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Original article

Assessment of the pressure of the main viral pathogens in cereal crops in the 2023/2024 and 2024/2025 seasons in Poland

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Abstract

Cereals, Poland's main crops, are infected by various pathogens. This nationwide study aimed to monitor and detect the presence of major viruses in cereal crops across the country. Samples were collected from various regions of Poland over two consecutive growing seasons, 2023/2024 and 2024/2025. A total of 502 plants were analyzed: 196 barley, 195 wheat, 91 rye, 11 triticale, and 9 oat samples. Virus detection was initially performed using DAS-ELISA, followed by molecular analyses (RT-PCR, RT-PCR-RFLP, and duplex IC-PCR) on selected samples. During the survey, infections of cereal plants caused by barley yellow dwarf viruses (BYDVs), wheat dwarf virus (WDV), and wheat streak mosaic virus (WSMV) were confirmed in different parts of the country. The occurrence of the viruses varied between years. The results revealed the highest proportion of BYDV complex infections (58.7% and 67.3%), followed by WDV (8.9% and 34.5%) and WSMV (7.7% and 16.4%) in the 2023/2024 and 2024/2025 seasons, respectively. Molecular analysis confirmed the continued dominance of BYDV-PAS and WDV-W in Poland. The observations indicate that WSMV is becoming an increasing threat to wheat crops in the country.

Key words: barley yellow dwarf virus PAS, cereals, diagnostics, wheat dwarf virus, wheat streak mosaic virus

Introduction

Despite variability in the structure of crop sowings, from both traditional agricultural practices and contemporary market demands, cereals remain the main group of cultivated plants in Poland. The total area under main cereals, together with cereal mixtures, exceeds 7 million hectares. The most grown cereal species in the country include wheat (2,518 thousand ha), triticale (1,233 thousand ha), rye (662 thousand ha), barley (639 thousand ha), and oats (466 thousand ha) (Statistical Yearbook of the Central Statistical Office 2023). Harvest size and yield levels of individual crops show considerable annual fluctuations depending on the meteorological conditions occurring in a specific growing season.

Observed climate changes, in particular the significant increase in autumn temperatures, lead to an extension of the growing season, enabling more intensive development of cultivated plants, as well as weeds, pests, and diseases (Walczak and Tratwal 2008). With ongoing global warming, viruses transmitted by vectors such as aphids, leafhoppers, and mites are expected to pose increasingly serious threats (Ordon *et al.* 2009). Elevated carbon dioxide (CO_2) concentration and environmental changes have significant impacts on plant–insect–pathogen interactions (*e.g.*, viruses) (Ryalls and Harrington 2017; Trębicki *et al.* 2017). Global warming contributes to changes in the development of many organisms. Aphids, due to their small body size and short generation time, respond rapidly to temperature changes (Bell *et al.* 2015; Strażyński and Ruszkowska 2015). Moderately humid autumn conditions, combined with extended periods of mild temperatures, are favorable for aphid activity, as well as for prolonged migration and development of subsequent generations of *Rhopalosiphum padi* L. (one of the most significant and widely distributed pests of cereal crops and an important virus vector) (Roik *et al*. 2026). Climate change has also led to extended periods of activity of *Psammotettix alienus* Dahlb - the vector of wheat dwarf virus (WDV) (Vacke *et al.* 2004) as well as to its expansion into new habitats, thereby increasing the importance of wheat dwarf disease across large parts of Europe (Pfrieme *et al.* 2023). It should be emphasized that the group of viruses mentioned above is classified among the major viral pathogens responsible for substantial yield losses in cereal crops (D'Arcy and Burnett 1995; Raus 2008; Singh *et al.* 2018).

For example, wheat streak mosaic virus (WSMV) (*Tritimovirus tritici* species, *Tritimovirus* genus, Potyviridae family), transmitted by the wheat curl mite *Aceria tosichella* Keifer, can lead to complete (100%) yield loss in heavily infected fields (Hasan *et al.* 2025), while losses caused by wheat dwarf virus (WDV) (*Mastrevirus hordei* species, *Mastrevirus* genus, Geminiviridae family) can reach up to 80% (Lindblad *et al.* 1999). The extent of crop loss depends on the plant's developmental stage at the moment of infection. Barley yellow dwarf (BYD) disease, resulting from autumn infections, can reduce grain yield by up to 63%, compared to around 41% in spring infections (Brakke 1987), with an average loss of approximately 30% (Perry *et al.* 2000). BYD is one of the most widespread and economically important viral diseases of cereal crops worldwide. It is caused by a group of related, spherical, positive-sense single-stranded RNA (+ss) RNA viruses transmitted by approximately 25 aphid species (Domier 1995). To date, several of these virus species have been confirmed as present in Poland, including barley yellow dwarf virus PAV (BYDV-PAV, *Luteovirus pavhordei*), barley yellow dwarf virus MAV (BYDV-MAV, *Luteovirus mavhordei*), barley yellow dwarf virus PAS (BYDV-PAS, *Luteovirus pashordei*), barley yellow dwarf virus SGV (BYDV-SGV, *Luteovirus sgvhordei*), and cereal yellow dwarf virus RPV (CYDV-RPV, *Polerovirus CYDV-RPV*) (Jeżewska *et al.* 2010; Trzmiel 2017). Recent studies indicate that BYDV-PAS is the dominant species in Poland (Trzmiel and Hasiów-Jaroszewska 2023). According to the current taxonomy, BYDV-PAV, BYDV-PAS, and BYDV-MAV belong to the genus *Luteovirus* within the family Tombusviridae (ICTV 2022), while CYDV-RPV belongs to the genus *Polerovirus* in the family Solemoviridae (ICTV 2023), and BYDV-SGV to the genus *Solemovirus*, also within

Solemoviridae (ICTV 2023). In addition to BYDVs, cereal crops in Poland are also exposed to other viral pathogens, such as WDV and WSMV (Jeżewska *et al.* 2010; Trzmiel 2018; Trzmiel *et al.* 2021).

A further concern is the increasing occurrence of mixed infections, involving the simultaneous presence of multiple pathogen species in a single plant. In the USA, mixed infections of WSMV with brome mosaic virus (BMV, *Bromovirus BMV*) and triticum mosaic virus (TriMV*, Poacevirus tritici*), as well as with High Plains wheat mosaic virus (HPWMoV, *Emaravirus tritici*), have been confirmed (Ranabhat *et al.* 2023). In Europe, the wheat mosaic disease complex (WSMV+HPWMoV) has been reported in Ukraine (Pozhylov *et al.* 2022). Another example of a mixed infection, involving WSMV, BYDVs, WDV, cereal yellow dwarf virus RPS (CYDV-RPS, *Polerovirus CYDVRPS*), and wheat yellow dwarf virus GPV (WYDV-GPV, *Polerovirus WYDVGPV*), has been documented in the Czech Republic (Singh *et al.* 2020). In Poland, co-infections of WSMV with BMV (Trzmiel *et al.* 2021), as well as BYDV-PAS with WDV and barley virus G (BVG, *Polerovirus BVG*), have also been described (Trzmiel *et al.* 2025). Tatineni *et al.* (2019) reported that synergistic interactions between different virus species increase viral titers and intensify disease symptoms already at early stages of infection.

Crop protection is a key approach to addressing major disease challenges. Since viral diseases cannot be controlled directly using conventional plant protection products, a comprehensive preventive strategy remains the most effective means of limiting the impact of these pathogens. In practice, this involves regular monitoring of crop conditions and a rapid response when insect vectors and/or disease symptoms appear. Fast and reliable diagnostics, based on laboratory testing, enable early detection of viruses in specific crops and facilitate the implementation of measures to prevent the spread of infection.

