Inter-relationships Amongst Grain Characteristics, Grain-Filling Parameters and Rice (Oryza sativa L.) Milling Quality

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With 2 figures and 2 tables

Abstract

Resistance to breakage is a desirable trait of the rice kernel. Many factors, such as the genetics of the cultivar, the plant growth environment and the conditions of the milling process, will affect kernel breakage. Although many papers have discussed the factors that may affect and improve rice milling quality, few have related the grain-filling process to head rice, the unbroken polished kernels obtained after milling. The objectives of this paper were: (i) to characterize the interrelationships amongst grain filling and grain structural characteristics; (ii) to determine whether the grain-filling process and grain characteristics affect head rice, and (iii) to suggest a pathway through which grain characteristics can influence head rice recovery. An analysis of the interrelationships amongst all grain characteristics suggested that variables of grain structure (size, volume and per cent hull) have a decisive influence on the grain-filling process (rate and duration of grain filling). The grain-filling process will affect final grain traits such as weight and density, which in turn will have a direct impact on head rice. In addition, non-uniformity, whether expressed in terms of variable grain size and shape or grain filling and maturity, has a detrimental effect on rice milling quality. The implication of these findings is that rice breeders need to pay more attention to selecting plant types that have a high degree of uniformity of grain characteristics on the panicle, and to those traits (such as greater grain size, weight and density) that have a positive impact on yield and milling quality.

Key words: grain characteristics — grain filling — head rice — non-uniformity — rice milling quality

Introduction

The utilization of rice (Oryza sativa L.) as a food involves the milling of rough rice or paddy to remove the hull and bran. Milled products include whole kernel rice (head rice) and partial kernels (broken rice). Head rice is grain that remains intact, completely or at least in 3/4 of the whole grain, after the milling process (Simpson et al. 1965). Milling quality is determined by the quantity of total milled rice and the percentage head rice that can be produced from a unit of rough rice. Head rice is a major determinant of price in the paddy markets of many countries, including the United States (Brorsen et al. 1984). Therefore, the value of rough rice is directly related to its milling quality and the prevailing market demands. Improvement in head rice yield is essential to meet consumer demand and to increase grower profitability.

Many studies have been conducted to investigate factors affecting head rice recovery. Matthews et al. (1970) and Jongkaewwattana et al. (1993) noted that medium-grain rice was more resistant to cracking than long-grain rice during milling, probably due to its more rounded and thicker grain shape of comparable length. Field practices such as plant density, and nitrogen and water management have also been found to be important to rice milling quality (Jongkaewwattana and Geng 1991, Perez et al. 1996, Gravois and Helms 1996). Goodman and Rao (1985) reported that head rice recovery was associated with hardness of the endosperm. Webb et al. (1986) reported that correlations between hardness and rice grain quality parameters showed some associations but were generally either low or insignificant. The degree of chalkiness, which varied greatly amongst cultivars and was higher in grain with a thicker shape than in slender-shaped grain of comparable length, was found to
be negatively related to rice milling quality (Nakatat and Jackson 1973, Somrith 1974). High-density grain was also reported to have higher head rice recovery than low-density grain (Venkateswarlu et al. 1986). Rice milling quality was also reported to be influenced by post-harvest factors such as drying temperature (Warnock and Wright 1983, Chen et al. 1999, Abud-Archila et al. 2000), rice processing (parboiling) (De Datta 1981) and the milling process (Esmay et al. 1979, Sahay et al. 1980, Reid et al. 1998).

Geng et al. (1984) reported that head rice recovery decreased after the replacement of intermediate and late maturity cultivars by very early and early cultivars in California. Hence, it seemed that differences in head rice recovery amongst cultivars were associated with cultivar maturity.

