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Lodging in soybean (*Glycine max*) as influenced by growth habit and other traits

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Soybean [*Glycine max* (L.) Merrill] is one of the most important leguminous seed crops for oil and protein and has a natural capacity to fix nitrogen from the atmosphere and is believed that it was domesticated from its annual wild relative, *G. soja* Sieb & Zucc, in China approximately 5 000 years ago (Carter *et al*. 2004).

Lodging can be caused by bending of stems near the base when the strength of the stem or soil is insufficient to hold the plant upright against the wind. Lodging occurs mostly in soils with low plant holding capacity, particularly after irrigation or rain. Yield loss is greatest with early lodging. In a lodged plant population, the normal canopy structure is affected adversely, resulting in reduced photosynthetic ability and dry matter production, and increased damage by different pathogens and pests, which finally reduces yield, quality and mechanical harvesting efficiency.

Most soybean varieties can be classified into two categories of stem growth habit (Curtis *et al.* 2000), indeterminate and determinate types which is based on the termination of apical stem growth. To understand how the agronomic traits interact with especially growth habit, stem diameter and height to induce lodging in soybean, the present experiment was carried out.

Thirty soybean varieties were grown in a Randomized Block Design with three replications during *kharif* 2008 and 2009 at the Directorate of Soybean Research, Indore (MP) which is situated at 22º 4'37''N latitude, 75º 52'7''E longitude and altitude of 540 meters above mean sea level. The varieties were sown in six rows in five meter length (spacing 45 cm × 10 cm). The experiments were carried out in deep black cotton soils with pH 7.6 to 8.1. The recommended dose of fertilizer (20N:60P:20K kg/ha) was applied before sowing in the form of commercial fertilizers.

The quantitative data, averaged over the two years included lodging score rated on a scale from 1 (erect) to 5 (prostrate); growth habit scored as 1 (determinate), 3 (semi-determinate) and 5 (indeterminate); stem diameter (cm); number of nodes; number of branches and seed yield. The seed yield was recorded on net plot basis (kg/13.5 m^2). Plant height (cm) and stem diameter were measured at maturity.

The data of both the years were pooled for statistical analysis. Means of the traits, standard errors, coefficient of variations (CV), critical differences (CD) and phenotypic correlations were estimated following Singh and Chaudhary (1985). Correlations between different traits were computed on the basis of mean values of two years.

Means of all the traits, standard errors, coefficient of variations, critical differences studied are shown in Table 1. The correlation study (Table 2) shows that plant height is significantly and positively correlated with lodging and growth habit. The plant height was the main target for improvement of lodging resistance; however, the susceptibility to lodging differs among varieties with similar plant heights (Fig 2). Stem diameter was not significant with the traits studied. Thus, plant height and stem diameter were not necessarily the most important factor for

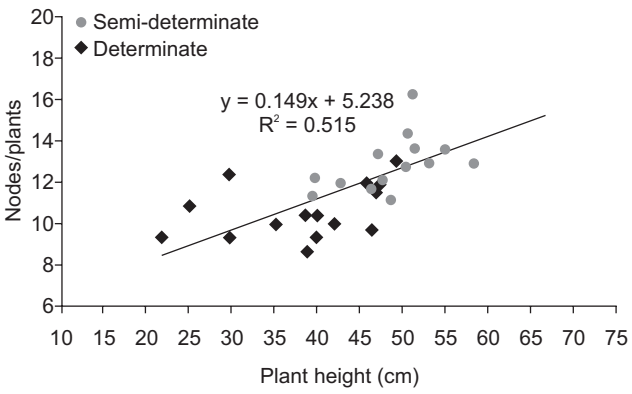

Fig 1 Relationship between plant height and nodes/plant

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Table 1 Mean of agronomic traits studied in 30 soybean genotypes