This study aimed to assess the incidence and distribution of the main viral pathogens affecting cereals in Poland. Monitoring and diagnostic analyses were conducted over two growing seasons: 2023/2024 and 2024/2025.

Materials and Methods

Plant sources

In this study, winter cereals — including barley, wheat, rye, triticale, and oats — showing leaf discoloration and mosaic and/or growth inhibition were analyzed. Symptomatic plants were collected and submitted by agricultural producers for diagnostic testing to the Laboratory of the Plant Disease Clinic and Bank of Pathogens (Institute of Plant Protection-National Research Institute, Poznań). Plant samples at both early and more advanced growth stages (BBCH 31-61) were collected during the spring to early summer period (March to June) from both commercial fields and experimental plots at plant breeding stations, with each field sampled only once. In the first season, samples were obtained from 63 locations across 15 voivodeships, whereas in 2025, they were collected from 15 locations in 9 voivodeships in Poland. In 2024, a total of 392 plants were analyzed, including 177 barley, 173 wheat, 22 rye, 11 triticale, and 9 oat samples. In 2025, 110 plants were collected and analyzed, with rye constituting the largest group (69 samples), followed by wheat (22) and barley (19). A detailed list of the tested samples is provided in Tables 1 and 2, which summarize the diagnostic results.

ELISA tests

For the screening assays, a double-antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA) (Clark and Adams 1977) was used, with specific commercial antibody and conjugate kits (Loewe, Sauerlach, Germany), which enable the detection of group-related barley yellow dwarf viruses (BYDV-MAV, BYDV-PAV, and BYDV-PAS) (cat. number 07 005/500), as well as WDV (cat. number 07082/500) and WSMV (cat. number 07048/500). Not infected wheat and barley plants grown under greenhouse conditions were used as negative controls, along with the commercial positive controls provided in the kits (Loewe). Diagnostic tests were performed following the manufacturer's recommendations. Absorbance was measured using an ELx800 microplate reader (BioTek Instruments, Winooski, VT, USA) at a wavelength of 405 nm. The infection rate was calculated as the number of positive samples divided by the total number of tested plants. In addition, selected samples were subjected to molecular analysis to verify the results of the serological assays.

RNA extraction

Total RNA (TRNA) was extracted using the RNeasy Plant Mini Kit (Qiagen, Hilden, Germany) according to the manufacturer's protocol. RNA quality was assessed spectrophotometrically using a NanoDrop 2000 Spectrophotometer (Thermo Scientific, Waltham, MA, USA), and samples were stored at −20°C. In total, 72 RNA samples were extracted, including 55 in 2024 and 17 in 2025. For molecular analyses, selected samples representing different cereal species and collection sites were used. In the first season, 29 winter barley, 20 winter wheat, 3 rye, and 3 oat samples were analyzed. In the following season, 1winter barley, 2 winter wheat, and 14 rye samples were tested.

Reverse Transcription - Polymerase Chain Reaction (RT-PCR)

Detection of viruses causing barley yellow dwarf (BYV) disease was based on a one-step RT-PCR reaction combined with restriction fragment length polymorphism (RFLP) analysis, following the procedure described by Kundu *et al.* (2009). The specific primer pair BYDVcp-F and BYDVcp-R (Kundu 2008), together with the *Hpa*II restriction enzyme (Thermo Fisher Scientific), were used. The analyses were performed under the conditions described by Trzmiel and Hasiów-Jaroszewska (2023). Identification of WSMV was performed using a one-step RT-PCR reaction with the specific primer pair WSMV-V-F and WSMV-V-R (Trzmiel *et.al.* 2026), following the procedure described previously by Trzmiel *et al.* (2021).

Duplex-Immunocapture-Polymerase Chain Reaction (Duplex-IC-PCR)

The detection of WDV was carried out using duplex immunocapture PCR (duplex-IC-PCR) with a set of designed primers differentiating the wheat form WDV-W, *i.e.*, WDV-T-F and WDV-T-R, and the barley form WDV-B, *i.e.*, WDV-H-F and WDV-H (Trzmiel 2018). The reactions were performed following the protocol described by Trzmiel (2020) on 17 and 5 plant samples collected in 2024 and 2025, respectively.

RT-PCR and duplex-IC-PCR products were separated by electrophoresis on 1% and 2% agarose gels, respectively, stained with 2 µl of Midori Green (NIPPON Genetics Europe GmbH, Düren, Germany), and visualized under UV light.

DNA sequencing

The specificity of RT-PCR and duplex-IC-PCR products was confirmed by direct Sanger sequencing. PCR products of the expected size were excised from the agarose gels and purified using the Wizard® SV Gel and PCR Clean-Up System (Promega, Madison, WI, USA) according to the manufacturer's instructions. The eluted DNA was sequenced with the same primers used for amplification by Genomed S.A. (Warsaw, Poland). The obtained nucleotide sequences were edited using BioEdit software, version 7.2.5 (Hall 1999). Consensus sequences were analyzed using the NCBI Standard Nucleotide BLAST (https://www.ncbi.nlm.nih.gov/blastn).

Statistical analyses

A chi-square test was conducted to evaluate the association between viral infection and two growing seasons (2023/2024 and 2024/2025). The data were organized into a 2 x 2 contingency table to compare the frequencies of infected and healthy plants. The null hypothesis assumed that viral prevalence is independent of the season.

Additionally, Fisher's exact test was performed to assess the association between the virus and its host plant species. This test was selected to account for the small sample sizes in certain experimental groups. The null hypothesis stated that viral infection is independent of host plant species. All statistical analyses were conducted at a significance level of $p < 0.05$ using RStudio 2023.03.01 (R Core Team 2021).

Results

Over the two years of this study, diagnostic tests were conducted to determine the identity and incidence rate of the virus in cereal crops in Poland. The results of analyses of 502 plant samples confirmed the presence of all tested viral pathogens BYDVs, WDV, and WSMV in various regions of Poland, during both growing seasons. In this study, among 196 winter barley samples, BYDV species were detected in 130 plants (66.3%), representing the most significant threat. WDV was detected in 10 samples (5.1%), while WSMV was identified in only one case (0.5%). Winter wheat constituted the second most numerous cereal group (195 samples), of which 91 (46.7%) were infected with BYDVs, 43 (22.1%) with WSMV, and 20 (10.3%) with WDV. In this group, BYDVs were also the most frequently detected viruses. The third group consisted of 91 rye plants. BYDVs predominated, being detected in 78 samples (85.7%). WDV was the second prevalent virus, infecting 42 plants (46.2%). Notably, WSMV was not detected in this group.

Two other cereal species, oat and triticale, were evaluated over a single year. In oat, BYDVs were detected in 44.4% (4 samples), whereas WSMV and WDV were each detected in 22.2% (2 samples). In the last group (11 triticale plants), only single infections with BYDVs and WSMV were confirmed (9.1%). Additionally, WDV was not identified in this group.

Detailed results on the incidence of viral infections, including the plant species and their origin, are presented in Tables 1 and 2.

The statistical analysis showed that BYDV complex occurrence did not differ significantly between growing seasons ($p = 0.1284$). In contrast, WDV and WSMV exhibited significant seasonal variation ($p < 0.05$). Furthermore, a significant association between viruses and host plants was observed for all viruses except for BYDV in the second season, when the association was not statistically significant ($p = 0.0755$).

