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INFLUENCE OF INTEGRATED WHEAT PROTECTION AGAINST RUST IN THE FOREST-STEPPE ZONE OF NORTHERN KAZAKHSTAN

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Abstract
The studies evaluated the effectiveness of two schemes for applying protective agents and fertilizers on spring wheat of the Likamero variety, as well as their impact on the distribution pattern and crop yield.
The main difference between the application regimens was in the dosage of drugs. Both schemes used combined fungicides (benzisothiazolinone + tebuconazole, cresoxime-methyl) and fertilizers (amino acids, monopotamiumphosphate, humic fertilizers) during the key stages of development: tillering, flowering, and grain filling.
In parallel, phytosanitary monitoring was carried out, which showed the absence of pests in all variants of the experiment. During the studies, the following results were obtained: in the control area (without treatments), rust damage accounted for 97.2% of the affected leaves, while in the variants with a dosage of 700 ml/ha, this indicator on days 7 and 14 was 34.7% and 38.2%, respectively. In the variant with an increase in the dose to 900 ml / ha, these indicators were at the level of 22.5% and 27.3%.
Despite the best indicators of protection in the spread of the disease in Scheme 2, weak shoots and sparse grass stand were noted, which in turn led to a shortage of crops. In our opinion, this was due to the high dosage during the seed processing period, which caused the delay in the germination phase. In general, when determining the biological yield, the following results were recorded: on the control – 35.3 c/ha, according to the first scheme-39.4 c/ha and 26.7 c/ha according to the second scheme.

Keywords: spring wheat, rust, yield, disease spread, tebuconazole, fertilizers.

ВЛИЯНИЕ ИНТЕГРИРОВАННОЙ ЗАЩИТЫ ПШЕНИЦЫ ОТ РЖАВЧИНЫ В ЛЕСОСТЕПНОЙ ЗОНЕ СЕВЕРНОГО КАЗАХСТАНА

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Аннотация
В ходе исследований была оценена эффективность двух схем применения защитных средств и удобрений на яровой пшенице сорта Ликамеро, а также их влияние на характер распространения болезни и урожайность.
Основное различие между схемами заключалось в дозировке препаратов. В обеих схемах применялись комбинированные фунгициды (бензизотиазолинон + тебуконазол, крезоксим-метил) и удобрения (аминокислоты, монокалийфосфат, гуминовые удобрения) на ключевых этапах развития: кущение, цветение и налив зерна.
Параллельно проводился фитосанитарный мониторинг, который показал отсутствие вредителей во всех вариантах опыта. В ходе исследований были получены следующие результаты: на контрольном участке

(без обработок) поражённость ржавчиной составила 97,2% листьев, тогда как в вариантах с дозировкой 700 мл/га этот показатель на 7-й и 14-й дни составлял 34,7% и 38,2% соответственно. В варианте с увеличенной дозой до 900 мл/га данные показатели были на уровне 22,5% и 27,3%.
Несмотря на лучшие показатели защиты от распространения болезни во второй схеме, отмечались слабые всходы и разреженный травостой, что, в свою очередь, привело к снижению урожая. По нашему мнению, это связано с высокой дозировкой при обработке семян, что вызвало задержку фазы прорастания.
В целом при определении биологической урожайности были получены следующие результаты: контроль – 35,3 ц/га, первая схема – 39,4 ц/га, вторая схема – 26,7 ц/га.

Ключевые слова: яровая пшеница, ржавчина, урожайность, распространение болезни, тебуконазол, удобрения.

