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Analysis of Shoot Shear Strength to Determine the Lodging Tendency in Wheat

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Abstract: *Wheat is one of the most important cereal crop in the world. Lodging, in wheat crop degrades the grain quality and yield. Lodging is caused due to complex interaction of weather, soil and crop. Lodging risk is determined by cultivar, sowing date, irrigation scheduling, temperature, application ofplant growth regulating chemicals etc. In this study, traits such as plant shoot diameter, wall thicknessat the cross section, shear strengthof the shoot were investigated to characterize the loading resistance in wheat crop. Ultimate shear force and shear strength ofshoot nodeswere determined using texture analyzer in ten wheat (Triticum aestivum L.) cultivars under two different temperature conditions.Variation in shear strength among the different nodes tested, indicated less shear strength in the lowermost node. Results showed that the observed estimates of lodging in different cultivars were significantly correlated with the measured shear strength values. Thus shear strength can be a reliable parameterto screenwheat crop cultivars for lodging resistance to ultimately reduce the yield losses.*

Keywords: *Wheat, lodging, ultimate shear force, shear strength, yield.*

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most widely grown cereal crop in the world.It is grown on about 215 million hectares yearly in world. Wheat is first among the three major staple crops as a source of protein in developing countries,providing 20% of the daily protein and of the food calories for 4.5 billion people (CGIAR, 2015). Globally,nearly US $50 billion-worth of wheat is traded every year. The major wheat producing and consuming countries in Asia are China, India, Iran, Pakistan and Turkey (FAO, 2008). Now year-on-year there is decline in wheat yield In recent years, wheat production levels have not satisfied demand, triggering price instability and hunger riots (FAO, 2015). To meet this demand, annual wheat yield increases must rise from the current level of below 1% to at least 1.6%. There is need to increase wheat yield, tolerance to abiotic stresses, pathogens and pests, improve input use efficiency and at last should decrease the losses due to lodging for a sustainable wheat production. Wheat shoot possess many characteristic features. Among these characteristics physio-mechanical properties are responsible for strength of the wheat crop to withstand external trigger forces.If lodging before flowering, then plants may recover and grow upwards. Lodging can reduce yields and increase diseases. Lodging is when the crop falls over.

A normal vertical crop is finely balanced, so anything that upsets the balance will cause it to lodge: strong winds, heavy rain, a very wet soil during late grain filling, tall thin stems that bend, root or stem rots that weaken the plant base (Pinthus 1973). Winds associated with excess water are the worst combination.

Lodging destroys the canopy structure. Solar radiation is no longer intercepted efficiently with high light to young upper leaves and low light to old leaves. Heads are covered in the tangle and the collapsed crop becomes more susceptible to pests and diseases.

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From anthesis onwards the effects of lodging are large. For every day that the crop is lodged yield declines by more than 1%. So for crops severely lodged shortly after anthesis and remaining so, final yield will be less than half that of the upright crop.

Any lodging also makes harvesting more difficult and increases the likelihood of losing grain during harvesting (Tatnell 1995). Various studies have been conducted on plantanatomy, lodging processes, harvest optimisation, animal nutrition, industrial applications and the decomposition ofwheat shoot in soil (Annoussamy *et al.*, 2000; Skubisz *et al.*, 2006). Many researchers reported lodging in wheat (Crook and Ennos 1993; Sterling *et al.*, 2003). The stem lodging at the grain formation stage significantly decreased the grain yield. Among the lodging factors, increased supply of nitrogen increased lodging in wheat (Bremner, 1969; Crook and Ennos, 1995), and oats (Chalmers *et al.*, 1998). Research has been done on mechanical properties of plants during their growth. The wheat straw is tested for shear properties and it is found that it is brittleat low moisture content and hence easy to shear (Kushwaha *et al.*, 1985). The properties of wheat shoot (physical andmechanical) are different for different moisture content and also along with the height of the plant (Galedar *et al.*, 2008; Tavakoli *et al.*, 2009a). At four maturity stages of wheat straw, O'Dogherty *et al.* (1995) measured mechanical properties and reported the mean value of the shear strengthin a range of 4.91-7.26 MPa and Young's modulus mean value was in range of 4.76 to 6.58 GPa. Similar trends were reported for alfalfa crop, as increase in wetness level ofalfalfa stalk caused reduction in bending strength.

