Model of integrated resistant variety spring wheat for soil-climatic conditions of the Kurgan region

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Abstract. In the conditions of resource-saving or "zero" soil cultivation, when a mass of plant residues remains on the surface of the field, the phytosanitary situation for many leaf diseases of wheat, the primary infection of which hibernates on straw, as well as root rot, has become extremely aggravated. The complication of the phytosanitary situation, especially concerning septoria and pyrenophorosis, was also facilitated by the predominantly chemical strategy of plant protection. In this situation, the selection of wheat varieties for complex resistance to leading pathogens and unfavorable environmental factors acquires relevance. The introduction of new resistant varieties into the agroecosystem allows for a change in biological diversity, expansion of the ecological niche of antagonists, and the prevalence of the stabilizing type of natural selection in pathogen populations. In this regard, the work aimed to develop a conceptual model (idiotype) of a complex resistant wheat variety to the main pathogens with traits that are responsible for optimizing the relationship of plants with pests. The main objectives of the study were to identify the immunogenetic mechanisms of local spring wheat varieties that reduce the biotic potential of harmful organisms and restraining the rate of their adaptive population variability; development of a conceptual model of a comprehensively resistant variety and methods for selecting resistant forms of plants. For the first time, an assessment of all immunogenetic barriers can effectively and long-term protect plants from the effects of infectious and non-infectious agents, unfavorable abiotic environmental factors, as well as the analysis of the information available in the scientific literature on the mechanisms and parameters of plant resistance, a conceptual model of a variety of soft spring wheat, was developed for the conditions of the Southern Trans-Urals with resistance to a complex of phytopathogenic fungi and moisture deficit. Resistance should be focused primarily on pyramiding a block of resistance genes (polygenes) with the use of appropriate techniques, on the formation of complex resistance to stressors of different childbirth. Such models have no analogs since research in this direction in regional research institutes (Kurgan Research Institute of Agriculture, Chelyabinsk Research Institute of Agriculture, etc.) has not previously been carried out.

1. Introduction
The creation of varieties that are resistant to diseases and pests is a highly effective and environmentally friendly way of protecting plants from harmful organisms, reducing the loss of crop production and pollution of the environment with pesticides, mineral fertilizers, and other agrochemicals. A new variety is a new food and energy substrate for a causative agent of a disease or pest, which still needs to be mastered, which, of course, will take time. An unusual variety also means...
other temporary connections, other opportunities, a different microclimate in crops, a different level of
cultivation technology, and mineral nutrition. The environment-forming significance of varieties in
agrobiocenoses makes them one of the most important factors determining the structure of complexes
of harmful and beneficial organisms, their differential survival, population variability, and
microevolution [1–3].

Recently, methods of molecular biology, hybridization, and sequencing of plant genomic DNA the
PCR analysis method have begun to play a significant role in the development of breeding [4, 5]. The
use of molecular markers in plant breeding has significantly accelerated the process of obtaining new
varieties by pyramiding target genes and made it possible to implement a new approach in breeding -
molecular certification of varieties [6].

Today, the methods of marker-based selection are beginning to be applied by regional selection
centers of the Urals, Trans-Urals, and Western Siberia [7], including specialized research units of the
Kurgan State Agricultural Academy named after T.S. Maltseva (interdepartmental research laboratory
of molecular biology. Based on this laboratory, research has been launched on the development of
models of spring wheat varieties resistant to a complex of harmful organisms for soil and climatic
conditions of the Kurgan region, considering the molecular genetic mechanisms of immunity. The
work aims to create a conceptual model of the variety wheat based on the qualitative and quantitative
parameters of mechanisms and markers of resistance to key pathoagents (septoria, pyrenophorosis,
root rot, etc.).

2. **Research methodology and conditions**

Work on the creation of a model of cultivated wheat, which is resistant to a complex of pathoagents,
has been carried out over the past 10 years (2012 - 2021).

The development of conceptual models of various types of biological systems was carried out
based on information databanks of mechanisms that make up the structure of the immunogenetic
system of cereals, created as a result of many years of research carried out based on laboratories of
microbiology and phytopathology of the regional center for phytosanitary monitoring of agricultural
landscapes (Kurgan) and structural divisions of the Kurgan State Agricultural Academy, and also
based on genetic analysis using chromosome maps of spring wheat [8].

