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Seasonal variation in grain yield and quality in different rice varieties

Suwannee Laenoi[a], Benjavan Rerkasem[b], Sittichai Lordkaew[c], Chanakan Prom-u-thai[a,d,*]

[a] Agronomy Division, Department of Plant and Soil Sciences, Faculty of Agriculture, Chiang Mai University, Chiang Mai 50200, Thailand, Thailand
[b] Plant Genetic Resources and Nutrition Laboratory, Chiang Mai University, Chiang Mai 50200, Thailand
[c] Center for Agricultural Resource Systems Research, Faculty of Agriculture, Chiang Mai University, 50200, Thailand
[d] Lanna Rice Research Center, Chiang Mai University, Chiang Mai 50200, Thailand

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ABSTRACT

Rice grain quality and yield, which are adversely affected by suboptimum condition in the climatic environment, are expected to be affected more severely under climate change. Adaptation to climate variation therefore requires stability in grain quality as well as yield. Grain yield and quality of four modern rice varieties were shown to respond differently to the climatic condition of the wet, cool and hot season at Chiang Mai, Thailand. The variation in grain yield was associated with differential effects of season on grain filling in different varieties. A simple dilution effect on nutritional quality was indicated by inverse relation between grain yield and the concentration of nitrogen, phosphorus, iron and zinc in the endosperm, i.e. the white rice normally consumed by rice eaters. The rice varieties also showed differential response to season in their head rice yield, grain chalkiness and gelatinization temperature, independently of the grain yield. The relationship between head rice yield and grain chalkiness was not significant, although some complex physico-chemistry of the starch was suggested by the correlation between grain chalkiness and gelatinization temperature. The effects of variety and season found here suggested that evaluation of rice genotypes for adaptation to climate change will need to consider grain quality along with grain yield.

1. Introduction

In monsoonal Asia rice is generally grown in the wet season and in the dry season in irrigated area, which covers more than half of the rice land in the continent (GRiSP, 2013). The rice crop in each location is therefore subjected to different sets of environmental condition in the different cropping seasons, the difference that can be expected to be amplified with climate change. Seasonal effects on rice yield in the tropics are well established. For example, wet season yield is likely to be lower than dry season yield when the solar radiation reaching the canopy is limited by the clouds (Yoshida, 1981). Extreme temperature during the hot dry summer is also detrimental to grain yield through adverse effects on pollination and fertilization (Matsui et al., 2000, 2001; Nakagawa et al., 2002), with significant variation in the sensitivity among rice varieties (Satake and Yoshida, 1978; Jongjaidee et al., 2010).

Rice grain quality is determined by genetic control and environmental conditions during the growing season. Global warming and climate change pose a threat to rice yield, but the adverse effects on grain quality would also depress economic value of the harvest. Temperature is one of the factors affecting rice yield and quality. It has been reported that within a certain range nighttime temperature has more pronounced negative effects on rice than daytime temperature (Peng et al., 2004). High nighttime temperature during kernel development caused spikelet infertility (Jagadish et al., 2007; Matsui et al., 1997; Mohammed and Tarpley, 2009, 2010), lower grain weight and yield (Peng et al., 2004), greater proportion of chalky grain (Cooper et al., 2008; Ishimaru et al., 2009; Tashiro and Wardlaw, 1991; Tsukaguchi and Iida, 2008), lower head rice yield (Ambardekar et al., 2011; Cooper et al., 2008; Counce et al., 2005), and also affected grain physicochemical attributes by lowering amylose content (Cooper et al., 2008). Low temperature extended grain maturity period and ultimately resulting in higher thousand grain weight (Funaba et al., 2006).

However, the available information on the environment and grain quality has focused mostly on japonica rice of the temperate region and much less on indica rice, the main type of rice in the tropics. Furthermore, grain quality in rice is defined by many different characteristics (Juliano, 1993). Some of these are translated directly to price, e.g. head rice yield, aroma, and the physical appearance of the milled rice such as grain translucency and vitreousness (e.g. Leesawatwong et al., 2003), with some characteristics such as grain chalkiness being more critical in certain markets (Sriswasdilek et al.,

* Corresponding author at: Agronomy Division, Department of Plant and Soil Sciences, Faculty of Agriculture, Chiang Mai University, Chiang Mai, 50200, Thailand.
E-mail addresses: chanakan15@hotmail.com, chanakan.p@cmu.ac.th (C. Prom-u-thai).

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1992; Efferson, 1985). The grain nutrient content, on the other hand, has important nutritional implications for rice eaters (IFPRI, 1999). Therefore, this present study set out to explore how the different quality characteristics of 4 indica varieties of Thai rice are affected along with yield when grown in different cropping seasons.

2. Materials and methods

2.1. Rice varieties and culture

A field experiment was conducted at Chiang Mai University, Thailand (18°47′N, 98°57′E) with three of Thailand's mega-varieties, Suphan Buri 1 (SPR1), Chai Nat 1 (CNT1) and Pathum Thani 1 (PTT1), plus RD21, a modern variety adapted to the highlands, grown in a randomized complete block design with four independent replications. The varieties were of long (> 6.61–7.50 mm of grain length) and slender grain shape (length/width ratio > 3.0) (Jennings et al., 1979). The experiment was repeated over 3 seasons: wet season (13 Aug–23 Nov 2009), cool season (13 Oct 2009–10 Feb 2010) and hot season (5 Feb–16 Jun 2010). One month old seedlings were transplanted into 4 × 4 m plots, one plant per hill at 0.25 × 0.25 m spacing.