Genotype	Plant height (cm)	Nodes/ plant	Bran-ches/ plant	Stem dia-meter	Lodging (score 1-5)	Yield (kg)/ plot	Growth habit (D=1, SD=3, ID=5)
Bragg	47.00	11.83	3.67	0.62	1.33	1.67	1
DS 228	58.33	12.83	4.00	0.53	1.4	1.94	3
JS 335	39.83	12.17	4.00	0.77	2.80	2.56	3
JS 93-05	39.33	11.33	5.33	0.55	1.56	2.49	3
JS 95-60	35.17	10.00	4.50	0.53	1.15	3.03	1
JS 97 52	55.00	13.50	5.83	0.80	1.74	2.01	3
Kalitur	66.67	17.50	5.50	0.58	3.10	1.26	3
LSb-1	25.00	10.83	4.83	0.52	1.11	1.90	1
MACS 450	50.17	12.67	4.50	0.60	3.81	2.07	3
MAUS 61	46.50	11.67	5.83	0.92	1.61	1.35	3
MAUS 71	50.50	14.33	5.17	0.77	1.76	2.30	3
NRC 37	51.33	16.17	4.00	0.88	1.39	2.24	3
NRC 7	29.67	12.33	3.50	0.72	1.70	1.78	1
Palam Soya	46.50	9.67	4.67	0.55	1.48	1.27	1
PRS-1	21.83	9.33	2.83	0.37	1.15	1.34	1
PS 1024	38.83	8.67	5.17	0.55	1.73	0.99	1
PS 1029	42.00	10.00	3.50	0.58	1.41	1.94	1
PS 1042	38.67	10.33	4.50	0.72	1.69	1.49	1
PS 1092	40.00	10.33	3.83	0.85	1.26	1.87	1
PS 1225	53.00	12.83	5.50	0.75	1.70	2.24	3
PS 1241	49.17	13.00	6.67	0.73	2.18	0.95	1
PS 1347	45.67	12.00	4.67	0.75	1.41	1.86	1
PS 564	29.67	9.33	6.67	0.83	1.68	1.17	1
Pusa 97-12	48.67	11.00	4.67	0.75	1.58	2.01	3
Pusa 98-14	51.33	13.67	4.67	0.72	1.48	1.44	3
RKS 18	46.83	11.50	5.00	0.83	1.84	2.52	1
Shivalik	47.33	13.33	3.50	0.70	1.52	1.24	3
SL 525	40.00	9.33	3.33	0.65	1.41	1.76	1
SL 688	42.83	12.00	3.83	0.68	2.93	1.42	3
VLS 47	47.50	12.00	4.33	0.67	1.84	0.90	3
Grand Mean	44.14	11.85	4.60	0.68	1.76	1.77	
SE ±	4.19	1.22	1.28	0.12	0.20	0.29	
CV	11.77	12.66	34.91	21.25	13.87	18.86	
CD (*P*=0.05)	8.39	2.45	2.56	0.24	0.40	0.59	
CD (*P*=0.01)	11.17	3.26	3.40	0.31	0.53	0.78	

Table 2 Correlation coefficient of agronomic characteristics of soybean genotypes

	Plant height (cm)	Nodes/ plant	Bran-ches/ plant	Stem dia-meter	Lodging (1-5)	Yield (kg)/ plot
Nodes/plant	0.718**					
Branches/ plant	0.266	0.166				
Stem diameter	0.266	0.295	0.350			
Lodging (1-5)	0.366*	0.391*	0.179	0.057		
Yield (kg)/ plot	–0.008	0.078	–0.125	0.080	–0.067	
Growth habit	0.607**	0.651**	0.118	0.231	0.419*	0.123

determining lodging resistance. The reduced plant height gave increased resistance to lodging in soybean (Jin *et al*. 2010, Ramteke *et al*. 2011, 2012). Shorter plants tend to be more resistant to lodging (Cober and Morrison 2010). Panthee *et al.* (2007) observed significantly positive correlation between plant height and lodging, whereas the correlation between lodging and yield is significantly negative.

