LODGING CAUSE HEIGHT AT THE CENTRE OF GRAVITY CHANGES DURING VEGETATION PERIOD FOR OAT

Linda Brunava[1,2], Ina Alsiņa[1]
[1]Latvia University of Agriculture
[2]State Stende Cereals Breeding Institute, Latvia
linda.brunava@gmail.com

Abstract
Height at the center of gravity is a part of mathematical model to interpret risk of lodging used for cereal crops. Because of the anatomical changes during vegetation period, several measured parameters in early milk stage (stem and panicle weight) will differ from over-ripe stage results in their values. The aim of this study was to define approximate values of calculated parameters describing oat (*Avena sativa* L.) height at the center of gravity in early milk and over-ripe stages as well as determine connection with lodging risk. The trial was carried out at the State Stende Cereals Breeding Institute in 2013. There were 5 oat cultivars studied. At the investigated growing stages plant samples were taken from a field and in laboratory conditions stem/panicle weight and length measured. The height at the center of gravity and gravity ratio were calculated using mathematical model by Berry (1998). Results showed that the value of the height at the center of gravity in over-ripe stage was significantly higher ($p<0.01$) than in early milk stage, but correlation with risk of lodging remained. Such lodging resistance describing mathematical model can be useful for oat as well as wheat cultivars.
Key words: oat, stem lodging, centre of gravity, vegetation period.

Introduction

Lodging is a complicated process observed in field conditions, usually after the ear or panicle has emerged. It is the process by which the cereals are displaced from their upright position. Lodging in cereals generally occurs only after the ear or panicle has emerged and can seriously reduce profitability through reduced yield, delayed harvest, increased grain drying costs and reduced grain quality. It is especially unwelcome and dangerous in early milk stage, when the grains are in forming process (Tripathy et al., 2003; Berry et al., 2004).

There are two possible points of failure in the plant structure, the stem and the root. The elongated stem consists of a series of jointed hollow internodes connected by solid swollen meristematic nodes. The stem is strengthened by lignin, but may fail due to bending or buckling of the lower stem internodes. Root lodging results from a failure in root-soil integrity so that straight, unbroken culms lean or fall from the crown. Commonly lodging in oat occurs as a result of culm structural failure rather than loss of root anchorage.

Lodging risk is strongly influenced by wind, rain, cultivar and agronomical factors (variety choice, sowing date, seed rate, drilling depth, rate of nitrogen application, as well as the application of growth regulators). It is clear that weather plays an important role in determining lodging risk, but there is little published information quantifying the weather conditions needed to cause lodging event. Lodging was also found to be more closely associated with the occurrence of rainfall than the amount of rainfall (Baker et al., 1998). Dwarfing genes and growing regulators have been very effective tools for reducing lodging risk and maintaining steady improvements in yield. But on the other hand, in years of severe lodging, the applications of growth regulators have not prevented lodging completely and an analysis of the effects of dwarfing genes on wheat yield showed that the minimum crop height for optimum yield can be 0.7 m (Sterling et al., 2003, Berry et al., 2004).

A model of wheat canopy/root/soil system has been developed, which calculates the risk of stem and root lodging from crop parameters and soil characteristics. The two of the most important components of bending moment model, which describes lodging: height at the center of gravity of the shoot and ear area, are closely related to height and yield respectively (Baker, 1995). It would be important for agronomists and breeders. The model is attempted to work for wheat (*Triticum aestivum* L.), because most is known about the lodging mechanism of this cereal species (Baker et al., 1998; Berry et al., 2000; Berry et al., 2003). As this model is developed for all small-grained cereals it would be necessary to test it for oat (*Avena sativa* L.) as well.

Because of the anatomical changes during vegetation period, several measured parameters in early milk stage (stem and panicle weight) will differ from over-ripe stage results in their values. The task of trial was to define approximate values of calculated parameters describing oat height at the center of gravity in early milk and over-ripe stages and determine connection with lodging risk.

