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Role of plant viral infection in the inhibition of potato immune responses to the damage caused by leaf-eating pests

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ABSTRACT

Relevance. There are very few studies on the role of plant viral infection in inhibiting the immune response of potato plants to the damage caused by leaf-eating pests; the available data has a fragmental character.

Materials and Methods. The research was carried out in an experimental field of FSBSI "FSC of Agricultural Biotechnology of the Far East named after A.K. Chaiki" in 2020-2023. The following potato varieties of Russian and foreign breeding origin were used in the experiment: Belmonda, Sante, Dachnyi, Yantar', Avgustin, Yubilyar, Kazachok, Red Lady, Labella, Queen Anne, Laperla, Smak, Lilly, Arktika, Svitanok Kievskii, Nakra, Dal'nevostochnyi, and Severnyi. The progression of plant viral infection and the degree of the damage caused by *Henosepilachna vigintioctomaculata* were assessed on a point scale.

Results. The research established a direct correlation between a decrease in the immune response of potato plants to leaf-eating insects and the accumulation of viral infection without the renewal of planting material. Potato varieties Svitanok Kievskii, Nakra, Dal'nevostochnyi, and Severnyi were observed to have latent viral infection (from 0 to 0.5 points) in the first year of the experiment (2022) and were not susceptible to the potato ladybird beetle. Mixed plant viral infection manifested itself on potato plants in 2023 decreasing the immunity of the plants to phytophagous insects, particularly to the potato ladybird beetle. The progression of plant viral infection on variety Svitanok Kievskii reached four points while the degree of the damage caused by the potato ladybird beetle to potato plants was 1.2 points. The progression of plant viral infection scored about two points on varieties Nakra and Severnyi with a damage degree of one point. Variety Dal'nevostochnyi was the least susceptible to plant viral infection and the degree of damage was minimum as well.

KEYWORDS:
plant virus, phytophage, immunity, potato

Роль фитовирусной инфекции в ингибировании иммунного ответа картофеля на повреждения листогрызущими вредителями

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РЕЗЮМЕ

Актуальность. Исследований, посвященных роли фитовирусной инфекции в ингибировании иммунного ответа растений картофеля на повреждения, вызванные листогрызущими вредителями, крайне мало; имеющиеся данные носят фрагментарный характер.

Материал и методы. Исследования проводили на опытном поле ФГБНУ «ФНЦ агробиотехнологий Дальнего Востока им. А.К. Чайки» в 2020–2023 годах, в эксперименте использовали сорта отечественной и зарубежной селекции: Belmonda, Sante, Дачный, Янтарь, Августин, Юбиляр, Казачок, Red Lady, Labella, Queen Anne, Laperla, Смак, Lilly, Арктика, Свитанок Киевский, Накра, Дальневосточный, Северный. Проявление фитовирусной инфекции на растениях картофеля и балл повреждения растений картофеля *Henosepilachna vigintioctomaculata* оценивали в баллах.

Результаты. Нами обнаружен факт уменьшения иммунного ответа картофеля по отношению к листогрызущим насекомым от накопления вирусной инфекции в условиях отсутствия обновления посадочного материала картофеля. Так сорта Свитанок Киевский, Накра, Дальневосточный, Северный в первый год изучения (2022 год), имели латентное протекание фитовирусной инфекции (от 0 до 0,5 баллов проявления фитовирусов на растениях) и не поедались картофельной коровкой. В 2023 году смешанная фитовирусная инфекция проявилась на растениях, вследствие чего снизился иммунитет картофеля к фитофагам, и в частности к картофельной коровке. На сорте Свитанок Киевский проявление фитовирусной инфекции составила 4 балла, соответсвенно и повреждения от картофельной коровки на этом сорте составили 1,2 балла, сорта Накра и Северный имели около 2-х баллов проявления фитовирусной инфекции и по 1 баллу поражения картофельной коровкой, сорт Дальневосточный минимально поразился фитовирусной инфекцией и повреждения от фитофага тоже были минимальные

