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REVIEW

Beet moth (*Scrobipalpa ocellatella* [Boyd]): a review of bionomics, distribution, harmfulness, and control strategies

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Abstract

Beet moth (*Scrobipalpa ocellatella*) is a major pest of sugar beet crops in Europe, North Africa and Asia. Since its first detection in Poland a few years ago *S. ocellatella* has spread rapidly, causing extensive damage and is now one of the most serious threats to sugar beet. This problem is linked to climate change, high pest fecundity, its polyvoltinism and initially almost latent feeding. *Scrobipalpa ocellatella* causes crop losses directly by feeding on plants and indirectly by creating favorable conditions for the growth of pathogens causing rot diseases. Heavy contamination of the beet crown with larval excrement creates ideal conditions for secondary fungal and bacterial infections. Sugar beets with severe root rot delivered to sugar plants are in many cases unsuitable for processing.

Keywords: *Gnorimoschema ocellatellum*, rib miner, sugar beet pest

Introduction

Sugar beet (*Beta vulgaris* L.) (Amaranthaceae) is considered the second most important sugar crop after sugarcane (*Saccharum officinarum* L.) (Poaceae), especially in climate zones where sugarcane is not cultivated (Shalaby 2001; Draycott 2006; Shalaby and El-Samahy 2010; Bazazo and Mashaal 2014; El-Samahy *et al.* 2015; Duraisamy *et al.* 2017; Thalooth *et al.* 2019; El Aalaoui *et al.* 2025). Sugar beet is an important industrial crop and 25% of the world's sugar production comes from this plant (Biancardi *et al.* 2010; Hossain *et al.* 2021; Garcia Gonzalez and Björnsson 2022). The amount of sugar beet produced in 2019 was about 278 million metric tons in the world and about 112 million tons in the EU (Shahbandeh 2025). The European harvest area of sugar beet was estimated at 2,000,000 ha (Virić Gašparić *et al.* 2021) and Poland is one of the leading producers in Europe (CEFS 2021/22; Virić Gašparić *et al.* 2020). Recently, new non-food markets for sugar have emerged. For example, sucrose has been shown to be a useful raw material for the production of valuable chemicals such as 2,5-furandicarboxylic acid (van Putten *et al.* 2013), polylactic acid and biopolyethylene (Bos *et al.* 2012). Sugar beet is also an alternative source of energy. It has been used to produce bioethanol, which is the base material for biofuels, an alternative to fossil fuels (Zhang *et al.* 2008; Börjesson and Tufvesson 2011; Salazar-Ordóñez *et al.* 2013).

Sugar beet plants store very large amounts of pure sucrose in their roots and the root yield depends on many factors, including field location, soil fertility, soil moisture, season length, and the activity of pests and pathogens causing diseases (Ali *et al.* 2014). From the moment of sowing until harvest sugar beet can be infested by at least a dozen species of insect pests (Rashidov and Khasanov 2003; El-Dessouki *et al.* 2014; Hauer *et al.* 2017; Khalifa 2018). In recent years, increasing economic losses in Europe and other regions have been caused by the feeding of *S. ocellatella* (Boyd, 1858) (Lepidoptera: Gelechiidae) (Abdel R-ahman 2018; Ibrahim 2020; Piszczek *et al.* 2020a; Allahvaisi *et al.* 2021; Holý 2022a), which is currently one of the most serious threats to sugar beet (Ahmadi *et al.* 2018; Allahvaisi *et al.* 2021; Fergani *et al.* 2022). This problem is associated with climate change, high fecundity, its polyvoltinism and initially almost latent feeding. The restrictive European Union (EU) policy and the withdrawal of active substances suitable for the effective control of *S. ocellatella*, for example chlorpyrifos, (Commission Implementing Regulation EU 2020/18) are not without significance. The EU withdraws active substances plant protection products for several key reasons, based on its policies and legal regulations, primarily Regulation (EC) No. 1107/2009 (2009). The main reasons include health risks to humans (e.g., new evidence indicating carcinogenic, mutagenic, or endocrine-disrupting properties), and the need to protect non-target organisms. Substances that are highly persistent and mobile in the environment are subject to more stringent evaluation. The EU applies the precautionary principle, meaning that if there are scientific indications of potential risks – even without full scientific certainty – preventive measures can be taken, including the withdrawal of a substance. However, some of them were highly effective against *S. ocellatella*. According to Fergani *et al.* (2022), insecticides based on chlorpyrifos have shown high efficiency against *S. ocellatella*. The effectiveness of the organophosphorus insecticides was measured as a percentage of reduction in infestation density of the larvae. After 10 days post-treatment, 100% reduction was achieved. Hegazy (2018) reported a 90% reduction for chlorpyrifos. Ghada and Heba (2022) also demonstrated its high field effectiveness, achieving reductions ranging from 90.72% to 98.19%. *Scrobipalpa ocellatella* causes crop losses directly by feeding on plants and indirectly by creating favorable conditions for the growth of pathogens, such as *Penicillium claviforme* Bainier, *Phoma betae* Frank and *Botrytis cinerea* Persoon causing rot diseases (Fugate and Campbell 2009; Razini *et al.* 2016). Heavy contamination of the beet crown with larval excrement creates ideal conditions for secondary fungal and bacterial infections. These infections cause a 50% or greater decrease in sugar concentration in roots. Sugar beets with severe root rot delivered to sugar plants are in many cases unsuitable for processing (NASBG 2023). This article presents a review of the available literature on the geographical distribution, biology and damage caused by *S. ocellatella*, as well as control strategies, including the use of natural enemies and other environmentally-friendly control methods.