Materials and Methods

The field trials were carried out at State Stende Cereals Breeding Institute in 2013. Five oat cultivars (int. al. four varieties – 'Stendes Darta', 'Laima', 'Arta', 'Kirovec'; and one breeding line – '33122')

Table 1

Meteorological data in the experimental period (Stende meteostation data, 2013)

Month	The mean daily temperature, °C			Sum of precipitation, mm		Percentage of monthly precipitation from long term average, %
	Monthly	Long term average	Long term average +/-	Monthly	Long term average	
April	4.0	4.3	-0.3	34.9	37.0	94.3
May	13.7	10.2	3.5	86.1	45.0	191.3
June	16.9	14.2	2.7	74.5	57.0	130.7
July	16.9	16.3	0.6	36.2	87.0	41.6
August	16.6	15.5	1.1	45.2	87.0	52.0

were used. The soil of the site was sod-podzolic, the humus content – 20 g kg^{-1}, the soil pH KCl – 6.6, the available for plants content of phosphorus P – 39 mg kg^{-1}, and that of potassium K – 53 mg kg^{-1}. The pre-crop was barley. All agro-technical operations were carried out at optimal terms according to the weather conditions during the vegetation period, depending on the plant development phases. Seed rate was 500 seeds per 1 m^2. Before cultivation of the soil a complex mineral fertilizer was applied: N – 51, P – 30, K – 42 kg ha^{-1}. Variants were arranged in four replications with a plot size 10 m^2 in a randomized block design.

The temperature and moisture conditions provided perfect oat field germination in 2013 and are represented in Table 1. The mean daily temperature changes were insignificant. Precipitations exceeding long term average and sufficient mean daily temperatures in May and June provided good conditions for germination and tillering. Low sum of precipitation and mean daily temperature close to long-term average in July and August ripened oat grains and gave excellent yield. However, strong wind gusts through all vegetation period provided good conditions for stem lodging.

Twice in vegetation period in principal growth stages – early milk (code 73 after BBCH-scale) and harvest-ripe (code 92 after BBCH-scale) – there were taken a bundle of examples containing 40 plants from each cultivar (10 from each replication). Plants were used for measurement from tillering node to the end of panicle. In experimental investigation the length and weight of stem and panicle for each plant were measured. All measured parameters were used for calculation the height at the center of gravity and gravity ratio of the height at the center of gravity and plant height, by setting them in formulas (1) by P.M. Berry, 1998 and (2) by authors.

$$X = \frac{(S_L S_W + 2 S_L E_W + E_L E_W)}{2(S_W + E_W)} \qquad (1)$$

$$k = \frac{X}{(S_L + E_L)} \qquad (2)$$

where

X – height at the center of gravity (cm),
S_L – stem length (cm),
S_W – stem weight (g),
E_L – panicle length (cm),
E_W – panicle weight (g),
k – gravity ratio.

Before harvesting the lodging resistance was observed on field for each cultivar in 9 point system:
9 points – very high lodging resistance – all stems are on their upright position,
7 points – high lodging resistance – 25% of stems are laid down in 30°,
5 points – average lodging resistance – 50% of stems are laid down in 45°,
3 points – low lodging resistance – 75% of stems are laid down in 60°,
1 point – very low lodging resistance – all stems are laid down, harvesting is not possible.

The obtained results were statistically processed by MS Excel program package using the methods of descriptive statistics; arithmetic mean value and standard division were calculated for each measured and calculated parameter. ANOVA procedures were used for data analysis. P-values less than 0.05 were considered to be statistically significant.

Results and Discussion

The cultivars selected for study varied in their anatomical measurements and are represented in Table 2. Stem length varied among tested cultivars from 89.13 ('Kirovec') to 109.50 cm ('Arta') in GS 73 and from 81.56 ('Kirovec') to 103.57 cm ('Arta') in GS 92. Panicle length varied from 17.28 ('Kirovec') to 20.43 cm ('Arta') in GS 73 and from 14.48 ('Kirovec') to 17.34 cm ('Arta') in GS 92. Both stem and panicle length was significantly ($p<0.01$) lower in GS 92, compared with GS 73. By physiological processes in plants, it is explainable with ripening process. Plant cells are still green and full with water and nutrients in milk development stage, but through dough and ripening stages plant cells are drying and dwindling. As cells are becoming smaller also full plant becomes shorter compared with milk development stage. Unfortunately, there is a lack of literature describing plant stem structure changes in ripening process.

Stem and panicle weight has significant ($p<0.01$) difference between growing stages as well. Stem weight varied from 5.73 ('Kirovec') to 9.25 g ('Laima') in GS 73 and from 1.17 ('Kirovec') to 2.04 g ('Stendes Dārta') in GS 92 (represented in Figure 1). The weight in GS 73 was approximately 3.5 to 4.9 times heavier than in GS 92.

