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ORIGINAL ARTICLE

Commercial availability of invertebrate biological control agents targeting plant pests in Germany

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Abstract
Biological control is a recognized and well-implemented strategy to protect crops from pests and diseases, and there is an urgent need to expand biocontrol-based crop protection further, also in Germany. Specially, the use of invertebrate biological control agents (IBCA) is considered as a fundamental method in integrated pest management and organic farming. The objective of this article is to give an overview of the current commercially available and used IBCA species in Germany. Of those, individual non-indigenous species are critically examined for potential environmental risks. Furthermore, the current legal situation in Germany about the use of IBCA is described. Based on this information, this article clarifies the need for an environmental impact assessment for IBCA species that do not occur naturally in Germany. An outlook for their safe use in the future is discussed.

Keywords Biological control agent · Plant protection · Risk assessment · Biodiversity · Invasive species

Introduction

Biological control is a recognized and well-implemented strategy to protect crops from pests and diseases. Various plant extracts, microorganisms (bacteria fungi and viruses) or invertebrate biological control agents (IBCA) such as predatory and parasitic insects, predatory mites and entomopathogenic nematodes are used to control arthropod pests on plants (Lacey et al. 2015; Stenberg et al. 2021; van Lenteren et al. 2018), worldwide and also in Germany (Koch et al. 2019). Biological control methods are recognized as a basic method in integrated pest management (Naranjo et al. 2015) and are indispensable for organic farming. Due to the current shift in policies towards more sustainable and agroecological principles and the increasing restriction on various chemical pesticides, there is a very high demand for new and readily available biocontrol options (Buitenhuis et al. 2023; Lamichhane et al. 2017; van Lenteren et al. 2018).

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Political demands to reduce pesticide use and to favour biocontrol

In recent decades, the public awareness for biodiversity decline and loss of ecosystem services due to environmental pollution has increased. This trend is also reflected in political decisions taken at European Union (EU) level and implemented into national legislation. In 2009, the European Parliament and Council implemented the directive on the sustainable use of pesticides to reduce the risks and impacts of pesticides on human health and the environment (2009/128/EC) by promoting the strict use of integrated pest management (IPM) and of alternative approaches or techniques such as priority for non-chemical and low-risk substances. According to the directive, EU member states had to develop a national action plan aiming to reduce pesticides, which for Germany resulted in the "National Action Plan on Sustainable Use of Plant Protection Products" (BMEL 2013). Since 2014, it has been mandatory for growers to apply the eight general principals of IPM (Annex III EU Directive 2009/128/EC), reviewed by Barzman et al. (2015) for different farming situations. Despite this, ongoing negative effects of pesticide use on non-target organisms (e.g. risk for beneficial arthropods like pollinators and natural enemies) and the environment (including ecosystem services) have been frequently reported, also in recent years

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(Chagnon et al. 2015; Serrão et al. 2022; van Lexmond et al. 2015). Since 2020, the Farm to Fork strategy of the European Commission (COM/2020/381) states the goal of an "environmentally friendly food system". Furthermore, several amendments to the regulation regarding the application of plant protection products (Pflanzenschutz-Anwendungsverordnung—PflSchAnwV) came into force in Germany because of European legislation. These documents now address—among others—the reduction in the use of certain plant protection products, their use in a minimum distance to water bodies and their prohibition in protected areas (e.g. nature reserves, national parks). The legal imperative to reduce pesticides evokes the need of alternatives for plant protection, especially in conventional agricultural production, and biological control can play a major role in this context (Hulot and Hiller 2021; Naranjo et al. 2015).

Consumer demands to reduce pesticide use

One major difference between organic and conventional farming is that no synthetic pesticides are used in organic farming (regulation (EU) 2018/848 on organic production and labelling of organic products (European Parliament and of the Council)). There is an increasing popularity of organically produced food in Germany, which is reflected in the agricultural area used for organic farming. This area increased from under 2% in 1995 to over 11% in 2022 (BMEL 2022) with the aim of reaching 30% in 2030 (BMEL 2024). In a representative survey of consumers of organic products in Germany, 92% named "healthy diet" and 90% "avoiding residues from pesticides" as a reason for choosing them (multiple responses allowed (BLE 2021)). Furthermore, in the same survey, 84% responded that they buy ecological products because of the "contribution to the preservation/promotion of biodiversity" (BLE 2021).

Use of IBCA as alternative to pesticides

Agricultural systems are complex, and it will not be possible to replace one tool (e.g. chemical pesticide) by another non-chemical alternative. For a significant reduced use of synthetic pesticides or other inputs, like fertilizers, a more holistic or agroecological approach relying on increased natural soil fertility or resistant crop varieties is needed to change the system, which should also consider topics like social responsibility and climate change (Boeraeve et al. 2020; Tittonell 2014). In IPM, pesticides are usually applied when pest densities exceed an economic threshold; this approach is often not feasible with alternative control methods such as biological control, which act more preventively. For instance, conservation biological control mainly relies on safe use of pesticides without non-target risks and habitat management to sustain natural enemies in the agroecosystem. Adjacent structures next to the fields as, for example, flower strips or hedges can provide a refuge, alternative food and shelter, thus keeping natural enemy populations on site and at high levels (Boller et al. 2004; Judt et al. 2023). Due to these measures, naturally occurring antagonists are promoted (Holland et al. 2016) and—in an ideal scenario—pest densities are kept under economically relevant levels. In addition, the targeted use and regular augmentative application of IBCA like beneficial arthropods and entomopathogenic nematodes can play an important role in this context (Buitenhuis et al. 2023; Hulot and Hiller 2021). In recent decades, a trend towards the use of more specific IBCAs has been observed (see below). Thus, the majority of the IBCA are closely linked to the pest under consideration as a preferred host or prey and therefore operate very specifically. In addition, IBCA have the great advantage of being able to actively search and locate for their hosts and prey. This active and often specific host/prey location behaviour helps to localize the pest even at low densities and thus, ideally, to act preventively before pest outbreaks occur. As a consequence, applications of IBCA have to happen earlier to reduce pests in an earlier stage, meaning a preventive instead of a curative treatment.

In Germany, the use of IBCA in pest management is seen primarily in two biological control strategies: (1) as mentioned above, conservation biological control focuses on promoting naturally occurring antagonists in the respective agroecosystem through habitat management methods, as well as strict use of pesticides according to the principles of IPM; and (2) solutions of augmentative biocontrol are based on regular releases of mass-produced specific natural enemies as standard pest control in various cropping systems. Horticultural crops are managed with the inclusion of IBCA, especially under protected conditions, and this type of pest control has already reduced the use of pesticides for decades (Koch et al. 2019). The same applies to the use of one of the most successful natural enemies in Germany, the egg parasitoid *Trichogramma brassicae* against the European corn borer *Ostrinia nubilalis* in the open field. Application today reaches more than 40,000 ha/year (LTZ Augustenberg 2023) mainly in the south of Germany. The use is expected to increase due to attractive application methods (e.g. unmanned aerial vehicles—UAV) and also in more north-eastern regions of Germany as a result of further spread of the pest.

