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Double-purpose rice (*Oryza sativa* L.) variety selection and their morphological traits

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ABSTRACT

This study was to investigate double-purpose (grain as human food and straw as roughage) rice (*Oryza sativa* L.) variety selection and their morphological traits at harvest. Eight *japonica* cultivars and one *indica* cultivar grown in 2011, and nine japonica cultivars and two indica cultivars grown in 2012 were used. At harvest, the grain yielding related traits such as 1000-grain weight and one-panicle weight, and the feeding quality related traits of straw (such as nonstructural carbohydrates (NSC)), crude protein (CP) and acid detergent fiber (ADF) contents and *in vitro* dry matter digestibility (*IV*DMD)) were investigated in 2 years from 2011 to 2012. The grain yielding (GY) and straw yielding (SY) of 10 plants, the fermentation quality related traits (pH, lactic acid (LA) and NH_3-N concentration) of straw, plant height (PH) and green leaf area per tiller (GLA) at harvest were analyzed in 2012. The top 3rd internodes of stem were used to make free hand sections to visualize the morphological traits of stem. The results indicated that Wuxiangjing 14, Wuyujing 3 and Nanjing 44 had good straw feeding quality (with high NSC content, *IV*DMD and good fermentation quality such as low pH and NH_3-N concentration and high LA concentration) and were suitable for double-purpose use. The good-quality double-purpose rice varieties were of relatively low plant height and large green leaf area per tiller at harvest and were of thick culm diameter and wall thickness, and high-percent parenchyma and low-percent vascular bundle area for the top 3rd internode in stem.

1. Introduction

In recent years, herbivorous animal production has developed rapidly in the southeastern agricultural region of China, resulting in an increasing demand for good quality roughage. Rice (*Oryza sativa* L.) is the staple crop in China, grown in about 29.9 million ha in 2010 (Sheng, 2011a). About 181–195 million tons of rice straw is produced yearly (Sheng, 2011b), but only a low proportion of the straw is utilized as roughage because of its poor dry matter digestibility. The remainder is used as fuel, or burnt in the field causing serious air pollution. If the feeding quality of rice straw could be improved, there would be more rice straw utilized as roughage in animal production reducing straw burning at the same time. Studies on improving the feeding quality of rice straw mainly increase its digestibility by physical, chemical and microbial treatments (Fadel-Elseed et al., 2003; Selim et al., 2004), and reports on whole-plant silage forage rice have been published (Nakano and Morita, 2007, 2008; Nakano et al., 2008, 2009, 2011a,b).

However, whole-plant silage forage rice does not meet with Chinese situation where demand for grain by the increasing population is overwhelming (Zhou et al., 2001) and it is impossible to use large areas of farmland to produce roughage. The physical, chemical and microbial treatments for better feeding quality of rice straw may partly change the physical structure of straw (Fadel-Elseed et al., 2003; Selim et al., 2004), but will not increase its content of digestible nutrients such as nonstructural carbohydrates and crude protein. Selecting rice varieties with high content of digestible nutrients in straw may help to realize the double purpose of satisfying the increasing demand for grain and alleviating the shortage of roughage in animal production in China. However, data on the double-purpose rice variety selection are scarce.

This study was to investigate ten common rice varieties in the Jiangsu area for their grain yielding, straw yielding and feeding quality and morphological traits to select varieties of better straw quality, and then to define their morphological traits so as to provide instructions for production.

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Table 1
Rice varieties used in this study.

Variety	Type
Yandao 830	Late maturing medium japonica
Wuyujing 3	Late maturing medium japonica
Nanjing 44	Early maturing late japonica
Nanjing 5055	Early maturing late japonica
Wuxiangjing 14	Early maturing late japonica
Zhendao 10	Early maturing late japonica
Nanjing 47	Medium maturing late japonica
Nanjing 46	Medium maturing late japonica
Liangyoupeijiu	Late maturing medium indica
Tianyouhuazhan	Late maturing medium indica

Table 2
The feeding quality related traits of rice straw among nine varieties in 2011.

	NSC (%)	CP (%)	ADF (%)	*IV*DMD (%)
Yandao 830	10.80c	5.35d	40.37a	36.09c
Wuyujing 3	14.29a	6.46a	35.41d	40.84a
Nanjing 44	12.27b	6.28a	36.85c	40.15a
Nanjing 5055	10.35c	5.56c	39.67ab	39.18b
Wuxiangjing 14	14.43a	5.72c	38.61b	39.86ab
Zhendao 10	11.80b	6.01b	39.08b	36.32c
Nanjing 47	6.02e	6.89a	41.14a	35.02c
Nanjing 46	8.32d	6.26a	39.89ab	36.30c
Liangyoupeijiu	8.21d	5.75c	39.99ab	39.74ab

Note. Means with different lowercase letters in the same column are significantly different at 0.05 level. NSC: nonstructural carbohydrates; CP: crude protein; ADF: acid detergent fiber; *IV*DMD: *in vitro* dry matter digestibility.

2. Materials and methods

Eight *japonica* rice cultivars and one *indica* rice cultivar grown in 2011, and nine *japonica* rice cultivars and two *indica* rice cultivars grown in 2012 were used in this study (Table 1). All the rice cultivars were the common grain rice varieties in the Jiangsu area.