СОЛТҮСТІК ҚАЗАҚСТАННЫҢ ОРМАНДЫ-ДАЛА АЙМАҒЫНДА ЖАЗДЫҚ БИДАЙДЫ ТАТ АУРУЫНАН ИНТЕГРАЦИЯЛАНҒАН ҚОРҒАУДЫҢ ӘСЕРІ

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Аңдатпа
Зерттеулер барысында Ликамеро сортының жаздық бидайында қорғау құралдары мен тыңайтқыштарды қолданудың екі схемасының тиімділігі, сондай-ақ олардың аурудың таралуына және өнімділікке әсері бағаланды.
Схемалар арасындағы негізгі айырмашылық препараттардың мөлшерінде болды. Екі схемада да біріктірілген фунгицидтер (бензизотиазолинон + тебуконазол, крезоксим-метил) және тыңайтқыштар (аминқышқылдары, монокалийфосфат, гуминді тыңайтқыштар) өсімдіктің негізгі даму кезеңдерінде қолданылды: түптену, гүлдеу және дәннің толысуы.
Сонымен қатар фитосанитарлық мониторинг жүргізілді, оның нәтижесінде барлық тәжірибе нұсқаларында зиянкестердің болмағаны анықталды. Зерттеу нәтижесінде мынадай көрсеткіштер алынды: бақылау учаскесінде (өңдеусіз) тат ауруымен зақымдану 97,2% құрады, ал 700 мл/га мөлшеріндегі нұсқаларда 7 және 14 күндері сәйкесінше 34,7% және 38,2% болды. 900 мл/га мөлшерінде бұл көрсеткіштер 22,5% және 27,3% деңгейінде болды.
Аурудың таралуын тежеу бойынша екінші схема жақсы нәтиже көрсеткенімен, әлсіз өскіндер мен сирек өсімдік жамылғысы байқалды, бұл өз кезегінде өнімнің төмендеуіне әкелді. Біздің ойымызша, бұл тұқымды өңдеу кезінде жоғары мөлшер қолданылуына байланысты, соның салдарынан өну кезеңі кешікті.
Жалпы биологиялық өнімділік бойынша мынадай нәтижелер тіркелді: бақылау –35,3 ц/га, бірінші схема – 39,4 ц/га, екінші схема – 26,7 ц/га.

Кілт сөздер: жаздық бидай, тат ауруы, өнімділік, аурудың таралуы, тебуконазол, тыңайтқыштар.

Introduction

Cultivation of spring wheat in the forest-steppe zone of Northern Kazakhstan is the basis of grain production in the region. However, in recent years, due to the generally rainy spring during the sowing period, the stability of grain production is under constant threat due to the widespread spread of leaf diseases, among which brown rust (Puccinia triticina) occupies the leading role [1, 2]. The spread of this disease is facilitated by favorable weather conditions for the development of the pathogen (moderate temperatures and heavy dews), as well as, to a lesser extent, the cultivation of susceptible varieties, which leads to epiphytic outbreaks, which cause significant yield losses, reaching 30-50% or more, and also sharply worsen the quality of grain [3, 4].

The current phytopathological situation dictates the need to develop and implement effective crop protection systems based on an integrated approach. As practice shows, the most effective method of controlling and spreading diseases is the use of chemical fungicides [5, 6]. In turn, the chaotic and lack of consistency in their use not only does not provide reliable protection, but can also provoke the development of resistance in pathogens, have a stressful effect on plants and have a negative impact on the production of this crop. Based on the above, it is relevant to provide a scientific justification for the use of protective equipment schemes, starting with seed dressing and ending with vegetation treatments, which would maximize the potential of variety productivity with a minimum number of operations performed. The spring soft wheat variety "Likamero" was chosen as the objects of research, as well as the preparations benzizothiazolinone 2.3% + fludioxonyl 1.7% used for seed treatment, and for vegetation benzizothiazolinone 2% + tebuconazole 25% CE and cresoxime-methyl 30% SC and their effect on the distribution of brown rust (Puccinia triticina).

The aim of our research was to reduce the spread and harmfulness of brown rust in spring wheat crops in the forest-steppe zone of Northern Kazakhstan by applying various protection schemes together with leaf fertilization with fertilizers.

Based on this goal, the following research objectives were set:

– to test two complex schemes of crop protection, including seed treatment and treatment during the growing season (in the phases of tillering, flowering and grain filling), in comparison with the control without treatments.

– carry out visual phytosanitary monitoring and evaluate the dynamics of brown rust development on days 7 and 14 (leaf infestation, degree of development and disease index) in various experimental variants.

– determine the influence of the studied schemes on biological yield and elements of the crop structure.

Experimental

3.1. Conditions and scheme of the experiment

The research was conducted in 2024 in the forest-steppe zone of Northern Kazakhstan on spring soft wheat crops of the Likamero variety. The experience included three options:

– control (without treatment with plant protection products),

– scheme 1 (standard drug dosages)

– scheme 2 (increased dosage of drugs).

The treatments were carried out in the key phenological phases of plant development: pre-sowing seed treatment, tillering phase, flowering phase and grain filling phase.