In the 2023/2024 season, viral infections were detected in most surveyed locations, except in Zachodniopomorskie, Podlaskie, and Lubuskie voivodeships. The most serious and widespread viral disease affecting all examined cereal species was BYD (Fig. 1). BYDVs were found in 230 out of 392 cereal samples, 58.7% (Table 1). The incidence of this disease was very high in many regions (Fig. 2a). Characteristic symptoms, such as leaf discoloration and growth reduction, were observed in up to 80% of the plants within a given crop (Fig. 3). RT-PCR-RFLP and sequencing results (data not shown) indicated the presence of BYDV-PAS species. Among 230 BYDV infections, 187 were single infections, whereas 33 were mixed infections with WDV, eight with WSMV, and two samples contained all three viruses simultaneously (BYDVs/WDV/WSMV) (Fig. 4a). WDV was the second most frequent viral pathogen of cereals in the 2023/2024 season (Table 1). Locations of WDV-involved infections are shown in Figure 2b. WDV occurred only in mixed infections, mainly with BYDVs, and occasionally with BYDVs and WSMV (Fig. 4a). The virus infected all examined cereal species except triticale, but it was most frequently detected in wheat plants (Fig. 5). Results of duplex-IC-PCR tests, performed for selected samples from different locations (data not shown), revealed the presence of the wheat-specific form of WDV (WDV-W).

Among the 30 cases of WSMV infections detected in the 2023/2024 season (Table 1), in 20 cases the virus occurred alone (Fig. 4a), causing a clearly visible leaf mosaic. The infections' locations are presented in Figure 2c. WSMV infected wheat, triticale, and oat plants (Fig. 6).

In the 2024/2025 season, BYD disease remained a threat to all collected cereal crops (Fig. 1). The causal agent was detected in 74 out of 110 tested plants, 67.3% (Table 2), particularly in the southern regions of Poland (Fig. 2a), where it constituted a significant problem in rye and barley crops. As in the previous season, RT-PCR-RFLP results (data not shown), confirmed by

Sanger sequencing, revealed the presence of BYDV-PAS in the examined samples. Moreover, most detected BYDVs infections (42/74) were single infections. Among the mixed infections, BYDVs were detected simultaneously with WDV in 29 cases and with WSMV in only two cases. A tripartite infection (BYDVs/WDV/WSMV) was detected in just one sample (Fig.4a).

WDV, as the second prevalent viral pathogen of cereal crops in the 2024/2025 season, had a similar distribution range (Fig. 2b). It was detected in all examined species (Table 2, Fig. 5). Moreover, as in the case of BYDV-PAS, a large proportion of WDV-infected plants was rye (33 out of 69 examined samples) (Table 2). Additional molecular analyses using duplex-IC-PCR confirmed the presence of the wheat and barley-specific forms (WDV-W and WDV-B) in rye plants (Fig. 7). In the 2024/2025 season, among the 38 detected WDV infections, mixed BYDVs/WDV infections predominated (29 cases). Additionally, eight cases involved single infections in rye, and only one case involved a tripartite infection with BYDVs and WSMV mixed infection (Fig. 4b).

The obtained results indicated that WSMV posed the greatest threat to wheat plants in the 2024/2025 season. Moreover, the virus was also confirmed as a pathogen of barley (Table 2, Fig. 6). The analyses revealed a prevalence of single infections (Fig. 4b). The infected plants were collected from central and southern Poland (Fig. 2c).

Discussion

The results of this study concern the incidence of viruses in cereal crops across different regions of Poland. Over two years of research, it was confirmed that BYD remained the primary viral disease of cereal crops in the country. Molecular analyses confirmed the continued dominance of BYDV-PAS, which was detected from northern Poland (the Warmińsko-Mazurskie Voivodship) to southern Poland (the Podkarpackie Voivodship), and it can still be considered the main virus species causing BYD disease in the country (Trzmiel and Hasiów-Jaroszewska 2023). BYDV-PAS had previously been detected in the Czech Republic (Singh *et al.* 2020), Estonia (Sõmera *et al.* 2021), the USA (Hodge *et al.* 2020), and New Zealand (Delmiglio 2008), and more recently also in Ireland (Byrne *et al.* 2024), Australia (Nancarrow *et al.* 2024), and Türkiye (Ilbaği 2025), indicating an ongoing expansion of its geographical range.

Statistical analysis indicates that BYDVs infection remained stable across the two growing seasons, as no significant differences were observed between years. This finding suggests relatively consistent infection levels throughout the study period. In contrast, WDV and WSMV exhibited significant seasonal variation, indicating that their infection pressure fluctuated between years and was influenced by growing season conditions. Such variation in viral pressure across growing seasons is a natural phenomenon frequently reported (Bukvayová *et al.* 2006; Milgate *et al.* 2016; Pfrieme *et al.* 2023; Armand *et al.* 2023; Sultanowa *et al.* 2025). Furthermore, BYDVs showed a significant association with host plant species in general; however, this relationship was not significant in the second season. In contrast, the remaining viruses were significantly associated with host plants, indicating variable host–virus interactions depending on the season. Overall, the results suggest that viral pressure differed among viruses, with BYDVs showing more stable dynamics than WDV and WSMV, which were more strongly affected by seasonal factors.

In the 2023/2024 season, the incidence of BYDVs in certain regions, such as south-western and western Poland, was relatively high, resembling the last epidemic recorded during the 2014/2015 season (Jeżewska and Trzmiel 2016). Furthermore, this viral disease was shown to constitute a significant problem in rye and barley crops. The occurrence of infections in winter barley is not surprising, as this species is a host for various viruses, *e.g.*, BYDV-MAV, BYDV-PAV, BYDV-PAS, CYDV-RPS, and CYDV-RPV (Mar *et al.* 2013; Wei *et al.* 2023; Byrne *et al.* 2024). Although rye is one of the commonly cultivated cereals in Poland and, according to the Statistical Yearbook of the Central Statistical Office (2023), its sown area is comparable to that of barley, no significant levels of virus infection have been reported to date. BYDVs and WDV infections in rye crops have so far occurred only sporadically (Jeżewska *et al.* 2010; Jeżewska and Trzmiel 2016; Trzmiel 2018). The results of this study indicate a high susceptibility of the analyzed plant samples, as the average infection rates of BYDVs and WDV were 85.7% and 46.2%, respectively (78 and 42 infected out of 91 samples). Further studies are needed to determine whether this relatively high level of infection will persist or whether it was a random phenomenon. Nevertheless, in light of these findings, it is worth considering research on rye resistance to BYDVs and WDV, similar to studies conducted extensively on barley and wheat (Jarošová *et al.* 2016; Walls *et al.* 2019; Pfrieme *et al.* 2022).

Duplex-IC-PCR results confirmed the presence of WDV-W in wheat and both WDV-W and WDV-B in rye plants. The obtained data indicate the continued dominance of the WDV-W form over WDV-B in Poland (Trzmiel 2018), which is consistent with results from Serbia (Stanković *et al.* 2024), but in contrast with observations from Hungary (Petrics *et al.* 2025).

The results of these analyses showed that WSMV posed a serious threat to wheat plants in the 2024/2025 season. Infected plants originated from central and southern Poland. In many regions, such as the USA and Australia, WSMV is considered the main virological threat (Byamukama *et al.* 2014; Singh *et al.* 2018; Jones *et al.* 2022). Moreover, in some European countries, including the Czech Republic and Ukraine, WSMV is regarded as a re-emerging pathogen, as infection rates have risen sharply after a prolonged period of low incidence (Chalupniková *et al.* 2017; Pozhylov *et al.* 2022).

While most infections with BYDVs and WSMV were single infections, WDV was typically detected in mixed infections with BYDVs, whereas triple infections involving BYDVs, WDV, and WSMV occurred only rarely. Mixed infections pose a greater threat to infected plants. According to the literature, synergistic interactions between WSMV and TriMV led to enhanced viral replication and more pronounced symptoms, such as increased chlorosis and stunting, ultimately resulting in greater yield losses (Nunna *et al.* 2025). Furthermore, quadripartite infection of wheat by BMV, WSMV, TriMV, and barley stripe mosaic virus (BSMV, *Hordeivirus hordei*) has been shown to have severe effects, leading to the death of most infected plants (Tatineni *et al.* 2022).

