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CABI Agriculture and Bioscience (2024) 5:58
https://doi.org/10.1186/s43170-024-00264-9

CABI Agriculture and Bioscience

REVIEW

Open Access

Augmentative biological control of stink bugs on soybean: the Brazilian scenario

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Abstract

Augmentative Biological Control (ABC) is one of the essential strategies for building a more sustainable agriculture, especially in commodities such as soybean, where the overuse of insecticides has been the subject of much concern over the last years. Due to its high potential for parasitism, the egg parasitoid *Telenomus podisi* has been considered one of the main ABC agents of stink bugs, especially *Euschistus heros*, one of the major pests of soybean in South America. In this context, this article presents a review of the current situation of ABC against stink bugs with *T. podisi*. Despite promising results, it should be taken into account that parasitoids are fragile organisms of small size, and biotic and abiotic factors can negatively impact their parasitism efficacy. Thus, we present published results with *T. podisi* to introduce a more sustainable management of stink bugs and discuss the existing challenges related to the correct adoption of *T. podisi* in ABC programs which need more attention in order to reach the greatest potential benefits.

Keywords Sustainability, Integrated pest management, Scelionidae, *Euschistus heros*

Introduction

Stink bugs (Hemiptera: Pentatomidae) form one of the largest families within the suborder Heteroptera (Panizzi 2008). As mostly polyphagous pests, they have caused significant economic loss to various crops (Grabarczyk et al. 2021). Their economic importance varies greatly from species to species, as well as within species, depending on the plant attacked (Panizzi et al. 2000). On soybean, stink bugs rank among the most important pests in South America, especially in Brazil (Bueno et al. 2023a) and Argentina (Dellapé 2021), as well as in Southeastern USA (Ademokoya et al. 2022), with their range expanding northward and westward as average yearly temperatures continue to increase (Kistner 2017).

Pest control against these piercing-sucking pests can be responsible for up to 60% of all insecticide sprayed on soybean fields (Carnevalli et al. 2022). Stink bugs feed directly on soybean pods, seriously reducing yields (Bueno et al. 2015). In addition, they impact the physiological and sanitary quality of the seeds (Corrêa-Ferreira and Azevedo 2002). These damages can trigger annual losses of millions of dollars if improperly managed (Maciel and Bueno 2022; Hayashida et al. 2023).

Among the different species of stink bugs attacking soybean, the Neotropical Brown Stink Bug, *Euschistus heros* (Fabricius, 1974) (Heteroptera: Pentatomidae) must be highlighted as the most abundant species in Brazil, accounting for around 82% of adults and 84% of nymphs (Saldanha et al. 2024). This species is widely distributed in tropical and subtropical regions (Soares et al. 2018) and well adapted to feed on several crops, including corn, cotton and beans, with a special preference for soybean (*Glycine max* L.) (Ziller 2023).

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Chemical control has been the first line of defense against stink bugs for farmers (Stacke et al. 2020; Bueno et al. 2021). However, when overused, insecticides endanger human health as well as the environment, especially if the most toxic chemicals are applied (Jacquet et al. 2022). Synthetic chemical insecticides can be responsible for significant adverse side-effects (Desneux et al. 2007). Their overuse can reduce natural biological control agents (Torres and Bueno 2018) and pollinators (Kuldna et al. 2009), select stink bug populations for resistance (Sosa-Gómez et al. 2020), and trigger pest resurgence or outbreaks of secondary pests, among other negative side-effects (Bueno et al. 2021). Consequently, reducing synthetic chemical use in agriculture in order to mitigate such damaging side-effects in pursuit of a more sustainable pest management (Maciel and Bueno 2022) has become a global objective (Lee et al. 2019).

Among the most sustainable stink bug control methods available, Augmentative Biological Control (ABC) programs deploying the egg parasitoid *Telenomus podisi* Ashmead, 1893 (Hymenoptera: Scelionidae) has been pointed out as one of the most promising alternatives to manage *E. heros* in soybean (Bueno et al. 2020a) due to the high parasitism capacity of this parasitoid (Silva et al. 2018) and its availability on the market as a commercial biocontrol agent (Bueno et al. 2022). Despite its high potential in stink bug control, the release of *T. podisi* in Brazil has only been done in around 200,000 hectares (Bueno et al. 2020b; Parra and Coelho 2022) each soybean season, which correspond to around 0.44% of the 45 million hectares cultivated in the country each year. This difficulty to scale up *T. podisi* releases is especially due to the challenges imposed to extensive fields cultivated with the crop, which will be further discussed in this review.

