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BREEDING AND USAGE OF SUGAR BEET CULTIVARS AND HYBRIDS RESISTANT TO SUGAR BEET NEMATODE *HETERODERA SCHACHTII*

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Heterodera schachtii Schmidt, 1871 is one of the most economically important pests of sugar beet (*Beta vulgaris* L.) worldwide. It is also widespread in most sugar beet growing regions in Ukraine causing serious yield reduction and decreasing sugar content of sugar beet in infested fields. An advanced parasitic strategy of *H. schachtii* is employed to support nematode growth, reproduction and harmfulness. In intensive agriculture systems the nematode control measures heavily rely on nematicides and good agricultural practice (crop rotation in the first place). But alternative strategies based on nematode resistant sugar beet cultivars and hybrids are required as none of nematicides approved for the open field application are registered in Ukraine. Here we review the achievements and problems of breeding process for *H. schachtii* resistance and provide the results of national traditional breeding program. Since the beginning of 1980s five sugar beet cultivars (Verchnyatskyi 103, Yaltuschkivska 30, Bilotcerkivska 45, BTs-40 and Yuvileynyi) and seventeen lines partly resistant or tolerant to *H. schachtii* have been obtained throughout targeted crossing and progenies assessment in the infested fields. The further directions for better utilization of genetic sources for nematode resistance presented in national gene bank collection are emphasized. There is a need for more accurate identification of resistance genes, broader application of reliable molecular markers (suitable for marker-assisted selection of nematode resistant plants in the breeding process) and methods for genetic transformation of plants. Crop cash value and national production capacity should drive the cooperation in this field. Knowledge as well as germplasm exchange are thereby welcomed that can benefit breeding progress at national and international level.

Key words: sugar beet, *Heterodera schachtii,* nematode resistance, breeding.

INTRODUCTION

Sedentary cyst-forming nematodes of family *Heteroderidae* are the most dangerous obligate parasites, damaging the root system of many cultivated crops and causing their diseases and serious yield reduction. Several species are considered to be the most harmful, including grass *(Punctodera punctata*), oat (*Heterodera avenae),* soybean (*H. glycines*), potato golden (*Globodera rostochiensis*) and pale (*G. pallida*), hop (*H. humuli*), clover (*H. trifolii*), alfalfa (*H. medicaginis),* pea (*H. goettingiana)* and sugar beet (*H. schachtii*) cyst nematodes. The latter is the agent of heteroderosis – a sugar beet disease, wide-spread in many countries of the world [1, 2].

The distribution and harmfulness of sugar beet nematode in sugar beet fields

Sugar beet nematode is known for its spreading in 18 European countries where sugar beet is cultivated: in the Netherlands and Poland (on 25 % fields), on the territory of former Czechoslovakia (20 %) and Yugoslavia (10−12 %), Germany (20 %), Italy (19 %), Sweden (10−15 %), Spain, Great Britain (10 %), and France (3 %) [3]. In addition, it was found in Belgium, Denmark, Finland, Ireland, Switzerland, Austria and Bulgaria [1−3]. Sugar beet nematode was also registered in the USA, Canada, Romania, Latin America, Japan, Australia, India, Morocco, Algeria, Turkey, Israel, Tunisia, Iran and on the African continent (Senegal and Gambia) [1–3].

In the former USSR sugar beet nematode was first discovered by Professor Korab in Ukraine in August of 1923 on the fields of the Pii sugar beet farm, Kyiv region [4] (at present it is spread in 18 regions of Ukraine) [5–7]. Later (in 1932) it was found in Lithuania [8] and Kazakhstan (in 1939) [9]. Much later – in 1964 – the outbreak of heteroderosis was registered in Moldova [10], and in 1966 – in Kirghizia [11]. Similar outbreaks were reported in Belarus, Estonia, Tajikistan [10], Uzbekistan [12], Georgia [13] and Russia [14].

