

Use of effective sources of winter wheat resistance in breeding for immunity

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Abstract. Winter wheat is one of the most important crops in Ukraine, and modern varieties have the potential to produce high yields under favourable conditions. The realisation of the genetic yield potential of a variety is the result of a complex interaction of genotype and environmental variables. In order to find effective sources of resistance, a collection of winter wheat accessions of different ecological and geographical origin was studied. The research was conducted in 2017-2019 in the Right-Bank Forest-Steppe, and the analysis of plant resistance of the winter wheat collection of the National Centre of Plant Genetic Resources of Ukraine was tested against a synthetic infectious background of septoria, brown rust and smut as opposed to the natural background of powdery mildew, leaf yellowing (pyrenophorosis) and other root rot. The collection of 32 varieties was represented

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by 9 countries, most of them of Ukrainian origin. In the field, on artificial and natural infectious backgrounds, we identified varieties characterised by group resistance to pathogens of major diseases. The studies of adult plant resistance under conditions of infectious natural background and the use of the method of artificial complex infectious background have established that it is possible to investigate and identify sources of resistance to both individual pathogens and a complex of pathogens. As a result, no accessions were found to possess group resistance against the six pathogens presented. The selected varieties, Zdobva Kyivska, Vykhovanka Odeska and Feonia, can be used as sources of group resistance, which allows for excellent breeding efforts leading to the development of resistant wheat varieties. The selected sources are suitable for inclusion in breeding programmes as starting material for the development of modern high-yielding winter durum wheat varieties resistant to diseases and other environmental factors

Keywords: wheat samples; artificial infection background; group resistance; plant damage; hydrothermal coefficient

INTRODUCTION

Plant diseases are a factor of great importance in reducing the amount of food available and increasing its cost. Due to the tremendous growth rate of the world's population, the problem of food will continue to grow. The development of resistant varieties would be the ideal solution to the problem of diseases. However, it is not always possible to control important diseases through resistant varieties alone (Motsnyi *et al.*, 2022). However, many diseases can be controlled by combining resistance building with the use of reliable fungicides. Even partial or temporary resistance often reduces spraying costs (Mykhaylenko & Jam, 2022).

The problem of agricultural plant immunity has been relevant to researchers for a long time. This is due to the large losses caused by various diseases and pests to agricultural production around the world, including Ukraine. One of the most effective and environmentally friendly ways to combat this is to develop resistant varieties that are genetically engineered to resist diseases and pests. This approach is economically viable and reduces losses in agriculture. The same opinion is shared by O. Shevchuk & S. Mykhaylenko (2022) in their research on the resistance of wheat samples to a complex of pathogens.

Plant resistance to disease arose as a result of a long evolutionary process. This mechanism has evolved in different centres of plant origin over thousands of years. When plants acquired resistance genes, pathogens could still attack them due to the emergence of new physiological traits resulting from hybridisation, mutations, heterokaryosis and other processes. This approach allowed plants to adapt to a changing environment and provide greater resistance to disease (Lisova, 2021).

Breeding for immunity is based on the same principles as breeding for other plant characteristics, but it is much more sophisticated and specific. The main elements of this methodology are regular monitoring

of the pathogenic environment, studying the morphological and physiological properties of populations of particularly dangerous pathogen species, objective assessment of the immunological characteristics of varieties and hybrids, establishing plant-pathogen interactions, and identifying and selecting highly effective sources and donors that are adapted to specific zonal conditions (Langridge & Reynolds, 2021).

Successful breeding mainly depends on the availability of high quality source material, where donors with high efficiency, especially those with dominant resistance genes, are a key factor. Existing varieties of Ukrainian and Western European breeding can serve as resistance donors. At the same time, it is important to create sustainable source material that is not only resistant to pathogens, but also has other economically valuable characteristics and properties (Miedaner & Juroszek, 2021).

Developing varieties with high resistance requires specialised breeding programmes that select only the most resistant plants. The main objective of these programmes is to develop methods for creating controlled infection conditions to assess the resistance of the material under study at all stages of the breeding process (Mahdavi *et al.*, 2022).

