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Optimization of the breeding process of lodging-resistant varieties of spring triticale

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Abstract. During the field and laboratory studies, selection samples of spring hexaploid triticale were studied according to breeding valuable traits and physical and mechanical properties of the stem. As a result of the research, an information database was created, which contains information on the study of samples according to economically valuable characteristics, product quality, a set of characteristics of biometric and physical and mechanical properties of the tissue of spring triticale stems. The set of data contained in the database, can be used in the selection of parent pairs for hybridization, selection of valuable genotypes from hybrid populations, in the breeding of new lodging-resistant varieties.

1 Introduction

Wheat-rye triticale amphidiploids triticale (Triticosecale Wittmack & A.Camus) are of considerable theoretical and practical interest among synthetic allopolyploids. This crop has surpassed its parental forms in yields and product quality. Triticale combines the multicoloured character of rye with the multicoloured character of wheat. This is what makes it particularly attractive. High grain and green mass productivity, stable adaptive potential, and the ability to produce high-quality feed by amino acid and fractional protein composition ensure growing interest in the culture [1-2].

The yield of triticale, like other crops, is a complex feature and depends on the potential productivity of the plants, their response to growing conditions and the relationships of the plants within the biocoenosis [3]. Individual productivity is genetically determined and depends on the structure of the plant, the rate of their development and the intensity of physiological processes [4].

Due to the advantages in relation to the parent forms, modern triticale varieties can rationally use the available soil and climatic resources and significantly diversify and reduce the cost of production of high-quality feed and food grains [5]. Recent studies of global and domestic breeding scientists have shown that the yield of triticale grain under optimal conditions can compete with wheat [6-9].

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A disadvantage of triticale is the high risk of lodging and pre-harvest germination of grains [1-2, 10-11]. To create new crop varieties of spring triticale, characterized by high productivity and resistance to lodging, it is necessary to obtain a set of data on architectonics and physical and mechanical characteristics of plants of the initial breeding material using easy and informative methods. In the future, this breeding material can be used as a source of valuable traits.

In the process of performing a multifactorial breeding experiment, there is an accumulation of large amounts of data describing field and laboratory studies of phenotypic and economically valuable plant traits. Data processing requires the use of new technologies for organizing and analyzing data. It is very important to have modern methods of plant phenotyping to obtain data. Specialised databases using ontologies are needed to collect, systematise and store information in order to unify and standardise the data. Analysis of the information requires the development of models to describe the experimental data [12].

The use of computer technologies in the selection process will reduce the routine operations for obtaining, processing and presenting data, significantly improve the accuracy and speed of information processing, and make data analysis more visual and efficient. The methods used will significantly increase the efficiency of breeding and genetic experiments and optimise the breeding process towards the creation of new high-yield varieties and lines of triticale crops.

2 Materials and methods

The success of creating new non-lodging varieties of spring triticale is based on the choice of source material and depends on its genetic diversity. That is why the source material should be presented as samples of the world collection, as well as forms with high economically valuable characteristics adapted to growing in a particular region. The object of the research was the field experience data (2021-2022) on the study of spring hexaploid triticale plants of 19 breeding samples. The 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 (Table 1). The samples were studied on natural background without fertilizers. The repetition of the experiment was three times.

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	К-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.

The studied breeding forms belong to the group of grain direction and are used to produce food and fodder grain for feed industry. The samples belong to different ripeness groups and are distinguished by their field resistance to leaf diseases, dusty and hard smut, stem rust and yellow rust.

A systematic study of the source material according to a set of economically valuable traits makes it possible to evaluate and select promising breeding forms capable of intensive use of natural resources.

In order to select promising samples and identify the influence of plant structure on lodging resistance, the research was methodologically divided into the following stages:

- carrying out phenological studies under field conditions during the growing season using the unified phenological scale - BBCH code [13];
- conducting a visual assessment of lodging resistance under field conditions using a 9-point scale according to the methodology [14];
- study of the features of the stem architectonics;
- study of the physical and mechanical properties of the stem;
- determination of the yield of breeding samples during the study period;
- evaluation of the influence of the architectonics and physical-mechanical properties of the stem on the yield and lodging resistance of the plants.

Macrometric parameters were studied on 25 representative specimens of each breeding sample as they reached the phase of full ripeness. The experiment included the determination of the following numerical characteristics: the length of the stem, the number of internodes, the lengths of the 2nd, 3rd and upper internodes (the distance from the upper stem node to the base of the ear), the diameters and thickness of the 2nd and 3rd internodes, the mass of the segment (10 cm long) of the straw of the 2nd internode.

The physical and mechanical properties of plant stems were determined on an experimental device made at SibNIIRS, the construction of which includes a stable platform, crossbars for fixing the sample and a slot for placing a dynamometer. The strength of the internode fracture was determined using a DACELL DN-FGA-K2 electronic dynamometer. The tests were stopped in the event of a fracture of the sample or reaching the maximum load at which the "flow" of the stem tissue occurred. Peak readings of the device were recorded. The following mathematical methods were used to determine the criteria for assessing the parameters of lodging resistance in the samples: determination of stem tissue density by cross-sectional area and linear mass of the stem sample; analysis of variation; analysis of variance and correlation.