Apart from H. schachtii distribution rate, external symptoms of plant damage have been studied and described, which are rigorous in the field with a high level of soil infestation with this pest (over 300 eggs and larvae of nematode (e + l) in 100 ccm of soil). Due to such nematode population density the majority of plants are repressed in their growth and development, their leaves become pale green, later the outer leaves discolor to yellow and die back. Crop damage by heteroderosis usually appears as patches of poorly growing plants (late June – early July). If the plants are lifted out in this period, the beet-roots look “bearded” due to a high number of side roots bearing white bodies of nematode females. The most severe symptom of the disease is complete plant death [1, 2].

At the low (1–100 e + l/100 ccm of soil) and medium (101–300 e + l/100 ccm of soil) sugar beet nematode population densities in soil the infested plants do not differ from the healthy ones, however in the afternoon, when the air temperature reaches 20 °C and above, their leaves wilt and fall to the ground [1, 2].

Sugar beet nematode parasitizing in the root system leads to the impairment of its main function and the plant does not receive necessary mineral substances and water from the soil. At the same time there are pathological changes of a whole number of physiological processes: reduction in the total number and area of plant leaves, in the content of green pigments, carotinoids, phosphor, nitrogen compounds and potassium, as well as decrease in photosynthesis intensity; growth regulation is impaired and the breathing process is slowed down [1, 2, 15]. Stunted and wilted plants are not capable of fighting the other ptytopathogens of the root system and leaves completely. Therefore, the fields, infested with sugar beet nematode, are in danger of even wider infestation of sugar beet with Pythium disease, cercosporosis and root rot during the vegetation season [16–18].

The reason of high harmfulness of sugar beet nematode is the impairment of the recommended shift of crops in the crop rotation and the reduction of the terms of returning the plants – nematode hosts – to the field (all species of beet, cabbage, radish, mustard, ripe, spinach, rutabaga, turnip), disrespect of scientifically grounded systems of the soil cultivation and the systems of fertilization, insufficient application with plant protection products. The build up of nematode populations in soil is also promoted by weeds of *Chenopodiaceae*, *Brassicaceae*, *Caryophyllaceae*, *Labiateae*, and *Polygonaceae* families [1, 2, 4, 15, 16, 18–22].

Negative changes, occurring in a plant organism under the impact of *H. schachtii* invasion, lead to a remarkable reduction in the average weight of sugar beet roots and their sugar content, which eventually ends up in the crop yield reduction and sometimes in the death of plants [1−5, 15, 16, 18−22]. It is discovered that the degree of such losses depends on the pre-sowing density of sugar beet nematode population in soil, plant-predecessor, planting time, soil-climatic conditions of the region, weather conditions of the vegetation period *etc*. Sugar beet seed crop is the most susceptible to heteroderosis, because of these plants root system, which is not as deep as that of plants of the first vegetation year [1, 2, 15, 16, 18–21]. For instance, there was a noted sharp reduction in the sugar beet productivity with the pre-sowing density of sugar beet nematode population in the range of 210–2600 e + l/100 ccm of soil [19]. In particular, if 100 ccm of soil contains 210–280 e + l of nematodes, sugar beet yield reduction is 5–10 %, for 500 e + l/100 ccm of soil – 20 %, and for 850 e + l/100 ccm of soil – 30 %. The reduction of sugar beet seeds for the abovementioned infestation levels of nematode in soil will be 7–14, 29 and 42 %, respectively. Further increase in nematode population densities from 1,550 to 2,600 e + l/100 ccm of soil will promote the reduction in the root weight by 40–50 %, and the seeds – by 57–70 %. The reduction in the sugar content of roots is statistically reliable only at a high level of soil infestation with sugar beet nematode and may range from 0.8 to 2 % [19]. In the developed countries, the losses of sugar beet root weight and reduction in their sugar content from heteroderosis at the level of 25–30 % are estimated as 600 USD per 1 ha [23].