In conclusion, the presented data indicate the continued presence of three virus species in Poland. Due to the lack of effective methods for the direct control of plant viruses, as well as the progressive reduction in the availability of insecticides targeting their insect vectors, prevention remains the primary approach to minimizing this threat, including systematic monitoring and continuous control of infections in cultivated plants. This study expands current knowledge of the virus population structure in Poland. These findings are important for the development of effective virus management strategies. Moreover, reliable monitoring and detection of viral infection are essential for both farmers and plant breeders.

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References

Armand T., Souquet M., Korn L., Gauthier K., Jacquot E. 2023. Asymmetric interactions between barley yellow dwarf virus -PAV and wheat dwarf virus in wheat. Frontiers in Plant Science 14:1194622. DOI: https://doi.org/10.3389/fpls.2023.1194622

Bell J.R.; Anderson L.; Izera I.D.; Kruger T.; Parker S.; Pickup J.; Shortall C.R.; Taylor M.S.; Verrier P.; Harrington R. 2015. Longterm phonological trends, species accumulation rates, aphid trait and climate: Five decades of change in migrating aphids. Journal of Animal Ecology 84: 21–34. DOI: https://doi.org/10.1111/1365-2656.12282

Brakke M.K., 1987. Virus disease in wheat. p. 585-603. In: "Wheat and wheat improvement" (E.G. Heyne, ed.). ASA-CSSA-SSSA, Madison, USA, 765 pp.

Bukvayová N., Henselová M., Vajcíková V., Kormanová T. 2006. Occurrence of dwarf virus of winter wheat and barley in several regions of Slovakia during the growing seasons 2001-2004. Plant Soil Environ. 52 (9): 392-401. DOI: https://doi.org/10.17221/3457-PSE

Byamukama E., Wegulo S.N., Tatineni S., Hein G.L., Graybosch R.A., Baenziger P.S., French R. 2014. Quantification of yield loss caused by triticum mosaic virus and wheat streak mosaic virus in winter wheat under field conditions. Plant Disease 98: 127-133. DOI: https://doi.org/10.1094/PDIS-04-13-0419-RE

Byrne S., Schughart M., Ballandras V., Carolan J.C., Sheppard L., McNamara L. 2024. The first survey using high-throughput sequencing of cereal and barley yellow dwarf viruses in Irish spring and winter barley crops. Irish Journal of Agricultural and Food Research. 63(1):1-16. DOI: https://doi.org/10.15212/ijafr-2023-0110

Chalupniková J., Kundu J.K., Singh K., Bartaková P., Beoni E. 2017. Wheat *streak mosaic virus*: incidence in field crops, potential reservoir within grass species, and uptake in winter wheat cultivars. Journal of Integrative Agriculture 16 (3): 523-531. DOI: https://doi.org/10.1016/S2095-3119(16)61486-7

Clark M.F., Adams A.N. 1977. Characteristics of the microplate method of enzyme-linked immunosorbent assay for the detection of plant viruses. Journal of General Virology 34: 475-483. DOI: https://doi.org/10.1099/0022-1317-34-3-475

D'Arcy C.J., Burnett P.A. (eds). 1995. Barley yellow dwarf: 40 years of progress. APS Press, St. Paul, MN, USA, 374 pp.

Domier L.L. 1995. Genome structure and function of barley yellow dwarf viruses. p. 181-201. In: „Barley yellow dwarf 40 years of progress" (C.J. D'Arcy and P.A. Burnett, eds). APS Press, St. Paul, MN, USA, 374 pp.

Delmiglio C. 2008. The incidence and Phylogenetic analysis of viruses infecting New Zealand's native grasses. Ph.D. Thesis, University of Auckland, Auckland, New Zealand

Hall T.A. 1999. Bioedit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. In: Nucleic Acids Symposium Series 41: 95–98.

Hasan N., Pushpalatha R., Manivasagam V.S., Arlikatti S. 2025. Wheat streak mosaic virus: transmission, its impact, and crop protection strategies—a systematic review. Journal of Plant Diseases and Protection 132: 8. DOI: https://doi.org/10.1007/s41348-024-01012-x

Hodge B.A., Paul P.A., Stewart L.R. 2020. Occurrence and High-Throughput Sequencing of Viruses in Ohio Wheat. Plant Disease 104(6):1789-1800. DOI: https://doi.org/10.1094/PDIS-08-19-1724-RE.

İlbağı, H. 2025. First report of barley yellow dwarf virus PAS in maize in Türkiye. Journal of Plant Pathology 107: 753. DOI: https://doi.org/10.1007/s42161-024-01757-2

Jarošová J., Beoni E., Kundu J.K. 2016. Barley yellow dwarf virus resistance in cereals: Approaches, strategies and prospects. Field Crops Research 198: 200–214. DOI: https://doi.org/10.1016/j.fcr.2016.08.030

Jeżewska M., Cajza M., Buchowska-Ruszkowska M. 2010. Monitoring and molecular diagnostics of cereal viruses. p. 157–180. In: 'Reducing Losses in Crop Yields with Food Safety' (D. Sosnowska ed.); Instytut Ochrony Roślin–PIB: Poznań, Poland, 284 p.

Jeżewska M., Trzmiel K. 2016. Outbreak of barley yellow dwarf in winter cereals in Poland in the season 2014/2015. Progress in Plant Protection 56: 296-301. DOI: https://doi.org/10.14199/ppp-2016-048

Jones R.A.C., Sharman, M., Trębicki, P., Maina, S., Congdon, B.S. 2021. Virus diseases of cereal and oilseed crops in Australia: current position and future challenges. Viruses 13: 2051. DOI: https://doi.org/10.3390/v13102051

Jones R.A.C., Vazquez-Iglesias I., Hajizadeh M., McGreig S., Fox A., Gibbs A.J. 2022. Phylogenetics and evolution of wheat streak mosaic virus: Its global origin and the source of the Australian epidemic. Plant Pathology 71: 1660-1673. DOI: https://doi.org/10.1111/ppa.13609

Kundu J.K. 2008. First report of barley yellow dwarf virus-PAS in wheat and barley grown in the Czech Republic. Plant Disease 92: 1587. DOI: https://doi.org/10.1094/PDIS-9211-1587B.

Kundu J.K., Jarošova J., Gadiou S., Červena G. 2009. Discrimination of three BYDV species by one-step RT-PCR-RFLP and sequence-based methods in cereal plants from the Czech Republic. Cereal Research Communications 37: 541-550. DOI: https://doi.org/10.1556/CRC.37.2009.4.7

Lindblad M., Sandgren M., Sigvald R. 1999. Epidemiology and control of wheat dwarfs. p. 114. In: Proceedings of VIIth International Plant Virus Epidemiology Symposium.11–16 April 1999. Aguadulce, Spain.

Mar T.B., Lau B., Schons J., Yamazaki-Lau E., Nhani Jr. A. 2013. Molecular identification based on coat protein sequences of the *Barley yellow dwarf virus* from Brazil. Scientia Agricola 70 (6): 428-434. DOI: https://doi.org/10.1590/S0103-90162013000600008.

Milgate A., Adorada D., Chambers G., Terras M.A. 2016. Occurrence of winter cereal viruses in New South Wales, Australia, 2006 to 2014. Plant Disease 100: 313-317. DOI: https://doi.org/10.1094/PDIS-06-15-0650-RE

Nancarrow N., Kinoti W.M., Rodoni B., Lam S.K., Trębicki P. 2024. First report of Barley yellow dwarf virus PAS (*Luteovirus pashordei*) in oat in Australia. Plant Disease 108(4): 1123. DOI: https://doi.org/10.1094/PDIS-10-23-2195-PDN.

