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Original Article

The influence of viral load on morphometric and biochemical parameters of potato plants

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Abstract

Viruses significantly affect various aspects of potato plants by inhibiting their growth and development and reducing their yield. Different potato varieties vary in their resistance to viruses, ranging from highly susceptible to completely resistant, and this is influenced by many factors including rational zoning. In this work, the effect of the PVX, PVY, PVM, PLRV, PVA, PVS and PSTVd viruses on the potato varieties Gala, Red Scarlett and Rosara were investigated. All three varieties were resistant to PVY in accordance with official registers. Mono-infection confirmed this resistance through the absence of morphological manifestations. The Gala variety was characterized only by poly-infection, which only led to a drop in the chlorophyll and carotenoid content, an increase in the malonic dialdehyde level and, accordingly, was manifested by leaf deformation, chlorosis and stem thinning. A proportion of 20.5% of the Rosara variety potatoes were infected with PVY. Poly-infection decreased the chlorophyll a level, increased the carotenoid and peroxidase levels, and slightly increased the MDA level, which resulted in leaf chlorosis. The uninfected Red Scarlett potatoes had low peroxidase levels, high MDA levels, and the lowest number of stems. The occurrence of PVY was highest in this cultivar (87.8%). Infection with the PVY and PVM viruses was accompanied by a decrease in chlorophyll a, an increase in MDA and slight chlorosis. Thus, viral infection, especially polyinfection, by increasing the level of malondialdehyde and disrupting the photosynthetic system, will lead to increased susceptibility of plants to biotic and abiotic factors.

Keywords: Potato viruses, Polyinfection of potatoes, Chlorophylls, Peroxidase, MDA, Carotenoids, Oxidation-reduction balance

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Introduction

Potato is an important crop consumed worldwide. Potato plants are exposed to various biotic and abiotic factors that affect their growth and development (Raymundo et al., 2018). Each stressor induces a complex cellular and molecular response implemented by the plant to prevent damage and ensure survival and leads to changes in a number of morphological and physiological parameters (Atkinson and Urwin, 2012; Jiang and Zhou, 2023). Among the biotic factors affecting the metabolism of potato plants, potato viruses have the most damaging effect by disrupting growth, development and reducing root yield and quality (Kapinga et al., 2009).

Viruses interfere with a wide range of plant processes, disrupting normal plant cell physiology, redirecting resource allocation, and diverting host plant energy to ensure replication and assembly of viral particles (Hyodo and Okuno, 2020). Changes in this case affect many different plant systems, including metabolism, hormonal system, photosynthesis process and antioxidant protection of plants. One of the serious effects of viral infection is the complex negative impact on the photosynthetic apparatus of the plant, which ultimately lead to the suppression of the photosynthesis process (Cheaib and Killiny, 2025). A decrease in chlorophyll content was shown in Nicotiana benthamiana infected with potato virus X (PVX) (Grishina et al., 2021) and tomato yellow leaf curl virus (Farooq et al., 2019); in cassava plants infected with cassava common mosaic virus (CsCMV) (Zanini et al., 2021), in potato plants infected with the PVY (Huseynova et al., 2018).

A decrease in photosynthetic activity leads to the manifestation of a number of morphological changes in potato plants, such as stunting, reduction of leaf plates, thinning of leaves and stems, necrosis and leaf death.

The plant antioxidant system is one of the main lines of defense of plants against stress factors such as viruses. In plant cells, the antioxidant defense system and the accumulation of ROS maintain a stable balance, which under stress conditions shifts towards the formation of ROS, resulting in cell damage and reduced plant productivity (Hasanuzzaman et al., 2012; Mittler, 2017). The repair reactions and normal ROS levels are maintained by the enzymatic and non-enzymatic antioxidant defense systems of plants (Hasanuzzaman et al., 2012).

Carotenoids belong to the non-enzymatic plant defense system, neutralizing peroxide radicals and preventing damage to cellular lipids and membranes (Stahl and Sies, 2003). In the photosynthetic system, carotenoids protect photosystems from photooxidative damage (Brody and Lemoin, 1989; Fang et al., 2008). In non-photosynthetic organs, carotenoids act as precursors of phytohormones and also exhibit antioxidant and photoprotective properties (Britton et al., 2009). Carotenoids are essential for plant survival under various biotic and abiotic stressors, such as high light, drought, salt stress, and pathogen attacks (Gomez-Sagasti et al., 2023). Carotenoid accumulation depends not only on the plant species but also on its cultivar (Sun et al., 2022).

Another important enzyme involved in both photosynthetic processes and redox reactions is peroxidase. On the one hand, peroxidase decomposes hydrogen peroxide, blocking the development of free radical processes that cause oxidative destruction of cells. On the other hand, it is itself capable of forming H_2O_2, which directly or through other free radicals suppresses the development of the infectious process (Wu et al., 1997). Viral invasion most often leads to rapid and extensive accumulation of reactive oxygen species (ROS) in infected tissues (Hernández et al., 2016; Akbar et al., 2020). Hyperproduction of ROS leads to oxidation and damage to cell membrane lipids, induces the accumulation of MDA as a product of lipid oxidation (García-Marcos et al., 2009).