Genetic analysis was supplemented by the method of marking at the level of plant phenotype of
groups of polygenes responsible for the formation of constitutional resistance barriers (the method of
marker genes, or reporter genes) [9, 10].

The water status of plant tissues (determination of the intensity of transpiration by the gravimetric
method; determination of the water deficit of plants; determination of the water-holding capacity of
plants by the “wilting” method; determination of the intensity of plant respiration) was determined
using standard methods of plant physiology and biochemistry [11, 12].

The assessment of the capacity of the ecological niche for antagonists is given using the Simpson
index [13].

3. **Research results**

An analysis of the work of regional breeding institutions shows that the assessment of varieties for
resistance is carried out mainly in the field, selecting less infected varieties, as well as plants on which
the disease developed more slowly. At the same time, the parameters that determine the resistance of
plants to diseases and pests are not specified, are not modeled and are not explicitly included in the
model of the variety created by the breeder [14].

In this regard, when developing a model of a resistant cultivar, considering all immunogenetic
barriers that are capable of effectively and long-term protection of plants from the effects of infectious
and non-infectious agents should become a mandatory measure. For the conditions of the Southern
Trans-Urals, no one has ever created such models; therefore, it seemed important to assess the state of
barriers of the immunogenetic system for regionalized varieties and develop a regional conceptual
model of a spring wheat variety with complex resistance to several negative factors.
The resistance of grain crops to pathogens in the initial period of development is determined mainly by anatomical and morphological factors - the degree of leaf pubescence, the thickness of the cuticle, the degree of lignification of leaf and root tissues, the degree of development of leaf mesophyll cells, as well as the water status of plant tissues; the main attention was paid to the assessment of these parameters. The integral indicator of the state of the plant immunogenetic system (IIS) was used for the assessment, which was determined by converting the values of the studied plant parameters into the so-called desirability scale, where 0 corresponds to an unacceptable state of the parameter, and 1 - to such a value that can be called ideal. Intermediate indicators of parameters are expressed by numbers from 1 to 0, which determine the degree of optimality of each of them. Partial desirability (di) is calculated by transformations: $d_i = N_i / N_{opt}$, if $N_i < N_{opt}$, $d_i = 1 - N_i / 10 \cdot N_{opt}$ if $N_i > N_{opt}$, where $N_i$ is the average value of the measured plant parameter, $N_{opt}$ - ideal (desired) value of the measured parameter. The integral indicator of the state of the plant's immunogenetic system was determined as the geometric mean of the individual di:

$$IIS = \sqrt[d_1, d_2, d_3, \ldots, d_i]$$

The desirability function used by ecologists in monitoring studies of the state of the environment served as a prototype for creating an index of the immunogenetic system [15]. When interpreting the obtained index values, the desirability scale was divided into intervals (Table 1):

| State of the immunogenetic system | IIS       |
|----------------------------------|----------|
| Excellent                        | 1.0 – 0.8|
| Good                             | 0.8 – 0.6|
| Satisfactory                     | 0.6 – 0.4|
| Bad                              | 0.4 – 0.2|

The Zhigulevskaya spring wheat variety, widespread and zoned in the Kurgan region, was selected as the object of assessment (now it has been removed from the list of zoned varieties but is still cultivated on individual farms; it is strongly affected by septoria, pyrenophorosis).

As a result of the studies, it was found that the degree of leaf pubescence in the tillering stage in the Zhigulevskaya variety does not exceed 19 - 20 hairs per mm$^2$, which is significantly lower than the desired level (more than 50 hairs / mm$^2$). Cuticle thickness (0.57 μm - actual; desired level - 1.5 μm), level of lignin accumulation (0.21 mg g$^{-1}$ - actual; more than 0.48 mg g$^{-1}$ - desired level) and content in leaves of dry matter (8% - actual; 11% or more - desirable) is also significantly below the optimal level. The index of the state of the plant immunogenetic system (IIS), calculated according to 8 indicators, does not exceed 0.6, which on the scale of desirability corresponds only to a satisfactory level.