Telenomus podisi biology, distribution and parasitism capacity

Telenomus podisi is a ~ 1.0-mm-long wasp of the family Scelionidae. Its development under 25 °C takes ~ 17, 105 and 120 h for egg, larva and pupa stages, respectively (Bueno et al. 2012). Its geographical distribution ranges from the Mid- and Northwest to the South of Brazil (Ramos et al. 2024), having been registered in at least 10 of the country's 26 states (Paz Neto et al. 2015). The states include Piauí (natural parasitism from 33.9 to 100%) (Silva et al. 2021), Goiás (natural parasitism from 36 to 88%) (Medeiros et al. 1997), Minas Gerais (natural parasitism from 94.4 to 100%) (Vezon et al. 1999) and Paraná (natural parasitism from 80 to 100%) (Pacheco and Corrêa-Ferreira 2000), evidencing the parasitoid's adaptation to the different climatic conditions across the country (Torres et al. 1997). One single female of *T. podisi* can parasitize between 104 and 211 eggs during her lifetime in laboratory studies (Pacheco and Corrêa-Ferreira 2000; Silva et al. 2018). After releases of 6,500 parasitoids per hectare by Bueno et al. (2020a) and Pernambuco-Filho et al. (2022), more than 70% and 91% parasitism of *E. heros*, respectively, were recorded in these soybean field trials. Consequently, *T. podisi* has been considered the most important natural enemy not only of *E. heros* but also of other stink bug species (Koppel et al. 2009; Laumann et al. 2010; Bueno et al. 2012; Bueno et al. 2020a; Hoback et al. 2024).

Telenomus podisi mass rearing

Mass rearing of any biocontrol agent is a critical step for its successful release within an ABC program (Parra 2010; Parra and Coelho 2022). ABC programs against stink bugs using *T. podisi* are based on mass releases of the egg parasitoid for an immediate control of these pests to prevent them from reaching economic injury levels. Therefore, an efficient and economic mass rearing that provides *T. podisi* in large numbers at low costs is crucial to make the ABC program competitive with other pest control strategies (Macedo et al. 2006; Bernardo et al. 2008; Carvalho et al. 2008; Colinet and Boivin 2011; Queiroz et al. 2017), thus allowing it to be widely and successfully adopted (Corrêa-Ferreira and Moscardi 1993; Lenteren and Tommasini 2002). Even though *T. podisi* mass rearing has been studied for around 20 years (Peres and Côrrea-Ferreira 2004) with significant recent advances (Parra et al. 2023), some challenges still remain which will be further discussed.

a) Rearing hosts: Three different strategies exist for rearing any of the egg parasitoid species (Parra, 2010): (**1**) on the natural host, (**2**) on factitious hosts (both in vivo) and (**3**) on an artificial diet (in vitro). So far, to the best of our knowledge, *T. podisi* has only been reared on a natural host with all pros and cons of this strategy.

An advantage of using natural host eggs for *T. podisi* mass-rearing is the possibility of storing the host eggs at low temperatures (liquid nitrogen at −196 °C) for up to six months as reported for both *E. heros* (Favetti et al. 2014) and *Piezodorus guildinii* eggs (Westwood, 1837) (Hemiptera: Pentatomidae) (Cingolani et al. 2018), with no harm to host quality. *Telenomus podisi* requires host eggs with sufficient nutritional value to fully complete parasitoid development (Ramos 2020). Therefore, host quality control is mandatory to guarantee sufficient nutrient content, ensuring a high rate of parasitism, and consequently, positively favoring parasitoid mass rearing (Parra et al. 2023).

One negative aspect of using natural host eggs for mass rearing of *T. podisi* might be the labor-intensive work necessary for rearing the stink bug host in the laboratory to obtain the required number of eggs (Hayashida et al.

