Genetic resistance of cultivated oat and the influence of the mineral nutrition level on stem lodging in Western Siberia

A.V. Lyubimova[1], *M.N.* Moiseeva[2], and *D.I.* Eremin[1,*]

[1] The Research Institute of Agriculture of the Northern Trans-Urals - a branch of the Federal State Budgetary Institution of Science of the Federal Research Center Tyumen Scientific Center of the Siberian Branch of the Russian Academy of Sciences, Tyumen, Russia
[2] State Agrarian University of the Northern Trans-Urals, Tyumen, Russia

Abstract. The genetic resistance to stem lodging of cultivated oat of the Western Siberian selection with different levels of mineral nutrition in the conditions of the Northern Trans-Urals has been studied. The experimental scheme provided for three new varieties of intensive oat: Talisman, Otrada, Foma. Various levels of the agricultural background were created by applying mineral fertilizers that ensure the planned yield of 3.0, 4.0, 5.0 and 6.0 t/ha of grain. In the course of research, it was found that the Talisman variety has a tendency to lodging at the genetic level. The Otrada variety is able to withstand a yield of up to 5.0 t/ha of grain, Foma – at least 6.0 t/ha. It was revealed that the resistance to lodging has a negative correlation with the length of the upper internode (r=-0.7) and panicles (r=-0.8), as well as a positive correlation with the plant height (r= 0.8). Resistance to stem lodging by 34.3% depends on the level of mineral nutrition, 11.5% - on the genetics of the variety and 6.1% - on the growing season's weather conditions.

1 Introduction

Cereal plants have a characteristic type of stem, which is usually called a straw. According to its structure, it is rounded in shape, usually hollow inside, and from a few centimeters to a meter or more in length. It is this structure that ensures the formation of seeds at a height, and they are scattered after maturation due to the amplitude.

Intensive-type varieties were created in the process of grain crops selection, which are capable of forming a yield of up to 10.0 t/ha of grain [1]. However, they were created at the time when not so much attention was paid to the problem of grain crops lodging. The absence of high agricultural backgrounds in production providing consistently high yields can be considered the reason for this.

Cultivated oats were the most vulnerable in relation to stem lodging from cereal plants. It is usually sown as the last crop in rotation. Therefore, the yield formation is due to the after-effect of fertilizers or residues of nutrients unspent by the predecessor. However, the

* Corresponding author: soil-tyumen@yandex.ru

attitude to oats has changed after agrarians assessed the nutritional value of this crop and its beneficial properties for humans [2]. In some farms, high doses of fertilizers are applied under oats to obtain maximum yield. Very often this leads to complete oat lodging in the second half of the growing season. Therefore, breeders must necessarily provide for genetic resistance to lodging in new varieties at high agricultural backgrounds, where a yield of 6.0 t/ha and higher is formed.

The lodging of grain crops is a rather complicated process, although even 30-40 years ago it was believed that this problem exists only for long-stemmed varieties [3]. However, after analyzing the world collection of cereal plants, scientists have found that there are tall varieties of oats with the straw reaching one meter, but the resistance to stem lodging is very high. Short-stemmed varieties were also bred, which lodged even with minimal yield. Practice indicates that grain crops' lodging cannot be considered only from the position of the straw length [4]. It is also necessary to consider the panicle structure – a loose panicle gives a very high sailing capacity, which contributes to grain lodging from the second half of the growing season. High yield also leads to stem lodging since the first and second internodes do not withstand the panicle mass. This is especially evident in the phase of milky ripeness.

Currently, breeders pay special attention to the lodging tendency; as a result, modern varieties have a restriction on internodes' growth at the genetic level. But this solves the problem only partially. When grown on a natural or moderate agricultural background with the formed oat crop of no higher than 3.5-4.0 t/ha, lodging is practically not manifested. However, with further increase in the agricultural background providing a yield of up to 6.0 t/ha, the lodging problem appears on multiple varieties, despite that they were declared as non-lodging. Therefore, it is essential to conduct additional tests of the varieties being created at a high agricultural background to understand their potential with respect to the straw's mechanical strength, which can keep the maximum yield in an upright position [5].

The purpose of this research was to study the nature and mechanics of Siberian oat varieties' lodging with different levels of mineral nutrition ensuring the formation of grain yields up to 6.0 t/ha.

