CHAPTER 2. VIRAL DISEASES OF CRUCIFEROUS PLANTS: PREVALENCE, BIOLOGY AND DEVELOPMENT CYCLE, EFFECTIVE CONTROL TACTICS

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2.1. Prevalence and species specificity of cruciferous viral diseases

Viral diseases in cruciferous plants are an important factor in reducing the yield of modern adapted varieties. The virological pathogenesis of cruciferous plants has a long history. Thus, the cruciferous mosaic virus was found on radish [1] in 1925. It was observed that both wild and cultivated radish (*Raphanus raphanistrum* L. and *R. sativus*) were affected by mosaic disease, which caused distortion and often blistered areas on the leaves (Figure 2.1).

In 1933 it was reported [2] on mosaic radish disease on the cultivated Daikon variety in Japan.

Additional reports of viral diseases occurring in other closely related species have been found, and their mention may be of interest. In 1924, it was described [3] mosaic disease of snake radish (*Raphanus sativus* L. var. *caudatus* Alef.), known in India as Mogri. This disease caused spotting on leaves, stems and pods in the early stages of infection. Later symptoms included pallor, swelling and deformation of leaves and pods, abnormal flower and fruit shape, and stunted plant growth.

In 1932, it was described [4] mosaic disease *Raphanus macropoda* Lév.

Viral disease of wild radish (*Raphanus raphanistrum* L.) from South Africa in 1931 was reported in other studies [5]. The virus known as ramen has also infected turnips and daikon [6].

The symptoms caused by radish mosaic virus were identical in the field and in the greenhouse. In greenhouse conditions, at temperatures between 13 °C and 19 °C, the first symptoms consist of small, roughly circular or irregular chlorotic lesions that appear randomly between and adjacent to the veins. Some of these lesions often merge. Over the course of several days, the chlorotic lesions become more numerous and soon replace the normal dark green tissue, giving it a distinctly chlorotic color and rough spotting, in contrast to the normal, healthy state.

After 10 days to 2 weeks, the normal dark green tissue appears as irregularly shaped, non-rising islands against a prominent yellowish-green chlorotic background (Figure 2.1). There is little or no leaf distortion, although sometimes raised dark green islands were observed on radish plants in the greenhouse for up to a month after inoculation. Necrotic lesions and stunting of infected plants were not observed in the field or in the greenhouse.

Symptoms caused by radish mosaic virus after mechanical inoculation in a greenhouse at 13 to 19°C – normal dark green tissue appears as irregularly shaped, non-raised islets on a prominent, yellowish-green, chlorotic background.

Viral diseases of other cruciferous crops have also been studied. Thus, viral diseases of rapeseed [8] (Table 2.1) are of particular importance in the epidemiology of viral infections, as rapeseed is an ideal host for overwintering viruses that infect other plants of the cabbage family. More than 12 viruses from different viral groups are known to infect rapeseed, among which the most common and harmful are: Turnip yellows virus (TuYV), Cauliflower mosaic virus (CaMV) and Turnip mosaic virus (TuMV).

A detailed list of viruses from different virus groups that infect and cause varying degrees of losses in rapeseed cultivation [9] is represented by such viruses as Beet western yellow virus (BWYV), Cauliflower mosaic virus (CaMV), Turnip mosaic virus (TuMV), Cucumber mosaic virus (CMV), Tomato spotted wilt virus (TSWV), Tobacco mosaic virus (TMV), turnip yellow mosaic virus (TYMV), broccoli necrotic yellow (BNYV), turnip rosette virus (TRoV), turnip wrinkle virus (TCV) and radish mosaic virus (RMV) have been reported to infect canola from various growing areas around the world. Yield reductions due to BWYV, CaMV and TuMV, which exhibit severe viral symptoms, are estimated to be between 70 and 79%. In China, viruses that cause rapeseed mosaic caused 30% of the yield loss, which is estimated to be 50–80% of the yield loss (Figure 2.2) [10].

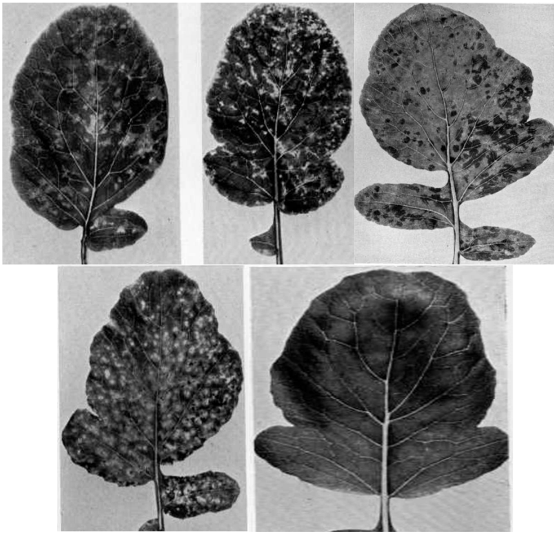

Figure 2.1 – Symptoms caused by mosaic virus on white radish leaves after mechanical inoculation in a greenhouse at 13° to 19°C: The leftmost position is symptoms consisting of small, round to irregularly shaped spots, chlorotic lesions (lesions scattered indiscriminately). The following positions are symptoms of interinfectious lesions consisting of irregularly shaped light and dark green areas that together form spotting. Lower rightmost position – control without inoculation [7]

Figure 2.2 – Massive infection of winter oilseed rape plants in the fall with a virus infection [11]

Turnip yellows virus (TuYV) is one of the most harmful and misunderstood viral diseases of the crop. It is believed that TuYV is one of the main reasons why commercial oilseed rape crops do not reach their genetically "programmed" yield potential. Viral symptoms can be difficult to recognize and can be easily confused with other diseases or nutrient deficiencies (Figures 2.3–2.5).

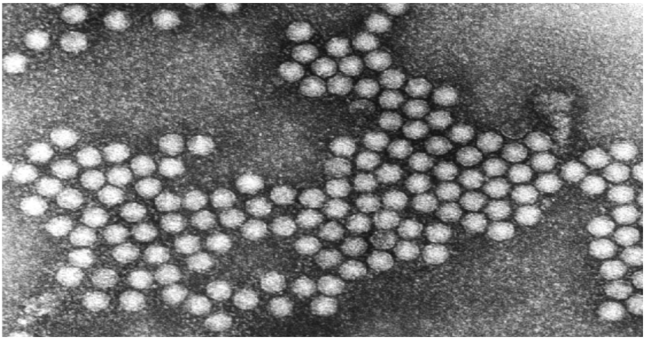

Figure 2.3 – Electron micrograph of TuYV virus particles [12]

Figure 2.4 – Spectrum of symptoms caused by natural infection of TuYV on rapeseed leaves collected from commercial crops during May [13]

Figure 2.5 – Foliar symptoms of TuYV virus in rapeseed [14]

Until recently, Turnip yellows virus, like Brassica yellows virus and Brassica yellowing virus, was considered to be an isolate of a single virus, Beet western yellows virus (BWYV). However, in 2002, the International Committee on Classification and Taxonomy of Viruses recognized *Turnip yellows virus* as an independent virus. How to recognize this viral disease? Typically, the leaf margins of affected plants turn red or purple, while yellow mosaic patterns develop on the entire leaf blade (Figures 2.6–2.7).

