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Assessment of the resistance of flax varieties to flaxseed rust

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Abstract. The purpose of the work is to identify samples of flax, resistant to one of the most dangerous fungal disease - flax rust. The assessment of resistance to rust of varieties and samples of flax-long-lived (Linum ussitatissimum var. elongata L.) from the "Collection of Russian flax" of the Flax Research Institute (NIIL, Torzhok) was carried out. The experiment was conducted on the field condition in Tver oblast, Russia Federation for three years from 2019 to 2021. All main marks were research with standart methods that was explored in VNIIL in XX century. For the receive most objective results the researchers had made infection conditions with adding to the soil pathogen of flax rust, and to the rich provocative effect was made inoculating by uredospores of the pathogen. Most of the samples showed high resistance to the disease. The greatest degree of resistance to rust (87.5-99,9%) were shown by 4 varieties Fakel (99,4%), Start (97,7%), Rhythm (96,6%), Melina (95,0%) and 3 varieties were shown absolute immunity to flax rust Peresvet (100%), Quartet (100%), Krepish (100%). The identified immune varieties (Peresvet, Quartet, Krepish) are recommended as donors for breeding new rust-resistant flax cultivars.

1 Introduction

Flax (Linum usitatissimum L.) is an important industrial crop cultivated for fiber and oil. Significant damage to flax crops (Linum usitatissimum L. var. elongata) is caused by such fungal diseases as fusarium, rust, pasmo, polysporosis, anthracnose. Conducting breeding for immunity to major diseases allows you to reduce the level of infection. The fact that this is possible is evidenced by the results of the resistance of flax varieties to rust [2].

The causative agent of flax rust is a single-farm specialized phytopathogen Melampsora lini. Currently, it belongs to the Melampsoraceae family, the order Uredinales, the class Urediniomycetes of the Basidiomycota type [7]. The mushroom has a full development cycle consisting of five stages. Infection occurs in conditions of high humidity through the leaves of the plant [3].

Symptoms of the disease are manifested on aboveground organs. Basidia develop on the dead host plant, whose spores infect seedlings. Flax fabrics form pale yellow thickenings, where two types of spring sporulation are laid. First, light brown spots covered with yellow-orange pycnids appear on cotyledons, hypocotyl, and young leaves. Then, on the same organs, yellow-orange echelons form under the epidermal layer, due to which the epidermis later ruptures [4, 10].

Fig. 1. Symptoms of rust (tele-stage).

Fig. 2. Symptoms of rust (uredo-stage).

The most pronounced signs of rust are expressed during budding and flowering. Rusty-orange in color, small, convex pustules with urediniospores are formed on leaves, stems and sepals (Fig. 2). On adult flax plants, black, shiny, dense bodies with spores develop under the epidermal tissue of stems, on petioles, boxes (Fig. 1). This stage is quite harmful, since the crusts the teliospores formed on the stems are poorly separated from the wood, which in turn affects the length and quality of the fiber [5, 6].

The main source of the phytopathogen is infected plant residues. During the growing season, the fungus can produce 4–5 generations of uredinia. The infection is spread by rain, wind, and insects. Later flax crops are more severely affected [8].

The harmfulness of Melampsora lini lies not only in the deterioration of the quality of the fiber, but also leads to a decrease in the yield of seeds, Severe rust damage reduces seed productivity by 90%, fiber weight by 2-3 times, and its quality by 3-9 numbers [9].

Compliance with crop rotation, the use of fertilizers, post-harvest plowing, and the cultivation of resistant varieties are effective measures to prevent flax rust outbreaks [1, 6].

2 Materials and Methods

2.1 Materials

The infectious nursery for rust resistance was located in the experimental farm of VNIIL in the village of Pobeda, Tver Oblast, Russia.

Fig. 3. General view of the infection nursery.

2.2 Characteristics of the studied flax varieties

The study included 19 accessions of long-fibered flax (*Linum usitatissimum* var. elongata) from the «Collection of Russian Flax» of the All-Russian Flax Research Institute (VNIIL, Torzhok). The varieties differed in origin, maturity group, and economic use.

Peresvet, Quartet, and Krepish are varieties of Russian breeding that demonstrated absolute immunity to rust throughout all three years of the study. They are characterized by medium stem height (75–85 cm) and high technical length, which makes them valuable for fiber production.