3.2. Methods of drug administration

Pre-sowing treatment of seeds was carried out by the method of moistening. The preparation, measured using a laboratory dish (measuring cylinder) to ensure the accuracy of the dosage, was dissolved in water and evenly sprayed on the seeds scattered on a clean tarpaulin. After application, the seeds were thoroughly mixed to ensure a uniform coating of each grain with the working solution.

Vegetation treatments were carried out using a satchel sprayer in the early morning hours in calm weather to minimize the demolition of the drug. The working solution was prepared immediately before use. The preparations were dosed using laboratory utensils, after which they were introduced into the sprayer tank filled with water, with constant stirring to achieve a homogeneous suspension. During spraying, a uniform supply of working solution was provided and the vegetative mass of plants was completely covered.

3.3. Methods of phytosanitary monitoring

Pest control and disease development assessment were performed twice: on the 7th and 14th days after each vegetation treatment.

3.3.1. Pest control

A visual method was used to record pests. On each plot, according to the "five points" method, 10 plants were selected at each point (a total of 50 plants from the plot). A thorough inspection of the plants was carried out for the presence of flying, sucking and gnawing pests.

3.3.2. Assessment of brown rust damage

To assess the distribution and development of brown rust, the five-point sampling method was used. In each of the five points of accounting, 50 leaves were selected on the plot (a total of 250 leaves per experiment option). For each selected sheet, the following was visually determined:

Percentage of affected leaves (P, %): Calculated as the ratio of the number of leaves with rust symptoms to the total number of leaves examined, multiplied by 100.

The degree of leaf surface damage (D, %): Evaluated on a 5-point scale (1%, 10%, 40%, 80%, 100%) using the visual method. The average degree of lesion (D) for the variant was calculated by the formula:

$$D = (\Sigma(i \times l\_i)) / L,$$

Where * i* is the lesion score, l_i is the number of leaves with this score, and L is the total number of leaves examined.

Disease index (I): A complex indicator that takes into account both the prevalence and intensity of disease development, was calculated by the formula:

$$^{*}I = (F \times D) / 100^{*},$$

Where F is the leaf lesion (in fractions of a unit), and D is the average degree of lesion (in fractions of a unit).

3.4. Accounting for crop structure elements

In the phase of full ripeness, the yield and its structure were taken into account. Mowing samples were taken from each variant of the experiment with an accounting area of 1 m2. The following indicators were determined:

– Stalk density for harvesting (pcs/ m2)
– Plant height (cm)
– Productive bushiness (pcs/plant)
– Number of productive stems (pcs/ m2)
– Grain weight from 1 m2 (g/m2), converted to c / ha
– Weight of 1000 grains (g)

Results

According to the results of phytosanitary monitoring conducted according to the methodology on the 7th and 14th days after processing, pests were not detected on spring wheat crops. The absence of flying, sucking and gnawing pests was established both in the control areas without the use of plant protection products, and in all variants of the experiment with the use of drugs. Thus, during the observation period, the phytosanitary situation was in favorable conditions, and the level of population with entomological pests did not exceed the economic threshold of harmfulness and did not require additional protective measures.

Table 1. Calculation of leaf damage in the control group

Point	Examined leaves	Affected leaves	Lesion by point (%)
1	50	49	98,0
2	50	48	96,0
3	50	50	100,0
4	50	47	94,0
5	50	49	98,0
Total	250	243	97.2 (average)

Based on the results of the survey of five selection points, it was found that the total leaf lesion was 97.2%, which indicates an extremely high degree of disease development in the site. The lesion rate for individual points varied from 94.0% to 100.0%, while in four of the five points the indicator exceeded 96%. Such a narrow range of values indicates a uniform spread of infection across the field without pronounced local foci or areas with a lower intensity of damage.

Fixing the maximum level of lesion (up to 100%) at one of the points, as well as a high average value of affected leaves in the sample (243 out of 250 examined) allows us to conclude that the critical phase of the disease development requires immediate measures to contain its further spread. This situation can lead to a significant loss of plant productivity, reduced yields, and poor product quality.

Table 2. Calculation of leaf damage on day 7 after treatment according to scheme 1

Point	Examined leaves	Affected leaves	Lesion by point (%)
1	50	18	36,0
2	50	17	34,0
3	50	16	32,0
4	50	18	36,0
5	50	18	36,0
Total	250	87	34.7 (average)

On the 7th day after treatment with protective drugs, leaf damage decreased to 34.7%, which indicates a pronounced deterrent effect of the applied protective agents. The disease persists, but the intensity of its development has significantly decreased compared to the initial indicators, and the range of values by points (32-36%) shows a relatively uniform positive response of plants to treatment. The achieved level of infection indicates the effectiveness of the selected drug and the scheme of use, which allows us to expect a further reduction in the spread of the disease while maintaining protective measures.

