Biological effectiveness of using fungicides and IFO PZN suspension in combination with fungicides against yellow rust and powdery mildew diseases of winter wheat

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Abstract. In this study, effective protection methods were applied against fungal diseases commonly found in soft winter-sown wheat grown in the foothill regions of the Kashkadarya region, using fungicides and suspensions. The research identified the impact of these treatments on plant health and the progression of disease development. During the 2019–2020 growing season, in untreated control plots, the average number of wheat plants per 1 m² was 410, with the initial incidence of yellow rust (Puccinia striiformis) affecting 230 plants (infection rate: 56.1%). During the disease's peak and decline phases, infection rates increased to 73.41% and 76.1%, respectively, with 301 and 312 infected plants. Between 2020 and 2022, disease severity increased significantly. For instance, during the epidemic stage of 2020–2022 and 2021–2022, infection levels rose by 2.43% to 5.72% compared to 2019–2020, and by 1.65% to 4.24% in the final stage, with yields reduced by 1.5 to 3.2 c/ha. In field trials, the biological effectiveness of combining fungicides (Duazol 40% EC at 0.25 l/ha (reference), Bi-Kanazol 400 g/l at 0.3 l/ha, AZOTE 320 SC 32% SC at 0.3 l/ha, Rauma 490 EC at 1.25 l/ha, Alta Super 40% at 0.3 l/ha, Altus Duo 32.5% at 0.3 l/ha) with IFO PZN suspension (3.0 l/ha) was tested against yellow rust and powdery mildew (Erysiphe graminis). Results showed that disease incidence in untreated control plots ranged from 74.2% to 54.4%, while combining AZOTE 320 SC and Rauma 490 EC with IFO PZN reduced disease levels to 0.8% and 0.5%, respectively. Biological effectiveness reached 98.6–99.1% against yellow rust and 99.0% against powdery mildew. Thus, using a combination of IFO PZN suspension with AZOTE 320 SC or Rauma 490 EC fungicides is recommended for chemical control of these diseases in winter wheat. The combined application enhances chlorophyll content and improves biochemical composition in plant tissues, increasing resistance to

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both diseases and environmental stress. These methods contribute to high-quality yields and effective disease prevention in wheat production.

1 Introduction

Several countries dominate global wheat cultivation, with India planting nearly 30 million hectares, followed by Russia with around 27 million hectares and Spain with close to 26 million hectares. China allocates approximately 24 million hectares to wheat, while the United States cultivates about 15 million hectares. Combined, China, India, and Russia account for nearly 46% of the world's total wheat output. Numerous scientific reports indicate that fungal pathogens—particularly yellow rust and powdery mildew—are major constraints on wheat productivity in key grain-growing regions across the world. Losses associated with yellow and brown rust often approach 20–25%, whereas powdery mildew commonly results in yield reductions of around 15–20%.

In Uzbekistan, enhancing control approaches for fungal pathogens affecting cereal crops is of critical importance. Key strategies involve cultivating varieties with strong resistance to disease and applying agronomic practices that limit pathogen transmission. The use of chemical treatments is typically recommended once infection levels reach approximately 5–20%. In areas where rust outbreaks frequently occur, applying fungicides preventively—prior to visible disease onset—can suppress epidemic development and support the preservation of grain yield.

Wheat cultivation is a key component of Uzbekistan's agricultural system and is fundamental to maintaining the country's food security, with winter wheat serving as the primary grain crop. Despite its importance, various plant diseases continue to limit both yield potential and grain quality. In recent years, two fungal pathogens—yellow rust (Puccinia striiformis) and powdery mildew (Erysiphe graminis f.sp. tritici)—have expanded significantly across wheat-growing areas, leading to notable declines in harvest volume as well as overall grain quality.Wheat cultivation is a key component of Uzbekistan's agricultural system and is fundamental to maintaining the country's food security, with winter wheat serving as the primary grain crop. Despite its importance, various plant diseases continue to limit both yield potential and grain quality. In recent years, two fungal pathogens—yellow rust (Puccinia striiformis) and powdery mildew (Erysiphe graminis f.sp. tritici) have expanded significantly across wheat-growing areas, leading to notable declines in harvest volume as well as overall grain quality.

Yellow rust generally emerges at the beginning of spring and can damage multiple plant parts, including the leaves, stems, and spikes. Powdery mildew primarily colonizes the leaf surface and blades, impairing photosynthesis and reducing the plant's capacity to absorb and utilize essential nutrients. As a result, yield losses in affected fields often fall within the range of 20–40%, and under severe infection, the reduction can exceed these levels. For this reason, early prevention and efficient management of these diseases are of utmost importance. Although numerous fungicide products are currently available, their selection must take into account environmental compatibility, economic feasibility, and the need to avoid phytotoxicity to the crop. [1].

In this context, evaluating the combined application of IFO PZN—a biologically active microbial formulation—with chemical fungicides is particularly pertinent. The IFO PZN preparation enhances the plant's innate defense mechanisms and boosts its overall biological functions. When applied in conjunction with fungicidal agents, it generates a synergistic interaction that improves the effectiveness of disease management in crops.

2 Literature review

As a result of the study, in the irrigated fields of Andijan region, when treated with DRUNK 300 EC fungicide in the chemical control of wheat yellow rust and powdery mildew diseases, yellow rust showed 85.4% biological efficiency compared to the control and other treatment methods, resulting in an increase in yield of 8.4 centners per hectare. When Abacus Ultra fungicide was applied at a rate of 1–1.5 L/ha in field trials targeting rust diseases in winter wheat, it inhibited the development of rust spores by 93.7–96.3%, achieving a biological efficacy between 87% and 89% [2]. One of the most effective methods for protecting plants from fungal diseases is the development of resistant cultivars, which offer high biological efficacy and are environmentally sustainable.

Using fungicides containing propiconazole and tebuconazole, applied via knapsack and tractor sprayers at a rate of 0.2–0.3 liters of concentrate per hectare diluted in 600 liters of water, and treating 2 hectares, has proven effective [3]. To protect cereal crops from rust diseases, the combined use of mineral fertilizers (potassium ammonium phosphate) and suspensions such as “Alto Super” fungicide at 0.3 l/ha, diluted in 200–300 liters of water and sprayed, is an efficient method [4].