However, the shear strength increased towards lower region (Galedar *etal.*, 2008). Tavakoli *et al.* (2009b) determined the values of shear strength (6.81-11.78 MPa), bending strength (6.81-11.78 MPa) and Young's modulus (0.65-1.82 GPa) of wheat straw (Alvand, Iranian variety). Consequence of moisturecontent, loading rate and stalk region on barley straw shearand bending properties has also been reported (Tavakoli *et al.*, 2009a,b). Shear strength of rice and wheat shoots increasedwith loading at all stem node positions (Zareiforoush *et al.*, 2010; Chandio *et al.*, 2013). Changes in mechanicalproperties were also reported by Shahbazi and Galedar (2012)for safflower and by Hoseinzadeh and Shirneshan (2012) forcanola stem. It seems that there is not much published work relatingto shearing properties in relation to tendency to lodge in wheat shoot and its nodal variation. Therefore, the objective of this study was to investigate the effects ofmoisture stress and node position on some physicalproperties including major and minor diameters, thickness, cross-section area, and mechanical properties, namely, shear strength.

MATERIALS AND METHODS

For conducting experiment ten wheat cultivars with three replica of each in two different temperature conditions were used. The wheat varieties were sampled from ICAR-Indian Agricultural Research Institute field area. The primary wheat tillers were collected inharvesting stage and their three nodes from the bottom of the shoot were separated and labeled as node 1, node 2 and node 3 respectively (Figure 1). Leaf blades and sheaths wereremoved prior to any treatment or measurement. To determine the average moisture content of the shoots, the specimens were weighed and then oven-dried at 103°C for 24 h (ASAE, 2006) and finally reweighed. Each node of the shoot was described by measuring its major and minor diameter, and thickness of the elliptical wall to the nearest 0.01 mm using a micrometer. Among the measured mechanical properties shearing force and

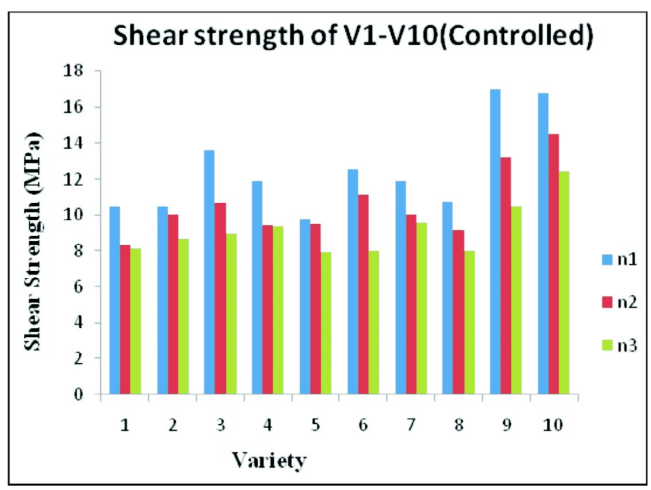

Figure 1: Variation of shear strength at different nodes in controlled wheat cultivars

shearing stress were measured. Shearing force at the point of breaking or cutting of shoot along with the distance for different wheat cultivars was measured in the similar way as is assessed and described for different crops by O'Dogherty *et al.* (1995), Yiljep *et al.* (2005), Nazari Galedar *et al.* (2008) and Shahbazi *et al.* (2012). In present work TA.XT plus Texture Analyser from Stable Micro Systemswas used for shear test of wheat samples. It had force capacity of 500N with force resolution: 0.1 g. The speed of loading can be varied in the range 0.01–40 mm/s. During calibration and setting of the instrument the contact and trigger forces were 0.25 Kg each for a target distance of 10 mm. During the test, the data on force and extension at failure were generated automatically and forces versus displacement curves were obtained. The data was exported using exponent software within the system. The Each wheat sample was tested under 5mm/sec loading speed. The applied force required to break the shoot node was measured. Shear strength or shear failure stress was calculated by dividing the applied force by the cross-sectional area of the node at its rupture point.The shear failure stress(or ultimate shear strength), t_s, of the specimen wascalculated from the following equation:

$$\tau_s = \frac{F_s}{A}$$

Where, F_S is the shear force at failure (N) and A is the wallarea of the specimen at the failure cross-section (mm^2). Shear strength calculated was taken as the measure of shoot strength.

RESULT AND DISCUSSION

Wall Thickness

Lodging resistance in the ten wheat genotypes was positively correlated with stem wall thickness. Researchers have also suggested that thicker stem walls increase lodging resistance in wheat (Packa *et al.*, 2015). In our study for the correlation between lodging score obtained and average wall thickness is poor as R^2 values are very less at all nodes in controlled and stressed conditions. In controlled conditions, variety 7 has highest average wall thickness of 0.898 mm at node 1and has least value of 0.392 mm for variety 6 at node 2. While in moisture stress the maximum wall thickness of 0.683 mm appeared in variety 8 at node 2 and 3, and least value of 0.323 mm for variety 6 at node 1. Thus the variation in wall thickness does not reflect the tendency of lodging in different wheat cultivars accurately.

