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EVALUATION OF UKRAINIAN POTATO VARIETIES AND BREEDING MATERIAL FOR RESISTANCE TO PATHOTYPES OF *SYNCHYTRIUM ENDOBIOTICUM* OCCURRING IN GEORGIA AND UKRAINE

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Aim: To evaluate new Ukrainian potato breeding material for resistance to the common pathotype 1(D1) of the potato wart pathogen *Synchytrium endobioticum*. Furthermore, to re-evaluate during 2021–2023 seventeen Ukrainian potato varieties for the validity of previously determined resistance towards the common pathotype 1(D1), and also to assess resistance to 4 virulent pathotypes present in Ukraine and one virulent pathotype occurring in Georgia. This all to introduce new sources of resistance in Ukrainian breeding programs and to use resistant material (more) effectively in disease foci in the respective countries. **Materials and Methods:** In our present study 971 samples of potato breeding material were used in the first year of laboratory testing and 306 samples in the second year. The breeding material used originated from of the Institute of Potato Research of the NAAS of Ukraine (IPR NAAS), and its Polissia Experimental Department (PED). Seventeen Ukrainian potato varieties (**Table 3**) were used for field studies to validate the earlier assessment of resistance to *S. endobioticum* common pathotype 1(D1), and to evaluate resistance to virulent pathotypes present in Ukraine (11(M1), 13(R2), 18(Ya), 22(B1)), and one virulent pathotype found in Georgia (38(N1)). The resistance to the potato wart pathogen was assessed under laboratory conditions against an artificial infectious background, using winter and summer zoospores for the breeding material and a natural infectious background in some foci of the pathogen in Ukraine and Georgia, according to EPPO Standard PM 7/28(2) and the national methodology harmonized with the EU requirements. **Results:** Resistance to winter zoospores of the common pathotype 1(D1) was determined in 949 out of 971 samples (97.7%) in the first year of testing and in 300 out of 306 samples (98%) in the second year, using summer zoospores. Resistance to 11(M1) was present in 14 varieties (82.4%): Alians, Glazurna, Khor-

tytsia, Podolianka, Rodynna, Shchedryk, Skarbnytsia, Slauta, Slovianka, Solokha, Strumok, Tyras, Vzirets, and Zhytnytsia. Resistance to 13(R2) was also present in 13 varieties (76.5 %): Alians, Aria, Glazurna, Khortytsia, Kniahynia, Rodynna, Shchedryk, Skarbnytsia, Slauta, Solokha, Strumok, Tyras, and Vzirets. Resistance to 18 (Ya) was present in 8 varieties (47.1 %): Aria, Glazurna, Kniahynia, Rodynna, Skarbnytsia, Slauta, Vzirets, and Zhytnytsia. Resistance to 22(B1) was found in 12 varieties (70.6 %): Alians, Charunka, Glazurna, Khortytsia, Kniahynia, Rodynna, Shchedryk, Solokha, Strumok, Tyras, Vzirets, and Zhytnytsia. The most virulent pathotype was found to be 38(N1), re-confirming unpublished results of the authors. Only two varieties (11.8 %), Kniahynia and Rodynna, were resistant to this pathotype, proving the need for enhanced detection and breeding work to determine the distribution of this pathotype and to adequately control it, once found. The variety Polisska Rozheva, used as a susceptible control, was affected by all pathotypes, which confirms its high susceptibility to the pathogen. **Conclusions:** In an evaluation for resistance of new Ukrainian breeding material against the common pathotype 1(D1) of *S. endobioticum*, c. 98% was found to be resistant, when subjected to inoculation with winter, as well as summer spores. Potato varieties that are resistant to one or more pathotypes can be recommended to be used in foci where the occurrence of that pathotype or those pathotypes is known. In case of not fully tested foci, the planting of varieties Glazurna (resistant to all 5 pathotype known to occur in Ukraine, but sensitive to pathotype 38(N1), till now only reported to be established in Turkey, Bulgaria and Georgia) or Rodynna (resistant to all six tested pathotypes) should be enforced. The data on resistance of our testing can be used in further breeding programs. Finally, it is strongly recommended that molecular methods such as marker assisted selection and microsatellite diagnostics are incorporated in Ukrainian and Georgian breeding activities.

Key words: potato wart disease, aggressiveness, virulence, field tests

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INTRODUCTION

Synchytrium endobioticum (Schilb.) Perc. is a biotrophic, chytrid soil-based fungal pathogen causing potato wart disease. It is believed that this pathogen originated in Andes region of South America, where it evolved along with its solanaceous host plants (van de Vossen et al., 2022). At present, *S. endobioticum* is classified as a quarantine organism in 31 countries, reported from all continents where potato is grown, and deemed to be one of the most dangerous pathogens, infecting this crop (EPPO, 2024).

The legislative provisions, including strict phytosanitary control, prohibition to grow susceptible potato varieties on infected soils for a long time (longer than 20 years) and wider introduction of resistant varieties, made elimination of *S. endobioticum* in some regions possible (Langerfeld et al., 1994; Fiers et al., 2012; EPPO 2017a, b, c, 2021; EFSA, 2018). However, even such a long prohibition period may be insufficient to solve the problem completely. An example is Prince Edward Island (Canada), where this pathogen was first detected in 2000, causing an economic loss of \$30 million already during the first year after the introduction of the regulatory measures (Franc, 2007). It took many years, considerable efforts, further resources, and personnel to solve the problem and minimize the impact of the disease. Despite the introduction of all measures the pathogen was detected again in 2021 on two farms and in

2022 on one farm (Canadian Food Inspection Agency, CFIA, 2022, 2023a and b).

However, even if the source of the wart outbreak is considered to be eliminated, new outbreaks can happen again. For instance, it is probable that *S. endobioticum* which first appeared in the province of Groningen, the Netherlands in 1907 was eliminated by 1970, but it re-appeared in this province again in 1973 (Baayen et al., 2006; EFSA, 2018). In Denmark, *S. endobioticum* spread from the end of the 19th century till the 1950s. The eradication of its foci was declared in 1989, yet new outbreaks of the disease were registered in 2014 and 2016 (EPPO, 2014; Nielsen, 2017; EFSA, 2018; van de Vossen et al., 2022).

A combination of factors makes elimination of foci very difficult, including the absence of efficient chemical or physical methods to destroy the inoculum in the soil. Chemical control of potato wart has been studied worldwide for over 70 years. Yet even now, the chemical methods are unreliable, and/or toxic to the environment, and prohibited in many regions, including the EU (Obidiegwu et al., 2014; EFSA, 2018). Other factors include the resistance of winter sporangia of *S. endobioticum* to high temperatures, microbial antagonism and competition, their uneven localization in the soil, and difficulties in determining their viability. In addition, the insufficient sensitivity of classical and modern molecular methods compli-

cates the early detection of low levels of inoculum and (new) pathotypes in soil (EFSA, 2018). It may lead to the accumulation of a hidden initial population, since, as Przetakiewicz (2015a) demonstrated, under favourable conditions the relapse of the disease may occur even from one winter sporangium 43 years later. Laidlaw (1985) reported that winter sporangia preserved their viability in soil even for 71 years. At present, the only efficient approach to disease control and prevention of further distribution of the pathogen is the early detection and identification of pathotypes of *S. endobioticum* and furthermore implementation of strict phytosanitary and regulatory measures, along with the cultivation of potato varieties, resistant to pathotype(s) of the pathogen, present in the infected fields (EFSA, 2018; EPPO, 2017b and c; EU, 2022).