Thus, through the breeding approach, it is possible to add resistance characteristics to various pathogens to wheat varieties. An important factor is the diversity of genetic composition in donors, which contributes to effective selection for immunity. A key role in solving this problem is played by the source material from the world's collections, which contains a wide range of immune plant forms. Both cultivated and wild relatives of wheat are the main sources of genes that provide resistance to pathogens, which is important for one of the key crops – wheat. Therefore, the aim of the work was to study the source material of the winter wheat

collection and search for effective sources with group resistance to major pathogens.

MATERIALS AND METHODS

Based on the results of previous research conducted at the Crop Immunity Laboratory of the Institute of Plant Protection (IPP), a technology for creating an artificial complex infection background (ACIB) was developed. This background includes the pathogens of brown rust, leaf septoria and cercospora root rot caused by powdery mildew in winter wheat plants (Golosna *et al.*, 2019). A method of artificial infection of winter wheat plants with hard smut was also developed. Protection against smut infestation is necessary because these diseases are very harmful: they cause the formation of spore mass instead of grain, reduce plant resistance to other negative environmental factors and degrade crop quality.

In the period from 2017 to 2019, in the conditions of the Right-Bank Forest-Steppe, at the research farm of the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine (NAS) in the village of Glevakha, Kyiv Region, the resistance of the winter wheat collection presented by the National Centre of Plant Genetic Resources of Ukraine was assessed. This evaluation was conducted using an artificial infection background that included Septoria, brown rust and hard smut against a background of natural spread of powdery mildew, yellow leaf spot (Pyrenophora) and root rot. The collection included 33 accessions from 9 countries. The majority of them were of Ukrainian breeding (20 varieties), while the rest were represented by Russia, Hungary, the Czech Republic, Bulgaria, Lithuania, the Netherlands, the USA and Kazakhstan.

The artificial infection backgrounds for leaf blight

and downy mildew were created at the optimum time for plant infection. The assessment of resistance-susceptibility to leaf diseases and downy mildew was carried out during the phase of maximum disease development using the 9-point immunological scale used in the member countries of the Council for Mutual Economic Assistance (CMEA) during the peak development of the disease, where 9 points corresponded to very high resistance and 1 point – to very high susceptibility. The assessment of root rot damage to plants was carried out according to the method of A.F. Korshunova at the stage of milk-wax ripeness (Golosna *et al.*, 2019). The use of infectious material of pathogens of different diseases on the same plant material makes it possible to identify samples with signs of group resistance (Hovmøller *et al.*, 2021).

The study complies with all ethical standards in accordance with The Convention on Biological Diversity (2022). However, it is worth noting that in the period 2017-2019, the experimental plots experienced unfavourable conditions for the development and spread of cercospora root rot. Therefore, the surveys were carried out for the whole complex of root rot, due to the fact that the laboratory staff of the Institute of Plant Protection of the National Academy of Agrarian Sciences (IPP NAAS) annually create an artificial population of brown rust, septoria and cercospora root rot pathogens to form an artificial complex infectious background.

RESULTS AND DISCUSSION

Analysis of the resistance of the collection of winter wheat varieties to the main leaf diseases indicated a high level of powdery mildew infection in 2017, which was 54.5% against the background of provocation (Table 1).

Table 1. Damage to wheat plants by major diseases in 2017-2019, %

The causative agent of the disease	Year of accounting		
	2017	2018	2019
Powdery mildew	54.5	18.0	39.2
Septoria	44.8	53.4	63.3
Pyrenophorosis	48.4	35.4	20.3
Hard smut	-	55.2	78.4
Root rot	11.3	19.6	10.4