Fakel, Start, Rhythm, and Melina are highly resistant varieties (resistance 95–99%). Fakel is distinguished by early maturity and uniform ripening. Start also shows increased resistance to fusarium wilt. Rhythm is characterized by high field tolerance to adverse conditions. Melina is a mid-season variety with good stem stand density.

Tomich is a variety that showed variable resistance (from 75% in 2019 to 100% in 2020–2021). This indicates a possible dependence of resistance gene expression on weather conditions.

Accession K-3529* is a collection sample of unknown origin, distinguished by the lowest resistance (76.1%). It can be used as a susceptible control in crosses to study the genetics of resistance.

The remaining varieties (Aley, Borets, Zakaz, Novotorzhskii, Orshanskiy, Surprise, Fenix, Surskiy, B-100, Lirica) are classified as highly resistant (resistance 84–94%). They are of interest as sources of polygenic resistance, which may be more durable compared to monogenic resistance.

To create a more effective infection, each tier bordered with protective strips. On these strips, the susceptible variety Polessky 4 was sown, at the same time, flax straw infected with tele-stage was decomposed along the seedlings. Also, after 10 numbers, susceptible varieties were sown. To increase infection, spraying with uredospores (uredospores mixed with talc in a ratio of 1:10) was carried out. Sowing in an infectious and provocative nursery for rust was carried out at a late date (May 25). 25 seeds were sown in a row of 0.5 m in a triple repetition. Accounting plots were sown with rust-susceptible varieties, on the shoots of which, in cloudy wet weather, tele-spore infectious material was laid out at the rate of 3-4 kg per $100m^2$. To enhance the infectious background, on June 9, seedlings of susceptible flax varieties were inoculated with uredospores mixed with talc (1:20). VNIIL methodology, (2000). Before the start of rapid growth, nitrogen fertilizers were fertilized (0.5-1c/ha). The flax rust infestation was accounted for twice: at the moments of maximum development of the uredostady and tele-stage of the fungus. The development of uredo-stage was taken into account during the flax flowering period with an eye, noting in the whole plot: the absence of uredopustules, weak, medium and strong development of uredopustules. The final assessment of the studied collection samples of flax to rust was carried out after harvesting by tele-stage, counting the number of affected plants and the degree of development of the disease.

During the ocular assessment, accounting was carried out according to a four–point system, where 0 corresponded to a plant that did not have uredopustules, 1 corresponded to plants with a weak manifestation of the disease (usually 1-2 uredopustules), 2 – with an average manifestation of the disease, and 3 corresponded to a plant with a strong manifestation of rust, such plants were completely in uredopustules, and on some of them, teleitopustules have already begun to form due to hot, dry weather.

The evaluation of the manifestation of the tele-stage was carried out according to a five–point system, where 0 corresponded to plants without spots, or with single spots, 1 – plants with no more than 5 spots with an average size of no more than 0.5 cm, 2 - plants with five spots of 1 cm, as well as plants with undeveloped boxes, or plants with covering spots (diameter no more than 1 cm), 3 – plants with a number of one-centimeter spots up to 10 pieces, which also have a lot of small spots and undeveloped boxes, 4 – samples with covering spots of large diameter.

Climatic conditions are of great importance for the development of rust in a field infectious and provocative nursery.

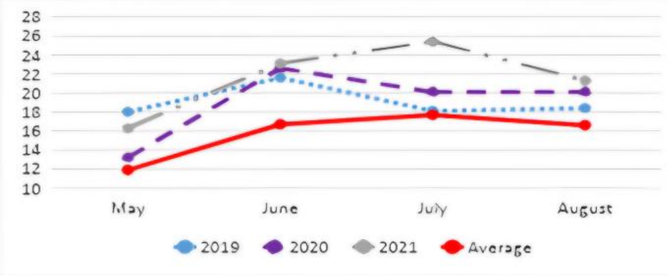

Fig. 4. Average monthly temperatures during the growing season (°C), 2019-2021.

Analysis of temperature conditions. In 2019, average monthly temperatures during the growing season (May–July) ranged from 12.5 to 18.2 °C, which is close to the long-term average. This contributed to moderate pathogen development. In 2020, May was relatively cool (13.2 °C), which slowed the initial development of rust, but June temperatures (16.8 °C) proved optimal for eciospore germination. The hottest was July 2021 (21.5 °C), which led to rapid drying of uredinia and premature transition of the fungus to the telial stage. Such temperature fluctuations made it possible to assess the resistance of varieties under different stress conditions.

