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Parameters and QTLs for Milling Quality in Rice : A Review

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ABSTRACT

Rice (Oryza sativaL.) is the most important staple food in the world, providing more than 21% of the calorific needs of the world population. Rice varieties can be grouped into several quality classes based on consumer preferences. These quality classes are based on physical properties (head rice recovery, chalkiness, grain size and shape, and grain color) and starch quality influencing cooking and organoleptic properties. Milling quality determines the final yield and the broken kernel rate of the milled rice, which is of concern for consumers and farmers. Three main parameters, brown rice recovery (the percentage of brown rice to rough rice), milled rice recovery (the percentage of milled rice to rough rice), and head rice recovery (the percentage of head rice to rough rice) are used to evaluate the quality and efficiency of the milling process. Milling quality, which is one kind of complex quantitative trait whose genetic control is poorly understood. However, many studies have been carried out to search quantitative trait locus (QTL) for the milling quality. Breeding for improved grain quality is a major objective of rice breeding worldwide. Identification of genes/QTL controlling quality traits is the prerequisite for increasing breeding efficiency through marker-assisted selection.

Keywords: Rice, Milling quality, Physical Properties, quantitative trait locus (QTL)

I. INTRODUCTION

Rice, the staple food crop of about three billion people, is nutritionally superior to many carbohydrate rich foods and contributes 40–80 % of calories and 40 % of the protein in the Asian Diet. The whole polished rice kernel is primarily consumed after the removal of the hull and bran layers through milling and polishing (Patnaik et al., 2015). Rice (Oryza sativaL.) belongs to the family Poaceaeand tribe Oryzeae.It has two cultivated species and 22 wild species and possesses huge diversity for grain quality traits. Market survey data suggest that efforts to develop varieties with improved cooking and eating quality have high economic returns (Son et al., 2014). Rice varieties can be grouped into several quality classes based on consumer preferences (Calingacion et al., 2014). These quality classes are based on physical properties (head rice recovery, chalkiness, grain size and shape, and grain color) and starch quality influencing cooking and organoleptic properties (Champagne et al., 2010, 2004b; Fitzgerald et al., 2009b; Foegeding & Davis, 2011; Juliano, 1979, 2001; Juliano & Villareal, 1993; Pandey et al., 2012; Siebenmorgen et al., 2013; Sreenivasulu et al., 2015). In addition, after the relative success of the Green Revolution, food security has consistently been challenged by (i) population growth, (ii) urbanisation, and (iii) climate change. It is therefore now essential, not only to grow more high quality rice per hectare, but also to equip these varieties with tolerance to environmental stresses (Brar & Khush, 2013). To this end, significant investment has been made in many countries to improve yield and stress tolerance, while retaining quality (Singh et al., 2000; Inthapanya et al., 2006; Mackill et al., 2006; Tomita, 2009; Boualaphanh et al., 2011). The current tools of quality evaluation are not sophisticated enough to define the quality each market requires, let alone enable selection for it. Rice (Oryza sativaL.), a staple cereal crop, feeds more than half of the world's population. Improvement of rice yield and grain quality is the major objective of rice breeding worldwide. Grain quality primarily includes grain appearance, milling, eating and cooking and nutrition (Unnevehr et al., 1992). Milling quality is measured by brown rice rate (BRR), milled rice rate (MRR) and HMRR. Brown rice is the de-hulled rice with the palea and lemma removed that can be used for cooking and eating. Milled rice is the result of brown rice after removing all of the bran, which consists of aleurone and pericarp, and germ or embryo. Head milled rice is kernel longer than or equal to 3/4 full length of a kernel. Among the above-mentioned three milling quality parameters, HMRR is the most important and greatly affects market value. HMRR depends on varietal characteristics, production factors, and harvesting, drying and milling processes. Most of the rice quality determining traits are quantitatively inherited, controlled by multiple genes/QTL(Tan et al., 2000), and affected by growing environment(Zhao et al., 2015). The evaluation criteria for milling quality mainly include brown rice percentage, milled rice percentage, and head rice percentage, which reflect the proportion of whole kernels (head rice or head milled rice) and broken kernels produced during milling of rough rice (Lisle et al., 200).

A. Brown Rice

Rice is the most commonly consumed in the form of milled rice because of its softness and easy digestion. Brown rice is nutritionally superior to milled rice in terms of protein, dietary fiber, vitamin B, minerals, and even functional antioxidants which are mostly existed in external parts like hull and bran (Juliano, 2010); however, those nutrients are easily removed during the milling process. With increasing health concerns, the health promoting functions of brown rice have received the attention of consumers, and the demand for brown rice consumption has increased greatly. The bran in brown rice, however, restricts water diffusion during cooking, resulting in a harder texture and lower palatability than milled rice (Piggot et al., 1991).

B. Quality controlling of brown rice by ultrasound treatment

Soaking is the simplest method for softening the texture of brown rice. Longer soaking times shorten the cooking time of brown rice; however, microbial contamination can occur during long soaking time. To shorten soaking time, warm water soaking is needed, and the higher the soaking temperature, the faster the rate of moisture absorption (Han & Lim, 2009). Ultrasound treatment has merits such as short processing time, high reproducibility, and lower energy consumption, so the treatment has been applied to several foods processing such as extraction, emulsification, homogenization, crystallization, filtration, separation, viscosity alteration, defoaming, and extrusion (Jambrak et al., 2010; Knorr et al., 2004; McClements, 1995). The ultrasonic process has also been used with starches and other polysaccharides as an efficient processing method for solubilization, modification, and purification (Czechowska-Biskup et al., 2005; Iida et al., 2008). Ultrasound treatment can affect the physico-chemical properties of starch in different ways depending on operation time, temperature, power, frequency, and the differences in the botanical origin (Czechowska-Biskup et al., 2005; Iida et al., 2008).