Nunna H., Palmer N.A., Sarath G., Wegulo S.N., Tatineni S. 2025. Synergistic interaction between wheat streak mosaic virus and Triticum mosaic virus modulates wheat transcriptome to favor disease severity. Frontiers in Plant Science 15: 1504482 DOI: https://doi.org/10.3389/fpls.2024.1504482

Ordon F., Habekuss A., Kastirr U., Rabenstein F., Kühne T. 2009. Virus resistance in cereals: sources in resistance, genetics and breeding. Journal of Phytopathology 157:535-545. DOI: https://doi.org/10.1111/j.1439-0434.2009.01540.x

Perry K.L., Kolb F.L., Samsons B., Lawson C., Cisar G., Ohm H. 2000. Yield effects of barley yellow dwarf virus in soft red winter wheat. Phytopathology 90: 1043-1048. DOI: https://doi.org/10.1094/phyto.2000.90.9.1043

Pertics B.Z., Tholt G., Kis A., Szita E., Gerő K., Gernstenbrand R., Simon J., Samu F. 2025. Widely based full-genome analyses enable development of universal and strain-specific PCR toolkit for wheat dwarf virus detection, revealing new alternative hosts and challenging strain-host specificity. Plant Methods 21: 100. DOI: https://doi.org/10.1186/s13007-025-01420-6

Pfrieme A.K., Ruckwied B., Habekuß A., Will T., Stahl A., Pillen K. Ordon F. 2022. Identification and Validation of Quantitative Trait Loci for Wheat Dwarf Virus Resistance in Wheat (*Triticum spp.*). Frontiers in Plant Science 13: 828639. DOI: https://doi.org/10.3389/fpls.2022.828639

Pfrieme A.K.,Will T., Pillen, K.; Stahl, A. 2023. The Past, Present, and Future of Wheat Dwarf Virus Management—A Review. Plants 12: 3633. DOI: https://doi.org/10.3390/plants12203633

Pozhylov I., Snihur H., Shevchenko T., Budzanivska I., Liu W., Wang X., Schevchenko O. 2022. Occurrence and Characterization of Wheat Streak Mosaic Virus Found in Mono- and Mixed

Infection with High Plains Wheat Mosaic Virus in Winter Wheat in Ukraine. Viruses 14: 1220. DOI: https://doi.org/10.3390/v14061220

Ranabhat N.B., Fellers J.P., Bruce M.A., Rupp J.L.S. 2023. Brome mosaic virus detected in Kansas wheat co-infected with other common wheat viruses. Frontiers in Plant Science 14: 1096249. DOI: https://doi.org/10.3389/fpls.2023.1096249

Raus A. 2008. Viruses diseases in cereal crops: Effect of global warming in crop protection in the 21th century. Agrotip 9: 8-9.

R Core Team. 2021. R: A language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria.

Roik K.; Małas S.; Trzciński P.; Bocianowski J. 2026. Impact of Meteorological Conditions on the Bird Cherry–Oat Aphid (*Rhopalosiphum padi* L.) Flights Recorded by Johnson Suction Traps. Agriculture 16: 152. DOI: https://doi.org/10.3390/agriculture16020152

Ryalls J.M.W., Harrington R., 2017. Climate and atmospheric change impacts on aphids and vectors of plant diseases. p.148-175. In: "Global change and terrestrial invertebrates." (Johnon S.N.J. and Jones T.H. eds.) Wiley-Blackwell, Hoboken, New Jersey, USA, 416 pp.

Singh K., Wegulo S.N., Skoracka A., Kundu J.K. 2018. Wheat streak mosaic virus: A century old virus with rising importance worldwide. Molecular Plant Pathology 19: 2193-2206. DOI: https://doi.org/10.1111/mpp.12683

Singh K., Jarošová J., Fousek J., Chen H., Kundu, J. K. 2020. Virome identification in wheat in the Czech Republic using small RNA deep sequencing. Journal of Integrative Agriculture 19 (7): 1825-1833. DOI: https://doi.org/10.1016/S2095-3119(19)62805-4

Stanković I., Zečević K., Ristić D., Vučurović I., Krstić B. 2024. Molecular characterization of wheat dwarf virus isolates from Serbia based on complete genome sequences. Frontiers in Microbiology 15:1469453. DOI: https://doi.org/10.3389/fmicb.2024.1469453

Strażyński P.; Ruszkowska M. 2015. The life cycle functional response of *Rhopalosiphum padi* (L.) to higher temperature: Territorial expansion of permanent parthenogenetic development as a result of warmer weather conditions. Journal of Plant Protection Research 55 (2): 162–165. DOI: https://doi.org/10.1515/jppr-2015-0021

Sultanova N., Amirli F., Aghayeva T., Arabzada A., Rastgou M. 2025. Prevalence and natural impact of major wheat viruses in Azerbaijan. Acta agriculturae Slovenica 12(3): 1-8. DOI: https://doi.org/10.14720/aas.2025.121.3.21670

Sõmera M., Massart S., Tamisier L., Sooväli P., Sathees K., Kvarnheden A. 2021. A Survey Using High-Throughput Sequencing Suggests That the Diversity of Cereal and Barley Yellow Dwarf

Viruses Is Underestimated. Frontiers in Microbiology 12: 673218. DOI: https://doi.org/10.3389/fmicb.2021.673218

Tatineni S., Alexander J., Gupta A.K., French R. 2019. Asymmetry in synergistic interaction between Wheat streak mosaic virus and Triticum mosaic virus in wheat. Molecular Plant-Microbe Interactions 32(3): 336-350. DOI: https://doi.org/10.1094/MPMI-07-18-0189-R

Tatineni S., Alexander J., Qu F. 2022. Differential Synergistic Interactions Among Four Different Wheat-Infecting Viruses. Frontiers in Microbiology 12: 800318. DOI: https://doi.org/10.3389/fmicb.2021.800318

Trębicki P., Dáder B., Vassiliadis S., Fereres A. 2017. Insect-plant-pathogen interactions as shaped by future climate: effects on biology, distribution, and implications for agriculture. Insect Science 24: 975-989. DOI: https://doi.org/10.1111/1744-7917.12531

Trzmiel K. 2017. Identification of Barley Yellow Dwarf Viruses in Poland. Journal of Plant Pathology 99: 493-497. DOI: http://dx.doi.org/10.4454/jpp.v99i2.3869

Trzmiel K. 2018. Detection and discrimination of barley- and wheat-specific forms of wheat dwarf virus in Poland. Cereal Research Communications 46: 301-310. DOI: https://doi.org/10.1556/0806.46.2018.11

Trzmiel K. 2020. Occurrence of Wheat dwarf virus and Barley yellow dwarf virus species in Poland in the spring of 2019. Journal of Plant Protection Research 60: 345-350. DOI: https://doi.org/10.24425/jppr.2020.133959

Trzmiel K., Hasiów-Jaroszewska B. 2023. Molecular Characteristics of Barley Yellow Dwarf Virus—PAS—The Main Causal Agent of Barley Yellow Dwarf Disease in Poland. Plants 12: 3488. DOI: https://doi.org/10.3390/plants12193488

Trzmiel K., Szydło W., Hasiów-Jaroszewska B. 2021. Biological and molecular characterization of the two Polish Wheat streak mosaic virus isolates and their transmission by wheat curl mites. Plant Protection Science 57: 171-178. DOI: https://doi.org/10.17221/104/2020-PPS

Trzmiel K., Zarzyńska-Nowak A., Hasiów-Jaroszewska B. 2025. Occurrence and Molecular Characteristics of Polerovirus BVG Isolates from Poland. Pathogens 14: 1087. DOI: https://doi.org/10.3390/ pathogens14111087

Vacke J., Kvarnheden A., Lindbland M., Lindsten K. 2004. Wheat dwarf. p. 590–593. In: “Viruses and Virus Diseases of Poaceae (Gramineae)” (H. Lapierre, P.A. Signoret, eds.). INRA, Paris, 857 pp.