In our study, growth habits, i e stem termination into determinate or semi-determinate was significantly correlated with plant height, nodes and lodging. Other workers also have shown that growth habit has great effects on plant height, flowering period, node production, maturity, water-use efficiency, and soybean yield (Specht *et al*. 2001, Heatherly and Smith 2004). Curtis *et al*. (2000) have shown determinate lines, compared to isogenic indeterminate lines, were early maturing. Equivalent yields (Table 1, Fig 3) were produced by determinate and indeterminate varieties although the determinate varieties were shorter. This was also observed by Cober and Morrison (2010). In our experiment, no significant correlation was established between growth habit and yield. However, Out of 30 varieties, JS 95-60 was the highest yielder followed by JS 335, RKS 18, JS 93-05, MAUS 71, NRC 37 and PS 1225.

Data showed semi-determinates were comparatively taller (Fig 1 and 2) than determinates and susceptible for

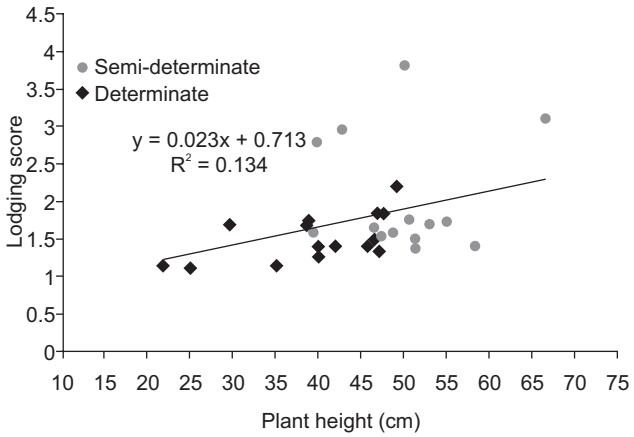

Fig 2 Relationship between plant height and lodging score (1-5)

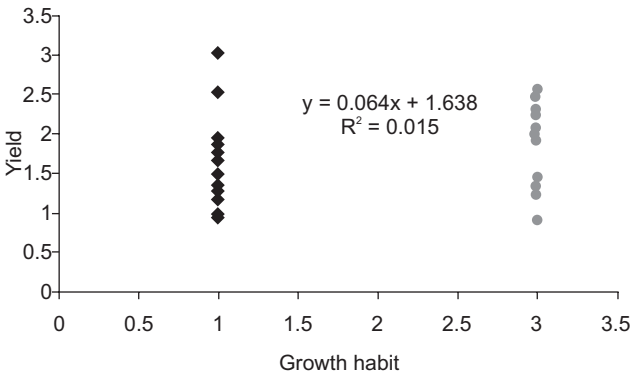

Fig 3 Relationship between growth habit and yield

lodging. However, extreme dwarfism is also associated with decreased biomass, shrunken seeds, premature senescence, and increased susceptibility to diseases, resulting in reduced yield in rice (Islam *et al*. 2007).

Strategies are needed to reduce lodging risk while maintaining a profitable yield level. Lodging is not easy to predict, but was linked to tall, thick canopies. Even the shading effect of a thick canopy weakens the stems, while the increased height and biomass of a high-input crop produces a longer lever that is more likely to bend the stem or displace the roots during high winds. For lodging resistance, determinate growth habit with reduced height may be selected for further soybean improvement. Recently, Chen *et al*. (2011) has suggested stem strength measured by 'prostrate tester' and other related traits should be taken in to consideration while selecting lodging resistant genotype.

SUMMARY

Thirty soybean varieties were grown for consecutive two years to study how the growth habit, stem diameter and plant height influence the lodging in soybean. Plant height was found to be significant and positively correlated with lodging and growth habit. The reduced plant height showed increased resistance to lodging in soybean. Growth habit was significantly correlated with plant height, nodes and lodging. Stem diameter was not significant with any of the traits studied. Although the determinate varieties were shorter, equivalent yields were produced by determinate and semi-determinate. No significant correlation was established between growth habit and yield; however, JS 95-60 was the highest yielder followed by JS 335, RKS 18, JS 93-05, MAUS 71, NRC 37 and PS 1225. Semi-determinate varieties were comparatively taller than determinates and susceptible for lodging.

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