Often in plants, co-infection with viruses causes more severe disease symptoms than mono-infection (Byarugaba et al., 2020). Alberto Garcia-Marcos showed that co-infection with potato PVX and PVY viruses caused severe oxidative stress in *N. benthamiana* leaves, as manifested by increased lipid peroxidation and superoxide radical formation in chloroplasts.

Different potato varieties differ in virus resistance, ranging from strong susceptibility to complete resistance (Baebler et al., 2020). This depends not only on the genetic characteristics given by the originator, but also on zoning and compliance with cultivation and crop protection conditions, as well as on timely monitoring of virus contamination of seed potatoes. In most cases, the register data contain information on resistance to potato cancer, golden potato nematode, and late blight. European registers contain incomplete information on varieties and on the resistance of specific varieties to viruses [The State Register of Selection Achievements Authorized for Use for

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Production Purposes. Vol. 1. Plant Varieties (official publication). Moscow: Rosinformagrotekh Publ., 2019. (in Russian); Agriculture and Horticulture Development Board (AHDB), 2018. Available online: https://potatoes.ahdb.org.uk (accessed on 10 November 2024].

In this study, we analyzed the resistance of three varieties of foreign selection: Gala, Red Scarlett (Netherlands), and Rosara (Germany) to viruses PVX, PVY, PVM, PLRV, PVA, PVS, and PSTVd, as well as their effect on some biochemical and morphometric indices.

Material and Methods

Experimental design

The study used potato plant samples of early maturing potato varieties Rosara (n = 36), Red Scarlett (n = 26) and mid-early variety Gala (n = 25), selected from potato farms in Novosibirsk region of the Russian Federation. Potato tubers of each variety were cultivated in plastic pots (0.7 L volume) in boxes at +24±1°C, photoperiod 16/8 hours: light/dark.

Determination of viruses in potato samples

Leaf samples for determining the incidence rate of viral were taken on the 4th week after planting from the upper, middle and lower tiers of plants. Viral RNA was isolated from the collected potato leaves using the PhytoSorb kit produced by SINTOL (Russia) according to the manufacturer's recommendations. RNA analysis was performed on a Rotor-Gene Q amplifier (QIAGEN, Germany). The presence of viruses in potato leaf samples was determined using SINTOL PV-005 reagent kit (potato virus X (PVX), virus Y (PVY), virus M (PVM), leafroll virus (PLRV), virus A (PVA), virus S (PVS) and tuber spindle viroid (PSTVd)). The presence of viruses was determined qualitatively, as an internal control reactions it was used a commercial recombinant plasmid produced by company SINTOL (Russia), included in the PCR reagent kit.

Morphometric and biochemical studies

Samples for biochemical parameters were taken from plants at the 4th week after planting. Also, on the 4th week after planting, morphometric indices of plants were measured: length of the above-ground part, number of stems and leaves. Biochemical parameters were determined by spectrophotometry using a Thermo Scientific Varioskan LUX spectrophotometer (THERMO FISHER Scientific, USA) in three repeats. Samples were homogenized using a MagNA Lyser homogenizer (ROCHE, Switzerland).

Determination of peroxidase activity (PO)

To determine peroxidase activity, potato leaves (100 mg) were homogenized in 0.15 M Na-phosphate buffer, pH 5.4. Guaiacol was used as hydrogen donor and hydrogen peroxide (0.15%) was used as substrate. The activity was determined by the formation of the reaction product tetraguaiacol (TG). The optical density was measured at 470 nm. The change in the optical density of the solution in 1 min was taken as the unit of enzyme activity. Activity A was expressed in relative units per 1 g of crude mass (or per unit of protein) according to the formula (Maechlay and Chance, 1954):

$$A = (D\_2-D\_1)VV\_2\times60/((t\_2-t\_1)V\_1H)$$

Determination of malonic dialdehyde

The level of lipid peroxidation (LPO) was determined by MDA content using the reaction with thiobarbituric acid (TBA). Optical density was measured in 96-well black plates at a wavelength of 532 nm (Stewart and Bewley, 1980).

Determination of photosynthetic pigment content

Plant leaves were sampled in the middle of the day when the pigment content of the plants is maximum. The samples (100 mg) were homogenized, centrifuged for 10 min at 10000 rpm, poured into 70% ethyl alcohol and placed in a dark place so that the pigments were not destroyed by light. Carotenoids were determined at 440.5 nm, chlorophyll a at 665 nm and chlorophyll b at 649 nm. The concentrations of chlorophyll a and b in the extract were calculated using Vernon's formula (Vernon, 1960):

$$Ca"(mg/l)"=11,63\cdot D665-2,39\cdot D649$$
$$Ca"(mg/l)"=11,63\cdot D665-2,39\cdot D649$$

where Ca, Cb are concentrations of chlorophylls a and b, mg/l.

