35 Sugar Beet Nematodes: Their Occurrence, Epidemiology, and Management in Ukraine

K. A. Kalatur, J. D. Janse, and L. A. Janse

Abstract

This chapter describes plant parasitic nematode species of sugar beet, their occurrence, biology, and harmfulness, and presents a system of integrated nematode prevention and control methods for sugar beet under Ukrainian cultivation conditions. It is shown that the beet cyst nematode (*H. schachtii*) is by far the most important one in terms of spread all over the country (18 regions), plant damage, economic losses, and research and monitoring activities. It is followed by the stem nematode (*Ditylenchus dipsaci*) and the needle nematode (*Longidorus elongatus*). Root-knot nematodes (*Meloidogyne* spp.) and stubby root nematodes (*Trichodorus* and *Paratrichodorus* spp.) are of lesser importance and their occurrence in Ukraine less documented. The false root-knot nematode (*Nacobbus aberrans*) is not known to occur in Ukraine. The spread of these nematodes is facilitated by the reuse of sugar factory waste (sludge, washing water, heads, leaves, and root tips), especially when returned to the farm land or used as cattle fodder. Furthermore, wind, animals, man, and his machinery play a role. A system of prevention and control adapted to the Ukrainian cultivation conditions has been developed over the years and is presented here.

Keywords

Beet cyst nematode · Control · Docking disorder · Occurrence · Sugar beet

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Abbreviation

PEBV	Early browning virus of pea
PepRSV	Ring spot virus of pepper
RRV	Raspberry ringspot virus
TBRV	Tomato black ring virus
TRV	Tobacco rattlesnake virus

35.1 Introduction

Sugar beet (*Beta vulgaris* subsp. *vulgaris* convar. *Vulgaris* var. *altissima*) is in Ukraine, as in many countries, the only crop for the production of sugar, which is an important food product for the humans. By the end of the twentieth century, the cultivated area of sugar beet had reached 1.6 million hectares. There were 195 operating sugar factories in Ukraine, and the average annual production volume of beet sugar exceeded five million tons, with a sugar beet root production volume of 45–50 million tons. There are favourable conditions for sugar beet cultivation in the right-bank (Dnipro river) forest-steppe area (Vinnytsia, Cherkasy, Kyiv, Khmelnytskyi, Ternopil, Chernivtsi, Lviv, Rivne, Volyn, and Zhytomyr regions), as well as in the left-bank (Dnipro river) forest-steppe area (Poltava, Sumy, Kharkiv, and Chernihiv regions). Small acreages are cultivated in the northern steppe and the southern Polissia (Roik 2001; Prymak et al. 2009). The experience of many farms demonstrated that sustained adherence to good agricultural practice allows obtaining stable yields of sugar beet at the level of 55–70 t/ha and higher (Roik 2001; Prymak et al. 2009). However, in the last decade (2010–2020), the total cultivated area did not exceed 300,000 hectares, and in many regions of the country there was a significant decrease in the crop yield (Table 35.1) (Trybel and Stryhun 2012).

Table 35.1 Cultivated area and productivity of sugar beet in Ukraine[a]

Year	Cultivated area (1000 hectares)	Yield (t/ha)	Sugar yield (t/ha)
2011	515.8	36.3	4.51
2012	448.9	41.1	4.77
2013	270.5	39.9	4.67
2014	329.6	47.7	6.23
2015	238.9	43.6	6.19
2016	292.4	48.2	6.97
2017	318.0	47.5	6.87
2018	279.1	50.9	6.63
2019	220.6	46.1	6.69
2020	218.9	42.4	5.32

[a]Data from State Statistics Service of Ukraine (http://www.ukrstat.gov.ua/)

According to Trybel and Stryhun (2012), the main factors of a low root yield are insufficient fertilisation, violation of cultivation technology, and unsatisfactory levels of pest and pathogen control. Among the latter, the most important are the plant parasitic nematode (eelworm) species that live in the soil and feed on living plant tissues that they use as food and, often, also as an environment for reproduction and development (Decker 1969; Perry et al. 2018; Turner and Rowe 2006; Kazachenko and Muhina 2013; Borzykh et al. 2017; Sigareva et al. 2017). The infestation of sugar beet crops by these microscopic plant parasitic organisms not only causes yield reduction, but may even result in a complete yield loss (Cooke 1993; Marić and Čamprag 1982; Kalatur 2008a; Sigareva and Kalatur 2014; Kalatur et al. 2015; Pylypenko et al. 2016).

This chapter is a full update of an earlier review of the nematodes in sugar beet published before (Pylypenko et al. 2016), and presents the last survey and monitoring data as well as new insights into the taxonomy, biology, and management of the nematode diseases of sugar beet under Ukrainian growing conditions.

35.2 The Species of Plant Parasitic Nematodes in the Sugar Beet-Cultivated Areas in Ukraine, Their Occurrence, Host Plants, Biology, Symptoms, and Harmfulness

Sugar beet is affected by a large number of plant parasitic nematode species; the most damaging ones are the beet cyst nematode (*Heterodera schachtii*), the root-knot nematode (*Meloidogyne* spp.), the false root-knot nematode (*Nacobbus aberrans*), the stem nematode (*Ditylenchus dipsaci*), the needle nematode (*Longidorus elongatus*), the and stubby root nematode (*Trichodorus* and *Paratrichodorus* spp.) (Decker 1969, Marić and Čamprag 1982, Cooke 1993. Turner and Rowe 2006, Kazachenko and Muhina 2013, Manzanilla-López et al. 2002).

For Ukraine, the beet cyst nematode (*H. schachtii*), the stem nematode (*D. dipsaci*), and the needle nematode (*L. elongatus*) are the most important in terms of economic loss (Korab 1924; Korab 1929; Korab 1961; Shcherbak 1973; Kitsno 1984; Sigareva and Fylenko 1983; Sigareva et al. 1996; Kalatur et al. 2015; Pylypenko et al. 2016; Borzykh et al. 2017).

35.2.1 Beet Cyst Nematode *Heterodera schachtii* (Nematoda, Order Rhabditida, Family Heteroderidae)

35.2.1.1 Occurrence

The beet cyst nematode occurs in most European countries (Albania, Austria, Azerbaijan, Belgium, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Russia, and Ukraine), some African countries (Algeria, Cape Verde, Gambia, Libya, Morocco, Senegal, and South Africa), in Asia (China, India, Iran, Iraq, Israel, Jordan, Kazakhstan, Korea, Kyrgyzstan, Pakistan, and Syria), in North and South America (Canada, Chile, Mexico, Peru, USA, and Uruguay), as well as in Oceania (Australia and New Zealand) (EPPO GD, https://gd.eppo.int).