Taxonomy

According to the established scientific classification (GBIF 2024), *S. ocellatella* belongs to**:**

kingdom: Animalia (animals)
subkingdom: Eumetazoa
type: Polymeria
subtype: Arthropoda (arthropods)
class: Insecta (insects)
subclass: Pterygota (winged insects)
order: Lepidoptera (b*utterflies/moths)*
suborder: Glossata
suprafamily: Gelechioidea
family: Gelechiidae
subfamily: Gelechiinae
tribe: Gnorimoschemini
genus: *Scrobipalpa*

Morphology

The body of adults is 6–8 mm long and the wingspan is 12–15 mm (Fig. 1) (Bažok *et al.* 2015). The wings are very narrow, elongated, with a light fringe on the margins. The forewings are gray-brown, with several black spots surrounded by clusters of orange or light-brown scales. The hindwings are light-gray, with a notch on the apex (Chod *et al.* 1984). At rest, the wings are held close to the body in a roof-like arrangement. Sexual dimorphism is clearly marked in moths (Al-Keridis 2016). The female is slightly larger than the male (Bažok *et al.* 2015). Both sexes can also be distinguished by the color of the head, the color of the abdominal sternites (much darker in the male), and the shape of the abdomen, which is shorter and

Fig. 1. Moth of *Scrobipalpa ocellatella* (source: Zdzisław Klukowski)

narrower in the male (Al-Keridis 2016). A freshly deposited egg is 0.5 mm long, oval, yellowish and darkens to yellow-green shortly before hatching (Bažok *et al.* 2015; Al-Keridis 2016; Abdel R-ahman 2018). The caterpillar has a brown head, three pairs of thoracic legs and five pairs of abdominal prolegs on segments 3, 4, 5, 6 and 10. Caterpillars molt five times (Bažok *et al.* 2015), reaching a length of up to 12 mm (Maceljski 2002), and the last instar is gray with five dotted pinkish stripes running along the body (Fig. 2). Larva can be distinguished from related species, e.g., the goosefoot moth *Scrobipalpa atriplicella,* based on the arrangement of setae on the frontal part of the head and the prothorax (Chod *et al.* 1984).

Fig. 2. Larva of *Scrobipalpa ocellatella* (source: https://mariboseed.com/poland/szkodniki/#afsnit_5)

The pupa is initially light brown and darkens with age. It is 5.0–6.5 mm long, hiding in dense cocoons made of light silk thread. It is most often attached to fragments of leaves or roots. At the end of the abdomen the pupa has several pairs of larger and smaller bristles (Bažok *et al.* 2015).

Biology

Scrobipalpa ocellatella is an oligophage and feeds on sugar beet, fodder beet and wild beet, as well as plants from the family Amaranthaceae (Allahvaisi *et al.* 2021; Skenderović 2021). It is a polyvoltine species (Razini *et al.* 2016), and produces three or more generations annually, depending on local conditions. For example, the number of recorded generations was 4–5 in Croatia, Ukraine and Russia (Bažok *et al.* 2015, 2018), 3–6 in Iran (Kheyri *et al.* 1981; Razini *et al.* 2016), 3–4 in Hungary, Czechia (Potyondi and Kimmel 2003; Bittner *et al.* 2019), and Poland (Piszczek *et al.* 2020a). Dry and warm weather, especially in early spring, and a long warm autumn promote its reproduction (Sekulić and Kereši 2003). The optimal temperature is 23–24°C (Bažok *et al.* 2015). Valič *et al.* (2005) recorded the first noticeable occurrence of *S. ocellatella* in Slovenia in 2003, which was clearly drier and warmer than previous years. Such weather conditions are particularly suitable for it. This was confirmed in a study by Čamprag *et al.* (2006). Analysis of data gathered in Serbia for 1961–2004 indicated that the incidence of *S. ocellatella*, a xerothermophilic species, was high in dry and hot years. Similar relationships were found by Sekulić and Kereši (2003), who analyzed 28 seasons between 1975 and 2002. Because of favorable weather conditions and the high population dynamics, *S. ocellatella* can very quickly invade new areas. For example, occurrence in Croatia was first recorded in 1947 in the Slavonia region, and just 3 years later was reported from almost all sugar beet fields in the country (Sekulić and Kereši 2003). Since the dry year of 2015, an increase in the number of occurrences and harmfulness of *S. ocellatella* has been noted in Czechia. Major damage of heart-shaped leaves was recorded in 2018 in almost all beet growing areas in this country (Bittner *et al.* 2019). Furthermore, recurrent outbreaks, at intervals of about 10 years, were observed, and in many cases followed an extremely dry and hot summer (EPPO Standards 1997; Bažok *et al.* 2015).

Scrobipalpa ocellatella initially flies onto field margins. Its subsequent generations overlap in time, and at the end of the growing season almost all developmental stages are found in one field (Bažok *et al.* 2015; Piszczek and Klukowski 2021). This is associated, for example, with the extended seasons of flying and oviposition. The first spring generation is responsible for reproduction and the large population size of subsequent generations, which later cause significant damage to crops (Bittner *et al.* 2019). The moth flight after wintering begins in late March and early April, depending on the region and weather conditions (Maceljski 2002), and can last up to two months (EPPO Standards 1997; Bittner *et al.* 2019). Individuals wintering in the pupal stage fly at the earliest date. In Czechia, it has been observed that the first moths leaving pupae usually appear from mid-April to early May, while those from wintering caterpillars appear from late May to mid-June (Miller 1956). Mating and oviposition occur shortly after the onset of flight (Bažok *et al.* 2015), and in the temperate climate zone, including Poland, it is usually in May (Sekulić and Kereši 2003). One female usually deposits 100–140 eggs, maximum 200 (Maceljski 2002). The largest number of eggs is deposited by females whose postembryonic development took place at an optimal temperature. Al-Keridis (2016) and Abdel R-ahman (2018) observed that eggs are deposited in single-layer clusters, in one or two rows. Eggs are usually deposited along the midrib on the underside of sugar beet leaves, on petioles, between the heart leaves or in the remains of dead leaves. Embryonic development takes one to two weeks, and after hatching the larvae very quickly bore into the plant tissue. Caterpillar development lasts three to four weeks in spring and 17 to 30 days in the warm summer months (Skenderović 2021). Fully grown larvae stop feeding and then enter the prepupal stage, which lasts two to three days and usually takes place inside larval tunnels in leaves. A small number of individuals pupate buried in fallen dry leaves or in the soil. The pupa is dark brown, and the average duration of this stage is six days (Al-Keridis 2016). The life cycle of one generation in the field is 40–60 days, depending on climate (Bažok *et al.* 2015). Observations have indicated that the female lives longer than the male (Abdel R-aheem 2018). The mean lifespan of the female is 15.6 days (Al-Keridis 2016).