Source: authors' development

On artificial infectious backgrounds, the development of septoria was at the level of 44.8%, and pyrenophorosis – 48.4%. When analysing the weather conditions in 2017, the first and second ten-day periods of May were weak in terms of moisture, and only in the third ten-day period was the moisture level optimal, with a hydrothermal coefficient of 1.2 (HTC) (Fig. 1). The whole of June was almost without precipitation, and

the moisture level was weak. The first and third ten-day periods of July were characterised by optimal moisture levels. In 2018, the development of powdery mildew was three times lower – 18.0, the development of Septoria was 13.4% higher and the development of Pyrenophora was 13% lower compared to 2017. This year was characterised by excessive moisture in the second and third decades of June and in July. In 2019, powdery mildew

development was at 39.2%, with the highest development of Septoria at 63.3% and the highest develop-

ment of Pyrenophora at 20.3%. In May-July, the growing season was characterised by optimal moisture levels.

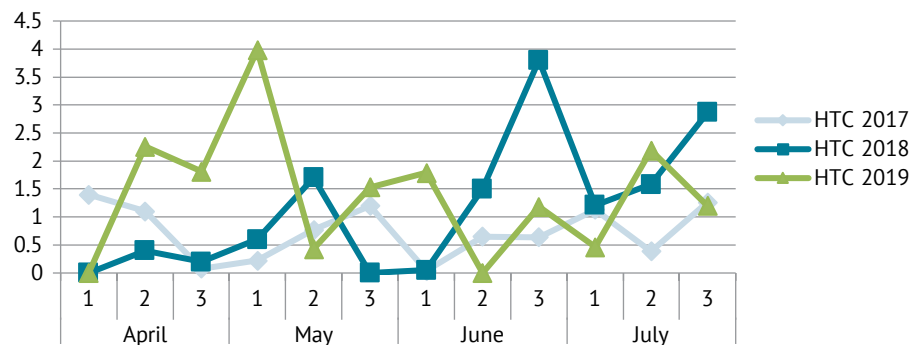


Figure 1. Hydrothermal coefficient (HTC) values over the years of research, 2017-2019

Source: authors' development

In a separate area of the collection, an artificial background of hard smut was created: in 2017, the development of the disease was 55.2%, in 2018 – 78.4%. There are only two varieties: Vykhovanka Odeska and Feonia were resistant to the pathogen, while all the others were affected by the pathogen *Tilletia caries*. During the years of research, no brown rust epiphytoses were observed on the winter wheat collection due to the avoidance of infection. In 2017, the development of the disease did not exceed 5%, in 2018 – up to 20%, in 2019 – 37.0%. One of the reasons is weather conditions. Only 7 varieties showed susceptibility to the brown rust pathogen: ErythrospERMUM 308-10, Borovytsia, Zoloto Ukrainy, Zelenyi Hai, Afina, MV Nador, OR 2070011. The evaluation for root rot was carried out against a natural background. Due to the low level of moisture in the periods optimal for root rot pathogens, a low level of infection was observed. In 2017, the development of rot was at 11.3%, in 2018 – 19.6%, and in 2019 – 10.4%. Over the 3 years of research, 14 varieties were found to be resistant. Among them: Buzhanka, Borovytsia, Talisman, Polianka, Koliada, Pochayna, Zdobna Kyivska, Niva Odeska, Vykhovanka Odeska,

Zelenyi Hai, Feonia, Ershovska 11, Manella, OR 2070011. According to the results of evaluations over the years of research, 12 varieties characterised by resistance (points 6-7) to powdery mildew were identified: Ladyzhynka, Koliada, Pochayna, Zdobna Kyivska, Niva Odeska, Vykhovanka Odeska, Afina, Feonia, Magia, Dagmar, Lucio, Turkoaz. None of the accessions showed resistance to Septoria. The following were characterised by weak susceptibility (point 5): L 137-26-0-3, L 137-26-0-2, ErythrospERMUM 308-10, Kalancha, Krasnopilka, Serpanok Kyivskyi, Zdobna Kyivska, Feonia, Ershovska 11, MV Pengo, Manella. Resistance to the pathogen of pyrenophorosis was shown by 17 accessions: L 137-26-0-3, ErythrospERMUM 308-10, Buzhanka, Kalancha, Krasnopilka, Talisman, Polianka, Koliada, Pochayna, Zdobna Kyivska, Niva Odeska, Vykhovanka Odeska, Zelenyi Hai, Afina, Dagmar, Lucio, Turkoaz. The immunological evaluation of the varieties over the years of research is presented in Table 2. It is important for the selection of varieties to have resistance to several phytopathogens at the same time. Among the collection under consideration, there are varieties that show resistance to one, two, three, four and even five pathogens.

