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Journal of Plant Biology and Crop Research

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# Increasing wall thickness is more effective than increasing diameter for improving breaking resistance of rice internode

***Xiaohong Yin; Zui Tao; Min Huang*; Yingbin Zou***

*Southern Regional Innovation Center of Grain and Oil Crops (CICGO), Hunan Agricultural University, Changsha, China*

***Corresponding Author(s): Min Huang,**

Southern Regional Innovation Center of Grain and Oil Crops (CICGO), Hunan Agricultural University,Changsha, China

Email: jxhuangmin@163.com

Received: Nov 29, 2017

Accepted: Jan 25, 2018

Published Online: Jan 29, 2018

Journal: Journal of Plant Biology and Crop Research

Publisher: MedDocs Publishers LLC

Online edition: http://meddocsonline.org/



**Keywords:** Breaking resistance; Dry matter; Morphological traits; Rice internode

## Abstract

Increasing internode breaking resistance is one of the primary targets for improving stem lodging resistance of rice in a breeding program. In this paper, we evaluated the relationships among breaking resistance, dry matter per unit length and related morphological traits (diameter and wall thickness) of rice internode by using the data extracted from published articles. Scatter plot and linear regression analyses showed that internode breaking resistance could slowly (210 g cm), moderately (551 g cm) or rapidly increase (1,254 g cm) with increasing dry matter per unit length of internode (10 mg $cm^{-1}$). The rapid increase of internode breaking resistance with increasing dry matter per unit length of internode was accompanied by relatively rapid increase in internode wall thickness but relatively slow increase in internode diameter. These suggest that a greater improvement in breaking resistance of rice internode can be achieved by increasing dry matter per unit length of internode combined with increasing investment of the dry matter into enhancing internode wall thickness.

## Mini-Review

Lodging is an important problem in rice production because it causes reductions in grain yield and quality and mechanical harvesting efficiency [1,2]. It is generally accepted that two types of lodging occur in rice, namely stem lodging and root lodging. Stem lodging, resulting from the bending or breaking of the lower internodes, is the main type of lodging in rice [3]. Increasing internode breaking resistance is one of the primary targets for improving stem lodging resistance of rice in a breeding program [4]. There have been reports showing that breaking resistance has very high correlation with dry matter per unit length of internode [4, 5]. Although dry matter per unit length of internode is not a visual trait, it can be reflected in morphological traits including internode diameter and wall thickness. In general, high dry matter per unit length of internode is accompanied by large internode diameter and/or thick internode wall. However, because increasing internode wall thickness requires more investment of dry matter than increasing internode diameter, there are some studies claiming that internode wall thickness should be minimized to avoid yield potential reduction [6] and increasing internode diameter is better than increasing internode wall thickness for enhancing internode breaking resistance [7]. But in fact, in many recent studies in China [8-13], internode wall thickness is an important parameter for assessing internode breaking resistance. Here, we under took a systematic review to explore the relationships among breaking resistance, dry matter per unit length and related morphological traits (diameter and wall thickness) of rice internode.

A literature search was performed in China National Knowledge Infrastructure database (cnki.net) using the keywords 'lodging' and 'rice'. Each identified article was examined to determine if it contained the data (or data which could be derived from the available data) of breaking resistance, dry matter per unit length, diameter and wall thickness of the basal internode. A total of 6 published articles with 72 observations were selected through this process **(Figure 1; Table 1)**. All the selected articles were published in the top agricultural journals in China, including Scientia Agricultura Sinica, Acta Agronomica Sinica and Chinese Journal of Rice Science. In the selected articles, large variations were observed in both internode breaking resistance (ranging from 944 to 6,313 g cm with an average of 2,999 g cm) **(Figure 2A)** and dry matter per unit length of internode (ranging from 12.0 to 66.0 mg cm$^{-1}$ with an average of 37.2 mg cm$^{-1}$) **(Figure 2B)**.