In rapeseed, infection with the virus can cause partial dwarfing of plants and reddening of the lower leaves, but infected plants usually do not show obvious symptoms. Symptoms of BWYV are often confused with symptoms of nutritional and physiological disorders. In Europe, BWYV infection leads to a 10–34% reduction in rapeseed yield, a decrease in seed oil content and an increase in glucosinolate content [18]. Viral symptoms were most noticeable in late winter and early spring before stem elongation and flowering of winter cruciferous crops.

Table 2.1

Rapeseed viruses [15–17]

Virus		The total number of reservoir plants	Method of transportation				
			mechanical	aphids: persistent	aphids: non-persistent	fleas	other insects
Cauliflower mosaic virus *cauliflower mosaic Caulimovirus*	CaMV	<100	+		–(–15)		
Cucumber mosaic virus *cucumis mosaic Cucumovirus*	CMV	>700	+		+(>80)		
Turnip mosaic virus *turnip mosaic Potyvirus*	TuMV	<100				+	
Turnip jaundice virus *turnip yellow* Luteovirus	TuYV	<50		+ (–17)			
Turnip yellow mosaic virus *turnip yellow mosaic* Tymovirus	TuYMV	>50	+			4–	+
Turnip wrinkle virus *turnip crincle* Carnnovirus	TuCV	<100	+		+	+	
Turnip rosette virus *turnip rosette* Sobemovirus	TuRV	<50	+			+	
Radish mosaic virus *radiscfi mosaic* Comovirus	RaMV	<50	4–			+	+

Figure 2.6 – Symptoms of rapeseed virus disease [19]

The discoloration is first seen on older leaves, but by early summer the symptoms can spread to all leaves. Often, the disease is asymptomatic in plants (both rapeseed and many weed species), so infected plants become a source of viral infection and contribute to the spread of the virus. Symptoms typical of TuYV can be easily confused with nutrient deficiencies and water shortages, frost damage, or even natural aging. For example, in England in 1968–1970, the discoloration of lettuce caused by a viral infection was mistakenly attributed to magnesium deficiency. Therefore, it is important to distinguish between a real virus infection and a nutrient deficiency by the symptoms on the same winter oilseed rape (Figs. 2.8–2.18).

Naturally, the main danger of the disease is not discoloration of the plants, but a significant reduction in crop yields (up to 30%). Subsequently, as a result of infection, plants become stunted, the leaf area is significantly reduced, the number of seeds per pod and oil content decrease, and, conversely, the glucosinolate content increases.

The virus is circulating in all key regions of global rapeseed production, including across Europe. In 2015–2016, heavy infestations were observed in Germany, France, Poland and the Czech Republic, and the average level of infection was observed in the UK.

Figure 2.7 – Typical symptoms on Capsella bursa-pastoris 10 weeks after inoculation with Turnip yellow yellow Luteovirus (TuYV)

Researchers identify three main reasons for the rapid spread of TuYV

1. Global warming (longer periods of aphid activity and, accordingly, an increase in the population of this pest).

2. Landscaping (more host plants for viruses and their vectors).

3. Prohibition of seed treatment with neonicotinoid insecticides (reduced protection of sown seeds).

Seed treatment with neonicotinoid insecticides allows its producers to reduce the aphid population by 85% and significantly reduce

Figure 2.8 – Manifestation of sulfur deficiency in rapeseed [20]

Figure 2.9 – Manifestation of boron deficiency in rapeseed [20]

the spread of the virus during the period when the crop is at its most vulnerable stage. Since 2013, the two main neonicotinoids – clothianidin and imidacloprid – have been banned in the European Union for use in open spaces, so only contact-acting insecticides are used. Among the pyrethroid insecticides against aphids, pimethroxine or thiacloprid-based products are effectively used.

Figure 2.10 – Manifestation of magnesium deficiency in rapeseed [21]

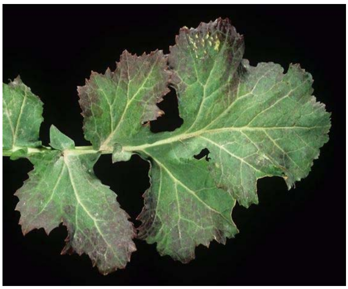

Figure 2.11 – Typical signs of phosphorus deficiency in rapeseed [22]

Figure 2.12 – Typical signs of potassium deficiency in rapeseed [23]

Figure 2.13 – Typical signs of nitrogen deficiency in rapeseed [24]

Figure 2.14 – Typical signs of iron deficiency in rapeseed [23]

Milder weather conditions in the fall and winter favor the reproduction of the main vector of the virus, the peach aphid Myzus persicae, and thus the rapid spread of the virus. Climate change may significantly worsen the situation, as warmer conditions will favor the survival and reproduction of M. persicae throughout the winter.

More than 150 species of cultivated plants and weeds from 20 families are susceptible to TuYV. The host range is very wide, including most types of cabbage (canola, kale, Brussels sprouts, broccoli, cauliflower, kale, rutabaga, turnip, Chinese cabbage), radish, lettuce, spinach, peas and beans. It has also been reported to attack a wide range of common weeds, including wild brassica, wild radish, shepherd's purse, shepherd's purse, shepherd's purse, tenacious marigold, dandelion, deaf nettle, tenacious marigold, and nettle. In addition to rapeseed, these weeds are a significant reservoir for

Figure 2.15 – Signs of molybdenum deficiency in rapeseed [25]

Figure 2.16 – Signs of manganese deficiency in rapeseed [23]

overwintering clubrooted moths, which threaten vegetable crops. They can be reservoirs of the virus in natural conditions and a source of possible viral epidemics.

Among the Iranian isolates, turnip mosaic virus (TuMV; family potyviridae, genus potyvirus) causes important diseases of crops worldwide,

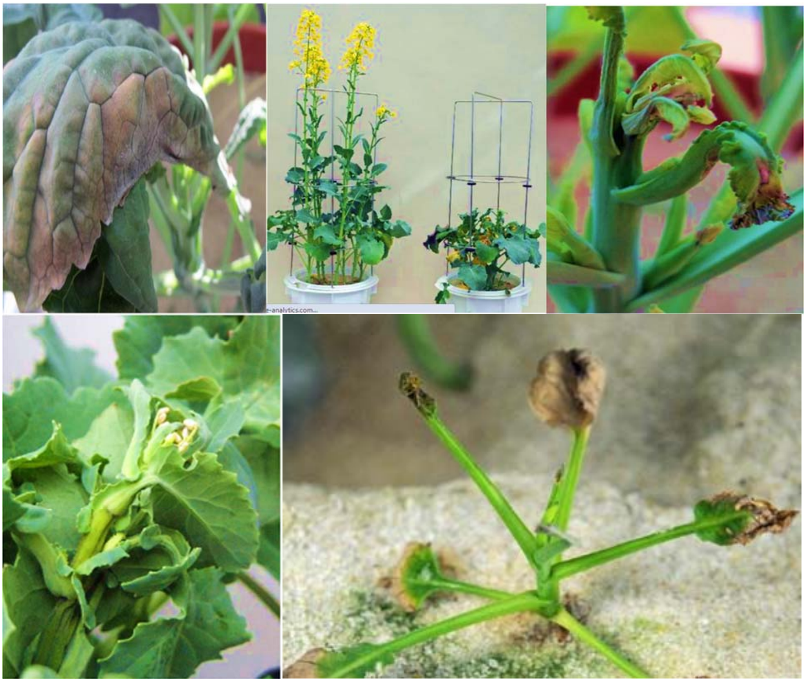

Figure 2.17 – Signs of calcium deficiency in rapeseed [26]