The measures and requirements mentioned above are conditioned by the ability of the pathogen to form new pathotypes, capable of breaking varietal resistance (Przetakiewicz, 2015a; van de Vossenberg et al., 2022). Thus, the knowledge about this aspect is extremely relevant for an accurate selection of resistant potato varieties to prevent the further spreading of potato wart in a specific area (EFSA, 2018). Only one pathotype of *S. endobioticum* was present in the European fields at the start of the introduction of the pathogen into Europe in the 1880s, namely 1(D1). Although the use of resistant potato varieties has achieved a good level of control of the pathogen, since 1941, new, more virulent pathotypes have emerged that have proven to be much more difficult to control and eradicate than the original pathotype 1(D1) (Baayen et al., 2006, van de Vossenberg et al., 2022). Already in the 1980s some 17 pathotypes were described in Central Europe (Bojnansky, 1984), while globally, more than 40 pathotypes have been recognized in recent years. The most common method is the determination of pathotypes by the virulence of *S. endobioticum* on a set of differentiating potato varieties (Przetakiewicz, 2017; EFSA, 2018; van de Vossenberg et al., 2022 and 2024). Among the latest described pathotypes are 38(N1) (Nevşehir), found for the first time in Turkey in 2009 (and also later reported from Bulgaria Georgia and the Netherlands), 39(P1) from Poland and 40(BN1) and 41(P2) from Poland and Sweden (Çakır et al., 2009; Przetakiewicz, 2015b; Boberg & Björklund, 2018; Sikharulidze et al., 2019, Ghoghoberidze et al., 2020; van de Vossenberg, 2022). Among all the detected patho-

types, currently the most relevant ones in the region from the standpoint of harmfulness are pathotypes 1(D1), 2(G1), 6(O1), 8(F1) and 18(T1) according to the European classification system (Van de Vossenberg et al., 2022).

In Ukraine, potato wart was first detected in 1938 (Melnik, 2003). The peak of the disease spreading was registered in 1996, when it was detected in 19 regions, 110 districts, 1,674 settlements, 86,434 household land plots, in total 12,134 ha (Melnik, 2003). In recent years, the area of potato wart foci decreased considerably, and as of January 01, 2025, the disease was spread in 5 regions, 14 districts, 204 settlements, 7,794 household land plots, on the total area of 2,313.41 ha. The highest density of potato wart foci and its virulent forms is in the Carpathian region of Ukraine (Review of quarantine pests spread in Ukraine as of 01.01.2025. <https://dpss.gov.ua/fitosanitariya-kontrol-u-sferinasinnictva-ta-rozsadnictva/fitosanitarnij-kontrol/oglyad-poshirennya-karantinnih-organizmiv-v-ukrayini>. Last retrieved April 2025, in Ukrainian).

The presence and diversity of potato wart pathotypes is documented in Ukraine since 1961. While in 1988 seven pathotypes were identified (Saltykova, 1988), since 2003, only five pathotypes are found in the mountainous regions of Ukraine: the common pathotype 1(D1) and four virulent pathotypes, which were classified in a system deviating from the usual European classification system as: 11(M1) (detected in the village of Maidan, Khust district), 13(R2) (the town of Rakhiv, Transcarpathian region), 18(Ya) (the village of Yasinia, Rakhiv district, Transcarpathian region) and 22(B1) (the village of Bystrets, Verkhovyna district, Ivano-Frankivsk region) (Melnik, 2003). Virulent pathotypes, common in the Carpathian region, can affect up to 90% of potato varieties resistant to the common pathotype, so the selection of potato varieties with comprehensive resistance to all pathotypes of the wart pathogen present in the country is an important continuous task.

For more than 85 years, the Ukrainian Scientific Research Plant Quarantine Station of the Institute of Plant Protection of the NAAS of Ukraine has been working on the evaluation and selection of newly developed potato varieties and hybrids resistant to common and virulent pathotypes of the wart pathogen. The results of this evaluation are sent annually to the Ukrainian Institute for Plant Variety Examination in Kyiv for inclusion in the State Register of Plant Varieties Suitable for Spreading in Ukraine.

As of 2024, the State Register of Ukraine includes 200 potato varieties, of which 95 are Ukrainian bred and resistant to pathotype 1(D1) of *S. endobioticum* (State Register of Plant Varieties Suitable for Spreading in Ukraine, see <https://minagro.gov.ua/file-storage/reyestr-sortiv-roslin>). After registration, new resistant potato varieties are proposed for introduction in the country's wart foci.

The aims of this joint Ukrainian-Georgian study were 1) to evaluate new potato breeding material for resistance to the common pathotype 1(D1) of *S. endobioticum* and 2) to (re)-evaluate seventeen Ukrainian potato varieties for the validity of the previously determined resistance to the five pathotypes common in Ukraine and the virulent pathotype 38(N1), occurring in Georgia (Ghoghoberidze et al., 2020) for further use in the breeding process as sources of resistance to the potato wart pathogen and their effective use in the control of disease outbreaks in both Ukraine and Georgia.

MATERIALS AND METHODS

Plant material. The study involved breeding material and potato varieties of the Institute of Potato Research of NAAS (IPR NAAS), and its Polissia Experimental Department (PED): 971 potato samples for the first year of laboratory testing, and 306 samples for the second year of laboratory testing.

Seventeen Ukrainian potato varieties, viz. Alians, Aria, Charunka, Glazurna, Khortytsia, Kniahynia, Podolianka, Rodynna, Shchedryk, Skarbnytsia, Slauta, Slovianka, Solokha, Strumok, Tyras, Vzirets and Zhytnytsia, were used in field studies to validate the evaluation of the resistance to potato wart pathotypes, common for Ukraine and Georgia as determined in the year prior to the registration of these varieties and repeated at least every 5 years.

Location of laboratory and field experiments. Laboratory testing was conducted at the Ukrainian Scientific Research Plant Quarantine Station of the Institute of Plant Protection, the NAAS (UkrSRPQS, the IPP NAAS, the village of Boyany, Chernivtsi district, Chernivtsi Region) and the Transcarpathian base of the UkrSRPQS, the IPP NAAS (the village of Maidan, Khust district, Transcarpathian Region).

Field experiments were conducted in the following pathogen foci:

in Ukraine:

- 1) Berehomet (Vyzhnytsia district, Chernivtsi region) — common pathotype 1(D1);

- 2) Maidan (Khust district, Transcarpathian Region) — pathotype 11(M1), Mizhhirsky;
- 3) Rakhiv (Rakhiv district, Transcarpathian region) — pathotype 13(R1), Rakhivsky;
- 4) Yasinia (Rakhiv district, Transcarpathian region) — pathotype 18(Ya), Yasinivsky;
- 5) Bystrets (Verkhovyna district, Ivano-Frankivsk region) — pathotype 22(B1), Bystretsky;

and in Georgia:

- 1) Khulo (municipality, Adjara) — pathotype 38(N1), Nevshir.

The studies were performed within the framework of the Agreement of creative cooperation between UkrSRPQS, the IPP NAAS (Ukraine), and the Institute of Phytopathology and Biodiversity of the Shota Rustaveli Batumi State University (Georgia) in 2019–2024.

Methodology used for the evaluation of Ukrainian potato breeding material for resistance to *S. endobioticum*. The breeding material was tested for resistance to the common pathotype 1(D1) using artificial inoculation according to the Ukrainian Method of evaluating and selecting the breeding material of potato, resistant to wart *Synchytrium endobioticum* (Schilb.) Perc., which is harmonized with the requirements of the EU and is also taking EPPO Standard PM 7/28(2) (EPPO, 2017b) into account (Zelya et al., 2015; EU, 2022). The variety Glazurna, resistant to all five pathotypes of potato wart tested and found in Ukraine, served as resistant control and the variety Polisska Rozheva, susceptible to those pathotypes, as susceptible control. Each experiment was performed in triplicate.

1. *First year laboratory testing (inoculation of potato tuber sprouts with winter zoospores of zoosporangia of pathotype 1(D1)).*

Potato samples (5 tubers per sample, also for the controls) were artificially inoculated with winter zoosporangia distributed at a level of 50–60 zoosporangia per g of substrate (see below) under laboratory conditions, in specially prepared containers of 30×40 cm. The containers were filled with substrate, consisting of soil and perlite, in the 1:1 ratio. The containers were kept for 75 days under the following conditions: substrate humidity 80%; illumination 1600 lux, with a 12h/12h light/darkness regime; temperature 17–18 °C. The containers were watered every three days. After 75 days, the response of the potato samples to the infection was evaluated by inspecting sprouts,

tubers, stolons, and stems of each sample and the number of warts determined. The results were deemed reliable if score 4 or 5 of susceptible reactions were observed on the susceptible control on at least 80% tubers (Zelya, 2015).

2. *Second year laboratory testing (inoculation of potato tuber sprouts with summer zoospores from fresh warts, pathotype 1(D1)).*

A paper ring, fixed with a mixture of paraffin and vaseline in the 1:1 ratio, was attached around the sprout part of the potato tubers. Distilled water was poured into the ring with the addition of 0.5 cm³ of fresh wart, containing summer zoospores (**Fig. 1**). To stimulate the infection, samples were incubated in the thermostat at 11 °C and a relative humidity (RH) of 80% for 48 h. Subsequently incubation was continued in a climatic chamber at 17–18 °C and RH of 80% for 28 days without any illumination. The results were deemed reliable if score 4 or 5 (as defined in the following paragraph) of susceptible reactions were observed on the susceptible control on at least 80% tubers (Zelya et al, 2015).