КЛЮЧЕВЫЕ СЛОВА:
фитовирус, фитофаг, иммунитет, картофель

Introduction

The ecosystemic functions performed by the immunogenetic system of plants in agricultural landscapes are a complex and poorly studied aspect of plant immunology. Consequently, both strategies for creating plant genotypes with certain traits and the strategies of their use under the conditions of sustainably functioning agroecosystem are understudied as well. Plants constitute the basis of any ecosystem and have unique ecological relations with their environment. This determines their specific biogeochemical activity and ability to transform the environment making it suitable for heterotrophs such as phytophagous and entomophagous insects, microorganisms, and others populating a given ecosystem [1]. The immunogenetic features of both autotrophs and consumers of all trophic levels are among the key mechanisms preserving the stability in ecosystems [2]. According to the general principles of immunology, the immunity of a particular species manifests itself only in the process of interaction between members of specific ecological systems in the form of interaction among phenotypes [2]. The balanced management of the phytosanitary state of agroecosystems facilitates the stable production of high-quality and environmentally safe products [3]. Any agroecosystem is a totally new environment, which changes the species composition and structure of animal communities, and most of all it influences insects [4]. The predominance of a single plant species over a large area creates favorable conditions for the multiplication of phytophagous insects and determines their feeding specialization [5]. Besides causing direct damage to agricultural plants while feeding on them, phytophagous insects can be vectors of viral infections. A high number of insect vectors in combination with optimal weather conditions for the overwintering and further development of imagines are the main causes of the damage inflicted by plant viruses on agricultural crops [6]. The potato ladybird beetle is the most dangerous pest of potato in the Russian Far East. The insects appear on plants at the germination stage and remain in the fields until harvesting [7]. H. vigintioctomaculata is a vector of the potato viruses that might lead up to a 60% yield loss. Viral infection accumulates over time and can be transmitted to the next generation of plants via tubers. This results in the degeneration of a given potato variety and might decrease its yield by 30-80% [8, 9]. Moreover, it has been discovered that phytophagous insects prefer to feed on diseased plants more often than on non-infected ones [10-13]. However, there are very few studies on the role of plant viral infection in inhibiting the immune response of potato plants to the damage caused by leaf-eating pests; the available data has a fragmental character. This determined the goal of our research.

Materials and methods

The research was conducted in an experimental field of FSBSI "FSC of Agricultural Biotechnology of the Far East named after A.K. Chaiki" in 2020-2023. The following varieties of Russian and foreign breeding origin was used in the experiment: Belmonda, Sante, Dachnyi, Yantar', Avgustin, Yubilyar, Kazachok, Red Lady, Labella, Queen Anne, Laperla, Smak, Lilly, Arktika, Svitanok Kievskii, Nakra, Dal'nevostochnyi, and Severnyi. Over the four years of our research, the potato varieties were planted in the same experimental field and the planting material was not renewed but harvested from that location. The research assessed the progression of plant viral infection and the degree of the damage caused by the potato ladybird beetle to potato plants. The progression degree of plant viral infection was evaluated by the number of plants with symptoms from the total number of the studied plants (%) at the end of the germination stage, at the stages of bud development and flowering, and before harvesting. The 10-point scale established by the International COMECON List of Descriptors for *Tuberarium* (Dun.) Buk. species of the genus *Solanum* L. for evaluating virus resistance was used to assess the disease progression on particular plants [14]. The degree of the damage caused by *Henosepilachna vigintioctomaculata* to potato plants was evaluated according to Vilkova (2023) [15]. Potato variety Arktika was used as the standard because phytophagous insects preferred to feed on it.

RT-PCR was employed to check all the plants in the samples for viral infection. The presence of certain plant viruses in the samples was analyzed by one-step RT-PCR with fluorescent detection in real time using a QuantStudio 5 amplifier (Applied Biosystems) and commercial kits "Potato Virus X. Y. M. L. S. A – PB" (Syntol Llc), the Phytoscreen series, designed for the identification of PVX, PVY, PVM, PLRV, PVS, PVA, and PSTVd [16, 17]. The statistical processing of the research results was performed with Past v.4.03 [18, 19]. The experimental data were visualized using MS Exel.

Results

Mixed viral infection (viruses from mosaic group: PVY, PVX, PVA, PVS, PVM; potato leaf roll virus, and potato spindle tuber viroid) was found in an agroecosystem of the potato field in Primorsky kray [20].

