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The feeding quality of rice (*Oryza sativa* L.) straw at different cutting heights and the related stem morphological traits

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ABSTRACT

This study was to investigate the feeding quality of rice (*Oryza sativa* L.) straw at different cutting heights and the related stem morphological traits. Wuyujing 3, Yangfujing 8 and Liangyoupeijiu in 2010, and Wuyujing 3, Nanjing 44, Nanjing 46, and Liangyoupeijiu in 2011 were used in this study. In 2010, we investigated the feeding quality related traits (such as nonstructural carbohydrates (NSC), crude protein (CP), hemicelluloses and acid detergent fiber (ADF) contents) of rice straw among three cutting heights 10 cm, 20 cm and 30 cm. In 2011, we investigated the nutrient contents (such as NSC, CP, hemicelluloses and ADF contents and *in vitro* dry matter digestibility (IVDMD)) of leaf, sheath and stem in the top 1st, 2nd and 3rd nodes and the stem morphological characteristics by free hand sections. The results in 2010 indicated that the NSC content of rice straw at 10 cm cutting height was higher than that at 20 cm and 30 cm cutting heights, CP content of rice straw at 10 cm cutting height was lower than that at 20 cm and 30 cm cutting heights, hemicelluloses and ADF contents were not significantly different among 3 cutting heights. The results of 2011 indicated that the NSC content in stem of the top 3rd node was much higher than that in the 2nd and 1st node, and higher than that in leaf and sheath of the same node. CP content in leaf was much higher than that in stem and sheath. Hemicelluloses content in leaf and sheath was higher than that in stem, and ADF content was higher in sheath than that in leaf and stem, but all not significantly ($p > 0.05$). IVDMD of stem was higher than leaf and sheath. Those results could explain the feeding quality differences of rice straw at different cutting heights. Wall thickness (WT) and the parenchyma area percentage of stem were significantly positively correlated with NSC content and IVDMD ($p < 0.05$), which could be used as selection traits for more digestible rice straw.

1. Introduction

In recent years, herbivorous animal production has developed rapidly in the southeastern agricultural region of China, resulting in an increasing requirement of good quality roughage. Rice (*Oryza sativa* L.) is the staple crop in China, grown in about 29.9 million ha in 2010 (Sheng, 2011a). It produced about 181–195 million tons of rice straw yearly (Sheng, 2011b), but only a small proportion was utilized as roughage because of its low dry matter digestibility. The remainder was used as fuel, or directly burnt in the field so as to cause serious air pollution. If the feeding quality of rice straw could be improved, there would be larger amount of rice straw utilized as roughage in animal production and reducing the rice straw burning. There are some reports on the improvement of the feeding quality of rice straw by physical, chemical and microbial treatments (Fadel-Elseed et al., 2003; Selim et al., 2004), and reports on whole-plant silage forage rice (Nakano and Morita, 2007, 2008; Nakano et al., 2008, 2009, 2011a, 2011b), but few data are available on the improvement of feeding quality of double-purpose rice (grains as human food and straw as animal roughage) varieties by rapid cultivated methods. In China, developing double-purpose rice will help satisfy the demand for grain of the increasing population and alleviate the shortage of roughage in animal production in the same time.

In production, the cutting height of rice straw at harvest was rashly and there were few investigations of the differences of rice straw feeding quality at different cutting heights and what was the optimum cutting height. Investigation of the feeding quality of rice straw at different cutting heights among double-purpose rice varieties and the factors causing the differences would supply instructions in practice to select suitable cutting height of rice straw and cultivation methods to improve the feeding quality of rice straw, so as to obtain high feeding quality rice straw as roughage. This study was firstly to investigate the feeding quality differences of rice straw at three cutting heights 10 cm, 20 cm and 30 cm, then to investigate the effects of the nutrient contents of leaf, sheath and

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stem in different nodes on the feeding quality of rice straw at different cutting heights and the related stem morphological traits which might be used as selection traits for more digestible rice straw.

2. Materials and methods

Two *japonica* rice cultivars Wuyujing 3 (medium maturing *japonica*) and Yangfujing 8 (medium maturing *japonica*) and one *indica* rice cultivar Liangyoupeijiu (late maturing hybrid *indica*) in 2010, and three *japonica* rice cultivars Nanjing 44 (late maturing *japonica*), Nanjing 46 (late maturing *japonica*) and Wuyujing 3 and one *indica* rice cultivar Liangyoupeijiu in 2011 were used in this study. All the rice cultivars were the common grain rice varieties in Jiangsu area.

In 2010 and 2011, the plants were cultivated in the same experimental field of Jiangsu Academy of Agricultural Science 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 17, 2010 and May 15, 2011. 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 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 d after transplanting, 20% on the 15th d after transplanting, and 20% during booting period. All phosphorous fertilizer was used as basal fertilizer. The potassium fertilizer was 50% on the 7th d after transplanting and the other during booting period.

From the middle of each plot, 25 tillers (panicles were removed) from 5 plants were mowed by hand at 3 cutting heights of 10 cm, 20 cm and 30 cm for investigation of feeding quality related traits in 2010. The 25 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), hemicelluloses and acid detergent fiber (ADF) contents. NSC content was determined following the procedure of Yoshida (1976). CP content was assayed by Kjeldahl Method (KJELTEC2300, Foss, Denmark) (Huang et al., 2009). Hemicelluloses and ADF contents were determined according to the method of Van Soest et al. (1991).

