Morphometric parameters of the stem of lodging-resistant spring triticale in the conditions of the West Siberian region

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Abstract. In the course of field and laboratory research, selection samples of spring hexaploid triticale were studied for their selection-valuable traits and lodging resistance. The correlation analysis revealed a correlation between the individual traits that determine lodging tolerance. The most stable relationship of lodging resistance is with the length of the second and third internodes and the breaking strength of the straw. An additional selection criterion for lodging resistance is the sum of the lengths of the 2nd and 3rd internodes. Non-lodging varieties with high grain productivity that have significant differences in architectonics have been identified. These samples can be promising in lodging resistance selection without the involvement of sources of short stalkedness, having a number of negative traits.

1 Introduction

The main strategic direction in the breeding of cereal crops remains the creation of varieties with high productivity potential, which under production conditions would be realized by at least 70-80% [1].

Triticale is considered a promising crop for cultivation in the northern regions of the country due to its versatile use and high biological potential [2]. Compared to the parental forms, the new triticale varieties can use the available soil and climatic resources more rationally, as well as significantly diversify and reduce the cost of production of high-quality forage and food grains [3].

Yield of triticale, like other cereal crops, is an integral trait and depends on the individual potential productivity of plants, their response to growing conditions, resistance to adverse environmental factors and the relationship of plants in the biocenosis [4]. Individual productivity is genetically determined and depends on the structure of plants, the rate of their development and the intensity of physiological processes [5-6].

Most triticale varieties are generally long-stemmed and have low lodging tolerance, which disturbs normal plant growth and development [7-8].

When plants are lodged, the size of the photosynthetic surface decreases. With lodging, plants have reduced photosynthetic surface area, slowing down the assimilation of nutrients

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and water. The grain has a low content of nutrients [9]. Mechanized harvesting of such plants is difficult. In addition, under conditions of high humidity, the leaves of lodged plants can become a favorable environment for the spread of diseases. This reduces yield and grain quality [10].

Long-stemmed triticale plants tend to form a large ear; in this connection, a number of researchers note a positive correlation between grain yield and plant height [11].

The main direction of breeding is to obtain lodging-resistant forms of cereal grains with minimal outflow of assimilates into the stem without loss of ear productivity. One of the ways to solve this problem is a detailed study of the strength characteristics of straw tissues of breeding samples of cereal crops and their response to various types of loads.

This assessment is time-consuming in the field and is only possible in years when weather conditions are conducive to increased lodging. In addition, the results are subjective and give a general idea of the characteristics of the variety, but don't allow an individual assessment of the plants [12].

The use of assessing the strength characteristics of cereal varieties in laboratory conditions using instrumentation allows obtaining objective data on the resistance of plants to lodging [13].

The aim of the study: by using non-labor-intensive and informative methods, based on a set of data of architectonics and physical and mechanical properties of the stems of plants to identify lodging-resistant breeding samples of spring triticale.

2 Materials and methods

The study of the influence of the structure of triticale plants on lodging resistance included the following stages: phenological studies using a unified phenological scale – BBCH code [14]; field assessment of lodging resistance according to the method [15]; study of plant architectonics; determination of physical and mechanical properties of stems; assessment of the influence of elements of the stems architectonics and physical and mechanical properties on plant productivity and their lodging resistance.

The experiment was conducted in 2021-2022 on 19 breeding samples of spring hexaploid triticale (Table 1). The selection samples were obtained from the collections of the following institutes: All-Russian Institute of Plant Genetic Resources (VIR) and Siberian Institute of Plant Growing and Breeding – Branch of the Institute of Cytology and Genetics. The selection samples were represented by forage varieties of different ripeness groups, with different egological and geographical origins and with field resistance to leaf blight, dusty and hard smut, yellow rust and stem rust.The samples were grown on cereal precursors in triplicate under natural conditions without fertilizer and irrigation. The field trial was carried out in accordance with standard techniques.