In Ukraine, the beet cyst nematode was first reported in 1923 in the fields of the Pii State Sugar Farm in the Kyiv region (Korab 1924). Since then, monitoring of the areas of sugar beet cultivation for soil infestation by this parasite is done almost yearly. In the 1980s, *H. schachtii* was detected in 16 regions (Linnik 1978) and in the early 2000s, in 17 regions of Ukraine (Sosenko 1998).

Continuing the systematic monitoring of soils and sugar beet sowings during vegetation over the past 20 years has demonstrated the existence of new foci of *H. schachtii* in the traditional beet-growing areas in Ukraine. Thus, during the years 2000–2004, monitoring was conducted in the Vinnytsia, Zhytomyr, Kyiv, Kirovograd, Poltava, and Khmelnytskyi regions on a total area of 18969.7 ha, of which 11310.7 ha (59.6%) was found to be infested with the beet cyst nematode (Sigareva and Pylypenko 2001; Sigareva et al. 2004a).

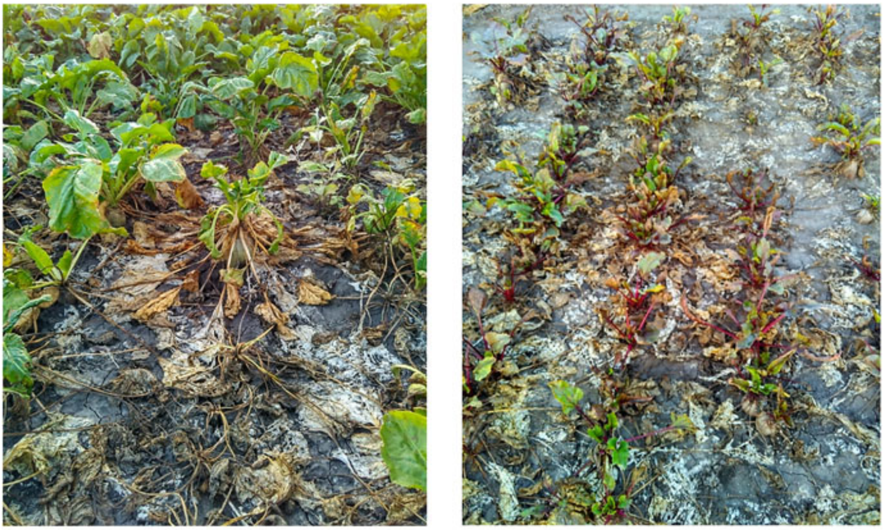
Monitoring conducted by the Institute of Bioenergy Crops and Sugar Beet NAAS during 2010–2020 in Kyiv, Chernihiv, Cherkasy, Khmelnytskyi, Kirovograd, Vinnytsia, and the Ternopil regions on a total area of 13271.9 ha detected the presence of the beet cyst nematode on 3471 ha (26.2%) of the total surveyed area.

Therefore, the results of nematological monitoring conducted over the past 40 years confirmed the presence of *H. schachtii* in 18 regions of Ukraine: Kyiv, Cherkasy, Vinnytsia, Sumy, Zhytomyr, Chernihiv, Khmelnytskyi, Ternopil, Rivne, Volyn, Lviv, Ivano-Frankivsk, Chernivtsi, Kharkiv, Poltava, Kirovograd, Dnipro, and Donetsk (Kalatur et al. 2015; Pylypenko et al. 2016). Given such a significant distribution of the beet cyst nematode, we can assume its presence in some of the remaining sugar beet-growing areas, for one reason or another not yet covered by nematological surveys. It is also necessary to point out that we found the beet cyst nematode not only in the production fields but also in small private vegetable gardens, where it parasitises on fodder and table beets (Fig. 35.1) (Pylypenko et al. 2016).

We consider that the main reasons for such a wide distribution of *H. schachtii* in the Ukraine area are (a) neglecting preventive measures (including the lack of systematic nematological survey and monitoring programs; poor sanitation of farm machinery leading to *H. schachtii* distribution, with the soil infested; application of infested sugar beet waste from the industry back to the field); (b) a large share (more than 20%) of nematode host plants other than sugar beet in crop rotations; (c) lack of availability of effective nematicides on the market (Korab 1961; Kitsno 1984; Sigareva and Pylypenko 2001; Sigareva et al. 2004a; Kalatur et al. 2015; Pylypenko et al. 2016).

35.2.1.2 Host Plants

Today, a wide range of host plants are known to us (Steel 1965). Host crops are all kinds of beet roots (*Beta* spp.), cabbage (*Brassica* spp.), rapeseed (*B. napus*), turnip (*Brassica rapa* subsp. *rapa*), radish (*Raphanus sativus*), mustard (*Sinapsis alba*,



A B

Fig. 35.1 Symptoms of beet cyst nematode infestation of fodder (**a**) and Table (**b**) beets (wilting, yellowing, stunting and complete necroses of the lower leaves, resulting in dead plants (Kyiv region, Ukraine. Photo: K. Kalatur)

B. juncea, B. nigra), and spinach (*Spinacia oleracea*) (Korab 1929; Korab 1961; Decker 1969; Kalatur et al. 2015; Borzykh et al. 2017).

About 235 species of weed hosts are known, of which almost 70% belong to 6 families: Brassicaceae (67 species), Chenopodiaceae (37 species), Fabaceae (23 species), Caryophyllaceae (19 species), Polygonaceae (12 species), and Asteraceae (12 species) (Kalatur and Pylypenko 2017). It has been found that weed infestation increases the number of nematodes in the ploughed soil layer. Thus, studies conducted in Ukraine (Babich 2004) showed that weed infestation of sugar beet crops with goosefoot (*Chenopodium album*) and wild turnip (*Barbarea vulgaris*) (8–10 plants/m^2) increased the number of *H. schachtii* in the soil 7.3–7.6 times within a period of 4 years. The presence of weed species in crops such as shepherd's purse (*Capsella bursa-pastoris*), wild radish (*Raphanus raphanistrum*), and goosefoot (*Chenopodium album*) increased the initial density of the nematode population by 50%, 56%, and 90%, respectively, over 4 years (Babich 2004). Such results show that host plants of both weeds and crops are important biological factors that contribute to the maintenance and preservation of the beet cyst nematode population in the soil at a high level (Kalatur and Pylypenko 2017).