3 Results and discussion

The results of phenological observations, structural analysis, a set of characteristics of biometric and physical and mechanical properties of the stem tissue of the studied samples during the study period represent a large amount of data, which requires systematization, structuring and integration into a single database.

The information received, including quantitative estimates, qualitative characteristics and digital images, was mixed. As a result, it became necessary to unify and normalize the data before entering it into a single database. This process was carried out on the basis of plant ontology systems [15]. These systems integrate different approaches, methods, technologies and protocols that can be used to obtain, process, store and analyse data at all stages of selection research [12]. The use of ontology terms to describe phenotypes and the accurate mapping of these descriptions into a database is important in studies of the phenotypic and economically valuable traits of the examined specimens [16].

To identify the interrelationships of traits and determine their contribution to plant productivity, as well as for the retrospective analysis of breeding data, digitized normalized data on a two-year study of a set of breeding samples of spring triticales were combined into a single information database. The database is based on the following types of local tables: Paradox as main and service tables, Dbase for storing sample information. These formats have been chosen on the basis of their ease of use and compatibility with a large number of applications.

The structure consists of the following blocks: the name of the crop and the description of the studied quantitative traits with a given calculation algorithm; a description of the variety (line, breeding sample); productivity of variety; biometric traits; physical and mechanical properties and graphic material for each variety.

The developed database was integrated into the computer program "Integral Evaluation of Crop Breeding Material", developed by the author's team in the previous stage of work. [17]. The computer program allows to enter, edit and store experimental data of breeding research of agricultural crops; to carry out software planning with the support of a graphical interface; to calculate the breeding value of samples on the complex of economically important characters based on the method of scalar ranking with the setting of algorithm for scoring the characters and weighting factors that determine the contribution of a character to the integral breeding score; to perform analysis of samples by methods of mathematical statistic [18]. The main window of the program is shown in Figure 1.

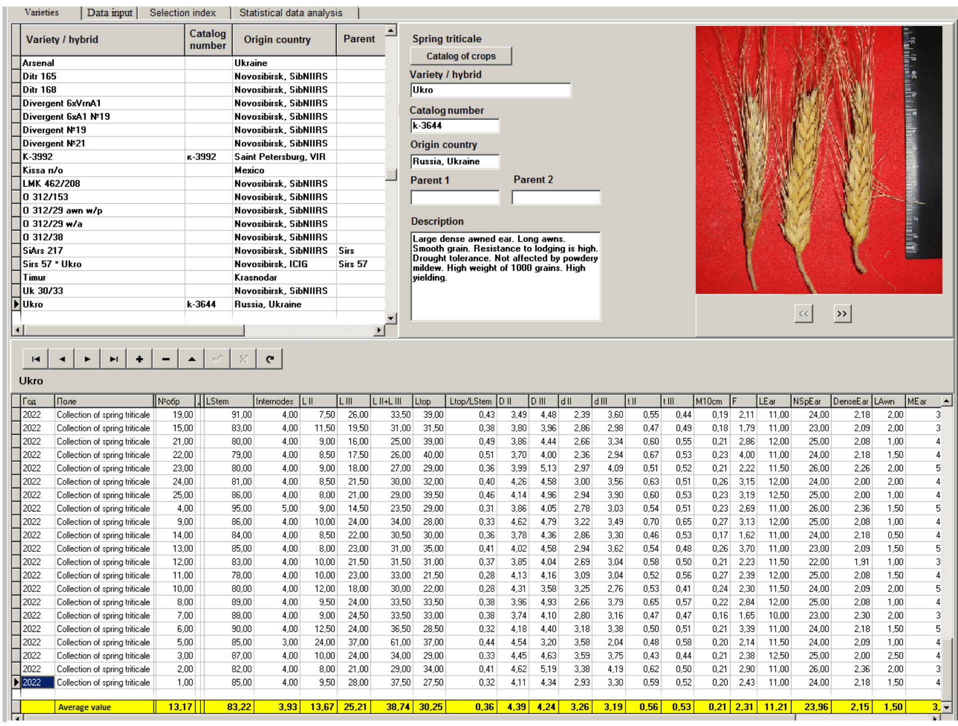

Fig. 1. The main database interface window.

The analysis of data from a two-year study of breeding forms of spring triticales, carried out by methods of mathematical statistics, made it possible to identify forms with a good expression of economic characteristics that are significant in assessing resistance to lodging.

The calculation of paired correlations of features was carried out by the Pearson method with an assessment of statistical significance according to the Student's t-criterion [19]. The analysis of the correlation matrix revealed the presence of direct or inverse relationships between individual traits that determine the lodging resistance of breeding samples of spring triticale.