2 Objects and methods of research

Studies on the mineral fertilizers' effect on the lodging of oat varieties were carried out on the experimental field of the State Agrarian University of the Northern Trans-Urals. The field is located near Uteshevo village in the Tyumen region. The natural and climatic zone is the northern forest-steppe. Coordinates 69º09/29$^{//}$north latitude; 65º19/42$^{//}$ east longitude. The soil is leached shallow heavy loamy chernozem formed on the surface carbonate loams [6]. The nature of organic carbon's vertical distribution is sharply decreasing. The organic carbon content in the plowing horizon is 4.44-5.25%. Deeper than 30 cm, its content decreases sharply to 2.56% [7]. The soil of the experimental site contains 0.43-0.44% of total nitrogen. The availability of nitrogen available to plants during the sowing period is very low (<8 mg/kg of soil). The gross phosphorus content in the plough layer is 0.16-0.18%. This element of nutrition is mainly found in the organic soil matter. The availability of mobile phosphorus available to grain crops is average and amounts to 80-120 mg/kg of soil. The potassium content in arable soils of the forest-steppe zone of the Trans-Urals is more than 180 mg/kg, which corresponds to high availability [8]. The exchange acidity is 5.5-5.7 units with base saturation degree of more than 90% of the cation exchange capacity.

Varieties of oats of Western Siberian selection were used in the experiment:

Talisman oat variety. Bred by the Research Institute of agriculture in collaboration with the Narymskaya SSS by the method of individual selection from a hybrid combination obtained from crossing Flamingsnova × Metis varieties. A *mutica* variety. This is a mid

ripening variety resistant to lodging. It is highly resistant to grain fall. The variety forms medium-size grain. Talisman is included in the list of valuable varieties in terms of grain quality.

Medium resistance to drought. It is recommended to use for grain and green fodder. It has been included in the State Register of Breeding Achievements in the Tyumen Region since 2002.

Otrada oat variety. Bred by the Research Institute of agriculture of the Northern Trans-Urals by the method of step-by-step hybridization followed by selection from a hybrid population (WW 170079 × Pc 39) × (Mutica 600 × Risto). A *mutica* variety. This is a mid ripening, high-yielding variety for grain feed use. The formed grain has high technological properties, high natural weight, medium-sized with low hoodness. The variety is resistant to lodging, grain fall and is moderately resistant to spring-summer drought. It has been included in the State Register of Breeding Achievements in the Tyumen Region since 2013.

Foma oat variety. Bred by the Research Institute of agriculture of the Northern Trans-Urals. Creation method: step-by-step hybridization followed by selection from a hybrid population (WW 1700079×Pc 39) × (Mutica 600×Risto). Sibs. A *mutica* variety. Mid ripening variety for grain use. Forms medium size grain with high natural weight and low hoodness. Plants of medium height with a strong straw, resistant to lodging. The variety is resistant to grain fall and is moderately resistant to spring-summer drought. It has been included in the State Register of Breeding Achievements in the Tyumen Region since 2014.

The studied varieties were sown at the following agricultural backgrounds:

1. Natural. The harvest was formed at the expense of natural reserves of nutrients. Mineral fertilizers were not applied. This agricultural background was used as control.
2. Moderate. In this option, mineral fertilizers were applied at the rate of obtaining a yield of 3.0 t/ha of grain. The average dose amounted to $N_{60}P_{20}$ kg/ha of the active substance.
3. Elevated. The dose of fertilizers of $N_{90}P_{40}$ kg/ha ensured obtaining 4.0 t/ha of oat grain.
4. High. To create it, $N_{150}P_{60}$ kg/ha of mineral fertilizers in the active substance were introduced.
5. Very high. This agricultural background was formed by applying the maximum dose of fertilizers in the experiment. Its mass amounted to $N_{200}P_{80}$ kg/ha and provided a yield of 6.0 t/ha.

Ammonium nitrate (N-NO_3 content - 34.5%) and ammophos (N – 12%; P_2O_5 – 52%) were used in the experiment. The provision of crops with potassium was high – its content was on average equal to 200-240 mg/kg of soil. Therefore, potash fertilizers were not used in the experiment.