3. *Evaluation of resistance to six different pathotypes of *S. endobioticum* of 17 Ukrainian potato varieties under field conditions (2021–2023).*

The validation of earlier determined resistance to *S. endobioticum* of 17 Ukrainian potato varieties included in the State Register of Plant Varieties Suitable for Spreading in Ukraine was carried out according to the government requirements (Regulations, 1993; Zelya et al., 2015) where it is recommended to do this validation every 5 years. The present validation was



Fig. 1. Inoculation of potato breeding material with summer zoospores from fresh warts of *Synchytrium endobioticum*

performed under field conditions, in existing foci of the common pathotype 1(D1) of *S. endobioticum* in Ukraine. Field evaluation of resistance towards the four virulent pathotypes present in Ukraine and one virulent pathotype occurring in Georgia was conducted in the existing foci in both countries (see under *Location of laboratory and field experiments*).

For each variety, 10 tubers were planted at a depth of 30 cm and with a row spacing of 70 cm, in triplicate, in a randomized plot. Variety Polisska Rozheva, susceptible to all 6 pathotypes, was used as susceptible control, and variety Glazurna, resistant to all known virulent pathotypes occurring in Ukraine, served as resistance control. Herbicides were applied before and after potato sprouting, where applicable in a tank mixture with growth regulators, fungicides and trace elements; potato crops were 1–2 times treated against the Colorado potato beetle; up to five applications of fungicides and foliar fertilization were given at an average interval of 7–10 days. The degree of plant resistance to *S. endobioticum* was determined on the 75th day after planting by digging potato bushes and examining each stem, stolon, and tuber per sample.

The response of potato samples after being infected with *S. endobioticum* was determined visually using the following scale (EPPO, 2020):

- Score 1, type R1: extremely resistant (total necrotized tissue);
- Score 2, type R1: resistant variety/variety sample (necrotized tissue);

NB: In our study score 1 and 2 are combined for reasons of practicability to the trade in the final evaluation table (Table 3)

- Score 3, type R2: weakly resistant (rare soruses, necrosis);
- Score 4, type S1: susceptible (dense soruses with the deformation of a potato sprout);
- Score 5, type S2: very susceptible (sprout deformation, wart growth (**Fig. 4**)).

Potato sprouts were analysed under a microscope (10×15 magnification), BioLight 300 (DELTA optical, Poland).

Meteorological characteristics of the growing seasons 2021–2023. During the potato growing season in 2021–2023, generally favourable meteorological conditions for the development of both potatoes

and the pathogen were observed in the foci of wart in the Chernivtsi, Ivano-Frankivsk, and Transcarpathian regions of Ukraine and in the municipality of Khulo (Adjara, Georgia). In particular, in the Chernivtsi region, during the growing seasons of 2021–2023, temperature conditions and precipitation had slight deviations from the norm. In 2021, temperature in May was 0.9 °C below normal, which could have reduced possibility of infection of sprouts with zoospores. In general, however, in 2021–2023, the weather conditions in the Chernivtsi region did not have any critical impact on the development of potatoes or pathogen. The optimal conditions for infecting the potato with wart pathogen were in June 2021. In the Carpathian region of Ukraine (Ivano-Frankivsk and Transcarpathian regions) in 2021–2023 temperature deviations and the distribution of precipitation impacted the development of potato and the pathogen, but not considerably. Although there was a deficit of precipitation in April–May 2022, it did not create irreversible consequences due to a sufficient amount of precipitation in June–July in the other years.

In the Khulo municipality (Adjara, Georgia) in 2021–2023 temperature deviations from the norm were insignificant, whereas the distribution of the precipitation varied considerably in these years, impacting the accessibility of moisture for plants. The temperature in March was close to the norm with minimal deviations: +0.4 °C in 2021, –0.1 °C in 2022 and in correspondence with the norm in 2023. The precipitation was considerably below the norm in all three years: 52.4% in 2021, 73.8% in 2022, and only 36.5% in 2023, which created a moisture deficit in the soil for the initial growth of the potatoes. The temperature in May had negative deviations in all three years: –0.4 °C in 2021, –0.5 °C in 2022, and –1.0 °C in 2023. In all in 2021–2023, the weather conditions in the Khulo municipality had insignificant temperature deviations, which did not create critical hindrances for potato development. However, a con-

siderable deficit of precipitation, especially in March–June 2021 and 2022, could have a negative effect on the moisture provision for plants, creating stressful conditions for their vegetation. In 2023, the amount of precipitation was higher, which ensured better conditions for growth. Since the vegetation period of potato development in Georgia lasts only from March to July, optimal weather conditions for the infecting of mid-ripe potato varieties by wart pathogens were observed in April. In 2023, the air temperature was within 12.3–13.0 °C, and the amount of precipitation was 88 mm (79.3%), which was favourable for the infecting of potatoes with the pathogen and for the disease development.

In Ukraine, in the wart foci of the Carpathian region, the vegetation period of potato development lasts from April to August, and the optimal conditions for infecting the potato with the pathogen were in May–June. The air temperature varied within 13.3–19.1 °C, and the precipitation amount in June was on average 95 mm (102%).

In conclusion: Although the weather conditions in the mountainous areas of Ukraine and Georgia are different, rapid fluctuations in daily temperatures (day — 19.1 °C, night — 4.3 °C) and high air humidity in the mountainous areas were generally favourable for the development of wart pathogen during the study period.

RESULTS

1. *First year laboratory testing (inoculation of potato tuber sprouts with winter zoospores of zoosporangia of pathotype 1 (D1).*

In the preliminary test for resistance to the common pathotype 1(D1) of the potato wart pathogens, 223 samples of IPR NAAS out of 225 (99.1%) were found to be resistant, while 726 samples of PED out of 746 (97.3%) were found to be resistant (**Table 1**). Resistance was at the level of score 1 and 2 (R1) as indicated and explained in the next paragraph. The

Table 1. Results of first year of laboratory testing of Ukrainian breeding material in 2021–2023 using inoculation of sprouts with winter zoospores of pathotype 1(D1)

Breeding institute	Number of samples	Resistant Number of samples and (%)	Susceptible Number of samples and (%)
Institute of Potato Research, the NAAS (IPR NAAS)	225	223 (99.1%)	2 (0.9%)
Polissia Experimental Department, the IPR NAAS (PED)	746	726 (97.3%)	20 (2.7%)
Total number of samples	971	949 (97.7%)	22 (2.3%)

Table 2. Results of the second year of laboratory tests of Ukrainian breeding material in 2021–2023, using inoculation of sprouts with summer zoospores of fresh warts, infected with pathotype 1(D1)

Breeding institute	Number of samples	R1 extremely resistant	R1 resistant	R2 weakly resistant	S1 susceptible	S2 very susceptible
		Number and (%)				
Institute of Potato Research, the NAAS (IPR NAAS)	80	63 (78.8)	14 (17.5)	2 (2.5)	1 (1.2)	0
Polissia Experimental Department, IPR NAAS (PED)	226	162 (71.7)	49 (21.7)	10 (4.4)	5 (2.2)	0
Total number of samples	306	225 (73.5)	63 (20.6)	12 (3.9)	6 (1.9)	0

weakly resistant and non-resistant material was rejected for further breeding, the resistant material continued to be evaluated for degree of resistance, see below.

2. *Second year laboratory testing (inoculation of potato tuber sprouts with summer zoospores from fresh warts, with pathotype 1(D1)).*

Results of the second year of laboratory testing, using inoculation with summer zoospores from fresh warts, are represented in **Table 2**. Some 63 out of 80 IPR NAAS bred potato samples (78.8%) with the highest resistance degree (R1, extremely-resistant) were identified; 14 (17.5%) with a high resistance degree (R1, resistant); 2 (2.5%) with a poor resistance degree (R2, weakly resistant). Some 162 (71.7%) out of 225 PED bred potato samples with the highest resistance degree (R1, extremely-resistant) were iden-

tified; 49 (21.7%) — with a high resistance degree (R1, resistant); 10 (4.4%) with a poor resistance degree (R2, weakly resistant).