From each breeding form, 25 representative plants were selected when they reached the phase of full ripeness.The following macrometric parameters were determined for the plants: stem length, number of internodes, length of the 2nd, 3rd and upper internodes (distance from the upper stem node to the base of the ear), diameter of the 2nd and 3rd internodes, thickness of the 2nd and 3rd internodes, weight of a piece (10 cm length) of the straw of the 2nd internode.

Straw strength was determined on 10-cm sections of second internode straw, which were fixed using a made experimental device. The strength of the internode fracture was determined by the peak reading of a DACELL DN-FGA-K2 electronic dynamometer.

The following mathematical methods were used to identify the criteria for assessing the parameters of lodging resistance in samples: determination of stem tissue density by cross-sectional area and linear weight of the stem sample; analysis of variation; analysis of variance and correlation.

Table 1. Trial forms of spring hexaploid triticale.

№	Name sample	Group ripeness	Origin	Most valuable characteristics of the variety
1	Arsenal	mid-early	Ukraine	Awned, medium-dense ear. Straw of medium length. High yielding.
2	Divergent No.19	mid-late	Novosibirsk, SibNIIRS	Awned, dense ear. Straw is short. Resistant to powdery mildew and bunted grass. Medium yielding.
3	Divergent No.21	mid-late	Novosibirsk, SibNIIRS	Dense ear. Straw is short. Resistant to lodging.
4	Divergent 6xA1 No 19	mid-late	Novosibirsk, SibNIIRS	Awned, dense ear. Medium yielding.
5	Divergent 6xVrnA1	mid-late	Novosibirsk, SibNIIRS	Awned, dense ear. Medium yielding.
6	Ditr 165	mid-maturing	Novosibirsk, SibNIIRS	Awned, dense ear. Grain is well made. Resistant to powdery mildew and buntings.
7	Ditr 168	mid-maturing	Novosibirsk, SibNIIRS	Semi-awny, dense spike. Grain is well made. Resistant to powdery mildew and types of smut.
8	K-3992	early maturing	Saint Petersburg, VIR	Awned spike. Medium dense ear. Resistant to lodging. Medium yielding.
9	Kissa h/a	mid-maturing	Mexico	Dense ear, fully spiky. Well executed grain. Resistant to lodging. Drought-resistant. Not affected by powdery mildew.
10	LMK462/208	mid-late	Novosibirsk, SibNIIRS	High density of ear. Medium stemmed. Smooth grain. Medium yielding.
11	O312/29 w/a	mid-late	Novosibirsk, SibNIIRS	Semi-awned, high-dense ear. Long-stemmed. Grain well done. Medium yielding.
12	O312/29 awn w/p	mid-late	Novosibirsk, SibNIIRS	Awned, highly dense spike. Spike neck without hair. Long-stemmed. Smooth grain. Medium yielding.
13	O312/38	mid-late	Novosibirsk, SibNIIRS	Awned ear, high-dense ear. Long-stemmed. Medium yielding.
14	O312/153	mid-late	Novosibirsk, SibNIIRS	Awned ear. High density ear. Hairy ear neck. Long-stemmed. Smooth grain. Medium yielding.
15	SiArs 217	mid-late	Novosibirsk, SibNIIRS	Awned, long, high-dense prismatic ear. Average weight of 1000 grains. Thick straw. Medium brown rust resistance. High yielding.
16	Timur	mid-maturing	Krasnodar	Awned, medium-dense ear. Grain of medium size. Medium yielding.
17	Sirs57× Ukro	late maturing	Novosibirsk, ICIG	Low stem, resistant to lodging. Spike dense, awnless. Not affected by powdery mildew.
18	UK 30/33	mid-late	Novosibirsk, SibNIIRS	Awned, high-density of ear. Long-stemmed. Smooth grain.
19	Ukro (k-3644)	mid-maturing	Russia, Ukraine	Large dense awned ear. Long awns. Smooth grain. Resistance to lodging is high. Drought tolerance. Not affected by powdery mildew. High weight of 1000 grains. High yielding.