The Wettstein formula (Von Wettstein, 1957) was used to determine the concentration of carotenoids (mg/L) in the total pigment extract:

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$$Ccar(mg/l)=4,695\cdot D440,5-0,268(Ca+b)$$

where Ca+b is the total content of chlorophylls a, b in the solution, mg/l.

Statistical analysis

Data obtained as a result of morphometric and biochemical studies are presented in the form of boxplot diagrams indicating median ("-"), mean ("x") upper and lower quartiles [Q1-Q3]. Pairwise comparisons were made between the control group ("no virus") and groups of plants infected with viruses using the nonparametric Mann-Whitney U-criterion with Bonferroni correction for multiple comparisons. In the case of 3 groups, differences were considered reliable at $p<0.025$ (0.05/2), in the case of 4 groups at $p<0.0167$ (0.05/3), and in the case of 5 groups at $p<0.0125$(0.05/4). Spearman's correlation coefficient was used for correlation analysis. The type of data distribution was determined using the Shapiro-Wilk criterion. The significance of differences between the studied groups was determined using STATISTICA 13 software package (StatSoft Inc., USA).

Results

Potato virus diagnosis

Based on the results of PCR testing of 85 samples, PVY and PVM viruses were detected on Red Scarlet variety. The percentage of plants affected by the two viruses was 53.8%, with the occurrence of PVY being the highest in this variety (87.8%). Gala variety had predominantly mixed virus load, with a combination of X, Y, M and S viruses at 48%. On variety Rosara, the percentage of plants infected with PVY was 20.5%, and polyinfection with PVY inclusion was 52.9% (Table 1). It should be noted the high infestation of plants of the studied potato varieties with PVY, which poses the greatest threat to the plant and has the most detrimental effect on potato yield.

Table-1. Data on the prevalence of potato viruses (%) in the Novosibirsk region, RF.

Variety		Red Scarlett	Gala	Rosara
Number of plants, pcs.		26	25	34
Types of Viruses, %	No viruse	11,5	36	14,7
	PVY	34	-	20,5
	PVS	*-	16	11,7
	PVY + PVM	53,8	-	-
	PVY + PVS	-	-	38,2
	PVX + PVY + PVM	-	12	-
	PVY + PVM + PVS	-	24	14,7
	PVX + PVY + PVM + PVS	-	12	-

*- virus not detected

Effect of viruses on potato morphometric indices

During the analysis of plant height and number of leaves in Gala variety, it was revealed that infection of potatoes with the combination of PVY+PVM+PVS viruses resulted in a 2.5-fold decrease in the number of leaves ($p=0.0016$) (Figure 1). Potato cultivar Rosara was also susceptible to virus infection: these plants showed a decrease in the number of leaves when infected with the PVY+PVS virus combination (1.4-fold, $p=0.0064$). Infection with viruses and their combinations of the studied varieties was not reflected in changes in stem number and height. It should be noted that the initial number of stems in the variety Red Scarlett was statistically significantly lower than in the other two varieties, 1 (1; 2), for Rosara 4 (3.5; 5), for Gala 6 (3.8; 7).

In mono-infection, viral symptomatology in plants of the studied varieties was practically absent. At the same time, when co-infected, symptoms characteristic of viral infection was observed: shoot thinning and chlorosis were observed in Gala and Rosara cultivars, leaf deformation in Gala cultivar, and leaf chlorosis in Red Scarlett cultivar.

