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WEED PLANTS OF THE *ASTERACEAE* AND *MALVACEAE* FAMILIES AS RESERVOIRS OF HARMFUL VIRUSES OF VEGETABLE CROPS IN UKRAINE AND THE WORLD

The review provides an analysis of the current literature data on the prevalence of weeds of the Asteraceae and Malvaceae families, which act as reservoirs of agricultural plant viruses, in the agroecosystems of both Ukraine and the world. The main focus is on weeds that are common in the agrocenoses of agricultural crops. The primary sources of the main pathogens of viral diseases of vegetable crops (Tomato spotted wilt virus (TSWV), Tomato chlorosis virus (ToCV), Tomato yellow leaf curl virus (TYLCV), Cucumber mosaic virus (CMV), Cucumber vein yellowing virus (CVYV), Iris yellow spot virus (IYSV), and Pepino mosaic virus (PepMV)) in different climatic zones, as well as the main factors contributing to the spread of harmful viruses in agrophytocenoses are analyzed.

Keywords: *plant viruses, plant virus vectors, plant virus reservoir weeds.*

Today, the cultivation of agricultural plants has reached a global scale, causing the simultaneous spread of weeds that accompany agricultural crops everywhere. In the process of evolution, weeds have acquired the ability to successfully overcome adverse environmental factors. Due to better adaptability, particularly resistant weeds compete with cultivated plants in crops [1, 2].

In this regard, the fight against weeds is one of the factors of increasing the yield of agricultural crops, mainly due to the use of herbicides. But despite this, progress in the fight against weeds is hindered by their adaptation. Many weed species spread freely across the globe through introduction.

For example, such weeds as giant knotweed (*Reynoutria* spp.), common ragweed (*Ambrosia*

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artemisiifolia L.), and goosefoots (*Chenopodium* spp.) have such wide climatic niches that they spread over the entire range of temperate zones.

The plasticity of weeds gives them an advantage in the use of nutrients, especially for invasive species. Thanks to their plasticity, weeds adapt more easily to factors related to climate change, in particular, an increase in temperature, an increase in CO_2 emissions into the atmosphere, or a change in the humidity regime. Conversely, non-invasive species, adapted to more stable environmental conditions, are unable to quickly adapt to sudden changes in meteorological conditions. In addition, climate changes, which have deepened recently, can affect not only the spread of weeds but also the distribution areas of insects that participate in the invasiveness cycles of viral diseases, indicating a significant impact on productivity [2, 3].

Thanks to their ability to overcome adverse conditions, weeds gain a competitive advantage over cultivated plants, which is facilitated by climate change.

Weeds are reservoirs for many viruses of cultivated plants and thus serve as a source of viral infection [4, 5]. The basis for this is their biological features: high plasticity of growth and development, fertility, long-term viability of seeds and vegetative embryos, where, in turn, plant viruses can be stored [6].

Most research in the field of plant virology has focused on disease-causing viruses of agricultural and ornamental crops. However, metagenomic studies have established the widespread presence of viruses in wild plant species [7]. The role of viruses in wild plant populations becomes clear: the dynamics of viruses in the invasiveness of introduced plant species has been characterized; features of interaction between insects, plants, and viruses have been revealed. However, the diversity of phytopathogenic viruses of cultivated and wild plant species, which are reservoirs of these viruses, the role of insects in the virus-plant relationship, and the impact of viruses on the evolution and ecology of their hosts remain insufficiently studied [8].

Therefore, the study of the diversity of weed viruses attracts attention in connection with the significant harmfulness of viral infection and the prevalence of weeds as reservoirs of segetal vegetation viruses, with taking into account their species composition [1, 6].

Vegetable crops are the main diet of people all over the world. At the same time, vegetables are often affected by viral diseases, many of which cause serious loss of yield and quality. There are viruses specific to certain regions with a limited number of species, in particular *Lettuce necrotic yellows virus* (LNYV) in Australia, occasionally found in New Zealand, Italy, Spain, Great Britain, and China [9, 10], and there are those affecting a wide range of vegetable crops, as well as other species in most parts of the world, including *Cucumber mosaic virus* (CMV) [11, 12].