A significant negative correlation has been established between the resistance to lodging and the length of the 2nd internode (r = - 0.59*), with the length of the upper internode (r = -0. 60*) and the mass of the ear (r = - 0.65*). A strong negative relationship has been established between the magnitude of the load and the lodging capacity (r = - 0.86*). The sign of resistance to lodging significantly positively correlates with the diameter of the 2nd internode (r = 0.59 *), the mass of 10 cm of the length of the straw (r = 0.50 *). The sign of the ear mass showed a significant positive correlation with the length of the ear (r = 0.496*), with the length of the stem (r = 0.543*), with the diameter of the 2nd internode (r = 0.465*) and with the value of the fracture force (r = 0.578*). The straw length attribute in the studied samples has a positive correlation with the sign of the length of the upper internode (r = 0.84 *) and the mass of the ear (r = 0.54*), but weakly correlates with other signs and has a negative relationship with the degree of lodging of crops.

As the results of this research have shown, the lodging resistance trait has the most stable relationship with the length of the second and third lower internodes, as well as with the breaking strength of the straw. The sum of the lengths of the 2nd and 3rd internodes is used as an additional selection criterion for lodging resistance.

A cluster analysis method was applied to separate the samples according to a set of features. Cluster analysis is a kind of classification problem when there is no set of representations (standards). It consists in combining objects into groups (clusters) depending on the degree of similarity determined by a number of criteria (features, properties) and is used to identify stable groups, each of which combines objects with similar characteristics. [20-21].

Figure 2 shows the dendrogram of the clustering of selection samples by elements of yield structure and lodging resistance for the years 2021 to 2022.

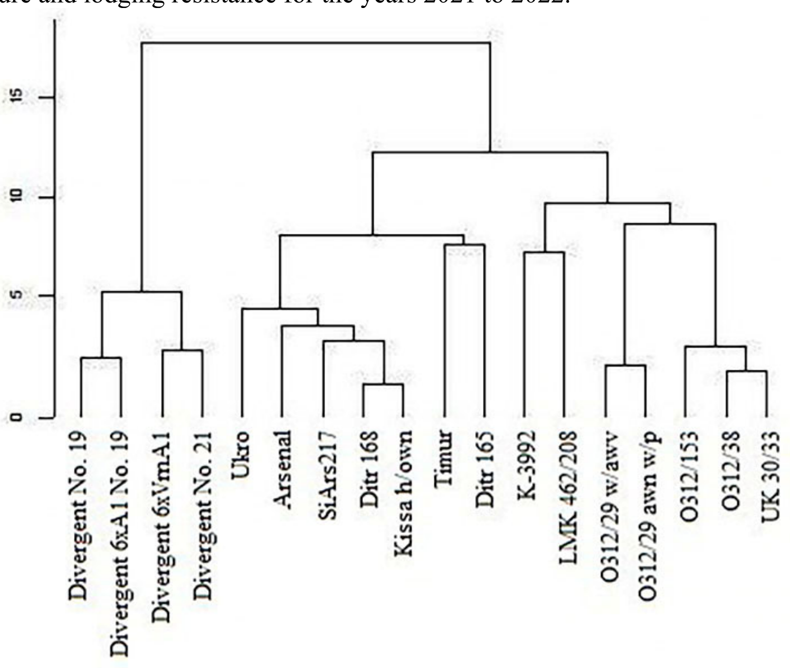

Fig. 2. Dendrogram of clustering of triticale breeding samples.

The results showed that there are five well-distinguishable clusters in this general population. Most of the samples were placed in clusters 1 and 5:

[cluster 1]: Timur, Ukro, Ditr 168, Kissa h/a, SiArs217, Ditr 165, Arsenal;

[cluster 2]: O 312/29 w/a, O 312/29 awn w/p;

[cluster 3]: K-3992, LMC 462/208;

[cluster 4]: O 312/153, O 312/38, Uk 30/33;

[cluster 5]: Divergent No. 19, Divergent 6X1 No.19, Divergent 6xVrnA1, Divergent No. 21.

A similar set of features within a cluster and significant differences with other clusters are typical for samples combined into one cluster.

The use of cluster analysis made it possible to group the influence of each attribute value on each other and their interaction as a whole over the entire study period. The involvement of divergent parental forms in the breeding process will contribute most to the creation of high-yielding, adaptive and lodging-resistant varieties. The accumulated information contained in the database can be used in the study and selection of new starting material for hybridization.

The optimal choice of parent pairs will reduce the number of combinations and provide sufficient volume for detailed study of valuable hybrid populations when breeding new non-lodging, high-yielding and high-quality varieties of spring triticale. Thus, the use of computer technologies in the selection of grain crops will provide information support for the selection process in solving classification and forecasting problems. The software product can be used by breeders, agronomists, scientists, specialists of agro-industrial complex.

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