It is noteworthy that most Ukrainian fields have the medium level of soil infestation with sugar beet nematode of 600 e + l/100 ccm of soil [5, 6], but on some farms this level reaches up to 7,000 e + l/100 ccm of soil and above, which leads to the death of plants [5, 6, 24]. Usually the fields of the greatest outbreaks of heteroderosis are located on the farms in old areas of beet growing; the farms, associated with sugar refineries and factories, specialized in breeding beet seeds production. In particular, the areas of the highest sugar beet nematode population densities in soil are located in Kyiv, Vinnytsia, Cherkasy, Sumy, Chernihiv, and Kharkiv regions, and the beet yield reduction due to heteroderosis in these regions reaches 70–80 % [5, 6, 19, 20, 21, 24–26]. Due to high density of nematode population in soil there were cases of death of sugar beet seed plants in Cherkasy, Kyiv, Zhytomyr, and Ivano-Frankivsk regions [20]. Thus, the usage of the nematode infested fields should be planned considering economic threshold which does not exceed 200 e +l/100 ccm of soil in the forest-steppe of Ukraine [19].

The analysis of the data obtained testify that sugar beet nematode is one of the most wide-spread and harmful pathogens of sugar beet in many countries of the world and the losses, incurred from it, are estimated as over USD 95 million [27]. Therefore, starting from the moment of its discovery the researchers tried to determine the factors, which would allow limiting the population densities and harmfulness of nematode in the soil, and to elaborate the recommendations on reducing the losses of sugar beet yield and seeds from heteroderosis. The modern and widely used system of integrated crop protection from sugar beet nematode involves preventive, agrotechnical, organizational, economic and chemical measures. In particular, the system foresees the next measures: prevention of nematode introduction into the fields along with the equipment, tools for soil tillage etc.; following the recommended crop rotation, use of better predecessors; timely and qualitative main and pre-sowing soil tillage; introduction of organo-mineral and microfertilizers, balanced for the needs of the field; high quality of the seeds and its pre-sowing treatment with protective and stimulating substances; optimal terms of sowing; weed control on all the crop rotation fields; timely nutrition of plants in the vegetation period, etc. [1–7, 14–22, 24–26].

The history and problems of breeding sugar beet cultivars and hybrids, resistant to sugar beet nematode

In addition to the abovementioned measures a relevant place in the modern system of protection from heteroderosis is attributed to breeding and use of resistant and tolerant sugar beet cultivars and hybrids. The scientists of many countries of the world proved that cultivation of nematode-resistant plants on the fields, infested with this pest, is the most ecologically safe and economically justified measure [28, 29]. The first selection work in breeding nematode-resistant sugar beet cultivars was started by Moltz in Germany in 1917 [3]. In 1936 the studies were continued by Hulsenberg [30] and since 1954 this task was also pursued by Rietberg [31] and Filutowicz, Kuzdowicz [32]. However, the most relevant scientific achievements in solving this problem were made by Savitsky, who had been working at breeding nematode-resistant sugar beet lines in the USA for over 25 years [33–40].

In 1950s the genes of resistance to *H. schachtii* were discovered in three wild beet species of the section *Patellares* Tran.: *Beta procumbens* Chr. Sm. (1815), *B. patellaris* Moq. (1849), *B. webbiana* Moq. (1840) [41]. At the same time there was the first crossing of cultivated *B. vulgaris* with the wild species *B. procumbens* [42]. The nature of resistance of these beet cultivars to heteroderosis is the inability of sugar beet nematode to develop and reproduce in their roots. It was also determined that nematode is capable of penetrating roots of both resistant and susceptible sugar beet cultivars. However, the nutrition of its larvae in the roots is possible only in presence of special gigantic cells or syncytia, formed due to the dissolution of cellular walls under the impact of enzymes of these larvae [1, 2]. The degradation of the syncytia formed takes place only in resistant plants, leading to the death of nematode larvae of the 2nd and 3rd stages of development [3].