The calculation of fertilizer doses was carried out by the method of elementary nutrients' balance required to form the planned yield and their actual content in the soil. The lack of nutrition was compensated with appropriate doses of mineral fertilizers. The coefficients of the nutrients' use from the soil and mineral fertilizers, as well as their amount required to create 1 ton of grain, were generally accepted for the forest-steppe zone of the Trans-Urals.

Fertilizers were introduced in the spring by gouging 2-3 days before sowing oats. The fertilization depth was at least 12 cm. The experiment was laid in a crop rotation with alternating crops: annual grasses (pea-oat mixture for green material) – spring wheat – oats. Crop rotation was expanded in space and time. The system of basic tillage - bladed of different depths. For annual grasses – 28-30 cm; for cereals – 20-22 cm. The experiment was laid in a four-fold repetition.

The growing season of 2020 was warm and moderately dry. From May to August, 189 mm of precipitation fell, which is 78% of the norm. Significant precipitation fell in the

second decade of May, which ensured optimal moistening of the plowing horizon and ensured fast and uniform oat sprouting. Heavy rains took place in the third decade of June again, which favorably affected the development of oats. They provided moisture to grain crops during the grain swelling period. Maturation took place under high temperature conditions with slight precipitation.

The growing season of 2021 was hot and acutely arid. Atmospheric and soil droughts were recorded during the growing season of oats. Grain crops' sprouts appeared much later and were uneven. Tillering and flowering took place in the absence of moisture in the plowing horizon at very high temperatures. Maturation was delayed due to a decrease in temperature against the background of moisture deficiency.

The assessment of oats' resistance to lodging was carried out according to the methodology of the state variety testing of agricultural crops before harvesting according to a 9-point system, where 1 is a complete crop lodging; 9 - no signs of straw's deviation from the perpendicular.

Morphological traits of oats were studied on 10 plants of each variety in a four-fold repetition. The following measurements were carried out: stem length (cm); length (cm) and diameter of the first and second internodes (cm); length of the upper internode (on which the panicle is formed) (cm); grain weight from one panicle (g). Resistance indices were calculated based on the measurements: the JG index (Galchenko), which is determined by the ratio of the straw length to the diameter of the first and second internodes (1):

$$JG = \frac{Ls}{d_{internode}}; \quad (1)$$

Where: JG – Galchenko's index; Ls – straw length, cm; d $_{internod}$ – diameter of the first and second internodes of straw, cm.

The ratio of the length of the first (*l $_{1)\ and\ second\ internodes\ (}$*l *2) to their diameter (*$_{d}$ l and d 2) was also calculated using the following formula (*l $_{1}$/d $_{1}$ and l $_{2}$/d $_{2}$)*. A quantitative indicator was also used in addition to morphometric ones, which was expressed as a relation of the grain weight from one panicle to the straw length MJ (2):

$$MJ = \frac{M_{grains}}{L_{straw}} \quad (2)$$

Where: MJ is the mexican index; M_{grains} is the grain mass from one panicle, g; L_{straw} is the length of the oat straw, cm

Statistical and variance analysis of the experimental results was carried out using Microsoft Excel.

3 Results and discussion

The research has shown that in the natural agricultural background with the absence of mineral fertilizers, the studied varieties of oats had no traits of lodging. The average resistance score amounted to 8.8 with a maximum of 9.0 (Table 1). The lodging resistance varied from 8.0 to 9.0 points with a coefficient of variation of 5%. The fertilizers' application in doses $N_{60}P_{20}$ and $N_{90}P_{40}$ kg/ha of active substance did not have a serious effect on the lodging of the studied varieties. The Foma variety was characterized by the greatest resistance; the values ranged from 8.0 to 9.0 points. Talisman and Otrada varieties showed a slight degree of lodging – the resistance score varied from 7.0 to 9.0. However, this was not critical for the yield formation in the conditions of the Northern Trans-Urals.

With a further increase in the mineral nutrition level (high and very high agricultural background), the varieties reacted differently. Thus, the lodging resistance of the Talisman variety was estimated on average by 7.3 points with a variation from 6.0 to 9.0 with a coefficient of variation of 14%. At a very high agricultural background ($N_{200}P_{80}$), the average resistance score decreased to 6.0 with a variation in the range of 4.0-8.0 points. The coefficient of spatial variation of resistance was the maximum and amounted to 25%. This fact indicates that the cultivation of Talisman oats on high agricultural backgrounds with a planned yield of more than 4.0 t/ha of grain is irrational in the conditions of the Northern Trans-Urals due to its tendency to lodging.