Old and new challenges: invasive pests

Due to different reasons, but mainly modern global trade, non-native organisms can be accidently introduced to new regions (Meyerson and Mooney 2007). Among them are highly polyphagous plant pests that spread in Germany causing serious economic impact. For this reason, they are often referred to as invasive pests, which might not always coincide with a nature conservation definition of “invasive”. Although effective methods of identifying and monitoring quarantine and unregulated pests exist through national and international plant health directives worldwide, the risk of non-native plant pests entering and reproducing in the "enemy-free space" in the invaded area remains. In recent years, many of the introduced plant pests have impaired well-functioning systems of integrated pest management (e.g. the tomato leafminer *Tuta absoluta* in tomato crops (Mansour et al. 2019; Desneux et al. 2022), the spotted wing drosophila *Drosophila suzukii* in fruit crops (Knapp et al. 2021; Tait et al. 2021), the marmorated stink bug *Halyomorpha halys* in horticultural and arable crops (Haye et al. 2015; Leskey and Nielsen 2018)). Some of them even caused environmental disasters by threatening or destroying certain plants with ecosystem functions also in natural habitats (e.g. *Cydalima perspectalis* on box trees (Michtell et al. 2018), *Anoplophora* beetles on various broadleaf trees (Haack et al. 2010), the gall wasp *Dryocosmus kuriphilus* on chestnut trees (Avtzis et al. 2019)). As native IBCA are often not adapted to newly introduced species, antagonists from the same origin as the pest may be more efficient. They could be introduced in the framework of the so-called classical biological control into the area were the pest occurs (Cornell and Hawkins 1993). Research and implementation of classical biological control are being undertaken worldwide (van Driesche et al. 2010). In Germany, the history of intentional classical biocontrol dates back to the introduction and release of the non-indigenous parasitoid *Aphelinus mali* against the woolly apple aphid, *Eriosoma lanigerum*, 100 years ago, and thirty years later of the parasitoid *Prospaltella perniciosi* against the San José scale *Quadraspidiotus perniciosus* (Krieg and Franz 1989). Unintentional classical biocontrol probably occurred more often, meaning that specialized natural enemies followed the path of their host and reached the invaded area a few years later (Weber et al. 2021). These events were not regularly monitored in the past, and observations are often based on anecdotal reports of the faunistic literature or unpublished results (Plichta 2023; Zimmermann 2023). However, recent monitoring showed that non-indigenous natural enemies like *Trissolcus japonicus* parasitizing *H. halys* (Dieckhoff et al. 2021) and *Leptopilina japonica* parasitizing *D. suzukii* (Martin et al. 2023) are already present in Germany.

Aim of the article

The well-established biocontrol manufacturer companies, the high level of acceptance by growers in at least some segments, consumer awareness and the support of biological control as part of integrated pest management by policy are reasons why Europe has the largest commercial market on IBCA worldwide (van Lenteren et al. 2018). In many European countries, the availability of IBCA for augmentative or classical biocontrol does require an approval process including risk assessment, though less comprehensive compared to authorization of chemical or microbial pesticides (Baratange et al. 2023; EC 2022; Robin and Marchand 2020). The use of IBCA in augmentative biocontrol in agriculture is therefore considered to be safe for users and the environment, because potential risks are considered *a priori*. In the case of mass releases in the open field, such as *T. brassicae* in maize (usual application rate of 100.000 wasps/ha per release) or entomopathogenic nematodes in orchards or nurseries (application rate up to millions/ha), the potential environmental impact of naturally occurring IBCA on non-target species in the surrounding environment is rated to be transient and localized (EPPO 2021; van Lenteren et al. 2006). The preferred use of non-indigenous IBCA in the greenhouse is also considered as safe for the environment, as under present climatic conditions these species will probably not be able to overwinter or to form free-living, persistent populations. Nevertheless, a scientifically sound and competent environmental impact assessment of such organisms prior to their first use in practice would help to assess possible risks in advance, especially in the intention to establish a non-indigenous IBCA for classical biocontrol (EPPO 2014, 2018, 2021, 2023; Nechols 2021).

In contrast to many neighbouring European countries, Germany does not have a legally approved list of IBCA that are officially recognized for being marketed and used in biological plant protection. Bathon (1999) published a systematic review of commercially available IBCA species in Germany and their use including consideration of potential non-target risks. Beside this, a list of commercially available IBCA and companies who sell them has been regularly updated and made available via the website of the Julius Kühn Institute[1] and is also published in respective reports (Jehle et al. 2013; Koch et al. 2019). Since the publication from Bathon (1999) and Koch (2019), some of the IBCA disappeared from the market, whereas others are still offered and new species arrived. Furthermore, the regulations about farm management, but also the legal situation about the use of IBCA changed, e.g. due to the reform of the Federal Nature Conservation Act in the year 2009 and also the Plant Protection Law in the year 2011 (see below). Because of these developments, there is an urgent need for an official approval procedure, especially for non-indigenous IBCA, which are of interest for the use against invasive plant pests and which will be or are already

[1] https://www.julius-kuehn.de/media/Veroeffentlichungen/Flyer/Nuetzlinge_zu_kaufen.pdf

applied in neighbouring countries. This article therefore provides an up-to-date overview of the IBCA commercially available in Germany, with individual non-indigenous species being critically examined for their potential risk to the environment. In addition, the current legal situation in Germany with regard to the use of IBCA is described. Based on this information, the need for an environmental impact assessment for IBCA species that do not occur naturally in Germany is discussed and an outlook for their safe use in the future is given.

Methods

In the year 2021, a total of 21 producers and distributors from Germany and one each from Belgium, Netherlands, Switzerland and Austria where asked which IBCA they currently offer for sale on the German market. In addition, websites and online shops of diverse companies were searched for new products to update the status in the year 2023. Resulting species lists were compared to Bathon (1999) as basis for commercial use of IBCA in Germany and to Koch et al. (2019) where a list of commercially used IBCA from the year 2014 was published. EPPO (European and Mediterranean Plant Protection Organization) Standard PM 6/3 (5) *Biological control agents safely used in the EPPO region* (EPPO 2021) with Appendices 1- 3 (2023 version) was consulted to check the status of the particular IBCA in EPPO region. Part of this Standard is an annually updated list by an expert panel, which consists of three appendices. The first two appendices ("Commercially or officially used biological control agents" and "Classical biological control agents successfully established in the EPPO region") form the so-called EPPO Positive List (further referred as "Positive List"). The third appendix contains species formerly listed in the "Positive List" but now removed because they no longer meet the criteria (EPPO 2021). Information on origin of the species followed description in Bathon (1999), but included also new information, mainly collected in GBIF database (GBIF 2024) and Fauna Europaea database (de Jong 2016). Information on target pests followed the recommendation by the producers.