In addition to species from the section *Patellares*, other subspecies and cultivars of *B. vulgaris* (namely, diploid and tetraploid sugar beet [31, 32, 34, 43–47], fodder beet [48], red beet [49], mangold [50] and *B. maritima* cultivar [51]) were studied for the most compatible interspecies crossing. Such species as *B. macrocarpa* and *B. atriplicifolia*, were used as maternal plants for the crossing with *B. procumbens, B. patellaris, B. webbiana,* as well as tetraploids, obtained as a result of hybridization of *B. procumbens* and *B. webbiana* [52]. The positive results were achieved in Poland while crossing tetraploid beet with three wild species from the section *Patellares*. However, the revealed resistance against nematodes was lost in backcrosses B_1 of the subsequent generations [53]. Similar results were obtained while crossing the cultivated forms of beet and *B. webbiana.* The first and second generations of the hybrids obtained were remarkable for some resistance to *H. schachtii* which was lost in the subsequent generations [44]. In addition, it was discovered that the sugar beet nematode resistance breeding, based on interspecies hybrids, faces other difficulties as well – it yields either inviable progeny or hybrids with low fertility [30, 40, 54, 55]. Summing up the researches conducted prior to 1970, Savitsky presented the data about low viability of hybrid progeny: only 53 out of 3,000 obtained plants proved to be viable [40]. Out of 618 inviable sprouts, grafted to floriferous shoots of sugar beet, only 57 plants reached the stage of flourishing, while most hybrids of the first generation did not form seeds or formed very little thereof [40]. Inviability and low fertility of hybrids, no resistance to nematode and the doubts regarding the possibility of gene exchange between *B. vulgaris* and cultivars of the section *Patellares* led to the termination of any work in this direction in almost all the countries [40].

Regardless of some problems which occurred while breeding nematode-resistant sugar beet hybrids, some scientists continued their work to solve these issues anyway with Savitsky gaining the highest progress. After crossing tetraploid *B. vulgaris* with diploid *B. procumbens,* out of 6,750 plants four nematode-resistant trisomics were selected that had 18 *B. vulgaris* chromosomes and one *B. procumbens* chromosome responsible for resistance. This *B. procumbens* chromosome and the nematode-resistant trait were transferred to the eighth backcross generation. As a result of the crossing-over between chromosomes of *B. vulgaris* and *B. procumbens* in trisome plants, two diploid nematode-resistant plants were obtained in the progenies of trisomics and resistance was transferred from both of these plants to the first generation of sugar beet hybrids. Due to these researches the chromosome segment of the wild species of *B. procumbens* bearing the gene for nematode resistance, was transferred to a sugar beet chromosome [40]. Savitsky explains the genetic basis of resistance to sugar beet nematode as follows: "*Nematode resistance is most likely controlled by a single gene, because it is transferred by one chromosome. In the nematode-resistant species B. procumbens, the genes for nematode resistance early bolting, long petioles, and elongated dark-green leaves belong to the same linkage group. Nematode resistance is a dominant character*" [39]. Since the 1960s, Pawelska joined the work of breeding nematode-resistant sugar beet hybrids [30, 53]. She used the material of trisomics, obtained by Savitsky in the USA, in her studies. In 1977 Pawelska isolated two diploid plants with resistance to sugar beet nematode out of 60 plants, obtained from the progeny of resistant trisomics. Later these plants were used in the selection work regarding resistance to nematode [30].

Savitsky's work on the transmittance of the trait of resistance to *B. vulgaris* was supported and continued by other scientists, in particular, by Speckmann, De Bock, De Jong [56, 57], Heijbroek *et al*. [58, 59], Loptien [60, 61], Jung *et al*. [62, 63], Lange *et al*. [64–66].