2018; Parra and Coelho 2022). When reared on a natural diet composed of fresh green bean pods (*Phaseolus vulgaris* L.), dry soybean seeds (*Glycine max* L.), raw shelled peanuts (*Arachis hypogaea* L.), sunflower seeds (*Helianthus annuus* L.), and water (Silva et al. 2008), parasitoid colony maintenance and diet replacement must be performed two to three times per week, which can be too labor intensive and, therefore, expensive (Hayashida et al. 2018; Parra and Coelho 2022). A strategy to mitigate this limitation and reduce the cost of stink bug egg production is the development of artificial diets to support mass rearing and production of the hosts (Parra 2009). However, the rearing of pentatomid species is still hampered by the lack of suitable artificial, cost-effective diets (Mendoza et al. 2016) that can completely replace the use of natural diets (Silva et al. 2008), which would reduce colony maintenance and, consequently, the high costs involved.

The development of artificial diets for the rearing of *E. heros* has been reported by several authors (Panizzi et al. 2000; Fortes et al. 2006; Siqueira 2007; Mendoza et al. 2016, Hayashida et al. 2018). However, despite the progress made in these studies, adjustments are still needed to improve the efficiency of pentatomid egg production. Mendoza et al. (2016) provided an artificial diet with lyophilized material that could meet the nutritional requirements of *E. heros* to produce insects of a quality comparable to field insects. However, the diet requires bean pod lyophilization, which can be an expensive and time-consuming process. Furthermore, the cost of acquiring and maintaining an industrial freeze dryer is an economic disadvantage for small biofactories. Considering all of this, Hayashida et al. (2018) proposed a cheaper diet without lyophilized components, thus reducing the cost of *E. heros* and, consequently, *T. podisi* rearing. However, this diet still needs to be improved by the addition of preservatives, to avoid contamination and the necessity of diet replacement.

b) Storage: Storage of parasitoids and their hosts at low temperatures is highly demanded by biocontrol production companies for various reasons (Lenteren and Tommasini 2003). Firstly, it helps to decrease production costs (Colinet and Boivin 2011) and maintain the production flow to provide a steady and sufficient supply of insects to be released in ABC programs. Secondly, storage of the parasitoids can build up reserve supplies of biocontrol agents to compensate for periods of low production or unexpectedly high demand. Lastly, storage allows synchronized field releases of natural enemies during critical stages of pest outbreaks (McDonald and Kok 1990; Leopold 1998; Venkatesan et al. 2000; Lenteren and Tommasini 2003). However, in contrast to host eggs, adults of *T. podisi* can only be stored for a short time. Adults of the parasitoid wasps can be stored for 6 days at 5 °C with no detectable injury to their biology or parasitism capacity (Silva et al 2019) before field release. Thus, due to the lack of a more efficient storage methodology for parasitoid adults (Colinet and Boivin 2011), *T. podisi* must be produced shortly before their intended use (Macedo et al. 2006). More recently, Roswadoski (2024) reported that adult wasps of *T. podisi* can be stored inside capsules with food for up to 15 days at 25 °C before release without any injury to parasitism capacity. This suggests the release of fed parasitoid adults inside capsules as a promising technology to increase parasitoid shelf life in addition to other benefits, providing a new and cost-efficient way of releasing this parasitoid in soybean fields.

c) Environmental rearing conditions: *Telenomus podisi* mass rearing can be performed at temperatures between 21 and 30 °C. Because the highest daily and lifetime parasitism rates besides the highest parasitoid emergence recorded at 25 °C, this temperature is generally adopted at *T. podisi* mass-rearing facilities. It is important to point out that the development of quality control protocols for both *T. podisi* rearing and release are crucial for a successful ABC using the parasitoid. However, such protocols still need to be developed. The official registration of *T. podisi* in Brazil took place only in 2019 and the commercialization of the parasitoid has been performed only since then (MAPA 2019).

One challenging aspect of *T. podisi* rearing is the risk of parasitoid fitness loss in long-term production systems. For other egg parasitoid species (*Telenomus remus*), which were kept at rearing facilities in constant ideal conditions, a reduction of foraging and flying abilities of adult wasps was recorded after several generations (Naranjo-Guevara et al. 2020). The establishment of varying rearing conditions (for example different regimes of light, temperature, and humidity), and the introduction of wild individuals (periodically) into the rearing facility have been suggested as possible solutions (Colmenarez et al. 2022).

As newly released parasitoids usually have to face field conditions with daily thermal fluctuations and periods of extremely high or low temperatures (Bannerman and Roitberg 2014; Colinet et al. 2015), Castellanos et al. (2019) proposed rearing *T. podisi* under fluctuating temperature conditions of 30 ± 2 °C during the day (12 h) and 20 ± 2 °C at night (12 h). This was considered more suitable for parasitoid mass-rearing since such temperature conditions resulted in fitness benefits (shorter developmental time, increased female longevity, higher fecundity/fertility) and a reduction of production costs by approximately 23.5%.