Walls J. III; Rajotte E., Rosa C. 2019. The Past, Present, and Future of Barley Yellow Dwarf Management. Agriculture 9: 23. DOI: https://doi.org/10.3390/agriculture9010023

Walczak F., Tratwal A. 2008. Zmiany klimatyczne jako czynnik wpływający na znaczenie gospodarcze agrofagów roślin rolniczych. Progress in Plant Protection 48(2): 808-813.

Wei S., Chen G., Yang H., Huang L., Gong G., Luo P., Zhang M. 2023. Global molecular evolution and phylogeographic analysis of barley yellow dwarf virus based on the cp and mp genes. Virology Journal 20: 130. DOI: https://doi.org/10.1186/s12985-023-02084-1

ICTV 2022 2022.015P. Tombusviridae remame sp [Online] [Available from: https://ictv.global/taxonomy/taxondetailstaxnode_id=202403768&taxon_name=Luteovirus%20pashordei] [Accessed 3 December 2025]

ICTV 2023 2023.019P. Solemoviridae rename sp [Online] [Available from: https://ictv.global/taxonomy/taxondetailstaxnode_id=202403793&taxon_name=Luteovirus%20sgvhordei] [Accessed 3 December 2025]

Statistical Yearbook of the Central Statistical Office 2023 [Online] [Available from: https://new.stat.gov.pl/] [Accessed 3 December 2025]

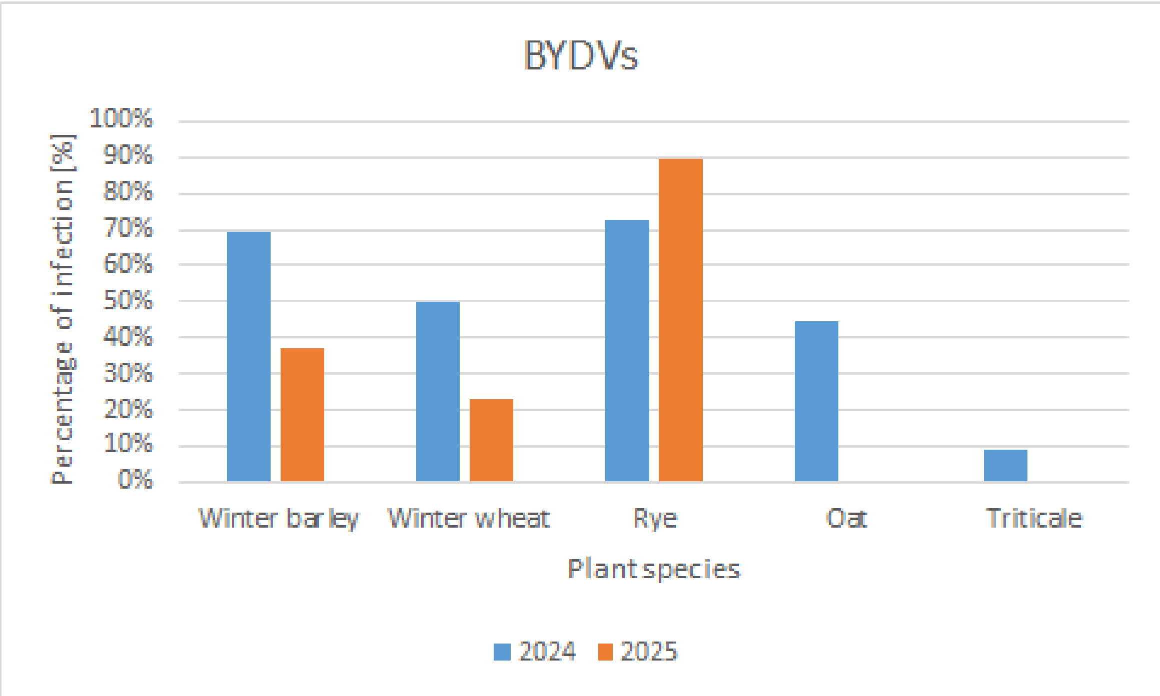

Fig. 1 Frequency of barley yellow dwarf virus complex detection in different virus-infected cereal crops

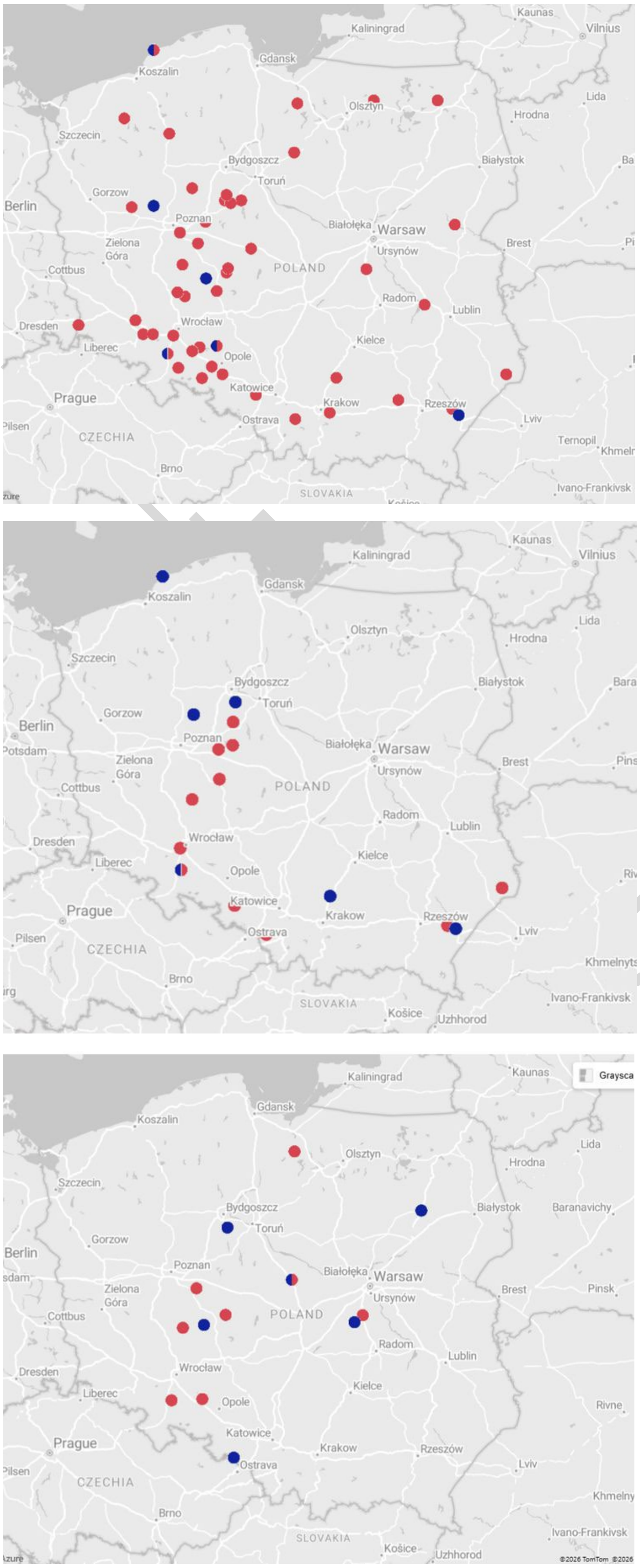

Fig. 2 Locations of winter cereal plants infected with barley yellow dwarf virus complex (a), wheat dwarf virus (b), and wheat streak mosaic virus (c), as detected in the 2023/2024 and 2024/2025 seasons