Table 3. Calculation of leaf damage on day 14 after treatment according to scheme 1

Point	Examined leaves	Affected leaves	Lesion by point (%)
1	50	19	38,0
2	50	18	36,0
3	50	20	40,0
4	50	19	38,0
5	50	20	40,0
Total	250	96	38.2 (average)

On the 14th day after the treatment with protective drugs, the leaf lesion rate was 38.2%, which indicates that the deterrent effect of the applied protective agents is preserved and the disease intensity is further reduced compared to the initial level. The range of values at the selection points (36-40%) indicates a consistently positive and uniform response of plants to the applied drug, without pronounced local foci of increased infection. Despite the fact that the disease is not completely eliminated, the preservation of moderate damage after two weeks confirms the long-term effect of the drug and the effectiveness of the chosen protection scheme, which allows us to expect a further decrease in the infection rate while maintaining protective measures.

Table 4. Calculation of leaf damage on day 7 after treatment according to scheme 2

Point	Examined leaves	Affected leaves	Lesion by point (%)
1	50	11	22,0
2	50	12	24,0
3	50	10	20,0
4	50	12	24,0
5	50	11	22,0
Total	250	56	22.5 (average)

On the 7th day after applying the protective drug in an increased dosage, the level of leaf damage decreased to 22.5%, which indicates a significantly more pronounced suppression of infection compared to previous treatment results. The range of values (20-24%) indicates a stable and uniform therapeutic effect, which indicates the correct decision to increase the dose. A significant reduction in the lesion confirms the improved effectiveness of the drug and the strengthening of its protective effect on the plant body.

Table 5. Calculation of leaf damage on day 14 after treatment according to scheme 2

Point	Examined leaves	Affected leaves	Lesion by point (%)
1	50	14	28,0
2	50	13	26,0
3	50	14	28,0
4	50	13	26,0
5	50	14	28,0
Total	250	68	27.3 (average)

On the 14th day after treatment with an increased dose of the drug, leaf damage was 27.3%, which indicates a stable retention of infection at a moderate level. Despite a slight increase in the lesion compared to the indicator of day 7, the range of values (26-28%) demonstrates the long-term effect of the drug and the preservation of the protective effect achieved due to the increased dosage. The data obtained confirm that the use of a higher dose provided longer-term disease control and prevented a second outbreak of infection during the observation period.

A comparative analysis of the data for four accounting options showed a marked decrease in leaf rust damage after the use of protective preparations compared to the control. In the control group, the lesion rate was 97.2%, which indicates the uncontrolled development of the disease and the lack of natural containment of infection. The use of the drug in a standard dose reduced the lesion to 34.7% on day 7, but by day 14 there was a slight re-increase in infection to 38.2%, which indicates an insufficient duration of protective action at the standard rate of application.

Increasing the dose of the drug provided a more pronounced and sustained protective effect: the lesion decreased to 22.5% on day 7, and by day 14 it reached 27.3%, which demonstrates better pathogen containment and slowing down re-infection compared to the standard dosage. The difference between the standard and increased norm of use was 12.2% on day 7 and 10.9 % on day 14 in favor of the increased dose.

Thus, it was found that the introduction of the drug in an increased dosage provides a longer and pronounced protective effect, significantly limiting the spread of rust and slowing down the development of a repeated infectious process.

2.2.2. Degree of disease development

The results are presented in the tables below. In the course of the research, data were obtained characterizing both the degree of plant damage by leaf diseases and the height and density of the stem of the Licamero wheat variety, depending on the applied schemes of protective and nutritional treatments. Table 5 shows the results of the distribution of plants by degree of damage in the control variant with the calculation of disease development indices.

Table 6. Distribution by degree of lesion in the control variant and calculation of indices

Degree (i), %	Number of leaves (l_i)	(i * l_i)
0 (healthy)	7	0
1	8	8
10	15	150
40	30	1 200
80	70	5 600
100	120	12 000
Total (L)	250 18,958	18 958

Average degree of damage:

$$D = \Sigma(i \times li) / L = 18\,958 / 250 = 75{,}8\%$$

Plant rust infestation in the control variant without treatment was extremely high. Of the 250 leaves examined, 243 were affected, which was 97.2%, indicating that the plants were almost completely infected. The average degree of damage reached 75.8%, which reflects the severe form of the disease development on most of the affected leaves. The results obtained confirm the intensive spread of the pathogen and a significant deterioration in the physiological state of plants in the absence of protective measures.