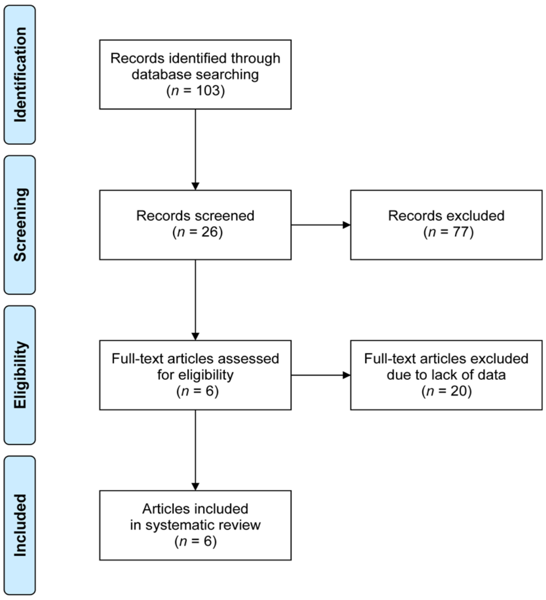


**Figure 1:** Literature search and selection flowchart.

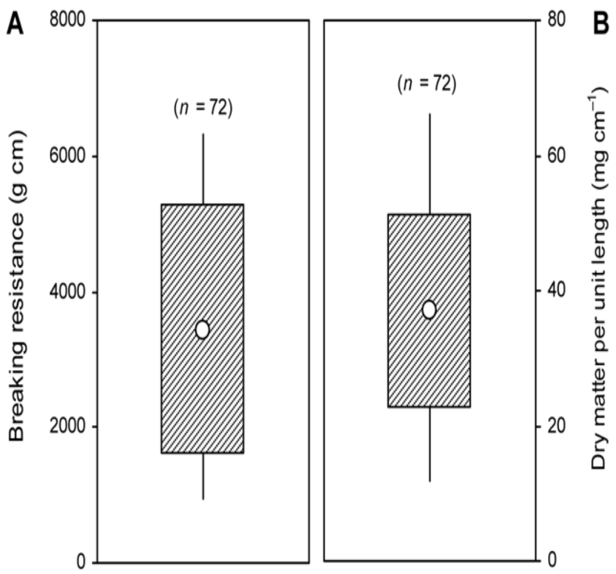


**Figure 2:** Breaking resistance (A) and dry matter per unit length (B) of the basal internode in rice. Data were collected from the selected articles listed in Table 1. Box-whisker diagrams include the range of 25–75% of the observations (rectangular box), the mean (circle within the box) and the minimum and maximum values (vertical lines).

We analyzed the obtained data set by using scatter plot and found that the data could be categorized into three groups on the basis of the relationship between internode breaking resistance and dry matter per unit length of internode **(Figure 3)**. Internode breaking resistance slowly, moderately and rapidly increased with increasing dry matter per unit length of internode in group I, II and III, respectively. Linear regression analysis (Statistix 8.0, Analytical Software, Tallahassee, FL, USA) indicated that, for each 10 mg cm$^{-1}$ increase in dry matter per unit length of internode, there was an increase of about 210, 551 and 1,254 g cm in internode breaking resistance in group I, II and III, respectively. These results are not entirely consistent with the results of single studies with only one type of cultivar (japonica or indica) [4,5], usually showing a simple positive linear relationship between internode breaking resistance and dry matter per unit length of internode. In this study, both japonica and indica cultivars were included **(Table 1)**, and the response of internode breaking resistance to increasing dry matter per unit length of internode was generally more dramatic in japonica than in indica cultivars **(Figure 4)**.

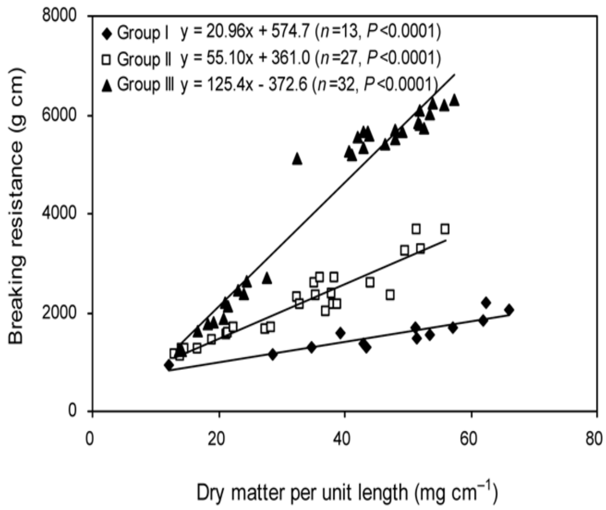


**Figure 3:** Relationship between breaking resistance and dry matter per unit length of the basal internode in rice. Data were collected from the selected articles listed in Table 1.

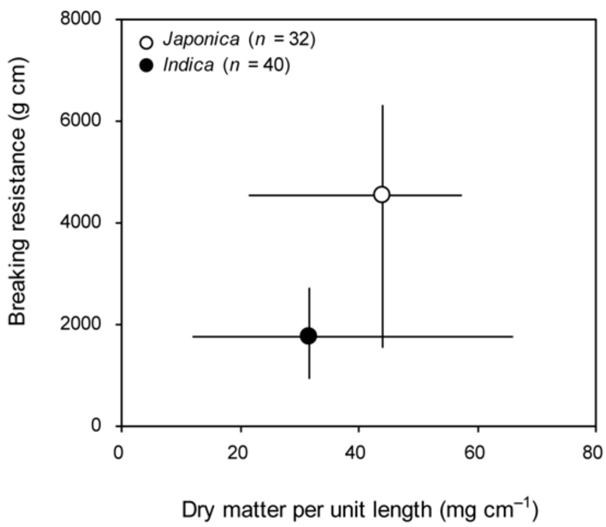


**Figure 4:** Breaking resistance and dry matter per unit length of the basal internode in japonica and indica rice. Data were collected from the selected articles listed in Table 1. The data are shown as the mean (circle) and the minimum and maximum values (horizontal and vertical lines).