In this regard, it is important to develop a theoretical basis for control measures, the components of which are an understanding of the ecology and epidemiology of phytopathogenic viruses and an understanding of the mechanisms of virus infection of the host plant. The methodological base of this issue includes the development of virus identification methods, assessment of the importance of vectors (if any), determination of ways of survival of viruses and their introduction into culture. In general, that makes it possible to develop a number of measures to prevent viral damage to agricultural plants [11].

In this regard, the purpose of this review was to accumulate information on viral groups of wild plants and summarize literature data on the ecological significance of weeds as possible reservoirs of viruses of important agricultural crops in agroecosystems of both Ukraine and the world.

Weed plants of the *Asteraceae* family as reservoirs of vegetable crop viruses. The production of vegetable products in Ukraine and the world is receiving increased attention due to their high food quality, especially under the conditions of martial law in Ukraine, when a lot of the land became unsuitable for growing agricultural products. Theworld international statistics shows the existence of more than 140 categories of vegetable plants on the market, and more than 100 types of vegetable crops grown in Ukraine, the sale object of which is most often fruits. It is worth noting that a significant share of fruits falls on tomatoes — more than 50% [13, 14].

The world production of vegetables in 2021 amounted to more than 1154.6 million tons, of which 189.13 million tons were tomatoes [15, 16]. In Europe, tomato production accounted for 24.48 million tons, of which 2.4 million tons — in Ukraine [16].

However, the unstable phytopathological situation in Ukraine is created by the annual introduction of new varieties and hybrids of foreign selection, with the potential threat of importing phytopathogenic viruses with seed material. Growing vegetable crops, particularly in protected soil, is important for providing the population with fresh vegetable products to prevent vitamin deficiency, especially in spring. Therefore, the problem of increasing the production efficiency of vegetable crops, including tomatoes, is important [17, 18].

Vegetable crops are affected by many viral diseases, among which *Tomato spotted wilt virus* is the most common in Ukraine and the world [20—22, 34, 37, 40].

Tomato spotted wilt virus (TSWV) belongs to the genus *Tospovirus*, which was later renamed *Orthotospovirus* (family *Tospoviridae*, order *Bunyavirales*) [23].

In Ukraine and the world, TSWV affects such important agricultural and decorative crops as tomatoes, potatoes, lettuce, pepper, tobacco, sunflower, peanuts, rice, petunia, and chrysanthemum, which causes significant economic losses to agriculture [19, 20—22].

TSWV is not transmitted by seeds and does not spread by contact but is spread from plant to plant only by thrips (Thysanoptera: *Thripidae*) and is able to replicate both in thrips vectors and in host plants [24, 25]. In Ukraine, thrips are widespread, and up to seven generations of this pest develop over the year [26]. TSWV is transmitted by several species of thrips, including common blossom thrips (*Frankliniella schultzei* Trybom), onion thrips (*Thrips tabaci* Lindeman), eastern flower thrips (F*rankliniella intonsa* Trybom), western flower thrips (*Frankliniella occidentalis* Pergande), and chilli thrips (*Scirtothrips dorsalis* Hood) [27, 28]. The most common vectors of the pathogen in the field are *Thrips tabaci* (Lindeman) and *F. schultzei* (Trybom), which transmit all TSWV strains reported worldwide. In European countries, the main one is *Thrips tabaci* (Lindeman) [26].

Thrips preferentially settle, lay eggs, and feed on TSWV-infected plants. A manifestation of primary infection are characteristic cells from which thrips, migrating during flight, spread the viral infection [29, 30].

The thrips vector hibernates in the soil, and the virus also hibernates in its body [31].

Therefore, TSWV is able to replicate both in the vector and in the host plant, providing the possibility of both direct and indirect (i.e., plant-mediated) effects on the vector [25, 32—34].

The main reservoir plants of the TSMV virus are weeds common in Ukraine and the world, namely: canadian horseweed (*Erigeron canadensis* L. (syn. *Conyza canadensis*)), chicory (*Cichorium intybus* L.), creeping thistle (*Cirsium arvense* (L.) Scop.), common sowthistle (*Sonchus oleraceus* L.), spear thistle (*Cirsium vulgare* (Savi) Ten.), common groundsel (*Senecio vulgaris* L.), and sowthistle (*Sonchus* spp.) (Table 1) [25, 27, 30, 34, 36—42].