Disease severity on individual wheat leaves was assessed using the Peterson scale for brown rust and the Manners scale for yellow rust. In chemically treated plots, yield was fully preserved when disease incidence was accounted for across ten plants per plot [5].

In winter wheat fields, fungicides Altazol EC, Adeksar EC, and Zantara EC were used for chemical control of yellow rust. Among these, Adeksar EC applied at 1.4 l/ha showed the highest biological and economic efficacy, with 99.2% disease control and a yield increase of 3.4 centners per hectare compared to Altazol EC and Zantara EC [6,7].

Yellow rust affects 70–100% of the plant during the entire growing season, resulting in 40–60% yield losses. Moreover, infected seeds become shriveled, reducing germination energy. Annual losses due to wheat rust range from 5–17%, and during epidemic years, infection levels may reach 45–70% [8]. Initial symptoms of powdery mildew appear as white powdery patches on the leaves; later, cottony layers form. The disease develops rapidly under relative humidity of 90–99% and temperatures between 15–20 °C [9].

Repeated use of a single fungicide against yellow rust and powdery mildew can lead to the development of resistance in the fungal pathogens [10]. The only reliable method to control rust diseases in wheat is timely fungicide applications. Fungicides can suppress rust development for 25–30 days. However, if the disease is widespread or leaf spot diseases occur alongside rust, a second treatment is recommended 15–20 days after the first, followed by a third treatment after the same interval, taking into account prevailing weather conditions [11].

Many scientists have conducted scientific research on the selection of genotypes resistant to yellow rust diseases of bread wheat in the southern regions of the Republic of Uzbekistan. It is noted that 350-400 genotypes are evaluated for their resistance to the disease annually in artificial field conditions. As part of field and laboratory studies, more than 30 genotypes with a resistance of 0-5R to yellow rust diseases of winter bread wheat were selected. Also, the resistance of bread wheat varieties cultivated in Uzbekistan to yellow and brown rust diseases was studied. [4-6].

3 Materials and methods

3.1 Disease incidence

Disease incidence was calculated as the percentage of infected plants relative to the total number of observed plants according to the following formula:

$$I = \frac{a}{b} * 100 \quad (1)$$

where:
I — disease incidence (%);
a — number of infected plants;
b — total number of observed plants per plot.
Visual evaluation of infection was carried out on 100–200 plants per plot within a 1 m² area in each replication. Scoring criteria is listed in Table 1.

Table 1. Scoring criteria of leaf inspection.

Score	Leaf area affected (%)	Description
0	0	Healthy
1	1-5	Very light infection
2	6-15	Moderate infection
3	16-30	Medium infection
4	31-50	Severe infection
5	>50	Heavy infection

Based on this scoring, the disease development index (R) was determined by the following formula:

$$R = \frac{\sum(ni*bi)}{N*B}*100 \quad (2)$$

where:
n_i – number of plants for each score;
b_i – corresponding score value;
N – total number of evaluated plants;
B – maximum score (5).

3.2 Biological efficacy of treatments

The biological efficacy (E, %) of each fungicide and fungicide + IFO PZN combination was determined using Abbott's formula (Abbott, 1925; EPPO Standard PP1/152(4)):

$$E = \frac{Ik-It}{Ik} * 100 \quad (3)$$

E – biological efficacy (%);

Ik – disease incidence in the untreated control (%);
It – disease incidence in the treated variant (%).

3.3 Disease severity and development index

The degree of leaf infection was estimated visually using a 0–5 scale (Mains and Jackson, 1926; Saari–Prescott, 1975):

The research was conducted using widely accepted methods in mycology and agricultural phytopathology. The infection level of yellow rust in winter wheat was assessed under field

conditions through visual inspection based on the Manners scale, while powdery mildew infection was evaluated using the Hasanov (%) scale. The spread of yellow rust and powdery mildew diseases in wheat was monitored following the methodologies of Chumakov (1974) and Murat Koyshibayev (2002); to select the experimental wheat fields, an initial monitoring was carried out in the study areas to determine the presence and development of diseases. During monitoring, if diseases were observed, their types, progression, and distribution were identified.

Additionally, along each diagonal of the wheat fields, 10 plant clusters (main stems) were randomly sampled from 5–10 points per 1 m² plot. The prevalence of fungal diseases and the number of infected plants were detected and recorded. The results of the study were analyzed and calculated using the empirical formula of B.A. Hasanov to determine the biological effectiveness of chemical treatment. [1-3].

During the field experiments, research was conducted in the Shahrisabz district of the Kashkadarya region, in the southern agroclimatic zone of the Rakhmatov Akbar Khurramovich farm. As a result of the study, the climatic conditions in this region are warm in winter, hot in spring, and drought in summer. From this point of view, this foothill is included in the agroecological zones. The agroclimatic conditions of the region play a decisive role in the epidemiology of fungal diseases of wheat such as yellow rust (Puccinia striiformis) and powdery mildew (Erysiphe graminis Ds), which develop very quickly in the changing temperature and humidity regimes characteristic of this zone.

Climate. This region has a sharply continental climate, with seasonal variations in temperature, humidity, and precipitation. According to the data of the Karshi Weather Control Station (2019–2022), the average monthly air temperature in the region ranged from 1.9 °C in January to 29.9 °C in June, while the average annual air temperature is 14–16 °C. On average, the relative humidity varies between 13–32%, with the highest values in the winter (December–January), and the lowest values in the late spring and early summer (May–June).

The average annual rainfall is 250–350 mm, and the main part of the precipitation falls in March-April, and the precipitation is high, which leads to the development of the disease during the active development of winter wheat and the formation of all vegetative organs.

The average wind speed in the region is observed in the range of 8–12 m/s, and sometimes in spring it reaches 18 m/s, which contributes to the development of fungal diseases and the spread of their spores in the air.

This agroclimate creates a favorable microenvironment for the emergence and spread of pathogens of wheat yellow rust and powdery mildew. As a result, in early spring the average temperature reaches (10–18 °C) and the humidity is high (60–80%). It is considered very favorable for the spread and development of fungal diseases.

