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Plant protection consequences in Hungary of the withdrawal of systemic active substances from sugar beet seed treatment

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After decades of development, neonicotinoids were widely used in Hungarian sugar beet production and seeds included *thiamethoxam* treatment by 2019 increasing protection against early spring pests. In Hungary, neonicotinoids' influence on bee health led to their removal of emergency authorization. In the absence of *thiamethoxam* in 2020, experience showed that multiple treatments were needed to protect beet from pests early spring pests. Repeated applications of mostly pyrethroids have proved suitable; however, in sugar beet, this has resulted in a multiple increase in environmental stress and honey bee mortality, as well as increased input values. The aim of this work is to explore the current state of production and collect new alternative options for applying effectively in Hungarian sugar beet production technology, against early spring pests.

KEYWORDS

insecticides, crop protection, in-crop treatment, juvenile arthropod pest, *Beta vulgaris* production, systemic mode of action

1 Introduction

Prior to the introduction of neonicotinoids in the early 1990s, insecticidal seed treatment in sugar beet was often supplemented with granules or sprays applied at sowing and insect pest control sprays during the growing season (Elbert et al., 2008). This was done using various organophosphates, carbamates or pyrethroids that were replaced by neonicotinoid seed treatment in recent decades and due to their high efficacy in controlling a wide range of pests and maintaining high yield stability, neonicotinoids became generally used on sugar beet seeds in most European countries (International Confederation of European Beet Growers, 2018). Since neonicotinoids provided adequate protection, in most cases, no further insecticide applications were necessary (Hauer et al., 2017; Viric Gasparic et al., 2021).

dangerous for juvenile sugar beet *Tanymecus species*, due to its dicotyledonous host plant preference (Keszthelyi et al., 2008).

Chaetocnema tibialis Illiger is the most widespread pest in Hungary, but it causes complete eradication less frequently than the *A. punctiventris*. They masticate the leaves during the juvenile period and the adults peel in the leaf surface. The imagos overwinter and leave their wintering places at average temperatures of 8–10°C and then seek out beet leaves (Kereši et al., 2006).

Aphis fabae Scopoli exhibit puncture wounds on the phloem side with their piercing-sucking mouthparts (Hurej and Werf, 1993). In Hungary, their population can undergo up to 14 generations, leading to potential harm from March to September. Beet necrotic yellow vein virus (BNYVV) is a notable viral disease that affects sugar beet. Its primary carriers are aphids. The National Association of Sugar Beet Growers (CTOSZ) has proactively advocated for the use of *thiamethoxam* as an emergency treatment for beet seeds in the past 3 years driven by the necessity to effectively defend against vectors (National Association of Sugar Beet Growers, 2020; Keszthelyi et al., 2022).

The period of damage by soil-dwelling and juvenile sugar beet arthropod pests is shown in Figure 2.

4 The effectiveness of neonicotinoid seed treatment in sugar beet production in the past decades

Neonicotinoids are a group of modern pesticides that are used to control various pest species in sugar beet production and were originally used as alternatives to halogenated hydrocarbons because of their systemic properties, which allow them to be absorbed and translocated in plants and were found to be highly effective (Bass and Field, 2018).

Neonicotinoids are substances that play an agonistic role at nicotinic acetylcholine receptors (nAChR), thereby opening ion channels (Casida and Durkin, 2013). In addition, their insecticidal action is also partially manifested in voltage-gated calcium channels (Jepson et al., 2006). Differences between arthropod and mammalian nAChRs, particularly in the properties and structure of the subunits, may explain the high selectivity of neonicotinoids for arthropods and their presumed relatively low toxicity in mammals (Tomizawa and Casida, 2003, 2005). Insecticide