In the former USSR the breeding of sugar beet cultivars and hybrids for resistance and tolerance to sugar beet nematode started in Ukraine and Russia [14, 54, 55, 67, 68]. Scientists worked in several directions, involving different methods of investigation, genetic in particular, to obtain hybrids of cultivated plants with wild beet species of the section *Patellares*, bearing resistance genes to sugar beet nematode, as well as the method of classic breeding with the search for new sources of resistance among different beet cultivars, which had already been obtained. However, due to the formation of inviable forms or hybrids with low fertility the desired results were not received [54, 55]. In addition, a number of undesired traits were transmitted to the gene pool of sugar beet along with the resistance to nematode. Therefore, the main efforts of researchers were directed towards the work in estimating and selecting nematode-resistant forms among the cultivars, lines and selection numbers of beet of different genetic origin. During 1925–1927 in Ukraine, on the fields of Pii and Nizov sugar refineries, Professor Korab tested 11 sugar beet cultivars for resistance to *H. schachtii* [67]. In Russia the determination of the nematode resistance degree of sugar beet and some wild beet species was pursued by Skarbilovich in 1940 [14] and Briushkova in 1971 [68]. However, these investigations did not yield any positive results – all the selective materials of sugar beet were found susceptible to sugar beet nematode.

Later (1982–1983) at the Institute of Sugar Beet (currently the Institute of Bioenergy Crops and Sugar Beet, NAAS) naturally infested fields (the level of sugar beet nematode in soil was 1,000 e + l/100 ccm of soil) were used to test 166 samples of mono- and polyspermic beet cultivars for resistance to nematode. The results of these experiments highlighted cultivars Verchnyatskyi 103, Yaltuschkivska monosperm 30 and six lines of sugar beet, the roots of which had 2–4 times less females of sugar beet nematode than other cultivars did. The researchers also noted that after growing of Verchnyatskyi 103 cultivar the number of nematode cysts in soil decreased by 7 % which also testifies to less susceptibility of this cultivar to the infestation with the pest [55].

During the subsequent years (1984–1990) about 300 samples, cultivars and lines of sugar beet were analyzed for resistance and tolerance to heteroderosis. Five lines, obtained from pair mating of the progeny of Yaltuschkivska and Yaltuschkivska monosperm 30 (12175, 12177, 12179, 12181, 12222), were isolated out of the selective material of Ivaniv experimental breeding station, and the degree of nematode infestation for them was estimated as the lowest (single cysts were found on the roots) attributed to 1 score (out of 1-5 score scale). Sugar beet cultivars (Bilotcerkivska 45, BTs-40 and Yuvileynyi) and six selective numbers (108-64, 108-6, 108, 59, 88, 126), tolerant to sugar beet nematode, were isolated [19, 54, 55]. The results, obtained by Ukrainian scientists, confirmed the possibility of breeding sugar beet forms, less susceptible to sugar beet nematode, in the course of screening of individual plants from relatively resistant (tolerant) forms on naturally infested fields with subsequent in-family reproduction of selected lines [54]. This work is still going on, although the classic breeding for resistance to nematode is known to last up to 15 years [69]. However, this approach to control *H. schachtii* spread and harmfulness is considered to be the most promising as there are no nematicides, accepted for use in field conditions in Ukraine.

Modern state of researches in breeding nematode-resistant sugar beet cultivars and hybrids

The development of genetic engineering and biotechnology methods launched a new trend of work in breeding nematode-resistant sugar beet cultivars and hybrids. At present such methods allowed mapping the genes, controlling resistance to sugar beet nematode, namely, $Hs1^{pro-1}$, $Hs2^{pro-7}$, $Hs1^{web-1}$, $Hs1^{web-7}$, $Hs1^{web-8}$ and $Hs1^{pat-1}$, where *Hs* − *H. schachtii*; *pro* − *B. procumbens*; *web* – *B. webbiana*; *pat* – *B. patellaris* [70, 71, 72, 73]; the figure at the end of the code indicates the chromosome of locating the mentioned locus – I, VII and VIII (Table). It is noteworthy that the chromosomes with genes of resistance of cultivars *B. webbiana* and *B. procumbens* are homologous [74, 75].