Erigeron canadensis L. (syn. *Conyza canadensis*) is characterized by high harmfulness and grows throughout Ukraine in fields, winter and spring grain crops, as well as vegetable and melon crops. If crops are heavily soiled by this weed, the yield of agricultural crops may decrease by 60—65% [35]. *Erigeron canadensis* L. can retain the TSWV

Table 1. **The most common weeds are reservoirs of family viruses *Asteraceae, Malvaceae* vegetable crops**

Vegetable crops	Weeds	References
	Asteraceae	
	Tomato spotted wilt virus **(TSWV)**	
Tomato (*Solanum lycopersicum* L. (syn. *Lycopersicon esculentum* (Mill.))), Pepper (*Capsicum annuum* L.)	Field sowthistle (*Sonchus arvensis* L.)	[42, 79—81]
	Creeping thistle (*Cirsium arvense* (L.) Scop.)	[34, 82]
	Chicory (*Cichorium intybus* L.)	[36, 38, 41]
	Common groundsel (*Senecio vulgaris* L.)	[27, 34, 38]
	Canadian horseweed (*Erigeron canadensis* L. (syn. *Conyza canadensis*))	[40]
	Common ragweed (*Ambrosia artemisiifolia* L.)	[42, 79, 80]
	Greater burdock (*Arctium lappa* L.)	[30]
	Dogfennel (*Eupatorium capillifolium* (Lam.) Small)	[83]
	Common sowthistle (*Sonchus oleraceus* L.)	[34, 37, 39, 40]
	Spear thistle (*Cirsium vulgare* (Savi) Ten.)	[34]
	Potato weed *(Galinsoga parviflora* Cav.)	[27]
	Tomato chlorosis virus **(ToCV)**	
Tomato (*Solanum lycopersicum* L. (syn. *Lycopersicon esculentum* (Mill.)))	Creeping thistle (*Cirsium arvense* (L.) Scop.)	[47]
	Canadian horseweed (*Erigeron canadensis* L. (syn. *Conyza canadensis*))	[46]
	Annual fleabane (*Erigeron annuus* (L.) Pers.)	[48]
	Horseweed (*Conyza* sp.)	[47]
	Tomato yellow leaf curl virus **(TYLCV)**	
Tomato (*Solanum lycopersicum* L. (syn. *Lycopersicon esculentum* (Mill.)))	Spiny sowthistle (*Sonchus asper* (L.) Hill)	[51]
	Cucumber mosaic virus **(CMV)**	
Pepper (*Capsicum annuum* L.) Tomato (*Solanum lycopersicum* L. (syn. *Lycopersicon esculentum* (Mill.)))	Greater burdock (*Arctium lappa* L.)	[58, 59]
	Dandelion (*Taraxacum officinale* L.)	[58, 59]
	Perennial sowthistle (*Sonchus arvensis* L.)	[58, 59]
	Cucumber vein yellowing virus **(CVYV)**	
Cucumber (*Cucumis sativus* L.), Squash (*Cucurbita pepo* L.)	Common sowthistle (*Sonchus oleraceus* L.)	[84]
	Prickly sow-thistle (*Sonchus asper* L.)	[84]
	Iris yellow spot virus **(IYSV)**	
Onion (*Allium cepa* L.)	Lesser burdock (*Arctium minus* Bernh.)	[85, 86]
	Chicory (*Cichorium intybus* L.)	[86, 87]
	Dandelion *(Taraxacum officinale* (L.) Weber ex F.H.Wigg)	[85—87]
	Greater burdock (*Arctium lappa* L.)	[85, 86]