Table 2. Resistance of varieties to various pathogens (average for 2017-2019), points

Nº	Variety name	Powdery mildew	Septoria	Pyrenophthora	Root rot	Smut	Brown rust
1	L 137-26-0-3	6.67*	6.00*	7.00*	4.19	3.50	8.00*
2	L 137-26-0-2	6.67*	5.67*	6.67	5.48*	2.50	8.00*
3	Erytr. 308-10	6.00	5.67*	6.67	5.88*	4.50	6.00
4	Buzhanka	6.33	5.00	6.67	3.54	3.50	8.50*
5	Borovytsia	6.33	4.67	6.00	2.88	3.50	6.50
6	Ladyzhynka	7.33*	5.00	6.33	4.51	2.50	8.00*
7	Vinok Podillia	6.67*	5.33*	6.67	5.56*	5.00	7.00
8	Kalancha	6.00	5.00	7.33*	4.12	5.50	7.50*
9	Krasnopilka	6.00	5.00	8.00*	5.62*	3.00	7.00
10	Zoloto Ukrainy	6.00	5.67*	6.00	5.49*	3.50	7.00
11	Serpanok Kyivskyi	7.00*	5.33*	6.33	4.47	2.00	8.00*

Table 2, Continued

Nº	Variety name	Powdery mildew	Septoria	Pyrenophthora	Root rot	Smut	Brown rust
12	Talisman	7.00*	5.33*	6.67*	3.30	5.50	8.00*
13	Polianka	7.00*	5.00	6.67*	3.40	4.00	7.00
14	Koliada	7.33*	5.67*	8.33*	3.49	6.00	7.50*
15	Pochayna	7.33*	5.67*	8.00*	3.28	5.00	8.00*
16	Zdoba Kyivska	7.67*	5.33*	7.33*	6.63*	3.00	8.00*
17	Niva Odeska	7.00*	5.33*	6.33	2.69	5.00	8.00*
18	Nasnaha	6.00	4.67	5.67	4.43	2.00	8.00*
19	Vykhovanka Odeska	7.50*	5.00	6.00*	6.32*	8.00*	9.00*
20	Zelenyi Hai	4.67	4.33	7.33*	3.52	3.00	6.50
21	Afina	7.50*	4.00	7.00*	4.80	1.00	7.00
22	Nastia	6.67	5.33*	6.33	5.91*	5.50	8.00*
23	Feonia	7.33*	5.00	5.67*	6.70*	7.50*	8.50*
24	Magia	7.50*	5.50*	7.00*	4.65	5.50	7.00
25	Ershovska 11	7.00*	5.67*	7.33*	3.42	4.50	8.00*
26	MV Pengo	5.67	5.00	6.33	7.03*	2.50	7.00
27	MV Nador	7.33*	4.67	6.00	6.92*	3.00	6.00
28	Dagmar	7.67*	5.00	7.33*	6.92*	3.00	6.50
29	Lucio	8.00*	5.33*	7.67*	4.54	2.00	6.50
30	Turkoaz	7.33*	5.00	7.67*	4.79*	2.00	8.50*
31	Manella	6.33	5.00	7.00*	4.57	4.50	7.50*
32	OR 2070011	5.00	4.67	7.33*	2.89	4.00	7.00
33	Podolianka, St	6.00	6.33*	6.33	5.10*	2.00	7.50*
	X average.	6.72	5.19	6.82	4.76	3.86	7.47
	HIP ₀₅	0.91	0.63	0.88	1.51	1.84	1.20