4 Soil characteristics

The soils of the experimental area of the region are flat irrigated areas. The soils are typical gray soils. These soils are medium loamy, and the physical and chemical composition of the soil, which is very suitable for growing cereal crops, is very suitable for growing these crops. The soils are mainly The main soil contains the following: The humus content is on average 1.4–1.9% in the 0–30 cm soil layer. The total nitrogen content is on average 0.12–0.14%. The available phosphorus content is on average 0.09–0.21%. The exchangeable potassium content is 1.40–1.90%. The soil pH is neutral to slightly alkaline (7.0–7.8) and the total porosity is 44.6–51.0%, which provides a favorable air-water balance for root respiration and microbial activity.

The mechanical composition of the soil is mainly medium loam, with 40–41% physical clay (<0.01 mm fraction). This structure provides sufficient moisture and a constant supply

of nutrients. At the same time, it prevents water stagnation and ensures optimal plant growth and development.

4.1 Soil mechanical composition

The granulometric composition of soil, which develops during soil formation, plays a crucial role in determining its agricultural value. Soils can be classified by texture into sandy, sandy loam, loam, and clayey types. Sandy and sandy loam soils are easy to cultivate, have good water permeability, favorable air conditions, and warm up quickly. However, these soils also possess several disadvantages — such as low moisture retention, low organic matter and nutrient content, limited cation exchange capacity, etc.

As a result, even in humid climatic conditions, plants growing in sandy and sandy loam soils often experience moisture deficiency. In the soils under investigation, the content of fine particles (i.e., physical clay), with a diameter smaller than 0.01 mm, ranges between 40.4% and 41.2% across the profile. The amount of dust particles sized 0.05–0.01 mm exceeds that of fine dust particles sized 0.01–0.005 mm.

4.2 Total porosity of soil

In the experimental plot, established on irrigated light-colored sierozem soils, the total soil porosity ranged from 44.6% to 51.0% across the soil profile. The plow layer, characterized by relatively lower bulk density, exhibited higher porosity at 51.0%, whereas the more compact subsurface layer showed a porosity of 44.6%.

4.3 Agro-ecological relevance

The agroclimatic and soil conditions of the Shahrisabz district make it an ideal representative area for field trials on winter wheat diseases. The region is highly productive but disease-prone, especially under irrigated conditions where high humidity and moderate temperatures prevail during the critical growth stages of wheat. Studying the effectiveness of fungicides and IFO PZN suspension under such natural epidemic pressure provides ecologically valid and transferable results for other piedmont wheat-growing areas of Uzbekistan and Central Asia.

4.4 Scientific importance

Classifying the research area agroclimatically allows for the correct interpretation of biological results, as the interaction between microclimate and pathogen activity determines both the onset of infection and the persistence of fungicidal protection.

By correlating disease development data with meteorological indicators (temperature, humidity, rainfall, and wind speed), this study provides an integrated understanding of how environmental dynamics influence the biological efficiency of fungicides and biostimulant combinations.

The experiments were conducted about the research - period from 2020 to 2022. Accepted laboratory and field methods were used for planning and executing the experiments, that are shown in Table 2. Kashkadarya region is located in the southern part of the Republic of Uzbekistan, with its northern and western sides bordered by mountains. This geographical feature creates a sharply continental climate in the area. The scientific research was carried out in the Shahrisabz district of Kashkadarya region, specifically at the farm of Akbar Khurramovich Rakhmatov in the Parda Sherboboyev locality.

Table 2. Average air temperature in Kashkadarya region according to Karshi meteorological station data (2019-2022), °C.

Average air temperatures of Shahrisabz for the 2020–2022 year interval, °C									
Decades	**October**	**Novemer**	**December**	**January**	**February**	**March**	**April**	**May**	**June**
2019-2020 years									
1st decade	14,8	13,8	3,8	4,5	9,6	9,1	11,6	20,4	27,5
2nd decade	14,5	3,5	1,5	0,3	4,9	14,7	15,4	20,8	27,3
3rd decade	11,5	2,9	0,5	3,5	10,3	13,7	20,9	26,8	28,3
Average air temperatur e, °C	13,6	6,7	1,9	2,8	8,3	12,5	16	22,7	27,7
2020-2021 years									
1st decade	15,6	14,5	4	-5,2	11,4	10,7	14,1	21,8	31,5
2nd decade	15,3	3,7	1,6	10,4	13,4	9,6	18,1	24,5	28,6
3rd decade	12,1	3,1	0,5	4,2	2,9	13,3	21,7	27,6	29,5
Average air temperatur e, °C	14,3	7,1	2	3,1	9,2	11,2	18	24,6	29,9
2021-2022 years									
1st decade	15,4	7,7	10,8	6,1	7,2	11,3	20,6	23,2	27,8
2nd decade	14,4	6,1	6,3	9,2	7,9	11,3	20,1	22,3	27,3
3rd decade	11,2	10,8	7,3	4,7	10,5	10,3	22,2	11,3	30,8
Average air temperatur e, °C	13,7	8,2	8,1	6,7	8,5	11	21	18,9	28,6

According to the research results from 2019 to 2022, the average air temperatures recorded in October were +13.6°C, +14.3°C, and +13.7°C, respectively. In November, the average temperatures were +6.7°C, +7.1°C, and +8.2°C; in December, +1.9°C, +2.0°C, and +8.1°C; in January, +2.8°C, +3.1°C, and +6.7°C; and in February, +8.3°C, +9.2° A sharp increase in air temperature was observed in March, the beginning of the spring season, with average temperatures of +12.5°C, +10.2°C, and +11.0°C for the respective years. In April, the temperatures were +16°C, +18°C, and +21°C, while in May, they reached +22.7°C, +24.6°C, and +18.9°C. By June, the average air temperature was recorded as +27.7°C, +29.9°C, and +28.6°C, respectively C, and +8.5°C, as listed in Table 3.

Between 2019 and 2022, the average relative humidity in October was recorded as 15.7%, 18%, and 17.7%, respectively, while in November, it reached 18%, 24%, and 20.3%. The highest minimum relative humidity values were observed in December and January. In December, relative humidity levels were 32.3%, 31.7%, and 16.3%, respectively. In January, the values were recorded as 31%, 23%, and 26%.

In February, due to relatively low precipitation across the decades, a decrease in relative humidity was observed, reaching 16.7%, 17.3%, and 16.3%, respectively. In March, relative humidity values were recorded at 23%, 19.3%, and 27%. In April, relative humidity levels were 25%, 13.7%, and 16%. By May, relative humidity further decreased to 22%, 17.7%, and 17%. A continuing decline was noted in June, with relative humidity values of 13.3%, 10%, and 12%.