Continuation of Table 1

Vegetable crops	Weeds	References
	Malvaceae	
	***Tomato spotted wilt virus* (TSWV)**	
Tomato (*Solanum lycopersicum* L. (syn. *Lycopersicon esculentum* (Mill.)))	Cheeseweed (*Malva parviflora* L.) Buttonweed (*Malva neglecta* Wallr.) Common mallow (*Malva sylvestris* L.)	[25, 39, 40] [39, 40] [81]
	***Cucumber vein yellowing virus* (CVYV)**	
Cucumber (*Cucumis sativus* L.) Summer squash *(Cucurbita pepo* L.)	Cheeseweed *(Malva parviflora* L.*)*	[71, 84]
	***Tomato yellow leaf curl Sardinia virus* (TYLCSV)**	
Tomato (*Solanum lycopersicum* L. (syn. *Lycopersicon esculentum* (Mill.)))	Common mallow *(Malva sylvestris* L.)	[51]
	Pepino mosaic virus (PepMV)	
Tomato (*Solanum lycopersicum* L. (syn. *Lycopersicon esculentum* (Mill.)))	Cheeseweed *(Malva parviflora* L.)	[74]

virus until the new growing season. Another most common species in Ukraine is common groundsel (*Senesio vulgaris* L.), which preserves the pathogen until the new growing season [43].

Thus, thrips-transmitters and virus-reservoir weeds are of great importance in TSMV epidemiology.

Tomato chlorosis virus (ToCV) belongs to the genus *Crinivirus*, family *Closteroviridae* [44]. ToCV infects important agricultural crops – tomatoes, beans, beets, pumpkins, lettuce, potatoes, and a wide range of wild plants, while some lesions of this virus can be asymptomatic and cause diseases only in mixed infections with other viruses [45].

Most often, ToCV is transmitted by whiteflies (Hemiptera: *Aleyrodidae*) belonging to the genera *Bemisia* and *Trialeurodes*. Transmission by whiteflies is highly infectious, and 100% of infection cases are often observed in the field [44].

ToCV has a relatively long latent period in infected host plants, often producing no symptoms for up to 3 weeks after infection. If plants in nurseries are exposed to virulent vector populations at an early age, ToCV-infected plants can be transported to new areas via infected plant material without symptoms [45].

The main host plants of ToCV are weeds common in Ukraine and the world, namely creeping thistle (*Cirsium arvense* L.), canadian horseweed (*Erigeron canadensis* L. (syn. *Conyza canadensis* (L.)), horseweed (*Conyza* sp.), and annual fleabane (*Erigeron annuus* (L.) Pers.) (Table 1) [46—48].

It is worth noting that this virus cannot be transmitted by mechanical inoculation, contact between plants, soil, pollen, or seeds. Therefore, the epidemiology of ToCV in Ukraine and the world may be related to the spread of its vector by whiteflies, as well as virus reservoir plants.

Tomato yellow leaf curl virus (TYLCV) belongs to the genus *Begomovirus*, family *Geminiviridae* [49], which often causes serious damage to greenhouse tomatoes. In addition to tomato (*Solanum lycopersicum* L. (syn. *Lycopersicon esculentum* (Mill.)), the virus can infect bell pepper (*Capsicum annuum* L.), *Capsicum chinense* Jacq., and common bean (*Phaseolus vulgaris* L.) and tobacco (*Nicotiana tabacum* L.). TYLCV infection causes severe symptoms in tomato plants and severe crop losses worldwide, for example, in greenhouse tomato crop, losses reached 100% [50].

TYLCV is transmitted by adults of the silverleaf whitefly (*Bemisia tabaci* (Gennadius)). Some host plants infected with TYLCV show visible symptoms, but the virus can be carried by whiteflies from asymptomatic infected plants to tomatoes. Also, the virus can be transmitted through seedlings taken from infected plants, which are then planted in a greenhouse. TYLCV is not transmitted by seeds or mechanically. On the other hand, there is evidence that TYLCV can be persistent and overwinter in soil on infected plant debris [50].

The host plant range of TYLCV weeds is limited and includes only spiny sowthistle (*Sonchus asper* (L.) Hill) [51].

The epidemiology of TYLCV in Ukraine and the world is closely related to the spread of its vector.

Cucumber mosaic virus (CMV; genus *Cucumovirus*, family *Bromoviridae*). This causative agent of diseases has many strains, which causes considerable variability in the symptoms of affected plants. It is known to occur in Ukraine and all over the world in both temperate and tropical climates, affecting many agricultural and horticultural crops as one of the most common viruses [52, 53].

CMV circulation on sweet pepper (*Capsicum annuum* L.) vegetable plants was detected in Ukraine [20].