Figure 2.18 – Signs of zinc deficiency in rapeseed [27]

including: vegetables, e.g., Brassica oleracea ssp. botrytis (cauliflower), *B. napus, B. rapa, B. junce* (mustard), *Raphanus sativus* (radish), *Rheum rhabarbarum* (rhubarb), and ornamental plants such as *Matthiola incana* (rosemary) and *Limonium vulgare* (statice). It also infects a wide range of naturally occurring weed species, including Raphanus raphanistrum (wild radish). This virus is transmitted intermittently by several different aphid species. It is considered one of the most important viruses infecting field cruciferous vegetables [28]. It also damages field crops of *B. napus* in many European countries, where TuMV infection was recorded on 14% of crops and 5% of plants in general, with yield losses in infected crops reaching 70% [29] (Figs. 2.19–2.24).

Figure 2.19 – Signs of TuYV virus on rapeseed [30]

Figure 2.20 – Symptoms of TuYV on rapeseed leaves [31]

Figure 2.21 – Symptoms of TuYV virus on rapeseed leaves (symptoms on the top and bottom of the leaf may differ) [32–33]

Figure 2.22 – Uninfected Brussels sprouts (left) and plants infected with TuYV (right). Note the difference in color between infected and uninfected plants, as well as the size of the plants [34]

Figure 2.23 – Symptoms of cabbage tip scorch caused by TuYV virus [35]

Figure 2.24 – Difference in leaf discoloration (autumn) in resistant and susceptible plants: left – TuYV resistant hybrid, right – susceptible hybrid [36]

Cauliflower mosaic virus (CaMV) causes canola mosaic, which is characterized by yellow ring spotting on the leaves (Figure 2.25) [37]. The veins on the infected leaves become noticeably lighter, and over time, necrotic spots appear on them. CaMV causes stunted growth of infected plants, young leaves are usually underdeveloped and deformed over time [38]. Plants infected with the virus at a young age become weak and develop fewer flowers. Rapeseed mosaic can cause underdevelopment of seeds:

the weight of 1000 seeds from infected plants is 40% less than that of healthy seeds, and their germination rate is reduced by 20% [39–40].

CaMV affects only cabbage crops – rapeseed, mustard, cauliflower, broccoli [41–42] The virus persists on plants of wild weeds or self-sowing rapeseed plants. CaMV is transmitted non-permanently by many aphid species, including green peach and cabbage aphids [43–44]. The virus remains in the insect's mouth for a short period of time and dies when the infected aphids feed on healthy plants. The virus is not transmitted by seeds [45–46].

Additionally, it is also noted that in many regions CaMV virus is the main viral disease infecting cruciferous crops, including: *Brassica oleracea* var. *capitata*, *B. oleracea* var. *italica*, *B. oleracea* var. *botrytis*, *B. oleracea* var. *acephala* and *B. oleracea* var. *rapa*, *B. napus, B. pekinensis* and *Raphanus sativus*, The virus causes mosaic and bright vein chlorosis in most hosts. In chronically infected plants, symptoms may be masked, especially on tall *Brassica oleracea* var. *capitata*, *B. oleracea* var. *italica*, *B. oleracea* var. *botrytis*, *B. oleracea* var. *acephala* and *B. oleracea* var. *rapa*, *B. napus, B. pekinensis* and *Raphanus sativus*. The virus causes mosaic and bright vein chlorosis in most hosts. In chronically infected plants, symptoms may be masked, especially at high temperatures.

Infected plants of turnip, Chinese cabbage and other species tend to flower prematurely. CaMV is widespread in temperate regions, and pulses are usually infected wherever they are grown [47]. Biodiversity of 21 CaMV isolates [48] from different regions and with different symptom severity were evaluated on turnip (*Brassica rapa*), clinging marigold (*Datura stramonium*) and kohlrabi (*B. oleracea* var. *gongylodes*). These isolates caused a variety of symptoms on turnip. Kohlrabi plants infected with all tested isolates eventually recovered and became symptom-free. All isolates were transmitted by the green peach aphid (*Myzus persicae*). The ORF VI gene of nine selected CaMVs was amplified using specific primers. Comparison of the sequences of the amplified fragments showed high identity (96.9–100%) of the studied isolates [49].

Autumn is considered to be the most critical period for growing rapeseed. It is during this period that early crops are most often infected. Infection of plants after the formation of the rosette has a slight effect on yield.

The main way to combat the virus is to take preventive measures to destroy the source of viral infection – cruciferous weeds and self-seeding

Figure 2.25 – CaMV symptoms on rape leaves [50]

of rapeseed (especially in summer). To prevent aphids from invading young rapeseed plants, the density of crops must be high enough. It is very important to control the time of sowing seeds so that the peak of aphid migration does not coincide with the period of development of young rapeseed plants.

In mustard, the viruses BMYV, TuMV and CaMV are widespread and very common (Figs. 2.26–2.27).

Turnip mosaic virus (TuMV) is found everywhere in temperate and tropical regions. It is the second most common pathogen in terms of

Figure 2.26 – TuMV virus on mustard [51]

Figure 2.27 – TuMV virus on mustard [52]

prevalence and harmfulness, second only to cucumber mosaic virus. It infects more than 300 plant species from 43 families, including all cultivated, ornamental, wild and weeds of the Cabbage family. Due to the deformation of the leaves caused by the virus, the marketability of the product decreases, and more severe damage causes the plant to die. Affected plants experience stunted growth, early defoliation, which leads to a significant reduction in yield (up to 100% depending on the crop) and significant economic losses. The harmfulness of TuMV is sharply increased when plants are co-infected with other viruses (Figure 2.28–2.29) [53–54].

The first signs of virus infection are pale chlorotic or necrotic localized lesions on the leaves. Over time, the veins lighten, and systemic necrosis appears, turning into a continuous mosaic (Figure 2.30). Severely affected plants become stunted and deformed. Fewer pods are formed on diseased plants, they become twisted and have fewer seeds.

Viruses are usually transmitted over short distances (up to several hundred meters). The main vectors of TuMV spread are green peach (*Myzus pericae*) and cabbage (*Brevicoryne brassicae*) aphids, and the infection is easily transmitted mechanically. Weather conditions and air temperature significantly affect the activity and migration processes of insects, which, in turn, affects the spread of TuMV.

Dry and warm weather favors the reproduction and spread of aphids, and thus the early and intense spread of the virus. In the event of a primary focus of infection in the field, insecticides should be applied immediately, otherwise (if the number of aphids is not controlled) the virus can spread from plant to plant quite quickly (Figs. 2.32–2.34). Seed transmission of the virus has not been observed.