Table 3. Average minimum relative humidity in Kashkadarya region according to Karshi meteorological station data (2019–2022), %.

Decades	October	November	December	January	February	March	April	May	Jue
2019-2020 years									
1st decade	13	11	33	28	8	23	25	24	13
2nd decade	18	26	40	36	20	18	31	26	14
3rd decade	16	17	24	29	22	28	19	16	13
Average minimum relative humidity, %	15,7	18	32,3	31	16,7	23	25	22	13,3
2020-2021 years									
1st decade	17	13	38	31	13	13	10	30	9
2nd decade	21	32	22	18	11	22	16	13	10
3rd decade	16	27	35	20	28	23	15	10	11
Average minimum relative humidity, %	18	24	31,7	23	17,3	19,3	13,7	17,7	10
2021-2022 years									
1st decade	22	21	16	36	14	22	14	17	12
2nd decade	15	22	17	22	21	34	14	19	14
3rd decade	16	18	16	20	14	25	20	15	10
Average minimum relative humidity, %	17,7	20, 3	16,3	26	16,3	27	16	17	12

According to the observations conducted during 2019–2022, the average precipitation in October ranged from 0.6 mm to 2.9 mm. In November, average precipitation values were 9.9 mm, 22 mm, and 7.9 mm, respectively. December recorded average precipitation between 2.6 mm and 10.6 mm. In January, the values ranged from 7.9 mm to 32 mm, while February precipitation averaged between 8.2 mm and 26 mm. March showed average precipitation of 26.7 mm, 37.9 mm, and 46.2 mm. In April, precipitation levels ranged from 4.9 mm to 47.1 mm. May precipitation averaged between 5.8 mm and 30.9 mm. By the third decade of June, average precipitation was about 10 mm.

During the spring season, average wind speeds in March were recorded at 10.7 m/s, 12.7 m/s, and 18 m/s. In April, the average wind speeds ranged from 9.7 m/s to 12.3 m/s. Wind speeds in May and June were observed to be somewhat higher than in previous months.

In May, the average maximum wind speed was recorded as 11.3 m/s, 13.7 m/s, and 12 m/s, respectively, while in June, this indicator averaged 11.3 m/s, 10.7 m/s, and 12.3 m/s (see Table 4).

The Hisor Mountains in the Shahrisabz district are situated at an altitude of 2200–2400 meters. The soils in this area are classified as typical and dark gray soils. In the irrigated typical gray soils, the highest total phosphorus content (0.169–0.21%) is found in the looser and sub-looser soil layers. In other cases, total phosphorus ranges from 0.09% to 0.179%,

with dark gray soils containing 0.095–0.115%, and dry and meadow-type typical gray soils also retaining phosphorus within this range.

The total potassium content across all soil layers studied fluctuates between 1.40% and 1.90%, indicating that the soils of Shahrisabz formed on mineralogically similar rock deposits. These soils are characterized by being humus-rich, non-saline, and not prone to salinization.

Table 4. Average precipitation in Kashkadarya region according to Karshi meteorological station data (2019–2022), mm.

Decades	October	November	December	January	February	March	April	May	June
2019-2020 years									
1st decade	-	-	4,3	32,2	15,6	12,7	55,8	64,7	0
2nd decade	0,6	11	0	22,3	50,3	18,8	77,7	26,9	-
3rd decade	-	8,8	3,4	31,4	12	48,5	7,7	1,2	0
Average precipitation, mm	0,6	9,9	2,6	28,6	26	26,7	47,1	30,9	0
2020-2021 years									
1st decade	-	-	4,7	0	5,7	21,8	22,4	8,9	0
2nd decade	-	34,3	2,1	0	1	46,8	0,3	-	-
3rd decade	-	9,7	23,2	23,6	17,8	69,9	-	2,6	-
Average precipitation, mm	-	22	10	7,9	8,2	46,2	11,4	5,8	0
2021-2022 years									
1st decade	0,7	9,4	0	51	20,9	32,3	0	41,5	-
2nd decade	-	13,4	6,9	30,2	0	70,4	8,3	1,5	10
3rd decade	5,1	0,8	24,8	14,7	8,1	11	6,4	36,7	-
Average precipitation, mm	2,9	7,9	10,6	32	9,7	37,9	4,9	26,6	10

The humus content in the dry typical gray soils of Shahrisabz is 51.73 tons per hectare in the 0–30 cm layer, while in the 0–50 cm layer, this value reaches 73.01 tons per hectare. In meadow and irrigated soils, the humus content ranges from 48.21 to 48.30 tons per hectare at 0–30 cm depth and from 66.72 to 68.54 tons per hectare at 0–50 cm depth.

Increasing soil fertility is a pressing issue today, and it cannot be solved by simply increasing the nutrients in the soil or increasing the amount of humus. Because it is very important to understand and determine the properties of the soil and soil moisture, air temperature, water permeability, soil composition, mechanical structure, as well as water demand and quality.

5 Results and discussion

During monitoring, when the presence of diseases in the region is confirmed, the primary focus is on identifying the development and spread of yellow rust. For this purpose, plant samples are collected by taking 10 plant bundles (main stems) from 5–10 points per 1 m² along each diagonal direction of the wheat field. These samples are then examined to determine the disease severity and the number of infected plants.

According to the results of the conducted research, the impact of yellow rust on wheat was analyzed. During the 2019–2020 growing season, an average of 410 wheat plants per 1

m² was recorded. Initially, the yellow rust was detected in 230 plants, with an infection rate of 56.1%. During the phase of widespread infection, the number of affected plants increased to 301, and at the final stage when the disease development ceased, 312 infected plants were observed. The corresponding infection rates at these stages were 73.41% and 76.1%, respectively.

During the research period from 2020 to 2022, the degree of disease infection significantly increased. For instance, at the peak of disease spread, infection rates in 2020–2022 and 2021–2022 increased by 2.43% and 5.72% respectively compared to 2019–2020. During the disease termination phase, infection rates rose by 1.65% and 4.24%, while yield decreased by 1.5 and 3.2 centners per hectare (see Table 5).