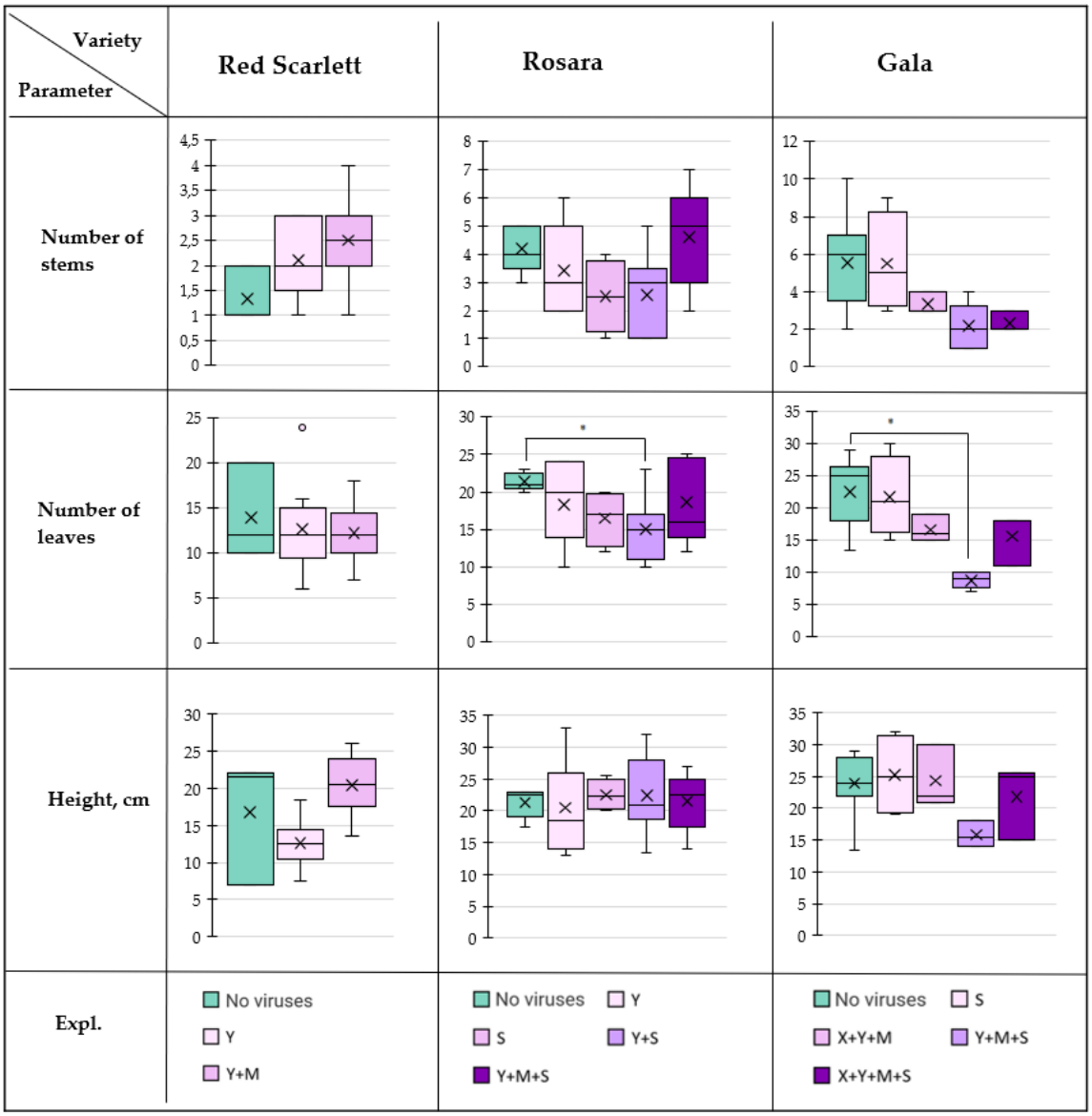

Figure-1. Morphometric parameters in infected and intact potato plants of different cultivars.

Effect of virus infection on biochemical parameters of potato plants

In potato plants of Red Scarlett, Gala and Rosara varieties, chloroplast pigments and carotenoids were analyzed, which take part not only in the functions of photosynthesis but also in plant defense. The levels of peroxidase and accumulated MDA were also evaluated. It was found that chlorophyll a concentration was reduced 1.6-fold (p=0.0098) in Red Scarlett plants infected with PVY and PVY viruses. Monoinfection with PVY also resulted in a decrease in chlorophyll b concentration (p=0.016). PVY+ PVY coinfection resulted in a 1.7-fold decrease in carotenoid concentration (p=0.0098) (Figure 2).

The activity of chlorophylls of chloroplasts involved in photosynthesis reactions is normally balanced by antioxidant systems of both chloroplasts themselves and the total enzymatic and non-enzymatic antioxidant systems of the plant. We analyzed the relationship between the parameters of peroxidase/carotenoids to MDA ratio, evaluating the contribution of these parameters to the disturbance of redox balance and accumulation of lipid peroxidation products.

A correlation analysis between the ratio of chlorophylls a and b and peroxidase to MDA was

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performed for all three analyzed cultivars (Figure 2, 3, 4). Figures 2, *c*; 3, *c;* 4 *c* show scatter plots and regression lines depicting the correlation between oxidative stress indices, as well as Spearman correlation coefficient values and their corresponding confidence levels ("p"). This relationship was not observed in plants of Red Scarlett variety (p>0.05) (Figure 2C).

