Environmental adaptive cultivar model development methods on the spring triticale example

I G Grebennikova, A F Cheshkova, P I Stepochkin, A F Aleynikov and D I Chanyshev

1Siberian Federal Scientific Center of Agro-BioTechnologies of the Russian Academy of Sciences, Krasnoobsk, Novosibirsk region, 630501, Russia
2Siberian Institute of Plant Growing and Breeding – Branch of the Institute of Cytology and Genetics, Krasnoobsk, Novosibirsk region, 630501, Russia
3Novosibirsk State Technical University, Novosibirsk, 630073, Russia

E-mail: sibfti.grig@ngs.ru

Abstract. Usage of the optimization algorithms for the service of requests for repair in certain examples. The methodology for developing a model of an ecologically plastic variety of agricultural crops is based on an integrated approach and is built using the following mathematical and software-algorithmic methods: multifactorial correlation and cluster analyzes, calculating the integral assessment coefficient of samples depending on the share contributions of valuable traits, assessing the stability of genotypes by the value of the selection index methods of static and dynamic concept. The general provisions of the method are determined, the results of which make it possible to determine the criteria for a future variety, a complex of qualitative, quantitative, morph-physiological and technological characteristics. A database was created based on the results of field tests for 2018-2020, three varieties of spring wheat and four forms of spring triticale. The database contains digitized data of phenological observations and structural analysis of the studied samples for the period of research and serves to identify the relationships of characters, determine their contribution to productivity and retrospective analysis of breeding data. In accordance with the stages of modeling with the help of the developed software, the elements of the model of an ecologically plastic variety of spring triticale were determined by 14 features. The proposed optimal parameters of the model will increase the efficiency of selection of economically valuable genotypes and targeted selection for adaptability to the conditions of the region to create new high-yielding varieties of spring triticale.

1. Introduction
The success of breeding any crop depends to a large extent on the objectivity of developing a variety model. A variety model is a scientific forecast showing what combination of traits plants should have in order to provide a given level of productivity, resistance and other qualities required by production [1]. The construction of the model should be based on specific knowledge of the genotype of the modeled variety and the ways of its synthesis. It is important to develop models of varieties for a specific agro-climatic cultivation zone, because the valuable properties inherent in the variety can be manifested only under certain growing conditions, on an agricultural background that provides the widest possible disclosure of the variety’s potential. Thus, when creating a variety model, it is necessary to take into account the natural conditions of the area for which a new variety is being created, the directions of its...
use, and with this in mind, search for donors and sources of the necessary economically valuable traits for their use in the breeding process.

A new approach to optimizing the construction of variety models is the use of information technologies, which are used to increase the efficiency of theoretical and applied research in the field of plant breeding [2]. The use of information technologies in solving this problem helps to determine the criteria for the future variety, to determine the complex of qualitative, quantitative, morph-physiological and technological characteristics of the developed variety model [3,4].

The purpose of the research is to develop a methodology for creating models of ecologically plastic varieties of agricultural crops. In accordance with the developed methodology, on the basis of experimentally obtained material, determine the criteria for a model of an ecologically plastic variety of spring hexaploid triticale for the climatic conditions of Western Siberia.

2. Materials and methods

When creating a model of an ecologically plastic variety of spring triticale for the climatic conditions of Western Siberia, it is necessary to have selection samples with a high adaptive potential, which is most clearly manifested against the background of the action of unfavorable environmental factors. The material was the data of tests of three varieties of spring wheat and four forms of spring triticale, obtained during field experiments in 2018-2020. (table 1).

| № | Culture          | Name sample | Group ripeness | Origin                  | Most valuable characteristics of the variety                                      |
|---|-----------------|-------------|----------------|------------------------|--------------------------------------------------------------------------------|
| 1 | Soft spring wheat | Novosibirskaya 15 | early maturing | Novosibirsk, SibNIIRS | Resistant to lodging, moderately drought-resistant. Moderately susceptible to head smut. Strongly susceptible to brown and stem rust, powdery mildew. |
| 2 | Novosibirskaya 31 | mid-early   | Novosibirsk, SibNIIRS | Resistant to lodging, moderately drought-resistant. Moderately susceptible to leaf rust and septoria. In the field, it was severely affected by a dusty smut. |
| 3 | Siberian 12      | mid-late    | Novosibirsk, SibNIIRS | Resistant to lodging, drought-resistant. Moderately susceptible to septoria, highly susceptible to head smut, brown rust and powdery mildew. |
| 4 | Spring triticale | K-3992      | early ripe | St. Petersburg, VIR | The ear is medium dense, spinous. Resistant to lodging. The ears of secondary shoots are affected by ergot. |
| 5 | Kissa (k-3721)   | Mid-maturing | Mexico        | Semi-awned forms were selected. The ear is dense. Well done grain. Resistant to lodging. Drought-resistant. Powdery mildew was not affected. |
| 6 | Ukro (k-3644)    | mid-maturing | Russia, Ukraine | The ear is large, dense, spinous. Well done grain. Resistant to lodging. Drought-resistant. Powdery mildew was not affected. |
| 7 | Siars57 × Ukro   | late maturing | Novosibirsk, ICIG | Obtained as a result of diallelic crosses. Low-stemmed, resistant to lodging. The ear is dense, awnless. Powdery mildew was not affected. |