Table 1. Resistance of oat varieties to lodging at different levels of mineral nutrition, score

Level of mineral nutrition	Variety	average	min	max	Standard deviation	CV, %
Natural (Control)	Talisman	8.8	8.0	9.0	0.5	5
	Otrada	8.8	8.0	9.0	0.5	5
	Foma	8.8	8.0	9.0	0.5	5
Moderate ($N_{60}P_{20}$)	Talisman	8.6	8.0	9.0	0.5	6
	Otrada	8.5	8.0	9.0	0.5	6
	Foma	8.8	8.0	9.0	0.5	5
Elevated ($N_{90}P_{40}$)	Talisman	7.9	7.0	9.0	0.6	8
	Otrada	8.1	7.0	9.0	0.8	10
	Foma	8.6	8.0	9.0	0.5	6
High ($N_{150}P_{60}$)	Talisman	7.3	6.0	9.0	1.0	14
	Otrada	7.8	7.0	9.0	0.7	9
	Foma	8.5	7.0	9.0	0.8	8
Very high ($N_{200}P_{80}$)	Talisman	6.0	4.0	8.0	1.5	25
	Otrada	6.8	5.0	8.0	1.0	15
	Foma	8.3	7.0	9.0	0.7	9

The variety Otrada was characterized by a higher resistance potential to lodging at high agricultural backgrounds compared to the Talisman variety. When applying fertilizers to the planned yield of 5.0 t/ha of grain, the resistance to lodging decreased to 7.8 points with a variation from 7 to 9 points. At a very high agricultural background, the plants began to lodge – the resistance decreased to 6.8 varying within 5.0-8.0 points. It is also necessary to note an increase in the coefficient of variation to 15%. This fact indicates that the practical yield level of the Otrada variety is 5.0 t/ha of grain. With a further increase in the mineral nutrition level, stem lodging and the appearance of grain losses during harvesting are possible.

The most stable was the Foma variety; it had no visible signs of lodging even at a very high agricultural background providing 6.0 t/ha of grain– the average score amounted to 8.3 with minimal variability (Cv= 9.0%).

The plant height is determined by genetic inheritance and reaction to external factors, which include: light intensity, temperature, moisture availability and mineral nutrition. In the process of work, breeders emped the plant height into the variety model and determine its ranking group of varieties according to this indicator. The studies have shown that the studied varieties significantly differed from each other at the control with no fertilizers. The closest varieties were Talisman and Otrada; their height was equal to 80.4 ±8.8 and 72.8 ±5.0 cm, respectively (Table 2). However, the coefficient of height variation differed significantly: Talisman had 11%, Otrada – 7%. On the natural agricultural background, the

Foma variety was characterized by a minimum height of 58.6 cm with a variation in the range from 52.9 to 66.0 cm (Cv= 7.3%).

The creation of a moderate mineral nutrition level by applying fertilizers at a dose of $N_{60}P_{20}$ significantly affected only the Talisman variety; its average height was 87.7 cm varying in the range of 68.9-109.8 cm (Cv=17.1%). Otrada and Foma varieties did not have a significant increase in height on a moderate agricultural background. A further increase in the mineral nutrition level contributed to an increase in the height of the studied varieties, but up to certain values. Thus, the plants of the Talisman variety were characterized by a maximum height of 92.3–94.4 cm. The maximum height of Foma was in the range of 80.7-85.0 cm, which characterizes it as the shortest among the studied varieties. Otrada responded with an increase in height at each studied level of mineral nutrition. When applying the maximum dose of fertilizers ($N_{200}P_{80}$), the plant length reached 97.5 cm, which was 34% higher than the plants in control.

The resistance degree to stem lodging is closely related to the internodes length of cereal crops [9]. This is especially critical for the first and second internodes, which are the weakest to the mechanical effects of a swinging panicle on a long straw. A fracture of the upper internode occurs quite often as well; this is where the panicle is directly fixed [10].