The overall testing resulted in finding 225 out of 306 (73.5%) samples of breeding material with the highest resistance degree (R1, extremely-resistant); 63 (20.6%), with a high resistance (R1, resistant); and 12 (3.9%) with poor resistance (R2, weakly resistant). Six (1.9%) potato samples were identified as susceptible (and no one as very susceptible), and rejected from further research. The test results were passed on to breeders to 1) be evaluated for economic valuable traits and 2) to breed from this material varieties, which can be included for further state evaluations for resistance to *S. endobioticum* in the field. It should be noted that, based on the results of this present work, only 23 potato samples (9 bred by the IPR NAAS and 14 bred by PED) were selected on the basis of the combination of sufficient valuable traits and passing the official state testing for resistance to *S. endobioticum* in 2021–2023. These resistant lines can be further developed into commercially available varieties (Zelya et al., 2023).

3. *Evaluation of resistance to six different pathotypes of *S. endobioticum* of 17 Ukrainian potato varieties under field conditions (2021–2023).*

3.1. Re-evaluation and validation of earlier determined resistance to the common pathotype 1(D1) of *S. endobioticum*. The field testing, conducted in foci of *S. endobioticum* in Ukraine, confirmed the validity of resistance to the common pathotype 1(D1) for all 17 varieties tested (**Fig. 2**).

3.2. Evaluation of the resistance to five virulent pathotypes of *S. endobioticum*. Out of seventeen potato varieties tested, fourteen (82.4%) were identified as resistant to the virulent pathotype 11(M1), Mizh-hirsky: Alians, Glazurna, Khortytsia, Podolianka,

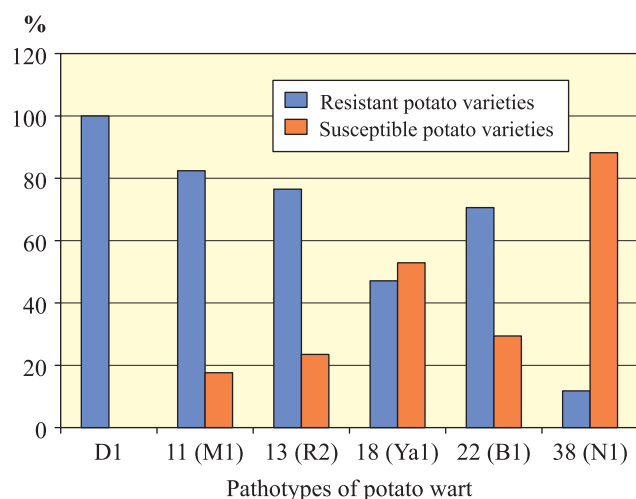


Fig. 2. Results of (re-)evaluation of 17 Ukrainian potato varieties for resistance to the common pathotype 1(D1) and four virulent pathotypes occurring in Ukraine and one virulent pathotype occurring in Georgia under natural infection conditions in five foci in Ukraine and one focus in Georgia

Rodynna, Shchedryk, Skarbnytsia, Slauta, Slovianka, Solokha, Strumok, Tyras, Vzirets and Zhytnytsia (**Table 3**). Varieties Aria, Charunka and Kniahynia were susceptible.

Thirteen potato varieties (76,5%) were resistance to pathotype 13(R2), Rakhivsky: Alians, Aria, Glazurna, Khortytsia, Kniahynia, Rodynna, Shchedryk, Skarbnytsia, Slauta, Solokha, Strumok, Tyras and Vzirets. Varieties Charunka, Podolianka, Slovianka and Zhytnytsia were susceptible. Eight varieties (47%) were resistant to the virulent pathotype 18(Ya), Yasinivsky: Aria, Glazurna, Kniahynia, Rodynna, Skarbnytsia, Slauta, Vzirets and Zhytnytsia. Nine other varieties were found to be susceptible (see **Table 3**). Twelve

potato varieties (70.6%) were resistant to the virulent pathotype 22(B1), Bystretsky: Alians, Charunka, Glazurna, Khortytsia, Kniahynia, Rodynna, Shchedryk, Solokha, Strumok, Tyras, Vzirets and Zhytnytsia. Five varieties namely Aria, Podolianka, Skarbnytsia, Slauta and Slovianka were susceptible. Only two varieties (11.8%) out of 17 tested ones were resistant to pathotype 38 (N1), Nevşehir: Kniahynia and Rodynna. The remaining 15 varieties (88.2%) were susceptible. The susceptible control, variety Polisska Rozheva demonstrated 100% infection with pathotype 38(N1), which confirmed its high susceptibility to this virulent pathotype, which is not present in Ukraine yet as far as known (**Table 3**).

Table 3. Response of 17 Ukrainian potato varieties exposed to the common pathotype 1(D1), four Ukrainian pathotypes and one Georgian pathotype of *S. endobioticum*

No.	Variety	Year of entry into the National Register	Pathotype <i>S. endobioticum</i>					
			1(D1) (common)	11(M1) (Mizhhirsky)	13(R2) (Rakhivsky)	18(Ya) (Yasinivsky)	22(B1) (Bystretsky)	38(N1) (Nevşehir)
1	Alians	2020	(R1)	(R1)	(R1)	(S1)	(R1)	(S1)
2	Aria	2014	(R1)	(S1)	(R1)	(R1)	(S1)	(S1)
3	Charunka	2010	(R1)	(S1)	(S1)	(S1)	(R1)	(S1)
4	Glazurna	2020	(R1)	(R1)	(R1)	(R1)	(R1)	(S1)
5	Khortytsia	2018	(R1)	(R1)	(R1)	(S1)	(R1)	(S1)
6	Kniahynia	2018	(R1)	(S1)	(R1)	(R1)	(R1)	(R1)
7	Podolianka	2006	(R1)	(R2)	(S1)	(S1)	(S1)	(S1)
8	Rodynna	2020	(R1)	(R1)	(R1)	(R1)	(R1)	(R1)
9	Shchedryk	2011	(R1)	(R1)	(R1)	(S1)	(R1)	
10	Skarbnytsia	2006	(R1)	(R1)	(R1)	(R1)	(S1)	(S1)
11	Slauta	2016	(R1)	(R1)	(R1)	(R1)	(S1)	(S1)
12	Slovianka	1999	(R1)	(R1)	(S1)	(S1)	(S1)	(S1)
13	Solokha	2016	(R1)	(R1)	(R1)	(S1)	(R1)	(S1)
14	Strumok	2013	(R1)	(R1)	(R1)	(S1)	(R1)	(S1)
15	Tyras	2004	(R1)	(R1)	(R1)	(S1)	(R1)	(S1)
16	Vzirets	2014	(R1)	(R1)	(R1)	(R1)	(R1)	(S1)
17	Zhytnytsia	2017	(R1)	(R1)	(S1)	(R1)	(R1)	(S1)
Total resistant, no			17/0	14/3	13/4	8/9	12/5	2/15
Total resistant, %			100	82.4	76.5	47.1	70.6	11.8
Polisska Rozheva (susceptible control)			(S2)	(S2)	(S2)	(S2)	(S2)	(S2)

Table 4. General characteristics of 17 Ukrainian potato varieties and resistance to the 6 pathotypes of *S. endobioticum* tested in this study

