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IDENTIFICATION OF SOURCES OF RESISTANCE IN WINTER WHEAT TO RUST SPECIES UNDER ARTIFICIAL INFECTIOUS BACKGROUND CONDITIONS

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Abstract. This paper presents the results of a comprehensive assessment of the resistance of winter soft wheat varieties and accessions to rust species under artificially created infectious background conditions in the southern region of Kazakhstan. The research was conducted in 2021 at the Research Institute for Biological Safety Problems. The objects of the study were varieties from Central Asia and Transcaucasia, as well as collection accessions from the international nurseries 27FAWWON-SA and 27FAWWON-IR. Resistance assessment was carried out based on a range of phytopathological parameters, including disease severity, infection type, area under the disease progress curve, and the coefficient of infection. The studies established that under an artificial infectious background, a significant differentiation of accessions by the level of resistance to stem, leaf, and yellow rust is observed. The maximum disease severity in susceptible accessions reached 60-80%, while in resistant forms this indicator did not exceed 10-20%. Weather conditions during the growing season influenced the development of yellow rust, whose severity remained low in most cases. The results showed that foreign accessions possess a higher level of resistance compared to varieties from CA&T. Specifically, the proportion of forms resistant to stem rust in the 27FAWWON-IR nursery reached 72.1%. Overall, 125 accessions with complex resistance to all three rust species were identified. It was established that the use of an artificial infectious background is an effective and reliable method for phytopathological screening, providing an objective evaluation of genotypes. The identified accessions are of significant interest for breeding practice and can be used as donors of resistance in the development of new high-yielding winter wheat varieties adapted to the conditions of Kazakhstan.

Keywords: stem rust, leaf rust, yellow rust, winter wheat, CIMMYT.

Introduction

Kazakhstan is one of the major grain-producing and wheat-exporting countries. Due to violations of agronomic practices, the cultivation of susceptible varieties, insufficient plant protection measures, and favorable weather conditions, there is a continued accumulation of infectious inoculum of plant pathogens in wheat fields. Among wheat diseases, the most widespread are rust diseases caused by *Puccinia graminis*, *Puccinia triticina*, and *Puccinia striiformis*, as well as leaf spot diseases caused by *Septoria tritici*, *Pyrenophora tritici-repentis*, and *Stagonospora nodorum* [1–4].

In this context, the development and introduction into production of disease-resistant cereal varieties is a priority objective of modern plant breeding, which is grounded in the theoretical principles of plant immunity. Addressing this problem requires an integrated approach involving phytopathologists, geneticists, and biotechnologists [3].

A key stage in phytopathological and breeding research is the evaluation of resistance to rust pathogens. In Kazakhstan, such studies are often constrained by the lack of inoculum necessary to establish an artificial infection background. Assessment under natural infection conditions, which depends on random spore introduction and weather variability, is not always effective, particularly under continental climate conditions with a low probability of annual epiphytotics. Therefore, the establishment of an artificial infection background represents a more reliable and controlled method for phytopathological screening. To obtain objective data, the infection nursery should be located on an irrigated site, isolated from commercial wheat fields (at a distance of at least 10–15 km), and managed in accordance with all agronomic requirements.

Materials and methods. Field and laboratory experiments were conducted at the Research Institute for Biological Safety Problems, located in Gvardeyskiy settlement, Korday District, Zhambyl Region. According to agroclimatic zoning, the field trial site belongs to an arid foothill agroclimatic region. Longterm data indicate that precipitation during the growing season of cereal crops ranges from 80 to 190 mm. The hydrothermal coefficient is 0.41 – 0.50. The sum of effective temperatures varies between 3000 and 3500 °C, while the annual precipitation ranges from 250 to 400 mm.

According to data from the Korday meteorological station, the mean air temperature (°C) and precipitation (mm) in 2021 were as follows: April – 9.7 °C and 37 mm; May – 17.2 °C and 15 mm; June – 21.2 °C and 5 mm; July – 25.8 °C and 5 mm; and August – 22.8 °C and 10 mm, respectively (Figure 1).