Due to the variety of meteorological conditions during the years of the experiments, contrasting growing conditions were provided, which made it possible to comprehensively study the samples under study. The acceleration of the process of testing genotypes for their differentiation according to the level of ecological plasticity was carried out using the following agro technical methods:
1) parallel testing of a set of breeding material for a variety of economically valuable traits in different soil conditions of the land plots of the bio polygon of the Siberian Institute of Physics and Technology of the Siberian Federal Scientific Center of Science and Technology of the Russian Academy of Sciences and the experimental field of SibNIIRS - a branch of the ICG SB RAS;

2) conducting a field experiment in three variants of the duration of daylight hours with an interval of 1 week.

The search for sources of valuable traits was carried out on the basis of the analysis of long-term data on the selection of the spring triticale culture according to early maturity, resistance to stress and productivity using the following mathematical and software-algorithmic tools.

Multivariate correlation analysis was used to identify and objectively assess the relationship between various features of the studied samples. The calculation of paired correlations of features was carried out by the Pearson method with an assessment of the statistical significance by Student's t-test [5].

The cluster analysis method was used to compare the studied samples by a complex of traits and to select a group of plants that most closely matched the model sample. The advantage of the method is that it allows you to split objects not by one attribute, but by a whole set of parameters. As a measure of similarity, feature correlations were used. The matrix of distances between features was defined as:

$$D = (1 - |r_{ij}|), (i, j = 1, ..., m),$$

where: $r_{ij}$ – correlation coefficients between the i-th and j-th features, m is the number of features.

For clustering, the Ward method was used [6].

Determination of the contribution of traits to yield and selection of initial forms with high economically valuable traits was carried out using a technique that allows calculating the coefficient of integral assessment of collection and selection samples depending on the share contributions of a number of valuable traits [7]. The breeding index of a plant was determined as a weighted sum of normalized productivity traits according to the formula:

$$Y = \sum_{k=1}^{K} q_k \cdot Y_k,$$

where: $K$ – number of features, $q_k$ – weighting expert coefficients satisfying the condition $\sum_{k=1}^{K} q_k = 1$, $Y_k$ ($k=1, ..., K$) – normalized characteristic values:

$$Y_k = \frac{X_k - X_{\min(k)}}{X_{\max(k)} - X_{\min(k)}},$$

where: $X_{\max(k)}$, $X_{\min(k)}$ – the maximum and minimum values of the k-th feature.

The assessment of the stability of genotypes by the value of the selection index was carried out using the methods of V.V. Khangildin. [8], Francis T.R. and Kannenberg L.W. [9], Eberhart S.A. and Russell W.A. [10], Nassar R. and Huehn M. [11]. Mathematical processing of the data was carried out using the computer program "Indicators of stability of varieties of agricultural crops" [12].

3. Results and discussion

In the Siberian region, the main use of triticale is as feed grain for feeding farm animals. Taking this into account, in order to develop a model of an ecologically plastic variety of spring hexaploid triticale for grain-fodder direction, a set of four breeding forms, characterized by different ecological and geographical origin, was studied for three years at different sowing periods. Studies have shown that the sowing time has a significant impact on all the studied parameters. Along with fixing the passage of phenological phases of plants and the dynamics of plant growth, the experimental program included a structural analysis of plants according to the following parameters: plant height, spike length, number of spikelets of an average spike, density of an average spike, number of spike grains, weight of spike grain, weight of 1000 grains, potential and actual productivity is calculated. To identify the relationships of characters and determine their contribution to productivity, as well as for retrospective analysis of
breeding data, the digitized data of phenological observations and structural analysis of the samples under study for the entire period of work were brought together in a single database.

