IRSTI 68.37.13

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Potato viruses in Kazakhstan and methods for obtaining virus-free seed material

Abstract. Potato (*Solanum tuberosum* L.) is a staple food worldwide, including in Kazakhstan. The potato yield in 2021 in the country was only 20 tonnes per ha, which is a rather low indicator. One of the main reasons for the insufficient yield of potatoes in Kazakhstan is the low quality of seed material, and the main requirement for high-quality seed material is the absence of viral diseases. Viral diseases in crops are a major impediment to sustainable potato production, as they cause large losses in crop quantity and quality. To date, 40 viral potato diseases have been discovered worldwide. Depending on the infection of viral diseases, the yield can be reduced by up to 90% in crop production. In this review, we discuss in detail the current state of potato viral diseases in Kazakhstan and characterise the most common potato viruses in the country, including potato virus M (PVM), potato virus (PVS), potato virus X (PVX), potato virus Y (PVY) and potato leafroll virus (PLRV). To ensure food security of the country and prevent the spread of infection with viral diseases, popular methods (ELISA, RT-PCR and detection of specific types of targets using microarrays) for the early detection of potato plant viruses in seed and field material are considered. For the mass production of virus-free potato plant material, the use of temporary immersion bioreactors is discussed, as well as the use of modern genetic engineering methods to obtain plant varieties resistant to the most common viral diseases.
Keywords: potato, viruses, PVM, PVS, PVX, PVY, PLRV.

DOI: 10.32523/2616-7034-2023-144-3-54-68

Introduction

With the growth of world trade, the possibility of migrating viruses, especially potato viruses, increases every day. To successfully combat potato viral diseases, constant monitoring of seed and plant materials is necessary. These activities are necessary to understand the current situation and assess the degree of development and spread of pathogens in the country. Additionally, such a procedure will allow assessment of the degree of viral infection in cultivation areas.

Viral diseases of potatoes in Kazakhstan pose a significant danger to the preservation of sowing quality and yield. Viruses cause a number of general symptoms in the aboveground parts of affected plants. This, as a rule, is a general suppression of the plant, twisting, wrinkling or spotting (mosaic) of the leaves. Symptoms may be typical of a particular virus, but to a greater extent, different viruses can cause similar symptoms. Moreover, different varieties of potatoes may react differently to infection with the same virus. In some cases, viral infections are asymptomatic. The production and certification of seed potatoes requires the complete absence of viruses in the source material and, if possible, the maintenance of the virus-free status of the plants when they are propagated. New molecular technologies are likely to benefit resistance

breeding in the future, as they promise to shorten the selection process by introducing desired traits, including virus resistance, more quickly and cost effectively.

Viral diseases of potatoes in Kazakhstan

Potato growing is one of the most important branches of agriculture in Kazakhstan. Due to its natural and climatic conditions, the republic has great potential to produce potatoes and a great export potential. Potato production in the country is growing every year. In 2021, 20.7 thousand ha were occupied by potatoes, while the gross harvest amounted to 4031.6 thousand tonnes [1]. However, low productivity remains the main problem. Thus, the yield in 2021 in the republic was only 20 tonnes per ha [1], which is a rather low figure. One of the main reasons for the insufficient yield of potatoes in Kazakhstan is the low quality of seed material, and the main requirement for high-quality seed material is the absence of viral diseases.

There are about 40 types of viral diseases to which potatoes are susceptible [2; 3; 4]. The main viral diseases of potato in Kazakhstan are potato virus Y (PVY), potato virus X (PVX), potato virus M (PVM), potato virus S (PVS) and potato leafroll virus (PLRV). The spread and control of viral diseases in potatoes is one of the most important and acute problems in potato seed production worldwide [5; 6; 7; 8]. Depending on infection by viral diseases, the yield drops to 90% in industrial crops [9]. In north Kazakhstan, infection with various combinations of PVX, PVM and PVS ranged from 95–99%, leaf curl from 30%, necrosis virus PSTVd (potato spindle tuber viroid) from 27%, and wrinkled mosaic from 16%. Kokshetau region is characterised by weak lesions from solanaceous viral diseases (0.2–12%), among them predominantly speckled mosaic [10]. In the southern region of the republic, potatoes are affected by the following viral diseases: wrinkled, striped, mottled mosaic, leafroll and necrosis [10; 11]. Most seed farms purchase seeds of dubious quality without examining them for the presence of virus contamination. This further leads to the accumulation of infection both in the soil and in the tubers of the new crop, so special attention should be given to the dynamics of the accumulation and spread of viral pathogens. At the same time, if potatoes are heavily infected with complex viruses, losses during long-term storage increase sharply. As a rule, it is impossible to visually determine whether the seed material is infected; therefore, it is necessary to check potatoes for viruses in specialised laboratories before planting and after harvesting.

