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IMPROVING PROSO MILLET VARIETY SAMPLES RESISTANCE TO LODGING

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Abstract. This article presents the results of research on proso millet breeding for resistance to lodging. While the Akmola region is one of the most favorable for cultivation of cereal crops, strong winds in the region can severely damage the plant structure, and therefore, limit potential yield. Therefore, plant breeding for lodging resistance, particularly in proso millet, which has a weak straw and root system, is an important and relevant area of research which is often understudied. The research is based on 2020-2025 field data from the Akmola region. The study includes variety samples of different origins, foreign and local. For statistical analysis lodging risk index, integral risk index, index of potential stability were calculated. By focusing on such traits as plant height (H), straw diameter (D), and number of internodes (N), we were able to identify the most resistant genotypes by different parameters which will be further included in plant breeding programs to increase proso millet yield.

Keywords: proso millet, genotypes, lodging, resistance assessment.

ТАРЫНЫҢ СОРТТАРЫ МЕН ҮЛГІЛЕРІНІҢ ЖАТЫП ҚАЛУҒА ТӨЗІМДІЛІГІН АРТТЫРУ

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Аңдатпа. Бұл мақалада тарының жатып қалуға төзімділіне бағытталған селекциялық зерттеу нәтижелері ұсынылды. Ақмола облысы аймағына ең қолайлы дәнді дақылдарды өсіру болып табылады, алайда күшті желдер өсімдік құрылымын қатты зақымдауынан, әлеуетті өнімділігін төмендетеді. Сондықтан, өсімдіктер селекциясында жатып қалуға төзімділік, әсіресе сабаны мен тамыр жүйесі әлсіз тары дақылында маңызды және өзекті. Талдау Ақмола облысынан алынған 2020-2025 жылдардағы далалық деректерге негізделген. Зерттеуге әртүрлі шығу тегі бар, шетелдік және жергілікті үлгілер кіреді. Статистикалық талдау үшін тәуекел индексі, интеграл тәуекел индексі, индекстың әлеует төзімділігі есептелінді. Сонымен қатар өсімдік биіктігі (H), сабан диаметр (D), және буынаралық саны (N)сияқты белгілеріне есепке алынды. Талдау барысында ең төзімді генотиптер іріктеліп, жоғары өнімділікке бағытталған селекция бағдарламаларына енгізу ұсынылды.

Кілт сөздер: тары, генотиптер, жатып қалуға төзімділік, төзімділік бағалау.

ПОВЫШЕНИЕ УСТОЙЧИВОСТИ К ПОЛЕГАНИЮ СОРТОВ И ОБРАЗЦОВ ПРОСА

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Аннотация. В данной статье представлены результаты исследований по селекции проса на устойчивость к полеганию. Хотя Акмолинская область является одной из наиболее благоприятных для выращивания зерновых культур, сильные ветры в регионе могут серьезно повредить структуру растений и, следовательно, ограничить потенциальный урожай. Поэтому селекция растений на устойчивость к полеганию, особенно проса, которое имеет слабую солому и корневую систему, является важной и актуальной областью исследований, которая часто остается недооцененной. Анализ основан на полевых данных 2020-2025 годов Акмолинской области. Исследование включает образцы сортов различного происхождения, как иностранных, так и местных. Для статистического анализа были рассчитаны индекс риска полегания, интегральный индекс риска и индекс потенциальной устойчивости. Учитывая такие признаки, как высота растений (H), диаметр стеблей (D) и количество междоузлий (N), мы смогли выявить наиболее устойчивые генотипы по различным параметрам, которые будут в дальнейшем включены в программы селекции растений для повышения урожайности проса.

Ключевые слова: просо, генотипы, полегание, оценка устойчивости.

Introduction. Proso millet is a vital drought-resistant cereal and forage crop, valued for its high yield, low maintenance, and low waste. The grain is used to produce nutritious cereal, alcohol and forage, while straw and green mass are used for hay and silage. Proso millet is also rich in protein, gluten-free, and improves soil structure (Dyussibayeva et al., 2024: 1-12). There is a multiple number of studies on this crop; the authors focus on studying diversity of the proso millet (Zargar et al., 2023: 1-14), its productivity (Yousif et al., 2025: 1-5), resistance to plant diseases (Dyussibayeva et al., 2017: 852-858); the lodging of proso millet plants is seriously understudied.