Refreshing the parasitoid colony with individuals collected from natural populations is also relevant

(Colmenarez et al. 2022). However, this procedure should be executed with caution since taxonomic knowledge is required to avoid colony contamination with other parasitoid species (Bowers 2015) or fungal and bacterial pathogens from the field, among other possible negative effects on colony maintenance (Colmenarez et al. 2022).

Release strategies of *Telenomus podisi*

The egg parasitoid *T. podisi* is an efficient biocontrol agent for release in soybean to manage stink bugs (Bueno et al. 2020a; Ramos et al. 2024), and several commercial *T. podisi* products available on the Brazilian market are already used by farmers. Despite this, essential challenges still need to be addressed to successfully release this parasitoid in the field within ABC programs (Bueno et al. 2022).

The most crucial considerations to enable the successful release of *T. podisi* proposed by Bueno et al. (2022) are:

a) **The number (density) of *T. podisi* to be released:** Releasing an ideal density of parasitoids is very important for the success of *T. podisi*. The biopesticide leaflet recommends two to three releases of 6,500 parasitoids per hectare. Weekly releases should add up to 13,000–19,500 wasps per hectare (Bueno et al. 2022). Following these recommendations, parasitism of *E. heros* eggs after three releases of 6,500 parasitoids per hectare at weekly intervals was higher than 70%, while the natural parasitism rate was only close to 10% (Bueno et al. 2020a).

In contrast to Bueno et al. (2022), Weber et al. (2022), using a computation model based on biological parameters of the parasitoid, recommended 3–4 releases of 5,000 female parasitoids per hectare. Assuming common sex ratio of *T. podisi* as 0.54 (Silva et al. 2018), Weber et al. (2022) recommendation would be equivalent to 30,000 to 40,000 wasps/ha, a number almost 100% higher than the current recommendation of the registered *T. podisi* as bioinsecticide.

b) **Release technology of *Telenomus podisi* considering dispersal, release frequency, predation, and timing for parasitoid release in the field:** *Telenomus podisi* release modes can be adult wasps or pupae close to adult emergence (Bueno et al. 2022). Releasing parasitoid pupae has been the preferred method by companies that sell this biocontrol agent, mainly because of the easy options for mechanization which facilitate the operation in the field. Automatization of the process reduces the need for labor and the operational costs involved (Zang et al. 2021). Usually, pupae are strategically bulk distributed in the field, at equidistant points (minimum of 50 points per hectare) (Bueno et al. 2022). Releasing pupae is a practice based on previous experience with another egg parasitoid, *Trichogramma pretiosum* Riley, 1879 (Hymenoptera: Trichogrammatidae). The release of this species is easily programmed to occur only hours before parasitoid emergence.

However, for *T. podisi*, males emerge around 24 h before females (Yeargan 1980). Thus, released *T. podisi* female pupae will stay longer in the field before emergence and can be susceptible to various biotic and abiotic causes of mortality, reducing overall parasitoid emergence. Brazil has an enormously diverse fauna, including many ant species and other predators. These can prey on the exposed and susceptible *T. podisi* pupae, reaching 100% predation within a few hours after parasitoid release (Parra 2014).

In addition to predation, temperature is highlighted as one of the most critical threats to parasitoids of all abiotic causes of mortality (Frazer and Mcgregor 1992) because it can affect the individual-level survival of insects, among other biological parameters (Denis et al. 2011). When *T. podisi* pupae were released in soybean crops during the vegetative period, before complete plant development and soil shading between rows, pupae exposed directly to sunlight between rows exhibited significantly reduced adult emergence, compared with pupae shaded under plants. Parasitoid emergence was strongly reduced from 76% to close to 20% (Braz et al. 2021).

Those causes of mortality are even more relevant for egg parasitoids when released as immobile pupae, unable to search for shelter to protect themselves from predators or adverse temperatures (Braz et al. 2021). Therefore, in order to increase adult emergence, releases of pupae should be performed in the late afternoon to avoid high temperatures (Grande et al. 2021). Moreover, Roswadoski (2024) proposed the release of fed *T. podisi* adults inside capsules as a strategy to increase the overall parasitoid performance. This approach not only extends the parasitoid shelf life (to up to 15 days as previously mentioned) but also reduces parasitoid causes of mortality during release by mitigating the negative effects of extreme temperatures and predation normally faced by pupae upon release, since adult parasitoid wasps can quickly escape from predation and seek shelter. Also, the parasitoid higher shelf life can for example be crucial for parasitoid transport or for postponing the release due to unfavorable weather, which is not possible when adopting a bulk release of pupae (Roswadoski 2024).