Figure 2.28 – Mosaic symptoms on rapeseed plants induced by turnip mosaic virus [55]

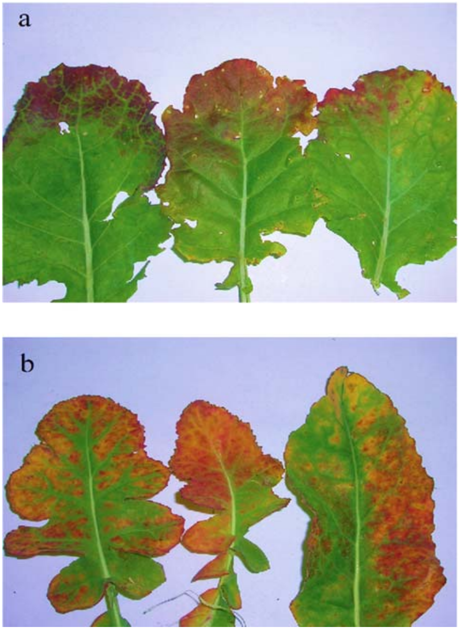

Figure 2.29 – Signs of turnip mosaic virus in rapeseed (A – onset, B – development of infection) [56]

Figure 2.30 – Turnip mosaic virus TuMV site in a rutabaga field showing premature yellowing of older leaves [57]

Figure 2.31 – A rutabaga plant infected a few weeks earlier with the Turnip mosaic virus TuMV. Note the old yellow leaves and young deformed leaves with a mosaic pattern of yellow and green areas [58]

Rapeseed mosaic, wrinkle mosaic and greening of rapeseed flowers are found on rapeseed. Rapeseed mosaic is characterized by light green spots on the leaves. The new leaves are underdeveloped and bent. The causative agent of the mosaic is the common cucumber mosaic virus *Cucumber mosaic virus*. It is spread by aphids and remains in overwintering plants. Cucumber mosaic can cause seed underdevelopment – the weight of 1000 seeds from affected plants is 40% or more less, and their germination rate is reduced to 20%. *Cucumber mosaic virus* affects a wide range of plants: 775 species belonging to 365 genera and 85 families. The largest number of species is represented by the following families: pumpkin, cabbage, nightshade, and Asteraceae [59].

Wrinkle mosaic causes lightening and fringing of the veins, mottling, and the formation of dark green spots with alternating yellow spots that are arranged in circles. Affected plants are stunted, have a depressed appearance, and the leaves often become wrinkled.

The causative agents of wrinkled mosaic are a mixture of cauliflower viruses *Cauliflower mosaic virus* and bean wilt virus [64]. Cauliflower mosaic virus is represented by a single DNA molecule, can be diluted at 10-3-10-4, and is inactivated at a temperature of 72–78 °C. The diameter

Figure 2.32 – The TuMV-infected turnip plant on the right has fewer leaves and a smaller root compared to the healthy plant on the left [60]

Figure 2.33 – Winter rapeseed carrion infected with TuMV [61]

of the virus particles is 50 nm. The viruses are spread by aphids, especially peach aphids, and remain in overwintering plants. Affected plants produce 2 times less seed yield and 1.5 times less green mass. Viruses that cause wrinkle mosaic affect cabbage and legumes.

Figure 2.34 – Green peach aphid on the undersurface of a rutabaga leaf. This common aphid is one of many species that can spread the disease. The virus is spread only by aphids [62]

Figure 2.35 – TuMV mosaic virus in rapeseed [63]

Black ring spot. Small black necrotic ring-shaped spots appear on the leaves. Later, the leaf blade turns yellow and dies. With a strong manifestation of the disease, the plants form a small number of flower-bearing branches. Seeds in the pods are underdeveloped or not formed at all. The causative agent of the disease is *Turnip mosaic virus*, a mosaic virus of black ring spot of cabbage. It is transmitted by contact, as well as by various types of aphids. It is not transmitted by seeds. In addition to rapeseed, it affects plants from the cabbage family. It hibernates in the tissues of living plants.

Greening of flowers is caused by underdevelopment of internodes and leaves, lightening of their veins [65]. The leaves become dense in texture. The flowers turn green and often proliferate. Affected plants usually do not form pods. Greening of flowers is a mycoplasma disease. The causative agent of the disease is the clover dwarf mycoplasma. It is spread by the cicadas *Euscelis plebejus* Fall and *Macrosteles laevis*. In addition to rapeseed, it affects cabbage, dope, chrysanthemum, terry, clover, etc. The pathogen does not spread with seeds. Mycoplasma bodies are stored in overwintering plants.

To combat viral and mycoplasma diseases, it is necessary to systematically control weeds, insect vectors, and to maintain spatial isolation of rapeseed crops from cabbage, clover and other crops of at least 1000 meters.

Since 1991 and 1996, symptoms have been observed in winter and spring rapeseed crops in England, France, Germany, the Czech Republic, and the United States, and research has shown that they are caused by a viral disease [66]. The first authors believed that the disease was caused by the beet western yellows virus (*Beet western yellows* Luteovirus). In Europe, the most common strain of this virus is the beet mild yellowing Luteovirus (BMYV), which in some years causes great damage to beet production, especially in Western and Central Europe [67]. However, analyzes have shown that rapeseed is infected by a separate virus from the Luteovirus group, which can be distinguished from unnamed viruses by monoclonal antibodies in an ELISA test and by the range of host plants. By its properties, the virus is identical to the virus, which was described by a number of authors in the 50s and 60s under the name turnip yellows virus (*turnip yellows Luteovirus* TYV) [68–71]. Later it was described under the name tunip mild yellowing virus (TuMYV). We refer to this virus as turnip yellows virus (TYV) after its first description. Although it belongs to the Luteovirus group, which includes such important pathogens of crops as beet mild yellowing virus (BMYV) and potato leafroll virus (PLRV), the host range of crops is very different, as shown by our analyses (Table 2.2).

According to our studies, the following crop plants are not infected by any of the above viruses: barley (*Hordeum vulgare*), sunflower (*Helianthus annuus*), cucumber (*Cucumis sativus*), alfalfa (*Medicago sativa*), meadow clover (*Trifolium pratense*), carrot (*Daucus carota*) and parsley (*Petroselium crispum*).

The range of host plants for turnip yellows virus is much larger (>50) than for beet mild yellow virus (<30) and potato leaf curl virus (<40). Of the weeds and wild plants that may play an important role in the epidemiology of this disease as reservoir plants and sources of infection, all important cruciferous weeds are affected by turnip yellow virus: field bindweed (*Lepidium camprestre*), weed bindweed (*Lepidium ruderale*), common bursage (*Capsella bursa-pastoris*), field mustard (*Sinapis arvensis*), field thistle (*Thlaspi arvense*), wild radish (*Raphanus raphanistrum*), as well as medium stellaria (*Stellaria media*), common buttercup (*Senecio vulgaris*), dandelion (*Taraxacum officinale*), medicinal arugula (*Fumaria officinalis*), stinging nettle (*Lamium amplexicaule*), self-sown poppy (*Papaver rhoeas*) and Veronica ssp. Among them, the host plants for turnip yellow virus and mild beet yellow virus are *Capsella bursa-pastoris*, common buttercup (*Senecio vulgaris*), common arugula (*Fumaria officinalis*), stem-med stinging nettle (*Lamium amplexicaule*) and self-sown poppy (*Papaver rhoeas*).