Measurements of internodes showed that the first and second internodes of Talisman and Otrada varieties are identical – 1.9-2.0 and 5.9-6.1 cm. The Foma variety differed from them by a shorter length – 1.3 and 4.2 cm, respectively. The application of fertilizers for the planned yield (moderate agricultural background) did not have a significant effect on the length of the first and second internodes. Elongation of the analyzed internodes was recorded in the option with an increased level of mineral nutrition. Thus, in the Foma variety, the length of the first internode increased from 1.4 to 3.2, while the length of the second remained the same. In Otrada, the result was the opposite – the first internode lengthened slightly, yet the second reached 8.2 cm. High ($N_{150}P_{60}$) and very high ($N_{200}P_{80}$) agricultural backgrounds did not have a serious effect on internodes' lengthening, and in the Otrada variety they had an inhibitory effect on the second internode's development, the length of which decreased to 6.8 cm.

Table 2. Elements of straw structure of various oat varieties when applying increasing doses of mineral fertilizers

Level of mineral nutrition	Varieties	Length, cm				Plant height, cm	Diameter of the first internode, cm	Diameter of the second internode, cm
		Upper internode	First internode	Second internode	Panicles			
Natural (Control)	Talisman	31.5	2.0	6.1	15.6	80.4	0.30	0.29
	Otrada	26.8	1.9	5.9	13.8	72.8	0.32	0.32
	Foma	18.7	1.3	4.2	11.1	58.6	0.31	0.30
Moderate ($N_{60}P_{20}$)	Talisman	32.7	2.3	7.0	16.6	87.7	0.31	0.32
	Otrada	26.8	2.1	6.5	13.3	74.4	0.35	0.34
	Foma	16.1	1.4	4.7	12.2	61.3	0.34	0.34
Elevated ($N_{90}P_{40}$)	Talisman	33.0	2.7	5.9	17.8	92.3	0.32	0.32
	Otrada	30.6	3.3	8.2	15.5	80.3	0.34	0.34
	Foma	25.8	3.2	4.3	18.8	80.7	0.33	0.33
High ($N_{150}P_{60}$)	Talisman	34.1	4.5	6.1	17.6	92.7	0.30	0.30
	Otrada	32.5	4.3	7.4	16.8	88.5	0.31	0.32

	Foma	25.5	3.2	4.2	18.5	79.8	0.36	0.35
Very high ($N_{200}P_{80}$)	Talisman	37.1	2.9	5.9	22.7	94.4	0.30	0.31
	Otrada	39.7	3.8	6.8	19.5	97.5	0.33	0.33
	Foma	24.2	2.7	5.2	16.1	85.0	0.36	0.36

Strong elongation of the upper internode can also negatively affect the oats' resistance to stem lodging. Therefore, preference should be given to varieties of intensive type with limited growth of this stem's part. In these studies, the varieties had different lengths of the upper internode with a natural level of mineral nutrition. The introduction of increasing mineral fertilizers' doses significantly increased this indicator, yet the varietal characteristics of oats did not disappear. The maximum length was in the Talisman variety. At the control, it was equal to 31.5 cm, which was 39% of the plant height. On the contrary, the Foma variety formed an upper internode with a length of 18.7 cm (32% of the height). The Otrada variety occupied an intermediate position – 26.8 cm.

The fertilizers' introduction for the planned yield of 3.0 t/ha did not significantly affect the length of the upper internode in the studied varieties. The creation of an elevated mineral nutrition level caused the elongation of the upper internode in the varieties Otrada and Foma, yet further increase in the fertilizers' dose had a minimal effect. The Otrada variety reacted the most – the length of its upper internode at a very high agricultural background was 39.7 cm, which is 48% more than the control values.

The size of the oat panicle is also a very important indicator. The projective area directly affects the sailing capacity. And the more compact the panicle is, the less impact the wind will have on it. The maximum stem lodging is manifested during the period of milky ripeness after strong winds. It was noted that varieties with a compact panicle were less prone to lodging [11]. In these experiments, the interaction of varietal oats' characteristics and the mineral nutrition level on the length of the panicle is clearly traced. The role of mineral fertilizers in the formation of this indicator is 11%; variety – 10%. But the factors' interaction of the variety and fertilizers causes 43% of the influence on the length formation of an oat panicle.