In 2011 and 2012, the plants were cultivated in the same experimental field of Jiangsu Academy of Agricultural Sciences in Nanjing, China (East Longitude 118°46′ and North Latitude 32°03′), with a complete randomized block design in three replications. The germinated seeds were sown in a seedling bed on May 15, 2011 and May 11, 2012. The seedlings were transplanted to paddy fields 30 d later with one plant per hill. Each plot included 10 lines at a 30 cm interval, and each line consisted of 10 plants at a 20 cm interval. The field management was similar to the common practice for rice production in the Jiangsu area. The field received chemical fertilizer containing N 26.9 g, P_2O_5 15.0 g and K_2O 15.0 g m^{-2} during the whole growth period. The application of nitrogen fertilizer was 60% on the 7th day after transplanting, 20% on the 15th day after transplanting, and 20% during booting. All the phosphorous fertilizer was used as basal fertilizer, but the potassium fertilizer was used in two treatments: 50% on the 7th day after transplanting and 50% during booting.

From the middle of each plot, 50 tillers (panicles were removed to get one-panicle weight and 1000-grain weight) from 10 plants were mowed by hand at a cutting height of 10 cm for investigation in 2011 and 2012. The 50 tillers were dried at 75 °C in an oven until constant weight, and then they were ground through a 1 mm sieve for subsequent analyses of nonstructural carbohydrates (NSC), crude protein (CP) and acid detergent fiber (ADF) contents and the *in vitro* dry matter digestibility (*IV*DMD). The NSC content was determined following the procedure of Yoshida (1976). Briefly, about 150 mg powder of each sample was extracted using 80% ethanol (v/v) for 40 min at 80 °C. The water soluble carbohydrates (WSC) content in the extract was calculated by the absorbance at 625 nm after addition of anthrone reagent. The residue remaining after soluble sugar extraction was extracted in 9.2 and 4.8 mol/l perchloric acid and starch content (as glucose equivalent) was also determined with the anthrone reagent. The NSC content was calculated by the following formula: NSC (%) = WSC (%) + starch (%). The CP content was assayed by the Kjeldahl Method (KJELTEC2300, Foss, Denmark) (Huang et al., 2009). The ADF content was determined according to the method of Van Soest et al. (1991). Briefly, about 500 mg of each sample was placed in a filter bag (F57, Ankom Technology Macedon, NY, USA), soaked in acid detergent solution for 1 h, and rinsed three times in boiling water for 5 min (Ankom Fiber Analyser, Ankom Technology). The residue was dried at 80 °C until constant weight for the calculation of the content of ADF. *IV*DMD was analyzed according to the method of Jones and Hayward (1975). Briefly, about 500 mg of each sample was soaked in 2% pepsin solution for 24 h at 39 °C; then, the pepsin solution was filtered and added with 1% cellulase solution for 48 h at 39 °C. Later, the cellulase solution was inactivated for 0.5 h at 80 °C before filtering, and the residue was dried at 80 °C until constant weight for calculation of *IV*DMD.

In 2011 and 2012, the top 3rd internodes of stem were taken to make freehand sections using double-sided blades, and the sections were mounted onto a slide glass to visualize the morphological traits of stem under a Nikon microscope (ECLIPSE80I, NIKON, Japan). Then, Motic Images Plus 2.0 was used to measure culm diameter (CD), wall thickness (WT), and the percentage of mechanical tissues area (MTA), vascular bundle area (VBA) and parenchyma area (PA) in stem. The MTA, VBA and PA in stem were calculated using the following formulas: MTA (%) = mechanical tissues area in the section of stem × 100/the section area of stem; VBA (%) = vascular bundle area in the section of stem × 100/the section area of stem; PA (%) = parenchyma area in the section of stem × 100/the section area of stem. In 2012, the plant height (PH) was measured by a straight edge, and the green leaf area per tiller (GLA) was measured by a leaf area meter (LI-3100C, LI-COR, Taiwan) at harvest.

In 2012, 10 plants in middle of each plot were mowed by hand to a stubble height of 10 cm at harvest. The panicles and straw of the 10 plants were used for yield estimation such as straw yielding of 10 plants (SY) and grain yielding of 10 plants (GY), and then the straw was used to make silage. The fresh tillers were chopped into 3–5 cm lengths, prepared with lactic acid bacteria inoculants (*Lactobacillus plantarum*, Chikuso-1, Snow Brand Ltd., applied at 1×10^5 cfu/g of fresh material), vacuum-packed in 30 cm × 20 cm polyethylene bags with 3 replications for each treatment, and then stored at ambient temperature for 60 d. The pH was determined using a glass electrode pH meter (HANNA pH211 Microprocessor pH Meter). Lactic acid (LA) concentration was determined by a colorimetric method (Madrid et al., 1999). NH_3-N concentration was determined by the method of phenol-hypochlorite colorimetry (Weatherburn, 1967).

The variance analysis and correlation analysis were tested in SAS (The SAS System for Windows V8, 1999–2001 by SAS Institute Inc., NC, USA). Multiple comparisons were explored using Fisher's protected least-significant difference (LSD) test, and the broad sense heritabilities of feeding quality related traits were estimated with the formula $H_{B2} = S_{g2}/(S_{g2} + S_{e2}/n)$, where S_{g2}, S_{e2} and n represented genetic variance, error variance and the number of replications in the trial, respectively.

3. Results

3.1. Feeding quality of rice straw of different varieties in 2 years

The feeding quality related traits of rice straw of 9 varieties in 2011 were shown in Table 2. There were large differences in NSC content among varieties with Wuxiangjing 14 having the highest