In addition, it is important that the parasitoid release is performed when the vulnerable stage of the host egg is available in the field. Therefore, one of the biggest challenges for successfully managing stink bugs using *T. podisi* is the release of the parasitoid at the right time. Despite *Telenomus podisi* adults having a longer lifespan than *T. pretiosum*, reaching 80% of their lifetime parasitism only after 14 to 16 days (Silva et al. 2018) and showing similar parasitism capacity on *E. heros* eggs at 24, 48, 72, and 96 h of embryonic development (Queiroz et al. 2019), their release still need to be performed at the right time. The success of *T. podisi* depends on a release strategy that allows 14-day-old to 16-day-old adult parasitoids to match a host egg age of up to four-day-old in the field. The bioinsecticide leaflets recommend the releases to be made at one-week intervals (Bueno et al. 2022). However, considering that *T. podisi* only reaches 80% of its lifetime parasitism around 14 days after adult emergence under laboratory conditions (Silva et al. 2018), longer intervals between releases could be tested in future studies in an attempt to improve parasitoid field performance. Such a strategy could be advantageous even when taking into consideration a possible reduction of survival rates and other possible negative effects in the agroecosystem. Moreover, a rigorous monitoring of stink bugs in the field is crucial, in addition to a fast response of the bioindustry in order to allow the fast release of the parasitoid in the area after being acquired by the farmer.

Aiming to improve release protocols, Weber et al. (2022) determined that *T. podisi* should be released at points or strips spaced 25 m apart in a tested computational model. However, the studies of the dispersion capacity and spatial distribution of *T. podisi* bring contrasting results, and therefore, can still be considered incipient (Ramos et al. 2024). Previous research studying *T. podisi* dispersion indicates approximately 39 m from the release point 24 h after the release (Bueno et al. 2013). More recent field studies have supported the recommendation of release points no more than 30 m apart for optimal distribution of *T. podisi* in the field (Hoback et al. 2024).

Regardless of a release as pupae or adults, it is important to consider that *T. podisi* is a tiny insect whose dispersal is strongly influenced by wind direction (Fig. 1) and speed (Hoback et al. 2024). Wind has been reported in the literature to impact the dispersion of other parasitoids of the order Hymenoptera which due to their small size have little flight control under windy conditions (Corbett and Rosenheim 1996). Therefore, the release method should preferably adopt a distribution perimeter taking into account the prevailing wind direction in the area, whenever this is possible (Pomari-Fernandes et al. 2018). Moreover, plant architecture, besides its size and chemistry may also impact the dispersal capacity of the parasitoid in the field (Hoback et al. 2024). Soybean leaf area index (LAI) increases according to plant development up to a maximum, after which LAI decreases due to leaf senescence (Hayashida et al. 2021). Also, volatile organic compounds released by soybean have altered parasitoid behavior (Dias et al. 2016).