The most compact panicle among the studied varieties of oats was in Foma – its length at the control was 11.1 cm, while the Talisman variety had 15.6 cm. At a very high agricultural background designed to obtain 6.0 t/ha of grain, the panicle length of Foma was 16.1 cm, while Talisman had 22.7 cm.

Correlation analysis showed that lodging resistance has a negative correlation with the length of the first (r=-0.6) and the upper internode (r=-0.7), as well as with the panicle length (r=-0.8) (Fig. 1). A positive correlation was also established with factors such as yield (r=0.6) and the plant height (r=0.8). Weak correlation (r <0.3) was found between lodging resistance and the length of the second internode; the diameter of the first and second internodes. Perhaps this was due to that the studied varieties have a certain degree of genetic similarity [12].

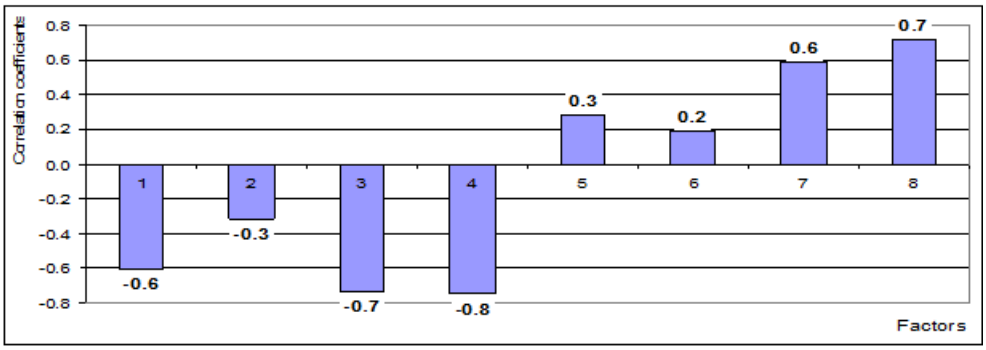

Fig. 1. Correlation between the elements of the structure of oats, yield and resistance to lodging

1 – length of the first internode; 2 – length of the second internode; 3 – length of the upper internode; 4 – length of the panicle; 5 – diameter of the first internode; 6 – diameter of the second internode; 7 – yield; 8 – height of plants

During the analysis of variance, an influence strength indicator of individual factors on morphometric indicators and lodging resistance was calculated. The following were taken as a source of variation: the level of mineral nutrition (factor A); variety (factor B) and weather conditions of the growing season (factor C).

To the maximum extent, the height of oats depends on the weather conditions of the growing season. The indicator of influence strength amounts to 40.4%. The role of mineral fertilizers is two times less – 20.5%. It should be noted that the interaction of these factors causes another 11% of the influence strength. The role of the variety was minimal among the studied factors – 14.5%. The experimental accuracy to identify the influence of the studied indicators on the plant height is quite high – 1.66% with the smallest significant difference of 3.83 cm.

The diameter of the first and second internodes mainly depended on the weather conditions of the growing season – the influence strength indicator was 48.4 and 43.1%, respectively. Mineral fertilizers had a significant impact ($F_{fact}>F_{teor.}$), but to a minimum extent - 6.4-8.1%. The role of the variety is obvious – the influence strength indicator was 12.9 and 11.7%, respectively. During the analysis, it was not possible to establish a strong interaction of the studied factors. It is possible that besides them there were others that were not considered in the work.

Table 3. Analysis of variance and the factors' influence strength indicator

Source of variation	Plant height	Diameter of internodes		Resistance to lodging
		First	Second	
Factor A (mineral nutrition level)	20.5	6.4	8.1	34.3
Factor B (Variety)	14.5	12.9	11.7	11.5
Factor C (vegetation weather conditions)	40.4	48.4	43.1	6.1
AB interaction	3.8	9.3	6.6	10
AC Interaction	11.9	1.5	2	6
BC Interaction	2.2	4	4.3	-
ABC Interaction	1.5	6	5.1	-
Error of mean	1.36	0.004	0.004	0,33
Experiment's accuracy, %	1.66	1.86	1.88	4.12
Difference error	1.92	0.006	0.006	0.47

Student criterion	2	2	2	2
Least significant difference	3.83	0.012	0.012	0.94

The analysis of the complex indicator showed that the resistance to stem lodging depends on the level of mineral nutrition by 34.3%; by 11.5% - on the variety and by 6.1% - on the weather conditions of the growing season. There was no reliable interaction influence of BC factors, as well as ABC ($F_{fact}<F_{teor.}$). The accuracy of the experiment was moderately high – 4.12% with the least significant difference of 0.94 points.