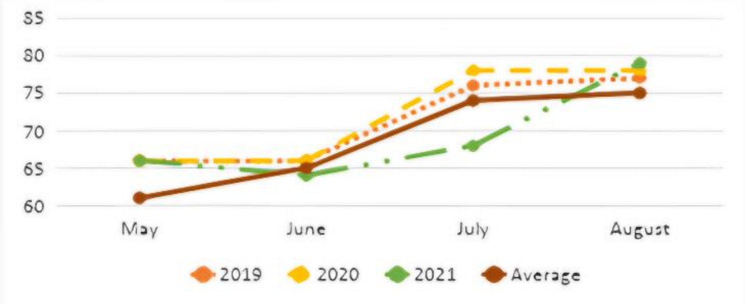

Fig. 5. Average monthly humidity during the growing season (%), 2019-2021.

Analysis of air humidity. Relative air humidity is a critical factor for the development of Melampsora lini, since urediniospores require free moisture for germination. In 2019, average humidity in June–July was 68–74%, creating moderately favorable conditions. In 2020, humidity during the flax flowering period reached 78%, which promoted maximum development of uredinia. The driest was July 2021 (humidity 58–62%), which limited secondary infection and provoked early formation of teliospores. Differences in moisture conditions across years made it possible to identify varieties with stable resistance (Peresvet, Quartet, Krepish) and varieties with unstable resistance (Tomich).

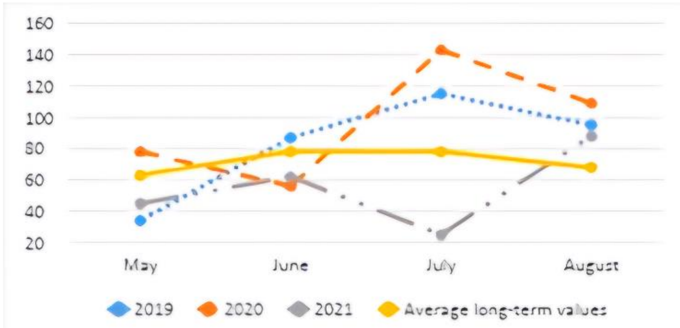

Fig. 6. Average monthly precipitation during the growing seasons (mm).

Analysis of precipitation. The distribution of precipitation varied significantly across years. In 2019, total precipitation for May–July was 210 mm, which is slightly above the norm. This led to uniform pathogen development but without epiphytotic outbreaks. In 2020, the main amount of precipitation (85 mm) fell in the third decade of June, coinciding with the budding phase of flax and causing severe infection on susceptible varieties. In 2021, total precipitation was below average (145 mm), with most of it falling in the first decade of June — specifically, the last three days of that decade. This created a short-term "window" for infection, after which drought set in. Such weather dynamics explain why premature teliospore formation was observed in several varieties in 2021. The greatest stability of resistance under precipitation fluctuations was shown by the varieties Peresvet, Quartet, and Krepish.

The temperature regime and the amount of precipitation in 2019 contributed to the moderate development of the pathogen throughout the growing season. More favorable conditions fell on the second and third decade of June.

In 2020, suitable weather for the formation of the mushroom fell on the period from the third decade of June to the second decade of July. However, in May, a fairly low temperature was observed (13.2 °C), with the optimal for the germination of eciospores +14°C–+16°C. Lowering the air temperature to 12-13 °C slows down the formation and intensity of sporulation.

High temperatures in July 2021 were unfavorable for the causative agent of rust. The pustules of this pathogen dried out quickly and then burned out in the sun. All this provoked the early appearance of teleitopustules on the stems of flax. The amount of precipitation in the same year turned out to be less than the annual average. The main amount of precipitation that fell in the first decade of June fell on the last 3 days of the decade, which had a beneficial effect on the causative agent of rust. The end of June turned out to be wet, which caused a strong manifestation of rust.

3 Results

Mathematical processing of the collected data (from 2019 to 2021) was performed using analysis of variance and is presented in Table 1.

Table 1. Results of flax variety resistance to rust (%), average for 2019-2021.