Table 7. Distribution by degree of lesion on the 7th day after treatment according to the first scheme

Degree (i), %	Number of leaves (l_i)	(i × l_i)
0 (healthy)	163	0
1	18	18
10	28	280

40	28	1 120
80	10	800
100	3	300
Total (L)	250	2,518

$$D= \sum(i\times li)/ L= 2518/250=10{,}1\%$$
$$F=87/250=34{,}8\%$$

On the 7th day after the protective treatment according to scheme 1, a noticeable inhibition of rust development was noted. The lesion rate was only 34.7%, which is almost three times lower than the control value. The average degree of damage to the affected leaves was also low – about 10.1%, which indicates the predominant manifestation of the disease in a mild form. The recorded data indicate a pronounced preventive effect of the drug in the first week after treatment, which effectively limits both the spread of infection and the intensity of the lesion.

Table 8. Distribution by degree of lesion on the 14th day after treatment according to the first scheme

Degree (i), %	Number of leaves (l_i)	(i × l_i)
0 (healthy)	154	0
1	16	16
10	30	300
40	35	1 400
80	10	800
100	5	500
Total (L)	250	250 3,016

$$D= \sum(i\times li) / L =3016/250=12{,}1\%$$
$$F=96/250=38{,}4\%$$

On the 14th day after applying the drug according to scheme 1, leaf infestation increased to 38.2%, remaining significantly lower than the control, but there is an increase in infestation compared to the 7th day. The average degree of damage increased to 12.1%, which indicates a gradual increase in the symptoms of the disease after a decrease in the protective effect of the drug. Despite this, the development of rust remained moderate, which confirms the presence of a continuing but weakened protective effect two weeks after treatment.

2.2.3. Disease index

Disease index for the control variant. In the course of the research, a comprehensive analysis of the phytosanitary condition of crops and production indicators of wheat of the Licamero variety was carried out, depending on the applied schemes of protective and nutritional treatments. The results obtained cover both the degree of development and prevalence of leaf diseases in the control variant, as well as the morphometric characteristics of plants and elements of the crop structure for all studied experimental variants.

$$I = F\times D\times 100=0{,}972\times 0{,}75832\times 100= 73{,}71\%.$$

A high disease index (73.71%) in the control variant indicates an extremely intensive development of rust without the use of protective measures. The disease not only spread widely, but also manifested itself in a severe form, which led to a significant decrease in the phytosanitary status of plants. This level of damage confirms the need for fungicidal protection to prevent serious crop losses.

Disease index for control variant 1 of the scheme 7 days after treatment

$$I=F\times D\times 100=0{,}348\times 0{,}10072\times 100=3{,}5\%$$

7 days after using the drug according to scheme 1, the disease index was 3.5%, which indicates a significant decrease in both the prevalence and intensity of rust compared to the control. The treatment had a pronounced protective effect, effectively curbing the development of the disease at the initial stage after applying the drug.

Disease index for control variant 1 of the scheme 14 days after treatment

$$I=F\times D\times 100=0{,}384\times 0{,}12064\times 100=4{,}63\%$$

After 14 days, the disease index according to scheme 1 increased to 4.63%, which indicates a gradual weakening of the drug's effect two weeks after treatment. Despite a slight increase in the lesion, the level of infection spread and the degree of leaf damage remain significantly lower than the control level, which confirms the continued, albeit weakened, protective effect.

Disease index for control variant 2 of the scheme 7 days after treatment

$$I=F\times D\times 100=0{,}224\times 0{,}0456\times 100=1{,}02\%$$

Such a low value of the disease index indicates almost complete suppression of the disease on day 7 with the use of an increased dosage of the drug. The disease was present only in a very weak form, which proves the high effectiveness of the enhanced protection scheme in the first days after treatment.

Disease index for control variant 2 of the scheme 14 days after treatment

$$I=F\times D\times 100=0{,}272\times 0{,}06632\times 100=1{,}8\%$$

A disease index of 1.80% after 14 days indicates that the increased dosage provided a long-term and sustained protective effect. Despite a slight increase in the lesion, the development of the disease remained minimal, which confirms the advantage of an increased application rate compared to the basic scheme.