The water-retention capacity of plant leaves (hatching phase) is on average at the level of 75.3% (the desirability $d_i$ is 0.94, i.e., the indicator is close to optimal), the water content in the leaves is 87.3% (the desirability $d_i$ is 0.97), dry matter content - 10.8% (the desirability $d_i$ is 0.83), leaching of organic matter from leaves (amount of organic matter per 1 g of the wet weight of leaves in ml 0.01N KMnO$_4$ – 10.6, the desirability $d_i$ is 0.90) is almost normal (slightly increased). All this provides good conditions for the development of plants in dry summer conditions. A significant amount of phytoncides, phytoalexins, and inhibitor proteins are accumulated in leaf sap.

The moisture requirement of plants is determined by the amount of water (in grams) required to create 1 g of dry matter, i.e., transpiration coefficient. The best drought-tolerant forms of cereals are distinguished by economical water consumption for transpiration, which ensures normal productivity with a moisture deficit. Researchers note a high conjugation of indicators of the water-holding capacity of the upper developed leaves at the IV stage of organogenesis with a direct assessment of drought resistance [16].

Observations of the water exchange parameters of different varieties of spring wheat carried out during two growing seasons with contrasting moisture availability (2014 - drought; 2015 - normal in
terms of moisture level), made it possible to concretize the parameters of the model of a resistant and adaptive variety (Tables 2, 3).

**Table 2.** Intensity of transpiration (mgH₂O / dm²·h) of plant leaves various varieties of spring soft wheat (Kurgan, 2014 - 2015)

| Option | Plant development phases | 2014 drought | 2015 norm |
|--------|-------------------------|--------------|-----------|
|        |                        | tillering    | stem elongation | bloom    |
| Zhigulevskaya |                        | 122.4 ± 3.5  | 390.4 ± 3.3    | 442.9 ± 6.1 |
| Lutescens 70  |                        | 133.2 ± 4.5  | 425.4 ± 6.1    | 658.0 ± 9.2 |
| Tulunskaya 12 |                        | 136.1 ± 5.1  | 623.2 ± 4.3    | 783.6 ± 13.1|
| Tertsiya     |                        | 88.0 ± 2.4   | 166.9 ± 2.5    | 369.5 ± 7.6 |
| Zhigulevskaya |                        | 91.6 ± 4.1   | 299.1 ± 5.2    | 384.0 ± 10.2|
| Lutescens 70  |                        | 98.0 ± 4.3   | 315.4 ± 8.7    | 617.2 ± 11.0|
| Tulunskaya 12 |                        | 105.4 ± 6.5  | 399.9 ± 7.3    | 623.2 ± 10.2|
| Tertsiya     |                        | 75.1 ± 4.2   | 154.3 ± 5.9    | 289.4 ± 9.8 |

Observations showed that all wheat varieties had a higher transpiration rate in a dry year. However, the Tertsiya variety (characterized as very drought-resistant due to the dense tomentose leaf pubescence) consumed water very sparingly, in contrast to the Tulunskaya 12 variety, which lost a lot of water, protecting itself from overheating. Under drought conditions, the water-holding capacity of the leaves also decreased most strongly in this cultivar. Variety Lutescens 70, which is known to be highly sensitive to moisture deficit during seed germination, turned out to be close to Tulunskaya 12.

**Table 3.** Water-holding capacity * (%) of leaves various varieties of spring soft wheat (Kurgan, 2014 - 2015)

| Option | Plant development phases | 2014 drought | 2015 norm |
|--------|-------------------------|--------------|-----------|
|        |                        | tillering    | stem elongation | bloom    |
| Zhigulevskaya |                        | 77.9 ± 2.4   | 71.4 ± 2.2    | 70.2 ± 1.2 |
| Lutescens 70  |                        | 67.1 ± 2.5   | 65.0 ± 2.1    | 60.7 ± 1.5 |
| Tulunskaya 12 |                        | 63.7 ± 2.8   | 60.8 ± 2.3    | 58.6 ± 1.7 |
| Tertsiya     |                        | 91.0 ± 1.9   | 89.1 ± 1.8    | 88.0 ± 1.3 |
| Zhigulevskaya |                        | 81.5 ± 2.6   | 79.7 ± 2.3    | 79.6 ± 1.4 |
| Lutescens 70  |                        | 80.6 ± 2.7   | 78.9 ± 3.0    | 73.3 ± 1.6 |
| Tulunskaya 12 |                        | 80.0 ± 2.6   | 79.2 ± 3.5    | 70.5 ± 1.7 |
| Tertsiya     |                        | 96.0 ± 2.4   | 94.2 ± 2.3    | 91.3 ± 1.2 |

* - determined by the "wilting" method according to Arland on leaves from 20 plants

As you can see, the xeromorphic structure of the tissues, the more powerful development of the network of the conducting system, the strong pubescence of the plants, the thickness of the leaves contributes to the conservation of water in the plant, ensuring the implementation of the mechanism for avoiding drought.

