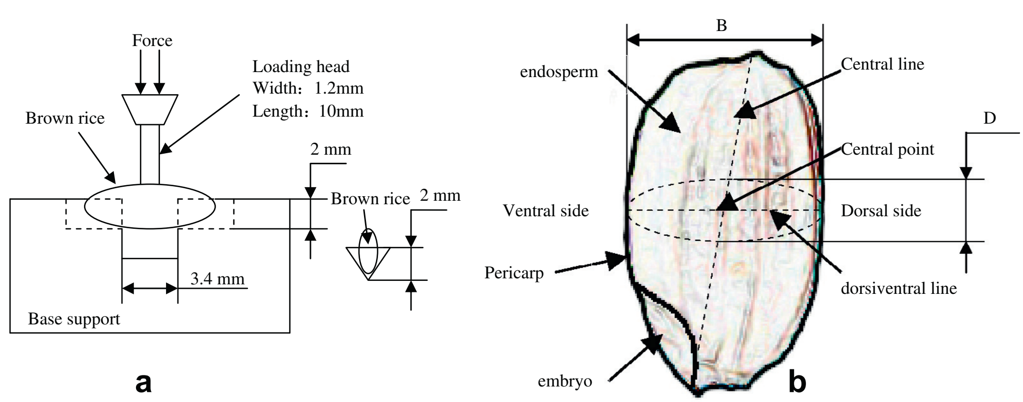

Fig. 1. Experimental test device for a brown rice under three-point bending (a) and ventral and dorsal side of brown rice kernel (b).