Similar situation was observed with panicle weight, only the difference is 1.5 to 2.2 times (comparing with stem weight approximately four times). It is explained with grain filling process in scale. Panicle is drying and loses its weight, instead of grains in it which are ripening and getting heavier. Stems have no component (internode, nodes, and leaves) which would get heavier; moreover, part of nutrients from straw to grains is increasing their weight.

Plant height is depicted in Table 3. The statement that cultivars with higher plants have higher lodging risk is false. Results of this study showed that the cultivar 'Kirovec' whose characteristics is a shorter plant length; lodging was the highest – 3 points, observed on field. A mathematical model is given for calculating height at the center of gravity in literature (Berry et al., 2004), but unfortunately physiological processes and results are not mentioned. Height at the center of gravity describes the place of the plant, where the force line of gravity is going through. If this parameter is located lower, the risk of lodging is larger.

Table 2

Values of measured parameters used in the model of lodging risk determination, mean ± sd[1]

Cultivar	Stem length, cm		Stem weight, g		Panicle length, cm		Panicle weight, g	
	GS 73a[2]	GS92b	GS 73a	GS92b	GS 73a	GS92b	GS 73a	GS92b
Stendes Dārta	100.28 ±4.72	92.44 ±3.75	7.13 ±0.59	2.04 ±0.23	17.56 ±0.27	15.75 ±0.77	2.57 ±0.20	1.71 ±0.30
33122	96.23 ±4.91	87.27 ±4.93	8.64 ±1.91	1.90 ±0.39	19.06 ±1.04	15.65 ±1.31	3.73 ±0.59	1.71 ±0.58
Arta	109.50 ±2.66	103.57 ±2.84	8.02 ±0.87	1.84 ±0.27	20.43 ±0.60	17.34 ±1.49	3.56 ±0.43	1.68 ±0.27
Kirovec	89.13 ±5.20	81.56 ±5.82	5.73 ±1.29	1.17 ±0.16	17.28 ±1.43	14.48 ±0.78	3.18 ±0.57	1.62 ±0.28
Laima	102.83 ±1.46	97.38 ±7.35	9.25 ±0.49	1.95 ±0.37	18.48 ±0.86	15.33 ±1.68	3.53 ±0.41	1.57 ±0.50
$LSD_{0.05}$	3.01		0.54		0.71		0.28	
$LSD_{0.01}$	4.05		0.73		0.96		0.38	

[1]sd – standard deviation, [2]Trait means followed by different letters are significant by different growing stages at the level of $p<0.01$.

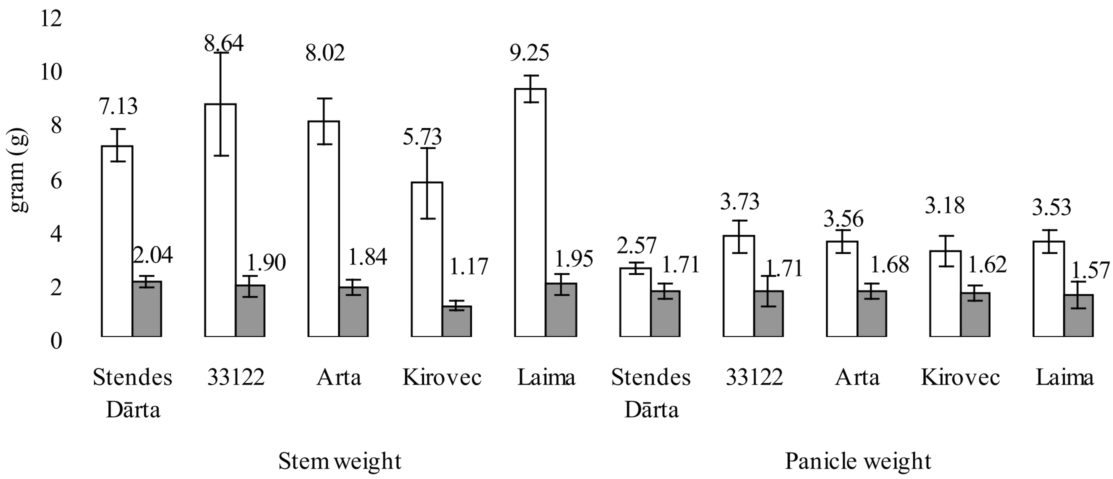

Figure 1. Stem and panicle weight (g) changes during vegetation period; where GS 73 □, GS 92 ■.