The disease index is a complex indicator that allows you to simultaneously take into account the proportion of affected leaves and the intensity of infection development, which makes it more informative than analyzing only the lesion or the degree of damage separately. Calculations have shown that the use of fungicides significantly reduces the index value compared to the control, and an increase in the treatment dose contributes to a more pronounced and long-term containment of rust, which is important for evaluating the effectiveness of protective measures in dynamics.

2.3. Indicators for assessing crop yields

Table 8 shows data on plant height and stem density of Licamero wheat, depending on the applied protective and nutritional treatment schemes. An analysis of the results shows that the studied variants had an ambiguous effect on morphometric indicators and elements of crop productivity. Significant differences have been established between the experimental variants in plant height, the density of standing for harvesting, the number of productive stems and productive bushiness, which makes it possible to assess the degree of impact of the drugs and fertilizers used on the formation of wheat yields in specific growing conditions.

Table 8. Determination of the height and stalk densityof Licamero wheat»

Experiment option	Indicators			
	Plant height, cm	Density to harvest, pcs/m2	Number of productive stems from 1 m2, pcs/m2	Productive bushiness, pcs/plant
Control	75	357	392.7	1.1
Schema1	77	357	428.4	1.2
Scheme 2	65	240	290.4	1.21

The presented data indicate a positive effect of protective and nutritional treatments on the growth and productivity of wheat. In the control group, the plant height was 75 cm with a productive bushiness of 1.1 and the number of productive stems of 392.7 pcs/ m2. The use of scheme 1 contributed to a slight increase in height up to 77 cm and the growth of productive stems up to 428.4 pcs/ m2 due to an improvement in bushiness (1.2 stems/plant), which indicates the stimulating effect of fungicides and fertilizers on the preservation of productive shoots. The variant of scheme 2, despite the higher productive bushiness (1.21), was characterized by the lowest plant height (65 cm) and significantly reduced standing density (240 pcs/m2), which led to the minimum number of productive stems (290.4 pcs/m2). This indicates a possible stressful effect of a higher dose, which reduced plant survival, although the remaining plants formed more productive stems.

Table 9. Determination of biological yieldof Likamero wheat»

Experience option	Indicators	Density to harvest, pcs/m2	Productive bushiness, pcs/plant.	Number of productive stems per 1 m2, pcs/m2	Average grain weight per 1 productive stem, g	Weight of 1000 grains, g	Grain weight per 1 m2 (biological yield), c/ha	Gluten content, %
Control		357	1.1	392.7	0.9	37	35.3	28.3
Schema1		357	1.2	428.4	0.92	38	39.4	28.3
Schema 2		240	1.21	290.4	0.92	38.7	26.7	28.3

In the control variant, without the use of fungicides and additional fertilizers, the density for harvesting was 357 pcs/ m2 with a productive bushiness of 1.1, which ensured the formation of 392.7 productive stems and a biological yield of 35.3 c/ha. The gluten content was 28.3%, which corresponds to the level of strong wheat in the region. The application of scheme 1 led to a noticeable improvement in production indicators: while maintaining the same density of standing (357 pcs/ m2), an increase in productive bushiness to 1.2 and an increase in the number of productive stems to 428.4 pcs/m2 were noted. The weight of 1000 grains increased to 38 g, which positively affected the biological yield, which reached 39.4 kg/ha – 4.1 kg/ha higher than the control. This indicates an increase in the efficiency of photosynthesis and a better realization of the productive potential of plants due to the reduction of rust damage and the maintenance of the leaf apparatus in a functional state.

The variant according to scheme 2, despite its higher efficiency in reducing the disease index, showed a lower yield – 26.7 c/ha. A significant decrease in the density for harvesting (up to 240 pcs/ m2), most likely due to the high rate of processing and the resulting stress, led to a decrease in the total number of productive stems (290.4 pcs/m2). Despite the slightly higher weight of 1000 grains (38.7 g) and the preserved high quality of grain (28.3% gluten), the low density of plants did not allow realizing the yield potential.

Thus, the optimal combination of indicators is scheme 1, which provided an improvement in the structural elements of the crop, an increase in grain weight per unit area and maintaining high quality. Scheme 2 showed better protection of plants from rust, but reduced stem density limited productivity.