Variety and number of pathotypes to which it has resistance	Institute and year of introduction IPR NAAS, PED	Crossing (line/variety)	Ripeness E, M, L*	Purpose T, I, S**	Colour skin P, R, W, Y***	Colour flesh C, P, V, W#	Colour flowers P, R, RV, W##	Pathotype resistance 1, 11, 13, 18, 22, 38 (also see Table 3)	Starch content	Yield, t/ha	Recommendation cultivation zone P, FS, S###
Alians 4	PED, 2020	02.49/146 / 00.31./26	M	T	R	C	RV	1, 11, 13, 22	15.5	38	P, FS, S
Aria 3	IPR, 2014	Delikat/Tyras	M	T	P	C	RV	1, 18	15.3	47	P, FS
Charunka 2	PED, 2014	H.95. 256-3/ Tyras	E	T	Y	C	W	1, 22	12.5	42	P, FS, S
Glazurna 5	IPR, 2010	Horlytsia/ Dobrochyn	E	T	P	C	RV	1, 11, 13, 18, 22	15.3	47	P, S
Khortytsia 4	IPR, 2020	Umo 101117/ Santarka	L	T	R	P	RV	1, 11, 13, 18	19	37	P, FS
Kniahynia (4+1)	IPR, 2018	Slovianka/ Bellarossa	M	T	P	C	R	1, 13, 18, 22, 38	11.4	52	P, FS, S
Podolianka (2)	IPR, 2006	Ausonia/ 88.1439s6	M	T	W	C	W	1, 11	15	37	P, FS, S
Rodynna (5+1)	IPR, 2020	Viryneya/ Mylovytsia	M	T	R	C	R	1, 11, 13, 18, 22, 38	13.4	48	P, FS, S
Shchedryk (4)	IPR, 2006	85.2391s12/ Bahriana	E	T	W	C	W	1, 11, 13, 22	15.4	60	P, FS, S
Skarbnytsia (4)	IPR, 2006	77.583/16/ Liu	E	T	W	C	W	1, 11, 13, 18	13	33	P, FS, S
Slauta (4)	IPR, 2016	Slovianka/ Dina	M	T	W	W	W	1, 11, 13, 18	13.4	38	P, FS, S
Slovianka (2)	IPR, 1999	KE 78.5053/ Kondor	M	T	V	V	RV	1, 11	13	50	P, FS, S
Solokha (4)	IPR, 2016	Umo 101117/ Tyras	L	T	V	V	RV	1, 11, 13, 22	19.2	44	P, FS
Strumok (4)	IPR, 2013	92.306/3/ Tyras	M	T	P	W	P	1, 11, 13, 22	15.4	46	P, FS, S
Tyras (4)	PED, 2004	88.95-5/ 88.12-17	E	T	P	W	P	1, 11, 13, 22	14.4	42	P, FS
Vzirets (5)	PED, 2017	Kuroda/ Santarka	E	T	W	W	W	1, 11, 13, 18, 22	17	49	P, FS, S
Zhytnytsia (4)	IPR, 2018	Zdabytok/ Santarka	E	T	P	C	R	1, 11, 18, 22	15	52	P, FS, S

IPR = Institute of Potato Research; PED = Polissia Experimental Department; * E = early, M = medium, L = late; ** T = trade, I = industry, S = starch; *** P = pink, R = red, W = white, Y = yellow; # C = cream, P = pink, V = violet, W = white; ## P = pink, R = red, RV = red-violet, W = white; ### P = Polyssia, FS = forest steppe, S = steppe.



Fig. 3. The susceptible control, potato variety Polisska rozheva, affected by zoospores of the wart pathogen *Synchytrium endobioticum* pathotype 1(D1)

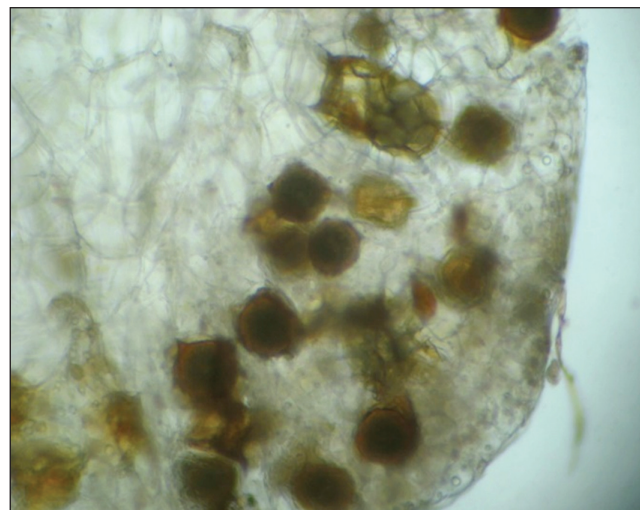


Fig. 4. The tip of a sprout of the susceptible control, variety Polisska Rozheva, affected by summer zoospores of the wart pathogen *Synchytrium endobioticum* pathotype 1(D1) (150× magnification)

Only one variety, Rodynna, was found to be resistant to all five virulent pathotypes of potato wart pathogen. Three varieties (Glazurna, Kniahynia, Vzirets) were resistant to four virulent pathotypes (where Kniahynia apart from Rodynna was the only one to have resistance against 38(N1). Nine varieties (Alians, Khortytsia, Shchedryk, Skarbnytsia, Slauta, Solokha, Strumok, Tyras, and Zhytnytsia) were resistant to three virulent pathotypes. Only one variety, Aria, was resistant to two virulent pathotypes and three varieties (Charunka, Podolianka, Slovianka) were resistant to only one virulent pathotype. For the exact pathotypes to which each of the 17 varieties is resistant, see **Tables 3** and **4**.

In the variety validation tests using all six pathotypes, infection of the susceptible control, the fully susceptible variety Polisska Rozheva, was 100%, accompanied by the presence of zoosporangia on the tip of the sprouts, observed under a microscope with 150-fold magnification (**Fig. 3** and **4**).

DISCUSSION

Some 97.7% of the breeding material tested this time showed resistance to *S. endobioticum* common pathotype 1 (D1) in the first year of testing. These data indicate and reconfirm the high efficiency of the breeding program of the Institute of Potato Research, the NAAS (IPR NAAS), and its Polissia Experimental Department (PED) (Zeleya et al., 2022, 2024). In the second year of laboratory tests, 73.5% of the

306 samples tested showed extreme-resistance (R1), 20.6% showed a high degree of resistance (R1), 3.9% showed poor resistance (R2), and only 1.9% of the samples were susceptible (S1). The differences in results between IPR NAAS and the PED show the influence of the genetic specificity of the breeding lines used in the crosses by both institutions. During the years 2021–2023, the following lines were used for the crossing: F09.209-3/P14.3/12, Svitana/Mezhyrichka, Vyhoda/Svitana, Radomysl/Svitana, Vzirets/Svitana, P10.10/35/Svitana, 81.13.9/1/Svitana, P12.14-8/Partner, Zvizdal/P10.109/35, Mezhyrichka/Sontsedar, Levada/Rostavytsia, Svitana/Rostavytsia, Nahoroda/Rostavytsia, VM12.24-15/Vyhoda, Floatka/Rostavytsia, Mezhyrichka/Dorohyn, Agave/Aria, 08.102/4/Miranda, Ivankivska rannia/Alians, Vektar/Radomysl, Charunka/Alians, Tyras/ 9.715s88 and 100% potato progeny, resistant to pathotype (1D1), were obtained (this study and Zelya et al., 2020, 2023).

The validation of the resistance trait for 17 Ukrainian varieties under field conditions confirmed the results of laboratory tests and allowed evaluation of not only resistance to the common pathotype, but also to the virulent pathotypes 11(M1), 13(R2), 18(Ya), 22(B1) and 38(N1). Only one variety, Rodynna, was resistant to all five virulent pathotypes of potato wart pathogen. Three varieties (Glazurna, Kniahynia, Vzirets) are resistant to four virulent pathotypes. The most virulent pathotypes were 18(Ya)

and 38(N1), to which the least number of varieties showed resistance.

The virulent pathotype 38(N1) is known to occur in Turkey, Georgia and Bulgaria, but not in Ukraine (Çakır et al., 2009; Ghoghoberidze et al., 2020; van de Vossenbergh, 2022). Its absence in Ukraine should be further confirmed by additional surveys. According to the research results, only two out of 17 tested potato varieties of Ukrainian breeding showed a resistance reaction to this pathotype, namely Kniahynia and Rodynna. These potato varieties were bred at the Institute of Potato Research of the NAAS and, after repeated testing, are recommended for introduction in the foci of pathotype 38 (N1), in Georgia and possibly in other infested countries such as Bulgaria and Turkey.