The diapause in *S. ocellatella* is induced by low temperature combined with a short day. Two-year field monitoring showed that 50% of individuals start winter diapause in the pupal stage at the beginning of September, and this ratio increases in response to reduced day length and temperature (Ahmadi *et al.* 2018). It also overwinters in the caterpillar stage, which is resistant to low temperatures (Maceljski 2002; Čamprag and Jovanić 2005). Ganji and Moharramipour (2015) studied seasonal changes in the frost resistance of caterpillars, including the supercooling point (SCP). The SCP is the temperature at which the body fluids of the organism begin to freeze (Somme 1999). Below this temperature, the organism dies as a result of damage caused by crystals formed from freezing body fluids (Gartych *et al.* 2014). Studies have demonstrated that the mean supercooling points for larvae collected in the field between September and March ranged from −15.0 to −17.8°C.

Geographical distribution

Originally, *S. ocellatella* was probably a species occurring in the basins of the Mediterranean Sea and the Black Sea, and in the coastal areas of Portugal and France, and further east into southwestern Asia, through central to eastern Asia, from where it was distributed variously far north. However, more accurate historical distribution data are not available. In addition, the species develops on Amaranthaceae plants, which are often widespread and do not limit the former historical range in any way. Now, *S. ocellatella* occurs widely in Europe (Fig. 3), including Great Britain (Emmet and Langmaid 2002), Spain (King and Viejo Montesinos 2011), Portugal (Neves Evaristo 1983), France, Germany, Austria (Lichtenberger 2000),

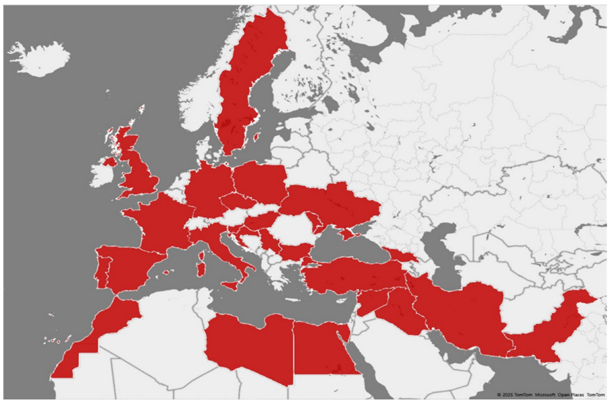

Fig. 3. Geographical distribution of *Scrobipalpa ocellatella* in Europe, North Africa, and the Middle East
Countries where the presence of *S. ocellatella* has been confirmed and described in scientific literature are marked in red. Countries with no data are marked in white

Poland (Piszczek *et al.* 2020b; Piszczek and Klukowski 2021), Czechia (Holý 2022b), Slovakia, Bulgaria (Arnaudov *et al.* 2012), Hungary (Potyondi and Kimmel 2003), Croatia (Bažok 2010; Bažok *et al.* 2018), Slovenia (Valič *et al.* 2005; Biancardi *et al.* 2010), Serbia (Čamprag *et al.* 2006), Ukraine (Sabluk *et al.* 2002), Moldova, Georgia, and Turkey (Neves Evaristo 1983; Emmet and Langmaid 2002; Sabluk *et al.* 2002; Potyondi and Kimmel 2003; Valič *et al.* 2005; Čamprag *et al.* 2006; Bažok 2010; Biancardi *et al.* 2010; King and Viejo Montesinos 2011; Arnaudov *et al.* 2012; Bažok *et al.* 2018; Lichtenberger 2000; Piszczek *et al.* 2020b; Piszczek and Klukowski 2021; Holý 2022b). In 2018 *S. ocellatella* was found in Sweden (Bengtsson 2019). *Scrobipalpa ocellatella* also occurs in North Africa – Libya and Morocco (El Aalaoui and Sbaghi 2024), in the Middle East – Iraq and Iran (Kheyri *et al.* 1981; Razini *et al.* 2016; 2017, Ahmadi *et al.* 2018), Egypt (Shalaby 2001; Bazazo 2005; Amin *et al.* 2008; Bazazo and Mashaal 2014; El-Dessouki *et al.* 2014; Bazazo and Ibrahim 2019; Awadalla *et al.* 2020) and in Asia, including Russia, Pakistan, Syria and China (Kheyri *et al.* 1981; Shalaby 2001; Bazazo 2005; Amin *et al.* 2008; Bazazo and Mashaal 2014; El-Dessouki *et al.* 2014; Razini *et al.* 2016, 2017; Ahmadi *et al.* 2018; Bazazo and Ibrahim 2019; Awadalla *et al.* 2020).

Harmfulness

The harmfulness of *S. ocellatella* depends primarily on the developmental stage of sugar beet, weather conditions and caterpillar density (Sekulić and Kereši 2003). In a temperate climate caterpillars can feed in petioles even until November. The maximum number of larvae is recorded during the harvest period, in August and September (Vrabl 1992). Feeding larvae cause a decrease in root yield and deteriorate root quality (Shalaby 2001; Bazazo 2010; El-Dessouki *et al.* 2014; Ahmadi *et al.* 2018). Newly hatched larvae mine leaves (Chod *et al.* 1984), then hide between the heart leaves and inside petioles (Fig. 4), in which they bore tunnels

Fig. 4. Larva *Scrobipalpa ocellatella* feeding on heart-shaped sugar beet leaves

Fig. 5. Feeding tunnel at the base of the leaf

(Fig. 5). Several larvae can feed inside one tunnel (Al-Keridis 2016). The tunnel exit is contaminated with dark excrement and in some cases tunnels can be seen through the epidermis of the petiole. The damage heals over time, but is still visible during leaf growth (Górski *et al.* 2023). Leaves with heavily damaged petioles break off and necrotize (Renou *et al.* 1980). The outer leaves wither, turn yellow, and die back completely, forming a crown of dead foliage. In addition, the caterpillars roll up the edges of the leaves with a silk web and feed inside these shelters (Sekulić and Kereši 2003; Valič *et al.* 2005; Bažok 2015). The growth of the heart leaves is inhibited and the plants produce many young leaves from the lateral buds, which reduces the sugar content in roots. Heavily infested sugar beets lose up to 24% of their sugar content (Ghada and Heba 2022). Beet crown damage (Fig. 6) becomes a site for the invasion of fungal pathogens causing root rot (Fig. 7) (Valič *et al.* 2005), which leads to the greatest losses in sugar yield. The root crown turns black, and infections often penetrate deeper into the root. Roots do not store well in piles and often rot (Vičar 2004). Rhizopus root rot causes further losses during longer storage. Affected sugar beets are usually unsuitable for long-term storage and processing (NASBG 2023). In addition, damage to sugar beet roots activates invertase, which contributes to post-harvest sucrose losses (Rosenkranz *et al.* 2001). Processing parameters of sugar beets deteriorate, including an increase in the content of molasses-forming substances.