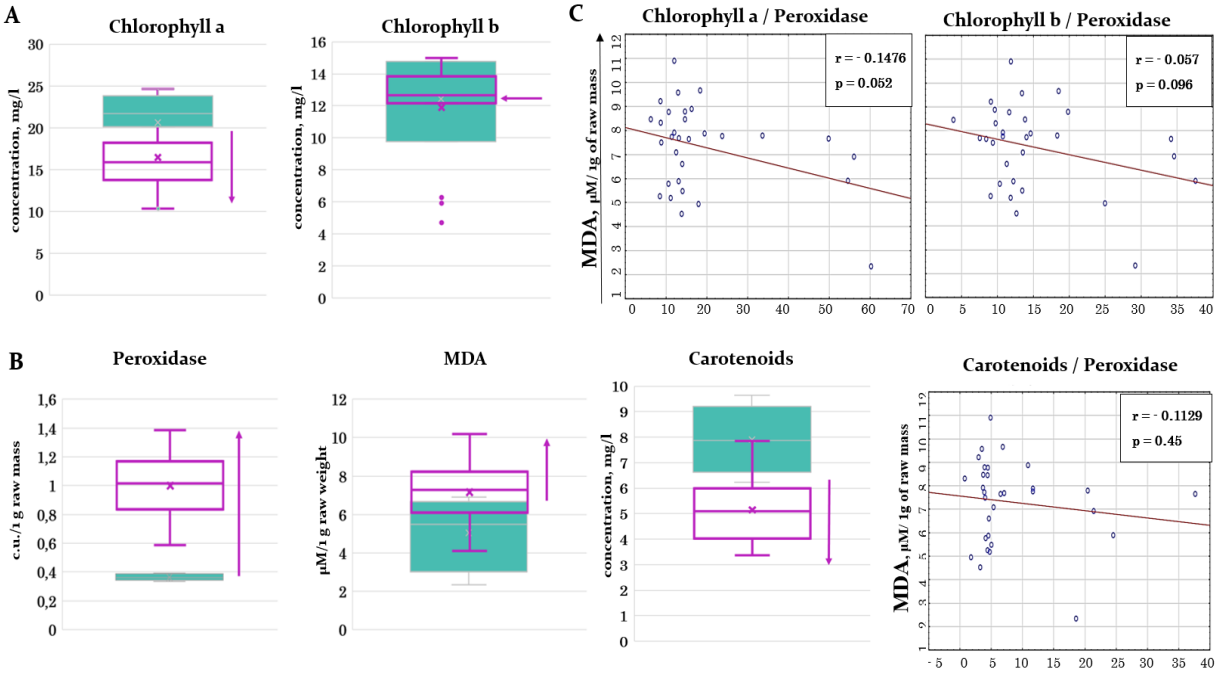

Figure-2. Change in biochemical parameters of potato plants under total virus load on Red Scarlett variety (initial level in virus-free plant - green; change during infection - pink). A - photosynthetic system; B - antioxidant system. C - Correlation analysis of biochemical parameters between carotenoid concentrations to peroxidase activity and MDA content.

It should be noted that plants of the Red Scarlett variety initially had the lowest peroxidase level, 0.37 (0.34; 0.39) units per 1 g of crude weight, and the highest initial MDA level, 5.9 (2.3; 6.9) µM/ 1 g of crude weight. Viral infection statistically significantly increased peroxidase levels (Figure 2B). Thus, in the case of coinfection (PVY+PVM), plants of Red Scarlet variety had statistically significantly increased peroxidase levels, 3.14-fold (p=0.0098), and 1.9-fold (p=0.016) in the case of PVY mono-infection, with no statistically significant increase in MDA levels.

The index of carotenoids to MDA content reflects the tension of antioxidant defense system of plant organism and its decrease indicates the quantitative pre-dominance of lipid peroxidation products over antioxidants. A 2.8-fold (p=0.014) decrease in the carotenoids/MDA ratio was observed in potato plants of the Red Scarlet variety under coinfection (PVY+PVM).

The correlation coefficient between the ratio of carotenoids/peroxidase and MDA content can serve as a complex indicator indirectly reflecting the efficiency of nonspecific defense systems of a plant organism. The presence of a strong negative relationship between the above-mentioned indicators testifies in favor of an effective response of the organism to viral infection. The balanced content of peroxidases generating ROS, low content of lipid peroxidation products and high content of natural antioxidants (carotenoids) can significantly retard viral invasion.

In our study, no significant relationship of carotenoids/peroxidase activity to MDA parameters was found for plants of the Red Scarlett cultivar, which may indicate the presence of other parameters significantly affecting the redox balance in plants of this cultivar (Figure 4C).

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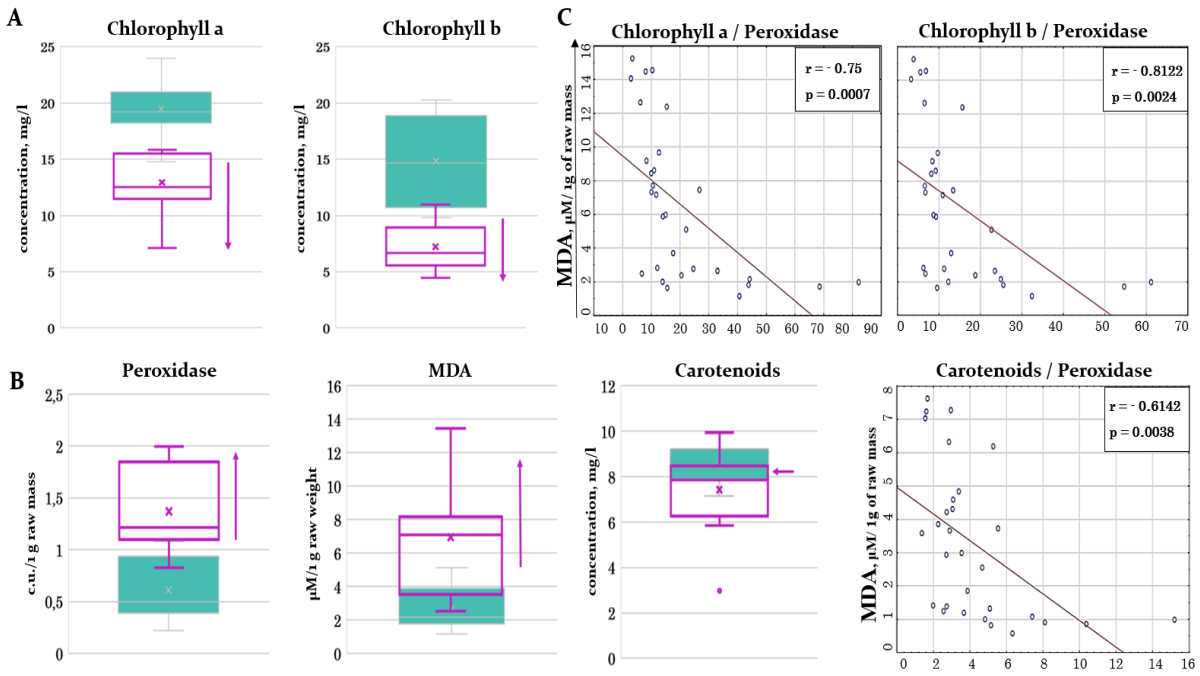