Our results confirm again the relative easiness to obtain sources of resistance against the common pathotype 1(D1), its resistance based on the gene Sen1, which is present on chromosome XI, near DNA marker N125 and has been widely used in breeding (Gebhardt et al., 2006; Prodhomme et al. 2020). This marker can be used to facilitate identification of further resistant sources against common pathotype 1(D1) in Ukrainian breeding material and the responsible institutes are considering to introduce the molecular method for its detection in their respective breeding programs. Unfortunately this marker assisted selection is not yet available for virulent pathotypes of *S. endobioticum*, because the basis of resistance against them appears to be polygenic, although further Sen genes (Sen2 to Sen5) have been described, which potentially can be used to breed for resistance to a broader range of (virulent) pathotypes, including 2, 6 and 18. Sen3 has been found to confer resistance in many German and Polish varieties (Ballvora et al., 2011; Obidiegwu et al., 2015; Przetakiewicz & Plich, 2017; Bartkiewicz et al. 2018; Prodhomme et al. 2019, 2020). When additional diagnostic markers would be described, the spectrum of diagnostic varieties as used by EPPO (containing all the S genes) and in Ukraine could be further widened and standardized and the basis of resistance of the varieties presently used in the panels further enlightened (EPPO, 2004; 2017a, b and 2020; van de Vossenbergh et al., 2022). Bonants et al. (2015) developed a Taqman real-time PCR where pathotype 1(D1) can be distinguished from at least pathotypes 2(G1), 6(O1) and 18(T1). Busse et al. (2017) developed a further molecular method using a sequence-characterized amplified

region (SCAR) marker and five simple sequence repeat (SSR) markers, useful in the detection of certain pathotypes, viz. 1(D1), 2(G1), 6(O1) and 18 (T1), which could also be of use in the breeding activities of the institutes in Ukraine and Georgia.

CONCLUSIONS

During the first year of laboratory testing in 2021, 971 samples of Ukrainian breeding material were tested to determine its resistance to the common pathotype 1(D1) of the potato wart pathogen *S. endobioticum*, using the method of infecting with winter zoospores. Of these, 949 samples (97.7%) were found to be resistant.

In laboratory tests of the second year (inoculation with summer zoospores), 300 (98%) of the 306 samples tested showed resistance to pathotype 1(D1), which demonstrated high stability of the resistance trait using the two different evaluation methods.

Seventeen Ukrainian potato varieties were re-evaluated under field conditions, and all of them (100%) confirmed their resistance to the common pathotype 1(D1).

The 17 Ukrainian varieties were also (re-)evaluated for resistance against 4 virulent pathotypes, occurring in Ukraine (11(M1), Mizhhirsky; 13(R2), Rakhivsky; 18(Ya), Yasinivsky; 22(B1), Bystretsky) and one (38(N1), Nevşehir), reported till so far from Turkey, Bulgaria, Georgia and the Netherlands.

Resistance to pathotype 11(M1) was present in 14 varieties (82.4%): Alians, Glazurna, Khortytsia, Podolianka, Rodynna, Shchedryk, Skarbnytsia, Slauta, Slovianka, Solokha, Strumok, Tyras, Vzirets and Zhytnytsia.

Resistance to pathotype 13(R2) was present in 13 varieties (76.5%): Alians, Aria, Glazurna, Khortytsia, Kniahynia, Rodynna, Shchedryk, Skarbnytsia, Slauta, Solokha, Strumok, Tyras and Vzirets.

Resistance to pathotype 18(Ya) was present in 8 varieties (47%): Aria, Glazurna, Kniahynia, Rodynna, Skarbnytsia, Slauta, Vzirets and Zhytnytsia.

Resistance to pathotype 22(B1) was found in 12 varieties (70.6%): Alians, Charunka, Glazurna, Khortytsia, Kniahynia, Rodynna, Shchedryk, Solokha, Strumok, Tyras, Vzirets and Zhytnytsia.

The most virulent pathotype was found to be 38(N1). Only two varieties (11.8%), Kniahynia and Rodynna, were resistant to this pathotype, proving the need for enhanced detection and breeding work

to determine the distribution of this pathotype and to adequately control this pathotype once it is found.

The potato varieties that were resistant to the different pathotypes are recommended for further introduction and use in the foci of these pathotypes in the Carpathian region of Ukraine.

The two Ukrainian potato varieties resistant to the virulent 38(N) pathotype, are recommended for cultivation in its foci in Georgia.

Scientific cooperation between Ukrainian and Georgian Institutes will continue for 2025–2029 within the framework of the agreement signed 5 years ago and research on the screening of wart-resistant varieties of potatoes of Ukrainian and foreign selection will continue.

It is recommended that molecular methods such as marker assisted selection and microsatellite diagnostics are incorporated in Ukrainian and Georgian potato breeding activities and pathotype labelling will be matched with the European one.

Prospects of further studies. In the future, the research on the evaluation and selection of wart-resistant potato breeding material is intended to continue. Breeders need to use parental forms resistant to the common 1(D1) pathotype and Ukrainian virulent pathotypes of the wart pathogen for further crossing. Use of molecular selection and identification methods can be introduced in the breeding and testing laboratories. Last but not least it is highly desirable that virulent pathotypes found and labelled in Ukraine are compared with the standard European differential variety panel (EPPO, 2017b). It may well be that at least some of them are congruent with pathotypes labelled differently in the EU. This was e.g. established for an isolate/pathotype labelled as D25 in Denmark, that was identified as the German pathotype 8(F1) by Busse et al. (2017).

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REFERENCES

- Baayen RP, Cochius G, Hendriks H et al. (2006) History of potato wart disease in Europe — a proposal for harmonisation in defining pathotypes. *Eur J Plant Pathol* 116:21–31 (2006). <https://doi.org/10.1007/s10658-006-9039-y>
- Ballvora A, Flath K, Lübeck J, Strahwald J, Tacke E, Hofferbert H-R and Gebhardt C (2011) Multiple alleles for resistance and susceptibility modulate the defense response in the interaction of tetraploid potato (*Solanum tuberosum*) with *Synchytrium endobioticum* pathotypes 1, 2, 6 and 18. *Theor Appl Genet* 123:1281–1292.
- Bartkiewicz A, Chilla F, Terefe-Ayana D, Lübeck J, Strahwald J, Tacke E, Hofferbert H-R, Flath K, Linde M, Debener T (2018) Improved genetic resolution for linkage mapping of resistance to potato wart in monoparental dihaploids with potential diagnostic value in tetraploid potato varieties. *Theor Appl Genet* 131:2555–2566. doi: 10.1007/s00122-018-3172-9.
- Boberg J, Björklund N (2018) *Synchytrium endobioticum* — pathotypes, resistance of *Solanum tuberosum* and management. Report by Unit for Risk Assessment of Plant Pests at the Swedish University of Agricultural Sciences. 38 p. URL: https://www.slu.se/globalassets/ew/org/centrb/riskv/pub/rapport-synchytrium-endobioticum_21sept2018.pdf
- Bojnansky V (1984) Potato wart pathotypes in Europe from an ecological point of view. *EPPO Bull.* 14(2):141–146. <https://doi.org/10.1111/j.1365-2338.1984.tb01861.x>
- Bonants PJM, van Gent-Pelzer MPE, van Leeuwen GCM, van der Lee TAJ (2015) A real-time TaqMan PCR assay to discriminate between pathotype 1(D1) and non-pathotype 1(D1) isolates of *Synchytrium endobioticum*. *Eur J Plant Pathol* 143:495–506.
- Busse F, Bartkiewicz A, Terefe-Ayana D, Niepold F, Schleusner Y, Flath K, Sommerfeldt-Impe N, Lübeck J, Strahwald J, Tacke E, Hofferbert HR, Linde M, Przetakiewicz J, Debener T (2017) Genomic and Transcriptomic Resources for Marker Development in *Synchytrium endobioticum*, an Elusive but Severe Potato Pathogen. *Phytopathology* 107(3):322–328. <https://doi.org/10.1094/PHTO-05-16-0197-R>
- Çakir E, van Leeuwen GCM, Flath K (2009) Identification of pathotypes of *Synchytrium endobioticum* found in infested fields in Turkey. *EPPO Bull* 39:175–178. <https://doi.org/10.1111/j.1365-2338.2009.02285.x>
- Canadian Food Inspection Agency (CFIA) (2022) Recommendations of the International Advisory Panel on Potato Wart Disease management on Prince Edward Island 2022 — inspection. <https://inspection.canada.ca/en/plant-health/invasive-species/plant-diseases/potato-wart/potato-wart-pei/current-investigation/potato-wart-disease-management-prince-edward>. Last retrieved April 2025
- Canadian Food Inspection Agency (CFIA) (2023a) Potato wart facts and figures. <https://www.canada.ca/en/food-inspection-agency/news/2023/04/potato-wart-facts-and-figures.html>. Last retrieved April 2025