Information on the current situation of infection with viral diseases in potatoes in Kazakhstan is very limited. Studies have mainly been carried out in local areas and have characterised the situation in individual regions. The cultivation area of potatoes in the Republic of Kazakhstan for 2021 amounted to 195.8 thousand / ha, while the gross harvest: 4031.6 tons / ha, and potato yield was 207.4 cents / ha [1]. Recently conducted research on monitoring large seed and commodity farms in the republic revealed that the most common viruses in almost all regions were PVM and PVS. Moreover, most of the viruses came from commercial farms. As a result of the analysis of plants selected in the fields, the most common viruses in the regions were PVM (46%) and PVS (35.3%) [12]. In the northern regions of Kazakhstan, infection with PVS varies from 11 to 30%. Pavlodar and Zhambyl regions were the cleanest ones, and infection with PVS was not detected. PVM was detected in Akmola and Almaty regions within 19 and 27%, respectively. In Aktobe and Pavlodar regions, infection with PVM was not detected. The only region for infection with PVX was Pavlodar region (3%). When analysing samples in Karaganda region, as well as in the seed material, infection with PLRV was 3%, which is rare within the country.

In another study on the spread of PVY in various regions of Kazakhstan, the highest infection was found in southern Kazakhstan (55%), followed by eastern Kazakhstan (42%), northern Kazakhstan (39%) and central Kazakhstan (28%). The lowest infestation of viral diseases was established in western Kazakhstan (17%) [13]. The most common virus is PVM, as studies conducted on the territory of Almaty and Kostanay regions showed. The presence of PVM (84.03 and 80.84%), PVS (46.11 and 36.97%), PVY (24.37 and 5.99%) and PVX (2.52 and 2.99%) has been evaluated in Almaty and Kostanay regions, respectively. PLRV has not been detected in

these regions [14]. The presented studies were carried out only in the local territories of the Experimental and production farms of research institutes of the Ministry of Agriculture.

Characteristics of the main viruses prevalent in Kazakhstan

Potato virus X. PVX belongs to the *Potexvirus* group and is present worldwide in potato-growing areas [15]. PVX is one of the viruses causing mosaic in almost all potato varieties. A plant infected with PVX alone is often asymptomatic. Infection symptoms appear if the plant is also infected with other viruses, particularly PVY or PVA. PVX has a simple filamentous flexible structure about 500 nm long and 15 nm wide. The virion has a helical assembly and a deeply furrowed, highly hydrated surface [16]. It consists of a single-stranded RNA genome with a positive sense strand of approximately 6.4 tbp, wrapped with approximately 1300 single-coated protein (CP) units and 8.9 CP units per helix turn [18]. PVX causes yield losses of about 10–40% in single infections and is especially dangerous when combined with PVY or PVA. This is due to its synergism with both potyviruses, resulting in a loss of tuber yield of up to 80% [19].

PVX is transmitted by infected potato plants mainly through contact. Predominantly mechanically, in contact with plants subjected to friction (wind, technology, people, animals, etc.). In practice, most infections are transmitted by agricultural machinery, such as sprayers or tractors passing through crops. In fact, PVX is highly contagious upon contact, as it is highly concentrated in plant tissues and its stability in sap is quite long [20]. Often, there are no symptoms of plants infected with this virus. Symptoms range from mild yellow–green mottling to severe plant mottling with leaf roughness. Spotting is more noticeable after a few days of cloudy weather and may almost disappear after a few days of sunshine. Plants may be stunted and have small leaves. In some cases, the tops of plants may die.