Results

Currently available IBCA in Germany for augmentative biological control

According to our exploration from 2021 until mid-2023, 94 beneficial arthropod species are offered commercially in Germany (Table 1). This list contains species used for the purpose of plant protection, but also 16 species solely applied against pests in other commodities such as primary and secondary storage, material or hygiene pests or used for pollination (Fig. 1). Of these 78 species used in plant protection, 72 species (92%) are also on the "EPPO Positive List" (Table 1), which means that they have already passed a positive assessment by the EPPO Panel (i.e. "to have been used in several EPPO countries with no adverse effects, or with acceptable adverse effects, and approved by the EPPO Working Party for Phytosanitary Regulations", EPPO (2021)). The number of commercially available invertebrate species in Germany for biocontrol and pollination has steeply increased from less than five species in 1980 to 80 species in 2008 and a modest yearly increase since then (Fig. 2). Most of them belong to parasitoid wasps, followed by predatory mites, beetles, true bugs, entomopathogenic nematodes and finally other predators (Diptera, Thysanoptera and Planipennia) and pollinators (Koch et al. 2019). In comparison, nearly 350 IBCA were commercially available worldwide in 2016 (van Lenteren et al. 2018). The majority of the available species are highly specific for host or prey taxa belonging to plant sap-sucking arthropod pests (Fig. 3). Various Hemiptera, Thysanoptera and spider mites are target pests for biological control using IBCA. These (often exotic) pests are usually multivoltine, with populations growing rapidly under favourable conditions (in the greenhouse) and often developing resistance to pesticides. Augmentative biological control is therefore a very important alternative management option. Other pests like soil-dwelling larvae of Sciarid flies and beetles or various Lepidopteran species are target of more generalistic entomopathogenic nematodes, polyphagous predators (Chrysopidae) and parasitoids (*Trichogramma* species).

In 1998, a total of 91 IBCA species (including six species for pollination or against cockroaches or stable flies) were documented on the German market, of which 25 species were marked as "no longer in current supply in Germany" (Bathon 1999). This means that there were actually 66 IBCAs available. From this list, 15 species are not available anymore, whereas 40 new ones were commercially available in 2023. Comparing the current list with Koch et al. (2019), where only IBCA used for the purpose of plant and stored-product protection[2] were considered, 13 new species for plant protection became available within the last 10 years. Some of them had been listed by Bathon (1999), but were lost in between and are now again on the market: for example *Ephedrus cerasicola* and *Micromus angulatus*, both native natural enemies of aphids in Germany.

[2] Stored-product protection is defined under PflSchG § 2 as protection of products of plant origin in an unprocessed state or having undergone only simple preparation (Flingelli et al. 2014).

Table 1 Invertebrate species commercially offered in Germany for biological control and pollination in the year 2023

	Species	Origin & Distribution	Main Target Pest Group	Bathon (1999)	Koch et al. (2019)	EPPO (2021)
NEMATODA						
Rhabditidae						
PP	*Heterorhabditis bacteriophora* POINAR	Europe, North America	*Otiorhynchus* spp. (weevils), *Phyllopertha* (shining leaf chafers)	✓	✓	✓
PP	*Heterorhabditis downesi* STOCK	Part of Europe	Several Scarabaeidae	–	–	✓
PP	*Phasmarhabditis hermaphrodita* SCHNEIDER	Europe	Slugs	✓	✓	✓
Steinernematidae						
PP	*Steinernema carpocapsae* WEISER	Europe (Holoarctic)	Soil-borne insects, like weevils (*Otiorhynchus*), Noctuidae and other Lepidopteran species	✓	✓	✓
PP/HP	*Steinernema feltiae* FILIPJEV	Europe (Holoarctic)	Fungus gnats, codling moth, oak processionary moth and other Lepidopteran species	✓	✓	✓
PP	*Steinernema kraussei* STEINER	Europe, North America	*Otiorhynchus* spp. (weevils), *Phyllopertha* (shining leaf chafers)	–	✓	✓
ACARI						
Laelapidae						
PP	*Hypoaspis aculeifer* CANESTRINI	Europe	Fungus gnats, Thrips, springtails	✓	✓	✓
PP	*Stratiolaelaps scimitus* WOMERSLEY (*Hypoaspis miles* BERLESE)	Palaearctic	Fungus gnats, Thrips, springtails	✓	✓	✓
Macrochelidae						
PP	*Macrocheles robustulus* BERLESE	Europe, North/South-America	Thrips, fungus gnats, shore flies, springtails	–	✓	✓
Phytoseiidae						
PP	*Amblydromalus limonicus* GARMAN & MCGREGOR	North/South America, Australasia, Southern Europe	Thrips, whiteflies, spider mites	–	✓	✓
PP	*Amblyseius andersoni* CHANT	Cosmopolitan	Spider mites	–	✓	✓
PP	*Amblyseius swirskii* ATHIAS-HENRIOT	East of Mediterranean region, Africa	Thrips, whiteflies, mites	–	✓	✓
PP	*Iphiseius degenerans* BERLESE	Africa, Egypt, Southern Europe	Thrips	✓	✓	✓
PP	*Neoseiulus barkeri* HUGHES	Cosmopolitan	Thrips (*Thrips tabaci, Frankliniella occidentalis*), thread-footed mites	✓	✓	✓
PP	*Neoseiulus californicus* McGREGOR	North America, Part of Europe, North Africa	Spider mites	✓	✓	✓
PP	*Neoseiulus cucumeris* OUDEMANS	Cosmopolitan	Thrips (*Thrips tabaci, Frankliniella occidentalis*), thread-footed mites	✓	✓	✓
PP	*Phytoseiulus persimilis* ATHIAS-HENRIOT	Africa, Chile, Mediterranean	Spider mites	✓	✓	✓
PP	*Transeius montdorensis* SCHICHA	Australia	Thrips, whiteflies, spider mites	–	✓	✓

Table 1 (continued)

