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Short communication. Assessing lodging resistance in rice: A comparison of two indirect testing methods

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Abstract

Rice lodging is still a problem in many countries, as all rice-growing countries have some varieties that get lodged. Direct evaluation of lodging resistance requires visual estimates in plots, but is not feasible in early generations of breeding programs, where genetic variability is too high. The aim of this study was to compare two methods for indirect evaluation of lodging resistance, especially in field conditions: the recovery ability after bending (measured as the tiller angle difference before and after bending); and, to test the sturdiness of the lower part of the plant, we have measured its resistance to pulling. Sixteen rice varieties and two F_5 breeding lines were grown in plots and rows; 20 additional F_5 breeding lines were only tested in rows. Visual estimates of plot lodging were significantly correlated with their tiller angle difference (r = 0.56*), but not with plant height or pulling resistance, although the latter was also correlated with visual lodging when only susceptible accessions were considered (r = –0.72*). Tiller angle difference was not significantly correlated with pulling strength, but it correlates with plant height (r = 0.56*). The scoring of tiller angle difference is simpler and less dependent on the evaluator than pulling resistance. It is concluded that it can be a valuable trait to select for resistance to lodging in early segregating generations of a pedigree breeding program.

Additional key words: culm elasticity; lodging resistance; *Oryza sativa*; plant height; pulling strength; tiller angle.

Resumen

Comunicación corta. Evaluación de la resistencia al encamado en arroz: comparación de dos ensayos indirectos

El encamado del arroz sigue siendo un problema en muchos países, ya que todos los países cultivadores tienen algunas variedades que se encaman. La evaluación directa de la resistencia al encamado requiere estimas visuales en parcelas, pero no es posible en las primeras generaciones de un programa de mejora, cuya variabilidad genética es demasiado grande. El objetivo de este estudio fue comparar dos métodos de evaluación indirecta de resistencia al encamado en campo: la capacidad de recuperación tras doblado (medida como la diferencia angular de un tallo antes y después del doblado); y para probar la fortaleza de la parte inferior de la planta, se midió su resistencia a la tracción. Se cultivaron 16 variedades y dos líneas de mejora (F_5) en parcelas y líneas; 20 líneas de mejora adicionales (F_5) fueron sólo ensayadas en filas. Las estimas visuales de encamado en parcelas estuvieron significativamente correlacionadas con la diferencia del ángulo de sus tallos (r = 0,56*), pero no con la altura de planta ni con la resistencia a la tracción, aunque esta última también mostró correlación con el encamado visual cuando sólo se consideraron las entradas susceptibles (r = –0,72*). La diferencia del ángulo del tallo no estuvo significativamente correlacionada con la resistencia a la tracción, pero sí con la altura de planta (r = 0,56*). La medida de la diferencia angular de un tallo es más fácil y depende menos del evaluador que la resistencia a la tracción. Se concluye que puede ser un carácter útil para seleccionar la resistencia al encamado en las generaciones tempranas de un programa de mejora genealógica.

Palabras clave adicionales: altura de planta; ángulo del tallo; elasticidad del tallo; *Oryza sativa*; resistencia a la tracción; resistencia al encamado.

Lodging is a mechanical accident affecting rice (*Oryza sativa* L.) and other crops. During grain filling, or before, plants may bend, and even lay down, decreasing yield, quality of production, and mechanical harvesting efficiency. Lodging depends on genetic and environmental factors. It is enhanced by high doses of nitrogen fertilizer (mainly, because it increases plant height), plant density, rain, wind and certain fungi that

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attack the basal stem. But it is reduced by potassium fertilization (Tinarelli, 1988; Bhiah *et al.*, 2010), addition of silicon (Idris *et al.*, 1975) or 2,4-D spraying (Matsubayashi *et al.*, 1967).

Lodging resistance is a complex trait, determined by plant height, root thickness, culm diameter, strength and elasticity, and the weight of the upper part of the plant (Mulder, 1954; Ookawa and Ishihara, 1992; Kashiwagi and Ishimaru, 2004; Islam *et al.*, 2007). That makes lodging resistance a trait of low heritability, highly affected by the environment, and difficult to estimate in the early stages of breeding.

Direct evaluation of lodging resistance requires visual estimates in plots of advanced breeding lines or cultivars. A true assessment needs simulating conditions favorable to lodging, with a large investment of time, money and resources. But even routine plot scoring cannot be used to evaluate first generations in breeding programs, because their genetic variability is too high to grow plots.