Meanwhile, some crops do not promote the penetration, feeding, and/or reproduction of this parasite on their roots. These include alfalfa (*Medicago sativa*), asparagus (*Asparagus officinale*), barley (*Hordeum vulgare*), buckwheat (*Fagopyrum esculentum*), carrot (*Daucus carota*), chicory (*Cichorium intybus*), clover (*Trifolium* spp.), esparcet (*Onobrychus viciifolia*), flax (*Linum usitatissimum*), hairy vetch (*Vicia villosa*), hemp (*Cannabis sativa*), kidney bean (*Phaseolus* spp.), cucumber (*Cucumis sativus*), lettuce (*Lactuca sativa*), lupin (*Lupinus* spp.), maize (*Zea mays*), melon (*Cucumis melo*), millet (*Pennisetum glaucum*), oat (*Avena sativa*), onion (*Allium cepa*), pea (*Pisum sativum*), poppy (*Papaver* spp.), potato (*Solanum tuberosum*), rye (*Secale cereale*), tobacco (*Nicotiana spp.*), tomato (*Solanum lycopersicum*), sunflower (*Helianthus annuus*), watermelon (*Citrullus lanatus*), andwheat (*Triticum* spp.) (Korab 1929; Korab 1961; Decker 1969; Kitsno 1984; Kalatur et al. 2015; Borzykh et al. 2017). They are therefore useful alternatives in crop rotation.

35.2.1.3 Biology

The development cycle of beet cyst nematode includes six stages: eggs, four juvenile stages (invasive—second stage, parasitic—third and fourth stages), and adults (males: vermiform, i.e., worm-shaped, 1.3–1.6 mm long; females: lemon-shaped, 0.5–1.3 mm long and cysts, also lemon-shaped, which are dead females with eggs and juveniles inside) (Decker 1969; Turner and Rowe 2006; Sigareva et al. 2017).

In the beet-cultivated areas in Ukraine, hatching of the second-stage juveniles from cysts is observed during the spring at a soil temperature of 8–10°C (Ladygina 1961). The juveniles infest the roots and feed on the sap of living cells, moult twice, and then turn into adult females and males. The juveniles, which turn into males, keep the wormlike shape and leave the root of the plant where they have been developing. The body of the juveniles, which turn into females, rapidly increases in size, takes a lemon-like shape, and begins to press hard on the surface tissues of the root. Under this pressure, the root cover breaks and a mature female appears on its surface, where it is fertilised by a male that lives freely in the soil. After fertilisation, the female lays eggs in a mucous egg sac that is situated at the back of the body. The female produces 10–650 eggs with an average of 200–300 eggs. Subsequently, when the whole body of the female is filled with eggs, its internals die, and the white shell darkens from light to dark brown (Fig. 35.2). The mature cyst measures on average 1 mm in length, eventually drops from the root into the soil, and can stay there for up to 10 years without the eggs losing their viability. Depending on the environmental conditions (temperature, humidity, etc.) the development of one generation of the beet cyst nematode takes 42–67 days. In Ukraine, up to 2–3 generations of this parasite can develop during one growing season depending on the weather conditions and the availability of host plants (Korab 1929; Korab 1961; Kitsno 1984; Babich 1990; Sosenko 1998; Kalatur et al. 2015; Sigareva et al. 2017).

The main source of the long-distance spread of the beet cyst nematode is via wastes from sugar factories derived from washing and cutting sugar beet roots that is dumped untreated into the surface water or brought back to the fields, e.g., leaf and upper root material, soil, and root tips (tare). Another source is the mature sugar beet roots collected from the nematode-infested fields. Nematode cysts can furthermore be distributed with machines, transport vehicles, tillage tools, rain water, wind, animals (including birds), and humans (Korab 1961; Kalatur et al. 2015; Pylypenko et al. 2016).

Fig. 35.2 Mature cysts of the beet cyst nematode, *Heterodera schachtii*, c. 1 mm in length (photo: K. Kalatur, magnification 8× (МБС-10 Stereomicroscope)

35.2.1.4 Symptoms

The juveniles of beet cyst nematode penetrate the root system of beets in the early spring, but the symptoms of infestation become noticeable only in late June−early July (after the development of the first-stage generation) and can be found until the end of vegetation (Decker 1969; Kalatur et al. 2015; Pylypenko et al. 2016).

The degree of damage to beets depends on the pre-sowing density of the nematode population (juveniles + eggs) in the soil and a complex of abiotic factors, primarily temperature and humidity. In particular, at low (<200 juveniles and eggs/100 cm^3) and medium (201–600 juveniles and eggs/100 cm^3) numbers of nematodes in the soil, the affected plants will not look different from the healthy ones (Kalatur et al. 2015, Pylypenko et al. 2016). At daytime, however, when the air temperature reaches 20 °C and more, their leaves wither and eventually drop (Fig. 35.3). At a high level of soil infestation (>600 juveniles and eggs/100 cm^3), a vast majority of plants lag behind in growth and development; initially their leaves become pale green, then the outer leaves turn yellow and die. If such plants are dug up, the root would have a ‘bearded’ appearance, due to a large number of newly formed lateral roots, on which white, swollen female nematodes are clearly visible (Figs. 35.4 and 35.5). Sometimes there is a complete loss of crop plants in the foci of the infected area, resulting in the formation of patches of poor growth (roughly circular foci of stunting, yellowing plants) in the field (Fig. 35.6) (Korab 1961; Decker 1969; Marić and Čamprag 1982; Kitsno 1984; Cooke 1993; Turner and Rowe 2006; Kalatur et al. 2015; Pylypenko et al. 2016).

Fig. 35.3 Sugar beets infested by the beet cyst nematode, showing typical yellowing, necrosis, stunting, and wilting (Vinnytsia region, Ukraine, photo: K. Kalatur)

35.2.1.5 Harmfulness

Parasitism of the beet cyst nematode in beet roots, first of all, impairs the plant transport function and therefore it does not receive the necessary minerals and water from the soil. This in turn leads to pathological changes in a number of important physiological processes in the plant body: decreasing number of leaves and leaf area, the content of green pigments, carotenoids, phosphorus, nitrogen compounds, and potassium, slowing down the intensity of photosynthesis and respiration, and hormone balance (growth regulation) impairment (Kitsno 1984).