Notes: * – high resistance point

Source: authors' development

The following varieties were resistant to one pathogen: Buzhanka, Nasnaha, Zelenyi Hai, MV Pengo, OR2070011. Resistance to two pathogens was shown by 9 varieties: Erytr. 308-10, Ladyzhynka, Kalancha, Krasnopilka, Zoloto Ukrainy, Polianka, Afina, MV Nador, Manella. Among the studied varieties, the following showed resistance to three pathogens: Vinok Podillia, Serpanok Kyivskiy, Niva Odeska, Nastia, Magia, Dagmar, Lucio, Podolianka Standard. The following varieties were highly resistant to four pathogens: L 137-26-0-3, L 137-26-0-2, Talisman, Koliada, Pochayna, Ershovska 11, Turkoaz. Only 3 varieties were able to overcome the maximum number of five pathogens: two varieties of Ukrainian breeding Zdoba Kyivska, Vykhovanka Odeska and Feonia of Russian breeding. As a result of the research, no varieties with group resistance to the six pathogens presented were found.

The threat of disease damage to wheat plants remains high. The data provided by Y. Chai *et al.* (2022) show that 90% of wheat crops in the world are affected by at least one disease, and the yield shortfall is within 10%. At the same time, scientists also provide data on other important crops, with losses from diseases and pests as follows: wheat – 21.5%, rice – 30.0%, corn – 22.5%, potatoes – 17.2%, soybeans – 21.4%. At the same time, drought, cytological abnormalities or chemical

mutations pose significant threats to all crops. The research by V. Horshchar & M. Nazarenko (2023), which also uses various pathogens, is devoted to the confrontation of such factors and their transformation into benefits.

Scientists S. Kaur *et al.* (2022) drew attention to the biochemical nature of plant resistance to pathogens. They noted that various natural compounds, ranging from cell wall components to metabolic enzymes, protect plants from pathogen infection and provide specific plant resistance against pathogens, which is called induced resistance.

Scientists M. Figueroa *et al.* (2018) focused their efforts on the problem of the interaction between plants and microbes. They believe that this is a phenomenal manifestation of symbiotic or parasitic relationships between living organisms. Plant growth-promoting rhizobacteria (PGPR) are one of the most widely studied plant beneficial microorganisms due to their ability to stimulate plant growth and development, as well as protect plants from biotic and abiotic stresses (Mashabela *et al.*, 2023). A. Morgounov *et al.* (2018) gave wheat resistance to diseases and pests using synthetic forms that also possessed a number of biologically and economically valuable traits, such as weight of 1,000 seeds, etc. The cloning of some rust resistance genes opens up new prospects for rust control in the future through the development of multiple resistance gene cassettes

(Soko *et al.*, 2018). However, as of 2023, chemical control based on disease surveillance, large-scale introduction of new varieties with multiple race-specific genes or sufficient adult plant resistance (APR), and reduced cultivation of susceptible varieties in rust hotspots are still the best strategies for controlling stem rust (Singh *et al.*, 2015).

Based on the results of the work carried out to assess the resistance of collection samples to various pathogens of the most common diseases of winter wheat over 3 years, a number of varieties were identified that were resistant to one or more pathogens. The need to search for sources of resistance among the studied set of wheat samples as a more effective method of preventing a decrease in the productivity of varieties and reducing the burden of chemical treatments against diseases is an urgent task, as many scientists from around the world are trying to solve the problem of wheat variety resistance using various sources and donors of resistance, including them in the breeding process (Blyzniuk *et al.*, 2019; Pavlov *et al.*, 2021). However, there are also cases when it is not possible to achieve the desired result, as in the study (Kokhmetova *et al.*, 2021). Therefore, the study, identification and use of sources and donors of resistance against major pathogens among the collection and breeding material of winter wheat, by involving them in artificial hybridisation, is an effective way to increase crop yields.