Table 3

Relationship between lodging resistance and calculated plant parameters

Cultivar	Lodging (points)	Plant height (cm)		Height at the center of gravity (cm)		Gravity ratio	
		GS 73a[1]	GS 92b	GS 73b	GS 92a	GS 73b	GS 92a
Stendes Dārta	9	117.84	109.02	65.65	70.47	0.56	0.65
33122	9	115.30	102.91	65.53	66.84	0.57	0.65
Arta	7	129.93	120.91	74.70	80.60	0.58	0.67
Kirovec	3	106.41	96.04	63.59	68.33	0.60	0.71
Laima	9	121.30	112.71	68.11	73.41	0.56	0.65
$LSD_{0.05}$		3.39		2.54		0.01	
$LSD_{0.01}$		4.56		3.43		0.01	

[1]Trait means followed by different letters are significant by different growing stages at the level of p<0.01.

Table 4

Correlation coefficients (r) between lodging resistance and calculated plant parameters (n=5; $r_{0.05}$=0.878; $r_{0.01}$=0.959)

GS 73	Plant length	Height at the center of gravity	Gravity ratio	Lodging resistance
Plant length	1.000	*	*	*
Height at the center of gravity	0.935[a]	1.000	*	*
Gravity ratio	-0.416	-0.055	1.000	*
Lodging resistance	0.524	0.203	**-0.955[a]**	1.000
GS 92	Plant length	Height at the center of gravity	Gravity ratio	Lodging resistance
Plant length	1.000	*	*	*
Height at the center of gravity	0.905[a]	1.000	*	*
Gravity ratio	-0.504	-0.088	1.000	*
Lodging resistance	0.491	0.075	**-0.998[ab]**	1.000

[a] Correlation is significant at the level of p<0.05; [b] Correlation is significant at the level of p<0.01.

As the height at the center of gravity is hardly related to plant height and plant height for various cultivars is different, it is not comparable parameter among tested cultivars. For accurate comparison a mathematically determined parameter – gravity ratio, which shows the proportion between height at the center of gravity and plant height was established. The gravity ratio in GS 73 for cultivars with low lodging resistance (9 points) was the lowest 0.56 ('Stendes Dārta' and 'Laima') – 0.57 ('33122'), but for the variety 'Kirovec' – 0.60, at it is characterized with low lodging resistance (3 points). For the cultivar 'Arta' the gravity ratio was 0.58, but lodging resistance 7 points. In addition, there was observed the fact that gravity ratio in GS 92 is higher than in GS 73. It is explainable with physiological changes in plants during ripening. As the measurement of the plant parts differs in growing stages used for calculations, calculated parameters are also different. Plant physiological changes during ripening make the gravity ratio higher; for example, for the cultivar 'Stendes Dārta' the gravity ratio in GS 73 was 0.56, but in GS 92 – 0.65.

Correlation among mathematically calculated parameters and lodging resistance is performed in Table 4.

Strong negative correlation ($r = -0.955 > r_{0.05} = -0.878$ in GS 73 and $r = -0.998 > r_{0.01} = -0.959$ in GS 92) was observed between the lodging risk and gravity ratio as it was described previously. Consequently, if the gravity ratio is higher, lodging resistance will be lower. As the correlation between lodging resistance and height at the center of gravity is only r = 0.203, it is necessary to improve it. Authors offer a model (Formula 3) for lodging resistance detection combining model of P.M. Berry and their own formula of ratio calculation:

$$k = \frac{\dfrac{(S_L S_W + 2S_L S_W + E_L E_W)}{2(S_W + E_W)}}{(S_L + E_L)} = \frac{(S_L S_W + 2S_L E_W + E_L E_W)}{2(S_W + E_W)(S_L + E_L)} \quad (3)$$

By using such a model, it will be possible to detect lodging resistance for oat cultivars in both early milk and harvest-ripe growing stages. Furthermore, the gravity ratio could be useful for oat breeders at meteorological conditions, when lodging is not observed.

Conclusions

1. A significant ($p<0.01$) difference between the values of measured parameters in early milk and harvest-ripe stages, showing higher values in early milk stages was observed.
2. A strongly negative correlation ($r = – 0.998$) between the gravity ratio and lodging resistance for tested cultivars, meaning that lodging resistance could be calculated from height at the center of gravity was observed.
3. Gravity ratio changes were observed in both growing stages for all tested cultivars; for example, for the variety 'Kirovec' in early milk stage ratio was 0.60, but in over-ripe stage 0.71.
4. The formula for calculating gravity ratio could be used for oat lodging resistance determination in both early milk and over-ripe stages.

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