Figure-3. Change in biochemical parameters of potato plants under total virus load on Gala variety (baseline in virus-free plant - green; change during infection - pink). A - photosynthetic system; B - antioxidant system. C - Correlation analysis of biochemical parameters between carotenoid concentrations to peroxidase activity and MDA content.

As a result of the study of potato plants of Gala variety, there was a significant decrease in the concentration of chlorophyll a by 1.2 times (p=0.011) and chlorophyll b by 1.9 times (p=0.0018) when infected with the combination of viruses PVY+PVM+PVS compared to the control group. Despite the low chlorophyll a values in PVY+PVM+PVS+PVX polyinfection due to the small sample the data are not statistically significant, but Figure 3A clearly shows a significant decrease in chlorophyll a levels when all mono- and poly-infection data are considered. Correlation analysis between the ratio of chlorophyll a to peroxidase and MDA content revealed a strong (r = -0.75, p = 0.0007) negative relationship between these values; a strong negative relationship (r = -0.8, p = 0.0024) was also noted for chlorophyll b (Figure 3C).

In Gala plants, the concentration of peroxidases increased significantly 2.8 times only when carrying four PVX+PVY+PVM+PVS viruses (p=0.016). Infection with combinations of PVX+PVY+PVM and PVX+PVY+PVM+PVS viruses caused a 3-fold and 4.6-fold increase in MDA content, respectively (p=0.016). No statistically significant change in carotenoid levels was observed in either mono- or polyinfection (Figure 3B). Correlation analysis between peroxidase/carotenoid ratio and MDA content revealed a strong significant relationship between these parameters (r = -0.6142, p=0.0038) (Figure 5C).

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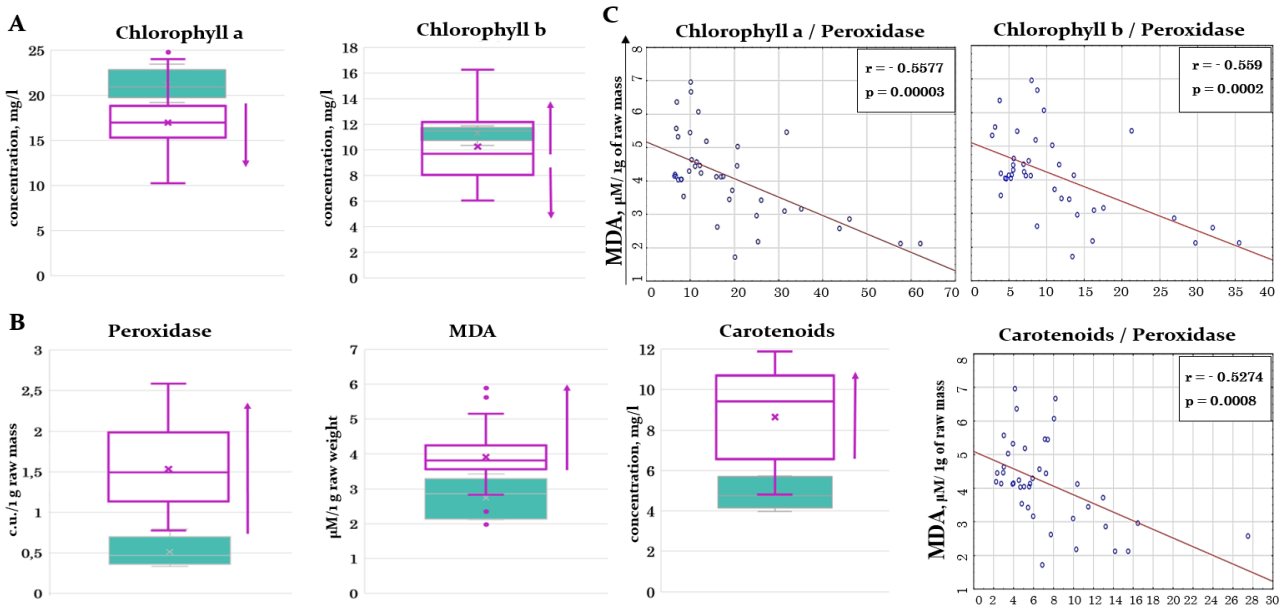

Figure-4. Change in biochemical parameters of potato plants under total virus load on Rosara variety (baseline in virus-free plant - green; change during infection - pink). A - photosynthetic system; B - antioxidant system. C - Correlation analysis of biochemical parameters between carotenoid concentrations to peroxidase activity and MDA content.