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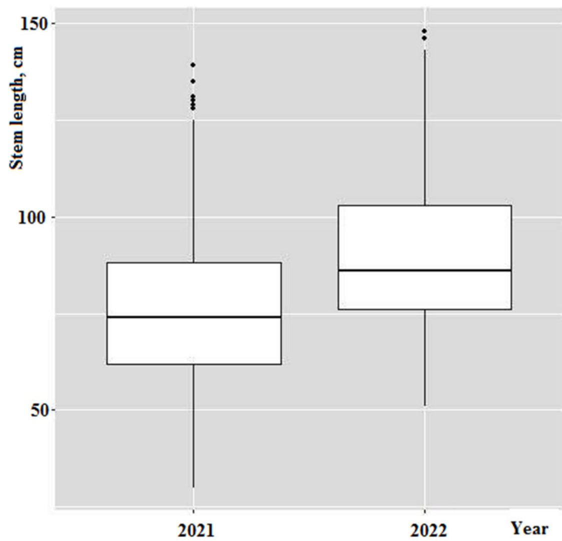
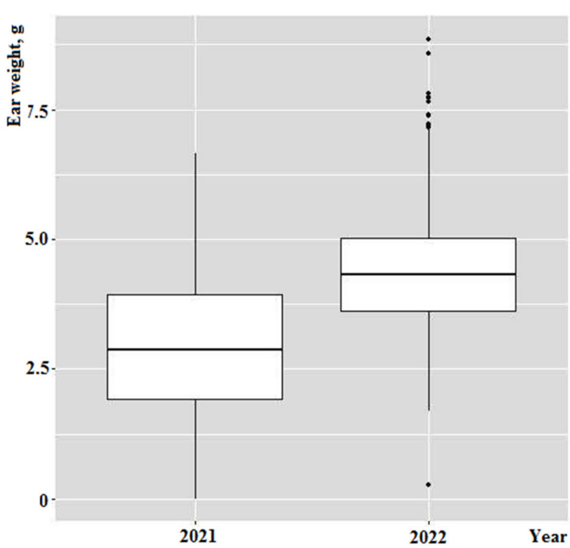
3 Results and discussion

During the observation period, a slight lodging in the waxing and ripening phases of the grain was observed in the following samples: O312/38, O312/153, O312/29 w/a, O312/29 awn w/p.

The architectonics features of the samples studied changed over the study period and were highly dependent on vegetation conditions (Figure 1, a). The unfavourable precipitation conditions of the first year of the trial occurred in stages VI to IX of organogenesis, which had a rather significant effect on plant height and productivity. This fact is pointed out by quite high coefficients of variation. (*V*, %).



a) stem length, cm; *V* = 28.08 % (2021); *V* = 22.64 % (2022);



b) ear weight, g; *V* = 31.02 % (2021); *V* = 27.03 % (2021).

Fig. 1. Scope diagrams of the trait values by year,

According to the VIR classification [16], the selection samples were grouped into 5 groups: dwarf, semi-dwarf, short, medium and tall (Figure 2). Sample O312/29 was the longest-stemmed (122.2 cm). Samples under the common name Divergent formed a group of dwarf forms (54.9 - 63.3 cm). The most of the samples belonged to the semi-dwarf and short groups.