Fig. 6. Highly damaged and contaminated root head

Fig. 7. Root rot caused by larvae feeding

Very early in 2018–2019 severe beet infestation in some regions of Germany was followed by serious fungal infections causing root rot in damaged plants, which resulted in up to 50% reduction of sugar yield in many sugar beet plantations (NASBG 2023). Abo-Saied Ahmed (1987) found that severe infestation of sugar beet with *S. ocellatella* caused a 38.20% decrease in root mass and a 52.40% decrease in sugar content. Sekulić and Keresi (2003) reported a 19% lower root yield and 48% lower sugar yield. According to Razini *et al.* (2016), a plant damage index of 20–25% under field conditions was associated with 2.3 to 3.8 t/ha lower root yield and 0.5 to 1.15% lower polarization. The annual mean losses caused by *S. ocellatella* in sugar beet plantations in Iran are higher than 10% (Anonymous 2020). Regardless of the percentage of above-ground parts damaged, *S. ocellatella* disrupts plant growth and has a negative effect on the normal development of beets. Damage caused by *S. ocellatella* may be mistaken for symptoms of feeding leafrollers (Tortricidae) (Fig. 8), herbicide-induced damage, symptoms of drought, two-spotted spider mite feeding and, later in the season, with heart leaf scorch of sugar beet (Fig. 9) and dry rot (Fig. 10) caused by boron deficiency (Piszczek *et al.* 2020b).

Fig. 8. Leafroller in sugar beet, may be mistaken for larva *Scrobipalpa ocellatella*

Fig. 9. Heart leaf scorch caused by boron deficiency, may be mistaken for damages caused by *Scrobipalpa ocellatella*

Fig. 10. Dry rot caused by boron deficiency may be mistaken for damages caused by *Scrobipalpa ocellatella*

Control strategies

Plant protection against harmful organisms requires a comprehensive approach and the combined use of all available methods (Tab. 1). Harmful organisms on plants should at first be controlled by agrotechnical, biological and biotechnical methods and, if economic injury levels are exceeded, by using chemical pesticides as the last resort (Górski *et al.* 2023). The main goals of these methods are to ensure normal plant development, control pest populations below the critical level, protect natural enemies, reduce the risk of pest resistance, and reduce hazards to humans and the environment (Bažok *et al.* 2015).

Early sowing of sugar beet and optimal fertilization according to plant needs and soil fertility ensure better yields and, above all, rapid plant growth and good vigor at the time of infestation (Bažok *et al.* 2015). New sugar beet plantations should be established at a distance from fields where this crop was grown in the previous year (Sekulić and Kereši 2003). Crop rotation is an important issue (Bittner *et al.* 2019). It is not advisable to grow sugar beet in the same field in subsequent years, and the risk of infestation is high if *S. ocellatella* has previously occurred in this field. The lack of crop rotation in such a case leads to very early infestation of the plants, severe damage to the beet heads and their rotting, which, combined with a further severe infection with cercospora leaf spot of beet results in the death of plants. In Poland, the yield of sugar beet harvested from previously infested fields was about 30 t/ha, the sugar concentration was 11% and the sugar loss was 2.8%, which is significantly below the standard parameters and the mean value for previous years (NASBG 2023). After beet harvest, deep winter ploughing is recommended to bury as many individuals as

Table 1. *Scrobipalpa ocellatella* control methods
Source: Author's own work based on literature cited in the text

Method type	Description	Advantages	Limitations
Agrotechnical methods	– early sowing of sugar beet – optimal fertilization – crop rotation (Skenderović 2021) – deep winter ploughing (Skenderović 2021) – irrigation (Sekulić and Kereši 2003; Bažok *et al.* 2015; Skenderović 2021) – distance from previous year's beet plantations	– strengthens plant resistance – reduces early pest colonization – improves phytosanitary conditions – environmentally friendly – no risk of resistance	– requires long term planning – does not eliminate the pest completely
Biotechnical methods	– pheromone traps (Valič *et al.* 2005; Dolenec 2012) – light traps (Bengtsson 2019) – extracts from non–host plants (Robert 1976; Robert and Blaisinger 1978; El-Gawad 2007)	– early detection – enables forecasting of pest occurrence – no risk of resistance – environmentally friendly	– does not reflect exact threat level – pheromones may attract non-target species
Biological methods	– biopesticides e.g., *Bacillus aryabhattai* (Ghada and Heba 2022), *Beauveria bassiana*, *Metarhizium anisopliae* (Al–Keridis 2016), *Nomuraea rileyi* (El-Gawad 2007) *Steinernema feltiae* (Lortkipanidze *et al.* 2014) – natural enemies – parasitoids, predators e.g., *Diadegma aegyphiator* (Bazazo and Hassan 2021) *Trichogramma evanescens* (Marie 2004; Mesbah *et al.* 2004), *Bracon intercessor* (El–Sheikh *et al.* 2022) *Chrysoperla carnea* (Hegazy 2018)	– environmentally friendly – allowed in organic farming – no risk of resistance	– often less effective and work slower than synthetic insecticides – effectiveness depends on environmental conditions and application precision – usually more expensive than chemical method
	– natural insecticides e.g., azadirachtin (Allahvaisi *et al.* 2021) garlic oil (El-Gawad 2007)	– multiple mechanism of action – low toxicity to humans and warm-blooded animals – relatively safe for beneficial fauna – low tendency to develop resistance	– slower action compared to chemical pesticides – sensitive to light and temperature – limited persistence in the environment – higher costs than synthetic insecticides
Chemical methods	– synthetic insecticides (Skenderović 2021) e.g., chlorantraniliprole, acetamiprid, lambda–cyhalothrin, deltamethrin (FMFA 2025; MACR 2025) emamectin benzoate (Farag *et al.* 2023) methomyl (Ghada and Heba 2022) chlorfenapyr (Mansour *et al.* 2023) chlorpyrifos (Fergani *et al*. 2022) profenofos (El-Gawad 2007)	– rapid effect – precise application possible	– risk of resistance – harmful to beneficial organisms – legal restrictions
Breeding methods	– resistant varieties (El-Rawy and Shalaby 2011; Awadalla *et al.* 2020; El-Sheikh *et al.* 2022)	– environmentally friendly – no risk of resistance	– time-consuming process – risk of loss or deterioration of other important traits (e.g. yield potential)