An alternative way for improving lodging resistance is the use of indirect selection criteria. Although the traditional target has been a reduction of height, pushing resistance has also been used in individual plants of maize and rice (Idris *et al.*, 1975; Terashima *et al.*, 1992), particularly that of the lower part of the rice plant (Kashiwagi and Ishimaru, 2004). Torró (2010) measured the pulling resistance of two F_3 populations of rice, which showed low heritability, but responded to selection.

Another way suggested for breeding programs is to estimate a plant's culm strength by bending it down to the soil, and estimate speed and/or degree to which it regains its upright position (Jennings *et al.*, 1979).

The aim of this study was to compare two methods for indirect evaluation of lodging resistance in rice, especially in field conditions: the recovery ability after bending (which we have measured as the tiller angle difference before and after bending); and, to test the sturdiness of the lower part of the plant, we have measured its resistance to pulling. We are not aware of previous publications that have validated any of these methods.

Sixteen rice varieties and two F_5 breeding lines (derived from two F_3 lines selected for high pulling resistance, Torró, 2010), mostly of *japonica* background and Spanish origin, were sown in field plots of 3 × 8 m (duplicated when allowed by seed availability) at a density of 180 kg ha^{-1} of viable seeds. They were also transplanted to field rows, with a spacing of 15 × 50 cm (between plants and rows). The trial took place in Valencia (Spain) in 2008. Twenty additional F_5 breeding lines, from the same crosses, were tested in rows but not in plots (due to shortage of seed).

Fertilization was designed to favour lodging and increase the expression of varietal differences: 5.14×10^{-2} kg m^{-2} ammonium sulphate, 3.43×10^{-2} kg m^{-2} ammonium phosphate, and no potassium, applied before sowing; and a top-dressing with 1.2×10^{-3} kg m^{-2} ammonium sulphate. At maturity, plant height was measured as the mean of five plants per plot, and the percentage of the plot area that was lodged was estimated visually (directly, without a class scale).

Two indirect methods for estimating lodging resistance were applied, also at maturity, to six plants per row (Fig. 1): i) tiller angle difference, or the difference between the angles formed by one healthy tiller with respect to the vertical, when measured before bending it from the panicle to the soil and after releasing it; angles were measured by marking 10º intervals on a sheet placed behind the tiller; ii) pulling resistance, or the pulling force needed to bend a whole plant, measured with a dynamometer tied to a ribbon encircling the plant at about 20 cm above the soil.

Pearson's linear correlation coefficient (r) was calculated between lodging measurements. Due to the non-normality of the percentage of plot area lodged, Spearman's rank correlation coefficient (ρ) was also calculated (Snedecor and Cochran, 1967).

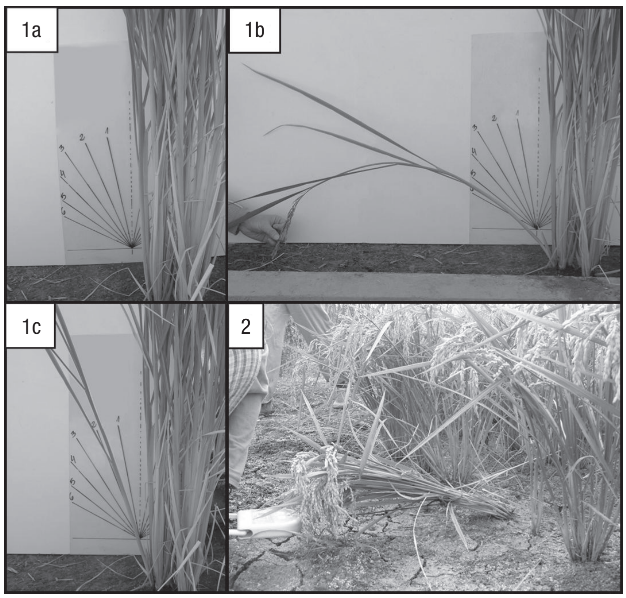

Figure 1. Two methods for indirectly testing lodging on individual rice plants. 1) Tiller angle difference: stem before (a), during (b) and after (c) bending. 2) Pulling resistance.