Figure 2.36 – Head of white cabbage (Brassica oleracea) infected with turnip mosaic virus [72]

The following weeds are not affected by turnip yellow virus: white quinoa (*Chenopodium album*), blue cornflower (*Centaurea cyanus*), soft-flowered galinsoga (*Galinsoga parviflora*), common mustard (*Polygonum lapathifolium*), common dope (*Datura stramonium*), stinging nettle (*Urtica urens*), dioecious nettle (*Urtica dioica*), clinging feverfew (*Galium aparine*), black nightshade (*Solanum nigrum*), chicken millet (*Echnicochloa crus-*

galli), fragrant chamomile (*Matricaria chamomilla*), white stinging nettle (*Lamium album*), pink thistle (*Cirsium arvense*), field thistle (*Sonchus arvensis*), garden thistle (*Sonchus arvensis*), vegetable thistle (*Sonchus oleracea*), plantain lanceolata, plantain major, annual meadowfoam (*Mercurialis annua*), yarrow (*Achillea millefolium*), and blunt sorrel (*Rumex obtusifolius*). These plants are also not affected by the mild beet yellow virus.

Table 2.2

Host plants of selected viral infections [73; 77]

Type of cultivated plant	Viruses		
	Beet mild yellowing virus (BMYV)	Turnip yellow virus (TuYV)	Potato leaf curl virus (PLRV)
Brassica napus var. *napus*	–	+	–
Brassica rapa var. *silvestric*	–	+	–
Sinapis alba	+	+	–
Raphanus sativus var. *oleiformis*	–	+	–
Camelina sativa	+	+	–
Brassica mapa var. *rapifera*	–	+	–
Brassica napus var. *napobrassica*	–	+	–
Brassica olecea	–	+	–
Raphanus sativus var. *niger*	–	+	–
Raphanus sativus var. *sativus*	–	+	–
Solarium tuberosum ssp. *tuberosum*	–	–	+
Beta vulgaris var. *altissima*	+	–	–
Beta vulgaris var. *crassa*	+	–	–
Beta vulgaris var. *conditiva*	+	–	–
Beta vulgaris var. *vulgaris*	+	–	–
Spinacia oleracea	+	+	–
Lactuca sativa	–	+	–
Capsicum annuum	–	–	+
Lycopersicon esculentum	–	–	+
Nicotiana tabacum	–	–	+
Phacelia tanacetifolia	+	+	–
Lupinus luteus	+	–	–
Lupinus albus	+	–	–
Pisum sativum	+	–	–
Vicia fabae	+	–	–
Cicer arietinum	+	–	–
Ornithopus sativus	+	–	–

In Western and Central Europe, as well as in the United States, the turnip jaundice virus is widespread. In commercial crops, 40 to 100% of plants are affected. Depending on the time of infection, virus isolate, susceptibility of the variety and degree of damage, the virus can cause yield losses of up to 50% and a reduction in oil yield of up to 15%. Experiments conducted in Aschersleben (Germany) over three years (1993-1995) with two virus isolates and two varieties of winter rape yielded the following results. Yield losses ranged from 12.1–34.3%, with an average of 20.4%, or 8 centner/ha. Symptoms of the virus on winter rape appear in the fall in the form of a purple-red color of the leaf margin. Later, whole leaf blades acquire this color. The symptoms are very similar to those caused by a lack of various nutrients, moisture and stagnant waterlogging of the soil of common sorrel (*Achillea millefolium*), blunt sorrel (*Rumex obtusifolius*). These plants are also not affected by the mild beet yellow virus [74]. Accurate diagnosis is possible only by means of virological analysis (ELISA). After mild winters, these symptoms are observed in the spring. Affected plants are stunted, branch less and form inferior pods. Similar symptoms are observed in spring rape and other susceptible crops.

Aphids play an important role in plant epidemiology. The virus is transmitted in a persistent manner with varying efficiency by at least 17 aphid species [75–77]. The main vectors are the following aphids: green peach, green-striped potato, currant, lupine, mealybug, cabbage, asparagus, large potato and corn aphids [78]. In addition to green peach and large potato aphids, none of the 17 aphids that transmit the turnip jaundice virus transmit the beet mild yellow virus [79]. Cauliflower mosaic virus (*Cauliflower mosaic Caulimovirus* CaMV) is one of the most dangerous pathogens for plants of the Brassicaceae family. In Southeast Asia, this virus infects various types of cabbage, daikon, seed radish, turnip, rapeseed, white mustard, sarepta mustard, and black mustard. Reservoirs of the virus in nature are weeds from the Brassicaceae family: watercress or common rape (*Barbarea vulgaris*), capsella bursa-pastoris, Sophia's descurainia (*Descurainia sophia*), field thistle (*Thlaspi arvense*), field mustard (*Sinapis arvensis*), and medicinal walker (*Sisymbrium officinale*). The virus persists in infected plants and in cabbage heads left unharvested in the field. The main symptoms of infection are lightening of all leaf veins

(Figure 2.37), dark green border of the main and middle veins, interveinal chlorosis, leaf disfigurement and stunted growth. Seed transmission was not observed. However, the virus infection affects seed germination, often reducing it by up to 100%, possibly due to damage to the embryo. At the same time, diseased plants produce small, dissimilar seeds with a thin, wrinkled shell.

The pathogen is effectively transmitted by aphids. Peach and mustard aphids are able to transmit cauliflower mosaic virus even after a single test puncture of a leaf. For cabbage aphids, the period of perception of infection is about 6 hours, while the ability to infect individuals of this species remains for more than 24 hours. Pea aphids, which are not specific for cruciferous plants, are also able to carry this virus, but after a longer perception of it (about a day).

In a number of countries, *Western yellow beet luteovirus* (BWYV) is introduced into rapeseed crops by aphid vectors that previously fed on infected host weeds such as wild radish and volunteer canola. BWYV can reach high levels in rapeseed crops if vector aphids emerge early in the growing season.

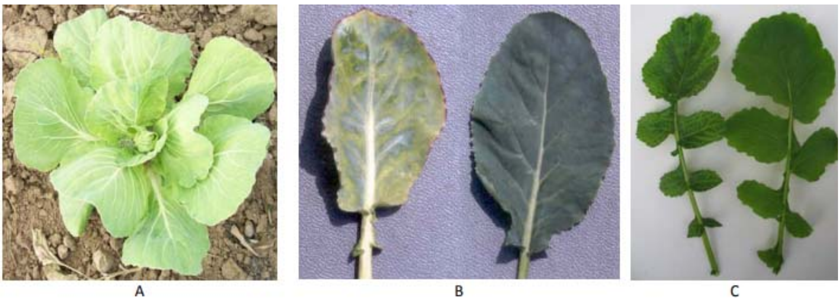

Figure 2.37 – Cauliflower mosaic virus: A – infected cauliflower (*Brassica oleracea*); B – leaves of infected (left) and uninfected (right) daikon (*Raphanus sativus* subsp. *acanthiformis*); C – leaf of infected (left) and uninfected (right) seed radish (*Raphanus sativus* var. *radicula*) [75]

2.2. Integrated systems and methods for controlling viral diseases in cruciferous crop agrocenoses

What are the main methods of controlling viral diseases of rapeseed?

First of all, weeds and insect vectors should be systematically controlled, and spatial isolation of rapeseed crops from cabbage, clover and other crops (at least 1000 m) should be maintained. The natural resistance of plants is the only possible, effective and environmentally friendly way to fight viruses.