possible, including those in crop residues, with at least 15 cm layer of soil. Deep ploughing prevents moths from moving to the soil surface in spring (Sekulić and Kereši 2003; Skenderović 2021). Another important measure is proper weed control in the sugar beet plantation (Bittner *et al.* 2019). *Scrobipalpa ocellatella* can also be controlled by selecting the most appropriate beet cultivar, since research has demonstrated that the activity of the larvae varies with the cultivar (Razini *et al.* 2016). In a 2-year study, El-Rawy and Shalaby (2011) investigated the susceptibility of cultivars to damage caused by larvae. Their study revealed that out of 11 tested cultivars, three were the least infested. The difference in root polarization value between the least and most damaged cultivars exceeded 5%. In a related study, Razini *et al.* (2017) examined the activity of *S. ocellatella* larvae in 24 sugar beet lines and cultivars, concluding that selection of resistant cultivars is a crucial factor that should be given due consideration. Similar conclusions were reached by Kandil *et al.* (2023) and El-Sheikh *et al.* (2022). It is recommended that cultivars with more abundant foliage be cultivated, as this has been shown to create an unfavorable microclimate, while promoting entomopathogenic organisms, predators and parasitoids (Sekulić and Kereši 2003; Bažok *et al.* 2015). A correlation was observed between the presence of large populations of caterpillars and the underdevelopment and low density of sugar beet plantations. Consequently, it is vital to maintain a uniform density of approximately 100,000 plants per hectare, without the presence of empty patches, to effectively prevent pest emergence (Tribel and Deryugin 1993). Irrigation has been identified as a significant factor limiting the harmfulness of *S. ocellatella* larvae (Maceljski 2002; Sekulić and Kereši 2003; Skenderović 2021). Minoranskii (1989) reported that irrigation significantly reduced damage caused by the feeding *S. ocellatella* larvae, suggesting that higher humidity in irrigated fields is unsuitable for the development of caterpillars and creates unfavorable conditions for *S. ocellatella* reproduction and growth. For instance, Bažok *et al.* (2015) observed that caterpillars colonized 100% of sugar beet plants in non-irrigated fields, while only 20% of plants in irrigated fields were colonized.

Scrobipalpa ocellatella flights can be monitored using pheromone traps (Renou *et al.* 1980; Valič *et al.* 2005; Bažok 2010; Biancardi *et al.* 2010; Dolenec 2012; Holý and Pavlů 2021; Górski *et al.* 2023). Regular monitoring allows for the detection of threats, identification of the onset of the moth flight season, and enables short-term and long-term forecasts occurrence, which is an important aspect of integrated pest management (Arnaudov *et al.* 2012). A single pheromone trap can lure moths within a maximum radius of several dozen meters, and therefore an adequate number of traps should be placed in the monitored plantation. The main component of the female sex *pheromone* of *S. ocellatella* is (E)-3-dodecenyl acetate (*E3DDA*). In laboratory tests, synthetic E3DDA at a concentration of 1 pg induced a complete sequence of sexual behaviors in the male. Field tests also demonstrated that E3DDA was a very strong attractant (Renou *et al.* 1980). However, pheromone traps are non-selective and E3DDA also lures males of several other related species, in particular *Metzneria* spp. (Gelechiidae), which creates a serious difficulty (Renou *et al.* 1980; Bažok *et al.* 2015; Bittner *et al.* 2019; Holý and Pavlů 2021). Pheromone traps should be set up early and take into consideration the large flight range of moths, resulting from local weather conditions and the emergence of the wintering stage (Bažok *et al.* 2015). The best effects are achieved when traps are used from April to mid-October (Dolenec 2012). Studies have demonstrated that the number of moths captured in lure traps does not necessarily reflect the threat associated with the number of caterpillars later feeding on the crop, and therefore it is recommended to start field monitoring one to two weeks after the maximum catch of moths to decide about chemical treatment. Diverse countries have different economic injury levels (EIL) for the control of *S. ocellatella*. For example, in Poland it has not been specified. In Hungary it was established at 1–5 caterpillars per plant, and 3–6 per plant in Ukraine (Bažok *et al.* 2015). The presence of 4–5 caterpillars on 50–70% of plants indicates the need for control treatment in Slovenia (Valič *et al.* 2005). In Croatia EIL is 0.5 caterpillars per plant with 6–8 leaves developed, and 0.8–1 caterpillars per plant at the beginning of root formation (Bažok *et al.* 2018). *Scrobipalpa ocellatella* can also be effectively captured using light traps. The first individuals were caught in Sweden using light traps (Bengtsson 2019).

Chemical factors play an important role in the host plant-insect relationship. Nevertheless, insects live in a complex environment consisting not only of host plants, but also of many non-host plants. The latter also release chemical signals that may be perceived by insects. For example, Robert (1976) and Robert and Blaisinger (1978) showed that a non-host plant (chestnut) affects the reproduction of *S. ocellatella*. Chestnut compounds inhibit mating behavior and mask the chemical stimulating effect of the beet on oogenesis and oviposition. These effects have been observed in laboratory and field experiments. Garlic extract at concentrations of 2% and 4% also proved effective. Mortality rates for third instar larvae of *S. ocelatella* which fed on sugar beet leaves treated with garlic oil reached 87.5% and 92.5%, respectively, after five days. After six days, mortality rates increased to 92.5% and 97.5%, respectively (El-Gawad 2007). Findings from these studies indicate the potential role of non-host plant compounds, and their identification will open new prospects in *S. ocellatella* control by manipulating the behavior of insects.