PP	*Typhlodromus pyri* SCHEUTEN	Europe, Nearctic	Spider mites	✓	✓	✓
THYSANOPTERA						
Aeolothripidae						
PP	*Franklinothrips vespiformis* CRAWFORD	Central America, Pantropical	Thrips	–	✓	✓
Phlaeothripidae						
PP	*Karnyothrips melaleucus* BAGNALL	Pantropical, Part of Europe	Scale insects	–	–	✓
HETEROPTERA						
Anthocoridae						
PP	*Anthocoris nemoralis* FABRICIUS	Palaearctic	Psyllids (*Cacopsylla pyri*)	–	✓	✓
PP	*Orius majusculus* REUTER	Europe	Thrips (*Frankliniella occidentalis, Thrips tabaci*)	✓	✓	✓
PP	*Orius laevigatus* FIEBER	Palaearctic	Thrips (*Frankliniella occidentalis, Thrips tabaci*)	✓	✓	✓
SP	*Xylocoris flavipes* REUTTER	Afro-tropical, Neartic, Oriental	Flour beetles (*Tribolium confusum*, *T. castaneum*)	–	✓	–
Miridae						
PP	*Macrolophus pygmaeus* RAMBUR	Europe	Whiteflies (*Trialeurodes vaporariorum* and *Bemisia* spec.), aphids, spider mites	✓	✓	✓
HYMENOPTERA						
Aphelinidae						
PP	*Aphelinus abdominalis* DALMAN	Europe	Aphids (*Myzus euphorbiae, Aulacorthum solani, M.persicae*)	✓	✓	✓
PP	*Aphytis melinus* DEBACH	India/Pakistan	Scale insects: Diaspididae (*Aonidiella aurantii*)	✓	✓	✓
PP	*Coccophagus scutellaris* DALMAN = *Coccophagus lycimnia* WALKER	Cosmopolitan	Scale insects: Coccidae	✓	✓	✓
PP	*Encarsia citrina* CRAW	Cosmopolitan	Scale insects: Diaspididae	✓	✓	✓
PP	*Encarsia formosa* GAHAN	Southern Nearctic	Whiteflies (*Trialeurodes vaporariorum, Bemisia tabaci*)	✓	✓	✓
PP	*Eretmocerus eremicus* ROSE & ZOLNERWICH	Southern Nearctica	Whiteflies (*Trialeurodes vaporariorum, Bemisia tabaci*)	–	✓	✓
PP	*Eretmocerus mundus* MERCET	Southern Europe	*Bemisia tabaci*	✓	✓	✓
Apidae						
P	*Bombus terrestris* LINNAEUS	Western Palaearctic	Pollinator**, tomato, berries, apple etc	✓	✓	–
Bethylidae						
SP	*Cephalonomia tarsalis* ASHMEAD	Great Britain, East Palearctic, Neartic, Tropical	Storage beetles (*Oryzaephilus surinamensis, Sitophilus sp., Tribolium castaneum*)	–	✓	–
Braconidae						
PP	*Aphidius colemani* VIERECK	Tropical Asia, Australia, Europe	Aphids (*Aphis gossypii, Myzus persicae, M. nicotianae*)	✓	✓	✓

Table 1 (continued)

PP	*(Habro)Bracon brevicornis* WESMAEL	Cosmopolitan, Germany	European corn borer (*Ostrinia nubilalis*)	–	✓	–
SP	*(Habro)Bracon hebetor* SAY	India, New England	Food moth (like *Ephestia kuehniella, Plodia interpunctella*)	✓	✓	✓
PP	*Dacnusa sibirica TELENGA*	Palearctic	Leaf-miner flies	✓	✓	✓
MP	*Dinarmus basalis* RONDANI	Nearctic, Afro-tropical, Oriental, Europe, East Palaearctic	Cloth moth (*Tineola bisselliella*)	–	–	–
PP	*Ephedrus cerasicola* STARÝ	Europe	Aphids	✓	–	✓
PP	*Lysiphlebus testaceipes* CRESSON	Nearctic (Neotropics)	Aphids (*Aphis gossypii, A. hederae, A. fabae, M. persicae*)	✓	✓	✓ but App. 3
PP	*Praon volucre* HALIDAY	Palaearctic	Aphids	✓	✓	✓
Encyrtidae						
PP	*Acerophagus (Pseudaphycus) maculipennis* MERCET	Afrotropical region, South Europe	Mealybugs (*Pseudococcus viburni*)	✓	✓	✓
PP	*Anagyrus fusciventris* GIRAULT	Australia	Pseudococcidae (*Pseudococcus longispinus*)	✓	✓	✓
PP	*Anagyrus vladimiri (syn. pseudococci)* GIRAULT	Mediterranean	Pseudococcidae	–	✓	✓
PP	*Coccidoxenoides perminutus* GIRAULT	China	Mealybugs	–	✓	–
PP	*Leptomastidea abnormis* GIRAULT	Mediterranean	Mealybugs (*Planococcus citri*)	✓	✓	✓
PP	*Leptomastix dactylopii* HOWARD	Neotropics	Mealybugs *(Planococcus citri, P. ficus)*	✓	✓	✓
PP	*Leptomastix epona* WALKER	Palaearctic	Mealybugs	✓	✓	✓
PP	*Metaphycus flavus* HOWARD	Nearctic	Coccidae, *Saissetia oleae, Coccus hesperidum*	–	✓	✓
PP	*Metaphycus helvolus* COMPERE	South Africa, Nearctic	Coccidae (*Saissetia oleae, Coccus hesperidum*)	✓	✓	✓
PP	*Metaphycus stanleyi* COMPERE	Afrotropical, Australia, Neartic, Southern Europe	Coccidae (*Saissetia oleae*)	–	✓	–
PP	*Microterys nietneri* MOTSCHULSKY	Holarctic	Coccidae (*Coccus hesperidum*)	As *flavus*	As *flavus*	✓
PP	*Cryptanusia aureiscutellum* GIRAULT	Australasia	Mealybugs (*Pseudococcus longispinus)*	–	–	–
Eulophidae						
PP/HP	*Aprostocetus hagenowii* RATZEBURG	Asia, Costa Rica, USA, Romania	Cockroaches (Blattodea)	✓	–	✓
MP	*Baryscapus tineivorus* FERRIERE	Germany*, Britain, Switzerland, Neartic, Afrotropical region	*Tineola biselliella* (clothing moth)	–	–	–
PP	*Diglyphus isaea* WALKER	Palearctic	Leaf-miner flies	✓	✓	✓
PP	*Thripobius semilutues/ javae* GIRAULT	Asia	Thrips	✓	✓	✓

Table 1 (continued)