Environmental factors (Kunze 1979, Warnock and Wright 1983, Kunze et al. 1988, Counce et al. 1990, Lu et al. 1992) and physical and chemical properties of the kernel (Khush et al. 1979, Bhashyam et al. 1984, Goodman and Rao 1985, Webb et al. 1986, Ried et al. 1998, Fan et al. 2000) have all been reported to influence head rice recovery. Few investigators (Jongkaewwattana et al. 1993), however, have related the grain-filling process to head rice recovery or suggested a mechanism through which head rice recovery is influenced by plant growth and developmental characteristics. An understanding of the interrelationships between plant characteristics and milling quality is essential to improve the head rice yield by means of breeding.

The objectives of this study were: (i) to characterize the interrelationships amongst grain filling and grain structural characteristics; (ii) to determine whether the grain-filling process and grain morphological traits affect head rice recovery, and (iii) to suggest a conceptual pathway through which grain characteristics may influence head rice recovery.

Materials and Methods

Field experiment

Field experiments were conducted at the Rice Experiment Station, Butte County (39° 26' N, 121° 49' W) and Colusa County (39° 9' N, 122° 9' W), California, during the 1984 and 1985 growing seasons, and at Rice Research Facility, University of California, Davis (38° N, 121° W) during the 1985 growing season. Six rice cultivars representing four maturity groups and three grain types (M101, a very early maturing medium grain; S201, an early maturing short grain; M201, an early maturing medium grain; L202, an early maturing long grain; M302, an intermediate maturing medium grain, and M7, a late maturing medium grain) were randomly assigned to a complete block design with four replications (Jongkaewwattana and Geng 1991).

Sampling procedures

Grain filling

Ten panicles were randomly collected from each plot every 3–4 days after 100 % heading until maturity. The panicle samples were oven-dried, weighed and divided into three parts (upper, middle and lower). One hundred grains from each part were randomly taken from the panicle samples and weighed.

A second-order logistic equation was used to fit the grain-filling data of each of the three panicle part samples for each cultivar. The duration of grain filling (DGF), the maximum rate of grain filling (MRGF) and the maximum grain weight (MGW) were all estimated from the model coefficients. The mean filling rate (MFR) was obtained by dividing the maximum grain weight by the duration of grain filling.

Grain characteristics

Ten panicle samples were taken at maturity from each plot. Each panicle was then separated into three parts as described above. Grains from each part were dehulled using the McGill sample sheller (South Exposure Seed Exchange, Suwanee, GA, USA). Ten dehulled grains (brown rice) were randomly sampled for measurement of length, width and thickness using a Vernier caliper (VMR International, VWR International, Suwanee, GA, USA). The volume of an ellipsoid [(4/3)π length × width × thickness] was used to approximate grain volume. Grain density was estimated by dividing grain weight by grain volume. Grain shape was derived by the ratio of length to width.

Milling quality

Panicle samples of 1 m² were taken at maturity from each plot. A 125-g sample of rough rice was taken from each of the upper, middle and lower parts of the panicle. Rough rice samples were dehulled in a McGill sample sheller. Brown rice samples were weighed and the percentage of the hull was calculated. Brown rice samples were subsequently milled in a McGill no. 2 miller for 40 s for short- and medium-grain rice (M101, M201, S201, M302 and M7), and 45 s for long-grain rice (L202). Milled rice samples were weighed before being separated into head and broken rice. Weights of head rice samples were obtained and the percentages of head rice recovery and total milled rice were subsequently calculated.

The range values of measurements made on samples of the three panicle parts were calculated for each of the measured grain characteristics and the grain-filling variables to represent the non-uniformity of the grain characteristics and grain-filling variables.
Results and Discussion

Significant (P < 0.05) correlation coefficients amongst grain characteristics, grain-filling parameters and milling qualities are presented in Table 1. Total milled rice is the sum of whole kernel and broken rice after milling. Thus, as expected, total milled rice is highly correlated with the percentage of head rice (Table 1). Both total milled rice and percentage head rice are significantly correlated with the volume and density of the grain and maximum grain weight (MGW) but negatively correlated with percentage hull. The percentage hull is positively correlated with grain shape and negatively correlated with grain volume and MGW. The positive correlation between grain shape and percentage hull and the negative correlation between grain shape and volume are the result of long grains being generally smaller in volume but having a greater proportion of hull than medium and short grains. Since the percentage of hull is negatively correlated with milling quality, this explains why long-grain rice tends to have lower head rice recovery – its slender-shaped grain and the higher percentage of hull would be more difficult to mill than the other grain types (Jongkaewwattana et al. 1993).