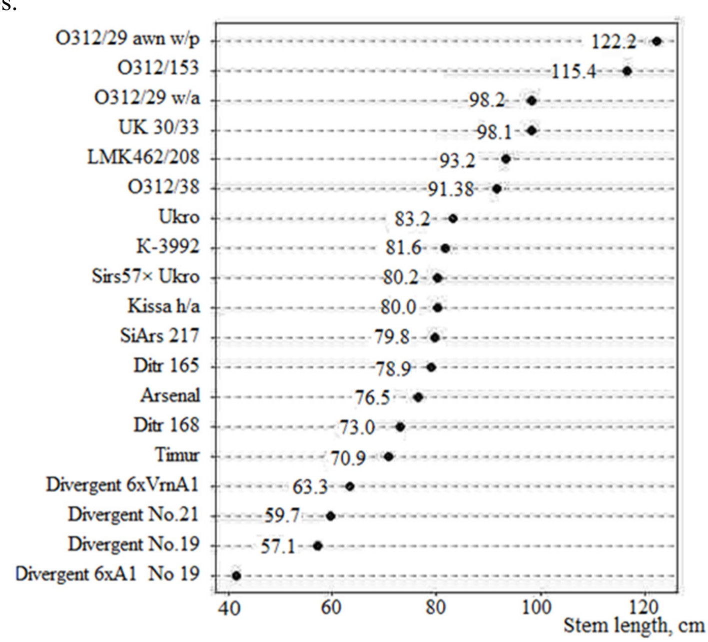


Fig. 2. Straw length distribution diagram.

A visual lodging resistance point of 8 was given to samples from the medium- and tall-growing groups. However, all of the tested samples formed a sufficient yield (Table 2).

Table 2. Yield and straw morphological parameters of breeding samples spring triticale.

Characteristic	**Sample size, pcs.**	**Straw length, cm**		**Lodging resistance, point**	**Ear weight, g**	**Internodes length, cm**			**Diameter of the second internode,**	**Thickness of the second internode, mm**	**Weight 10 cm of straw, g**
						second	**third**	**top**			
Dwarf	115	min	30.00	9	2.51	9.54	14.15	16.87	4.01	0.77	0.24
		max	83.00								
		average	54.87								
Semi-dwarf	504	min	39.00	9	3.78	11.98	20.84	26.79	4.25	0.64	0.26
		max	134.00								
		average	76.95								
Short	200	min	56.00	9	3.68	14.11	22.88	32.44	4.39	0.61	0.27
		max	130.00								

		average	95.32								
Medium	50	min	83.00	8	4.23	16.79	21.93	42.85	4.24	0.59	0.27
		max	143.00								
		average	116.49								
Tall	50	min	76.50	8	4.50	17.11	25.76	45.67	4.57	0.60	0.32
		max	148.00								
		average	122.21								

The results of the eye-tracking evaluation cannot be considered fully reliable, as the set of selection samples was studied in small-plot sowing, and the weather conditions during the study period were not conducive to the active lodging. On this basis, lodging tolerance testing was not limited to field assessment methods, which do not always allow the level of technological performance to be determined under unregulated environmental conditions. To assess the individual variability of the studied samples in terms of lodging resistance, methods based on determining the varietal characteristics of the architectonics and physical and mechanical properties of spring triticale plants were used.

Within each group, lodging-resistant varieties with high grain production with significant differences in architectonics were identified. Selection samples Divergent6×VrnA1, Divergent No 19 and Timur had the straw with the maximum wall thickness of the second internode (t_{II} = 0,8÷0.86 мм). The hybrid Sirs57× Ukro had the highest ear productivity with an ear weight of 6.35 g. This parameter was slightly inferior to the selection samples Ukro, LMK, Kissa h/a, O312/29 w/a, O312/29 awn w/p with an ear weight of 4 - 4.5 g (Table 3).

Table 3. Ear productivity and strength properties of triticale plant stem tissue.

№	Name of sample	Ear length, cm	Spikelets /ear, pcs	Ear density	Ear weight, g	Segment mass, g	Mechanical strength, kg	Stem tissue density, kg/м^3
1	Arsenal	9.59	20.19	2.19	3.63	0.21	2.43	321.31
2	Divergent No.19	9.26	24.2	2.65	3.07	0.27	2.83	305.03
3	Divergent No.21	9.53	22.48	2.38	2.68	0.22	2.72	308.12
4	Divergent 6xA1 No 19	8.98	21.84	2.63	1.28	0.23	1.76	350.02
5	Divergent 6xVrnA1	9.63	23.16	2.42	2.85	0.24	2.62	293.03
6	Ditr 165	10.89	24.06	2.22	3.36	0.21	2.49	348.99
7	Ditr 168	11.21	24.2	2.17	3.36	0.22	2.31	332.5
8	K-3992	11.34	23.62	2.09	3.61	0.42	1.96	465.4
9	Kissa h/a	11.68	24.76	2.13	4.17	0.24	2.34	397.46
10	LMK462/208	11.81	28.06	2.64	4.07	0.34	3.42	397.46
11	O312/29 w/a	10.19	27.28	2.7	4.5	0.32	3.7	441.63
12	O312/29 awn w/p	10.21	26.9	2.66	4.23	0.27	3.27	399.42
13	O312/38	12.0	29.96	2.52	3.07	0.25	2.61	392.09