spraying was only necessary in cases, where *A. punctiventris* pressure was high, so neonicotinoid seed treatment contributed to considerable reduction in the amount of insecticides (Bažok et al., 2012; Potyondi et al., 2014; Viric Gasparic et al., 2021). This was further enhanced with the emergence of neonicotinoid-treated seeds, such as banding, film coating, pelleting or multi-layer coating, are effective in protecting young plants from insect damage (Altmann, 1991; Meredith and Morris, 2003; Elbert and Nauen, 2004). Neonicotinoids have been widely used for seed treatment from the 1990s in including sugar beet (Viric Gasparic et al., 2021). Neonicotinoids have a significant advantage over previous soil-based insecticides because they have a wide range of target organisms and are effective for long periods against early spring pests (Figure 3). This method replaced the older, high-dose, full-area or broadcast applications. As a result, the environmental impact has been reduced (Altmann, 1991).

However, a growing number of studies have described that neonicotinoids may have adverse effects not only on the target species but also on others, in particular pollinators, such as bees (Godfray et al., 2014; Woodcock et al., 2016, 2017). As a consequence, concerns about neonicotinoids have increased significantly and public awareness of these issues has also increased.

5 Effects on pollinators and the environment

Neonicotinoids have potential impact on non-target organisms, including pollinators, such as bees (Lundin et al., 2015) as they accumulate in the pollen of treated plants and have toxic effects on pollinators, consequently classified by the Environmental Protection Agency (EPA) as II and III class toxicity agents (Buszewski et al., 2019). However, this classification does not apply to sugar beet in relation to bee populations, since sugar beet is a biannual crop, however it is harvested in the autumn of the first year, before flowering. It is important to mention that most of the studies (Krupke et al., 2012; Botías et al., 2017) have focused on flowering plants, as bees can readily gather pollen from them.

Regarding neonicotinoids or other active substances employed in sugar beet production, the insecticidal treatment affects pollinators indirectly through the accumulation in soil and through plant residues. Moreover, the soil type is significant for