Resistance indices were used to assess the impact of the mineral nutrition level, which considered the ratios of various morphometric indicators. The world scientific community uses a variety of calculated indicators (indices and coefficients) characterizing the lodging resistance of grain crops [13]. The most common is the Galchenko index, which shows the ratio of the straw length to the diameter of the first (second) internode. The higher this ratio, the stronger the tendency to lodging. It was found that the Talisman variety initially has a tendency to lodging as evidenced by the maximum Galchenko index, varying in options from 146 to 168 units (Table 4). The lodging resistance decreases with an increase in the mineral nutrition level, reaching a minimum when fertilizers are applied to the planned yield of more than 4.0 t/ha of grain. The variety Otrada also reduced resistance to lodging at a very high (N_{200} P_{80}) agricultural background – the Galchenko index corresponded to that of the Talisman variety. In the option with a high mineral nutrition level ($N_{150}P_{60}$), this index was lower – 151 and 149 units for the first and second internodes, respectively. With moderate and increased agricultural background, the tendency to lodging was at the control level.

The minimum Galchenko index was for the Foma variety. It also increased under the influence of mineral fertilizers, but significantly less than that of the Talisman variety. At a very high agricultural background, the ratio of the straw length to the diameter of the first internode was 127 units, while Talisman had a significantly higher value even at the control.

Table 4. Indices of lodging resistance of oat varieties at different levels of mineral nutrition

Level of mineral nutrition	variety	JG (Lc/d1)	Lc/d2	L1/d1	L2/d2	MJ
Natural (Control)	Talisman	146	148	5	14	0.017
	Otrada	124	123	4	12	0.023
	Foma	103	105	3	9	0.027
Moderate ($N_{60}P_{20}$)	Talisman	150	149	5	15	0.017
	Otrada	117	118	4	12	0.024
	Foma	97	97	3	9	0.037
Elevated ($N_{90}P_{40}$)	Talisman	154	154	6	12	0.015
	Otrada	127	126	7	16	0.022
	Foma	127	127	7	9	0.022
High ($N_{150}P_{60}$)	Talisman	168	168	10	14	0.015
	Otrada	151	149	9	16	0.022
	Foma	113	116	6	8	0.026
Very high ($N_{200}P_{80}$)	Talisman	157	154	7	13	0.014
	Otrada	156	154	8	14	0.018
	Foma	127	127	5	10	0.023

The ratio of the first and second internodes' length to their diameter characterizes the level of lodging resistance due to their mechanical strength. The higher this ratio, the less

strong these internodes are. Calculations have confirmed that the Talisman variety has a genetic tendency to lodging, and the level of mineral nutrition significantly increases the breakage probability of the second internode. The Otrada variety also has a high lodging probability when applying fertilizers for a yield of 4.0 t/ha of grain or more – the ratio of the length of the second internode to its diameter was 16 units. Foma proved to be the most stable. L1/d1 varied from 3 to 7 units, and the ratio of the second internode was significantly higher – 8-10 units.

The mexican Index (MJ) is an indicator of the grain load on the straw. This index is considered the most important because it has the maximum correlation with lodging resistance [14-15].

In the course of the conducted studies, it was found that the Talisman variety was characterized by the stability of the Mexican index at different levels of mineral nutrition – 0.014-0.017 units. Varieties Otrada and Foma had a higher grain load per unit length of straw. MJ was equal to 0.018-0.023 units, which corresponds to lodging-resistant varieties of oats [16]. It was found that at a very high agricultural background with fertilizers applied at the rate of 6.0 t/ha of grain, the mexican index significantly decreased to 0.018 units relative to the control. This confirms the previously established yield potential of the Otrada variety, in which the stem lodging will not be fully manifested.