The application of a systematic approach to creating a model of an ecologically plastic variety became possible after analyzing the conditions determined by a set of the following factors: the requirements for agricultural products, the ability to produce it in the required volumes under the conditions of a particular region were formulated, and the presence of suitable traits and properties in the genplasm of the selection sample was experimentally. On the basis of long-term data of breeding studies, pairwise correlations of 10 traits were calculated:

- stem length,
- ear length,
- the number of spikelets in an ear,
- ear density,
- the number of grains in an ear,
- grain weight of the spike,
- weight of 1000 grains,
- number of stems per plot,
- yield,
- number of germination-earining days.

In the absence of a standard for spring triticale, comparison was made with wheat varieties of Siberian selection. Analysis of the correlation matrices allowed us to conclude that the traits “spike length”, “number of grains per ear”, “number of spikelets in an ear”, “grain weight of an ear” and “number of seedling-earining days” form a correlation group for both wheat and for tritical. There is a high level of correlation dependences between all pairs of characters in this group (0.46 ≤ r ≤ 0.91). An average linear relationship is observed between the traits “1000 grain weight” and “ear density” in wheat (r = 0.31) and between the traits “1000 grains weight” and “stem length” in triticale (r = 0.5). The yield showed a high level of correlation with the trait “number of stems per plot” for both crops (r = 0.68; r = 0.71).

To visualize the correlation groups, a cluster analysis was performed based on the similarity correlation matrix. The analysis for wheat and triticale made it possible to group the traits and, by combining them, to identify the closest ones (Figure 1). As a result, three clusters of interrelated features were identified that have a similar set of features within the cluster and significant differences with other clusters. The number of clearly distinguishable clusters for wheat and triticale is the same, but the set of features that make up the clusters is different.

![Dendrograms of quantitative traits](image)

**Figure 1.** Dendrograms of quantitative traits: a) wheat, b) triticale.

Different rates of development of plants, varieties and crops, as a result, significantly influenced the integral indicator - grain yield, which is based on numerous correlations between a whole complex of interrelated traits. At different sowing times, the critical stages of plant development take place in different light and temperature regimes, which changes the metamerism of the plant and ear, and
ultimately affects the productivity of the plant. The lowest yield of all studied samples was observed during the third sowing period. The highest yield, mainly due to the better grain content of the ear and the high mass of grain from the ear, had the samples of triticale Ukro and Kiss p/o, which maximally realized their productivity potential during the first two sowing periods - 54.2 100kg/ha and 54.5 100kg/ha, respectively (table 2).

Table 2. Mean grain yield (100kg/ha) of three spring wheat and four spring triticale varieties tested at three sowing dates, 2018-2020.

| Variety             | Variety | 2018 | 2019 | 2020 | Average | Rank |
|---------------------|---------|------|------|------|---------|------|
| Novosibirskaya 15   | 18.8    | 36.5 | 28.5 | 41.7 | 31.0    | 31.2 | 39.8 | 34.3 | 29.3 | 32.4 | 7    |
| Novosibirskaya 31   | 28.5    | 55.1 | 29.9 | 56.0 | 47.2    | 40.2 | 75.4 | 58.1 | 44.2 | 48.3 | 4    |
| Siberian 12         | 31.8    | 54.4 | 45.9 | 62.4 | 45.9    | 38.9 | 61.8 | 57.5 | 45.0 | 49.3 | 3    |
| K-3992              | 40.6    | 36.9 | 17.3 | 45.4 | 37.0    | 28.6 | 43.8 | 28.7 | 17.8 | 32.9 | 6    |
| Siars 57 x Ukro     | 25.9    | 26.2 | 19.2 | 53.3 | 53.1    | 39.4 | 57.1 | 46.5 | 34.8 | 39.5 | 5    |
| Ukro                | 41.2    | 94.0 | 32.0 | 46.3 | 57.1    | 41.5 | 70.2 | 56.8 | 49.0 | 54.2 | 2    |
| Kissa p/o           | 38.3    | 78.0 | 27.3 | 74.6 | 50.8    | 26.1 | 79.3 | 59.8 | 55.9 | 54.5 | 1    |
| Average             | 32.2    | 54.5 | 28.6 | 54.3 | 46.0    | 35.1 | 61.1 | 48.8 | 39.4 | 44.4 |      |

Summarizing the research results, we can conclude that the elements of the yield structure studied by us, the plant productivity was most influenced by the length of the ear, the number of grains in the ear, the number of spikelets in the ear, the weight of the ear grain and the number of stems from the plot. To a lesser extent, the yield is related to the height of the plants and the weight of 1000 grains. It should also be noted that the variability of the vegetation conditions of plants in different years significantly influenced the yield of selection samples. The difference between the average value of the yield in the experiment in terms of sowing dates within a year was: 2018 - for wheat 36.3 100kg/ha, for triticale 76.7 100kg/ha; 2019 - 31.4 100kg/ha and 48.4 100kg/ha; 2020 - 46.0 and 61.5 100kg/ha, respectively. At the same time, the maximum yield level of the samples in terms of sowing dates varied from year to year. It was found that under favorable conditions and observance of agricultural techniques, the studied triticale samples are capable of surpassing wheat in yield.