Grain-filling parameters, the maximum rate of grain filling (MRGF) and the duration of grain filling (DGF), were not significantly correlated with milling quality (total milled and head rice) but significantly correlated with MGW and grain density, which are significantly correlated with milling quality. These results indicated that grain filling did not directly affect milling quality but affected it indirectly through an influence on grain characteristics that can be measured at harvesting time; such characteristics as weight and density have a direct influence on milling quality. MRGF is negatively correlated with DGF and is positively correlated with grain density and volume. These correlations imply that the size of a grain will influence the rate of grain filling which in turn determines the duration of grain filling. Jones et al. (1979), Sasahara et al. (1982) and Fujita et al. (1984) reported similar results. Gardner et al. (1985) offered the explanation that a greater sink size could create a greater pulling force for translocating the assimilate from the source.

Based on the sequence of occurrence of the grain developmental events and the observed significant correlations among the grain growth and morphological traits, a conceptual model of the pathway
through which various grain characteristics affect head rice can be constructed (Fig. 1). This model illustrates the way in which grain structural variables (shape, size and percentage hull) affect grain growth variables (rates and duration of grain filling), which in turn influence final grain characteristics (weight, volume and density). Together, the structural variables and final grain characteristics determine the potential milling qualities (total milled and head rice) of the rice plant.

In this study, grain samples were taken from the upper, middle and lower parts of the panicle. The range values that were calculated from these samples provided a measure of non-uniformity of the grain characteristics. The coefficients of correlation analysis of these range values and the percentage head rice are shown in Table 2, from which two main results are clear: first, all significant associations between the non-uniformity variables (of grain shape, volume, density and MGW) and percentage head rice are negative, and, secondly, all significant correlations amongst the non-uniformity range values are positive. These results imply that the less uniform the grain, the lower will be the milling quality, and that the non-uniformity of one grain characteristic will perpetuate the non-uniformity of the other grain characteristics through the growth process of the grain. Thus variability in grain shape and size on the panicle contributes to variation in the rate of grain filling, which causes variation in the duration of grain filling. Similarly, a non-uniform grain-filling process will produce great variation in weight and density amongst grains on the panicle which will

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**Table 2: Significant correlation (P < 0.05) coefficients among non-uniformity measures of grain-filling parameters, grain characteristics, total milled rice and head rice recovery**