Potato virus Y. PVY is the type species of the genus *Potyvirus*, family Potyviridae, the second largest family of plant viruses. PVY is the most economically important and one of the oldest viruses infecting potatoes worldwide, affecting both yield and tuber quality [21; 22]. PVY has a filamentous and tortuous shape with a single-stranded RNA genome with a size of approximately 9.7 kb [23]. Like all potyviruses, the PVY genome has a poly(A) tail at the 3′ end and a covalently linked VPg protein at the 5′ end; both terminal structures are involved in genome protection and genome replication, as well as in the regulation of genome expression [24; 25]. The PVY virion is about 730 nm long and 11 nm wide [26]. Several strains of PVY exist and are one of the most economically important potato pathogens [27]. The first strains recognised were O (ordinary), N (necrotic) and C (common). These strains are characterised by biological properties and symptoms in potato hosts carrying strain-specific resistance genes (hypersensitive (HR) or N genes) [28]. Symptoms range from mild to severe mottling on most hosts to banding resulting from long necrotic lesions along the veins on the underside of the leaflets of some potato varieties. Various varieties have hypersensitive reactions to PVY. This results in the rapid death of the infected area and a small dead area around the infection. Due to hypersensitivity, the leaves of the plant can become deformed and brittle, often taking on a wrinkled and rough appearance. Coexisting with PVX, PVY causes a 'wrinkled mosaic' in which plants become dwarfed and tubers shrink. Symptoms on plants are expressed depending on the strains of the virus and the potato variety; sometimes, they differ greatly from each other.

PVY accumulates in all studied tissues of leaves and stems, in shoot tips, roots and tubers; however, the level of virus accumulation is specific to each organ or tissue. The highest amount of viral RNA and viral particles has been found in symptomatic leaves and stems [29]. PVY is transmitted mainly by aphids. It is also mechanically transmitted, and in potatoes, PVY can be vegetatively transmitted through potato tubers. In the case of a single infection with PVY, the yield can be reduced by up to 40%, and in combination with PVX or PLRV viruses, losses can reach up to 80%. The virus can accumulate in tubers and, from year to year, further reduce the yield of the plant.

Potato virus M. PVM is a well-characterised virus of the *Carlavirus* genus of the Betaflexiviridae family [30]. The virus has a single-stranded polyadenylated genomic RNA of 8.5 kb [31]. PVM is

not known to be transmitted by pollen or seeds. It is transmitted vegetatively (through tubers) and can be transmitted mechanically, for example, by contaminated tools and wounds [30]. PVM is relatively uncommon in most countries and, similar to PVS, generally causes only minor yield losses in tubers, with the exception of mixed infection caused by PVX or other viruses [32].

PVM can cause a 10-40% reduction in potato yields, and in some regions, potato varieties can be 100% infected. The virus is transmitted non-persistently by aphids and by mechanical inoculation with the juice of young leaves. PVM causes mottling, mosaic, wrinkling and curling of leaves and stunting of shoots. The symptoms of infection in potato plants caused by PVM infection are similar to those caused by several other common potato viruses, including PVS, PVX and the common strain of PVY. The severity of symptoms varies greatly depending on the combination of potato cultivars and PVM isolates [31].

Potato virus S. About 57 viruses infect potato varieties, and PVS of the Betaflexiviridae family, genus *Carlavirus*, is one of the most widespread viruses in the world. It often causes mild symptoms or infects potato plants without causing symptoms; however, more severe symptoms develop after infection with virulent strains, which are less common. When present alone, PVS reduces the size of tubers, and although the yield losses it causes are usually minor, they can be as high as 20% [33]. PVS is rarely transmitted by pollen or seeds. It is mainly transmitted vegetatively (through tubers) and can be transmitted mechanically, such as by contaminated tools and wounds. There are two different strains of the virus, PVSo and PVSa, which have about 81% similarity to each other, and they do not have significant differences in the methods of distribution [34; 35]. PVS is filamentous and has a single-stranded genomic RNA of 8.5 kb.