Ichneumonidae						
SP	*Venturia canescens* GRAVENHORST	Cosmopolitan	Several Lepidopteran species (like *Plodia interpunctella* or *Ephestia* spp.)	–	✓	–
Megachilidae						
P	*Osmia cornuta* LATREILLE	Europe	Pollinator**, cherry, strawberries, blueberry etc	–	✓	–
P	*Osmia bicornis (*syn. *O. rufa)* LINNAEUS	Europe, North Africa	Pollinator**, apples, pear, strawberries etc	–	✓	–
Pteromalidae						
SP/MP	*Anisopteromalus calandrae* HOWARD	Cosmopolitan* (introduced)	Storage beetles	–	✓	–
SP/MP	*Lariophagus distinguendus* FÖRSTER	Cosmopolitan* (introduced)	Storage and material pest beetles	–	✓	–
HP	*Muscidifurax raptorellus* KOGAN & LEGNER	South America	Stable flies (*Stomoxys chalcitrans, Musca sp.*)	–	–	–
HP	*Nasonia vitripennis*	Palearctic, Afro-tropical region, Australia	Stable flies	✓	–	–
SP	*Theocolax elegans* WESTWOOD	America, Europe, Africa (introduced)	Wheat weevil (*Sitophilus granarius*)	–	✓	–
Scelionidae						
PP	*Trissolcus basalis* WOLLASTON	Africa, cosmopolitan*	Pentatomid bugs: *Nezara viridula*	–	–	✓
Trichogrammatidae						
PP	*Trichogramma brassicae* BEZDENKO	Europe, Asia, North America, Australia	Lepidoptera, but mainly *Ostrinia nubilalis*	✓	✓	✓
PP	*Trichogramma cacoeciae* MARCHAL	Europe, Asia, Africa, South America	Several Lepidopteran species like codling moth, plum moth	✓	✓	✓
PP	*Trichogramma dendrolimi* MATSUMURA	Europe, Asia	Lepidoptera, mainly codling moth	✓	✓	✓
SP/PP	*Trichogramma evanescens* WESTWOOD	Europe, Asia, Africa, South America	Storage and greenhouse pests (different lepidopteran species)	✓	✓	✓
COLEOPTERA						
Coccinellidae						
PP	*Adalia bipunctata* LINNAEUS	Palaearctic, introduced in other regions	Aphids	–	✓	✓
PP	*Chilocorus nigritus* FABRICIUS	South Asia, East Africa	Scale insects: Diaspididae	✓	✓	✓
PP	*Coccinella septempunctata* LINNAEUS	Palaearctic	Aphids	✓	✓	✓
PP	*Cryptolaemus montrouzieri* MULSANT	Australia	Mealybugs	✓	✓	✓
PP	*Delphastus catalinae* HORN	Colombia, introduced to North America	Whiteflies (*Trialeurodes vaporariorum, Bemisia tabaci*)	–	✓	✓
PP	*Delphastus pusillus* LeCONTE	North America	Whiteflies (*Trialeurodes vaporariorum, Bemisia tabaci*)	✓	–	✓

Table 1 (continued)

PP	*Exochomus quadripustulatus* LINNAEUS	Europe	Scale insects	–	–	✓
PP	*Propylea quatuordecimpunctata* LINNAEUS	Palearctic	Aphids	–	–	✓
PP	*Rhyzobius forestieri* MULSANT	Australia, part of Europe	Scale insects	–	✓	✓
PP	*Rhyzobius lophantae* BLAISDELL	Australia, South Europe, Neotropical region	Scale insects and mealybugs	✓	✓	✓
PP	*Rodolia cardinalis* MULSANT	Australia	Cottony cushion scale *(Icerya purchase)*	–	✓	✓
Cybocephalidae						
PP	*Cybocephalus nipponicus* ENDRÖDY-YOUNGA	Asia, partially in Europe naturalized (Italy, France, Belgium, Luxembourg, Poland)	Scale insects: Diaspididae	–	–	–
Staphylinidae						
PP	*Dalotia coriaria* KRAATZ	Europe, Northern Asia, North America, Oceania	Diptera (fungus gnats, *Delia sp.*)	–	✓	✓
DIPTERA						
Cecidomyiidae						
PP	*Aphidoletes aphidimyza* RONDANI	Central Europe, North America, Japan	Aphids (*Aphis gossypii, Myzus persicae, Macrosiphum sp., Aulacorthum* sp.)	✓	✓	✓
PP	*Feltiella acarisuga* VALLOT	Western Europe, Mediterranean	Spidermites (*Tetranychus urticae, T. cinnabarinus*)	✓	✓	✓
Calliphoridae						
P	*Lucilia caesar* LINNAEUS	Europe, East Palaearctic	Pollinator** in vegetables	–	✓	–
Muscidae						
HP	*Hydrotaea aenescens* WIEDEMANN	North America	Stable flies	✓	–	–
Syrphidae						
PP	*Episyrphus balteatus* DE GEER	Europe, Palaearctic	Aphids	✓	✓	✓
PP	*Eupeodes corollae FABRICIUS*	Europe, Palaearctic	Aphids	–	–	✓
PP	*Sphaerophoria rueppellii* WIEDEMANN	Europe	Aphids	–	–	✓
PLANIPENNIA						
Chrysopidae						
PP	*Chrysoperla carnea* STEPHENS	Cosmopolitan	Aphids, mealybugs, small insects	✓	✓	✓
PP	*Micromus angulatus* STEPHENS	Cosmopolitan	Aphids	✓	–	✓

Origin and naturalized distribution (sources: GBIF, Fauna Europaea and others) of species and the main target pests of their use is given

Main Usage: *PP* Plant protection, *SP* stored product protection, *MP* material protection, *HP* hygiene/health protection, *P* pollination

Listing of species in Bathon (1999), Koch et al. (2019) and EPPO (2021) PM 6/3(5) (Appendices 1-3 (version 2023)) is indicated: ✓ = yes, – = no

As some species spread with time, native origin might not be traceable anymore and get confused with current distribution; * in Germany naturalized/established; **pollinator is the ecosystem function

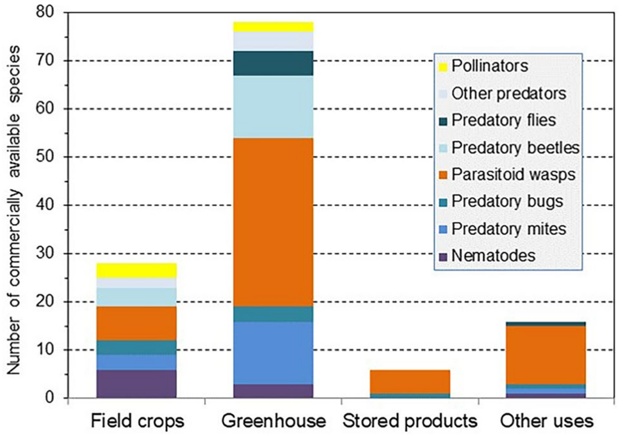


Fig. 1 Number of commercially available species of invertebrate biological control agents in Germany in 2023 differentiated by scope of application and respective functional groups