The use of natural enemies has been an increasingly popular subject of studies due to the requirements of integrated pest management, problems caused by the withdrawal of some active substances, restricted use of pesticides, and ecological and environmental aspects (Trdan *et al.* 2023). Biological methods can effectively complement other measures for the control of *S. ocellatella* in beet crops. Bioinsecticides represent a promising tool with no toxic pollution to the environment, but work slower and are usually less effective than chemical pesticides (Farag *et al.* 2023). *Scrobipalpa ocellatella* has natural enemies, as confirmed by numerous field studies. Parasitoid *Diadegma pusio* was identified in Iran (Abbasipour *et al.* 2012), and four species of predators in Egypt: *Coccinella undecimpunctata*, *Scymnus interruptus*, *Chrysoperla carnea* and *Paederus alfierii* (El-Dessouki *et al.* 2014; Farag *et al.* 2023). El-Serwy (2008) reported the pupal parasitoid *Pachycrepoideus vindemmiae*. Larval parasitoid *Agathis* sp. (Shalaby 2001; Bazazo 2010) and the larval-pupal parasitoid *Diadegma* sp. (Khalifa 2018; Hawila 2021) have been reported. Three other larval-pupal parasitoids are *Bracon intercessor*, *Microchelonus subcontractus* and *Enicospilus repentinus* (Abbasipour *et al.* 2012; Mahmoudi *et al.* 2013; El-Sheikh *et al.* 2022). Several years ago, new parasitoids were discovered in sugar beet fields in Egypt. One was a pupal parasitoid identified as *Diadegma oranginator* (Bazazo and Ibrahim 2019), and the other was a larval-pupal parasitoid identified as *Diadegma aegyptiator* (Bazazo and Hassan 2021). *Trichogramma evanescens* parasitizes the eggs of *S. ocellatella* (Marie 2004; Mesbah *et al.* 2004). Also, five predatory formicid species were recorded: *Tetramorium depressiceps*, *Tetramorium brevicoryne*, *Camponotus thoracicus*, *Tapinoma simrothi* and *Solenopsis latro.* As for predation and food preference, the predatory formicid species prefer *S. ocellatella* larvae over eggs and pupae (El-Sheikh *et al.* 2023).

Insect-pathogenic nematodes have been known for decades as effective biological agents against insect pests (Webster 1973; Lacey and Unruh 1998; Georgis *et al.* 2006). Lortkipanidze *et al.* (2014) demonstrated high effectiveness of *Steinernema feltiae* against larvae of *S. ocellatella*. In experiments conducted under field conditions in June and August, two concentrations of nematode suspension (2000 and 4000 nematodes/ml of water) were applied. The results showed that in June, at an air temperature of 27–28°C and relative humidity of 50–54%, larval mortality ranged from 63.2% to 83.6%. In August, at relatively higher temperatures (32–34°C) and lower humidity (45–50%), larval mortality decreased to 37.5–77% after treatment with the same suspensions.

One very promising example involves entomopathogenic fungi, whose spores adhere to the cuticle of insect larvae, germinate, and the mycelium penetrates their bodies. The fungus grows inside the host, releasing toxins that ultimately cause its death (Klukowski and Piszczek 2021). Biopesticides containing *Beauveria bassiana* can be used for spraying plants, and thorough application on the leaves is crucial to ensure contact between fungal spores and larvae (Budziszewska and Bereś 2024). *B. bassiana* is widely used and has enormous potential in pest control. For example, *B. bassiana* is highly effective against boxwood moth larvae, with a mortality rate of 66–100%, depending on the concentration and duration of exposure (Zamani *et al.* 2023). Al-Keridis (2016) investigated two entomopathogenic organisms: *Metarhizium anisopliae* and *Beauveria bassiana*. The experimental infection of the fourth instar larvae revealed higher virulence of *B. bassiana* to *M. anisopliae*. Ten days after treatment the mortality rate of *S. ocellatella* caterpillars infected with three concentrations of *B. bassiana* (2×10^3, 2×10^4 and 2×10^5) was 69, 95 and 100%, respectively. For the same concentrations of *M. anisopliae*, the mortality rate was 55, 70 and 85%, respectively. *B. bassiana* also caused greater mortality of pupae. Seven days after treatment with concentration 2×10^5 the mortality rate was 100% vs 80% for pupae infected with *M. anisopliae*. However, *M. anisopliae* was faster-acting, and three days after treatment caused 55–70% mortality in pupae, depending on the used concentration, while mortality for *B. bassiana* was 60–90%, with the first effects observed on day 5 after treatment. According to El-Gawad (2007), the effectiveness of *Nomuraea rileyi* at a concentration of 10^6 spores $\cdot$ ml^{-1}, applied to third instar larvae, was 85% and 90% after five and six days, respectively. Also, *Bacillus aryabhattai* B8W22 effectively reduced the *S. ocellatella* population (by 71.91–80.17% under field conditions) while causing significantly lower losses among natural enemies than traditional pesticides. It reduced predator populations by approximately 22–24% and parasitoid populations by 48–56%. In contrast, chlorpyrifos and methomyl used in the same research virtually eliminated naturally occurring predators and parasitoids, causing nearly 100% mortality (Ghada and Heba 2022).

Chemical control remains a key strategy in protecting sugar beet crops against *S. ocellatella*. It relies on the use of synthetic insecticides, which must be applied strictly in accordance with the manufacturer's guidelines and relevant national regulations. Many chemical pesticides have a harmful effect on beneficial insects, so their use should be limited to cases where other methods are ineffective (Bartkowiak-Broda *et al.* 2020). To reduce the risk of developing resistance in pest populations, it is crucial to use insecticides containing different active substances. The number of active substances approved for the control of *S. ocellatella* varies from country to country. For example, in the EU, in Poland, there are three chemical substances approved: chlorantraniliprole (anthranilic diamide), acetamiprid (neonicotinoid), and lambda-cyhalothrin (pyrethroid) (MARD 2025). In Austria, only deltamethrin (pyrethroid) is registered (AFOFS 2025), while in Germany (FMFA 2025) only chlorantraniliprole. In Czechia, both chlorantraniliprole and acetamiprid are approved (MACR 2025). Iranian research (Farag *et al.* 2023) showed that emamectin benzoate (macrocyclic lactone) was highly effective against *S. ocellatella*, reducing its population by 88.96% to 91%. According to Ghada and Heba (2022), methomyl (oxime carbamates) achieved reductions ranging from 89.97% to 98.10%. Similar results for methomyl were obtained by Mansour *et al.* (2023). Moreover, they showed the high effectiveness of chlorfenapyr (chlorinated pyrrole). Profenofos at a concentration of 2.5% demonstrated 90% effectiveness against third instar larvae the following day. It achieved 100% effectiveness after four days, while a concentration of 2.0% reached 100% effectiveness after five days (El-Gawad 2007).