In field experiments, the biological effectiveness of fungicides and a suspension of IFO PZN at 3.0 l/ha, applied in combination, was studied against yellow rust and powdery mildew on wheat. For this purpose, experimental plots measuring 360 m² were allocated in three replications in a wheat field at the "Rakhmatov Akbar Khurramovich" farm in Parda Sherboboyev area, Shahrisabz district, Kashkadarya region during 2020–2022. Preliminary trials against yellow rust and powdery mildew were conducted.

The biological efficacy of fungicides was evaluated based primarily on two parameters: the spread of diseases and their intensity of development (degree of infection).

Table 5. Maximum wind speed in the atmosphere in Kashkadarya region according to Karshi meteorological station data (2019–2022), m/s.

Dekadalar	October	November	December	January	February	March	April	May	June
2019-2020 years									
1st decade	5	7	10	6	16	8	10	16	10
2nd decade	3	9	6	6	11	10	9	8	14
3rd decade	6	8	9	15	13	14	18	10	10
Average maximum wind speed, m/s	4,7	8	8,3	9	13,3	10,7	12,3	11,3	11,3
2020-2021 years									
1st decade	7	8	7	7	11	18	16	9	11
2nd decade	7	8	9	20	11	18	10	14	11
3rd decade	7	18	7	20	9	18	10	18	10
Average maximum wind speed, m/s	7	11,3	7,7	15,7	10,3	18	12	13,7	10,7
2021-2022 years									
1st decade	9	9	8	14	20	15	15	11	9
2nd decade	7	10	16	20	10	15	7	10	14
3rd decade	10	6	18	20	8	8	7	15	14
Average maximum wind speed, m/s	8,7	8,3	14	18	12,7	12,7	9,7	12	12,3

According to the three-year scientific research results from 2020 to 2022 (see Table 6), the development of yellow rust (Puccinia striiformis) and powdery mildew (Erysiphe graminis f.sp. tritici) on the winter soft wheat variety "KESH-2016" was studied. Treatments included fungicides such as Duazol 40% k.e.k at 0.25 l/ha (standard), Bi-Kanazol 400 g/l at 0.3 l/ha, AZOTE 320 SC 32% k.s at 0.3 l/ha, Rauma 490 k.e at 1.25 l/ha, Alta Super 40% at 0.3 l/ha, Altus Duo 32.5% at 0.3 l/ha, and a suspension of IFO PZN at 3.0 l/ha. The experiments aimed to identify the most effective fungicide for potential production recommendation.

The results of the study showed that the use of IFO PZN suspension in combination with fungicides was significantly more effective against yellow rust and powdery mildew than the use of fungicides alone. The increase in the effectiveness of the variants studied in this study was due to several physiological and biochemical processes that occur as a result of the interaction between the plant and the fungicide. Because through this process, the plant lagged behind in the variants treated with fungicides alone, in our studies, we additionally treated the fungicides with IFO PZN suspension so that it would not be exposed to this stress.

IFO PZN 3.0 l/ha suspension. Produced by the Ifoda company in the Namangan region. The suspension has a contact effect. The composition is total nitrogen (N) 3%, total phosphorus (P2O5) 25%, total water-soluble zinc (Zn) 5%, pH 1-3%. The preparation form is a liquid NP fertilizer. When applied through the leaves, it provides the necessary energy for biochemical processes in the crop body. Accelerates the growth of buds, ensures full and uniform flowering even at low temperatures. As a result, the systemic effect of fungicides is enhanced, which ensures better development and distribution in plant tissues and long-term protective activity.First, the IFO PZN suspension contains biologically active surfactants, amino acids, and trace elements that improve the wetting and spreading properties of fungicide droplets on the leaf surface. These surfactants form a uniform film layer that enhances fungicide adhesion and penetration into the epidermal tissues. As a result, the systemic action of fungicides is intensified**,** ensuring better distribution and prolonged protective activity within plant tissues.

Table 6. Maximum wind speed in the atmosphere in Kashkadarya region according to Karshi meteorological station data (2019–2022), m/s.

Years	Initial spreading of Yellow Rust			Widespread infection phase		Kasallanish darajasi		Harvested crop, n/ha
	Number of plants in 1m²	Number of infected plants	Incidence of infection, %	Number of infected plants	Incidence of infection, %	Number of infected plants	Incidence of infection, %	
2019-2020	410	230	56,10	301	73,41	312	76,10	31,5
2020-2021	418	237	56,70	317	75,84	325	77,75	30,0
2021-2022	412	256	62,14	326	79,13	331	80,34	28,3

According to the results of the study, before fungicide treatment, when assessing the level of damage by yellow rust (Puccinia striiformis), the average number of plants per 1 m² in the untreated control was 399 plants. After seven days, the number of damaged plants was 239, which is equal to the level of damage 59.9%. After fourteen days, the number of damaged plants increased to 287, the average level of damage over three years was 71.9%. As noted in the study, the number of damaged plants within 21 days was 296, which is equal to the level of damage 74.2%(see Table 7).

In the Duazol 40% concentrate treatment variant at 0.25 l/ha (standard), the plant count before chemical treatment was 392. Seven days after treatment, the number of infected plants averaged 34, corresponding to an infection rate of 8.7% and a biological efficacy of 85.5%. Fourteen days post-treatment, infected plants numbered 24 per m², with an infection rate of 6.1% and biological efficacy of 91.5%. After 21 days, infected plants counted 22, with an infection rate of 5.6% and biological efficacy of 92.4%.

For the AZOTE 320 SC 32% solution applied at 0.3 l/ha, the initial plant count was 395. Seven days post-treatment, the infected plants numbered 22, with an infection rate of 5.6% and biological efficacy of 90.7%. Fourteen days after treatment, the infected plants were

reduced to 14, with an infection rate of 3.5% and biological efficacy of 95.1%. At 21 days, infected plants were 13, with an infection rate of 3.3% and biological efficacy of 95.6%.

In the variant treated with Rauma 490 concentrate at 1.25 l/ha, the initial plant count was 393. Seven days after treatment, infected plants numbered 23, with an infection rate of 5.9% and biological efficacy of 90.2%. Fourteen days post-treatment, infected plants numbered 16, with an infection rate of 4.1% and biological efficacy of 94.3%. After 21 days, infected plants were 12, with an infection rate of 3.1% and biological efficacy of 95.9%.