Our research established that the amount of plant viral infection increased in potato plants with each subsequent generation when potato was planted in the same field and the harvest of the preceding year was used as planting material. The epidemiological significance of the spread of plant viruses via tubers is determined by the fact that even a low initial amount of infection in seeds can increase through the multiplication of plant viruses in tubers and seeds with the successive transfer of those viruses to other plant parts. The transmission of plant viruses via potato tubers is important for the environment as well because it allows viruses to survive in the time between growing seasons [21]. According to our data, viral infection accumulated in potato tubers with each growing season – the average degree of the damage caused to the studied potato varieties was 1.1 in 2020 and 3.6 in 2022. Over the three years of our research, the influence of infected plant material on the manifestation of plant viral infection was the highest in potato varieties Belmonda, Sante, Dachnyi, Yantar', Avgustin, Yubilyar, Kazachok, Red Lady, Labella, and Queen Anne. The degree of damage increased with every growing season. The progression of plant viral infection decreased slightly on varieties Laperla, Smak, and Lilli in the second year of the research compared to 2020 and then increased drastically in 2022. Variety Belmonda displayed very few visual symptoms of plant viral infection in 2020; however, the performed PCR discovered latent viral infection in the tubers and other plant parts of this variety.

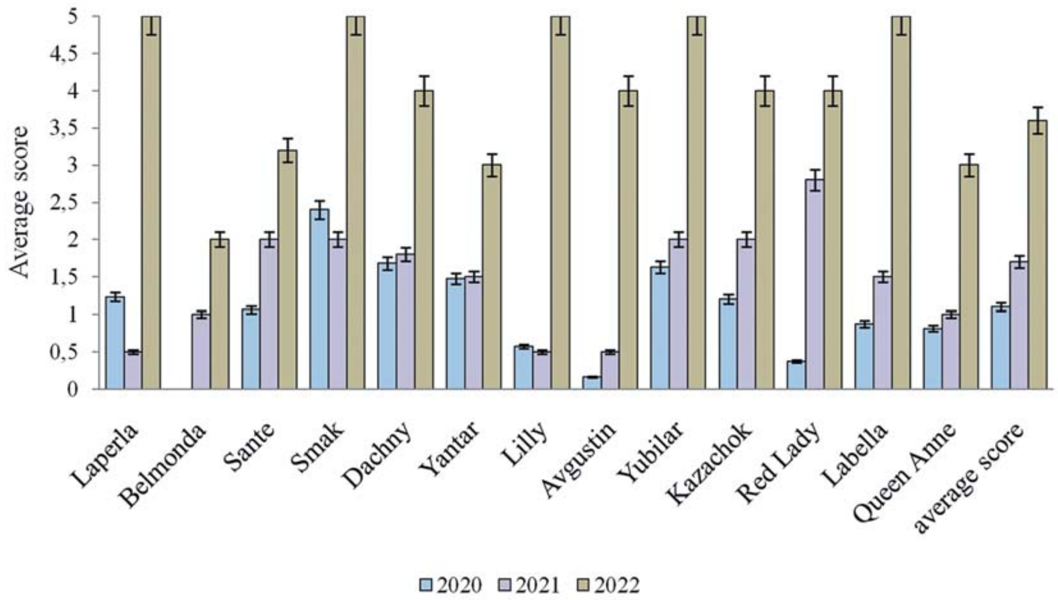

Fig.1. Progression of plant viral infection on the studied potato varieties (on a point scale) [22]
Рис.1 Повреждение сортов картофеля фитовирусной инфекцией (оценка в баллах) [22]

The same results were obtained for varieties Avgustin and Red Lady. Thus, the plant viral infection accumulated in tubers and led to an increase in the number of plants with visual symptoms in every subsequent growing season [22] (Figure 1). Our data are in agreement with the findings of Lapshinov N.A. (2010), whose field experiments demonstrated that viral infection accumulated in subsequent plant generations in most cases. For example, the degree of the damage caused by PVY, PVX, and PVM to potato plants in his research increased by 0.4-3.8% compared to the preceding year [23].

The manifestation of viral infection on potato leaves depends on the resistance of a particular variety. Susceptible varieties develop localized and systemic symptoms due to the multiplication and spread of viruses inside plants. Tolerant genotypes show very weak or no visual symptoms. The result of an interaction between a plant virus and a plant depends on the potato genotype, the environment, and the strain of the virus. Potato varieties have different genetic bases, which produce different responses to viral infection [24].