Sigareva et al. (2007) and Kalatur et al. (2020) noted that the penetration, feeding, and development of the beet cyst nematode juveniles inside the plant cells not only worsens the physiological state of plants but also 'opens the gate' for fungal pathogens that damage the root system, such as *Rhizoctonia solani*, *Aphanomyces*

Fig. 35.4 White, swollen females of beet cyst nematode on sugar beet (lateral) roots (Kyiv region, Vinnytsia region, Ukraine, photo: K. Kalatur, O. Polovynchuk)

Fig. 35.5 'Bearded' roots (newly formed lateral roots under the influence of nematode attack) of sugar beet (Kyiv region and Vinnytsia region, Ukraine, photo: K. Kalatur, O. Polovynchuk)

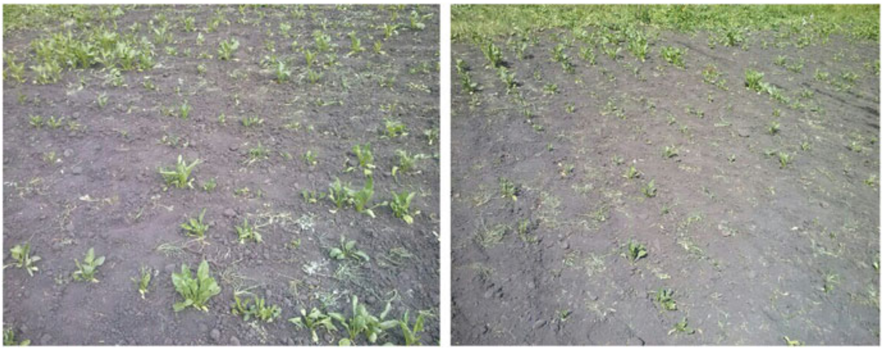


Fig. 35.6 Poor growth patches in a sugar beet field as a result of infestation by beet cyst nematodein Vinnytsia region, Ukraine (Source: Pylypenko et al. 2016)

cochlioides, Fusarium sp., *Pythium* sp., and *Phoma* sp. Sigareva et al. (2007) demonstrated that along with an increase in the soil infestation by the beet cyst nematode, the number of plants affected by *Pythium* and the degree of the infestation increased too. In a field plot, where the number of nematodes in the soil did not exceed 20 juveniles and eggs/100 cm^3, the incidence of *Pythium*-infected plants was 48.6% and the disease severity was 24.1%. Increasing the nematode population density from 500 to 1000 juveniles and eggs/100 cm^3 contributed to an increase in disease incidence of60.9–62.4% with a disease severity of up to 33.2%. Examination of the plants in the cotyledon stage showed that in a field plot where only soil fungi were present, 3.8% of the plants died, while in the treatment with fungi and high nematode invasion (1000 juveniles and eggs/100 cm^3) 10.5% of the plants died. The infestation of sugar beets by both the nematode and *Pythium* also negatively affected the weight of the plants. In the two-leaf stage, the weight loss of plants due to soil infestation by the beet cyst nematode alone was 12.5–15.0%, while co-infestation by fungi along with the beet cyst nematode led to 27.5–30.0% weight loss (Sigareva et al. 2007).

Negative physiological changes that occur in the beet plants due to the impact of the beet cyst nematode, along with a strong infestation by various fungal pathogens, lead to a significant reduction in root yield, reduced sugar content, and sometimes complete loss of plants. Sugar beet seed-bearing plants are particularly sensitive to infestation by *H. schachtii* (Korab 1961; Kitsno 1984; Sigareva et al. 2004a; Kalatur et al. 2015; Pylypenko et al. 2016).

Results of the studies conducted in Ukraine (Babich 1990) showed that beet cyst nematodes ranging from 210 to 280 juveniles and eggs/100 cm^3 caused a reduction of about 5–10% in the root yield. Along with the increase in population density to 500 juveniles and eggs/100 cm^3, the reduction reached 20% at 850 juveniles and eggs/100 cm^3 and 30% at 1550–2600 juveniles and eggs/100 cm^3–40 − 50%. The reduction in the yield of sugar beet seed-bearing plants at the above-mentioned levels of nematode infestation in the soil reached 7–14%, 29%, 42%, and 57–70%, respectively. A statistically significant decrease in the sugar content of roots occurred only at a high degree of soil infestation by beet cyst nematodes and ranged from 0.8 to 2% (Babich 1990).

The vast majority of fields infested by *H. schachtii* in Ukraine have an average to high level of beet cyst nematode in the soil, ranging from 200 juveniles and eggs/ 100 cm^3 to more than 600 juveniles and eggs/100 cm^3. However, in some foci, the population density of the nematode was 142,000 juveniles and eggs/100 cm^3, which led to the death of plants during vegetation (Pylypenko et al. 2016). The mortality rate in sugar beet seed-bearing plants in Kyiv, Zhytomyr, Cherkasy, and Ivano-Frankivsk regions of Ukraine was 40–100% (Sigareva et al. 2004a; Kalatur et al. 2015).

35.2.2 Rootknot Nematodes, *Meloidogyne* Spp. (Nematoda, Order Rhabditida, Family Meloidogynidae, *Meloidogyne*)

35.2.2.1 Species Composition and Occurrence

To date (2021), about 98 species of root-knot nematodes have been described and they are found world-wide (Subbotin et al. 2021). The most extensive damage to sugar beet crops, reported over the years in Greece, Italy, and the United States, is by the Javanese root-knot nematode (*Meloidogyne javanica*), south root-knot nematode (*Meloidogyne incognita*), and peanut root-knot nematode (*Meloidogyne arenaria*). In Kyrgyzstan, the former Yugoslavia, and Japan, the harmful nematode was reported to be the northern nematode (*Meloidogyne hapla*); furthermore, Japan and the United States also reported that the barley root-knot nematode (*Meloidogyne naasi*) was very harmful (Decker 1969; Matiashov 1971; Maas and Maenhout 1978; Marić and Čamprag 1982; Cooke 1993; Perry et al. 2018; Kazachenko and Muhina 2013; Subbotin et al. 2021).

In Ukraine, to date four species of root-knot nematodes have been identified. They are not found in sugar beet crops; however, they cause significant damage to vegetables, flowers, and ornamental crops in greenhouses. These four species include the Javanese root-knot nematode (*M. javanica*), which is found only in greenhouses in the Crimea, southern root-knot nematode (*M. incognita*), which is found all over the country, northern root-knot nematode (*M. hapla*), which is found in Zakarpattia, Lviv, Kyiv, Zhytomyr regions, and in the Crimea), and peanut root-knot nematode (*M. arenaria*), which is found in Kyiv and Kharkiv regions (Borzykh et al. 2017; Sigareva et al. 2017).