At the same time, there are bottlenecks in the system of plant immunogenetic barriers. Thus, the zoned varieties of spring wheat (Zhigulevskaya, Tertsiya, Tulunskaya 12, Lutescens 70, etc.) are dominated by biotypes with a small number of chlorenchymal strands in the stem (straw) - n = 32 (d₁ = 0.53), the strands are wide and represent an excellent niche for the introduction of stem rust, which can form large pustules with many spores in such strands. The leaf blades have a significant width (on average 9.2 mm, d₁ = 0.65), weak pubescence (29 - 30 hairs / mm², d₁ = 0.59), insufficient cuticle thickness (1.98 μm, d₁ = 0, 79) and relatively weak tissue lignification (0.38 mg g⁻¹, d₁ = 0.79). The general state of the immunogenetic system of the Zhigulevskaya variety (IIS = 0.8) is assessed only as good.

A special position is occupied by microbial sinusia of the ear and grain. The anatomical and morphological parameters of the plant (spike) are also of leading importance in the formation of this specific synusia: the shape and density of the spike are cylindrical of medium density (Tertsiya),
pyramidal medium-loosen (Fora, Aria), cylindrical medium-lobe (Kurgan 1, Maltsevskaya 110), cylindrical spinous (Collective 2), spindle-shaped medium density (Omskaya 18, Tulunskaya 12), prismatic medium density (Zhigulevsksaya, Omskaya 20).

Assessment of the architectonics of an ear of spring wheat variety Zhigulevsksaya, the level of concentration of water- and alcohol-soluble proteins in grain extracts indicate a good state of immunogenetic barriers (IIS = 0.8), nevertheless, even though that the ear of this variety has long awns (high windage), prismatic shape and average density, pubescent grain base, the capacity of the ecological niche of micromycetes-antagonists of phytopathogenic fungi (by the capacity of the ecological niche we mean here the measure of the diversity of resources used by the species of the community, more precisely, the number of microzones (habitats) of the ear occupied by the species of this synusia) relatively small. The calculation of the Simpson index (D) for the capacity of the econiche of antagonists gave a value of the order of 7.4, while its optimal value should be considered a value of 20 or more. Thus, the ecosystem of an ear of this variety has its own "problem" areas.

Based on the experimentally revealed qualitative and quantitative parameters of the resistance of grain crops to the dominant phytopathogens and key unfavorable abiotic environmental factors, as well as on the analysis of the information available in the scientific literature on the mechanisms and parameters of plant resistance, a conceptual model of the soft spring wheat variety was developed for the conditions of the Southern Trans-Urals with resistance to a complex of phytopathogenic fungi and moisture deficit (Table 4).

Table 4. Conceptual model of a variety of soft spring wheat with resistance to a complex of phytopathogens and moisture deficit

| Immune genetic system barriers | Mechanisms and parameters of immunological barriers | Pathogens |
|--------------------------------|-----------------------------------------------|-----------|
| **Features of the growth and development of plants** | | |
| Growth (growth rate of vegetative organs and root system) | Accelerated rates of growth and formation of aboveground and underground organs and shoots; | drought, dust smut, root rot |
| | Provision of seedlings and seedlings with embryonic roots - at least 5; | drought, root rot |
| | The length of the roots per unit area of the soil surface is 100 - 110 cm / cm²; | drought |
| | Accelerated passage of the stages of plant organogenesis (early ripening variety) | drought, infections |