However, while cultivating this crop in the north of the country lodging is often present because of winds. The Akmola region is characterized by strong winds (Imangulova et al., 2020: 77-82), the data obtained from the regional meteorological stations at the altitude of 10 m indicate that the average annual wind speed varies from 2.9 to 4.9 m/s, but the maximum speed can be up to 34 m/s (Energy Wind). Under these weather conditions, plant internodes quickly grow and stretch, and accumulation of skeletal formations (cellulose and hemicellulose biopolymers) and process of lignification of cell walls, which determine mechanical strength of stem tissues, are delayed (Yu et al., 2025; 1-12).

Lodging of plants leads to significant yield losses (Erndwein et al., 2020: 1-11), as carbohydrate and protein metabolism changes reduce grain quality and complicate harvesting. Lodged plants still can spring up. In cereals (wheat, rye, barley, etc.), internodes of the apical part of the stem are capable of re-growing thanks to intercalary meristem, which promotes stem elongation and development of key primary structures. Under the influence of geotropism and phototropism, in lodged plants underside of upper stem nodes grows, raising the upper part. Resistance to abiotic environmental factors, especially lodging, plays a crucial role in maximizing the productivity of agricultural crops with high yield potential (Wu et al., 2022: 133-144).

In irrigated and intensive farming conditions, resistance to lodging is a factor that significantly influences proso millet productivity. This indicator depends on certain morphological characteristics, including plant stem length, lower internode length, leaf blade attachment angle, straw diameter, and others. According to many researchers, dwarf varieties are more resistant than tall plants. Lodging resistance in cereal crops is determined not only by dwarfism, but also by a thick and strong stem, short lower internodes, a robust root system, and developed mechanical tissues. These traits lower the center of gravity, reduce windage, and increase straw structural strength, preventing breakage under its own weight or wind pressure. Therefore, dwarfism, straw diameter, and number of internodes can be used to evaluate varieties for lodging resistance. Lodging resistance can be improved by developing new varieties that possess these traits.

Materials and methods of research. Field experiments were conducted at the A.I. Barayev

Research and Production Centre for Grain Farming on experimental plots of the Laboratory of Genetic Resources of Grain Crops from 2020 to 2025.

The source material included both local and foreign proso millet variety samples to be used in further research on the creation of varieties adapted to the soil and climatic conditions of the zone.

While assessing resistance of genotypes to lodging, the traits such as plant height, straw diameter, and number of internodes were taken into account.

Statistical processing of data was carried out based on the phenological observations and measurements based on index and multivariate analysis. The index method uses a system of relative indicators to measure dynamics, compare complex subjects, and perform factor analysis. Multivariate analysis simultaneously examines the relationships between two or more variables, revealing hidden structures and causal relationships. Both approaches are essential for in-depth data processing and decision-making in the plant breeding process.

In plant breeding, the lodging risk index is often calculated to identify and establish a pattern when selecting the most resistant forms. LR is lodging risk index; SI is potential resistance index; LR_2 is integral risk index, calculated taking into account the three most significant traits affecting lodging, in many cases, straw diameter also influences potential resistance, as SI index was highest in potentially resistant genotypes (Kocherina et al., 2008: 1-87). This makes it possible to conduct targeted proso millet breeding, including not only dwarf forms with a small number of internodes, as is common with many agricultural crops, but also other genotypes in the proso millet collection.

Calculation of lodging resistance indices was performed in Excel program:

df["LR"] = df["Height"] / df["Diameter"]

df["SI"] = df["Diameter"] / df["Height"]

df["LR2"] = (df["Height"] * df["Internodes"]) / df["Diameter"]

The following indices were calculated for each genotype:

- LR = H/D - lodging risk index
- LR_2 = H × N / D - integral risk index
- SI = D / H - index of potential stability

Results. Under the drought-prone climatic conditions in 2020-2022, proso millet plants had short height (49-68 cm). Therefore, the 2023-2025 samples proved to be the most suitable for proso millet cultivation, accurately reflecting the plant height.