Fig. 3 Symptoms of barley yellow dwarf virus-PAS infection in barley cultivars growing in Opolskie voivodship in the 2023/2024 season

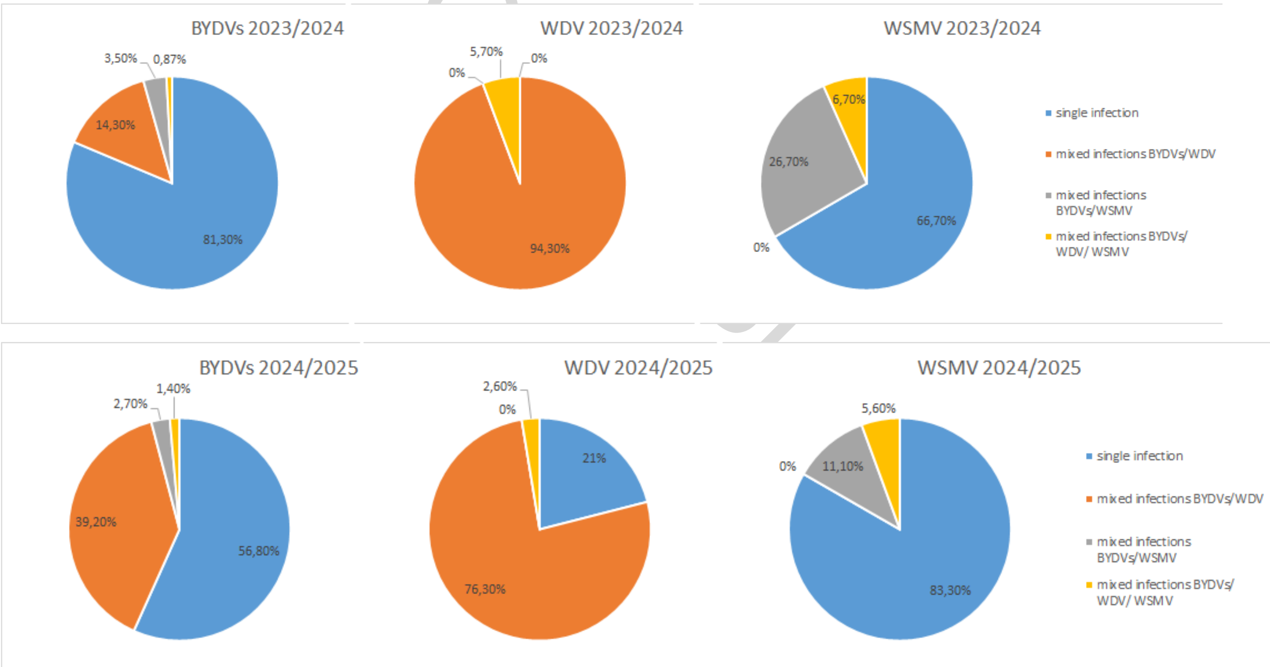

Fig. 4 Composition of viral infections in cereal plants collected in the 2023/2024 (a) and 2024/2025 (b) seasons

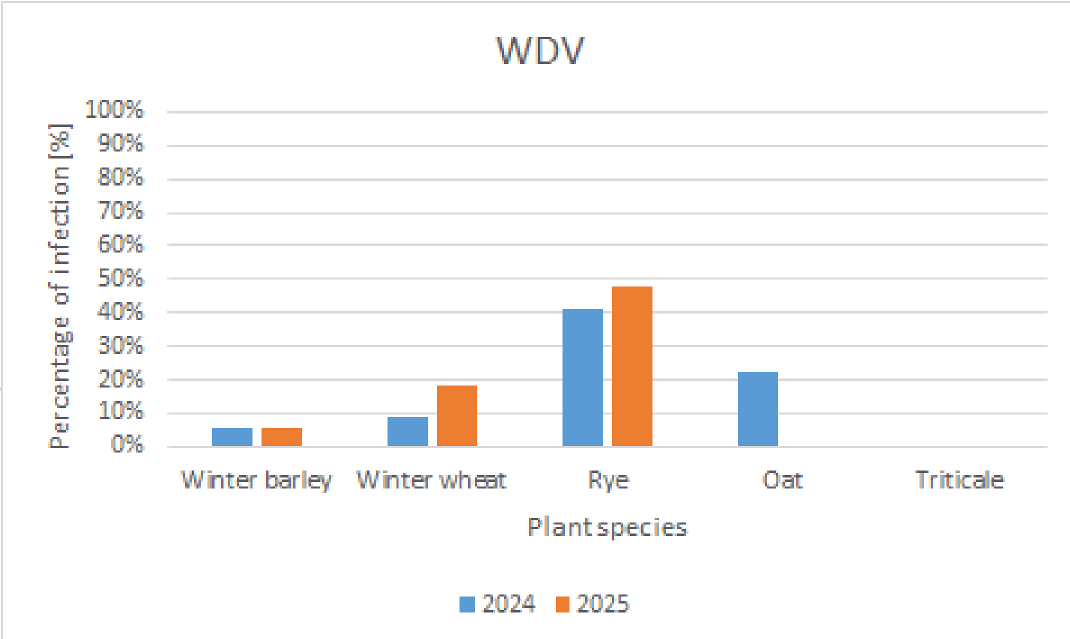

Fig. 5 Frequency of wheat dwarf virus detection in different virus-infected cereal crops

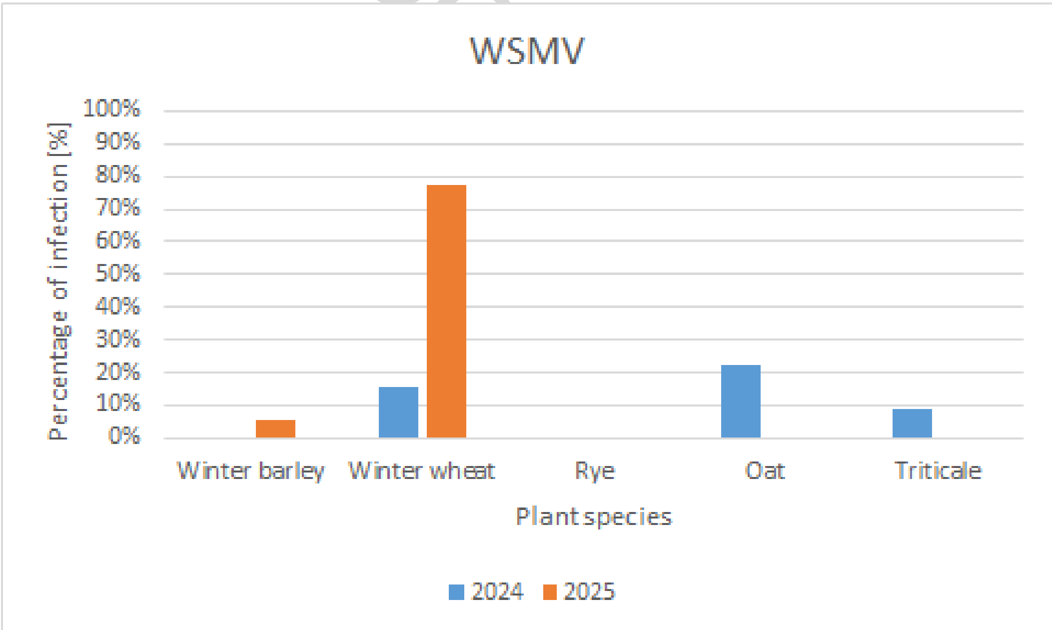

Fig. 6 Frequency of wheat streak mosaic virus detection in different virus-infected cereal crops