In fact, the following recommendations can be formulated for virus control in cruciferous crops based on a number of studies [76–77]:

– Where practicable, preserve stubble and use direct seeding. Stubble helps to keep aphids away from a number of crop species. Sow with equipment that minimizes stubble damage. Do not leave stubble directly over the seeds as this prevents germination.

– Control broadleaf weeds in crops, around the perimeter of crops and on fallow land. This is especially true for cruciferous weeds, which can serve as reservoirs and centers of virus infection. Broadleaf weeds of other families can be reservoirs of BWYV.

– Sowing at the recommended time. A 1–2 week delay can reduce virus infection in some seasons if aphid flight ends before emergence. Sowing should always be the first priority to optimize yields regardless of disease. However, early maturing rapeseed varieties and all mustard varieties produce optimal yields at later sowing dates. These varieties sown at the end of the optimal time may have an advantage in areas and seasons where the virus limits yields.

– For rapeseed, seeds treated with the active ingredient imidacloprid should be used. Aphid resistance to imidacloprid has not been reported.

– The prevalence of aphids should be monitored in rapeseed crops. Periodically check the plants, including the underside of the leaves, for aphids. A large number of aphids, especially green peach aphids, indicates the possibility of a virus infection. It is important to check the plants frequently between the stages of emergence and leaf formation. Spray and observe the destruction of aphids. If there are a lot of aphids between emergence and leaf formation, choose a registered afficide (recommended with the active ingredient pyrimicarb).

– Test for viruses. If virus-like symptoms are observed, organize laboratory testing. Tests should include BWYV for rapeseed and BWYV and TuMV for mustard. At least 5 plants with symptoms and 5 plants with relatively asymptomatic disease should be tested. This can establish which types of viruses occur in the agrocenosis.

It is also emphasized that [78], that due to the limited host range for CaMV, cruciferous growers should pay special attention to the control of cruciferous weeds around seed plots and production fields. This should be combined with early aphid control in crops and adjacent areas. BWYV, CaMV and TuMV have been detected on wild radish weeds. In general, cases of BWYV were recorded more on wild radish than on rapeseed.

Control of rapeseed virus diseases [75; 79] is based on the development of new varieties with natural or genetically engineered resistance to the viruses, early insecticide applications on BWYV-infected crops, removal of host weed reservoirs, and possibly cultural control measures that limit the spread of the virus, such as those used against non-host viruses. BWYV is not seed-borne and must survive the summer in living host plants. It is not known whether CaMV and TuMV can be seed-borne.

To reduce the impact of TuYV on rapeseed yields, a system of preventive measures should be applied, including the cultivation of virus-resistant varieties, pre-sowing seed treatment and the use of insecticides.

Identifying and introducing resistance genes into the crop is an alternative strategy to combat this viral disease. In 2014–2018, breeders introduced a new rapeseed variety, Amalie (Limagrain), the first commercial variety with TuYV resistance, to the market. The use of this variety on an industrial scale should provide a 30% increase in yields compared to non-tuYV resistant species. Many researchers consider the TuYV-resistant Architect (Limagrain) hybrid to be the most promising for the European market. At the same time, farmers should keep in mind that TuYV-resistant hybrids are not resistant to aphid damage, so insecticides should be used in case of mass migration.

List of references for the Chapter 2

1. Hawaii Agricultural Experiment Station (1938) Report of the hawaii agricultural experiment station. 1937. 117 p.
2. Tompkins M. (1939) A mosaic disease of radish in California. *Journal of Agricultural Research*. 1939. Vol. 68. № 2. P. 119–124.
3. Viral diseases of rapeseed (2023). URL: https://propozitsiya.com/ua/virusni-hvoroby-ripaku (accessed March 31, 2023).
4. Shahraeen N., Farzadfar S., Lesemann D.E. (2003) Incidence of viruses infecting winter oilseed rape (*Brassica napus* ssp. *olifera*) in Iran. *Phytopathology*. 2003. Vol. 151. P. 614–616.
5. Shen S.H., Pu Z.G. (1965) A priliminary study of the two strain of turnip mosaic virus on rape in Kiangsu province. *Acta Phytophylacsys S.N*. 1965. Vol. 4. № 1. P. 35.
6. Viral diseases of rapeseed (2023). URL: https://propozitsiya.com/ua/virusni-hvoroby-ripaku-11 (accessed March 31, 2023).
7. Stevens M., McGrann G., Clark B. (2008) *Turnip yellows virus* (syn *Beet western yellows virus*): an emerging threat to European oilseed rape production? Bury St Edmunds Sufolk: HGCA: Broom's Barn Research Centre. 107 p.
8. Zhu M.L., He Y.W., Li Y., Ren T.R., Liu H., Huang J.B. (2020) Two new biocontrol agents against clubroot caused by Plasmodiophora brassicae. *Frontiers in Microbiology.* Vol. 10. e3099.
9. Zamani-Noor N., Rodemann B. (2018) Reducing the build-up of *Plasmodiophora brassicae* inoculum by early management of oilseed rape volunteers. *Plant Pathology*. Vol. 67. P. 426–432.
10. Shukla D.D., Schmelzer K. (1972) Studies on viruses and virus diseases of cruciferous plants. VII. Occurrence and effects of cabbage black ring and cauliflower mosaic viruses on brassica crops. *Acta Phytopathology.* Vol. 7. № 4. P. 325–342.
11. Hardwick N.V., Davies J.L., Wright D.M. (1994) The incidence of 3 virus diseases of winter oilseed rape in England and Wales in the 1991/92 and 1992/93 growing seasons. *Plant pathology.* Vol. 43. № 6. P. 1045–1049.
12. Broadbent L. (1957) Investigation of virus diseases of Brassica crops. *Agricultural Research Council*. 14. P. 11–19.
13. Zamani-Noor N., Krohne I., Koopmann B. (2021) Greenhouse evaluation of clubroot resistant-Brassica napus cv. Mendel and its efficacy concerning virulence and soil inoculum levels of Plasmodiophora brassicae. *Pathogens*. Vol. 10. P. 151–166.
14. Zamani-Noor N., Brand S., Söchting H.-P. (2022) Effect of pathogen virulence on pathogenicity, host range and reproduction of Plasmodiophora brassicae, the causal agent of clubroot disease. *Plant Disease*. Vol. 106. P. 57–64.
15. Zhang Y.M., Shao Z.Q., Wang Q., Hang Y.Y., Xue J.Y., Wang B. (2016) Uncovering the dynamic evolution of nucleotide-binding site-leucine-rich repeat (NBS-LRR) genes in Brassicaceae. *Journal of Integrative Plant Biology*. Vol. 58. P. 165–177.
16. Zheng J., Wang X., Li Q., Yuan S., Wei S., Tian X. (2018) Characterization of five molecular markers for pathotype identification of the clubroot pathogen Plasmodiophora brassicae. *Phytopathology.* Vol. 108. e 92.

17. Microfertilizers and their role in pathogen resistance (2023). URL: https://www.yara.ua/crop-nutrition/oilseed-rape/741/ (accessed March 31, 2023).

18. Zhou J.-M., Zhang Y. (2022) Plant immunity: danger perception and signaling. *Cell.* Vol. 181. P. 978–989.

19. Zhang Y., Edwards D., Batley J. (2021) Comparison and evolutionary analysis of brassica nucleotide binding site leucine rich repeat (NLR) genes and importance for disease resistance breeding. *Plant Genome.* Vol. 14. e20060.