Thus, the threat of disease infection in wheat remains high, which is why scientists are studying the biochemical nature of plant resistance to diseases, pointing to induced resistance. This study, as well as similar ones, focuses on the use of modern breeding methods and genetic resources to ensure disease resistance in wheat varieties and increase crop yields.

CONCLUSIONS

The presented results provide an assessment of the resistance of wheat collection varieties against various pathogens. Resistance against two or more pathogens that differ in the biology of development, degree of damage and period of damage to wheat plants was revealed. The wide range of wheat collection samples of different origin (countries, scientific institutions –

originators of varieties) studied allowed us to identify a number of sources of resistance to various diseases, which in turn opened up the possibility of their further use in the breeding process to create new original material that will have group resistance. The identification and use of new sources of resistance (including race-specific resistance) in wheat breeding as a promising method should take a worthy place among traditional methods (increasing yields, product quality, etc.). Therefore, the search for new sources of resistance (group, individual) in the study of various materials (collection, breeding, etc.) is always of great importance and will be relevant in scientific institutions when creating varieties more adapted to growing conditions.

The study of the resistance of adult plants under natural infection conditions and the use of the ACIB method made it possible to investigate and identify sources of resistance to both individual pathogens and a complex of pathogens. The varieties Zdoba Kyivska, Vykhovanka Odeska and Feonia were identified as sources of group resistance, which makes it possible to carry out high-quality breeding work to create resistant wheat varieties. The identified sources are recommended for inclusion in breeding programmes as starting material for the development of modern high-yielding soft winter wheat varieties with increased resistance to diseases and abiotic factors. There is also the problem of finding resistant samples against three or more pathogens among the wide range of collection material available at the National Plant Genebank in Kharkiv. Therefore, further study of wheat varieties using ACIB is especially important in identifying and studying resistance to various pathogens in the creation of new promising material in breeding to enhance immunity and yield of wheat.

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CONFLICT OF INTEREST

None.

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Використання в селекції на імунітет ефективних джерел стійкості пшениці озимої

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Анотація. Пшениця озима є однією з найважливіших культур в Україні, сучасні сорти мають потенціал для отримання високих урожаїв у сприятливих умовах. Реалізація генетичного потенціалу врожайності сорту є результатом складної взаємодії генотипу та змінних чинників навколишнього середовища. З метою пошуку ефективних джерел стійкості, досліджено колекцію пшениці озимої різного еколого-географічного походження. Дослідження було проведено впродовж 2017-2019 рр. в умовах Правобережного Лісостепу, аналіз стійкості рослин колекції пшениці озимої Національного центру генетичних ресурсів рослин України протестований у синтетичному інфекційному фоні септоріозу, бурої іржі та суцільної сажки на противагу природному фону борошністої роси, пожовтіння листків (піренофорозу) та інших кореневих гнилях. Колекція з 32 сортозразків була представлена 9 країнами світу, більшість з них української селекції. В польових умовах на штучних та природних інфекційних фонах були виділені сортозразки, які характеризувалися груповою стійкістю проти збудників основних хвороб. Проведеними дослідженнями стійкості дорослих рослин в умовах інфекційного природного фону та використання методу штучного комплексного інфекційного фону встановлено, що можливо досліджувати та виявляти джерела стійкості як до окремих патогенів, так і до комплексу патогенів. В результаті не було виявлено жодного сортозразка, який володів груповою стійкістю проти шести представлених збудників хвороб. Відібрані сорти Здоба Київська, Вихованка одеська та Феонія, можуть бути використані як джерела групової стійкості, що дозволяє створювати чудові селекційні зусилля, які призводять до створення стійких сортів пшениці. Вибрані джерела доцільні для включення в селекційні програми як вихідний матеріал при створенні сучасних високоврожайних сортів м'якої пшениці озимої, стійких проти хвороб та інших факторів навколишнього середовища

Ключові слова: зразки пшениці; штучний інфекційний фон; групово стійкість; ураження рослин; гідротермічний коефіцієнт