The characteristics of mapped genes of resistance to *Heterodera schachtii*

Gene	Origin	Chromosome of mapping	Literature
$Hs1^{pro-1}$	*B. procumbens*	I	[71]; [72]
$Hs1^{pat-1}$	*B. patellaris*	I	[72]
$Hs1^{web-1}$	*B. webbiana*	I	[73]
$Hs2^{web-7}$	*B. webbiana*	VII	[73]
$Hs2^{pro-7}$	*B. procumbens*	VII	[72]
$Hs3^{web-8}$	*B. webbiana*	VIII	[73]

The genes $Hs1^{pro-1}$, $Hs2^{pro-7}$, $Hs1^{web-1}$, $Hs1^{web-7}$ and $Hs1^{pat-1}$ are dominant and provide absolute resistance of the corresponding wild beet species to sugar beet nematode, contrary to partial resistance, ensured by the gene $Hs1^{web-8}$ [63, 72, 76].

The gene $Hs1^{pro-1}$ has been studied the most and it was proven that it encodes the plant disease resistance NBS-LRR proteins, which contain an amino-terminal domain, nucleotide-binding site (NBS) and leucine-rich repeats (LRR) [71, 77, 78]. Still an unusual aminoacid composition of these proteins allows referring gene $Hs1^{pro-1}$ to a specific independent class of resistance genes, encoding cytoplasmatic proteins [79, 80, 81].

The manifestation of resistance mechanism for plants with gene $Hs1^{pro-1}$is evident in syncytia (the system of nematode–induced cells used as specific feeding structure) degradation, which is observed with delay – on the 14th day after the nematode larvae penetration into the root of plants, but actually – after the period of determining the sex of nematodes, which explains the formation of a great number of females that do not mature [71, 82, 83].

Although the introgression of gene $Hs1^{pro-1}$ from wild species *B. procumbens* to cultivated *B. vulgaris* was generally successful, it was accompanied with the transmittance of undesired agronomic traits, in particular, low productivity of plants on nematode-free soil [69]. In addition, it was noted that sugar beet plants, carrying the locus of gene $Hs1^{pro-1}$, often suffer from the formation of tumors on leaves and root system and the occurrence of so called multi-top phenotype. To prevent this phenomenon, there was an attempt to decrease the introgression segment down to 35 and 17 % from the initial state. The plants obtained demonstrated resistance to sugar beet nematode though the molecular analysis testified to the loss of gene $Hs1^{pro-1}$, which here may indicate the presence of another gene of nematode-resistance in the introgression segment [84].

The discovery of the mentioned genes of resistance allowed accelerating the selection process of breeding sugar beet cultivars and hybrids, resistant to heteroderosis. The crossing of sugar beet cultivars and wild species with resistance genes leads to the formation of one of three genotypes: with the addition of the chromosome from wild species (monosomy phenomenon, $2n$ =

= 18 + 1) [57, 62, 85], with the addition of the chromosome fragment of wild species ($2n$ = 18 + F) [86, 87] and the introgression of the chromosome fragment of wild species to the genome of the cultivated cultivar ($2n$ = 18) [84]. It is noteworthy that three genes of resistance, descending from wild species *B. procumbens* ($Hs1^{pro-1}$), *B. webbiana* ($Hs1^{web-1}$, $Hs2^{web-7}$) and located on the first and seventh chromosomes respectively, were mapped on the fourth chromosome of *B. vulgaris* after the introgression [88].

With any type of transferring resistance genes to a new genotype its nematode-resistance is usually lower than of the paternal resistant form. So the resistance trait may be lost in the subsequent generations. It may indicate the presence of other, undetected yet, resistance genes in wild species, the combination of the former is the basis of absolute resistance of the initial paternal form [89], which was evidently demonstrated for gene $Hs1^{pro-1}$, already mentioned above [84].

However, regardless of these specificities the breeding and use of resistant cultivars allowed both obtaining a considerable surplus of beet yield on the infested fields, and decreasing the number of nematode in soil down to 73 %, while the nematode population densities in soil under the susceptible plants increased by 35 % [90, 91].