Table 1 shows plant height and lodging estimates of the accessions, and the correlation coefficients (linear and rank) between the traits. Plant height was higher than usual in most of the accessions measured, when compared to regular nitrogen fertilization. The percentage of the plot area lodged

Table 1. Lodging and height measurements (including usual height under normal fertilization in brackets for comparison) and their correlation

Accession	Lodging (%)	Plant height	Pulling resistance (N)	Tiller angle difference (º)
'Montsianell'	70[1]	113 (~105)	4.1	35
'Senia'	90[1]	110[1] (~105)	3.1[2]	25[2]
'Bomba'	95	165 (~140)	4.2	30
'L-202'	0[1]	107 (~95)	4.9	25
'Ullal'	0	93 (~85)	3.4	17
'Fonsa'	85[1]	84 (~80)	3.5	13
'Alena'	0	101 (~80)	3.4	17
'Cormorán'	25[1]	95 (~90)	4.1	15
'Jsendra'	0[1]	85 (~75)	4.6	10
'Sivert'	25[1]	91 (~85)	4.1	7
'Gavina'	50[1]	85 (~85)	4.7	20
'Sarcet'	3[1]	90 (~85)	4.4	8
'Albufera'	50[1]	107 (~105)	4.7	7
'Apollo'	95	110 (~90)	3.3	38
'Fragrance'	90	98 (~85)	3.9	18
'Asia'	80	97 (~90)	4.6	17
(Z9 × L2) × JS 115	0	108	4.9	13
(Z9 × L2) × MS 53	0	98	8.8	10
(Z9 × L2) × JS 29-4-2	–	–	7.3	23
(Z9 × L2) × JS 64-2-4	–	–	7.5	19
(Z9 × L2) × JS 65-4	–	–	5.8	12
(Z9 × L2) × JS 65-5	–	–	6.4	38
(Z9 × L2) × JS 76-1-4	–	–	4.2	27
(Z9 × L2) × JS 76-1-6	–	–	5.4	11
(Z9 × L2) × JS 92-4-3	–	–	4.2	14
(Z9 × L2) × JS 92-4-5	–	–	4.6	22
(Z9 × L2) × JS 124-6-1	–	–	3.7	18
(Z9 × L2) × JS 124-6-3	–	–	6.0	29
(Z9 × L2) × JS 124-6-4	–	–	3.9	19
(Z9 × L2) × JS 126-5-2	–	–	4.1	13
(Z9 × L2) × JS 126-5-4	–	–	3.8	13
(Z9 × L2) × JS 126-5-6	–	–	3.3	10
(Z9 × L2) × JS 135-6-1	–	–	5.1	20
(Z9 × L2) × MS 10-6-5	–	–	5.4	15
(Z9 × L2) × MS 46-3-3	–	–	3.0	17
(Z9 × L2) × MS 65-5-3	–	–	4.1	8
(Z9 × L2) × MS 86-4-1	–	–	4.5	12
(Z9 × L2) × MS 86-4-6	–	–	5.9	5
% Lodging		r = 0.39 ns ρ = 0.45 ns	r = –0.38 ns ρ = –0.34 ns	r = 0.56* ρ = 0.50*
(% Lodging ≥50%)		r = 0.39 ns ρ = 0.46ns	r = –0.72* ρ = –0.67*	r = 0.47ns ρ = 0.53ns
Plant height			r = –0.05 ns	r = 0.56*
Pulling resistance				r = 0.01 ns

[1] Mean of duplicate plots or rows ([2] of triplicate); (r) linear and (ρ) rank correlation coefficients; ns: not significant; *: significant at p (α) ≤ 0.05.

was significantly correlated with tiller angle difference. But there was no correlation between percentage of the plot area lodged and plant height, or pulling resistance, nor between the two indirect testing methods. However, when only susceptible accessions (with lodging ≥50%) were considered, its correlation with the pulling resistance became significant.

Tiller angle difference measures culm elastic recovery. According to Aliaga *et al.* (1986), culm elasticity is correlated with internode length, but not with culm thickness, which is in agreement with the correlation found in this work between tiller angle difference and plant height. However, the lack of correlation between plant height and pulling force might reflect stem characteristics other than length, such as thickness or strength, and matches results obtained by Kashiwagi *et al.* (2008) when studying height and pushing resistance.

In our study, tiller angle difference appears as a good estimator of the lodging resistance of individual rice plants, and a better criterion for selection than plant height or pulling force, although the latter is also an indicator of susceptibility. Since breeding requires methods that are easy and quick to apply to a large number of individuals, determining tiller angle difference would also be the method of choice, because its scoring is simpler and less dependent on the evaluator. Nonetheless, if this trait is to be used as a reliable selection method in the first segregating generations of a breeding program, its heritability should be estimated.

Two conclusions can be drawn from this study: i) culm's resistance to pulling and elasticity are characters fairly independent; ii) at least in these varieties and lines, tiller angle difference of individual plants (before and after bending and releasing) can predict lodging.

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