<table>
<thead>
<tr>
<th>Non-uniformity</th>
<th>Head rice (%)</th>
<th>Total milled rice (%)</th>
<th>Hull (%)</th>
<th>Shape</th>
<th>Volume (mm⁻³)</th>
<th>Density (mg mm⁻³)</th>
<th>MRGF [mg (100 grains)⁻¹ day⁻¹]</th>
<th>DGF (Days)</th>
<th>MGW [g (100 grains)⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head rice (%)</td>
<td>-0.38</td>
<td>1.00</td>
<td>-0.50</td>
<td>-0.36</td>
<td>-0.55</td>
<td>-0.21</td>
<td>-0.34</td>
<td>-0.24</td>
<td>1.00</td>
</tr>
<tr>
<td>Total milled rice (%)</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Hull (%)</td>
<td>-0.50</td>
<td>1.00</td>
<td>-0.55</td>
<td>-0.36</td>
<td>-0.34</td>
<td>-0.34</td>
<td>-0.34</td>
<td>0.79</td>
<td>0.34</td>
</tr>
<tr>
<td>Shape</td>
<td>-0.36</td>
<td>1.00</td>
<td>-0.34</td>
<td>-0.55</td>
<td>-0.21</td>
<td>-0.21</td>
<td>-0.21</td>
<td>1.00</td>
<td>0.38</td>
</tr>
<tr>
<td>Volume (mm⁻³)</td>
<td>-0.55</td>
<td>-0.36</td>
<td>1.00</td>
<td>0.34</td>
<td>0.21</td>
<td>0.24</td>
<td>0.24</td>
<td>1.00</td>
<td>0.34</td>
</tr>
<tr>
<td>Density (mg mm⁻³)</td>
<td>-0.34</td>
<td>-0.34</td>
<td>-0.34</td>
<td>1.00</td>
<td>0.38</td>
<td>0.38</td>
<td>0.38</td>
<td>1.00</td>
<td>0.38</td>
</tr>
<tr>
<td>MRGF [mg (100 grains)⁻¹ day⁻¹]</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>DGF (Days)</td>
<td>-0.24</td>
<td>1.00</td>
<td>-0.24</td>
<td>0.79</td>
<td>0.34</td>
<td>0.38</td>
<td>0.38</td>
<td>1.00</td>
<td>0.34</td>
</tr>
<tr>
<td>MGW [g (100 grains)⁻¹]</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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**Fig. 1:** Relationships between grain-filling parameters, grain characteristics and milling yield. The solid lines represent positive correlations and the dashed lines represent negative correlations.
then have a major negative impact on the milling quality of head rice recovery. The concept of the impact of non-uniformity on percentage head rice is illustrated in Fig. 2.

**Conclusion**

Head rice recovery is influenced by such factors as the genetics of the cultivar, the environmental conditions under which the plant is grown and harvested, and the mechanical process of milling. Most reported research on rice milling quality has focused on the conditions of harvest (Perez et al. 1996, Gravois and Helms 1996) and milling processes (Lu et al. 1992, Reid et al. 1998, Chen et al. 1999, Fan et al. 2000, Imoudu and Olufayo 2000). In this study we have collected data to show that plant type, grain-filling process, and grain characteristics are intricately interrelated and have a clear effect on the potential milling quality of rice. Furthermore, a common perception that non-uniformity of the grain characteristics on a panicle may affect the percentage of recoverable head rice is validated statistically in this study.

Variability in grain structure (size, volume and percentage of hull) has a decisive influence on the grain-filling process (rate and duration of grain filling). The grain-filling process will affect final grain traits such as weight and density which in turn will have a direct impact on head rice. This chain of developmental events affects the quality of head rice, but represents only part of the impact of grain filling and other grain characteristics on milling quality. The impact of this series of developmental events on head rice is termed the ‘directional effect’ in this paper.

Uniformity of grain structural and filling characteristics on a panicle also has a major impact on potential head rice recovery. Non-uniformity, whether in terms of grain size and shape or grain filling and maturity, has a detrimental effect on rice milling quality. Thus there are two distinguishable and identifiable ways in which grain characteristics affect milling quality. One is the directional effect (which has a positive impact), and the other is the degree of non-uniformity (which has a negative impact).

In addition, Jongkaewwattana et al. (1993) showed that the uniformity of grain characteristics on a panicle is closely associated with a plant type index expressed as the ratio of panicle length to the phytomass. The smaller the ratio, the more uniform the grains will be on a panicle. These findings suggest that breeders should pay attention to plant types whose grains on the panicle are highly uniform. A selection of the desired plant type and those beneficial grain traits (such as greater seed size, weight and density) will increase yield as well as the potential milling quality.

**Zusammenfassung**

Beziehungen zwischen Korneigenschaften, Kornfüllungsparametern und Reis (*Oryza sativa* L.)-Vermahlungsqualität


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References