In turn, in plants of the variety Rosara, the content of chlorophyll a decreased by 1.3 times (p=0.012) during PVY+PVM+PVS coinfection, while the level of chlorophyll b did not have statistically significant changes either during mono- or polyinfection (Figure 4A). The chlorophyll a/peroxidase to MDA ratio on the cultivar Rosara shows a strong inverse relationship between these parameters (Figure 4C).

Infection of plants of different cultivars with combinations of viruses leads to an increase in the content of peroxidases in a given cultivar (Figure 4B). Their con-tent increased on average 3-fold relative to the control when co-infected with PVY+PVS (p=0.0022) and PVY+PVM+PVS (p=0.012). MDA analysis revealed that infection with PVY+PVS combination promotes its level increase 1.6 times (p=0.0016), and with PVY+PVM+PVS combination 1.8 times (p=0.012). Infection with PVY+PVM+PVS virus combination of Rosara variety increased carotenoid content compared to intact plants (p=0.012), which was not observed in plants of Gala and Red Scarlett varieties. Plants of two varieties (Gala and Rosara) show a strong negative relationship between the carotenoids/peroxidase ratio and MDA concentration (correlation coefficients lie in the range (-0.7 -0.5) (Figure 3C, 4C). This proves that these parameters contribute significantly to the maintenance of redox balance in plants of these cultivars.

Discussion

Potato is the fourth most important food crop in the world and the first most important non-grain crop (Makarova et al., 2017). Viral potato pathogens cause significant damage to potato agrocenoses (Beriso et al., 2024), increasing their susceptibility to several other pathogens, reducing their yields and product quality. In Russia and abroad, viral diseases are monitored in potato seed material (Daurov et al., 2023; Maslennikova et al., 2024). Both mono-infections and combined infections are detected.

In our studies, a high level of both mono-infection (PVY, PVS) and co-infection (PVY+PVM; PVX+PVY+PVM; PVY+PVM+PVS; PVX+PVY+PVM+PVS) in the potato plants was revealed, which amounted to 80% of all tubers. The high degree of infection of plants with PVY should be noted. All three analyzed varieties are resistant to PVY according to Russian and foreign registers. The high level of infection found in this study is probably due to the untimely diagnosis of seed material, as well as the cultivation of virus-susceptible and not adapted to the region potato varieties.

In response to a stressor (in this case, viral invasion), plants react by changing a number of biochemical parameters. One of the main systems of the plant response to pathogens is redox reactions. In the defense response of plants to pathogen attack, peroxidases are often the first to alter their activity, producing ROS (Passardi et al., 2005). An excess of oxidants in the case of antioxidant deficiency becomes a destructive factor contributing to the formation of lipid peroxidation products. A high MDA content can further stress the plant, facilitating invasion by other pathogens (Morales and Munné-Bosch, 2019). Huseynova et al. showed that viral infection resulted in 1.5-2-fold higher MDA content in tomato plants compared to that in uninfected plants. Unexpectedly, the highest MDA increase, and the most detrimental effects were observed in the plants infected with a single virus compared to those exhibiting poly-infection (Huseynova et al., 2018). In our experiments, on the contrary, the maximum increase in the MDA level (1.6-4.6-fold) was observed in the co-infected potato plants and this affected their morphology, reducing the leaf number. It is possible that the discrepancies between our data and the results obtained by Guseinova are related to the varietal differences in plants when exposed to mono and mixed viral infections. Our study analyzed 3 different potato varieties, and the analysis showed slightly different results for each of them. It is worth noting that, initially, the Red Scarlett plants had the lowest peroxidase level and the highest MDA level, and a statistically significantly lower stem number out of the three studied varieties in terms of their morphological parameters.

Natural antioxidants such as carotenoids and ascorbic acid play an important role in the plant defense against elevated ROS levels. Anna Villalba et al. showed that the infection of potato plants with SPLCV led to a decrease in the carotenoid and ascorbic acid content in the rhizomes of diseased plants (Villalba et al., 2024). In our study, we conducted a correlation analysis between the parameters of the carotenoid level and peroxidase activity and the formation of MDA. We showed a strong correlation between these parameters in two of the studied varieties - Gala and Rosara. This indicates the significant participation of carotenoids in the antioxidant defense system of these varieties. However, we did not observe any correlation of the mentioned parameters for the variety Red Scarlett. A rather unusual picture was observed for this variety: low levels of peroxidase and carotenoids against a back-ground of high MDA levels and no statistically significant changes in morphological traits during infection. High MDA levels make the plant more vulnerable to other pathogens and abiotic environmental factors. It is noteworthy that the variety is sensitive to various fungal pathogens (Available online:
https://www.hzpc.com/search?q=Red+scarlett).
However, our experiment excluded these factors when cultivated under artificial conditions, which may have prevented the plant from being infected by these pathogens. Perhaps the development of elevated MDA levels in the uninfected plants is due to the oxidants produced during photosynthesis and the insufficient levels of reducing agents of both chloroplasts and the major enzymes of the antioxidant system, the analysis of which was not included in this study.