The Foma variety had the highest mexican index among the studied varieties. It ranged from 0.023 to 0.030 units. There was no significant effect of fertilizers on the ratio of grain weight from one panicle to the straw length. One can only note the tendency of this indicator's deterioration with an increase in the level of mineral nutrition. The established fact confirms that the Foma variety has maximum resistance to stem lodging when forming yields up to 6.0 t/ha of grain, inclusively.

4 Conclusion

According to the results of a comprehensive study, it was found that resistance to stem lodging is fixed at the genetic level (11.5%), yet it can vary from the mineral nutrition level – the influence strength indicator is 34.3%. The lodging degree depends on the length of the first and upper internodes, the length of the panicle, yield and plant height. It was found that the Talisman variety has the minimum resistance to stem lodging among the studied varieties. This is confirmed by the analysis of morphometric indicators and resistance indices. The Foma variety is able to withstand a grain yield of up to 6.0 t/ ha without signs of lodging. The mexican index shows high genetic resistance to stem lodging, whereas in the Talisman variety, an increase in the mineral nutrition level leads to a decrease in this index.

Acknowledgements

The work was carried out according to state task No. 122011300103-0 and with the support of the world-class West Siberian Interregional Scientific and Educational Center.

References

1. A.V. Lyubimova, BIO Web of Conferences: International Scientific and Practical Conference, Tyumen, 19–20 July 202, 01015 (2021) DOI 10.1051/bioconf/20213601015.
2. R.I. Belkina, IOP Conference Series: Earth and Environmental Science, Omsk, 29–30 March 2021, 012045 (2021) DOI 10.1088/1755-1315/954/1/012045/

3. Y. Loginov, E3S Web of Conferences: 14th International Scientific and Practical Conference on State and Prospects for the Development of Agribusiness, INTERAGROMASH 2021, Rostov-on-Don, 24–26 February (2021) DOI 10.1051/e3sconf/202127301009.
4. M.N. Fomina, BIO Web of Conferences: International Scientific and Practical Conference, Tyumen, 19–20 July 2021 01018 (2021) DOI 10.1051/bioconf/20213601018.
5. D.I. Eremin, IOP Conference Series: Earth and Environmental Science, Yekaterinburg, 15–16 October 2021, 012066 (2021) DOI 10.1088/1755-1315/949/1/012066.
6. A.V. Chelovechkova, IOP Conference Series: Earth and Environmental Science: International Conference on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering, IPDME 2018 - Mining Ecology, Saint-Petersburg, 12–13 April 2018 092004 (2018) – DOI 10.1088/1755-1315/194/9/092004.
7. E.A. Demin, IOP Conference Series: Earth and Environmental Science, Yekaterinburg, 15–16 October 2021, 012084 (2021) DOI 10.1088/1755-1315/949/1/012084.
8. E.A. Demin, IOP Conference Series: Earth and Environmental Science, Krasnoyarsk, 16–19 June 2021, 22080 (2021) DOI 10.1088/1755-1315/839/2/022080.
9. Yu.S. Averyasova, The 10th International Oat Conference: Innovation for Food and Health: Abstracts of oral and poster presentation, Saint-Petersburg, Russia, 11–15 July 2016, 164-165 (2016)
10. Yu.S. Ivanova, Bioscience Research, **17(2),** 1183-1185 (2020)
11. V.G. Griguletsky, International Agricultural Journal, **1**, 62-67 (2020) DOI 10.24411/2587-6740-2020-11014.
12. A. V. Lyubimova, G. V. Tobolova, D. I. Eremin, I. G. Loskutov, Vavilov Journal of Genetics and Breeding, **24(2),** 123-130 (2020) DOI 10.18699/VJ20.607.]
13. H. Matsuyama, Y. Shimazaki, Y. Ohshita, Y. Watanabe, Japan.J. Crop Sc. **83(2),** 136-142 (2014)
14. A. Navabi, M. Idbal, K. Strenzke, D. Spaner, Canad. J. Plant Sc. **86(3),** 723-726 (2006)
15. I.V. Arinicheva, IOP Conference Series: Earth and Environmental Science, Yekaterinburg City, Virtual, 15–16 October 2020, 012046 (2020) DOI 10.1088/1755-1315/699/1/012046.
16. Yu.S. Ivanova, Agrarian science of the European North-East, **3(58),** 15-21 (2017)