Fertilizers applied to all plots was 28 kg N ha^{-1}, 28 kg P_2O_5 ha^{-1} and 28 kg K_2O ha^{-1} at 15 days after transplanting, followed by 43 kg N ha^{-1} urea top dressing at panicle initiation. Hand weeding was done at 3 weeks after transplanting and before panicle emergence. The experimental field was flooded to 10–15 cm depth and maintained until 7 days before harvest. Weather data (daily maximum/minimum temperature; rainfall, relative humidity and sunshine hours) for the whole growing seasons were obtained from the Northern Meteorological Centre, Chiang Mai, Thailand located 2.5 km from the experimental site, and having similar micro-climate as the experimental site.

2.2. Sample preparation and head rice yield

Two 1 × 1 m quadrats were harvested manually from each plot at physiological maturity to measure grain weight and grain size distribution was determined from the weight of individual un-husked (paddy rice) grain, including filled, partially filled and unfilled. Single grain weight was determined by weighing and recording the weight each grain individually from a randomly subsample of 300 grains from each replication (Leesawatwong, 2005). Grain size distribution was represented as percentage of grains belonging to each class of grain size. The grain samples were air dried to 11–12% of moisture content for grain quality evaluation. One-hundred g of the paddy rice was de-husked with a laboratory husker machine (model P-1, Ngek Seng Huat, Thailand) to produce brown rice (whole caryopsis with intact pericarp and embryo). The husker was Teflon-coated in all parts and handles to avoid Fe contamination during the de-husking process (Prom-u-thai et al., 2007a,b). Thirty g of whole grain brown rice were polished for 30 s with a laboratory milling machine (model K-1, Ngek Seng Huat, Thailand) to yield white rice, then manually separated into head rice (≥4/5 whole grain length, Ministry of Commerce, 2016) and remainder as broken rice. All grain samples were weighed for determination of head rice yield, defined as the weight of head rice as percentage of paddy weight.

2.3. Grain chalkiness and alkaline spreading value

Grain chalkiness was evaluated based on the Standard Evaluation System (SES Scale) (IRRI, 1979). Ten g of head rice were visually inspected for presence of chalky areas and manually separated into two categories, namely grain with chalky area ≥20% of rice grain area as chalky grain, and grain with chalky area < 20% of grain area as non-chalky grain. Percent grain chalkiness was calculated by chalky grain weight per head rice weight. Gelatinization temperature was assessed with alkali spreading assay (IRRI, 1979). One hundred whole grains of milled rice from each experimental unit were placed individually in Petri dishes (20 grains per dish, each containing 10 ml of 1.7% KOH, total of 5 Petri dishes per treatment), then kept at room temperature for 23 h. Four milled grains of KDML105 (low gelatinization temperature) and RD4 (high gelatinization temperature) grown in the wet season, 2009 at Chiang Mai University were used as checks. The degree of spreading was assessed at the 24th h, using a seven-point scale of 1–7, the lower score indicating higher gelatinization temperature.

2.4. Nitrogen, phosphorus, zinc and iron analysis

Ten g samples of brown and white rice were oven dried at 75 °C for 72 h then 1 g was dry-ashed in a muffle furnace at 535 °C for 8 h. The ash was dissolved in HCl (1:1; HCl to deionized water), the concentration of P was determined colorimetrically (Murphy and Riley, 1962), and Fe and Zn with a Hitachi Z-8230 atomic absorption spectrophotometer (AAS) (Zarcinas et al., 1987). Nitrogen was analyzed by the Kjeldahl method (Jackson, 1967). Soybean leaf powder was used for reference material in all samples to check the quality of the analyses.

2.5. Statistical analysis

Analysis of variance was conducted to detect differences in grain yield, and grain quality characteristics using Statistic 8 (analytical software, SXW). Data were analyzed in factorial in randomized complete block design. Data in percentage were arcsine transformed (as proportion of filled grain, head rice yield and chalk grain) to normalize the variance before analysis. The least significant difference (LSD) at $p < 0.05$ was applied to compare the means for significant differences between variety and cropping season.

3. Results

3.1. Climatic data during the growing season

The rice varieties in the experiment took 102 days from transplanting to harvest in the wet season, 119–126 days in the cool season and 111–131 days in hot season, with some variation in the climatic condition between the seasons (Fig. 1). The wet season received most of the rain at 522 mm, followed by the hot season with 236 mm in the hot season, almost all of which rain fell in the first 3 weeks, and the cool season had only 113 mm of rain. Relative humidity averaged 73.6% in the wet season, 68.1% in the cool season and 59.4% in the hot season. The temperature from transplant to panicle emergence averaged 28.7 ± 1.0 °C in the wet season, 26.2 ± 2.5 °C in the cool season, 28.7 ± 2.9 °C in the hot season; and from panicle emergence to harvest 27.3 ± 1.6 °C in the wet season, 24.2 ± 1.3 °C in the cool season, 31.6 ± 1.4 °C in the hot season. Although some of the average temperatures for the seasons were within the same or close range, there were clear differences between seasons in the patterns of daily minimum and maximum temperatures as well as in the temperatures during anthesis. The average daily sunshine was 6.9 h in wet season, 8.5 h in the cool season and 8.7 h in the hot season.

3.2. Grain yield and yield components

The grain yield of all four rice varieties, highest in the wet season and lowest in the cool season, were correlated positively with% of filled grain but negatively with the number of tillers and panicles (Table 1). The number of tillers and panicles per plant were affected by the interaction between variety and season with the highest number of tillers and panicles in the cool season compared with the wet and hot seasons in all varieties but in different ratio between seasons among varieties. The number of spikelets per hill was unaffected by season, although it differed among the varieties, with SPR1 and CNT1 producing the largest number of spikelets, followed by PTT1 and then RD21. Percentage