| **Features of the architectonics of a plant, the structure of its organs, tissues and cells** | | |
|-----------------------------------------------|---------------------------------------|-----------|
| Morphological (architectonics, macro- and microstructure of plants) | Xerophytic type of leaf (length and width of leaf mesophyll cells - 15 x 8 microns) | drought |
| | Narrow leaf with dense arrangement of veins (leaf width - 6 - 7 mm); | drought, infections |
| | High degree of leaf pubescence (more than 50 hairs per 1 mm²); | drought, infections |
| | The thickness of the leaf cuticle is 2 microns or more; | powdery mildew, brown leaf rust |
| | The spike is dense (2.3 - 2.8 spikelets per 1 cm of the length of the spikelet), spinous; | fusarium, helminthosporium |
| | Spikelet scales are densely pubescent; | drought, rust |
| | Closed flowering type; | fusarium, dust smut |
| | Stem with 50 - 60 chlorenchymal strands; | stem rust |
The number of root hairs per 1 cm is not less than 500 pcs. root rot

| Physiological and biochemical characteristics of plants, microbiological characteristics | root rot | drought |
|---|---|---|
| **Physiological level processes and metabolism of plants** | Intensity of leaf transpiration in the tillering phase - no more than 75 - 80 mg H2O / dm² · h; | root rot |
| | The coefficient of leaching of organic matter from leaves in the flowering phase is 9.5 or less; | drought |
| | Water-holding capacity of leaves in the tillering phase - not less than 85 - 90%; | complex of leaf infections |
| | The level of lignification of root and leaf tissues (lignin content - 0.50 mg g⁻¹ and more); | complex of leaf infections, root rot |
| | A high level of accumulation in leaf juice of phytoalexins, inhibitor proteins (no more than 30% of conidia of phytopathogens germinate). | complex of leaf infections |

The development of a wheat cultivar model with blocks of valuable genes (polygenes) was carried out based on genetic analysis using chromosome maps of spring wheat. Genetic analysis was supplemented by the method of marking at the level of plant phenotype of polygenic groups responsible for the formation of constitutional resistance barriers (marker genes method) [17].

Consider the chromosome map of Triticum aestivum L. to determine the blocks of useful genes involved in plant defense against leaf and root infections. In the short arm of chromosome 3A, the gene for resistance to septoria Stb-6 is localized. On the same chromosome, there is a gene responsible for the red color of the grain (R1 - Redgrain). Chromosome 6A contains genes for susceptibility to stem rust (Sr8 and Sr13), as well as genes modifying resistance to septoria blight [18].

The B genome is very interesting for a phytoimmunologist. On chromosome 2B (arm S), the wax plaque gene W1 (Waxy-1) is localized. The block of valuable genes of chromosome 7B is represented by the recessive gene el (early), located at locus 39 and determining early maturity. In 23 e.k. from it is the gene for the purple color of the stem (Pc). This gene is not directly related to immunity but controls the synthesis of anthocyanins - polyphenolic compounds that block the advancement of the mycelium of pathogenic micromycetes. In crosses, both genes can be preserved, depending on the tasks.

In chromosomes 3D, 5D, 6D, modifier genes affecting resistance to S. nodorum are localized. As for chromosome 7D, it is interesting in that it contains the Rc3 gene of purple coleoptile, pleiotropic concerning high resistance to root rot.

It is known that in the current agro-ecological conditions of the Kurgan region, the tandem “septoria + root rot” poses the greatest danger to spring wheat crops. It is also known that an early-ripening variety will avoid being affected by septoria, and a variety with an anthocyanin coloration of coleoptile is much less affected by root rot [19, 20].

Based on the available data, an example of a breeding task for creating a variety resistant to the tandem "septoria + root rot" can be the following: the gene for anthocyanin coloration of spring wheat straw is in the 16th, and in the 39th locus of the same chromosome - the gene for early maturity (el). To develop an early-ripening wheat variety for the 1st and 2nd agroclimatic zones of the Southern Trans-Urals, with an anthocyanin (purple) underground internode (pe +), resistant to common root rot and septoria blight.
4. Conclusion

The development of conceptual models of agricultural crop varieties based on qualitative and quantitative parameters of mechanisms and markers of resistance is one of the most effective ways to increase the efficiency of breeding work to create varieties with the group and complex resistance. Conceptual modeling is currently becoming an important theoretical and methodological direction in the design of new plant genotypes.

The creation of varieties of agricultural plants with the group and complex resistance to biotic and abiotic stressors should be carried out considering the block organization of the plant genome and polygenic control of traits that are valuable for breeding for resistance. At the same time, the key points of the breeder's work are genetic analysis of the localization of valuable gene blocks, mandatory consideration of the parameters of the plant's immunogenetic system when developing a variety model.

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