Area of Cross-section

In our study it was found that stem diameter of wheat plants decreases towards top. At lower nodes the area of cross section is higher than upper nodes. Due to this the shearing characteristics of stem are different at different heights due to cross-sectional heterogeneity. The node area of cross section increases down the plant stalk. Like wall thickness the average area of cross section also has positive correlation with the lodging score. The R^2 values of this correlation at different nodes and under controlled and stressed condition were found to be varying from 0.036 to 0.485. It is clear that merely area of cross section cannot be a reliable parameter to ascertain lodging risk in a crop.

Shear Force

The maximum shear force in each of the cultivars decreases from N1 to N3. This is due to the reason that cutting blades have to traverse more area of cross section at lower nodes than other higher nodes. It is found that at node 1 and 3, shear force is negatively correlated with the lodging score in wheat cultivars. While it has a positive correlation at node 2 and node 3 (stressed condition) (Table 2). The R^2 values range from 0.001 to 0.257 under different conditions. The variation in ultimate force or shear force does not follow a uniform trend when moving from one node to another.

Shear Strength

The lowest value of shear strength is 8.5 MPa for variety 8 and highest value is 14.2 MPa for variety 10 under stressed condition and these values are less as compared to corresponding values of minimum and maximum shear strength of 9.7 MPa and 16.9 MPa respectively in controlled conditions. Similarly the values of shear strength at lower nodes is higher than higher nodes for all cultivars. Thus the ultimate shear stress or shear strength decreases upwards from N1 to N3 (Figure 1 and 2).

Table 1
Variation of R^2 values at different nodes in controlled and stressed condition in wheat cultivars in relation to lodging

	Node 1		*Node 2*		*Node 3*	
Parameter	*CT*	*ST*	*CT*	*ST*	*CT*	*ST*
Wall thickness	0.041^{ns}	0.613***	0.451***	0.334**	0.158*	0.072^{ns}
Area of cross section	0.036^{ns}	0.485***	0.408***	0.311**	0.108^{ns}	0.406***
Shear force	0.172*	0.076^{ns}	0.001^{ns}	0.018^{ns}	0.131*	0.257**
Shear stress	0.776***	0.740***	0.592***	0.681***	0.526***	0.617***

Table 2
Variation of correlation coefficient values at different nodes in controlled and stressed condition in wheat cultivars in relation to lodging

	Node 1		*Node 2*		*Node 3*	
Parameter	*CT*	*ST*	*CT*	*ST*	*CT*	*ST*
Wall thickness	0.203^{ns}	0.784***	0.672***	0.578***	0.399*	0.269^{ns}
Area of cross section	0.191^{ns}	0.697***	0.639***	0.558**	0.329^{ns}	0.637***
Shear force	–0.415*	–0.276^{ns}	0.038^{ns}	0.134^{ns}	–0.362*	0.508**
Shear stress	–0.881***	–0.861***	–0.769***	–0.826***	–0.726***	–0.785***

Since the shear strength is directly proportional to shear force and inversely proportional to area of cross section, the shear strength is found to be low at higher nodes than lower node. N1 node has highest shear strength as compared with N2 and N3. The reason for this may be due to the decrease in stem diameter and cross sectional area with increasing plant height. This phenomenon may be explained by thatmaximum average shearing force increased rapidlythe diameter grew rapidly at thesame time and pull down the value of the shearing strength (Wangyuan *et al.*, 2012). These observations are in agreement with previous reports onmechanical properties of wheat straw (Annoussamy *et al.*,2000; Galedar *et al.*, 2008; Esehaghbeygi *et al.*, 2009). Similar pattern was also reported in wheat straw of Iranian variety (Tavkoli *et al.*, 2009c). The results related to theinteractional effect of the moisture content and internodeposition on the shear strength are also consistent withprevious studies on sunflower stalk (Ince *et al.*, 2005), alfalfastem (Galedar *et al.*, 2008), barley straw (Tavakoli *et al.*, 2009b) and safflower stalk (Shahbazi and Galedar, 2012). The result is significantly correlated with observed lodging in wheat cultivars (Figure 2 and 3). The coefficient of correlation among the lodging score and the obtained values of shear strength is highest for N1 in both controlled and stressed conditions. This depicts that lower nodes are more prone to lodging. Since the shear strength for wheat cultivars grown under moisture stress condition is lower than that in controlled one for all nodes, this indicates that under moisture stress the wheat stalks are more brittle and hence susceptible to lodging than their counterparts in controlled conditions. Less moisture means less shear strength with more risk of lodging vice-versa (Hemmatian *et al.*, 2012). The average moisture content in controlled conditions vary from 9.4-10.4 (%w.b.) and from 11.4-13.4 (%w.b.) under moisture stress in wheat varieties tested for lodging risk.