Scrobipalpa ocellatella must be controlled before the larvae gnaw into plant tissues (EPPO standards 1997). They produce spinnings on leaves to create a shelter. This makes effective pest control difficult, especially since damaged spinnings are immediately repaired, so it is necessary to use adjuvants and increased volume of the working solution 400–600 $l \cdot ha^{-1}$ (Holý and Pavlů 2018; Piszczek *et al.* 2020b). Preferably, treatments should be performed using a sprayer with an auxiliary airstream (AAS) (Bittner *et al.* 2019).

According to Polish reports, *S. ocellatella* populations were very effectively reduced when the control treatment was performed a month after the first moths appeared in pheromone traps. In years favorable to reproduction, a second or even third insecticide treatment is necessary (NASBG 2023). However, frequent use of the same active substance or those with similar mechanisms of action increases the risk of *S. ocellatella* resistance. This is a serious problem and at the same time a huge challenge that agriculture is currently facing. Future research should strongly focus on discovering new, effective substances suitable for the control of *S. ocellatella*. For example, azadirachtin (AZN) is an extremely interesting compound due to its chemical structure and biological activity as an insect repellent and compound disrupting the growth of many arthropods (Mordue *et al.* 2005; Ekukole 2006; Kilani-Morakchi *et al.* 2021). The advantages of AZN include very low toxicity to vertebrates and biodegradability. AZN has a variety of effects, such as feeding inhibition, delayed development of insects, incomplete molting, and deformity of pupae. AZN acts as a repellent and suppresses reproduction in some insects, which survive after exposure to pesticide, but their development is disrupted, so they pose a lower threat (Morgan 2009; Tome *et al.* 2013; Zhong *et al.* 2017; Zada *et al.* 2018). Azadirachtin has been approved for plant protection in organic farming and used in many European countries. Studies revealed that the best time for spraying azadirachtin was 5–6 days after *S. ocellatella* deposited eggs (Allahvaisi *et al.* 2021). AZN at a concentration of 0.5 $ml \cdot l^{-1}$ caused a several-fold decrease in the number of deposited eggs compared to non-treated control. In AZN at concentrations higher than LC 50 (1.14 $ml \cdot l^{-1}$), prolonged developmental times in larval stages, repellency and antifeeding were observed. AZN at concentrations of 2.0 and 2.5 $ml \cdot l^{-1}$ significantly affected the mortality of *S. ocellatella*, and consequently this concentration can be introduced as a biopesticide.

Climate impact on insect spreading and harmfulness

According to the Intergovernmental Panel on Climate Change (IPCC), each of the past three decades was warmer than the last, with the 2000s being the warmest. Depending on the adopted climate model, the Earth's temperature is expected to increase by 1.4–6.6°C over the next century (Ahmed *et al.* 2022). Such warming could cause huge changes in the natural environment (Ingole and Kakde 2013). Climate change is manifested, for example, in rising temperatures, changing precipitation patterns, droughts, milder winters, disappearing seasons or extreme weather events (Alshehab 2024). All these changes have a clear impact on agriculture, affecting not only crops but also organisms colonizing them, including pests (Prakash *et al.* 2014; Zeng *et al.* 2020; Ahmed *et al.* 2022; Abbas *et al.* 2025; Mecenero and Kirkman 2025). Increased crop losses caused by insects may be a threat to food security, especially in developing countries (Sharma 2014). Insects are cold-blooded organisms, and the ambient temperature directly impacts their metabolic rate, development rate and activity patterns (Altermatt 2009; Lehmann *et al.* 2021). Higher temperatures intensify insect development, accelerate molting, sexual maturation and reproduction rate, lead to the emergence of greater numbers of generations per season, earlier emergence of pests and changes in migration dynamics (Bergant *et al.* 2005; Ingole and Kakde 2013; Sharma 2014; Raza *et al.* 2014; Deutsch *et al.* 2018; Harvey *et al.* 2020; Bohinc *et al.* 2024). It is believed that temperature has a much greater effect on insects than other environmental factors (Bale *et al.* 2002). For example, a 10°C increase in temperature leads to about a two-fold increase in metabolic rate (Lehmann *et al.* 2020; Ma *et al.* 2021), which results in more intensive feeding, greater losses in agriculture and decreased profitability of farming. Moreover, studies suggest that increased temperatures may lead to lower effectiveness of chemical pesticides and biopesticides (Sharma 2014). There is a great deal of evidence of the ecological effects of climate change and the responses of flora and fauna to it concerning many ecosystems and organizational hierarchies, from a single species to entire communities (Walther *et al.* 2002). The geographical distribution of many terrestrial organisms is shifting in response to climate change (Logan and Powell 2001; Sharma 2014; Bebber 2015; Adler *et al.* 2022; Yadav *et al.* 2024). This shift is most pronounced in regions with the highest increase in temperature (Chen *et al.* 2011). Insects are migrating to new climate zones, including higher latitudes and altitudes above sea level (Raza *et al.* 2014). These changes result from insects' adaptive behavior to new conditions, longer growing seasons and milder winters (Bale *et al.* 2002). Many insect species are migrating farther north, beyond their previous climatic range (Raza *et al.* 2014). The dynamics of change varies significantly between species, indicating that the shift in the distribution of each species depends not only on environmental factors but also on species-specific characteristics. As a result of these shifts in distribution, many insects are attacking new host plants that were previously outside their range. This may lead to the establishment of new host-pest interactions, which poses a new challenge for the plant protection sector. The main reason for this is the fact that emerging new pest species require prompt identification and new control strategies (Raza *et al.* 2014). As a result of the above-described changes, the biological balance in nature may also be disturbed and the control of pest populations by natural enemies may be compromised. Although abiotic factors affect harmful and beneficial organisms at the same time and at the same level, Robinet and Roques (2010), Raza *et al.* (2014), Sharma (2014), and Bereś *et al.* (2020) have reported that ecological interactions may be disturbed and natural enemies can lose synchronization with their hosts.