20. Zhao Y., Bi K., Gao Z., Chen T., Liu H., Xie J. (2017) Transcriptome analysis of Arabidopsis thaliana in response to Plasmodiophora brassicae during early infection. *Frontiers in Microbiology*. Vol. 8. 673.

21. Zhao Y., Gao Z.X., Tian B.N., Bi K., Chen T., Liu H.Q. (2017) Endosphere microbiome comparison between symptomatic and asymptomatic roots of Brassica napus infected with Plasmodiophora brassicae. *PLoS One*. Vol. 12. e0185907.

22. Zhao Y., Chen X., Cheng J., Xie J., Lin Y., Jiang D. (2022) Application of Trichoderma Hz36 and Hk37 as biocontrol agents against clubroot caused by Plasmodiophora brassicae. *Journal of Fungi*. Vol. 8. P. 777.

23. Tomlinson J.A. (1987) Epidemiology and control of virus diseases in vegetables. *Annals of Applied Biology.* Vol. 110. P. 661–681.

24. Coutts A.B., Walsh J.A., Roger A.C.J. (2007) Evaluation of resistance to turnip mosaic virus in Australia Brassica napus genotypes. *Australian Journal of Agriculture Research*. Vol. 58. P. 67–74

25. Turnip yellows virus (TuYV) (2023). URL: https://projectbluearchive.blob.core.windows.net/media/Default/Horticulture/Publications/Turnip%20yellows%20virus%20%28TuYV%29.pdf (accessed March 31, 2023).

26. Boissinot S., Ducousso M., Brault V., Drucker M. (2022) Bioluminescence Production by Turnip Yellows Virus Infectious Clones: A New Way to Monitor Plant Virus Infection. *International Journal of Molecular Sciences.* Vol. 23. e 13685.

27. Slavíková L., Ibrahim E., Alquicer G., Tomašechová J., Šoltys K., Glasa M., Kundu J.K. (2022) Weed Hosts Represent an Important Reservoir of Turnip Yellows Virus and a Possible Source of Virus Introduction into Oilseed Rape Crop. *Viruses.* Vol. 14 e 2511.

28. Turnip yellows virus (TuYV) in western Victoria (2023). URL: https://extensionaus.com.au/FieldCropDiseasesVic/tuyv-western-vic/ (accessed March 31, 2023).

29. Graichen K., Rabenstein F. (1996) European isolates of Beet western yellows virus (BWYV) from oilseed rape (Brassica napus L. ssp. napus) are non-pathogenic on sugar beet (Beta vulgaris L. var. altissima) but represent isolates of *Turnip yellows virus* (TuYV). *Journal of Plant Diseases and Protection.* Vol. 103. P. 233–245.

30. Matevz R., Florence F., Michel T., Ion G.-A., Agnès D., Laurent G., Maja K., David D., Kristina G., Emmanuel J. (2015) Fluorescently Tagged Potato virus Y: A Versatile Tool for Functional Analysis of Plant-Virus Interactions. *Molecular Plant-Microbe Interactions.* Vol. 28. P. 739–750.

31. Viral diseases of rapeseed (2023). URL: https://propozitsiya.com/ua/virusni-hvoroby-ripaku-10 (accessed March 31, 2023). (in Ukrainian)

32. Shepherd R., Wakeman R. (1971) Observation on the size and morphology of cauliflower mosaic virus. *Phytopathology*. Vol. 61. № 2. P. 188–193.

33. Namba R., Sylvester E. (1981) Transmission of cauliflower mosaic virus by the green peach, turnip, cabbage, and pea aphids (Homoptera, Aphididae). *Journal of Economic Entomology.* Vol. 74. Is. 5. P. 546–551

34. Melcher U. (1989) Symptoms of cauliflower mosaic virus infection in Arabidopsis ithaliana and turnip. *Botanical gazette.* Vol. 150. № 2. P. 139–147.

35. Natti J.J. (1956) Influense of cauliflower mosaic and turnip mosaic viruses on yields of cabbage in New York state. *Plant Disease*. Vol. 40. № 2. P. 591–595.

36. Schoelz J.E., Shepherd R.J., Richins R.D. (1986) Properties of unusual strain of cauliflower mosaic virus. *Phytopathology*. Vol. 76. № 4. P. 451–454.

37. Alkaff N.S., Covey S.N. (1995) Biological diversity of cauliflower mosaic-virus isolates expressed in 2 brassica species. *Plant pathology.* Vol. 44. № 3. P. 516–526.

38. Pirone T., Paund G., Shepherd R. (1981) Properties and serology of purified cauliflower mosaic virus. *Phytopathology.* Vol. 51. № 8. P. 541–546.

39. Raybould A.F., Maskell L.C., Edwards M.L., Cooper J.I., Gray A.J. (1991) The prevalence and spatial distribution of viruses in natural populations of Brassica oleracea. *New Phytopatologist.* Vol. 141. № 2. P. 265–275.

40. Saunders K., Lucy A.P., Covey S.N. (1990) Susceptibility of Brassica species to cauliflower mosaic virus infection is related to a specific stage in the virus multiplication cycle. *Journal of General Virology.* Vol. 71. № 8. P. 1641–1647

41. Shababi M., Schoelz J. (1994) Characterization of the Solanaceous host rang of five strains of cauliflower mosaic virus. *Phytopathology.* Vol. 84. № 10. P. 1133–1142.

42. Viral diseases of rapeseed (2023). URL: https://propozitsiya.com/ua/virusni-hvoroby-ripaku 10789 (accessed March 31, 2023).

43. Goyal G., Harsimran K.G., McSorley R. (2022) Common Weed Hosts of Insect-Transmitted Viruses of Florida Vegetable Crops; ENY863; University of Florida Institute of Food and Agricultural Sciences: Gainesville, FL, USA. URL: https://edis.ifas.ufl.edu/publication/in931 (accessed March 31, 2023).

44. Farzadfar Sh., Pourrahim R., Golnaraghi A.R., Ahounmanesh A. (2005) Occurrence of Cauliflower mosaic virus in different cruciferous plants in Iran. *Plant pathology*. Vol. 54. P. 810.

45. Stevens M., McGrann G., Clark B., Authority H. (2018) Turnip yellows virus (syn Beet western yellows virus): An emerging threat to European oilseed rape production? *HGCA Research Revuer.* Vol. 69. P. 1–37.

46. Virus diseases in canola and mustard (2022). URL: https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/148377/virus-diseases-in-canola-and-mustard.pdf (accessed March 31, 2023).

47. Nancarrow N., Aftab M., Hollaway G., Rodoni B., Trębicki P. (2022) Symptomless turnip yellows virus infection causes grain yield loss: A three-year field study in south-eastern Australia. *Front Plant Science.* Nov. 23. Vol. 13. e1049905.

48. Liu X., Lu W., Liu Y. (1990) A study of TuMV strains differentia- tion of cruciferous vegetables from ten provinces in China. *Chinese Science Bulletin*. Vol. 35. № 20. P. 1734–1739.

