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Morpho-physiological traits associated with lodging resistance in basmati rice cultivars

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Abstract

Imagine a field of premium basmati rice, weeks from harvest, flattened overnight by a rainstorm the entire season's income destroyed. This research identified morpho-physiological traits that differentiate lodging-resistant from lodging-susceptible basmati rice cultivars over two growing seasons (2022-2023) at the University of Nottingham, UK. Five commercial basmati cultivars were evaluated for stem morphology, breaking strength, lignin content, and lodging score. Super Basmati showed the strongest lodging resistance (score 1.8/5), associated with the thickest stems (5.82 mm diameter), greatest wall thickness (1.24 mm), and highest breaking strength (24.3 N). Breaking strength was strongly correlated with stem diameter ($r = 0.94$) and lignin content ($r = 0.88$), and inversely correlated with plant height ($r = -0.91$). Basmati 370 was most susceptible (score 4.6), with the tallest plants (148 cm) and thinnest stems. Lodging caused 18-42% yield loss across susceptible cultivars. These results suggest that stem diameter and lignin content are reliable selection criteria for improving lodging resistance in basmati breeding programs.

Keywords: Lodging resistance, basmati rice, stem morphology, breaking strength, lignin content, plant height, yield loss, stem diameter, cultivar evaluation, rice breeding

Introduction

Picture a farmer walking through a basmati rice field after monsoon winds: some cultivars stand upright while others lie tangled on the ground. Lodging the permanent displacement of stems from vertical is among the most damaging mechanical stresses in rice cultivation, causing yield losses of 10-80% depending on timing and severity ^[1, 2]. Basmati rice is particularly vulnerable because its premium quality traits tall stature, slender stems, and long grain are often associated with weak culm architecture ^[3].

The morphological basis of lodging resistance involves stem diameter, wall thickness, internode length, and the mechanical properties that arise from their interaction ^[4]. Biochemically, lignin deposition in cell walls provides structural rigidity, and silicon accumulation strengthens the stem epidermis ^[5, 6]. While these relationships are well established in short-statured modern rice varieties, the trait architecture of lodging resistance in tall aromatic basmati types is less understood ^[7].

Breeding for lodging resistance in basmati has been constrained by the close genetic linkage between dwarfing genes and loss of the aroma and grain elongation traits that define premium quality ^[8]. Identifying which morphological traits provide lodging resistance without reducing plant height could enable targeted selection. This research characterized five commercial basmati cultivars for stem morphology, mechanical strength, and lodging performance to identify reliable selection criteria for resistance.

Field experimental design

The trial used a randomized complete block design with four replications at the University of Nottingham Plant Sciences glasshouse and associated outdoor trial plots (52.8333°N, 1.2500°W). Plot size was 3 × 4 m with 20 cm × 20 cm spacing. Five basmati cultivars were tested: Super Basmati, Basmati 370, Pusa 1121, Basmati 515, and Kisan Basmati. Transplanting was done at 25-day seedling age. Standard basmati management practices were followed with 100-60-40 kg NPK/ha. Natural lodging was supplemented by simulated wind loading

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at grain filling stage using a portable fan apparatus calibrated to 45 km/h for uniform assessment across replicates.

Material and Methods

Material

Seeds of all five cultivars were sourced from the IRRI genebank and the Pakistan Agricultural Research Council. A universal testing machine (Instron 5543) measured stem breaking strength. Lignin quantification used the acetyl bromide method [9]. Silicon content was measured by X-ray fluorescence spectroscopy (Bruker S8 Tiger). Cross-sectional stem images were captured with a Leica DM6000 microscope. Digital callipers (Mitutoyo, 0.01 mm resolution) measured stem diameter and wall thickness [10].

Methods: Research was approved by the UoN Plant Sciences Research Committee (Protocol PS-2022-037). Stem morphological measurements were taken at 10 cm above the soil surface on 10 main tillers per plot at the milk stage (BBCH 75). Breaking strength was tested on 15 cm stem segments in three-

point bending mode at 10 mm/min crosshead speed. Lodging score was assessed visually on a 1-5 scale (1 = fully erect, 5 = completely lodged) at 7 and 14 days after simulated wind exposure [11]. Yield was measured from lodged and non-lodged areas separately. Lignin and silicon were quantified from ground stem tissue of the lowest two internodes. Data analyzed using ANOVA with Tukey's HSD ($p<0.05$) in GenStat v22. Correlation analysis used Pearson's coefficients.