Discussion

This review presents the current state of knowledge about *S. ocellatella*. This pest is gaining importance in many regions of sugar beet cultivation for many reasons. The most important ones are ongoing climate change (Robinet and Roques 2010; Sharma 2014) and a limited choice of approved insecticides (BAES 2025; BMEL 2025; MRiRW 2025; MzČR 2025). The restrictions imposed by the EU on the availability of active substances, such as the withdrawal from use of very effective seed dressings based on neonicotinoids (e.g., imidacloprid or thiamethoxam) and chlorpyrifos, significantly limit the possibilities of effective control in the Member States (Commission Implementing Regulation (EU) 2018/783). However, despite growing legal restrictions and few active substances approved for the control of *S. ocellatella*, growers most often use chemical methods. Chemical control provides high effectiveness in a short time, but is associated with the risk of developing resistance and is not neutral to the natural environment and beneficial organisms (Ghada and Heba 2022; Farag *et al.* 2023). From this perspective, biological methods based on microorganisms or entomopathogenic nematodes are safer (Fergani *et al.* 2022). They show promising effects, but their effectiveness under field conditions strongly depends on environmental conditions, which cannot be controlled. In addition, biopesticides are more expensive than synthetic insecticides, and require a longer time to achieve satisfactory effects of control. *Scrobipalpa ocellatella* flights on plantations can be monitored using pheromone traps (Valič *et al.* 2005). However, the non-selective pheromone used in traps also lures other species of the genus *Metzneria* spp., which can be misleading as to the actual level of threat (Bažok *et al.* 2015; Bittner *et al.* 2019; Holý and Pavlů 2021). In addition, the results of catching moths do not provide any information on the number of larvae which later feed on the crop. Despite numerous studies on the biology and distribution of *S. ocellatella* there are still huge gaps in knowledge. The clear geographical concentration of previous studies in the Middle East (Egypt, Iran) (El-Rawy and Shalaby 2011; Mahmoudi *et al.* 2013; Ganji and Moharramipour 2015) limits the possibility of extrapolating their findings to other regions. Therefore, it is necessary to investigate in more detail the flight dynamics, biology and development of *S. ocellatella* populations in European conditions. The causes of specific food preferences and lower degrees of damage to some crop varieties are still to be explained. This is also associated with the need to breed varieties tolerant to the European climate, with morphological and biochemical characteristics not promoting the development of pest larvae. It is necessary to develop an advanced system for monitoring and forecasting the occurrence of *S. ocellatella*, together with predictive models that will help sugar beet growers make decisions about chemical treatment. There is an urgent need to create an effective pest control strategy using many complementary methods, including irrigation (Sekulić and Kereši 2003) as a significant factor limiting the development of *S. ocellatella*. The range of available active substances should be expanded with new ones to enable their rotation and reduce the risk of resistance development (Ghada and Heba 2022; Farag *et al.* 2023; Mansour *et al.* 2023). Azadirachtin is a highly effective substance, and it is worth first focusing on it. AZN is a natural substance and friendly to the environment (Zhong *et al.* 2017; Allahvaisi *et al.* 2021). Methods that involve the use of essential oils and other substances from non-host plants that modify the behavior of *S. ocellatella*, and limit feeding and oviposition, should be tested and included in the plant protection strategy. It has been observed that they have a beneficial effect against many harmful organisms (Górski 2005; Dancewicz and Gabryś 2008; Dutka 2013; Souguir *et al.* 2013; Ismail *et al.* 2019; Isman 2000; Godoy da Silva *et al.* 2023; Jakubowska *et al.* 2023; Awad *et al.* 2024; Charkaoui *et al.* 2024). Differences in the level of pressure from the pest in different geographical regions suggests that control strategies should be adapted to local agroclimatic conditions, just like the economic injury level. EILs should also be defined more precisely in many European countries (Bažok *et al.* 2015). The effectiveness of methods using entomopathogenic fungi, bacteria and nematodes under temperate climate conditions should be tested, and faunistic studies conducted on naturally occurring natural enemies of *S. ocellatella* (Al-Keridis 2016). Despite significant advances in studies on the biology and ecology of *S. ocellatella*, there is an urgent need for a multidisciplinary approach to effectively and sustainably manage its population.

Conclusions

1. The control of *S. ocellatella* currently poses a serious challenge for sugar beet growers in many regions of the world, mostly Middle East (Egypt, Iran, Iraq) and Europe (Croatia, Serbia, Poland). The feeding pest can stay unnoticed for a long time, and its high fecundity, polyvoltinism and feeding symptoms are initially difficult to detect and can cause significant losses in yield volume and quality.
2. The withdrawal of active substances in the European Union has created a pressing need to search for alternative methods of crop protection. Microorganisms and entomopathogenic nematodes have demonstrated considerable potential in controlling *S. ocellatella* in numerous studies; however, their effectiveness under field conditions is highly dependent on environmental factors and is typically lower than that of synthetic insecticides.
3. Protection of plants against *S. ocellatella* should rely on integrated pest management (IPM), combining agrotechnical practices (plowing, irrigation, crop variety selection), monitoring (pheromone traps) and environmentally-friendly biopesticides.
4. Pheromone traps are suitable for the monitoring of *S. ocellatella* moth occurrence in plantations, but the pheromone used in traps also lures other species resembling the pest, which can be misleading as to its actual population size.
5. There is an urgent need for further research to establish economic injury levels in different geographical conditions, select crop varieties recommended for areas highly threatened by *S. ocellatella*, and develop control methods using substances isolated from non-host plants producing insecticidal effects (antifeedants, repellents, behavior modifiers, sterilants, insect growth regulators, and deterrents).
6. Future research should be conducted in different regions of Europe in order to better understand the biology of *S. ocellatella*, its flight dynamics and population growth.

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