From the middle of each plot, 40 tillers (panicles were removed) from 8 plants were mowed by hand at a cutting height of 10 cm for investigation in 2011. The 40 tillers were separated into leaf, sheath and stem of the top 1st, 2nd and 3rd node. They 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 NSC, CP, hemicelluloses, ADF and *in vitro* dry matter digestibility (IVDMD). NSC, CP, hemicelluloses and ADF contents were determined according to the method of 2010. IVDMD was analyzed according to the method of Jones and Hayward (1975).

In 2011, the top 1st, 2nd and 3rd internodes of four cultivars were taken to make freehand sections using double-sided blades, and the sections were mounted onto a slide glass to visualize the stem morphological traits under a Nikon microscope (ECLIPSE80I, NIKON, Japan). Then we used measuring software Motic Images Plus 2.0 to measure culm diameter (CD), wall thickness (WT), and the percentage of mechanical tissues area (MTA), vascular bundle area (VBA) and parenchyma area in stem.

The averaged phenotypic data for the traits over three replications were used to mapping in EXCEL. The variance analysis and correlation analysis were tested in SAS. Multiple comparisons were explored using Fisher's protected least-significant difference (LSD) test.

3. Results

3.1. Feeding quality of rice straw at different cutting heights

NSC, CP, hemicelluloses and ADF contents of rice straw at different cutting heights were in Table 1. For Wuyujing 3, the NSC content in rice straw decreased with the increase of cutting height, for Liangyoupeijiu, the NSC content in rice straw at 10 cm cutting height was higher than that at 20 cm and 30 cm cutting height, but it was lower at 20 cm cutting height than at 30 cm cutting height, for Yangfujing 8, the NSC content at different cutting heights were not significantly different ($p > 0.05$). CP content was increasing with the increase of cutting height except that the CP content in rice straw of Liangyoupeijiu at 10 cm cutting height was higher than that at 20 cm cutting height. The hemicelluloses and ADF contents of rice straw at different cutting heights were not significantly different ($p > 0.05$) for all the 3 cultivars. The differences of NSC and CP contents among varieties and cutting heights were all significant at $p < 0.01$, and the differences of hemicelluloses and ADF contents among varieties were significant at $p < 0.05$.

The NSC and CP contents in rice straw at 3 cutting heights of Liangyoupeijiu were significantly lower than that of Wuyujing 3 and Yangfujing 8, respectively. Hemicelluloses content in rice straw at 3 cutting heights of Yangfujing 8 and Wuyujing 3 was significantly higher than that of Liangyoupeijiu, but ADF content in rice straw at 3 cutting heights of Liangyoupeijiu was significantly higher than that of Yangfujing 8 and Wuyujing 3.

3.2. Feeding quality of leaf, stem and sheath in different nodes of rice straw

NSC, CP, hemicelluloses and ADF contents and IVDMD in different nodes of rice straw (plus leaf, stem and sheath) were in Table 2. NSC content and IVDMD in the top 3rd node of rice straw were higher than those in the top 2nd and 1st node for all the four cultivars, while the CP content in the top 1st node was higher than that in the top 2nd and 3rd node. NSC content in rice straw of Wuyujing 3 was the highest and Liangyoupeijiu was the lowest among the 4 cultivars. Hemicelluloses content in the top 1st node of rice straw was higher than that in the top 2nd and 3rd node for all the 4 cultivars. ADF content in the top 1st node was higher than that in the top 2nd and 3rd node for Nanjing 44 and Wuyujing 3, but it was not significantly different ($p > 0.05$) for Nanjing 46 and Liangyoupeijiu. For Nanjing46, the IVDMD of rice straw in 3 nodes was not significantly different ($p > 0.05$), but for the other 3 cultivars, the IVDMD of the top 3rd node was higher than the top 2nd and 1st node.

The differences of NSC and CP contents among varieties and nodes, and the interactions between varieties and nodes were all significant ($p < 0.01$). The differences of IVDMD among varieties and the interactions between varieties and nodes were significant at $p < 0.01$, and the differences among nodes were significant at $p < 0.05$. The differences of hemicelluloses among varieties were not significant ($p > 0.05$), but the differences among nodes and the interactions between varieties and nodes were significant ($p < 0.05$). The differences of ADF content among nodes were not significant ($p > 0.05$), but the differences among varieties and the interactions between varieties and nodes were significant ($p < 0.05$).

NSC, CP, hemicelluloses and ADF contents and IVDMD of leaf, sheath and stem in different nodes of rice straw were in Fig. 1. NSC content in the top 3rd node of stem was higher than that in the top 2nd and 1st node, while NSC content in leaf of the top 1st node was higher than that in the 2nd and 3rd node. NSC content in sheath of the top 1st node was higher than that in the 3rd node, but not significantly ($p > 0.05$). NSC content in stem of the top 2nd and 3rd node was much higher than that in leaf and sheath of the same node. CP content in leaf was significantly higher than that in