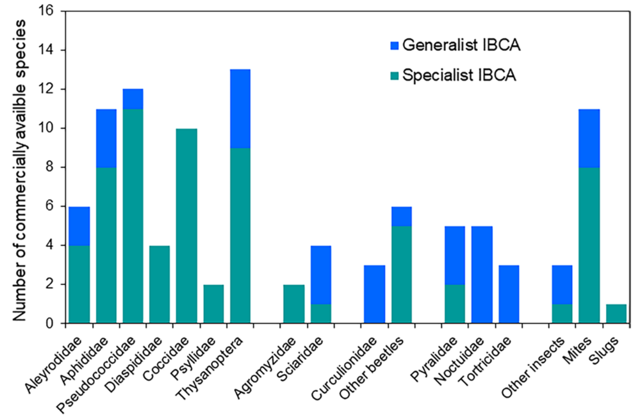


Fig. 3 Number of commercially available species of invertebrate biological control in Germany in 2023 differentiated according to their specificity for host or prey and the respective main target groups

This article is about IBCA species released against pests on living plants and plant parts (fruits, seeds) (sensu PflSchG § 2), so species solely used for other purposes (pollination, hygiene or material pests, storage pests including stored-product protection) are listed, but not included into further report and discussion. The use of natural enemies against stored-product insects in Germany is reviewed by Schöller and Prozell (2014).

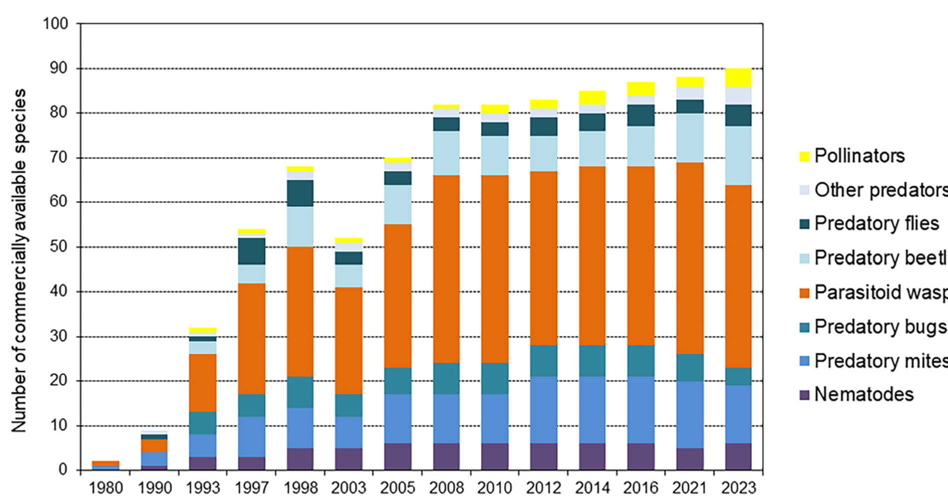
Need for environmental risk assessment for currently available IBCA in Germany?

Bathon (1999) critically reviewed 13 non-native IBCA with the potential to establish in Germany. He concluded that ten of them should not be used as IBCA in Germany either because there are not enough data to evaluate their effects on non-targets or because they have the potential to endanger native species.

Two species, namely *Leptomastidea abnormis* and *Delphastus catalinae* (former sold as *D. pusillus*), are still commercially available (Table 1) and listed on the "Positive List" of EPPO (2021), for which Bathon (1999) recommend not to use them as IBCA.

- For *L. abnormis,* he claimed that it probably could establish in Germany and potential effects on non-target species had not been evaluated. The species is native to the Mediterranean but—due to the use as IBCA targeting mealybugs—widely distributed (America and Africa). Attempts to establish the species in black Sea coast of Krasnodar (Russia) and Georgia failed as they could not hibernate (Trjapitzin 2009). The thermal threshold of development is estimated at 10.3 °C (Gutierrez et al. 2008), making an establishment in Germany unlikely at present.
- Bathon (1999) clearly advised against the use of *D. catalinae* as IBCA in Germany as it can compete with native

Fig. 2 Number of commercially available species of invertebrate biological control agents for plant protection and pollinators in Germany between 1980 and 2023 differentiated by respective functional groups



ladybirds for food resources. Interesting, this warning was given for two ladybird species, namely *Harmonia axyridis* and *D. catalinae*. Concern regarding *H. axyridis* was justified (see below), whereas *D. catalinae* did not establish in Germany. Hoelmer and Pickett (2003) reported about the misidentification of *D. catalinae* (sold as *D. pusillus*) in commercial insectaries and claimed a different distribution for both species. *D. catalinae* has a low tolerance for cold temperatures, even though it can survive mild winters and it is an oligophagous predator (Hoelmer et al. 1993; Simmons and Legaspi 2004, 2007). Taking into account different factors (e.g. host specify, probability of establishment and dispersal), *D. catalinae* had intermediate risk indices regarding environmental risk in Europe (van Lenteren et al. 2003). Currently, there are also sources available sold as *D. pusillus* as a synonym to *D. catalinae.*

For two other species, establishment was deemed likely but without non-target risks.

- *Aprostocetus hagenowii* (host specific to non-native cockroaches) was rated by Bathon (1999) with the potential to establish in Germany, but assumed to just survive on domestic waste dumpsite without any threat for native species.
- Similarly, *Macrolophus caliginosus* was rated by Bathon (1999) with the potential to established in Germany, partly due to natural immigration from Mediterranean countries, but without any threat for native species. *M. caliginosus* is not commercially available anymore in Germany. However, due to incorrect naming and identification, some suppliers have offered the sister species *Macrolophus pygmaeus*, which occurs naturally in Germany, under the name *M. caliginosus* until recently.

From 28 “new” IBCA available for plant protection for the year 2023 in comparison to Bathons’ list (stored-product protection and other uses excluded), 23 species are on the “Positive List” of biological agents widely used in the EPPO region, on either Appendix I (Commercially used biological control agents) or II (Successfully established classical biological control agents) (EPPO 2021, version 2023). Species listed in Appendix I or II are ranked by a panel of experts as beneficial species for plant protection and according to the current knowledge not harming for the environment. Therefore, they can be classified as safe for use in the EPPO region based on current knowledge. There remain several “new” IBCA for plant protection on living plants in Table 1 for which no scientific appraisal of potential risks of their use has been conducted.