Discussion

The results of phytosanitary monitoring revealed a sharp difference between the treated variants and the control for the development of brown rust. In the control area, a catastrophic development of the disease was observed: leaf damage reached 97.2%, and the average degree of damage was 75.8%, which led to an extremely high disease index of 73.71% (Table 3, 5). This indicates that crops are completely defenseless against the pathogen in the absence of protective measures and is consistent with the data [3] on significant crop losses during epiphytic years [7]. Both treatment schemes tested had a significant deterrent effect. At the same time, scheme 2 with increased dosages showed a statistically significant advantage, reducing the disease index to 1.02% on day 7, while in the variant with scheme 1, this indicator was 3.5% (Tables 1-3, 6-7). The more pronounced and prolonged efficacy of scheme 2 confirms the well-known principle of fungicidal action dose-dependent fungicidal action [8-9], however, as further observations showed, this advantage had ambiguous consequences.

Despite excellent disease control, the use of scheme 2 has had unintended consequences. Analysis of the crop structure revealed that in this variant there was a significant decrease in the density of the stem to 240 pcs/ m2 against 357 pcs/ m2 in the control and scheme 1 (Table 8). This is probably a consequence of phytotoxic stress from high doses of drugs, which led to the death of some plants. As a result, despite the highest productive bushiness in the experiment (1.21) and the mass of 1000 grains (38.7 g), the biological yield in the scheme 2 variant turned out to be minimal – 26.7 c/ha (Table 9). This result requires careful consideration, as it indicates that the maximum fungicidal efficiency is not always identical to the maximum yield [10], and exceeding the optimal doses can inhibit plant development.

On the contrary, scheme 1, providing reliable protection against rust (damage on the 14th day – 38.2%), contributed to the realization of the productive potential of the crop. Maintaining the optimal standing density (357 pcs/ m2) in combination with an increase in productive bushiness to 1.2 and the weight of 1000 grains to 38 g allowed us to obtain a reliable yield increase of up to 39.4 c / ha. Grain quality (gluten content at 28.3%) remained consistently high in all variants, including the control, which, however, does not compensate for losses in the amount of grain in untreated areas. Thus, it can be concluded that scheme 1 is the most balanced solution for the conditions of the forest-steppe zone of Northern Kazakhstan, providing an optimal ratio between protection costs, phytosanitary efficiency and final productivity of sowing spring wheat of the Likamero variety.

Conclusions

Based on the conducted studies, the following conclusions are formulated.

Complex application of plant protection products has shown high efficiency against brown rust in spring wheat crops. While the control variant without treatments showed a catastrophic development of the disease with a lesion of 97.2% of leaves and a disease index of 73.71%, both tested treatment regimens significantly reduced the development of the pathogen. At the same time, the scheme with increased dosages of drugs (Scheme 2) showed a more pronounced and prolonged fungicidal effect, reducing the disease index to 1.02% on day 7 and 1.80% on day 14 after treatment, which is significantly better than the results of the scheme with standard dosages (3.5% and 4.63%, respectively). This is consistent with the data of other researchers on the dependence of the effectiveness of protection on the applied doses of fungicides.

However, a significant contradiction was revealed between the level of pathogen control and the final crop productivity. Despite the excellent fungicidal efficiency of Scheme 2, its use had a stressful effect on plants, which resulted in a significant decrease in the stem density to 240 pcs/ m2 and, as a result, the lowest yield in the experiment — 26.7 c/ha. At the same time, Scheme 1 provided reliable protection against the disease and helped optimize the production process: an increase in the number of productive stems to 428.4 pcs/m2 and the weight of 1000 grains to 38 grams was noted, which allowed to obtain the maximum yield of 39.4 c/ha, which is 4.1 c/ha higher than the control.

The scientific novelty of the work consists in a comprehensive assessment of the impact of various intensity schemes of chemical protection, including seed treatment and vegetation spraying, not only on the development of the pathogen, but also on the elements of the structure of the spring wheat crop in specific soil and climatic conditions of Northern Kazakhstan. The practical value of the results obtained is to justify the choice of the optimal security system. It is established that for the variety "Likamero" in the forest-steppe zone of the region, Scheme 1 with standard dosages is recommended for use, since it provides a significant increase in the yield of high-quality grain while maintaining phytosanitary efficiency and economic feasibility. The use of increased doses of drugs (Scheme 2) can be justified only in years with an extremely strong development of rust epiphytosis, when the potential losses from the disease exceed the risks of reduced yields due to phytotoxicity.

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