35.2.2.2 Host Plants

Root-knot nematodes affect about 4000 plant species in both open and protected cultivation. Field crop hosts (apart from sugar beet) include alfalfa, barley, clover, cotton (*Gossypium hirsutum*), maize, rye, oat, soybean (*Glycine max*), tobacco, pea, potato, rice, and sugar cane (*Saccharum officinarum*); vegetables such as cabbage, carrot, celery (*Apium graveolens*), cucumber, lettuce, pepper (*Capsicum annuum*), okra (*Abelmoschus esculentus*), parsley (*Petroselinum crispum*), pumpkin (*Cucurbita moschata*), spinach (*Spinacia oleracea*), tomato, and zucchini

(*Cucurbita pepo)*; many flowers, ornamental plants, trees and bush species; and many weed species (Decker 1969; Perry et al. 2018; Rich et al. 2009; Kazachenko and Muhina 2013; Borzykh et al. 2017; Kalatur and Pylypenko 2017; Sigareva et al. 2017; Subbotin et al. 2021).

35.2.2.3 Biology

The morphology of the root-knot nematodes differs significantly from the other groups of plant parasitic nematodes. The juveniles and males of the second stage are colourless and are worm shaped. Juveniles of the third and fourth stages and mature females have a pear-like or globose shape; they are white, rarely slightly greyish, with a protruding head end. The developmental cycle of the root-knot nematodes starts with the release of juveniles of the second stage, which have a length of 0.4–0.5 mm. Once in the soil, they actively migrate in both horizontal and vertical directions and penetrate into the root near its tip. After a short migration in the root bark, the juveniles orient themselves parallel to the longitudinal axis of the root, become immobile, and then begin to feed on the contents of the cells. As a result, hypertrophy of the root bark cells occurs, which leads to the formation of root-knots. After that, the juveniles moult, passing the third and the fourth stages. After the third moult, the juveniles that turn into males elongate, and after the fourth stage, they acquire a needle shape, 1.0–1.4 mm long and 30–40 μm wide. The juveniles that turn into females acquire a pear shape, 0.5–1.0 mm long and 0.4–0.5 mm wide. Males leave the roots and enter the soil, where they fertilise the females. Mature females secrete a gelatinous substance, in which they lay about 400–800 eggs (Decker 1969; Perry et al. 2018; Kazachenko and Muhina 2013; Subbotin et al. 2021). Depending on the humidity and temperature of the soil, the development of one generation of the root-knot nematode in Ukraine lasts from 21 to 56 days (Borzykh et al. 2017, Sigareva et al. 2017).

35.2.2.4 Symptoms

A characteristic feature of the plant infestation by root-knot nematodes is the formation of galls (outgrowths) on the root system, i.e., root-knots. Usually, at a low number of these parasites in the soil and single root-knots on the root system, the affected plant will not look different from a healthy one. There is a high density of populations of root-knot nematodes in the soil and the formation of a large number of root-knots. As a result, the plant's underground part does not receive enough water and minerals. This affects the appearance of plants: they begin to lag behind in growth and development, lose turgor, and wither in the heat. They have small, pale-green leaves that gradually turn yellow and dry up (Decker 1969, Marić and Čamprag 1982, Cooke 1993, Kazachenko and Muhina 2013, Borzykh et al. 2017, Sigareva et al. 2017, Subbotin et al. 2021).

35.2.2.5 Harmfulness

Matiashov (1971), Marić and Čamprag (1982), and Cooke (1993) reported that in the fields infected with root-knot nematodes, sugar beet yield reduction can reach >30%. It is also noted that the parasitism of the southern root-knot nematode

(*M. incognita*) inside the root system of the beets contributes to the infestation of plants by fungal pathogens, in particular *Pythium ultimum* and *Rhizoctonia solani* (Pandey 1984; Kalatur et al. 2020).

35.2.3 False Root-Knot Nematode *Nacobbus Aberrans* (Nematoda, Order Rhabditida, Family Pratylenchidae)

The false root-knot nematode (*N. aberrans*) causes significant damage to sugar beet crops in the temperate and subtropical latitudes of North and South America, including Mexico, the United States (Arkansas, Colorado, Kansas, Nebraska, Montana, South Dakota, Wyoming, and Utah), Argentina, Bolivia, Chile, Ecuador, and Peru (EPPO GD, https://gd.eppo.int; CABI Crop Protection Compendium, https://www.cabi.org).

Infestation of beet crops with *N. aberrans* inhibits the growth and development of leaves and roots throughout the vegetation. In hot weather, the plants wither and turn yellow. The most characteristic symptoms of the infestation include the formation of irregularly shaped root-knots and the formation of numerous lateral roots (Marić and Čamprag 1982; Cooke 1993; Harveson 2014). Studies showed that *N. aberrans* can cause a root yield reduction of 10–20% (Harveson 2014).

In Ukraine, the false root-knot nematode *N. aberrans* has not been found until now (2021) in sugar beet crops, although there is no active monitoring of this nematode, and its symptoms are easily mistaken for those caused by *Meloidogyne* spp. (hence its common name). This nematode can only be diagnosed microscopically in a specialised laboratory (EPPO PM7/5 (2) 2009). It is included in the Ukrainian A-1list, whichcontains regulated pests that have the status of a quarantine organism, not found in the country.

35.2.4 Stem Nematode, *Ditylenchus dipsaci* (Nematoda, Order Tylenchida, Family Anguinidae, *Ditylenchus*)

35.2.4.1 Occurrence

The stem nematode, *D. dipsaci*, occurs in many European countries with temperate climates, as well as in Africa, Asia, South and North America, and Oceania (EPPO GD, https://gd.eppo.int; CABI Crop Protection Compendium, https://www.cabi.org). In Ukraine, the stem nematode, *D. dipsaci,* is placed in the list of regulated non-quarantine harmful organisms.

35.2.4.2 Host Plants

D. dipsaci is known to affect about 450 plant species, including beets, celery, garlic (*Allium sativum*), onion (*Allium cepa*), pea, pumpkin, rhubarb (*Rheum rhaponticum*), and strawberry (*Fragaria x ananassa*); ornamental bulb species (hyacinth, narcissus, and tulip), oat, rye, and many weed species (Decker 1969, Gubina 1982, Sigareva et al. 2017, EPPO GD, https://gd.eppo.int/taxon/DITYDI/

hosts; CABI datasheet; https://www.cabi.org/isc/datasheet/19287#tohostsOrSpeciesAffected). There are more than 30 physiological races of the stem nematode, many of which are named after the main host crop (for example, onion race, oat race, and beet race) (Decker 1969; Gubina 1982).