In treatments where fungicides were combined with IFO PZN suspension at 3.0 l/ha, the fight against yellow rust (Puccinia striiformis) yielded the following: in the untreated control, plant count was 400, with infected plants numbering 197, 211, and 218 at 7, 14, and 21 days, respectively. After chemical treatment, infection rates were recorded as 49.3% at 7 days, 52.8% at 14 days, and 54.5% at 21 days.

In the treatment variant with Duazol 40% EC at 0.25 l/ha (standard) combined with IFO PZN 3.0 l/ha, the average number of plants before treatment was recorded as 398. Seven days post-treatment, the number of infected plants per 1 m² was 33, which declined to 22 after 14 days and 21 after 21 days. The degree of infection in the field was recorded as 8.3% at 7 days, 5.5% at 14 days, and 5.3% at 21 days. Correspondingly, the biological efficacy was noted to be 83.2%, 89.5%, and 90.3%, respectively.

The highest efficacy during the study, compared to the control and the standard variant, was observed in the treatment variant AZOTE 320 SC 32% SC at 0.3 l/ha + IFO PZN 3.0 l/ha. The average number of plants before treatment was 400. Seven days post-treatment, the number of infected plants per 1 m² was 17; after 14 days, 6 plants; and after 21 days, 2 plants (see Figure 1).

Table 7. Maximum wind speed in the atmosphere in Kashkadarya region according to Karshi meteorological station data (2019–2022), m/s.

Variants	Type of infection/disease	Applied preparations	Number of plants after the application of chemical control measures, units per 1 m²									
			Before processing	Number of infected plants			Incidence of infection, %			Biological effectiveness, %		
				7	14	21	7	14	21	7	14	21
1	*Yellow Rust,(Puccinia striiformi)*	Control (untreated plots)	399	239	287	296	59,9	71,9	74,2	-	-	-
2		Duazol, 40% k.e.k 0,25 l/ha (ethalon)	392	34	24	22	8,7	6,1	5,6	85,5	91,5	92,4
3		Bi-Kanazol 400 g/l 0,3 l/ha	399	29	24	22	7,3	6	5,5	87,9	91,6	92,6
4		AZOTE 320 SC 32 % k.s 0,3 l/ha	395	22	14	13	5,6	3,5	3,3	90,7	95,1	95,6
5		Rauma 490 k.e 1,25 l/ha	393	23	16	12	5,9	4,1	3,1	90,2	94,3	95,9

6		Alta Super 40% 0,3 l/ha	394	33	21	20	8,4	5,3	5,1	86	92,6	93,2
7		Altus Duo 32,5% 0,3 l/ha	397	31	21	20	7,8	5,3	5	87	92,6	93,2
8		Control (untreated plots)	400	197	211	218	49,3	52,8	54,5	-	-	-
9		Duazol 40% k.e.k 0,25 l/ha (etalon)+IFO PZN 3,0 l/ha	398	33	22	21	8,3	5,5	5,3	83,2	89,5	90,3
10		Bi-Kanazol 400 g/l 0,3 l/ga+IFO PZN 3,0 l/ha	398	28	24	19	7	6	4,8	85,7	88,6	91,2
11		AZOTE 320 SC 32 % k.s 0,3 l/ha+IFO PZN 3,0 l/ha	400	17	6	2	4,3	1,5	0,5	91,4	97,2	99,1
12		Rauma 490 k.e 1,25 l/ha+IFO PZN 3,0 l/ha	399	13	7	3	3,3	1,8	0,8	93,4	96,7	98,6
13		Alta Super 40% 0,3 l/ha+IFO PZN 3,0 l/ha	399	32	19	17	8	4,8	4,3	83,7	91	92,2
14		Altus Duo 32,5% 0,3 l/ha+IFO PZN 3,0 l/ha	399	30	20	18	7,5	5	4,5	84,7	90,5	91,7

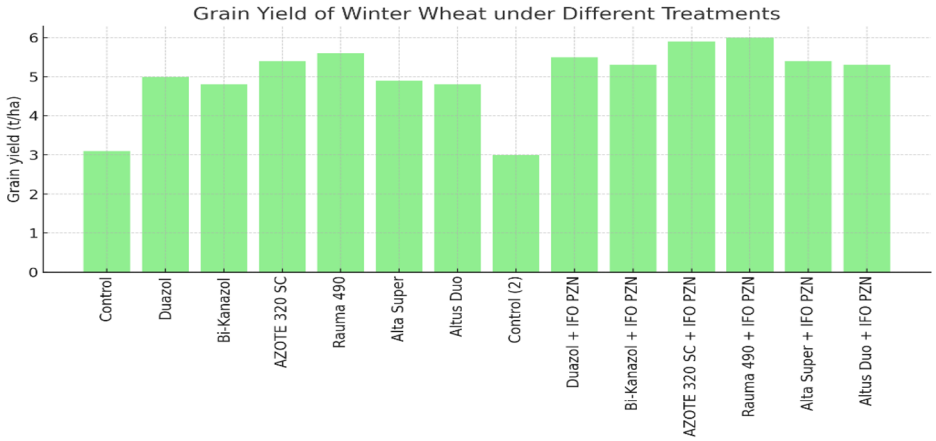

Fig. 1. Grain Yield of winter wheat under different treatments.

The infection rate was recorded as 4.3%, 1.5%, and 0.5%, respectively. The biological efficacy was correspondingly high at 91.4%, 97.2%, and 99.1%.

In the Rauma 490 EC at 1.25 l/ha + IFO PZN 3.0 l/ha treatment variant, the number of plants before application averaged 399. Seven days after treatment, the number of infected plants was 13; after 14 days, 7 plants; and after 21 days, 3 plants. The infection rates were 3.3%, 1.8%, and 0.8%, respectively, while biological efficacy reached 93.4%, 96.7%, and 98.6% (see Table 8).

According to the results of disease management trials against powdery mildew (Erysiphe graminis.f.sp tritici), in the untreated control variant, the plant count was 401. The number of infected plants per 1 m² was 172 after 7 days, 213 after 14 days, and 218 after 21 days. Corresponding infection rates were 42.9%, 53.1%, and 54.4%, respectively.