Variety/Sample	The average degree of resistance to flax rust by repetition, %			Average for 3 years, %
	2019	2020	2021	
Fakel	100	98.1	100	99.4
Aley	93.5	92.8	92.1	92.8
Peresvet	100	100	100	100.0
Tomich	75	100	100	91.7
Borets	82.2	90.5	100	90.9
Zakaz	91.9	90.8	92.2	91.6
Novotorzhskii	96	80	85.4	87.1
Start	95.1	98	100	97.7
Orshanskiy	82.6	81.1	90	84.6
Rhythm	92	97.7	100	96.6
Surprise	93.2	94.1	94.1	93.8
Quartet	100	100	100	100.0
Fenix	88.1	92	85.6	88.6
Surskiy	85.5	98	85.5	89.7
Krepish	100	100	100	100.0
B-100	80.2	90.3	90.3	86.9
Melina	96.4	94.8	93.9	95.0
Lirica	80.6	100	100	93.5
K-3529*	76.8	75.8	75.8	76.1
Standards (Control)				
Alfa (st)	100	100	100	100

Table 1 presents the results of three-year assessments of flax variety resistance to rust. The calculated actual Fisher criterion was 3.15, while the tabular Fisher criterion was 1.8, indicating statistically significant differences between the obtained results. As a result of the conducted studies, it was revealed that in comparison with the standard variety Alfa, most of the studied flax samples have high resistance to this fungal disease.

Specifically, three varieties - Peresvet, Quartet, and Krepish - demonstrated absolute immunity (100% resistance) in all three years. Fakel (99.4%), Start (97.7%), Rhythm (96.6%), and Melina (95.0%) also showed very high resistance. In contrast, accession K-3529* exhibited the lowest resistance (76.1% on average), which is more than 20% lower than the standard.

4 Discussion

Melampsora lini (Ehrenb.) Desm., the causative agent of flax rust, is of interest both economically and scientifically. The pathogen can lead to serious losses in seed yield, as well as to a decrease in fiber quality in plants grown for production. Currently, most flax varieties are only weakly affected by rust. However, plants protected by vertical resistance may gradually lose their resistance to pathogens as new races of the fungus emerge and accumulate.

The results of our study demonstrate that a significant number of the studied varieties and samples show high resistance to rust, with indicators at the level of the standard Alfa variety. Of particular note are the varieties Peresvet, Quartet, and Krepish, which showed absolute immunity (100% resistance) throughout all three years of the study. This indicates the presence of effective resistance genes in their genotypes, capable of withstanding the local pathogen population under varying weather conditions.

The high resistance indicators of the varieties Fakel (99.4%), Start (97.7%), and Rhythm (96.6%) also deserve attention. These varieties showed consistently high results, although not reaching absolute immunity. They can be recommended for inclusion in breeding programs as sources of high rust resistance.

It should be noted that weather conditions during the study years (2019–2021) varied significantly, which affected pathogen development. In 2020 and 2021, conditions were favorable for rust development during certain periods, allowing for a more objective assessment of the resistance of the studied samples. The variety Tomich is indicative in this regard, showing only 75% resistance in 2019 but 100% in 2020 and 2021, which may be related to both weather conditions and the genetic characteristics of the variety's stress response.

The sample K-3529* deserves special attention, showing the lowest resistance among all studied samples (76.1% on average over three years). The resistance level of this sample was more than 20% lower than that of the Alfa standard variety, which allows it to be classified as medium-resistant.This sample may be of interest for studying the mechanisms of susceptibility to the pathogen, as well as for use as a susceptible control in future studies.

The use of highly resistant varieties in production will reduce the virulence of the fungus and its accumulation in nature. Therefore, breeders need to carry out constant observations so that cultivated samples are genetically resistant to all biotypes and rust races. The identified varieties with absolute immunity (Peresvet, Quartet, Krepish) represent the greatest value for further breeding work to create new flax varieties with stable resistance to rust.

Practical implications for flax breeding**.** Based on the results obtained, the following recommendations can be made:

Varieties Peresvet, Quartet, and Krepish should be used as donors of absolute immunity in hybridization programs.

Varieties Fakel, Start, Rhythm, and Melina are recommended as sources of high (but not absolute) resistance, which may be more durable if based on polygenic inheritance.

The susceptible accession K-3529* can serve as a control for infection efficiency in future rust resistance screenings.

Multi-year testing is essential, as the variety Tomich demonstrated that resistance can vary significantly depending on weather conditions.

5 Conclusion

During the study of flax, the most rust resistance was presented by the varieties: Peresvet (100%), Quartet (100%), Krepish (100%). For all three years, they have results at the standard level.

Sample K-3529* (76.1%) had the lowest resistance to the fungal disease and is therefore classified as medium-resistant.

The remaining samples showed high levels of resistance to the pathogen, allowing them to be classified as highly resistant varieties.

The identified immune and highly resistant varieties are recommended for use in breeding programs as sources of resistance to flax rust.

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