49. Li X., Zhu T., Yin X., Zhang C., Chen J., Tian Y., Liu J. (2017) The genetic structure of Turnip mosaic virus population reveals the rapid expansion of a new emergent lineage in China. *Virology Journal*. Vol. 14. № 1. P. 165.

50. Hughes S.L., Hunter P.J., Sharpe A.G., Kearsey M.J., Lydiate D.J., Walsh J.A. (2003) Genetic mapping of the novel turnip mosaic virus resistance gene TuRB03 in Brassica napus. *Theoretical and Applied Genetics.* Vol. 107. P. 1169–1173.

51. Milošević D., Ignjatov M., Nikolić Z., Stanković I., Bulajić A., Marjanović-Jeromela A., Krstić B.B. (2016) The presence of turnip yellows virus in oilseed rape (*Brassica napus* L.) in Serbia. *Pesticidi I Fitomedicina.* Vol. 31. P. 37–44.

52. Turnip Mosaic Virus (TuMV) of rutabaga (2022). URL: https://www.ontario.ca/page/turnip-mosaic-virus-tumv-rutabaga (accessed March 31, 2023).

53. Jenner C., Keane G., Jones J., Walsh J. (1999) Serotypic variation in turnip mosaic virus. *Plant Pathology.* Vol. 48. P. 101–108.

54. Schroder M. (1994) Untersuchungen zur Anfalligkeit des Rapses (Brassica napus L. ssp. napus) gegeniiber verschiedenen Viruskrankheiten. *Z. Pfl.krankh. Pflschutz*. Vol. 101. P. 576–589.

55. Bramham L.E., Wang T., Higgins E.E., Parkin I.A.P., Barker G.C., Walsh J.A. (2022) Characterization and Mapping of retr04, retr05 and retr06 Broad-Spectrum Resistances to Turnip Mosaic Virus in Brassica juncea, and the Development of Robust Methods for Utilizing Recalcitrant Genotyping Data. *Frontiers in Plant Science.* Vol. 12. e787354.

56. Jenner C.E., Sanchez F., Nettleship S.B., Foster G.D., Ponz F., Walsh J.A. (2010) The cylindrical inclusion gene of turnip mosaic virus encodes a pathogenic determinant to the Brassica resistance gene TuRB01. *Molecular Plant-Microbe Interactions*. Vol. 13. P. 1102–1108.

57. Greer S., Hackenberg D., Gegas V., Mitrousia G., Edwards D., Batley J. (2021) QTL mapping of resistance to turnip yellows virus (TuYV) in Brassica rapa and Brassica oleracea and introgression of these resistances by resynthesis into allotetraploid plants for deployment in Brassica napus. *Frontiers in Plant Science*. Vol. 12. e781385.

58. Viruses of Canola (2023). URL: https://extensionaus.com.au/Field CropDiseasesVic/docs/identification-management-of-field-crop-diseases-in-victoria/viruses/viruses-of-canola (accessed March 31, 2023).

59. Schroder, M. (1996) Das Westliche Riibenvergilbungsvirus an Winterraps in Baden-Wurttemberg. Nachrichtenbl. Deut. *Pflanzenschutzd*. Vol. 48. P. 32–35.

60. Greichen K., Spaar D. (2023) Viral diseases of rapeseed and possibilities of breeding for resistance to them. URL: http://pdf/19970311.pdf (accessed March 31, 2023).

61. Spaar D. (1993) Wirtschaftliche und epidemiologische Bedeutung der Virusresistenz. B.: Kegler, H., Friedt, W.: Resistenz von Kulturpflanzen gegen pflanzenpathogene Viren. Gustav Fischer Verlag Jena Stuttgart New York. P. 21–34.

62. Spaar D., Kleinhempel, H. (1985) Bekampfung von Viruskrankheiten der Kulturpflanzen. VEB Deutscher Landwirtschaftsveriag. 440 p.

63. Gardner M.W., Kendrick J.B. (1921) Turnip mosaic. *Journal of Agricultural Research.* Vol. 22. P. 123–124.

64. Vandervalle R. (1950) La jaunisse des navets. Parasitica. Vol. 6. P. 111–112.

65. Watson M.A. (1963) Turnip mild yellows virus. Rothamsted Exp. Sta. Rep. for 1962. P. 112.

66. Brunt A.A., Crabtree K., Dallwitz M.J., Gibbs A.J. (1997) Viruses of plants. Descriptions and lists from the VIDE database. URL: http://agris.fao.org/agris-search/search.do?recordID=GB9620616 (accessed March 31, 2023).

67. Pitrat M. (2012) Vegetable crops in the Mediterranean basin with an overview of virus resistance. *Advances in Virus Research.* Vol. 84. P. 1–29.

68. Jenner C.E., Tomimura K., Ohshima K., Hughes S.L., Walsh J.A. (2022) Mutations in turnip mosaic virus P3 and cylindrical inclusion proteins are separately required to overcome two Brassica napus resistance genes. *Virology*. Vol. 300. P. 50–59.

69. Shopan J., Liu C., Hu Z., Zhang M., Yang J. (2020) Identification of eukaryotic translation initiation factors and the temperature-dependent nature of turnip mosaic virus epidemics in allopolyploid Brassica juncea. *Biotech.* Vol. 10. P. 75–13.

70. Jenner C., Walsh J. (1996) Pathotypic variation in turnip mosaic virus with special reference to European isolates. *Plant Pathology.* Vol. 45. P. 848–856.

71. Tomlinson J.A., Walker V.M. (1973) Further studies on seed transmission in the ecology of some aphidtransmitted viruses. *Annals of Applied Biology*. Vol. 73. № 1. P. 293–298.

72. Tompkins C.H. (1937) A transmissible mosaic disease of cauliflower. *Journal of Agricultural Research*. Vol. 55. № 1. P. 33–46.

73. Kennedy J., Day M., Eastop V. (1962) A conspectus of aphids as vectors of plant viruses. London, Comminwealth Institute of Entomology. 32 p.

74. Lung M.S., Pirone T.P. (1974) Acquisition factor required for aphid transmission of purified Cauliflower mosaic virus. *Virology*. Vol. 60. № 1. P. 260–264.

75. Schreinemachers P., Balasubramaniam S., Boopathi N.M., Cuong V.H., Kenyon L., Praneetvatakul S., Aer S., Nghia T.L., Srinivasan R., Mei-Huey Wu. (2015) Farmers' perceptions and management of plant viruses in vegetables and legumes in tropical and subtropical Asia. *Crop Protection*. Vol. 75. P. 115–123.

76. Coutts B.A., Jones R.A.C. (2000) Viruses infecting canola (Brassica napus) in south-west Australia : incidence, distribution, spread and infection reservoir in wild radish (Raphanus raphinistrum). *Australian Journal of Agricultural Research*. Vol. 51. P. 925–936.

77. Virus diseases in canola and mustard (2022). URL: https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/148377/virus-diseases-in-canola-and-mustard.pdf (date of application 31.03.2023).

78. Farzadfar Sh., Golnaraghi A.R., Pourrahim R. (2002) Plant viruses of Iran. Saman Company Publication, Tehran. 203 p.

79. Ghaderi M., Shahraeen N., Rakhshandehroo F. (2009) Study of genetic variation of different Cauliflower mosaic virus isolates infecting canola plants in Iran. *Phytopathology*. Vol. 99 (suppl. 6). P. 43.