The first nematode-resistant cultivars of sugar beet Evasion and Nemakill were registered in France in 1996. Later (in 1998) another sugar beet nematode-resistant cultivar – Nematop – was included to the existing list in Germany [92]. However, they did not have high crop yield and their cultivation was proven more economically efficient only on the fields, where the density of nematode population was up to 800–1,000 e + l/100 ccm of soil [93]. According to the observations of Belgian scientists nematode-resistant sugar beet cultivars were somewhat less productive than susceptible cultivars, but they had higher crop yield on the soils with the infestation rate of over 1,500 e + l/100 ccm of soil [28]. In the opinion of German researchers, resistant cultivars should be cultivated only on the fields, densely infested with nematode [94]. However, recent investigations proved the recommendation to cultivate nematode-resistant sugar beet cultivars even on the fields, where the nematode population denstity does not exceed 250 e + l/100 ml of soil. If the pre-sowing number of sugar beet nematode reaches 750 e + l/100 ml of soil and above, the use of the resistant cultivar will, first and foremost, promote the decrease in its density in soil which is more important than obtaining high crop yield [95]. Thus, it was proven that after cultivating resistant sugar beet cultivars on nematode-infested fields the level of soil infestation did not exceed 216 e + + l/100 ccm of soil, whereas after cultivating susceptible cultivars the density of the nematode population increased up to 7,690 (2,260–14,100) e + l/100 ccm of soil [95]. In addition, it was determined that using the susceptible sugar beet cultivar the multiplication rate for sugar beet nematode was 1.8–8.9 (with the infestation level of 5,600–17,560 e + l/100 ccm of soil), whereas with the resistant cultivar this index decreased by 30–50 % [96].

During last decade continuous breeding work resulted in over 15 nematode-resistant cultivars. At present foreign companies recommend cultivating the following resistant sugar beet cultivars: Nemata, Pauletta, Hella, Kleist, Brix, Belladonna KWS, Adrianna, Kristallina KWS, BTS 440, Vasco, Lisanna KWS, Finola KWS, Corvetta KWS, Theresa KWS and Kuhn [97]. Several nematode-resistant sugar beet hybrids, including Korrida KWS, Slawa KWS and Bison, were registered in Ukraine. Contrary to the first sugar beet nematode-resistant cultivars, the crop yield of modern cultivars increased by 10 % on average. At the same time their quality was improved. In particular, the content of treacle-forming substances in the cellular fluid decreased by almost 10 % compared to the best standard cultivars. It is also noteworthy that while the first bred cultivars had almost 60 % resistance to nematode, this index for modern cultivars may sometimes reach as high as 100 % [98]. However, the scientists note that it is not reasonable to rely only on resistant cultivars on the fields with high level of infestation with sugar beet nematode. An integrated crop protection system should be applied on such fields including the cultivation of resistant intermediate crops [1–7, 14–22, 24–26].

CONCLUSIONS

Sugar beet remains a strategically important crop in Ukraine and, taking into account a wide distribution of sugar beet nematode in the country, the problem of breeding domestic nematode-resistant cultivars and hybrids of this crop is still urgent. Further development of selection programs for sugar beet regarding resistance to nematode is related to clearer identification of resistance genes and products of their expression, reliable estimation of genetic potential of initial and selection material using genetic markers and to the development and introduction of the methods of genetic transformation of plants. Crop cash value and production capacity are good motivation to cooperate in solving these issues, whereas the exchange of fresh knowledge and germplasm will be beneficial both on the domestic and international levels.