35.2.4.3 Biology

D. dipsaci is a migrating obligate endoparasite that develops and reproduces in the living tissues of the host plant. Unlike the cyst-forming and root-knot species nematodes, males, females, and juveniles of the stem nematodes have a worm-like shape, with a body length of 1.0–1.3 mm. After penetrating the plant, the juveniles moult several times and turn into adult males or females. Once fertilised, the female lays an average of 207–408 eggs, from which the next generation of nematodes develops. Depending on the conditions of the environment, the development of one generation lasts from 19 to 23 days (Decker 1969; Gubina 1982; Marić and Čamprag 1982; Cooke 1993; Borzykh et al. 2017; Sigareva et al. 2017). Stem nematodes can be viable for a long time on dry plant residues in a state of anabiosis and come to life under favourable temperature and humidity conditions (Decker 1969, Gubina 1982).

35.2.4.4 Symptoms

Symptoms of sugar beet infestation with stem nematodes appear from the emergence of seedlings to the end of the growing season. In young plants, swellings may be formed on the leaves. Necrosis appears on the petioles and the base of the cotyledons. They begin to rot at high humidity. At the end of vegetation, necrotic zones or cracks are observed on the surface of the crown-root. Then they spread deep inside the root, forming the cavities (Decker 1969; Shcherbak 1973; Marić and Čamprag 1982; Cooke 1993). The affected roots may rot as a result of fungal and bacterial pathogens entering the wounded tissues (Hillnhütter et al. 2011).

35.2.4.5 Harmfulness

According to the research performed by Shcherbak (1973) in the Zaporizhzhia region of Ukraine in the year 1973, stem nematode can cause a sugar beet yield reduction of up to 54.6%. It was also noted that, in addition to yield reduction, the sugar content of roots decreased by 1–2% and dry matter by 2.5%, while the substances undesirable in sugar production were ash and nitrogen (Graf and Meyer 1973; Kuthe 1974).

35.2.5 Needle Nematode, *Longidorus elongatus* (Nematode, Order Dorylaimida, Family Longidoridae)

35.2.5.1 Occurrence

The needle nematode (*L. elongatus*) is common in most countries of Europe, Asia (India, Kazakhstan, Pakistan, Tajikistan, Uzbekistan, and Vietnam), North America (Canada and the USA), South Africa, and New Zealand (CABI database; https://

www.cabi.org). In Ukraine, *L. elongatus* is found in Sumy and Kharkiv regions (Sigareva and Fylenko 1983; Sigareva et al. 1996).

35.2.5.2 Host Plants

Host plants of *L. elongatus* include (apart from sugar beet) field crops such as cotton and maize, fruit and berry crops such as apple (*Malus* spp.), black currant (*Ribes nigrum*), cherry (*Prunus avium*), grape (*Vitis* spp.), peach (*Prunus persica*), pear (*Pyrus communis*), plum (*Prunus domestica*), raspberry (*Rubus idaeus*), strawberry, and forest tree species (Decker 1969; Sigareva et al. 2017).

35.2.5.3 Biology

The needle nematode (*L. elongatus*) is a large (5–10 mm) migrating, ectoparasitic nematode, which inhabits mainly deep (30–60 cm) soil layers. All stages of nematodes are vermiform. The female lays eggs in the soil, from which juveniles of the second stage emerge after 9–12 days of development. They quickly find the young roots of a plant, use their long stylet to pierce the epidermal cells, and begin to feed on their contents. After the fourth moult, the juveniles turn into adult individuals, males or females. Cool rainy spring and summer seasons promote the reproduction of this nematode species (Marić and Čamprag 1982; Cooke 1993; Sigareva and Kalatur 2014; Sigareva et al. 2017).

35.2.5.4 Symptoms

The infestation of plants with *L. elongatus* leads to the formation of slight swellings and galls at or just behind the tips of the lateral roots, as a result of which the main root dies, while lateral roots with a large number of minor roots are formed. Plants are delayed in growth and development (stunted) and have small, narrow leaves. The lower leaves may develop red discolouration at the edges (Decker 1969; Marić and Čamprag 1982; Cooke 1993; Sigareva and Kalatur 2014; Sigareva et al. 2017).

35.2.5.5 Harmfulness

It was found that at the number of *L. elongatus* in soil ranging between 65 and 100 individuals/100 cm^3 root, the yield reduction can reach 60% (Sigareva and Fylenko 1983). In addition to the negative impact on the yield, *L. elongatus* can transmit the tomato black ring virus (TBRV) (a Scottish strain of this virus causes ring spots on beets, see Cadman and Harrison 1960) and raspberry ringspot virus (RRV) (Harrison et al. 1961; Kalatur et al. 2016). This causes additional crop losses.

35.2.6 Stubby Root Nematodes, *Trichodorus* Spp. (Nematoda, Order Dorylaimida, Family Trichodoridae) and *Paratrichodorus* Spp. (Nematoda, Order Dorylaimida, Family Trichodoridae)

35.2.6.1 Occurrence

Nematodes of *Trichodorus* spp. and *Paratrichodorus* spp. are found in most countries of Europe, Africa, Asia, South and North America, and Oceania (CABI database; https://www.cabi.org).

35.2.6.2 Host Plants

Host plants of *Trichodorus* spp. and *Paratrichodorus* spp. include (apart from sugar beet) field crops (e.g., cotton, pea, potato, and tobacco), and many vegetables, flowers and ornamental crops (CABI database; https://www.cabi.org; Decker 1969).

35.2.6.3 Biology

Trichodorus spp. and *Paratrichodorus* spp. are ectoparasitic vermiform nematodes, 0.3–2.0 mm long. They feed externally on the tips of beet roots. The cycle of their development lasts for 21–22 days at a temperature of 22 °C, and for 16–17 days at a temperature of 30 °C (Decker 1969; Cooke 1993).

35.2.6.4 Symptoms of Infestation

Nematodes of these species mainly affect the cells at the tip of the main root or the cells behind it. As a result, the cells stop dividing and the root stops growing in length, and then dies. At the same time, a large number of lateral roots, growing in horizontal direction, are formed. On light sandy soils, these nematodes cause the so-called docking disorder, with symptoms of irregularly stunted plants with many side roots, giving a fangy appearance. Many of the stunted plants cannot be harvested, leading to important yield losses, especially after the heavy rainfall in spring (Decker 1969; Marić and Čamprag 1982; Cooke 1993; Sigareva and Kalatur 2014).

35.2.6.5 Harmfulness

It was found that when the number of *Trichodorus* spp. in the soil exceeds 500 individuals/kg, the yield reduction in sugar beets cultivated on sandy and light soils can reach 50% (Decker 1969; Marić and Čamprag 1982; Cooke 1993; Sigareva and Kalatur 2014). *Trichodorus* and *Paratrichodorus* spp. can transmit plant viruses, in particular, tobacco rattlesnake virus (TRV), early browning virus of pea (PEBV), and the ring spot virus of pepper (PepRSV) (Brown and Trudgill 1998; Kalatur et al. 2016).