Viral infections in plants alter various metabolic pathways, with photosynthesis and chloroplasts being the most frequently vulnerable and studied (Hou et al., 2020; Zhao et al., 2016). The effect of viruses on the chloroplast structure and function usually results in the depletion of photosynthetic activity, and the most common viral symptom reflecting structural changes in chloroplasts is leaf chlorosis (Zhao et al., 2016). In our study, infection with several viruses caused chlorosis and necrosis in plants, which was confirmed by data from biochemical studies, displaying a decrease in the chlorophyll a and b concentration. At the same time, in the case of mono-infection, in the potato leaves, there was no chlorosis symptomatology and no significant change in these biochemical parameters was detected.

Viral infection is known to reduce photosynthetic pigments (Li et al., 2016). A reduction in chlorophylls a and b by 40% and 32%, respectively, in susceptible plants compared to resistant plants has been reported for cowpea severe mosaic virus (CPSMV) (Souza et al., 2017). Milavec et al. (Milavec et al., 2001) evaluated the correlation between the chlorophyll content and the soluble and ion-bound peroxidase activity during the infection of the Igor cultivar with potato YNTN virus and showed an inverse correlation between these parameters. In our study, a typical drop in the chlorophyll a level during virus infection was observed for the three tested cultivars, but chlorophyll b remained unchanged in the Red Scarlett and Rosara varieties. The greatest total drop in chlorophyll a and b was observed for the Gala cultivar under poly-infection involving PVX. PVX has been shown to

accumulate in large amounts in chloroplasts, inhibiting its function (Qiao et al., 2009).

A correlation analysis between the ratio of chlorophyll a and b and peroxidase to the MDA level showed a significantly strong negative correlation for the Rosara and Gala cultivars and no correlation between these parameters for the Red Scarlett cultivar. Considering the data from Milavec et al. (Milavec et al., 2001), it can be assumed that the normal functioning of chloroplasts and the preservation of chlorophyll levels in relation to peroxidase activity protects plants from MDA accumulation. For the Red Scarlett variety, this is not obvious, which is most likely due to the disruption of the chloroplast redox balance system and the high and uncompensated ROS levels during photosynthesis. The Red Scarlett variety is resistant to PVY. This variety is strongly resistant, as there are practically no morphological signs of lesions and leaf chlorosis is insignificant. In our research more than 80% of the Red Scarlett plants were carriers of PVY without showing morphological signs of viral lesions, which is probably explained by the high level of ROS. Unfortunately, the databases of both the Russian Federation and the European Community do not provide information on the resistance to potato viruses other than PVY. All three analyzed varieties are resistant to PVY according to Russian and foreign registries.

The Rosara variety has high resistance to the PVA, PVY viruses (Solana Group. Available online: https://www.solana.de/list-of-varieties). The Gala variety's resistance to PVY has been confirmed by NORIKA GmbH. (Available online: https://norika.biz/Sortenkatalog). The Red Scarlett variety shows medium to high resistance to PVY. It is noted that the shoots of Red Scarlett plants are susceptible to PVY, while the tubers show high resistance (HZPC. Available online: https://www.hzpc.com/search?q=Red+scarlett). The Gala variety had the lowest number of plants infected with PVY (48%), and these exhibited poly-infection, showing a decrease in the leaf number. In the case of the Rosara variety, mono-infection (20%) did not lead to changes in either the biochemical or morphological parameters. Polyinfection changed the biochemical parameters, reducing the leaf number.

Excess peroxidase activity and insufficient chlorophylls and carotenoids may lead to plant energy stress and redox balance disorders, affecting the plant viability and susceptibility to pathogens.

Conclusion

The three potato varieties under study have different virus carriage and virus resistance. The strong negative relationship of chlorophyll and the carotenoid/peroxidase-to-MDA ratio indicates the contribution of these parameters in maintaining the redox balance and reducing lipid peroxidation in the Gala and Rosara varieties. The infection of these varieties with a complex of viruses resulted in increased MDA levels and a reduced leaf number. The Red Scarlett variety initially had an impaired redox balance characterized by high MDA levels and a reduced stem number. The Red Scarlett variety had the highest PVY infection rate both as a mono-infection and in combination with PVM, while showing no morphological signs of disease under artificial growing conditions, which shielded it from pathogenic effects. High levels of oxidants protect Red Scarlett plants from infection by other viruses, but MDA accumulation will reduce the resistance of these plants to various stressors under field conditions.

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Contribution of Authors

Maslennikova V: Conceptualization, research methodology, investigation, writing of original draft, review and editing.

Shelikhova E, Mosalev K & Tabanyukhov K: Research methodology, literature review, investigation and formal analysis.

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