It is known that the causative agent of diseases can be transmitted mechanically and by seeds, but plants are mainly infected non-persistently by many species of aphids, among which the most common are green peach aphid (*Myzodes persicae* (Sulzer)) and cotton aphid (*Aphis gossypii* (Glover)) [54].

CMV persists in a latent form in some biennial crops, such as parsley, celery, and others [55—57]. It is endemic in most temperate regions of the world and has a very wide host range [58].

The main host plants of CMV are annual and perennial grasses common in Ukraine and the world, namely: greater burdock (*Arctium lappa* L.), dandelion (*Taraxacum officinale* L.), and perennial sowthistle (*Sonchus arvensis* L.) [58, 59].

The epidemiology of CMV is related to the spread of its vector and reservoirs of plant viruses.

Iris yellow spot virus (IYSV), genus *Tospovirus*, family *Bunyaviridae* [60].

Onion (*Allium cepa* L.) is one of the most popular vegetable crops in Ukraine and the world. The production volume of greens (onions and shallots) in 2021 was 4.5 million tons in the world, of which 129.4 thousand tons were in Europe, and in Ukraine — 30.4 thousand tons. The volume of production of dried (onions and shallots) in the world — 106.6 million tons, of which 10.7 million tons in Europe and 1.02 million tons in Ukraine [16]. One of the reasons for the lack of onion harvest in most parts of the world and in Ukraine is the damage caused by onion diseases. The annual introduction of new varieties and hybrids of foreign selection creates an unstable phytopathological situation, as there is a potential threat of the introduction of pathogens of various etiologies, including viruses, with seed material [61].

IYSV is present in most regions of the world where onions (*Allium cepa* L.) are grown [62] IYSV is absent on the territory of Ukraine, but it has been identified in other European countries, which increases the risk of its penetration into the territory of Ukraine.

IYSV leads to lodging of the petioles, which in turn can lead to a decrease in the yield and its quality [63]. It is transmitted by onion thrips (*Thrips tabaci* Lindeman) (order Thysanoptera; family Thripidae) and, less efficiently, by tobacco thrips (*Frankliniella fusca* Hinds) [62, 63].

Thrips tabaci (Lindeman) can contribute to the spread of IYSV on the territory of Ukraine, as this insect is widespread in both closed and open soil conditions. The pest hibernates in the upper soil layer and under plant remains. In early spring, thrips begin to feed on weeds, then switch to seedlings in greenhouses and vegetable plants in open ground. On onions, pests settle in the axils of the leaves, then on the inflorescences. Before harvesting, thrips partially move under the dry scales of the bulb. The virus overwinters in live vectors on plants laid down for the winter. These can be seeds and bulbs of onions, bulbs of iris and other plants, on which thrips feed. The storage of thrips under onion scales creates a real possibility of their penetration with imported products into the territory of Ukraine [64–66].

The main host plants of IYSV are annual and perennial grasses common in Ukraine and the world, namely: spiny sowthistle (*Sonchus asper* (L.) Hill), greater burdock (*Arctium lappa* L.), dandelion (*Taraxacum officinale* L.), lesser burdock (*Arctium minus* Bernh.), and chicory (*Cichorium intybus* L.) (Table 1) [62, 64, 65, 67].

The epidemiology of IYSV is mainly due to vectors and virus reservoir plants.

Plants of the *Malvaceae* family as reservoirs of vegetable crop viruses. Mallow plants (*Malva* spp.) are widespread in various geographical regions of the world and Ukraine. Virus-like symptoms, such as mosaic, are often observed on these plants [68]. Worldwide, marshmallow has been identified as a host plant for viruses of several crops (for example, *Cassava mosaic virus*, *Faba bean necrotic yellows virus*, *Tomato spotted wilt virus, Cucumber vein yellowing virus, and Pepino mosaic virus*) [25, 39, 69, 71, 72]. Marshmallow and other types of mallow significantly affect crops yield and quality of pumpkins, lettuce, potatoes, capsicum, cabbage, and other vegetable crops [69].

Tomato spotted wilt virus (TSWV) has been identified in many species of weeds and wild plants, most of which are new hosts among Malva [36].