35.2.7 Other Nematode Species

In the course of the studies conducted in Ukraine, several other parasitic nematode species have been detected and identified in the rhizosphere of sugar beet, such as

Paratylenchus nanus, the meadow nematode (*Pratylenchus pratensis*), *Helicotylenchus dihystera*, and *Tylenchorhynchus dubius* (Kalatur 1998, 2008a; Galagan and Hryhoriev 2004; Sigareva and Kalatur 2014). These nematode species did not cause any significant damage to sugar beet crops at a low soil density, but a higher number of their population in the soil (1200 individuals/100 cm^3) at the beginning of the growing season had a negative effect on the plant weight (losses reach 35–55%), and contributed to stronger damage to the seedlings by *Pythium* pathogens (Sigareva and Sosenko 2001; Sigareva et al. 2004b; Kalatur 2008b).

35.3 Measures to Prevent and Control Parasitic Nematode Species in Sugar Beet Cultivation

From the above-mentioned research results, it is clear that the beet cyst nematode is the most common and harmful parasitic nematode on sugar beet in Ukraine (Kalatur et al. 2015; Pylypenko et al. 2016). To reduce its harmfulness in sugar beet crops, a system of integrated preventive and control measures, useful under the Ukrainian growing conditions, has been developed, which includes agrotechnical, chemical, and biological methods, and a laboratory analysis before sowing (Korab 1929, Korab 1961, Kitsno 1984, Kalatur 2008b, Kalatur and Polovynchuk 2012, 2013, Kalatur et al. 2015, Hauer et al. 2016, Pylypenko et al. 2016, Borzykh et al. 2017). For a review of the integrated control methods for the beet cyst nematode and use of trap plants, see Held et al. (2000), and Matthias (2020). For the preference of use of resistant varieties over trap plants, see Hauer et al. (2016). Chemical nematicides are not registered in Ukraine. For possibilities in this field from the past, see Cooke (1989); for a more recent urgent plea of the British sugar beet industry for the use of a pesticide on the basis of oxamil (with nematicide and insecticide activity), see https://www.nfuonline.com/sectors/nfu-sugar/nfu-sugar-news/british-sugar-beet-industry-applies-for-an-emergency-authorisation-for-vydate/. For the use of fungicides and insecticides that showed a positive effect on the yield under beet cyst nematode infections in southern Europe, see Sasanelli et al. 2021.

The present control system for nematode infested soil in Ukraine consists of the following:

(1) adequate field intelligence (soil sampling for nematode detection and identification to aid decision making in sugar beet production); (2) measures to prevent the spread of cysts into other fields together with tillage tools, sugar factory waste (sludge, washing water, heads, leaves, and root tips), etc. for which hygiene practice should be administered (Korab 1961; Kalatur and Polovynchuk 2012; Kalatur et al. 2015; Pylypenko et al. 2016); and (3) application of a crop rotation that includes crops that adversely affect the development and reproduction of beet cyst nematodes, such as trap crops, and resistant and/or tolerant varieties/hybrids (Korab 1961; Kitsno 1984; Babich 1990; Kalatur and Polovynchuk 2012; Kalatur et al. 2015; Pylypenko et al. 2016).

35.3.1 Soil Sampling

Soil sampling for lab analysis should occur in autumn or spring, before sowing. This not only enables detection of the fields infested with the beet cyst nematode, but also helps predict any future yield loss due to the infestation level determined. As a rule, detection of *H. schachtii* by external symptoms of the infestation on plants during sugar beet vegetation is late and does not allow prevention of its distribution and thereby mitigation of its negative impact on the yield (Kalatur et al. 2015, Pylypenko et al. 2016).

35.3.2 Crop Rotation Schemes

1. In the fields where the population density of *H. schachtii* reaches a medium or high level (from and above 600 juveniles and eggs in 100 cm^3), it is necessary to exploit a ten-field crop rotation with a two-field share of sugar beet; and the following crop alternation: maize for green fodder–winter wheat–sugar beet–barley–perennial grasses/pea–winter wheat–sugar beet–pea–winter wheat–maize.
   Other possible combinations (depending on farm specialisation and field availability) may include:
   (a) sugar beet–oat with alfalfa–alfalfa–alfalfa–potato–winter wheat–winter barley–rye for green fodder + silage maize;
   (b) sugar beet–pea–winter wheat with alfalfa–alfalfa–alfalfa–alfalfa–potato–rye;
   (c) rye + vetch + maize for green fodder–potato–sugar beet–barley with clover–clover–clover–winter wheat;
   (d) winter/ spring wheat–sugar beet–barley–potato/ chicory–maize–bare fallow;
   (e) alfalfa–alfalfa–alfalfa–alfalfa–potato–sugar beet–barley;
   (f) alfalfa–alfalfa–alfalfa–alfalfa–potato–barley–sugar beet.
2. To use the so-called ‘cleaning’ crop rotations, i.e. rotations without the main host plant sugar beet):
   (a) rye with vetch–maize for green fodder–winter wheat–chicory–barley with clover–clover/alfalfa–alfalfa–alfalfa;
   (b) alfalfa–alfalfa–alfalfa–chicory–barley/spring wheat–rye with vetch–maize.

In practice, often the following short rotations are performed:

1. maize for green fodder/pea–rye for green fodder/for grain;
2. maize for green fodder/pea–rye for green fodder/for grain–rye for green fodder/for grain;
3. pea–maize for green fodder–rye;

Table 35.2 Cultivated area of sugar beet and rapeseed in Ukraine[a]

Year	Cultivated area (1000 hectares)	
	Sugar beet	Rapeseed (winter and spring varieties)
2011	515.8	870
2012	448.9	566
2013	270.5	1017
2014	329.6	881.6
2015	238.9	684.4
2016	292.4	456
2017	318	789.1
2018	279.1	1042.4
2019	220.6	1285.4
2020	218.9	1115.2

a Data from State Statistics Service of Ukraine (http://www.ukrstat.gov.ua/)

4. barley with clover−clover−rye;
5. alfalfa−alfalfa–wheat

(Korab 1961, Kitsno 1984, Babich 1990, Kalatur and Polovynchuk 2012, Kalatur et al. 2015; Pylypenko et al. 2016).