It is well known that viruses are transmitted from diseased plants to healthy ones mainly by insect vectors [23, 21]. Infected plants are able to affect the behavior of insect vectors and make pests to feed on their diseased tissues more actively. The behavior of viral vectors and their choice of fodder plants depend both on the visual and attraction signals of plants [21]. According to our data, the potato ladybird beetle is the main vector of potato viruses in Primorsky kray [25]. It should be noted that that potato ladybird beetles did not choose potato plants of variety Belmonda for feeding in the first year of our experiment. The lesions caused by the pest were rarely found on plant tissues and the symptoms of plant viral infection were observed only around the bites. The degree of the damage was 4.5 points on varieties Smak, Yubilyar, and Yantar', and 3.2 points on variety Laperla. These varieties had the most advanced progression of viral infection as well (Figure 2).

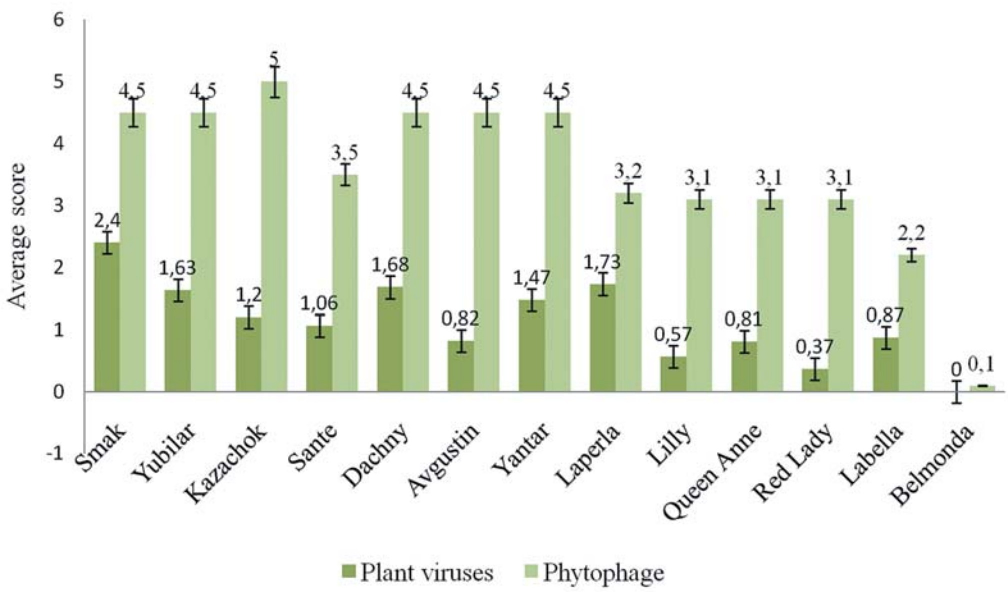

Fig. 2. Manifestation of plant viral infection on the studied potato varieties and the degree of insect damage (2020)
Рис. 2 Проявление симптомов вирусной инфекции и балл повреждения насекомыми на сортах картофеля (2020 год)

Plant viral infection accumulated in potato tubers over the second and third year of the experiment (2021 and 2022). As a result, the number of plants with visual symptoms of viral infection increased and the immunity of plants reduced. Thus, the inhibition of the immune response of potato plants to the damage caused by the potato ladybird beetle was observed. Even those potato varieties that initially had not been preferred by the pest became more attractive for the phytophagous insect in successive years. For example, variety Belmonda did not display any symptoms of plant viral infection in 2020 and was not preferred by the pest in 2021. However, the potato ladybird beetle was observed to actively feed on variety Belmonda after the progression of mixed viral infection reached two points during the growing season of 2022. The potato ladybird beetle did not feed on varieties Svitanok Kievskii, Nakra, Dal'nevostochnyi, and Severnyi in 2022 and these varieties were found to have only latent viral infection. The control variety Arktika had a damage degree of three points (Figure 3). In 2023, there were visual symptoms of mixed viral infection on plants and their immunity to phytophagous insects, particularly to the potato ladybird beetle, reduced. The progression of plant viral infection on variety Svitanok Kievskii reached four points and the degree of the damage caused by the potato ladybird beetle was 1.2 points. Viral infection progressed to about two point in varieties Nakra and Severnyi and the damage degree was about one point. Variety Dal'nevostochnyi was the least susceptible to plant viral infection and the degree of the damage caused by the phytophagous insect was minimum as well (Figure 3).