In 2021, the total precipitation during the spring period averaged 134 mm, which is insufficient for optimal growth of cereal crops and the initial development of fungal diseases. Therefore, to create favorable conditions for plant growth and disease development, the experimental plots were regularly irrigated and sprayed with water.

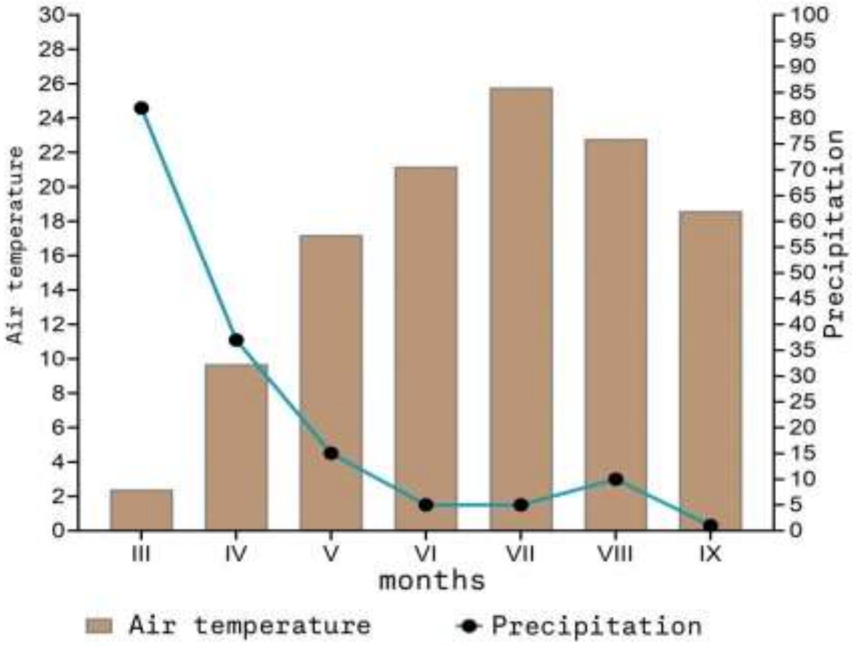


Figure 1 – Meteorological conditions of the region in 2021
(average for the spring–summer period)

In field experiments, urediniospores of local populations of rust pathogens preserved in the microorganism collection of the Research Institute for Biological Safety Problems were used as inoculum [5–7]. Field trials were established on an irrigated experimental site of the institute. Following moldboard plowing and harrowing, the field was cultivated using a SOLO 503 cultivator. Seeds were sown manually on plots of 0.4–3.0 m², with 20 cm row spacing and row lengths of 100–300 cm. Each row was sown with 65–80 seeds. The wheat cultivar *Steklovidnaya 24* was used as a control. To promote the accumulation and spread of infection within the nursery, susceptible spreader varieties (*Morocco* and *Bogarnaya 56*) were sown between tiers.

Prior to inoculation, the inoculum was activated at 40 °C for 10 minutes, followed by hydration in a moist chamber at 20 °C for 2 hours. In spring, at the tillering and stem elongation stages, spring wheat accessions were inoculated with an aqueous suspension of leaf and stem rust spores supplemented with the surfactant Sigma-Aldrich Tween 80. After inoculation, plots were covered with polyethylene film for 16–18 hours. Inoculation was performed in the evening under calm conditions after предварительного полива (pre-irrigation) of the experimental plots [8].

During the growing season, field resistance to diseases was assessed three times at two-week intervals, starting from the appearance of the first symptoms. The evaluation criteria included infection type and disease severity, assessed according to standard scales. Infection type for stem rust was determined using the Stakman scale [9], for leaf rust using the Mains and Jackson scale [10], and for stripe rust using the Gassner and Straib scale [11]. Disease severity (%) of rust infections was assessed using the Peterson scale (modified Cobb scale) [12].