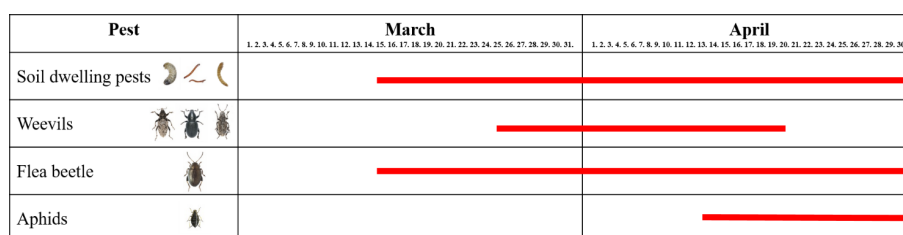
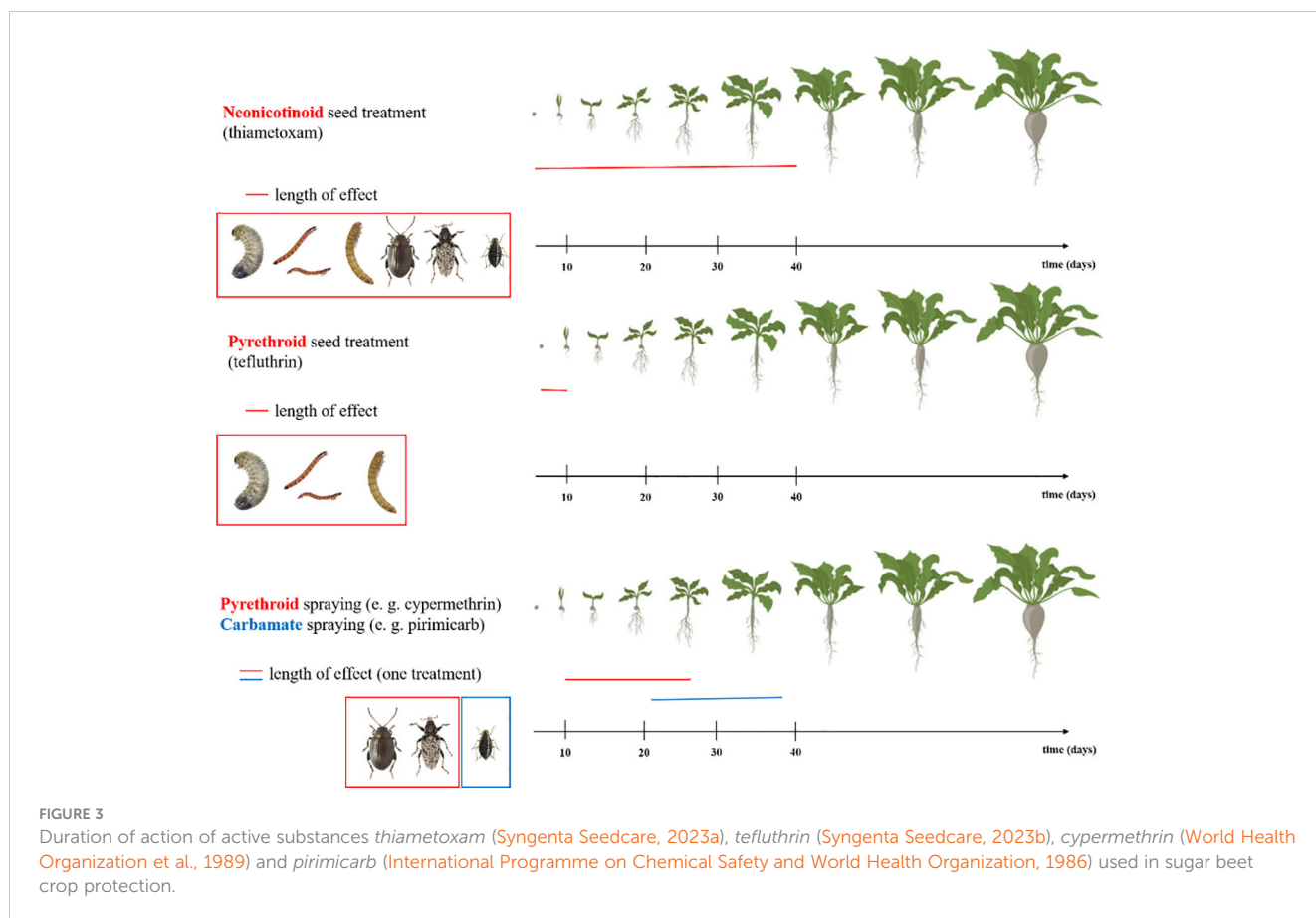


FIGURE 2 Soil-dwelling and juvenile sugar beet arthropod pests damage periods in Hungary. Based on Keszthelyi et al. (2022).



the leaching dynamics in the residual section. For example, concerning the elution profiles, neonicotinoids exhibit high mobility and are prone to leaching in sandy soil. However, their mobility is only moderate in loam soil, as demonstrated by Mörtl et al. (2016).

Similarly to neonicotinoids, questions have been raised about the environmental impact of pyrethroids, particularly on pollinators. Pyrethroids are derived from pyrethrins, which are naturally occurring component of chrysanthemum (Palmquist et al., 2012). They disrupt the regular functioning of the nervous system of insects by altering of voltage-sensitive sodium channels, which results in the cessation of their normal activity (Soderlund, 2010). A three-year investigation of pyrethroid residues in China revealed contamination of nectar-producing plants due to pyrethroid insecticides (He et al., 2023) that is, as it was the case with neonicotinoids, does not directly affect pollinators in sugar beet production.