14	O312/153	10.44	27.52	2.64	3.77	0.23	2.7	332.83
15	SiArs 217	11.84	27.7	2.35	3.94	0.28	3.2	333.07
16	Timur	11.2	25.8	2.31	6.35	0.28	3.47	373.01
17	Sirs57× Ukro	10.32	20.66	2.01	3.73	0.26	2.92	355.83
18	UK 30/33	10.35	28.74	2.81	3.82	0.24	2.76	334.17
19	Ukro (k-3644)	11.20	23.95	2.15	4	0.21	2.31	317.16

The susceptibility of the plants to lodging was assessed by the value of mechanical resistance determined by the value of the dynamometer reading (*F*, kg). The peak reading of the device characterised the yield strength of the sample tissue, exceeding which led to irreversible deformation and stem fracture.

The selection samples had significant differences in this parameter, indicating a different degree of lodging tolerance. The highest lodging strength values were found in samples O312/29 w/a (*F* = 3,7 kg), LMK 462/208 (F = 3,42 kg), Sirs57× Ukro (*F* = 3,47 kg), и O312/29 awn w/p (*F* = 3,27 kg) (tabe. 3). These can be promising in lodging resistance breeding without the use of short-stalked sources with a number of negative traits.

Paired correlations were calculated using Pearson's method and statistical significance was assessed using Student's t-criterion [17].

The analysis of the correlation matrix revealed the presence of direct or inverse relationships between individual traits that determine the lodging resistance of selection samples of spring triticale (Table 4). Significantly negative correlation relationships were found between lodging resistance and the length of the 2nd internode (*r* = - 0.59*), with the length of the top internode (*r* = -0, 60*) and ear weight (*r* = - 0.65*). A strong negative correlation was found between the load value and the lodging value (*r* = - 0.86*). The trait of lodging resistance is significantly positively correlated with the diameter of the 2nd internode (*r* = 0.59*), mass of 10 cm of straw length (*r* = 0.50*). The ear weight showed a significant positive correlation with ear length (*r* = 0.496*), stem length (*r* = 0.543*), 2nd internode diameter (*r* = 0.465*) and force on break (*r* = 0.578*). The trait stem length in the studied samples has a positive correlation with the trait of top internode length (*r* = 0.84*) and ear weight (*r* = 0.54*), but weakly correlated with the other traits and has a negative relationship with the degree of lodging of crops.

As shown by the results of the research, the most stable relationship of lodging resistance is shown with the length of the second and third internodes, the strength of the straw on the fracture. The sum of the length of the 2nd and 3rd internodes is used as an additional selection criterion for lodging resistance.

4 Conclusion

The realization of productivity and lodging resistance of selection samples of spring triticale depends on a complex of factors. The varietal characteristics of the macrostructure and physical and mechanical properties of the straw of the plants are informative for selection practice.

Consideration of the architectonics and physical-mechanical properties of the stems is informative when the plants grow under favourable conditions, when under field conditions the negative influence of environmental factors on lodging resistance is minimal and it is difficult to select resistant samples. Due to the significant correlation between the elements of productivity, macrostructural, dynamic features of the stem and the degree of lodging, it is recommended to use the selected parameters as selection criteria for assessing resistance to lodging. The lodging-resistant varieties with high grain productivity identified within each group are valuable source material for the selection of new varieties.

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