In many potato varieties grown around the world, PVS is asymptomatic or causes mild symptoms; therefore, it is called a latent virus [36]. However, its incidence can reach 100% in a crop or region due to efficient mechanical transmission or through seed tubers and aphids. Despite the latency of this virus, it has been estimated that it can cause potato yield losses ranging from 10 to 20%.

Potato leafroll virus. PLRV, belonging to the genus *Polerovirus* and the family Luteoviridae, is a widespread potato virus worldwide and is responsible for up to 90% crop loss worldwide [37]. The virus is found on all continents except Antarctica. With a single infection with the leafroll virus, potato yield is reduced by 20 to 60%. However, the virus is more common in synergy with other viruses, including PVY and/or PVX. PLRV has a single-stranded genomic RNA of approximately 5.8 kb. Being the most harmful potato pathogen, strain similarity can be 97–98%. The only carrier of the virus is the aphid *Myzus persicae*. It multiplies widely in phloem tissues, and disease symptoms reflect this [38]. Since the potato is a vegetatively propagated crop, once infected with viruses, it can easily spread in tubers (planting material). These viruses are found singly or in most cases as mixed infections in potato crops. Tubers used for planting in the next season may contain latent viruses, which subsequently reduce plant germination and yield [39].

The initial symptoms, which appear within a year after infection, are often mild and may go unnoticed. Upper leaves may develop a slight curl and a red-orange tint. Secondary symptoms vary; the lower leaves may curl, and the leaves themselves are dry and brittle and feel like paper. The plant shows slight yellowing and upturning of the upper leaves. Depending on the variety and conditions, plant growth may be slightly reduced or severely halted.

Methods for the detection of potato viral diseases

There are technologies that allow detection and identification of viral diseases at an early stage in seed and field material. Recently, serological methods have been widely used to detect and identify various potato viral diseases. In particular, the enzyme-linked immunosorbent assay (ELISA) is widely used for this purpose. However, the use of the enzyme-linked immunosorbent assay has sensitivity and specificity limitations. For more effective detection of viral diseases, polymerase chain reaction and reverse transcription (RT-PCR) assays are used, which have the advantage of being more sensitive, specific and accurate [40; 41]. Simplex RT-PCR can detect only one virus at a time; for the detection of a complex viral disease, multiplex RT-PCR is used,

which is more efficient and takes a minimum amount of time compared to simplex RT-PCR [42]. One reaction uses several pairs of primers to detect potato viral diseases. In addition to PCR and ELISA, technologies are currently focused on the detection of specific types of targets. Thus, the use of microchips makes it possible to simultaneously detect several of the most common potato viruses (PVY, PVX, PVA, PVS) with up to 80–90% identity [11; 43]. The advantage of this method is its detection at the level of internal variability found in the genomes of RNA viruses.

Temporary immersion bioreactors for mass production of virus-free seed

Currently, to obtain virus-free potato plant material, a bioreactor system is used that allows mass production of pathogen-free plant material. In bioreactors, agar is not used, and the liquid medium is used as a very thin layer instead of immersing the plant material. At the same time, many relatively small vessels are used that are manually assembled from various inexpensive parts. Mass production of plant material in bioreactors is usually carried out in liquid cultures using various systems [44; 45]. The use of liquid cultures in comparison with solid and semi-solid cultures leads to an increase in the length of shoots, an increase in the number of internodes, and the ability to obtain microtubers from all plant nodes [46; 47].

Cultivation in liquid culture results in better growth since a larger area of the explants is in contact with the medium. However, there are disadvantages to using liquid cultures, such as the high cost of traditional bioreactor equipment and hyperhydricity because of poor gas exchange, as the explants are continuously immersed in the medium [48; 49]. Several methods have been tested for the production of microtubers in bioreactors: flat liquid cultures [50], temporary immersion in liquid cultures [45], including the tidal flow method in glass fermenters [51], the Rita® system [52] and the dual glass vessels [46].