It should be noted that during assessments at the stem elongation–heading stages, two leaves from the lower and middle canopy layers were analyzed, whereas during the grain-filling stage, the upper two leaves, including the flag leaf, were evaluated. The final assessment of leaf and stripe rust was conducted at the milk–dough stage of grain development, while stem rust was assessed at the wax maturity stage.

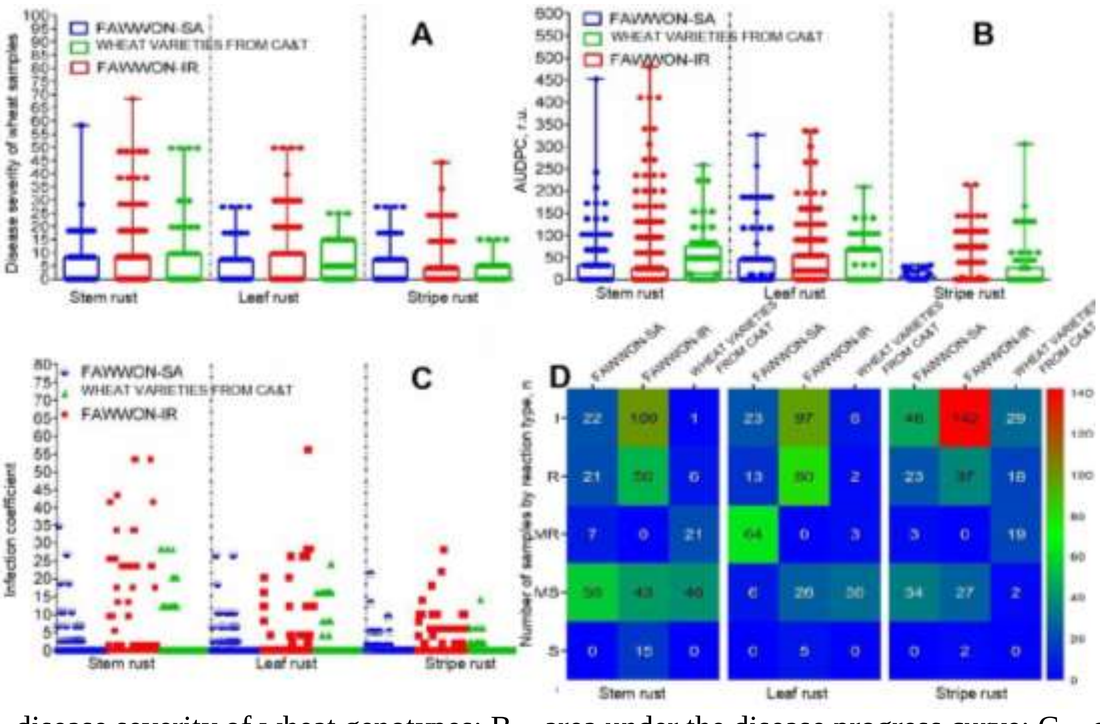
Field resistance data were plotted and subjected to statistical analysis using GraphPad Prism 9.2.0 (GraphPad Software, Inc., La Jolla, CA, USA). Statistical significance was set at P < 0.05.

Results. This section presents the results of evaluating disease severity (DS), infection type (IT), area under the disease progress curve (AUDPC), and coefficient of infection (CI) in the analyzed winter wheat accessions. Based on these parameters, the wheat genotypes were classified into groups according to their response in the studied nurseries (Figure 1).

As shown in Figures 2A–D, the studied winter wheat materials exhibited clear differences in field resistance depending on the nursery conditions and pathogen species composition. Under artificial infection background, maximum disease severity of stem and leaf rust in susceptible genotypes reached 60–80%. Climatic conditions during the 2021 growing season were unfavorable for the development of stripe rust; therefore, disease development remained low (0–30%) across most of the evaluated winter wheat accessions.