In the Akmola region, the optimal proso millet plant height for high lodging resistance is considered to be 65-80 cm. Short and medium-sized plants are more resilient, as taller plants are more susceptible to wind damage. In different years with varying climatic conditions, the shortest samples were the VIR (All-Russian Institute of Plant Genetic Resources) collection sample K-2374 (62.7 cm) and the local variety Barnaulskoye Kormovoe (74.4 cm).

When assessing stability, it's also important to consider the straw diameter, as thicker straws have greater structural stability. Foreign varieties with lower internode diameter of 0.9 cm or more are of particular interest: Ames 11555, PI 175798, PI 365844, PI 476399, PI 346938, PI 223792, PI 173752 K-9681, K-10215, K-10204, K-9598. Short lower internodes or the smallest number of them decisively ensure stability as the genotypes with the length of lower internodes of no more than 5.0-6.5 cm, including the accessions from the VIR collection K-3742 and K-9910, the accessions from foreign collections PI 182258, PI 289322, PI 346933; the Pamyati Bersieva variety from the domestic collection.

Figure 1. Morphological characteristics of proso millet varieties determining their resistance to lodging (2020-2025)

Thus, the genotypes identified by valuable morphological characteristics can be used in the selection of lodging-resistant proso millet varieties.

For each genotype, the lodging risk indices LR = H/D and LR_2 = H×N/D, as well as the index of potential stability SI = D/H, were calculated. SI values ranged from 0.00097 to 0.00843, indicating a high differentiation of genotypes in lodging resistance. The minimum LR and LR_2 values and the maximum SI values belonged to the Kokchetavskoe 6, Ames 11674, and Saratovskoe 6 genotypes, while the K-9539 genotype had extremely high LR and LR_2 values, indicating an extremely high lodging risk. The obtained data were used to calculate the index and multivariate analysis (Table 1).

Table 1. Genotypes with the highest resistance potential (highest by resistance index)

Genotype	H, cm	N	D (cm)	LR	SI	LR_2
Kokchetavskoe 6	106.8	5.6	0.9	118.7	0.00843	664.5
Ames 11674	95.2	6.0	0.8	119.0	0.00840	714.0
Saratovskoe 6	84.2	4.8	0.7	120.3	0.00831	577.4
Shortandinskoe 11	87.0	5.4	0.6	145.0	0.00690	783.0
Ames 11555	134.6	8.2	0.9	149.6	0.00669	1226.4

Notes: H - plant height; N - number of internodes; D - straw diameter; LR - lodging risk index; SI - potential resistance index; LR_2 - integral risk index.

The assessment of lodging resistance based on index and multivariate analysis showed that the genotypes Kokchetavskoe 6, Saratovskoe 6, Ames 11674, Shortandinskoe 11 and Ames 11555 combine relatively moderate height and increased straw diameter, indicating increased mechanical stability of the stem.

Based on the results of the data analysis, it was evident that the genotypes with the highest risk of lodging (highest by LR) were the variety samples K-9539 and PI 170589, and the Chinese samples NO.4, NO.2, NO.3 (Table 2).

Table 2. Genotypes with the highest risk of lodging (highest by LR)

Genotype	H, cm	N	D (cm)	LR	SI	LR_2
K-9539	309.6	5.0	0.3	1032.0	0.00097	5160.0
PI 170589	86.4	5.4	0.3	288.0	0.00347	1555.2
No. 4	79.8	4.8	0.3	266.0	0.00376	1276.8
No. 2	132.6	5.4	0.5	265.2	0.00377	1432.1
No. 3	125.4	4.8	0.5	250.8	0.00399	1203.8

Notes: H - plant height; N - number of internodes; D - straw diameter; LR - lodging risk index; SI - potential resistance index; LR_2 - integral risk index.

The above mentioned variety samples are characterised by an extremely unfavorable ratio of height and diameter, which indicates a high potential susceptibility to lodging.

Conclusion. Based on the results of the lodging resistance assessment, valuable genotypes were identified: K-2374 (62.7 cm), Barnaulskoe kormovoe (74.4 cm) - by dwarfism, regardless of climatic conditions; Ames 11555, PI 175798, PI 365844, PI 476399, PI 346938, PI 223792, PI 173752 K-9681, K-10215, K-10204, K-9598 - with more stable straw; K-3742, K-9910, PI 182258, PI 289322, PI 346933, Pamyati Bersieva - with short internodes.

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