Potato microtubers have been produced in large vessel bioreactors connected to a temporary immersion system (TIS), which is often used in a two-stream system [46; 49]. The idea is that the liquid medium is only in contact with the plant material for a short period of time to avoid hyperhydricity, lack of oxygen and other problems that are usually associated with liquid cultures. TISs consist of two vessels, one of which contains plant material connected to the other, which contains a growth medium. Typically, a pump transfers the liquid to a vessel containing plant material. The dive time and duration can be controlled. In addition, a two-vessel system is designed so that the vessels can be large. However, as the size of the vessels increases, the culture material becomes vulnerable to contamination. At present, several prototypes of simple and efficient TIS bioreactors have been developed [45; 46; 53]. Thus, in one of the bioreactors, 2.6 microtubers per explant were obtained, with a total number of 390 microtubers per 10-L bioreactor [45]. In another case, 229 tubers were obtained from 80 explants per 600 mL of medium in a 5-L bioreactor [54], while Piao et al. reported 80 microtubers from 50 explants per 1.5 L of MS medium in a 10-L TIS bioreactor [45]. Another factor to consider in a bioreactor microtuber culture study is the size of the tubers. There are different opinions regarding the optimal size of microtubers for storage; their range varies from 0.1–0.2 g [55; 56]. Microtubers larger than 1.1 g are optimal for direct planting in the field [45].

In addition to large glass vessels, TIS can also be made in small, inexpensive plastic containers. Commercial TIS, such as the product Rita®, uses transparent polysulfone vessels. Theisson and Alvard tested the Rita® system and obtained 48–90 microtubers per vessel within 10 weeks [52]. They received a maximum of three microtubers per node, depending on the potato variety. Most of the microtubers were larger than 0.5 g, but they were not tested in the field [56]. Another TIS, a system using small plastic containers called Plantima®, is affordable and has also been tested for tuber formation of *Dioscorea* sp. [57]. Core fermenters resemble TIS because they use two vessels where the plant material is stored in one and the nutrient solution remains mostly in another separate vessel. Akita and Ohta previously used air-fed fermentation jars [51]. In such fermenters, the aeration of cultures was obtained by aerosol spraying from the bottom of the jar. In these bioreactors using this semi-continuous surface control technique, 500 to 960 tubers were obtained from 100 explants in 10-L fermenters containing 6 L of nutrient solution [51].

Yu et al. developed an inexpensive bioreactor that used rotating plastic vessels with closed lids. In these bioreactors, microtubers larger than 1 g were obtained in 40% of explants, while 100 microtubers were obtained after 10 weeks of cultivation in tuber-forming media [58].

Akita and Ohta previously reported on a similar rotating system in which 100 microtubers were obtained in a vessel with 200 mL of tuber-forming medium [59]. Another new system using the thin-layer culture method is Liquid Lab™ [60]. In Liquid Lab™, the tilt mechanism is machine generated, causing the liquid inside the culture vessels to move from side to side. It has easy-to-control lighting and tilt time. In the LiquidLab™ system, the vessels have porous patches attached to each side to aerate the cultures. The machines can simultaneously operate up to 200 vessels. The system was tested for microtuber production, in which 75 microtubers were produced from 50 explants with 200 mL culture medium per vessel [58].

Using modern methods to obtain potato resistance to viral diseases

Genetic engineering is an effective way to obtain plants with the desired properties. Genetic engineering is an alternative to traditional plant breeding because it can lead to the development of disease-resistant material while retaining all other desirable traits. Several research groups have developed genetically modified potatoes resistant to PVM, PVS, PVX, PVY and PLRV using various foreign gene constructs. One resistance line expressing the PVY coat protein gene in combination with a Bt insecticidal protein was commercialised by a subsidiary of Monsanto. This 'Newleaf Y' cultivar was planted commercially in the late 1990s and early 2000s [59; 60]. Recessive potyvirus resistance genes have been identified and used for many decades in many crops, and these genes have recently been characterised at the molecular level [61]. The highly conserved eukaryotic translation initiation factor 4E (eIF4E) plays an important role in host protein translation, as well as in viral infection. The eIF4E protein binds to the mRNA 5′ cap and facilitates its recruitment into the host ribosomal complex [62]. A number of plant viruses, such as potyviruses, with single-stranded RNA genomes, also interact with eIF4E, often through a viral genome-associated protein (VPg) covalently linked to the 5′ end of the viral genome [63; 64]. This interaction is essential for successful viral infection and is believed to facilitate translation, replication, and/or intercellular movement of the viral genome [65; 66; 67].