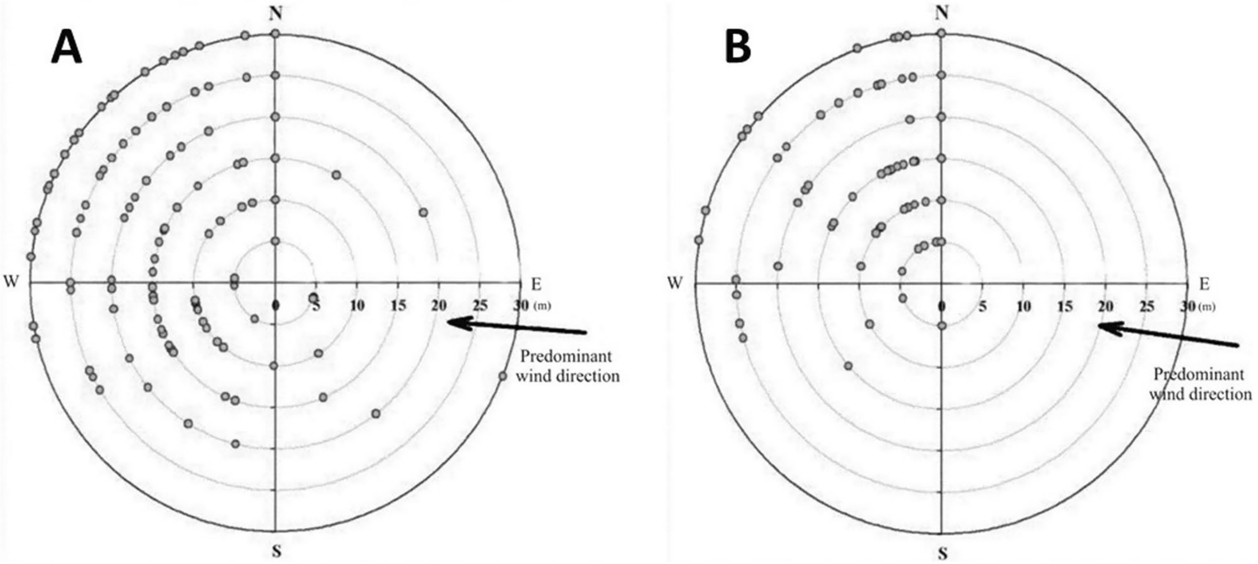

Fig. 1 The effect of the predominant wind direction on the dispersal of egg parasitoid *Telenomus remus* after releases performed at soybean stages of development V3 (**A**) and R3 (**B**). Each point represents a parasitized egg recovered at different distances (from 5 to 30 m) of the released point that was the cross of the axes. Adapted from Pomari-Fernandes et al. (2018)

c) **Stink bug density and climatic conditions at the time of release:** Unlike insecticides, *T. podisi* can prevent stink bug outbreaks by egg parasitism. Therefore, parasitoid release should begin when the first stink bug adults and their first eggs occur in the field (Bueno et al. 2022). This is a challenge, considering that research recommends that the sampling of pests in soybean fields should be performed by applying the beating cloth technique (Bueno et al. 2023b). The use of traps to capture stink bugs adults may be an option to determine the ideal time for parasitoid release. However, the relationship between adults captured in traps and the presence of eggs in the field still needs to be established. To date, *T. podisi* is released when the first adults and eggs are observed in the field, which is very subjective and its success is dependent on the farmers' perception.

The climatic conditions, especially rain and extreme temperatures, can negatively impact the success of biological control using egg parasitoids (Braz et al. 2021; Grande et al. 2021). Therefore, egg parasitoids should be released when more favorable climatic conditions for emergence and survival of adults from the released pupae are recorded. In this scenario, the usual recommendation is to release *T. podisi* in the early hours of the morning or alternatively in the late afternoon, since *T. podisi* parasitism is less affected by the absence of light (Grande et al. 2021). If the release of fed adults inside capsules as suggested by Roswadoski (2024) is adopted, farmers can wait until 15 days for better weather conditions without any reduction of parasitism.

d) **Interactions of *T. podisi* with other pesticides (biological or chemicals) used in crop management:** Despite the high potential of biological control using *T. podisi* releases against stink bugs, additional control strategies (chemical or biological) might still be needed. Thus, a detailed understanding of the threats that pesticides pose for *T. podisi*, as well as the possible use of selective pesticides is essential to allow both chemical and biological control to be used in combination within IPM programs (Torres and Bueno 2018).

Active ingredients belonging to the group of Insect Growth Regulators (IGRs), such as chlorfluazuron, teflubenzuron, novaluron and lufenuron, are relatively more selective to *T. podisi* (Stecca et al. 2018). In contrast, pyrethroids such as bifenthrin, beta-cyfluthrin, zeta-cypermethrin and organophosphates such as chlorpyrifos and acephate were among the most harmful pesticides to this parasitoid, especially to adults, which is generally the most susceptible parasitoid stage (Hassan et al. 1985; Carmo et al. 2010; Silva et al. 2018; Stecca et al. 2018). Therefore, the use of these broad-spectrum insecticides in the field should be strongly avoided around 10 days before and 15 days after *T. podisi* releases. Where stink bugs or chrysomelids need to be controlled, pyrethroids or organophosphates may be preferred by farmers, posing a challenge for *T. podisi* preservation. Fungicides and herbicides are generally less harmful to beneficial organisms than insecticides (Bueno et al. 2017; Zantedeschi et al. 2018). Moreover, adoption of integrated pest management (IPM), soybean cultivars resistant to pest or any other strategy that reduces traditional pesticide use will also benefit the preservation of *T. podisi* in the field and favor its parasitism.