In the CA&T nursery, the mean severity of stem rust was 29.40%, with an AUDPC of 196.61 (units) and a CI of 19.97, indicating moderate to high susceptibility among the tested wheat genotypes. The development of leaf rust in CA&T winter wheat was moderate; accordingly, the average disease severity at the end of the growing season (milk stage) reached 27.5%, with an AUDPC of 176.29 (arb. units) and a CI of 15.87.

A substantially higher number of CA&T genotypes demonstrated resistance to stripe rust compared to stem and leaf rust. Specifically, only 7 genotypes exhibited immune response or high resistance to stem rust, 8 to leaf rust, and 47 to stripe rust (Figure 2D).



A – disease severity of wheat genotypes; B – area under the disease progress curve; C – coefficient of infection; D – distribution of genotypes by reaction type to diseases, where color intensity increases with the number of wheat genotypes exhibiting the corresponding levels of disease resistance.

Figure 2 – Grouping of winter wheat genotypes according to field disease resistance traits

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A comparatively large number of sources with high resistance to stem rust were identified among the foreign germplasm: 43 immune and resistant genotypes in the 27FAWWON-SA nursery (40.6% of the tested entries) and 150 genotypes in 27FAWWON-IR (72.1%), respectively. In these nurseries, the mean disease severity ranged from 12.05 to 22.12%, with AUDPC values of 72.8–79.6 (units) and CI values of 5.2–6.5.

Evaluation of resistance to leaf rust in foreign winter wheat germplasm in the 27FAWWON-SA and 27FAWWON-IR nurseries in 2021 showed that more than 43% (46 genotypes) and 85% (177 genotypes), respectively, expressed resistance at the adult plant stage. In the same nurseries, 69 and 179 genotypes, respectively, were classified as immune or resistant to stripe rust, with disease severity not exceeding 10%.

Overall, statistically significant differences among the studied genotypes within the winter wheat nurseries were observed for disease severity, AUDPC, and coefficient of infection in response to rust pathogens ($P < 0.01$–0.0001).

Particular attention is given to genotypes exhibiting combined resistance to multiple prevalent diseases. In the present study, 125 winter wheat genotypes with combined resistance to rust species were identified, including 20 genotypes from 27FAWWON-SA and 101 from 27FAWWON-IR. Among the cultivars from CA&T, group resistance to all three rust diseases was observed in *Aychurek*, *Zhalyn*, *Zhemchug Odesskiy*, and *Zhetysu*. The selected genotypes may serve as valuable donors in breeding programs for rust resistance and as candidates for the development of future winter wheat cultivars.

Discussion. In the southern and southeastern regions of Kazakhstan, where winter wheat is predominantly cultivated, stripe rust remains one of the most widespread diseases. In addition, the global spread of the stem rust race Ug99 poses a substantial threat to winter cereals. In recent years, the incidence and harmfulness of leaf rust on winter bread wheat have also been increasing. Under favorable conditions, these diseases significantly reduce both yield and grain quality, primarily through negative effects on spike productivity. A key driver of large-scale rust epidemics is the widespread cultivation of genetically uniform wheat varieties with similar resistance profiles, coupled with the emergence of new virulent pathogen races. In this context, 68 winter wheat cultivars from CA&T, along with international nurseries 27FAWWON-SA and 27FAWWON-IR obtained from CIMMYT, were evaluated under artificial infection backgrounds of rust pathogens.

In Kazakhstan, winter wheat crops are annually affected by a complex of fungal diseases, resulting in substantial yield losses and deterioration of grain quality [1–4]. Leaf rust and Septoria leaf blotch frequently reach epiphytotic levels in northern regions, where yield losses in spring wheat have reached 20–30% over the past 15 years [2, 3, 13]. Stem rust, previously characterized by localized occurrence, has recently become one of the major diseases in northern Kazakhstan and Western Siberia, causing yield reductions of up to 30–40% in epidemic years [14–16].