Therefore, neither neonicotinoids, nor pyrethroids pose a direct risk to bees, it rather affects the next years' annual plant cultures (Krupke et al., 2012) via the uptake of their residues from soil (Schaafsma et al., 2015). Moreover, the methodology of investigation may also need consideration. In a systematic review conducted by Lundin et al. (2015), it was proposed that in addition to laboratory experiments using high dosages, which were commonly used to study the effects of neonicotinoids on honey bees (*Apis mellifera* L.), future research should focus on field studies that involve realistic exposure to neonicotinoids.

6 Impact of *thiamethoxam* withdrawal, current state of crop protection

In 2018, the European Union Commission banned the use of neonicotinoid insecticides *imidacloprid*, *clothianidin* and *thiamethoxam* in arable crops, because of their potential adverse effects on honey bee populations. However, this decision was taken with some exceptions, such as allowing the use of these active substances in permanent greenhouses (Official Journal of the European Union, 2018a, 2018b, 2018c). As a result, arable crops, including sugar beet, remained unprotected against pests, while the pressure of harmful organisms has continued to increase (Viric Gasparic et al., 2021). Nevertheless, the authorizing authority rejected the emergency use authorization for the insecticide Cruiser SB (600 g/L *thiamethoxam*) for the treatment of sugar beet seed as well as in 2020 initiated by the National Association of Sugar Beet Growers (2020). On the basis of the judgment of the European Court of Justice of 19 January 2023 in Case C-162/21, it is unlawful to grant an emergency authorization for the marketing of seed treatment products and for the marketing and use of seeds treated with those products where the marketing and use of seeds treated with those products is expressly prohibited by an implementing regulation (InfoCuria, 2023). Accordingly, alternative solutions for sugar beet protection should be explored in the next season in Hungary.

7 Pending and currently marketed systemic active substances

However, due to the withdrawal of neonicotinoid, seed treatment is currently achieved with contact pyrethroids, which do not always provide sufficient protection against severe pest presence, and therefore the use of soil disinfection as an additional treatment against juvenile pests of sugar beet becomes justified. This is also carried out with pyrethroid active substances, which may pose a higher insecticide pressure on the environment compared to previous practice. Considering this gap in knowledge, the study of Romanowski and Blake in 2023 looked into whether this was due to an absence of research, or whether alternatives to neonicotinoids are ineffective in this system (Romanowski and Blake, 2023). Therefore, it would be worthwhile to consider the possible inclusion of other new insecticides with systemic action in the seed treatment of sugar beet protection technology.

Alternatives to neonicotinoids in the sugar beet system have been less studied. Reasons for this are the delayed ban on non-flowering crops and the efficacy of *thiamethoxam* in this pest system. Much of the focus has been on flowering systems such as rape, where the negative consequences of the withdrawal were considered, and the potential alternatives became permitted as seed treatment (Scott and Bilsborrow, 2019). A 2017 study compared the use of *thiamethoxam* and alternative strategies on sugar beet as a preventive measure prior to the expected ban (Hauer et al., 2017).

However, biological control involved in Integrated Pest Management (IPM), have not been considered for pests of sugar beet (Romanowski and Blake, 2023), only aphids have been studied recently. Laurent tested non-neonicotinoid-based treatments against sugar beet aphids, and while some other insecticides were effective, biopesticides (non-chemical pesticides derived from natural products) were much less effective (Laurent et al., 2023). Biological control strategies for aphids and related virus transmission were investigated in a 2022 study. It concluded that the use of semiochemical agents, entomopathogenic fungi (EPF) and Plant Growth Promoting *Rhizobacteria* (PGPRs) in combination with resistant beet varieties is the most promising, and that this requires synergies to be created from experimental data provided by different partners (national research centers, universities, private companies and associations in the sugar beet industry) (Francis et al., 2022). According to one of the first studies to evaluate the use of virus prediction in this system based on public opinion, when viable alternatives to *thiamethoxam* seed treatment were evaluated, alternative pest management strategies were limited, particularly systems against sugar beet aphid (*Aphis fabae* L.), such as biological control and crop rotation, have proven to be weak responses to the threat of virus yellows (Romanowski and Blake, 2023). In a study by Furlan and Kreutzweiser (2015), they concluded that IPM has potential, but it requires time and investment both in research and public outreach. Jactel et al. (2019) studied alternatives to neonicotinoids against soil-dwelling *Agriotes* species and found that the most commonly used, highly effective alternative to neonicotinoids were pyrethroids; however,