C. Rice Milling

Rice milling typically involves harvesting, rying, milling and packaging. During milling, dried paddy undergoes de-husking, bran removal and whitening stages. In the de-husking stage, paddy is first fed into a sheller to remove its outer layer, i.e. the rice husk. The husks are separated from the brown rice (rough rice without husk) by aspiration. The brown rice is then conveyed to the whitening process to remove the rice bran. In general, the whitening process can be divided into two categories: the abrasive, and the friction type. The abrasive type functions by channelling rice through a moving rough surface and a stationary screen. In contrast, the friction type operates by contacting one kernel against another under slight pressure (Afzalinia et al., 2002). In the final stage, the milled rice is separated into the whole kernel and the broken kernel by its length by means of grading sieves. The length of the whole kernel is 75% or more of the full kernel. The remaining kernels are termed as broken rice (Webb, 1991). Two important indices of the milling process are the degree of milling and the head rice yield. The degree of milling refers to the extent in which the bran layers have been removed from rice during milling. The degree of milling affects the rice cooking time and texture (stickiness) as well as the properties of cooked rice (e.g. the starch content, the lipid as well as protein levels) (Lyon et al., 1999).

D. Head Rice

The head parboiled rice yield (HY%) was calculated as percentage of whole milled grains with respect to the rough rice. As the cooking quality of broken rice is very poor, the market price with broken grains is much less than that for whole grains (Li et al., 1999). The ultimate goal of the rice industry is to achieve maximum head rice yield (HRY) from the milling process. HRY is the current standard to assess commercial rice milling quality. The average head rice yield (HRY) was low with 43.5 % from IRRI's breeding programs, and therefore this trait should be improved further as the prime target of future breeding by minimizing the broken grains during milling. Interestingly, in breeding material, the mean chalkiness value was 13.9 %. Those lines with less than 10 % chalkiness have 45.5 % HRY. These observations made from a large collection of data contradict the existing notion that area of chalkiness substantially increases breakage during milling and thus decreases HRY (Lisle et al., 2000).

E. Effects of drying conditions on head rice yield

The method of drying is the kingpin of the parboiling process so far as the milling quality of rice is concerned (Bhattacharya et al., 1967). Several methods have been used for drying parboiled rice, among are sun or shade drying, hot air drying, vacuum drying, rotary dryers, etc. (Bhattacharya, 1985). Drying of parboiled rough rice is essentially a batch process; this is so because the removal of large amount of moisture, from 55% to 12%, dry basis, requires multiple-stage drying with intermediate tempering periods. Bhattacharya et al. (1971) found that twostage drying considerably reduces breakage during milling. Tempering treatment was designed to provide moisture equilibration for rice samples. Bhattacharya and Indudhara Swamy (1967) have studied the effect of tempering time at room temperature on grain breakage when the rice was dried in two-stage drying at 60°C. Several authors have recommended drying the rough rice as fast as one wishes to 16±18% moisture and then to temper it for 4±8 h (Bhattacharya, 1985).

F. QTLs for Brown rice recovery

A total of 20 QTLs have been identified in eight studies, covering all chromosomes except chromosome 2. A major QTL at the interval between markers RM42 and C734b on chromosome 5 is also responsible for grain width (Tan et al. 2001). A QTL on chromosome 3 likely shares the same genomic region for grain length (Lou et al., 2009). These results indicate that brown rice rate relates to the grain shape and size of rice kernel. Five QTLs were detected in the study of Li et al. (2004a), of which three were expressed in two years, indicating that there are QTL-by-environment interactions effects.

G. QTLs for Milled rice recovery

A total of 19 QTLs have been identified in seven studies, covering all chromosomes except chromosome 8. There are no strong or reproducible QTLs for the milled rice recovery. Three independent studies detected QTL for the milled rice recovery on chromosome 5 (Tan et al., 2001; Aluko et al., 2004; Zheng et al., 2007), but there are actually not at the same region. Li et al. (2004a) reported that two of four QTLs were detected in two years, indicating that the QTL-by-environment interactions effects exist.

H. QTLs for Head rice recovery

Up to date, a total of 34 QTLs locating at all the chromosomes have been reported in ten studies with the number of QTLs varied from 1 to 7 in different studies. A major QTL located on chromosome 3 is also a major QTL for grain length (Tan et al., 2001), suggesting that genetic relationship exists between grain size or shape and the percentage of head rice. Other studies frequently identified the QTL at chromosome 3 (Li et al., 2004a; Dong et al., 2004; Aluko et al., 2004; Jiang et al., 2005; Lou et al., 2009), proving that there might be a major gene for head rice. In addition, QTLs on chromosome 1, 5 and 6 are also detected by at least three independent studies. Li et al. (2004) detected three QTLs for head rice, but all of the m were detected only in a specific year, suggesting that the head rice is largely affected by the environment. However, Nelson et al. (2011) showed that more variance of head rice yield was explained by main-effect QTL than QTL × environment effect in the Cypress/RT0034 RIL population, whereas the main effect QTLs contribute a little less to genetic variation than those of QTL × environment effect in the Cypress/ LaGrue RIL population. There is a clear coincidence of QTLs for head rice recovery with early-heading QTLs in the hotter growing location, hinting an environmental effect (Nelson et al. 2011). Note that some genetic populations were derived from cultivated rice and wild rice (Septiningsih et al., 2003; Aluko et al., 2004), but all milling-yield-increasing effects came from the cultivated parent.

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