In the Duazol 40% EC at 0.25 l/ha (standard) variant, the number of plants before treatment was 404. The number of infected plants was 56 at 7 days, 24 at 14 days, and 22 at 21 days. Infection rates were recorded as 13.9%, 5.9%, and 5.4%, respectively. Biological efficacy was calculated at 61.7%, 88.8%, and 90.0%.

In the AZOTE 320 SC 32% SC at 0.3 l/ha variant, the pre-treatment plant count was 403.

Seven days after treatment, the number of infected plants was 21; after 14 days, 15; and after 21 days, 11. Infection rates were recorded at 5.2%, 3.7%, and 2.7%, respectively. The biological efficacy was 87.9% after 7 days, 93.0% after 14 days, and 95.0% after 21 days [12].

Before treatment with the fungicide *Rauma 490 EC* at a dose of 1.25 l/ha, the number of plants was determined to be 406 per square meter. Following treatment, the number of diseased plants was recorded as 21 after 7 days, 13 after 14 days, and 12 after 21 days. The disease incidence was found to be 5.2% after 7 days, 3.2% after 14 days, and 3.0% after 21 days. The biological effectiveness of the fungicide was calculated at 87.9% after 7 days, 94% after 14 days, and 94.6% after 21 days.

When a combination of fungicide and plant growth regulator (*Rauma 490 EC* 1.25 l/ha + *IFO PZN* 3.0 l/ha) was applied to control powdery mildew (*Erysiphe graminis f. sp. tritici*), the untreated control plot exhibited an average of 396 plants/m². In this control variant, the number of diseased plants was 169 after 7 days, 186 after 14 days, and 202 after 21 days. The disease incidence reached 42.7% at day 7, 47% at day 14, and 51% at day 21 [13].

Table 8. Biological effectiveness of fungicides and IFO PZN 3.0 l/ha against Powdery Mildew in the KESH-2016 variants of soft Wheat (2020–2022).

Variants	Type of infection/disease	Applied preparations	Number of plants after the application of chemical control measures, units per 1 m²									
			Before processing	Number of infected plants			Incidence of infection, %		Biological effectiveness, %			
				7	14	21	7	14	21	7	14	21
1	Powdery Mildew (Erysiphe graminis f.sp tritici)	Control (untreated plots)	401	172	213	218	42,9	53,1	54,4	-	-	-
2		Duazol, 40% k.e.k 0,25 l/ha (ethalon)	404	56	24	22	13,9	5,9	5,4	67,7	88,8	90
3		Bi-Kanazol 400 g/l 0,3 l/ha	403	31	24	22	7,7	6	5,5	82,1	88,8	90
4		AZOTE 320 SC 32% k.s 0,3 l/ha	403	21	15	11	5,2	3,7	2,7	87,9	93	95
5		Rauma 490 k.e1,25 l/ha	406	21	13	12	5,2	3,2	3	87,9	94	94,6
6		Alta Super 40% 0,3 l/ha	402	32	20	19	8	5	4,7	81,4	90,6	91,3
7		Altus Duo 32,5% 0,3 l/ha	403	29	20	18	7,2	5	4,5	83,2	90,7	91,8
8		Control (untreated plots)	396	169	186	202	42,7	47	51	-	-	-
9		Duazol, 40% k.e.k 0,25 l/ha (ethalon)+IFO PZN 3,0 l/ha	395	30	20	17	7,6	5,1	4,3	82,2	89,2	91,6
10		Bi-Kanazol 400 g/l 0,3 l/ha+IFO PZN 3,0 l/ha	394	25	19	15	6,3	4,8	3,8	85,1	89,7	92,5
11		AZOTE 320 SC 32% k.s 0,3 l/ha+IFO PZN 3,0 l/ha	398	12	5	2	3	1,3	0,5	92,9	97,3	99
12		Rauma 490 k.e1,25 l/ha+IFO PZN 3,0 l/ha	397	11	5	2	2,8	1,3	0,5	93,5	97,3	99
13		Alta Super 40% 0,3 l/ha+IFO	396	15	16	14	3,8	4	3,5	91,1	91,4	93,1

		PZN 3,0 l/ha										
14		Altus Duo 32,5% 0,3 l/ha+IFO PZN 3,0 l/ha	389	14	15	13	3,6	3,9	3,3	91,6	91,8	93,4

In contrast, consistent high effectiveness was observed in variants treated with the fungicide in combination with suspension. For instance, the standard treatment (*Duazol 40% EC* at 0.25 l/ha + *IFO PZN* 3.0 l/ha) showed 395 plants/m² before treatment, with the number of infected plants dropping to 30 after 7 days, 20 after 14 days, and 17 after 21 days. Disease incidence was recorded at 7.6%, 5.1%, and 4.3% respectively, with biological effectiveness calculated at 82.2%, 89.2%, and 91.6% over the same intervals [14].

The most effective results were observed in the variant treated with *AZOTE 320 SC* (32% SC) at 0.3 l/ha + *IFO PZN* 3.0 l/ha. Prior to treatment, plant density was recorded at 398 plants/m². The number of infected plants was reduced to 12 after 7 days, 5 after 14 days, and only 2 after 21 days [15].

Disease incidence in this variant was 3.0%, 1.3%, and 0.5% respectively. The biological effectiveness was determined to be 92.9% at 7 days, 97.3% at 14 days, and 99% at 21 days.

In the variant where *Rauma 490 EC* at 1.25 l/ha was applied in combination with *IFO PZN* at 3.0 l/ha, the plant density was recorded at 397 plants/m². The number of diseased plants was 11 on day 7, 5 on day 14, and 2 on day 21. Disease incidence was 2.8%, 1.3%, and 0.5%, respectively. Biological effectiveness was calculated to be 92.9% at 7 days, 97.3% at 14 days, and 99% at 21 days, thus confirming the high efficacy of this treatment in experimental studies.

6 A brief understanding of the classification of fungicides and IFO PZN suspension

6.1 Fungicide Duazol 40% k.e.c 0.25 l/ha

Duazol 40% k.e.c 0.25 l/ha. Produced by Nanjing Essence Fine-Chemical Co. Fungicide contact action. The composition consists of Propiconazole + Tebuconazole. Preparation form colloidal solution concentrate. The shelf life is 3 years from the date of manufacture. An effective remedy against yellow rust, powdery mildew, and brown rust diseases found in winter wheat. The effectiveness of the fungicide is 79.9-85.2%.