e) **Size of the field in which *T. podisi* is released:** Both *T. podisi* and all other macrooganism can be impacted by the size of the field when released. Macroorganisms move from plant to plant or place to place and, therefore, their migration to crops near the released field is always possible. Not only can *T. podisi* move to areas where they were not released but also *E. heros* adults can move to areas where the parasitoid was released. Therefore, the success of *T. podisi* release, with high parasitism, does not eliminate the need of stink bug control using other strategies such as chemicals since although the parasitoids will kill the stink bug eggs, adults of this pest from nearby areas can move to the area where the eggs had been controlled, increasing anyway the adult population, making pest densities to reach or surpass stink bug Economic Thresholds of 2 bugs/meter (Bueno et al. 2015). This possibility emphasizes the importance of other compatible control alternatives within IPM.

The smaller the size of the field, the higher the chances of either *T. podisi* or *E. heros* migration and hence of frustration of biological control. The minimum size of the field for *T. podisi* releases still needs to be determined in future research.

Final considerations

Further studies are still needed to precisely determine optimal release rates, release timing and frequency, number of release points, the best stage and equipment for releases, and other aspects such as field size to achieve efficient pest control when releasing *T. podisi*. Moreover, if releasing fed adults proves to be the best strategy, appropriate equipment to enable such release still needs to be developed or adapted. Unmanned aerial vehicles, such as agricultural drones, have been efficiently used to release

Trichogramma spp. at complex farmlands (Wang et al. 2018). However, for the release of fed adults, a design of a specific *T. podisi* delivery device that opens a biodegradable capsule only a few seconds before releasing is required. Similar automation techniques adopted in China led to major achievements in *Trichogramma* R&D and are used to control target pests in various crops (Zang et al. 2021).

Despite these needs, the release of *T. podisi* against stink bugs is already considered an efficient management option, apart from being already commercially available in Brazil. Undoubtedly, parasitoid releases should be adopted together with other IPM recommendations. The adoption of IPM, together with the reduction of synthetic insecticide use and the prioritization of the most selective pesticides, will generate a more favourable environment for the success of the biological control. Among the most selective insecticides to natural enemies, biological insecticides (entomopathogens) stand out, followed by insecticide growth regulators (IGRs) (Torres and Bueno 2018). Unfortunately, no IGRs are available against stink bugs. However, more recently, entomopathogens (*Metarhizium anisopliae* and *Beauveria bassiana*) have been officially registered and are commercially available in Brazil to control stink bugs. *Telenomus podisi*, in combination with those entomopathogens, promises to be a viable and sustainable solution to stink bug management for soybean fields. However, they still need to be tested in conjunction in future trials.

Furthermore, new disruptive stink bug management strategies still under development by different companies should also be reinforcing the benefits of IPM to sustainably manage this pest as medium-term and long-term goals. Not only should such newer management options include plant derived insecticides (Turchen et al. 2020), RNAi (Jain et al. 2021) and CRISPR (Cagliari et al. 2020) based control strategies but also more disruptive approaches such as, for instance, stink bug behavioral manipulation (Pinho 2024) and stink bug genetically modified insects (Scolari et al. 2011) that have been under study under different readiness levels but with great theorical potential for use in stink bug management, as they are intended to minimize the use of traditional chemical insecticides. Also, the adoption of flowering plants on the surrounds of soybean fields in order to enhance the effectiveness of natural enemies without negatively impacting crop management has been widely investigated as promising alternative to improve biological control effectiveness (Gurr et al. 2017) but very few studies have addressed the soybean agroecosystem and, thus, certainly new researchers to evaluate the potential of such strategies to improve *T. podisi* control inside the IPM approach are urgently needed.

Author contributions

AFB conceived the review plan and wrote the first version of the manuscript; WPS, LR and YCC contributed reviewing the subject and revising the paper. All authors read and approved the final manuscript.

Funding

This study was funded by Conselho Nacional de Desenvolvimento Científico e Tecnológico, 304052/2021-3, Adeney de Freitas Bueno.

Declarations

Competing interests

The authors that they have no competing interests.

Received: 2 February 2024 Accepted: 13 June 2024

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