Based on the monitored results in various regions of Ukraine in the recent years (Sigareva and Pylypenko 2001; Pylypenko et al. 2016), it was determined that for a number of economic reasons, over the past decade, some farmers have reduced the area under sugar beet (or not sown at all) and increased the cultivated area of rapeseed, which is the host plant of the beet cyst nematode (Table 35.2). Thus, the cultivated area of sugar beet in Ukraine for the period from 2011 to 2020 decreased almost 2.4 times, from 515.8 thousand hectares in 2011 to 218.9 thousand hectares in 2020. At the same time, the cultivated area under rapeseed gradually increased, reaching 1042.4–1285.4 thousand hectares in the years 2018–2020.

The favourite conditions for expanding the cultivated area of winter and spring rapeseed are provided in Vinnytsia, Volyn, Zhytomyr, Ivano-Frankivsk, Kyiv, Lviv, Rivne, Ternopil, Khmelnytskyi, and the Chernivtsi regions. For the cultivation of spring rapeseed only, Kropyvnytskyi, Poltava, Sumy, and most southern regions have favourable conditions. However, in some of these regions, outbreaks of the beet cyst nematode with a high number of cysts in the soil have already been detected (Kalatur and Polovynchuk 2013), particularly in some farms, where the interval between sugar beet and rapeseed was just a year. The shortening of the intervals between sowing the host plants of *H. schachtii* became one of the main reasons for the significant spread of beet cyst nematodes in Ukraine (Sigareva and Pylypenko 2001; Kalatur et al. 2015; Pylypenko et al. 2016). Thus, in farms growing the rapeseed, it is necessary to introduce dedicated rapeseed crop rotations with the share of the rapeseed not exceeding 20–25%, and with the maximum share of grain crops such as:

(a) winter rapeseed—winter wheat—winter rye–bare fallow;
(b) winter rapeseed—winter wheat–bare fallow—spring barley;
(c) spring rapeseed—spring wheat–bare fallow—spring barley.

In case such crop rotation is not an option, rapeseed should be placed in crop rotations in such a way that it returns to the previous place not earlier than 4–5 years.

The interval between rapeseed and sugar beet should also be at least 4–5 years, for example:

(a) perennial grasses—winter rapeseed—winter wheat—maize for silage–pea—winter wheat—spring rapeseed (sugar beet)—barley with perennial grasses;
(b) perennial grasses—winter wheat—spring rapeseed—maize for grain—pea—maize for silage—winter wheat—sugar beet—barley with perennial grasses.

Crop rotation is considered as one of the most effective methods to control the beet cyst nematode and other nematode species in sugar beet and rapeseed crops. Moreover, it is economically profitable and the safest method for the environment and humans (Kalatur et al. 2015, Pylypenko et al. 2016).

35.3.3 General Agricultural Practices

To adhere to the correct agricultural practices of sugar beet cultivation, steps such as timely and high-quality tillage and seedbed preparation, application of balanced rates of organo-minerals and microfertilizers, optimal timing of sowing, and systematic (chemical) weed control in all fields of crop rotation should be taken (Trybel and Stryhun 2012; Kalatur et al. 2015; Pylypenko et al. 2016).

35.3.4 Trap Crops

A good practice is a short-term cultivation of the so-called trap crops (mustard, oil seed radish, and rapeseed), which stimulate the hatching of nematodes. These crops should be sown in August or September after harvesting pea, winter wheat, and/or other early grain crops; then, after 40–45 days, they should be mowed and incorporated into the soil. A decrease in the number of nematodes in the soil (up to 50–60%) will be due to the release of juveniles from cysts, their penetration into the roots of plants, and death during ploughing (Babich 1990; Sigareva and Sosenko 1997; Kalatur et al. 2015; Pylypenko et al. 2016).

35.3.5 Resistant and Tolerant Varieties of Sugar Beet

Growing sugar beet hybrids that are resistant/tolerant to the beet cyst nematode is the best control method in the long term. Despite the fact that plants of tolerant hybrids are still invaded by *H. schachtii*, their yield in fields infested with the parasite is higher compared to the conventional hybrids. Such hybrids are already available in the portfolio of most sugar beet seed producers. In Ukraine, research work on the development of sugar beet hybrids that are tolerant to beet cyst nematodes began in the 1980s (Pylypenko and Kalatur 2015). About 556 breeding genotypes and hybrids of sugar beet have been tested for nematode resistance in the years 1982–1990 and 2013–2020, and this work continues to date. Two domestic sugar beet hybrids, 'Bilotserkivskyi Odnonasinnyi 45' and 'Yuvileinyi', are recognized as tolerant to the beet cyst nematode (Pylypenko and Kalatur 2015). A few resistant/tolerant varieties of foreign origin are also registered on the national variety list (Attack, Balu, Bison and Federica).

35.3.6 Resistant and Tolerant Varieties of Oil Seed Radish and Yellow Mustard

Growing nematode-resistant/tolerant varieties of oil seed radish and yellow mustard is also advised. In Ukraine, trials to determine the tolerance/resistance of local varieties are still ongoing and are in the stage of breeding lines (Sigareva and Pylypenko 2001).

35.3.7 Use of Pesticides

When seeds were treated with insecticides (in the absence of any allowed nematicides) with active compounds carbofuran, thiamethoxam, imidacloprid, and bifenthrin, there was a 40% reduction in the number of the first-generation beet cyst nematodes under Ukrainian growing conditions (Babich 1990; Kalatur 2007). By the end of the sugar beet-growing season, however, due to the development of the second and subsequent generations, this parasite reproduced, and in some places even exceeded its initial number in the soil, even when insecticides were applied (Kalatur et al. 2015, Pylypenko et al. 2016).

35.4 Future Prospects

Studies conducted abroad have shown that the application of the biological control formulation Clariva pn (containing the mycelial and endospore-forming bacterium *Pasteuria nishizawae*, see https://www.syngenta-us.com/seed-treatment/clariva-pn and Perry et al. 2018) together with an insecticide based on thiamethoxam as seed treatment may greatly improve the yield of the beet cyst nematode tolerant varieties. Clariva pn, however, has only been registered for sugar beet in the USA and Brazil. The hyperparasitic fungus, *Hyalorbilia* sp. strain DoUCR50, proved to be effective in reducing the yield loss in tolerant varieties in studies performed in Germany (Eberlein et al. 2020).

35.5 Conclusion

The proposed measures to control the beet cyst nematode in sugar beet crops will also be effective against the other nematode species mentioned in this chapter. In particular, to limit the harmfulness of the root knot and migrating root nematodes, it is necessary to collect and destroy nematode-infested roots. Also, it is necessary to adhere to the correct agricultural techniques of growing crops (Decker 1969; Cooke 1989; Cooke 1993).

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