6.2 Fungicide Bi-Kanazol 400 g/l 0.3 l/ha

Produced by Xinjiang moer chemscience So LTD. Fungicide contact action. Composition Propiconazole + Tebuconazole. The form of the drug is a colloidal solution concentrate (k.e.c.). Highly effective two-component fungicide against diseases of winter wheat. An effective remedy against leaf and spike diseases. The effectiveness of the fungicide is 83.2-86.3%.

6.3 Fungicide AZOTE 320 SC 32% k.c 0.3 l/ha

Developed in Uzbekistan by IP LANDCHEM LLC. Fungicide has a contact effect. The composition consists of Tebuconazole + Azoxystrobin. Ready-to-use colloidal solution concentrate. Shelf life is 3 years from the date of manufacture. It is effective in combating

yellow rust, brown rust and powdery mildew of wheat. The efficiency of the fungicide is 98.9-99.3%.

6.4 Fungicide Rauma 490 k.e. 1.25 l/ha

Produced by the Turkish company "Hektas". The composition consists of Propiconazole + Prochlorose. The drug is a mixture of imidazole and triazole groups. It is a fungicide with systemic and translaminar action. When treated with this fungicide, wheat is easily absorbed into the leaves and into the plant through the leaf veins. It is highly effective in the fight against fungal diseases such as yellow rust, brown rust, and powdery mildew. Fungicide can be treated by mixing with foliar feeding suspension preparations of insecticides. Excludes highly alkaline pesticides. The effectiveness of the fungicide is 99.1-99.2%.

6.5 Fungicide Alta Super 40%. k.e. 0.3 l/ha

Produced by "BIO AGROCHEMICALS" LLC, Yashnabod district, Tashkent city. Fungicide contact action. The composition consists of Propiconazole + Tebuconazole. Preparation form colloidal solution concentrate. Among fungal diseases, it is effective in yellow rust, brown rust, powdery mildew, and septoriosis. It is processed from the leaves of the plant. The effectiveness of the fungicide is 83.8-86.7%.

6.5 Fungicide Altus Duo 32.5% 0.3 l/ha

Produced by "BIO AGROCHEMICALS" LLC, Yashnabod district, Tashkent city. Fungicide contact action. The composition consists of Azoxystrobin + Difenoconazole. Preparation form colloidal solution concentrate. It is an effective remedy for yellow rust, brown rust and sptoriosis, which are fungal diseases of wheat leaves. The effectiveness of the fungicide is 83.6-86.2%.

6.5 IFO PZN 3.0 l/ha suspension

Produced in Ifoda company, Namangan region. Suspension contact effector. The composition consists of total nitrogen (N) 3%, total phosphorus (P2O5) 25%, total water-soluble zinc (Zn) 5%, pH 1-3%. Preparation form liquid NP fertilizer. Application provides the necessary energy for biochemical processes in the body of the crop when it is sprayed through the leaf. It accelerates the growth of buds and ensures full and uniform flowering even at low temperatures.

7 Conclusion

In the piedmont regions of the Kashkadarya province, when yellow rust (*Puccinia striiformis*) and powdery mildew (*Erysiphe graminis*) infections were observed in winter soft wheat crops, treatment with AZOTE 320 SC (32% SC) at 0.3 l/ha and Rauma 490 EC at 1.25 l/ha, in combination with IFO PZN at 3.0 l/ha as a suspension, significantly reduced disease incidence. The biological effectiveness of these treatments averaged 98.6–99.1% against yellow rust and 99.0% against powdery mildew.

- Therefore, for effective chemical control of *Puccinia striiformis* (yellow rust) and *Erysiphe graminis* (powdery mildew) in winter soft wheat, the application of AZOTE 320 SC (0.3 l/ha) and Rauma 490 EC (1.25 l/ha) in combination with IFO PZN (3.0 l/ha) suspension is considered a scientifically justified and recommended practice.

- -The field experiments demonstrated that all fungicide + IFO PZN combinations significantly improved biological efficacy compared to fungicide-only treatments.
- However, among the tested variants, AZOTE 320 SC (azoxystrobin + tebuconazole) + IFO PZN (3.0 L/ha) and Rauma 490 EC (propiconazole + difenoconazole) + IFO PZN (3.0 L/ha) provided the highest and most stable protection against Puccinia striiformis (yellow rust) and Blumeria graminis (powdery mildew), reaching up to 99% biological efficiency at 21 days after treatment. From a practical standpoint, these two combinations are most suitable for farmers, because: They combine broad-spectrum systemic fungicides with bioactive suspension, ensuring both curative and protective effects.
- It was found that the incidence of yellow rust (Puccinia striiformis) and powdery mildew (Erysiphe graminis) in winter soft wheat crops in the foothills of the Kashkadarya region was up to 42 and 39.2%, respectively, but due to the treatment with a suspension of AZOTE 320 SC 32% k.s 0.3 l/ha and Rauma 490 k.e 1.25 l/ha fungicides (IFO PZN 3.0 l/ha), the incidence of winter soft wheat decreased to 6.7-5.7% and 6.0-4.0%, respectively, while biological The efficiency indicators were 98.6-99.1% on average in wheat infected with yellow rust diseases, and 99.0% in wheat infected with powdery mildew. Therefore, in the chemical control of yellow rust (Puccinia striiformis) and powdery mildew (Erysiphe graminis) diseases of winter soft wheat in the foothills of the Kashkadarya region, it is advisable to apply a suspension of AZOTE 320 SC 32% k.s. 0.3 l/ha and Rauma 490 k.e. 1.25 l/ha fungicides (IFO PZN 3.0 l/ha).
- Among all tested treatments, AZOTE 320 SC + IFO PZN and Rauma 490 + IFO PZN are identified as the most effective and economically sustainable options for integrated management of yellow rust and powdery mildew in winter wheat.
- These combinations ensure up to 99% disease suppression, reduce chemical load on the environment, and enhance the biological resilience of the crop.
- Therefore, it is recommended that farmers adopt the IFO PZN + fungicide approach as part of a sustainable wheat protection strategy, optimizing both environmental safety and productivity.

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