Ry genes in potatoes ($Ry_{sto,}$ $Ry_{fsto,}$ and Ry_{adg}) confer resistance to certain strains of PVX and PVY. The Rysto gene, which provides resistance to a wide range of strains of PVY and PVA in potato and tobacco, is the only gene controlling high resistance isolated from the Ry locus [68]. World potato production depends on pathogen-free seed tubers, which are vulnerable to the accumulation and spread of viral diseases. Various strains of PVY (including PVYNTN and PVYN-Wi) are the most economically harmful viral pathogens involved in potato production, and genetic resistance to PVY is the main focus of breeding programmes [69]. Wild potato varieties and landraces are sources of NLR-specific PVY resistance genes that can be introgressed into commercial potato varieties. Loci conferring extreme resistance to PVY have been mapped in *Solanum chacoense* (Rychc), *S. tuberosum* Andigena (Ryadg), and *S. stoloniferum* (Rysto). Grech-Baran et al. used resistance enrichment sequencing (RenSeq) to isolate the gene conferring Rysto-mediated extreme resistance from the commercial potato cultivar 'Alicja' [70]. Rysto, introgressed from *S. stoloniferum*, is a Toll-interleukin receptor (TIR) NLR protein similar to other potato virus resistance genes (N, Pvr4, Y-1, etc.). The broad spectrum resistance provided by Rysto makes it an attractive trait for nightshade plant breeders. The Rysto gene is present in various commercial potato cultivars, including the American cultivars 'Payette Russet' and 'Castle Russet' and the European cultivars Alicja, 'White Lady' and 'Pirola'. The Rysto protein directly or indirectly recognises or binds the envelope proteins of PVY and PVA, causing an extreme resistance reaction [72].

In addition, genome editing technology has recently been used to breed crops for resistance to abiotic and biotic stress factors.

Genome editing of vegetatively propagated heterozygous potato (*Solanum tuberosum*) represents a promising avenue for the direct improvement of traits in elite varieties. With the

recent and successful development of the Regularly Spaced Short Palindromic Repeat (CRISPR)-Cas9 system in eukaryotic cells, plants have gained access to a powerful, inexpensive and easy-to-use set of tools to target and inactivate/modify specific genes [73].

Genome editing using the CRISPR/Cas9 system enhances the ability to build viral resistance by targeting host genes that are directly involved in host–virus interactions.

The CRISPR/Cas9 system has been used to create potyvirus resistance: Turnip mosaic virus (TuMV) in *Arabidopsis thaliana* by genomic deletion of eIF(iso)4E.62

TALEN technology has already been used to suppress the VInv gene in potatoes to minimise the accumulation of reducing sugars during storage. These studies clearly indicate the effectiveness of genome editing to improve traits, such as virus resistance, and safely store potato seed [74].

Conclusion

Potato growing is one of the most important branches of agriculture in Kazakhstan, and viral diseases cause significant damage to the safety of sowing quality and potato yield.

To solve this problem, it is necessary to use highly efficient methods for the mass production of virus-free plants. In particular, temporary immersion bioreactors can significantly accelerate the process of mass reproduction of virus-free potatoes on an industrial scale. It is necessary to use modern, highly sensitive and effective methods for timely analysis of the quality of potato seed material and control over the emergence and spread of viruses.

The use of genetic engineering in the future may prove particularly useful for the introgression of resistance genes from wild species to improve the agronomic performance of crops. The genome editing method can be used to increase the resistance of varieties to viruses.

Modern methods and technologies should be actively used to obtain virus-free potato varieties, which will make a significant contribution to the country's food security.