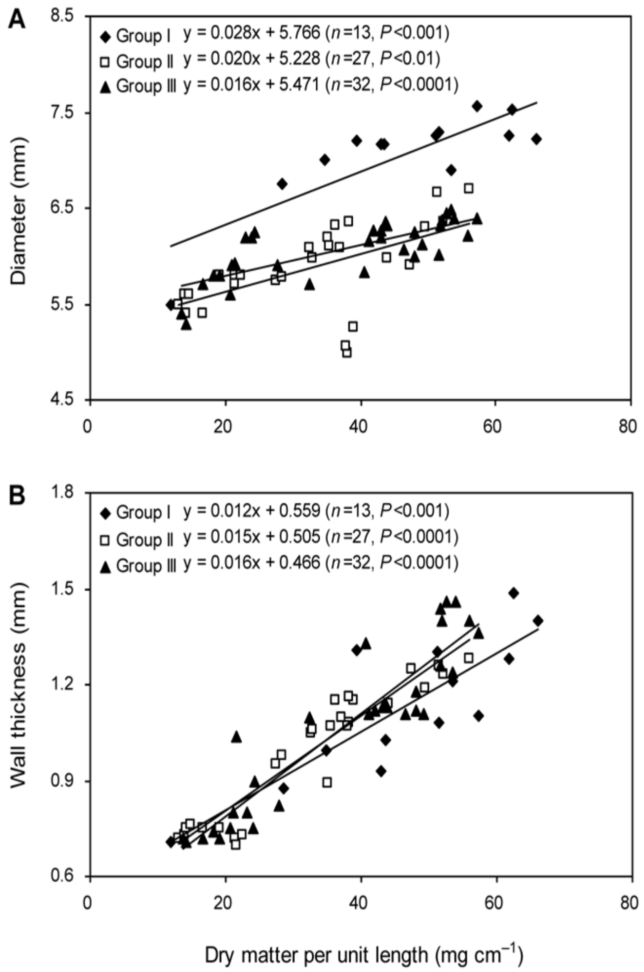


**Figure 5:** Relationships of diameter (A) and wall thickness (B) to dry matter per unit length of the basal internode in rice. Data were collected from the selected articles listed in Table 1. The groups are those shown in Figure 2.

Furthermore, although both internode diameter and wall thickness were tightly related with dry matter per unit length of internode in all three groups, the slopes of the regression lines differed among the three groups for each relationship **(Figure 5A and B)**. Group I had the highest slope of the relationship between internode diameter and dry matter per unit length of internode, followed by groups II and III **(Figure 5A)**. For each 10 mg $cm^{-1}$ increase in dry matter per unit length of internode, internode diameter was increased by 0.28 mm in group I, 0.20 mm in group II and 0.16 mm in group III. On the contrary, the highest slope of the relationship between internode wall thickness and dry matter per unit length of internode was recorded in Group III, and the lowest was in the Group I **(Figure 5B)**. Internode wall thickness was increased by 0.12, 0.15 and 0.16 mm for each 10 mg $cm^{-1}$ increase in dry matter per unit length of internode in group I, II and III, respectively. These results indicate that enhancing internode wall thickness was more powerful than enhancing internode diameter for increasing breaking resistance.

Taken together, the results of this study suggest that a greater improvement in breaking resistance of rice internode can be achieved by increasing dry matter per unit length of internode combined with increasing investment of the dry matter into enhancing internode wall thickness. However, as mentioned in the beginning, a worry about this strategy is that increasing internode wall thickness may cause a reduction in yield potential by requiring more investment of dry matter [6,7]. But actually, a japonica cultivar Nanjing 44 in the group III in this study produced a grain yield of more than 11 t $ha^{-1}$ [13], which is close to the current yield potential [14, 15]. This means [16] that the strategy proposed in this study does not necessarily lead to a reduction in yield potential. In this regard, it has been well documented that achieving higher rice yield mainly depends on increasing the dry matter production rather than the proportion of that dry matter allocated to grain [16-18]. These also demonstrate that high internode breaking resistance can be achieved together with high yield potential in rice.

## Table

**Table 1:** Description of the experimental studies in the selected articles.

| Reference | Year | Cultivar[a] | Experimental factor | No. of observations |
|---|---|---|---|---|
| Yang, et al. [8] | 2006 | Jinyou 527 (indica) | Nitrogen rate and planting density | 12 |
| Li, et al. [9] | 2008–2009 | Huaidao 9 (japonica) | Establishment method | 6 |
| | | III-you 98 (japonica) | | 6 |
| Li, et al. [13] | 2011 | Yinjingruanzhan (indica) | Nitrogen rate | 16 |
| Lei, et al. [10] | 2012 | F-you 498 (indica) | Establishment method and seedling age | 6 |
| Lei, et al. [12] | 2013 | F-you 498 (indica) | Establishment method and seedling age | 6 |
| Guo, et al. [13] | 2010–2011 | Nanjing 44 (japonica) | Establishment method and seedling number per hill | 10 |
| | | Wuyunjing 24 (japonica) | | 10 |

[a]The cultivar type is indicated in parentheses.

## Acknowledgements

This work was supported by the National Natural Science Foundation of China (31771722) and the Earmarked Fund for China Agriculture Research System (CARS-01).

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