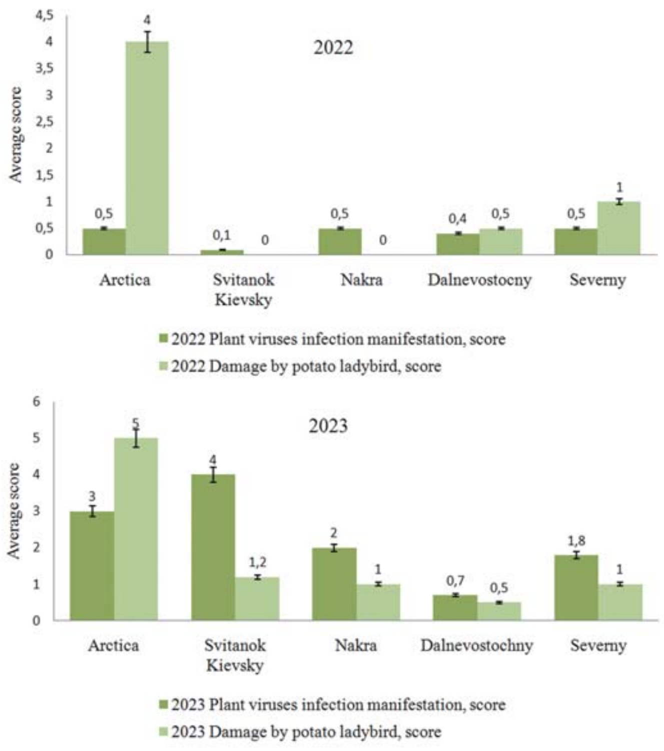

Fig. 3. Progression of plant viral infection and the degree of the damage caused by phytophagous insects in 2022 and 2023
Рис. 3. Повреждения сортов картофеля фитовирусной инфекцией и фитофагами в 2022 и 2023 годах

To verify the correlation between a decrease in the immune response of potato plants to the damage caused by leaf eating insects and an increase in the amount of the plant viral infection accumulated in those plants, we performed a correlation analysis according to Pearson. The Pearson correlation coefficient was 0.6873 demonstrating a high positive correlation, which revealed a tendency for the degree of the damage caused by phytophagous insects to increase depending on the amount of viral infection in potato plants. This was confirmed by a high coefficient of determination (0.4724). This might be connected to the activation of specific protective mechanisms, which in their turn affect the concentration of a virus in the organs of a host plant [26]. Viral infection significantly changes the metabolism of plants and reduces their photosynthetic activity suppressing the carbohydrate metabolism and other metabolic processes. Chloroplasts degrade, change, or are aggregated due to viral infection; this leads to the destruction of chlorophyll or its non-involvement in the synthesis. The degree to which photosynthesis is suppressed depends largely on the disease progression and the characteristics of a virus strain and a host plant as well as the environmental conditions [27]. When a plant is infected, a coordinated interaction of regulatory signal pathways can be observed. This results in the expression of resistance genes and the strengthening of plant protection against pathogens. Studying the mechanisms of antiviral protection in plants has shown that when an infection is present these mechanisms activate the genes that produce PR proteins, which are the proteins related to pathogenesis. The accumulation rate of PR proteins depends on the character and degree of the damage caused to plants. Some PR-proteins such as proteinases and β-1.3-glucanases facilitate the infection of plants by viruses. Other PR-proteins such as the inhibitors of proteinases, ribonucleases, and peroxidases, effectively protect plants against viruses [28]. The properties of viruses, their response to the presence of resistance genes in plants, and the interactions among vectors as well as the combination of the abovementioned factors in the epidemiological structure form the conception of plant viral infection management [26].

Thus, our research discovered a decrease in the immune response of potato to leaf-eating insects due to the accumulation of plant viral infection without the renewal of planting material. The planting material was not renewed in our experiment and the concentration of plant viruses rose in an agroecosystem increasing the amount of additional plant viral infection and facilitating the secondary infection of potato plants. The plant viral infection inhibited the immune response of potato plants to the damage caused by leaf-eating insects. As a consequence, the varieties that had not been susceptible to pests became less resistant to phytophagous insects. All these factors might be counted among the causes of the development of epiphytotic situations.

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