From both economic and environmental perspectives, chemical control of foliar diseases is not always effective or cost-efficient, particularly under conditions of low yield potential [2, 3, 17, 18]. Modern global crop production increasingly emphasizes resource-efficient technologies, in which the cultivation of disease-resistant varieties is a central component. Given that many regionally adapted wheat and barley cultivars exhibit insufficient resistance, phytopathological screening across different ontogenetic stages is an essential component of breeding programs.

The introduction of foreign genetic material from international research centers such as CIMMYT and ICARDA represents an important source of valuable traits, including disease resistance. However, the broad utilization of these materials in domestic breeding programs is constrained by the lack of comprehensive data on their resistance to local pathogen populations. The present evaluation under artificial infection conditions not only demonstrated a high resistance potential in a substantial proportion of the introduced lines, but also provided an objective assessment of commercially cultivated cultivars from CA&T. The observed genetic diversity for resistance traits, particularly the presence of genotypes with combined resistance, is critical for overcoming the genetic uniformity of cultivated varieties, which increases the vulnerability of agroecosystems to pathogen pressure.

Thus, the results of this study address an important applied objective–identification of effective donors of resistance to rust diseases. The selected genotypes can be incorporated into scientifically grounded plant protection strategies aimed at ensuring stable and high grain yields in Kazakhstan. Further integrated studies combining phytopathological, genetic, and biotechnological approaches will contribute to enhancing the resistance of domestic wheat and barley cultivars to economically significant phytopathogens.

Conclusions. The conducted study enabled a comprehensive assessment of resistance in winter bread wheat genotypes to major rust diseases under the conditions of southern Kazakhstan using an artificial infection background. The evaluated genotypes differed significantly in disease severity, infection type, area under the disease progress curve, and coefficient of infection, indicating substantial genetic variability for resistance traits.

The results demonstrate that an artificially established infection background ensures stable pathogen development and allows for the generation of reliable and reproducible data, in contrast to natural infection conditions, which are highly dependent on environmental variability. This confirms the methodological validity and practical utility of artificial infection nurseries for phytopathological screening under the continental climate conditions of Kazakhstan.

The analysis further revealed that a considerable proportion of foreign germplasm from the 27FAWWON-SA and 27FAWWON-IR nurseries exhibits high levels of resistance to stem, leaf, and stripe rust. In contrast, cultivars from CA&T predominantly showed moderate to high susceptibility, highlighting the need for their genetic improvement.

A total of 125 genotypes with combined resistance to all three rust diseases were identified, representing valuable material for breeding programs. These selected lines can be utilized as donors of resistance in the development of new cultivars with enhanced adaptive potential.

Overall, the findings have significant practical implications and provide a robust foundation for the design of effective breeding strategies. Future research should focus on elucidating the genetic basis of resistance and on the incorporation of promising genotypes into breeding programs to improve resistance of cereal crops to major phytopathogens.

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All authors have read and agreed to the published version of the manuscript.

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Abbreviations

The following abbreviations are used in this manuscript:

CA&T – Central Asia and Transcaucasia

CIMMYT – International Maize and Wheat Improvement Center

ICARDA - International Center for Agricultural Research in the Dry Areas

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ЖАСАНДЫ ИНФЕКЦИЯЛЫҚ АЯДА КҮЗДІК БИДАЙДЫҢ ТАТ ТҮРЛЕРІНЕ ТӨЗІМДІЛІК КӨЗДЕРІН АНЫҚТАУ