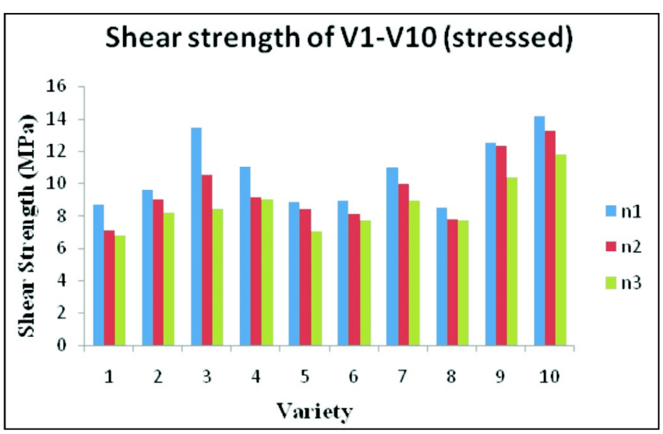

Figure 2: Variation of shear strength at different nodes in moisture stressed wheat cultivars

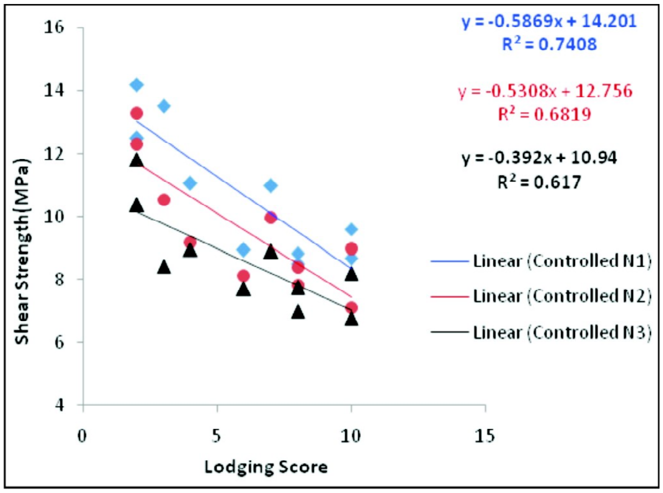

Figure 3: Variation of shear strength of wheat cultivars with lodging score in controlled condition

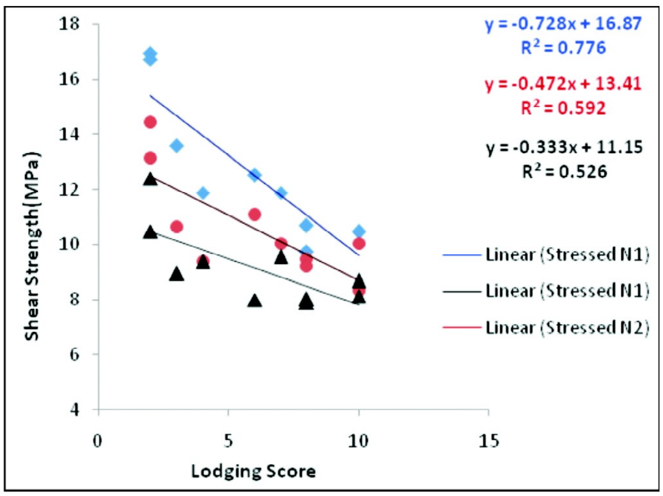

Figure 4. Variation of shear strength of wheat cultivars with lodging score in moisture stress

CONCLUSION

This study shows that among various physical, mechanical and shearing characteristics the shear strength is the most reliable to vividly predict the tendency of lodging in wheat cultivars. While amonst the various parameters measured merely physical propertiescan not be used to forecast or predict the lodging tendency. Not even shear force alone can do this task. It is the ultimate shear strength that depends on both mechanical and physical properties that can be used to predict lodging in a wheat variety. Ultimately this could help screening of varieties based on risk of lodging. This will reduce the production losses. After repetitive testing, a model can be established to predict lodging risk in any wheat cultivar. The technique has immense potential to be later used for other cereal crops also. Apart from this, the effect of varying loading speed of texture analyzer on shear stress and lodging relation can be further explored.

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