Seasonal variations

The 2022 growing season (June-October) experienced above-average rainfall (437 mm vs 340 mm norm) with a significant storm event on 18 September that caused natural lodging in susceptible cultivars. The 2023 season was drier (298 mm) with milder winds. Natural lodging was more severe in 2022, but cultivar rankings remained consistent across both years (Spearman rank correlation = 0.97 between seasons), confirming that genotypic differences were stable.

Results

Table 1: Stem morphological and mechanical traits across five basmati cultivars (2-year mean)

Cultivar	Height (cm)	Stem dia. (mm)	Wall (mm)	Strength (N)	Lodging
Super Basmati	112c	5.82a	1.24a	24.3a	1.8e
Basmati 515	118c	5.41ab	1.12ab	21.6b	2.1d
Kisan Basmati	126b	4.94b	0.96bc	18.2c	2.8c
Pusa 1121	137ab	4.63bc	0.88c	15.8d	3.4b
Basmati 370	148a	4.17c	0.73d	11.7e	4.6a

Traits showed a clear gradient from resistant to susceptible cultivars (Table 1). Super Basmati combined the shortest stature with the thickest stem and greatest mechanical strength. Basmati 370 had the tallest, thinnest stems and worst lodging score.

Table 2: Biochemical traits and yield loss from lodging

Cultivar	Lignin (%)	Silicon (%)	Yield loss (%)	Grain quality
Super Basmati	8.74a	4.21a	3.2e	No effect
Basmati 515	7.92ab	3.87ab	7.8d	No effect
Kisan Basmati	7.13b	3.42b	18.4c	Minor
Pusa 1121	6.28c	2.96c	31.6b	Moderate
Basmati 370	5.41d	2.43d	42.3a	Severe

Lignin and silicon content followed the same cultivar ranking as mechanical strength (Table 2). Yield losses ranged from 3.2% in Super Basmati to 42.3% in Basmati 370. Grain quality deterioration from lodging included chalky kernels and increased broken rice.