because of their mode of action and increased application occasions and environmental impact, this group may not provide an effective plant protection solution to replace neonicotinoids (Furlan et al., 2018), therefore alternative solutions would worth considering to include as seed treatment. Additional risk of the unilateral utilization of this group of insecticides can trigger further serious phytosanitary concern. The superior translocation of this active ingredient makes it well suited for seed treatment and there is less risk of cross-resistance, because of the different mode of action (Zeng et al., 2021), furthermore this substance is already in use in rape (*Brassica napus* L.) (Scott and Bilsborrow, 2019).

Diamides (IRAC MoA: 28) are one of the most advanced insecticides with specific target site activity that may be considered as an alternative to neonicotinoids. They are compounds with a broad pest spectrum and a systemic as well as a broad toxicological profile. Diamides activate the insect's ryanodine receptors (RyRy), which results in uncontrolled calcium release and inhibits muscle contraction (paralysis). This renders the insect immobile, unable to feed (Selby et al., 2013). Among them, *cyantranilipole* besides basipetal and translaminar translocation, it also translocates acropetally, and therefore successfully used in arable crops (oilseed rape, maize, soybean, rice) compared to other diamides. It is effective against several species of both chewing and sucking pests in plant cultivation (Mandal, 2012; Rath and Nayak, 2013; Keszthelyi et al., 2023). The currently developed diamides, as *cyclanilprole* and *tetranilprole* are systemic active substances have been available since 2015, but currently not yet permitted for sugar beet in Hungary (Keszthelyi et al., 2023).

Flupyradifurone, butenolide (IRAC MoA: 4D) derivatives have the similar mode of action as neonicotinoids and a related chemical structure. Butenolides are typical neurotoxins that induce paralysis by continuous stimulation of the nerve endings following muscle overactivity, especially in sucking pests (Shuai et al., 2022). It is characterized by systemic, good translaminar plant tissue spread (Nauen et al., 2015). However, some degree of cross-resistance has been shown for this active substance in *Bemisia tabaci* (Smith et al., 2016; Wang et al., 2020).

Spirotetramat, tetracyclic acid (IRAC MoA: 23) derivative, has a wide range of uses due to its bidirectional (basipetal and acropetal), systemic translocation, with fatty acid biosynthesis inhibition properties. It has favorable environmental and ecotoxicological properties but is also not yet available (Nauen et al., 2008).

Triflumuron (IRAC MoA: 15) is also a systemic compound and plays an important role in IPM programs. It acts by blocking chitin synthase of developing insect and it is effective against chewing mouth-breathing insects, also it has an egg-destroying effect (Belinato et al., 2013).

8 Conclusions

Neonicotinoids were widely used in sugar beet technology by 2010, and all seed treatments by 2019 that increased protection against early spring sugar beet pests, eliminating one of the most costly and serious beet production challenge. However, in Hungary,

due to the environmental influence of neonicotinoids, especially on honey bee health, led to the removal from emergency authorization. Experience has showed that in order to overcome the less effective applications, additional plant protection steps are needed to be included into the technology.

Therefore, future study into pest management alternatives to neonicotinoids seems to be inevitable. *Cyantraniliprole*, which has not been used in sugar beet, may be a good alternative, since current crop treatment methods pose a higher overall environmental impact than neonicotinoids, also the application of systemic substances in sugar beet production has less direct environmental impact compared to other flowering crops and pose less risk of resistance and cross-resistance. This would certainly be of great impact on solving the plant protection problems of sugar beet production.

Author contributions

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