The contrasting hydrothermal conditions of the research period and the application of an integrated approach to the assessment of varieties based on the methods of the static and dynamic concept [12] made it possible to reliably evaluate the studied genotypes in terms of stability and adaptability.

The analysis of the values of the coefficients of variation (σ) and homeostatic (H) made it possible to determine the form of triticale Sears 57 x Ukro as the most stable, the least stability was found in the wheat variety Novosibirskaya 31 (table 3).

Table 3. Stability and adaptability parameters of the studied varieties.

| Variety             | σ      | H     | b_i   | s^2_{di} | S_2 |
|---------------------|--------|-------|-------|----------|-----|
| Novosibirskaya 15   | 20.97  | 8.86  | 0.68  | 0.0009   | 3.36|
| Novosibirskaya 31   | 23.43  | 6.81  | 1.35  | 0.0004   | 3.61|
| Siberian 12         | 16.11  | 15.90 | 0.97  | 0.0012   | 3.50|
| K-3992              | 16.65  | 13.96 | 0.48  | 0.0029   | 8.44|
| Siars 57 x Ukro     | 11.00  | 42.55 | 0.79  | 0.0002   | 1.61|
| Ukro                | 15.13  | 15.34 | 1.08  | 0.0034   | 4.44|
| Kissa p/o           | 17.11  | 10.41 | 1.66  | 0.0010   | 6.36|

The regression approach to the assessment of stability parameters in accordance with the method of Eberhart & Russell [10] made it possible to determine that the varieties Siberkaya 12 (b_i=0.97) and Ukro (b_i=1.08) with regression coefficients closest to one, have an average responsiveness to changes
in environmental conditions. Such an assessment of genotypes indicates their agronomic (dynamic) stability, that is, the manifestation of an average response to changes in environmental conditions. The change in the indicators of the variety corresponds to the change in conditions: on a good agricultural background, they are high, on a low one, they tend to decrease.

Varieties Novosibirskaya 31 and Kissa p/o, with a regression coefficient $b_i > 1$, are more responsive to changes in growing conditions and require a higher level of agricultural technology. However, in unfavorable weather conditions, as well as on a low agricultural background, productivity of these varieties sharply decreases and there is a need for more plastic varieties with high adaptive potential. Varieties Novosibirskaya 15, K-3992 and Siars 57 x Ukro with a regression coefficient $b_i < 1$ can be recommended for cultivation in a poor agricultural background or under unfavorable climatic conditions. The variance of the deviation from the regression line $s^2_{di}$ characterizes the Siars 57 x Ukro variety as the most stable. The value of the nonparametric indicator $S_2$, based on the relative ranking of the data and calculated by the method of Nassar & Huehn [11], gave a similar assessment of stability. In general, all studied samples showed a high ability to develop under various environmental conditions.

Based on the methodology for calculating the coefficient of the integral assessment (formulas (2), (3)) and the developed software using long-term data of breeding research, the following optimal economically valuable features of the model of the spring triticale variety were determined for the conditions of the West Siberian forest-steppe of the Ob region: plant height - 90 cm; number of grains of the main spike - 65 pcs.; spike length - 12-13 cm; spike grain weight - 4 g; 1000 grain weight - 60 g; number of stems before harvesting - 167 pcs.; yield - 69.3 100kg/ha; germination-earing period - 33 days; spinousness - no; drought resistance - high, resistance to major diseases (powdery mildew, brown rust, dusty and hard smut) - high; ecological plasticity - high. Using cluster analysis, samples were identified that were identical to the model variety. This is Ukro, Kissa p/o and hybrid Siars 57 x Ukro.

Figure 2 graphically presents the elements of the model of the ecologically plastic variety of spring triticale in comparison with the variety Ukro.

**Figure 2.** The elements of the model of forage spring triticale variety, environmental adaptive to the West Siberian forest-steppe zone of the Ob region.

Involvement of these accessions in hybridization will most contribute to the creation of high-yielding, adaptive and resistant varieties. The proposed optimal parameters of the model will increase the efficiency of selection of economically valuable genotypes and targeted selection for adaptability to the conditions of the region to create new high-yielding varieties of spring triticale.
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