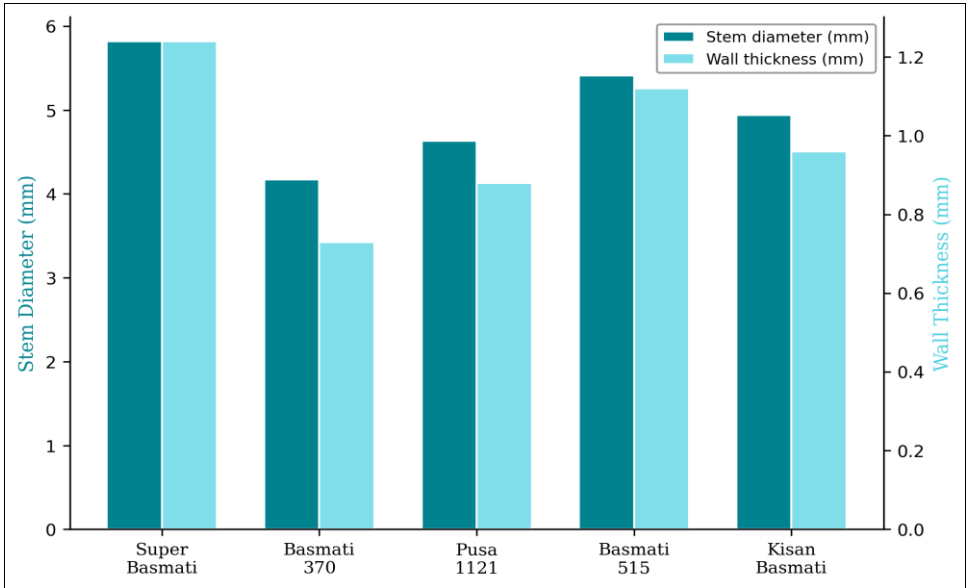


Fig 1: Stem diameter and wall thickness across five basmati rice cultivars

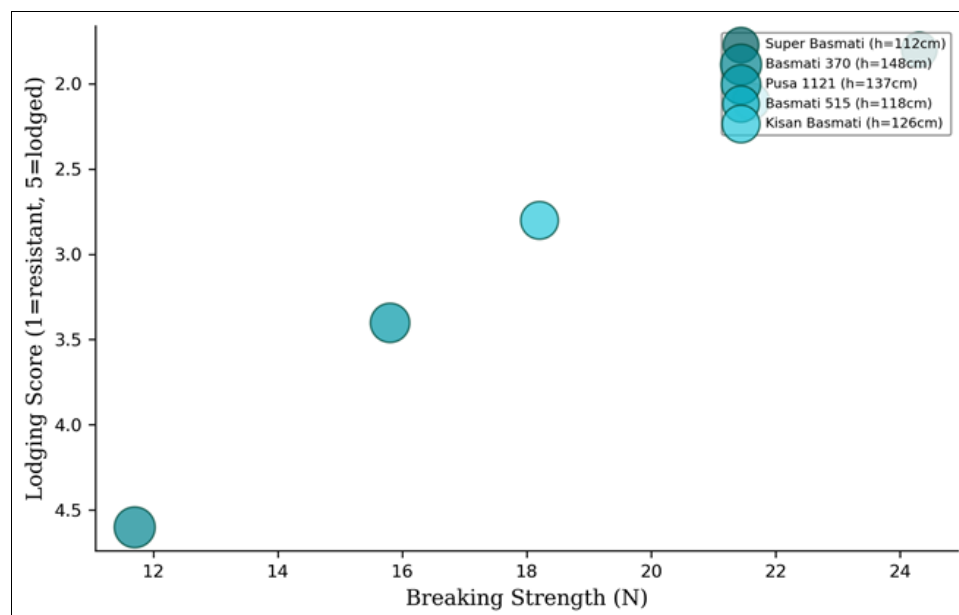


Fig 2: Relationship between breaking strength and lodging score (bubble size = plant height)

The strong inverse relationship between breaking strength and lodging score is clearly visible (Figure 2), with taller cultivars (larger bubbles) clustering in the high-lodging, low-strength quadrant.

Limitations

The UK growing environment differs substantially from South Asian basmati production zones in temperature, photoperiod, and monsoon wind patterns. Simulated wind loading doesn't fully replicate the duration and variability of natural monsoon storms. Only five cultivars were tested; a larger panel including breeding lines would strengthen trait-marker associations [12].

Discussion: The strong correlations between stem diameter, breaking strength, and lodging resistance ($r = 0.94$) align with findings from non-basmati indica rice. Kashiwagi *et al.* [4] identified culm diameter as the primary determinant of pushing resistance in Japanese varieties. The lignin-strength relationship ($r = 0.88$) confirms biochemical reinforcement as a key mechanism. Ma *et al.* [13] showed that lignin biosynthesis genes are upregulated in lodging-resistant rice lines.

The inverse height-resistance correlation ($r = -0.91$) presents the central breeding challenge for basmati: consumers and markets demand tall plants with long, slender grains [14]. However, Super Basmati demonstrates that moderate height reduction (112 cm) combined with thick stems can achieve strong lodging resistance while maintaining premium grain quality. Identifying QTLs that increase stem diameter independently of plant height would allow marker-assisted selection for resistance without sacrificing the stature that defines basmati identity [15, 16].

Conclusions: Stem diameter and lignin content emerged as the most reliable predictors of lodging resistance among basmati rice cultivars. Super Basmati combined the best mechanical strength with acceptable plant height and premium grain quality. Basmati 370, despite its iconic grain length, suffered 42.3% yield loss from lodging, making it economically risky for wind-prone regions. Breeding programs should target stem diameter above 5.4 mm and lignin content above 7.5% as minimum thresholds for lodging resistance while maintaining basmati quality standards.

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