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Андатпа. Бұл жұмыста Қазақстанның оңтүстік аймағында жасалды түрде қалыптастырылған инфекциялық аяда күздік жұмсақ бидай үлгілерінің тат түрлеріне төзімділігін кешенді бағалау нәтижелері келтірілген. Зерттеулер 2021 жылы Биологиялық қауіпсіздік проблемаларының ғылыми-зерттеу институтының базасында жүргізілді. Зерттеу нысандары ретінде Орталық Азия және Кавказ сорттары, сондай-ақ 27FAWWON-SA және 27FAWWON-IR халықаралық питомниктерінің коллекциялық үлгілері алынды.
Төзімділікті бағалау бірқатар фитопатологиялық көрсеткіштер бойынша жүргізілді, оның ішінде зақымдану дәрежесі, реакция типі, ауру даму қисығы астындағы аудан және инфекция коэффициенті. Зерттеу барысында жасады инфекциялық аяда сабақ, жапырақ және сары татқа төзімділік деңгейі бойынша үлгілердің елеулі саралануы байқалатыны анықталды. Әсерлі үлгілердің максималды зақымдану дәрежесі 60-80% жетті, ал төзімді формаларда бұл көрсеткіш 10-20% аспады. Вегетациялық кезеңнің ауа-райы жағдайлары сары таттың дамуына әсер етті, оның зақымдану дәрежесі көп жағдайда төмен деңгейде қалды. Нәтижелер шетелдік үлгілердің Орталық Азия сорттарымен салыстырғанда төзімділік деңгейі жоғары екенін көрсетті. Атап айтқанда, 27FAWWON-IR питомнигінде сабақ татына төзімді формалардың үлесі 72,1%-ды құрады. Жалпы, таттың үш түріне кешенді төзімділігі бар 125 үлгі анықталды. Жасады инфекциялық аяны пайдалану генотиптерді объективті бағалауды қамтамасыз ететін фитопатологиялық скринингтің тиімді және сенімді әдісі болып табылатыны анықталды. Бөлінген үлгілер селекциялық практика үшін айтарлықтай қызығушылық тудырады және Қазақстан жағдайына бейімделген, жоғары өнімді күздік бидайдың жаңа сорттарын жасау кезінде төзімділік донорлары ретінде пайдаланылуы мүмкін.

Түйін сөздер: сабақ таты, жапырақ таты, сары тат, күздік бидай, СИММИТ.

ВЫЯВЛЕНИЕ ИСТОЧНИКОВ УСТОЙЧИВОСТИ ОЗИМОЙ ПШЕНИЦЫ К ВИДАМ РЖАВЧИНЫ В УСЛОВИЯХ ИСКУССТВЕННОГО ИНФЕКЦИОННОГО ФОНА

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Аннотация. В данной работе представлены результаты комплексной оценки устойчивости сортообразцов озимой мягкой пшеницы к видам ржавчины в условиях искусственно созданного инфекционного фона в южном регионе Казахстана. Исследования проведены в 2021 году на базе Научно-исследовательского института проблем биологической безопасности. Объектами изучения являлись сорта Центральной Азии и Закавказья, а также коллекционные образцы международных питомников 27FAWWON-SA и 27FAWWON-IR.
Оценка устойчивости проводилась по ряду фитопатологических показателей, включая степень

поражения, тип реакции, площадь под кривой развития болезни и коэффициент инфекции. В ходе исследований установлено, что на искусственном инфекционном фоне наблюдается значительная дифференциация сортообразцов по уровню устойчивости к стеблевой, листовой и желтой ржавчине. Максимальная степень поражения восприимчивых образцов достигала 60–80 %, тогда как у устойчивых форм данный показатель не превышал 10–20 %. Погодные условия вегетационного периода способствовали слабому развитию жёлтой ржавчины. Зарубежные образцы показали более высокую устойчивость по сравнению с сортами Центральной Азии. В питомнике 27FAWWON-IR доля устойчивых к стеблевой ржавчине достигла 72,1 %. Выявлено 125 сортообразцов с комплексной устойчивостью к трём видам ржавчины. Применение искусственного инфекционного фона подтвердило свою эффективность для объективного фитопатологического скрининга. Выделенные образцы представляют значительный интерес для селекционной практики и перспективны в качестве доноров устойчивости при создании новых высокопродуктивных сортов озимой пшеницы, адаптированных к условиям Казахстана.

Ключевые слова: стеблевая ржавчина, листовая ржавчина, желтая ржавчина, озимая пшеница, СИММИТ.