Acknowledgement. This work was supported by the Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan under grant funding of the projects: BR10765038 "Development of methodology and implementation of scientifically based system of certification and inspection of seed potato and planting material of fruit crops in the Republic of Kazakhstan", and AP14870410 "Development and implementation of the accelerated production method of pre-basic seed potato in tissue culture".

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Қазақстандағы картоп вирустары және вируссыз тұқымдық материал алу әдістері

Аңдатпа. Картоп (*Solanum tuberosum* L.) дүние жүзіндегі, оның ішінде Қазақстанда да негізгі азық-түліктердің бірі болып табылады. 2021 жылы республика бойынша картоп өнімділігі гектарына небәрі 20 тоннаны құрады, бұл өте төмен көрсеткіш. Қазақстанда картоп өнімінің жеткіліксіз болуының басты себептерінің бірі – тұқымдық материал сапасының төмендігі, ал жоғары сапалы тұқымдық материалға қойылатын басты талап – вирустық аурулардың болмауы. Дақылдардағы вирустық аурулары картоп өндірісінің тұрақты өсуіне үлкен кедергі болып табылады, өйткені олар дақылдардың саны мен сапасына үлкен шығындар әкеледі. Бүгінгі күні әлемде картоптың вирустық ауруларының 40 түрі анықталған. Вирустық аурулар картоп өнімділігін 90%-ға дейін төмендетуі мүмкін. Бұл шолуда біз Қазақстандағы картоптың вирустық ауруларының қазіргі жағдайын егжей-тегжейлі талқыладық, сонымен қатар еліміздегі PVM, PVS, PVX, PVY, PLRV сияқты ең көп таралған картоп вирустарын сипаттадық. Елдің азық-түлік қауіпсіздігін қамтамасыз ету және вирустық аурулар инфекциясының таралуын болдырмау мақсатында тұқымдық және егістік материалдағы картоп өсімдігінің вирустарын ерте анықтаудың танымал әдістері (ИФА, КТ-ПТР және микрочиптерді қолдану арқылы нақты нысаналардың түрлерін анықтау) қарастырылды. Вируссыз картоп өсімдігін жаппай өндіру үшін уақытша иммерсиялық биореакторларды қолдану, сонымен қатар кең таралған вирустық ауруларға төзімді өсімдік сорттарын алу үшін заманауи гендік инженерия әдістерін қолдану талқыланады.

Түйін сөздер: картоп, вирустар, PVM, PVS, PVX, PVY, PLRV.

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Вирусы картофеля в Казахстане и методы получения безвирусного семенного материала

Аннотация. Картофель (*Solanum tuberosum* L.) является одним из основных продуктов питания во всем мире, в том числе и в Казахстане. Урожайность картофеля в 2021 году в республике составила всего лишь 20 тонн с гектара, что является довольно низким показателем. Одним из основных причин недостаточной урожайности картофеля в Казахстане является низкое качество семенного материала, а главным требованием к качественному семенному материалу является отсутствие вирусных заболеваний. Вирусные заболевания растительных культур являются основным препятствующим фактором для устойчивого производства картофеля, поскольку вызывают большие потери количества и качества урожая. На сегодняшний день в мире обнаружены 40 видов вирусных заболеваний картофеля. В зависимости от поражения вирусными болезнями урожайность может снизиться до 90% на производственных посевах. В данном обзоре мы подробно обсудили текущее состояние вирусных болезней картофеля в Казахстане, а также дали характеристику вирусам картофеля, наиболее часто встречающимся в республике, таким, как PVM, PVS, PVX, PVY, PLRV. В целях продовольственной безопасности страны и предотвращения распространения заражения вирусными болезнями рассмотрели популярные методы (ИФА, ОТ-ПЦР и обнаружение специфических видов мишеней с помощью микрочипов) ранней детекции растительных вирусов картофеля в семенном и полевом материале. Для массового получения безвирусного растительного материала картофеля обсуждается использование биореакторов временного погружения, а также применение современных методов генной инженерии для получения устойчивых сортов растительных культур к наиболее распространенным вирусным болезням.

Ключевые слова: картофель, вирусы, PVM, PVS, PVX, PVY, PLRV.

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