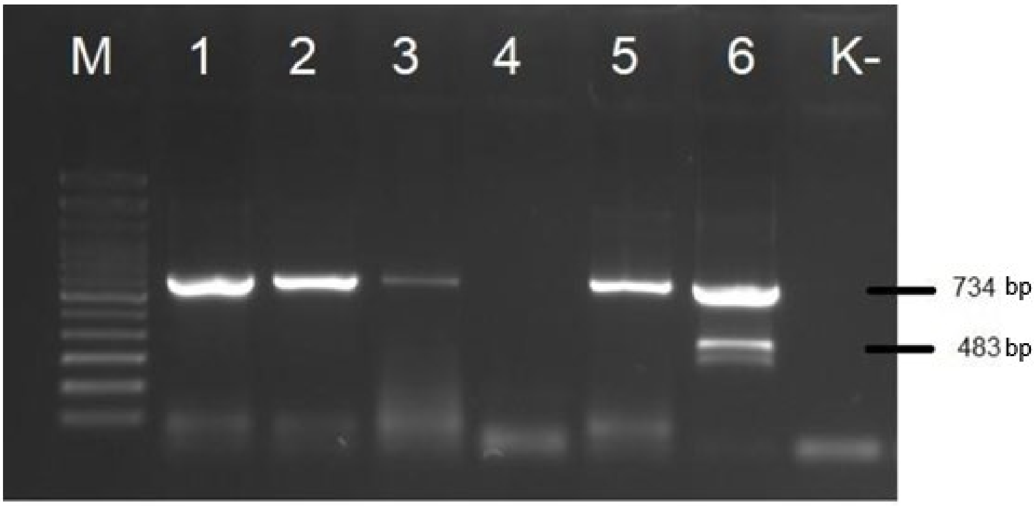

Fig. 7 Electrophoresis of duplex-IC-PCR products with WDV T-F/WDV T-R and WDV H-F/ WDV H-R primers pair

M – 100 bp DNA Ladder (Invitrogen, Thermo Scientific); 1 – positive control of wheat-specific form of wheat dwarf virus (WDV-W); 2- wheat samples from Kujawsko-Pomorskie voivodship infected with WDV-W; 3- rye sample from Wielkopolskie voivodship infected with WDV-W; 4- lack of reaction of wheat sample from Wielkopolskie voivodship; 5- rye sample from Dolnośląskie voivodship infected with WDV-W; 6- rye sample from Wielkopolskie voivodship co-infected with WDV-W and barley-specific form of wheat dwarf virus (WDV-B); K- – negative control

Table 1. Detection of barley yellow dwarf viruses, wheat dwarf virus, and wheat streak mosaic virus in winter form of cereals in Poland, in the season 2023/2024.

Cereal species	Locations (voivodeships)	DAS-ELISA results (number of infected plants/number of tested samples)		
		barley yellow dwarf virus	**wheat dwarf virus**	**wheat streak mosaic virus**
Winter barley	pomorskie	8/8	0/8	0/8
	warmińsko-mazurskie	7/8 [i]	0/8	0/8
	podlaskie	0/4	0/4	0/4
	lubuskie	0/2	0/2	0/2
	wielkopolskie	26/64 [A]	1/64	0/64
	kujawsko-pomorskie	2/6 [A]	0/6	0/6
	mazowieckie	4/4	0/4	0/4
	lubelskie	2/2 [A]	0/2	0/2
	dolnośląskie	29/30 [A]	1/30	0/30
	opolskie	37/37 [A]	5/37	0/37
	śląskie	1/1	0/1	0/1
	małopolskie	1/3 [A]	0/3	0/3
	podkarpackie	6/8 [A]	2/8	0/8
	In total	**123/177**	**9/177**	**0/177**
Winter wheat	zachodniopomorskie	0/6	0/6	0/6
	pomorskie	2/8 [A]	0/8	2/8 [ii]
	warmińsko-mazurskie	0/6 [A]	0/6	0/6
	podlaskie	0/8	0/8	0/8
	wielkopolskie	46/63 [A]	7/63	14/63 [B]
	kujawsko-pomorskie	5/9 [A]	5/9 [C]	0/9
	mazowieckie	0/2	0/2	0/2
	lubelskie	3/6 [A]	2/6 [iii]	0/6
	łódzkie	2/6	0/6	2/6 [B]
	dolnośląskie	10/16 [A]	0/16	2/16 [B]
	opolskie	18/32 [A]	1/32 [C]	5/32 [B]
	małopolskie	0/3	0/3	2/3
	In total	**86/173**	**15/173**	**27/173**
Rye	wielkopolskie	6/6 [A]	0/6	0/6
	mazowieckie	0/2	0/2	0/2
	dolnośląskie	10/14	9/14 [C]	0/14
	In total	**16/22**	**9/22**	**0/22**
Oat	wielkopolskie	1/4	1/4	1/4
	dolnośląskie	0/2 [A]	0/2	0/2
	opolskie	1/1 [A]	1/1	1/1 [B]
	małopolskie	2/2 [A]	0/2	0/2

	In total	**4/9**	**2/9**	**2/9**
Triticale	warmińsko-mazurskie	0/1	0/1	0/1
	podlaskie	0/4	0/4	0/4
	wielkopolskie	1/2	0/2	1/2
	mazowieckie	0/2	0/2	0/2
	opolskie	0/2	0/2	0/2
	In total	**1/11**	**0/11**	**1/11**
All Together		**230/392 (58.7%)**	**35/392 (8.9%)**	**30/392 (7.7%)**

Table 2. Detection of barley yellow dwarf viruses, wheat dwarf virus, and wheat streak mosaic virus in winter form of cereals in Poland, in the season 2024/2025.

Cereal species	**Locations (voivodeships)**	**DAS-ELISA results (number of infected plants/number of tested samples)**		
		barley yellow dwarf virus complex	**wheat dwarf virus**	**wheat streak mosaic virus**
Winter barley	wielkopolskie	1/2 [iv]	1/2	0/2
	śląskie	6/17	0/17	1/17
	In total	**7/19**	**1/19**	**1/19**
Winter wheat	podlaskie	0/2	0/2	2/2
	wielkopolskie	2/2 [A]	1/2	1/2 [v]
	kujawsko-pomorskie	1/4	2/4 [vi]	2/4 [B]
	mazowieckie	0/1	0/1	1/1
	łódzkie	0/10	0/10	10/10 [B]
	małopolskie	0/1	0/1	0/1
	podkarpackie	2/2	2/2	0/2
	In total	**5/22**	**5/22**	**16/22**
Rye	wielkopolskie	3/9	8/9 [Cvii]	0/9
	dolnośląskie	59/60 [A]	25/60	0/60
	In total	**62/69**	**33/69**	**0/69**
All together		**74/110 (67.3%)**	**39/110 (35.5%)**	**17/110 (15.5%)**

[i] Molecular confirmation of barley yellow dwarf virus – PAS
[ii] Molecular confirmation of wheat streak mosaic virus by sequencing
[iii] Molecular confirmation of wheat dwarf virus –W

[iv] Molecular confirmation of barley yellow dwarf virus - PAS
[v] Molecular confirmation of wheat streak mosaic virus
[vi] Molecular confirmation of wheat dwarf virus - W
[vii] Molecular confirmation of wheat dwarf virus - B