- Canadian Food Inspection Agency (CFIA) (2023b) Current investigation into potato wart in PEI — inspection. <https://inspection.canada.ca/en/plant-health/invasive-species/plant-diseases/potato-wart/potato-wart-pei/current-investigation>. Last retrieved April 2025.
- EFSA (2018) PLH Panel (EFSA Panel on Plant Health), Jeger M, Bragard C, Caffier D, Candresse T, Chatzivassiliou E, Dehnen-Schmutz K, Gilioli G, Grégoire J-C, Jaques Miret JA, MacLeod A, Navajas Navarro M, Niere B, Parnell S, Potting R, Rafoss T, Urek G, van Bruggen A, Van der Werf W, West J, Winter S, Vloutoglou I, Bottex B and Rossi V (2018) Scientific Opinion on the pest categorisation of *Synchytrium endobioticum*. *EFSA Journal* 16(7):5352, 37 pp. <https://doi.org/10.2903/j.efsa.2018.5352>
- EPPO (2004) Standard PM 7/28/1 *Synchytrium endobioticum*. *EPPO Bulletin* 34(2):213–218. <https://doi.org/10.1111/j.1365-2338.2004.00722.x>
- EPPO (2014) *Synchytrium endobioticum* found in Denmark. *EPPO Reporting Service*, 11, 4. <https://gd.eppo.int/reporting/article-3299>
- EPPO (2017a) PM 3/59 (3) *Synchytrium endobioticum*: descheduling of previously infested plots. *EPPO Bulletin* 47:366–368. <https://doi.org/10.1111/epp.12409>
- EPPO (2017b) PM 7/28/2 *Synchytrium endobioticum*. *EPPO Bulletin* 47(3):420–440. <https://doi.org/10.1111/epp.12441>
- EPPO (2017c) PM 9/5 (2) *Synchytrium endobioticum*. *EPPO Bulletin*, 47:511–512. <https://doi.org/10.1111/epp.12440>
- EPPO (2020) PM 3/88 (1) Testing of potato varieties to assess resistance to *Synchytrium endobioticum*. *EPPO Bulletin* 50:364–371. <https://doi.org/10.1111/epp.12688>
- EPPO (2021) Addendum — PM 3/59 (3) *Synchytrium endobioticum*: Descheduling of previously infested plots. *EPPO Bull* 51:622–622. <https://doi.org/10.1111/epp.12822>
- EPPO (2024) European and Mediterranean Plant Protection Organization (EPPO) Global Database (available online). URL: <https://gd.eppo.int>. Last retrieved, April 2025
- EU (2022) Commission Implementing Regulation (EU) 2022/1195 of July 11 2022 establishing measures to eradicate and prevent the spread of *Synchytrium endobioticum* (Schilbersky) Percival. *Official Journal of the European Union*, L 185, July 12, 2022, pp. 1–10. https://eur-lex.europa.eu/eli/reg_impl/2022/1195/oj
- FAOSTAT (2023) FAOSTAT crop data. Food and Agriculture Organization of the United Nations. <https://reliefweb.int/report/world/fao-statistical-yearbook-2023-world-food-and-agriculture>
- Fiers M, Edel-Hermann V, Chatot C, Le Hingrot Y (2012) Potato soil-borne diseases. A review. *Agro Sustain Dev* 32(1):93–132. <https://doi.org/10.1007/s13593-011-0035-z>
- Flath K, Przetakiewicz J, van Rijswijk PCJ, Ristau V, van Leeuwen GCM (2014) Interlaboratory tests for resistance to *Synchytrium endobioticum* in potato by the Glynne-Lemmerzahl method. *EPPO Bull* 44:510–517. <https://doi.org/10.1111/epp.12167>
- Franc GC (2007) Potato wart. The American Phytopathological Society. <https://www.apsnet.org/edcenter/apsnet/features/Pages/PotatoWart.aspx>. <https://doi.org/10.1094/APSnetFeature-2007-0607>
- Gebhardt C, Bellin D, Henslewski H, Lehmann W, Schwarzfischer J, Valkonen JPT (2006) Marker-assisted combination of major genes for pathogen resistance in potato. *Theor Appl Gen* 112:1458–1464.
- Ghoghoberidze S, Sikharulidze Z, Tsetskhladze Ts, et al. (2020) Occurrence of the Pathotype 38 of *Synchytrium endobioticum* in Khulo Municipality of Georgia. *Bull Georgian Natl Acad Sci* 14(1):114–119. http://science.org.ge/bnas/t14-n1/17_Ghoghoberidze%20et%20al_Agrarian%20Sciences.pdf
- Laidlaw WMR (1985) A method for the detection of the resting sporangia of potato wart disease (*Synchytrium endobioticum*) in the soil of old outbreak sites. *Potato Res* 28:223–232. <https://doi.org/10.1007/BF02357446>
- Langerfeld E, Stachewicz H and Rintelen J (1994) Pathotypes of *Synchytrium endobioticum* in Germany. *EPPO Bull* 24:799–804. <https://doi.org/10.1111/j.1365-2338.1994.tb01100.x>
- Melnik PO (2003) Potato wart etiology, bioecological justification of measures, its prevention and restriction of development. Chernivtsi Prut, 284 p. (in Ukrainian)
- Nielsen BJ (2017) Redegørelse for kategorisering og bestemmelse på europæisk plan af kartoffelsorters resistens overfor *Synchytrium endobioticum* (kartoffelbrok). Report from DCA — Nationalt Center for Jordbrug og Fødevarer. Retrieved from https://pure.au.dk/ws/files/114706744/20170309_Besvarelse_kartoffelbrok_resistens.pdf
- Obidiegwu JE, Sanetomo R, Flath K et al (2015) Genomic architecture of potato resistance to *Synchytrium endobioticum* disentangled using SSR markers and the 8.3k SolCAP SNP genotyping array. *BMC Genetics*. 16:38. <https://doi.org/10.1186/s12863-015-0195-y>
- PM 3/59 (3). (2017) *Synchytrium endobioticum*: descheduling of previously infested plots.
- Potato News Today (2023) <https://www.potatonewstoday.com/2023/01/21/global-potato-statistics-latest-fao-data-published>
- Prodhomme C, van Arkel G, Plich J, Tammes JE, Rijk J, van Eck HJ, Visser RGF, Vossen JH. A (2020) Hitchhiker’s guide to the potato wart disease resistance galaxy. *Theor Appl Genet*. 133(12):3419–3439. doi: 10.1007/s00122-020-03678-x.