Створення та впровадження у виробництво сортів і гібридів цукрових буряків, стійких до бурякової нематоди *Heterodera schachtii*

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Heterodera schachtii Schmidt, 1871 є одним з економічно найзбитковіших паразитів цукрових буряків (*Beta vulgaris* L.) в усьому світі. Бурякова нематода широко розповсюджена у більшості бурякосіючих регіонів України, спричиняючи істотні втрати врожайності та зниження вмісту цукру у цукрових буряках із заражених угідь. Унікальні паразитарні властивості бурякової нематоди сприяють її росту, розмноженню та шкодочинності. В інтенсивних системах землеробства заходи контролю бурякової нематоди полягають переважно у використанні нематицидів та дотриманні належної сільськогосподарської практики (у першу чергу сівозмін). Оскільки жоден з нематицидів, дозволених до застосування за польових умов, не зареєстрований в Україні, актуальною лишається альтернативна стратегія, в основі якої лежить створення і використання стійких сортів і гібридів цукрового буряку. Зроблено аналіз досягнень і проблем процесу селекції на стійкість до *H. schachtii* та наведено результативність національної селекційної програми, що базується на традиційних підходах. З початку 1980-х років п'ять сортів цукрового буряку (Верхняцький 103, Ялтушківський однонасінний 30, Білоцерківська 45, БЦ-40 і Ювілейний) та 17 ліній, частково стійких або толерантних до *H. schachtii*, одержано внаслідок цілеспрямованого схрещування та відбору стійких форм на природних інвазійних фонах. Показано перспективні напрями подальшої роботи для ефективнішого використання джерел і донорів нематодостійкості, наявних в національному банку генетичних ресурсів рослин. Існує нагальна потреба в точнішій ідентифікації генів нематодостійкості, широкому застосуванні надійних молекулярних маркерів (для маркерної селекції) і впровадженні методів генетичної трансформації рослин. Ринкова цінність культури та потужності з її виробництва є добрим підґрунтям для кооперації з вирішення цих завдань, тоді як обмін новими знаннями та генетичною плазмою стануть корисними як на національному, так і міжнародному рівні.

Ключові слова: буряки цукрові, *Heterodera schachtii,* стійкість до нематод, селекція.

Создание и внедрение в производство сортов и гибридов сахарной свеклы, устойчивых к свекловичной нематоде *Heterodera schachtii*

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Heterodera schachtii Schmidt, 1871 является одним из наиболее экономически убыточных паразитов сахарной свеклы (*Beta vulgaris* L.) во всем мире. Свекловичная нематода широко распространена в большинстве свеклосеющих регионов Украины, вызывая существенные потери урожайности и снижение содержания сахара в сахарной свекле с зараженных угодий. Уникальные паразитарные свойства свекловичной нематоды способствуют ее росту, размножению и вредоносности. В интенсивных системах земледелия меры контроля свекловичной нематоды заключаются преимущественно в использовании нематицидов и соблюдении надлежащей сельскохозяйственной практики (в первую очередь севооборотов). Поскольку ни один из нематицидов, разрешенных к использованию в полевых условиях, не зарегистрирован в Украине, актуальной остается альтернативная стратегия, основанная на создании и использовании устойчивых сортов и гибридов сахарной свеклы. Сделан анализ достижений и проблем процесса селекции на устойчивость к *H. schachtii* и приведены результаты национальной селекционной программы, основанной на традиционных подходах. С начала 1980-х годов пять сортов сахарной свеклы (Верхняцкий 103, Ялтушковская односемянная 30, Белоцерковская 45, БЦ-40 и Юбилейный) и 17 линий, частично устойчивых или толерантных к *H. schachtii*, получены целенаправленным скрещиванием и отбором устойчивых форм на природных инвазионных фонах. Показаны перспективные направления дальнейшей работы для более эффективного использования источников и доноров нематодостойкости, имеющихся в национальном банке генетических ресурсов растений. Существует настоятельная потребность в более точной идентификации генов нематодостойкости, широком применении надежных молекулярных маркеров (для маркерной селекции) и внедрении методов генетической трансформации растений. Рыночная ценность культуры и мощности по ее производству являются хорошим основанием для кооперации по решению этих задач, в то время как обмен новыми знаниями и генетической плазмой будут полезными как на национальном, так и международном уровне.

Ключевые слова: сахарная свекла, *Heterodera schachtii*, устойчивость к нематоде, селекция.

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