- *(Habro)Bracon brevicornis* (Hymenoptera: Braconidae) is a cosmopolitan IBCA, also native to Germany. Starting in 2006, this parasitoid was extracted from nature, bred commercially and first trials performed to use it against *Ostrinia nubilalis* (European corn borer) (Wührer and Zimmermann 2008). The species was also synonymized with *Habrobracon hebetor*, but according to actual data can be considered as valid species (Kittel and Maeto 2019). Due to its naturally occurring status, the release even in open field can be considered as safe.
- *Coccidoxenoides perminutus* (Hymenoptera: Encyrtidae) probably originates from China and has widely distributed into tropical and subtropical areas. In Germany, it is used in greenhouses (recommended temperature between 20 and 30 °C) targeting mealybugs. Ceballo et al. (2010) modelled with the climate-matching program CLIMEX the potential worldwide distribution of *C. perminutus* and it seems that Germany is not a suitable habitat.
- *Metaphycus stanleyi* (Hymenoptera: Encyrtidae) was introduced as IBCA from Africa to California (USA), Israel and Italy (via Israel) targeting scale insects (Blumberg and Swirski 1977; Compere 1940; Viggiani and Mazzone 1977). In Germany, *M. stanleyi* is used targeting Coccidae in greenhouses and indoor plantings. The establishment in Germany in nature seems unlikely due to the given climatic conditions.
- *Cryptanusia aureiscutellum* (Hymenoptera: Encyrtidae) was first described in Australia and has accidently been introduced to New Zealand where it established (Charles et al. 2010; Girault 1926; Jamieson et al. 2009). In Germany, it is applied in greenhouses and indoor plantings to control long-tailed mealybugs (*Pseudococcus longispinus*). An establishment in Germany of *C. aureiscutellum* seems unlikely because of temperate climate and host availability, but data are lacking.
- *Cybocephalus nipponicus* (Coleoptera: Cybocephalidae) was introduced to several countries as IBCA against different armoured scale insects (Diaspididae). Establishment has been shown in Eastern United States (Blumenthal et al. 2005; Drea and Carlson 1988). In 2002, it was found in Italy, which was the first record in Europe, followed by detections in 2015 in France and 2017 in Hungary, with unknown source of introduction (Lupi 2002; Merkl et al. 2017). GBIF lists also Belgium, Luxemburg and Poland since 2020. Taking into account this information, an incidence also in Germany seems to be plausible, in case if prey species are available and habitat conditions are favourable. *C. nipponicus* is known to prey on nearly 20 different armoured scale insect species (Smith and Cave 2006; Song et al. 2012). Beetles were also observed in a laboratory study to feed on

Panonychus citri (citrus red mite), even though females did not oviposit (Tanaka and Inoue 1980). Similar, Song et al. (2012) reported from a laboratory study that *C. nipponicus* feeds on different scale species (e. g. the striped mealybug *Ferrisia virgata*) but has a narrow prey range (successful oviposition), namely mainly on *Aulacaspis* scale species. In Germany, it is commercially advertised for indoor use against Diaspididae.

- In addition, the aphid parasitoid *Lysiphlebus testaceipes* was already listed in Bathon (1999), thus commercially available in Germany since decades. However, this species was removed in 2008 from the "Positive List" of EPPO (Appendix I and II) to Appendix III (no longer recommended). There were reports on unintended spread and attack on non-target host species with potential risk to displace other naturally occurring parasitoid species in South Europe (EPPO 2021, Appendix 3). The species was introduced in 1970 from Cuba to France to control exotic aphids (Starý et al. 1988). It dispersed and established over the Mediterranean area also moving inlands with a broad host range (Lumbierres et al. 2007; Starý et al. 2004). In Germany, *L. testaceipes* has been one of the preferred and efficient species for aphid control in greenhouses since many years (Albert et al. 2007). Due to its tropical origin, the risk of establishment in nature was assumed negligible (Bathon 1999). However, Hughes et al. (2011) showed that *L. testaceipes* has a high cold tolerance and therefore suggested that this IBCA could establish in northern Europe if host species are available over the course of the whole year. So far, however, there are no reports on the establishment or non-target effects of this species in Germany, and its use is limited to indoor areas. Nevertheless, monitoring the establishment of these and other non-native aphid parasitoids (e.g. *Aphidius colemani* (Adisu et al. 2002)) used in greenhouses with a variety of potential outdoor hosts may be advisable given the milder winter conditions in Germany due to global warming.

Discussion

Biological control and nature conservation

In Germany, most of the commercially available IBCA species are used for augmentative biological control in greenhouses and indoors, even though *Trichogramma* egg parasitoids and entomopathogenic nematodes are also applied regularly in open field. Non-indigenous IBCA species are used augmentatively under protected conditions and usually target exotic pests that multiply rapidly under these conditions and are otherwise difficult to control. The demand for such IBCA will increase in the future (e.g. van Lenteren et al. 2018). Their application does not aim at establishing used species; an establishment in nature is considered unlikely. However, climate change may contribute to an increase in the risk of unintentional species establishment (Nechols 2021), even under Central European climatic conditions. Another aspect is classical biological control, which has been little used in Germany to date, but is currently discussed as an interesting option for area-wide control of invasive plant pests. This method is being explored in neighbouring countries and candidate species of IBCA are being evaluated and released (e.g. the larval parasitoid *Ganaspis kimorum (c.f. brasiliensis)* against *D. suzukii* in North Italy (Fellin et al. 2023)). It is therefore important to assess the environmental impact of these non-indigenous species also for the situation in Germany.

First introduction of non-indigenous IBCA in Europe go back to the end of the nineteenth century (Gerber and Schaffner 2016). Back then, polyphagous predators were highly recommended as they were efficient against various pests and could also survive with very low density of target pests. Nearly a century later, Howarth (1983) published an article expressing concern about the non-target effects of released IBCA, which raised a controversial discussion in the following years (Clarke et al. 1984; Hajek et al. 2016; Howarth 1991). Effect of non-indigenous IBCA can be direct, like predation or parasitization of native non-host species or indirect like competition for resources. Beside host range, main criteria, whether non-indigenous IBCA could threaten local diversity, refer to their ability to establish populations and spread. The discussion and concern about non-indigenous IBCA are not just between experts (e.g. biological control scientists and conservation biologists) but have also reached a broad public interest. One reason might be the general and global awareness of biological diversity resulting in the Convention on Biological Diversity, which also addresses the topic of alien species (CBD 1993). During this period, the maybe most prominent case of problematic IBCA, the ladybird beetle *H. axyridis*, was noted. This polyphagous beetle with East Asia origin was commercially released in greenhouses in different European countries, mainly as flightless strain. In the late 1990s, first outdoor populations were observed in Europe, which established and dispersed (Brown et al. 2011). Their origin were probably accidentally introduced populations from North America (Rondoni et al. 2021 and references cited therein). In Germany, first proof of the presence of *H. axyridis* was in the year 2000 (Klausnitzer 2002). It was shown that in several habitats *H. axyridis* has become the most dominant ladybird species in Europe (Brown and Roy 2018). Due to several factors, e.g. being a highly polyphagous top predator including intraguild predation, a (potential) danger for native biodiversity, especially for native ladybirds, was investigated (Kenis et al. 2010; Pell et al. 2008; Roy et al. 2012). However, the long-term effect of *H. axyridis* on native biodiversity is probably less severe than originally suspected (Rondoni et al. 2021).