- Przetakiewicz J (2015a) The viability of winter sporangia of *Synchytrium endobioticum* (Schilb.) Perc. from Poland. *Amer J Potato Res* 92:704–708. <https://link.springer.com/article/10.1007/s12230-015-9480-6>
- Przetakiewicz J (2015b) First report of new pathotype 39(P1) of *Synchytrium endobioticum* causing potato wart disease in Poland. *Plant Dis* 99(2):285. <https://doi.org/10.1094/PDIS-06-14-0636-PDN>
- Przetakiewicz J (2017) Sampling, maintenance and pathotype identification of *Synchytrium endobioticum* (Schilb.) Perc. *Plant Breeding and Seed Science* 76:29–36. <https://doi.org/10.1515/plass-2017-0018>
- Przetakiewicz J, Plich J (2017) Assessment of potato resistance to *Synchytrium endobioticum*. *Plant Breeding and Seed Science*, 76, 37–43.
- Saltykova L.P. (1988) Potato wart pathotypes identification in USSR. *Zashchyta rastenyi*.11:27–28. (In Russian). Салтыкова Л. П. Дифференциация патотипов рака картофеля в СССР. *Защита растений*. 1988. № 11. С. 27–28.
- Sikharulidze Z, Ghoghoberidze, S Mentink NM, Meparishvili G, Tsetskhladze Ts, van Leeuwen GCM (2019) Identification of the pathotype of *Synchytrium endobioticum*, causal agent of potato wart disease, present in Georgia. *EPPO Bulletin*, 49(2):314–320. <https://doi.org/10.1111/epp.12582>
- Regulations on the procedure for potato hybrids and varieties testing for resistance to potato wart disease and golden potato cyst nematode. Chernivtsi, 1993: 7 p. (In Ukrainian).
- van de Vossenbergh BTLH, Prodhomme C, Vossen JH, van der Lee TAJ (2022) *Synchytrium endobioticum*, the potato wart disease pathogen. *Mol Plant Pathol* 23(4): 461–474. <https://doi.org/10.1111/mpp.13183>.
- van de Vossenbergh BT, van Gent M, Meffert JP et al. (2024) Molecular characterization and comparisons of potato wart (*Synchytrium endobioticum*) in historic collections to recent findings in *Canada and the Neth J Plant Pathol* 106:363–375. <https://doi.org/10.1007/s42161-022-01299-5>
- Zelya GV, Zelya AG, Gunchak VM, Pylypenko LA (2015) Methods for evaluation and selection of potato breeding material resistant to wart *Synchytrium endobioticum* (Schilb.) Perc., harmonized with EU requirements. Chernivtsi: Prut, 24p. (in Ukrainian).
- Zelya AG., Zelya GV., Oliynik TM., Pylypenko LA et al. (2018) Screening of potato varieties for multiple resistance to *Synchytrium endobioticum* in western regions of Ukraine. *Agric Sci & Pract* 3:3–11. <https://doi.org/10.15407/agrisp.5.03.003>
- Zelya AG, Oliynik TM, Zelya GV (2020) Selection of sources of potato resistance to wart *Synchytrium endobioticum* (Schilbersky) Percival. *Peredhirne ta hirske zemlerobstvo i tvarynyntstvo* 67(2):75–91. [https://doi.org/10.32636/01308521.2020-\(67\)-2-5](https://doi.org/10.32636/01308521.2020-(67)-2-5) (In Ukrainian)
- Зеля А.Г., Олійник Т.М., Зеля Г.В. Відбір джерел стійкості картоплі до раку *Synchytrium endobioticum* (Schilbersky) Percival. *Передгірне та гірське землеробство і тваринництво*. 2020. Вип. 67(II), 75–91.
- Zelya A, Zelya G, Sonetsi T, Makar N (2022) Selection of potato varieties resistant to wart *Synchytrium endobioticum* Schilbersky Percival. *Karantin i Zahist Roslin*, 2(262): 15–20. DOI: <https://doi.org/10.36495/2312-0614.2022.2.15-20> (In Ukrainian) Зеля А.Г., Зеля Г.В., Сонець Т.Д., Макар Т.Й. Відбір сортів картоплі, стійких проти збудника раку *Synchytrium endobioticum* Schilbersky Percival. *Карантин і захист рослин*, 2022, 2(262):15–20.
- Zelya AG, Zelya GV, Oliynik TM, Pisarenko NV, Zakharchuk NA (2023) Search for resistance sources to potato wart *Synchytrium endobioticum* (Schilbersky) Percival causative agent. *Phytosanitary Security* 69:228–253. <https://doi.org/10.36495/PHSS.2023.69.228-253> (In Ukrainian) Зеля А.Г., Зеля Г.В., Олійник Т.М., Писаренко Н.В., Захарчук Н.А. Пошук джерел стійкості картоплі проти збудника раку *Synchytrium endobioticum* (Schilbersky) Percival. *Фітосанітарна безпека*, 2023. Вип. 69:228–253.
- Zelya A (2025) New potato wart *Synchytrium endobioticum* (Schilbersky) Percival pathotypes in Ukraine. Interdepartmental Thematic Scientific Collection of *Phytosanitary Safety* (70):104–114. <https://doi.org/10.36495/PHSS.2024.70.104-114> (In Ukrainian) Зеля А.Г. Нові патотипи раку картоплі *Synchytrium endobioticum* (Schilbersky) Percival в Україні. *Фітосанітарна безпека*. 2024. Вип. 70:104–114.

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**ОЦІНЮВАННЯ УКРАЇНСЬКИХ
СОРТІВ КАРТОПЛІ ТА СЕЛЕКЦІЙНОГО
МАТЕРІАЛУ НА СТІЙКІСТЬ ДО ПАТОТИПІВ
SYNCHYTRIUM ENDOBIOTICUM,
ПОШИРЕНИХ У ГРУЗІЇ ТА УКРАЇНІ**

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Мета. Оцінити новий селекційний матеріал картоплі на стійкість до звичайного патотипу 1(D1) та збудника рака картоплі *Synchytrium endobioticum* і перевірити 17 сортів картоплі української селекції впродовж 2021–2023рр. на валідність попередньо визначеної ознаки стійкості до звичайного патотипу 1(D1), а також оцінити стійкість до чотирьох інших вірулентних патотипів збудника раку, поширених в Україні, та одного вірулентного патотипу, поширеного у Грузії, для використання у селекційному процесі в якості джерел стійкості до збудника раку картоплі та більш ефективного впровадження у вогнищах хвороби в цих країнах. **Матеріали та методи.** У даному дослідженні в перший рік лабораторного тестування було використано 971 зразок селекційного матеріалу картоплі, а в другий рік — 306 зразків. Селекційний матеріал походив з Інституту картоплярства НААН (ІК НААН) та його Поліської дослідної станції. Для польових досліджень було використано сімнадцять українських сортів картоплі (таблиця 3) з метою перевірки та підтвердження раніше встановленої стійкості до *S. endobioticum* звичайного патотипу 1(D1) та вірулентних патотипів 11(M1), 13(R2), 18(Ya), 22(B1), а також одного патотипу, виявленого в Грузії — 38(N1). Стійкість до збудника раку картоплі оцінювали в лабораторних умовах за штучного інфекційного фону із використанням зимових і

літніх зооспор для селекційного матеріалу, а також на природному інфекційному фоні в окремих осередках патогену в Україні та Грузії згідно зі стандартом ЕРРО РМ 7/28(2) і національною методикою, гармонізованою з вимогами ЄС. **Результати.** Стійкість до зимових зооспор звичайного патотипу 1(D1) була встановлена у 949 із 971 зразків (97,7%) у перший рік тестування, а у другий рік за використання літніх зооспор — у 300 із 306 зразків (98%). Стійкість до вірулентного патотипу 11(M1) виявлено у 14 сортів (82,4%): Альянс, Глазурна, Хортиця, Подолянка, Родинна, Щедрик, Скарбниця, Слаута, Слов'янка, Солоха, Струмок, Тирас, Взірець та Житниця. Стійкість до вірулентного патотипу 13(R2) також була присутня у 13 сортів (76,5%): Альянс, Арія, Глазурна, Хортиця, Княгиня, Родинна, Щедрик, Скарбниця, Слаута, Солоха, Струмок, Тирас та Взірець. Стійкість до вірулентного патотипу 18(Ya) виявлена у 8 сортів (47,1%): Арія, Глазурна, Княгиня, Родинна, Скарбниця, Слаута, Взірець та Житниця. Стійкість до вірулентного патотипу 22(B1) зафіксовано у 12 сортів (70,6%): Альянс, Чарунка, Глазурна, Хортиця, Княгиня, Родинна, Щедрик, Солоха, Струмок, Тирас, Взірець та Житниця. Найбільш вірулентним патотипом виявився 38(N1), що підтвердило раніше неопубліковані результати авторів. Лише два сорти (11,8%), Княгиня та Родинна, виявилися стійкими до цього патотипу, що свідчить про необхідність посиленої діагностики та селекційної роботи для визначення поширення цього патотипу та ефективного контролю у випадку його виявлення. Сорт Поліська рожева, використаний як сприйнятливий контроль, був уражений усіма патотипами, що підтверджує його високу сприйнятливість до збудника. **Висновки.** Під час оцінювання стійкості нового українського селекційного матеріалу до звичайного патотипу 1(D1) збудника *S. endobioticum* було встановлено, що близько 98% зразків є стійкими як до зимових, так і до літніх зооспор. Сорти картоплі, стійкі до одного або кількох патотипів, можуть бути рекомендовані для використання у вогнищах, де достеменно відомо про наявність відповідного патотипу чи патотипів. У випадках, коли інформація про патотипи у вогнищах є неповною, слід віддавати перевагу сортам Глазурна (стійка до всіх п'яти патотипів, поширених в Україні, але чутлива до патотипу 38(N1), який наразі зафіксований лише в Туреччині, Болгарії та Грузії) або Родинна (стійка до всіх шести досліджених патотипів). Отримані дані щодо стійкості можуть бути використані в подальших селекційних програмах. Крім того, рекомендовано впровадити в українські та грузинські селекційні програми молекулярні методи, зокрема селекцію з використанням маркерів та мікросателітну діагностику.

Ключові слова: картопля, рак картоплі, агресивність, вірулентність, польові випробування.