TSWV is transmitted by several species of thrips, including common blossom thrips (*Frankliniella schultzei* Trybom), onion thrips (*Thrips tabaci* Lindeman), tobacco thrips (*Frankliniella fusca*), eastern flower thrips (*Frankliniella intonsa* Trybom), western flower thrips (*Frankliniella occidentalis* Pergande), and chilli thrips (*Scirtothrips dorsalis* Hood) [30, 69].

Only plant species that are infected with TSWV and on which thrips can complete their entire life cycle play an important role in the disease cycle. Among the important weeds is cheeseweed (*Malva parviflora* L.) [25, 27, 39, 40].

The epidemiology of TSWV results from complex interactions between primary host plants, other crops and host weeds, and thrips vector insects.

Cucumber vein yellowing virus (CVYV; genus *Ipomovirus*, family *Potyviridae*) [70].

CVYV naturally infects cucumber, cantaloupe, watermelon, and squash, and some weed species are also natural hosts of cheeseweed virus (*Malva parviflora* L.). CVYV is semi-resistant to the vector — whitefly (*Bemisia tabaci* (Gennadius)), which retains the virus for less than 6 hours. Therefore, individuals that move to non-host plants may not remain virulent long enough to transmit the virus. Whether CVYV is transmitted by seeds has not been established [71].

Pepino mosaic virus (PepMV), genus *Potexvirus*, family *Alphaflexiviridae*) [72] is identified as a disease agent occurring in protected tomato (*Solanum lycopersicum* L. (syn. *Lycopersicon esculentum* Mill.)) crops in the Netherlands. Later, PepMV was detected in England, Germany, Italy, Morocco, Portugal, and Spain. The virus disease has become a serious problem for the production of tomatoes in Europe [73, 74], and this in turn carries the risk of the virus entering the territory of Ukraine.

The virus is easily transmitted from plant to plant by contact, vectored by bumblebees, or seedborne-transmitted [75—77].

The host plant range of PepMV weeds is limited and includes, in addition to the *Solanaceae*, also of the *Malvaceae* — cheeseweed (*Malva parviflora* L.) common in Ukraine and the world (Table 1) [74, 78].

Very little information is on the PepMV economic impact on vegetable production, and even more so on the importance of wild in viral epidemiology.

Conclusions. This literature review has analyzed the role of weeds as reservoirs of viruses of agricultural plants growing in Ukraine and the world. Our knowledge of the role and influence of weeds and wild plants on the distribution of viruses in ecosystems and natural plant communities can be considered incomplete at best. Rather, this may be due to the fact that the efforts of plant virologists are primarily focused on crops and the viruses that affect them. Despite the fact that plant viruses and vectors can be found in agricultural and wild habitats in the same region, the movement of vectors between habitats and the role of each of the participants: viruses, vectors, and host plants (reservoir weeds) of virus infection, remain still not well studied. Many weed species remain uncertain about their ability to host vegetable crop viruses, but new plant hosts continue to be identified. Thus, virologists need to study more closely the possible role of weeds and wild plants in the epidemiology of plant virus diseases.

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РОСЛИНИ-БУР'ЯНИ РОДИН *ASTERACEAE ТА MALVACEAE* ЯК РЕЗЕРВАТОРИ ШКОДОЧИННИХ ВІРУСІВ ОВОЧЕВИХ КУЛЬТУР В УКРАЇНІ ТА СВІТІ

В огляді наведено аналіз сучасних літературних даних щодо пошireності бур'янів родин *Asteraceae* та *Malvaceae* як резерваторів вірусів сільськогосподарських рослин в агроекосистемах України і світу. Основна увага зосереджена на бур'янах, поширених саме в агроценозах сільськогосподарських культур. Розглянуто первинні джерела головних збудників вірусних хвороб овочевих культур, а саме *Tomato spotted wilt virus* (TSWV), *Tomato chlorosis virus* (ToCV), *Tomato yellow leaf curl virus* (TYLCV), *Cucumber mosaic virus* (CMV), *Cucumber vein yellowing virus* (CVYV), *Iris yellow spot virus* (IYSV), та *Pepino mosaic virus* (PepMV)) в різних кліматичних зонах, а також розглянуто основні фактори, що сприяють розповсюдженню шкодочинних вірусів в агрофітоценозах.

Ключові слова: *віруси рослин, вектори вірусів рослин, бур'яни-резерватори вірусів рослин.*