Even though there is a potential risk for nature in the use of IBCA, reported non-target effects have been relatively low compared to number of introduced IBCA (Parry 2009; van Lenteren et al. 2006). Yet, the growing awareness for negative impacts has led to new provisions (Baratange et al. 2023; EPPO 2014, 2018; EC 2022; FAO 2017) and is reflected in the use of IBCA. Van Driesche and Hoddle (2017) showed the development within the past three decades (1985–2015) from more generalistic parasitoids (family level of hosts) released towards more specific (genus level of hosts) ones. The list published here (Table 1), which reflects the currently used IBCA in Germany, is also dominated by specialists (specific parasitoids and predators). Newly added polyphagous species are mainly native hoverflies, lacewings, predatory bugs or entomopathogenic nematodes.

Legal situation in Germany and the need for assessment of non-indigenous IBCA

In Germany, there are currently two laws to be applied for the use of IBCA in plant protection, namely the Federal Nature Conservation Act (BNatSchG) and the Plant Protection Act (PflSchG). According to the BNatSchG, the release of plants and animals into the wild may require a permit from the Federal Agency for Nature Conservation (BfN), but shall be denied if a threat to Member States' ecosystems, biotopes or species cannot be ruled out. However, there are also exceptions related to the legal norms. One of them is biological control in plant protection (BNatSchG, § 40 (1) 2.). According to this legal regulation, the release of species that occur or have occurred in the wild in the last 100 years is not subject to authorization (BNatSchG, § 40 (1) 2.a)). Meaning that for instance a farmer transferring earwigs from one orchard to another or releasing purchased lacewing larvae on field or greenhouse vegetables is allowed to do so without any permit needed. For "other species", the BfN is responsible for granting release approval. According to BNatSchG (§ 40 (1) 2.b)), a permit could also be issued under the PflSchG as an alternative. The possibility of approving an authorization procedure for the use of IBCA in plant protection is given (PflSchG, § 6 (1) 16.) but has not yet been implemented. This means that no authorization under plant protection law can actually be granted and the BfN is the only competent authority for release authorization.

Some of the species listed in Table 1 can be regarded as "other species" sensu BNatSchG (§ 40 (1) 2.b)), as they are non-indigenous or have not occurred and established naturally in Germany. In fact, their use does not have official approval. Recently, the BfN published a compilation of alien arthropod species (Coleoptera and Stenorrhyncha yet excluded) in terms of their potential nature conservation invasiveness by applying the "German method of risk assessment for alien species" (Nehring et al. 2015; Rabitsch and Nehring 2022, 2023). The aim of such an assessment is to identify possible negative impacts on biodiversity and to recommend certain measures to prevent them. Most of the introduced species in Table 1 were also mentioned in the publications of Rabitsch and Nehring (2022, 2023), but none of them was listed as being invasive. According to the PflSchG (§ 3 (3)), the use of invasive species for pest control is prohibited, but, consequently, this does not apply for the species in Table 1.

In contrast to the recommendations of EPPO standard PM6 (e.g. PM6/4 (1) (Decision-support scheme for import and release of biological control agents of plant pests, EPPO (2018)) or authorization procedures in other countries (e.g. EC 2022), the current practice in Germany does not allow the evaluation of non-indigenous IBCA as an environmentally friendly pest management tool, especially in the case of invasive pests. The current nature conservation assessment of arthropod species (Rabitsch and Nehring 2023) does not consider benefit (e.g. for plant protection and/or the environment due to the reduced need for pesticides or preventing the supersession of naturally occurring species by the invasive pest (Heimpel et al. 2024)) resulting from the introduction and use of a particular non-indigenous IBCA species. Possible positive (economic) effects are mentioned, but in our understanding they are not used in the assessment process. As a result, potential IBCA may be considered more critically than the pest itself, as was seen in the assessment of the samurai wasp (*T. japonicus*) expecting potential non-target effects on biodiversity in comparison to its preferred host, the brown marmorated stink bug *H. halys* (Rabitsch and Nehring 2023). This assessment may have been judged differently from a plant protection point of view, as *H. halys* is a serious invasive plant pest worldwide, which is difficult to control, even with chemical pesticides (Haye et al. 2015). The samurai wasp is currently being considered for release in several countries, including neighbouring European countries (Italy, Switzerland), following a comprehensive environmental risk assessment. This example in Germany illustrates the consequences of assessment by a single authority point of view instead of a more comprehensive evaluation based on additional criteria introduced by other competent authorities.

Comparable to the "EPPO Positive List", a "German Positive List" may be based on Table 1, on which the authorities could plead and officially accept. According to the Federal Nature Conservation Act (§ 40 (1) 2.a)), we understand that species that occur naturally and are established in Germany can be used for plant protection without further authorization. As soon as such species are going to be commercialized, they could be added to the “German Positive List” in a simple notification process. Alternatively, either a regular transfer of new entries from the “EPPO Positive List” or the status report of biological plant protection published regularly by the Julius Kühn Institute could be an option for a “German Positive List". New knowledge on geographic range, diversity and taxonomic classification of particular taxa should be shared between taxonomists and applied entomologists (Shimbori et al. 2023) to help recognizing the species diversity found in Germany up to date (e.g. Pirvu and Vasilita 2023) and to support this process. Although this article clearly focuses on IBCA for plant protection, it would be desirable to include other beneficial invertebrates on the "German Positive List", such as pollinators that contribute to crop productivity, IBCA used in other commodities like stable fly control or insects used for Sterile Insect Technique (Kapranas et al. 2022).

For species to be introduced from different regions outside (species not naturalized in Germany), an authorization process following recommendations, e.g. made by EPPO Standard PM 6 (EPPO 2014, 2018, 2021, 2023), needs to be followed. These are often also the basis of decision-making in neighbouring European countries, so environmental impact assessments could be shared to harmonize the decision. In this case, a more comprehensive assessment must be carried out. First, an environmental impact assessment taking into consideration the purpose of the release (augmentative or classical biological control) needs to be conducted. In addition to assessment of adverse effects, also the balancing versus a "doing nothing" or the benefit of biological control given by the candidate species (also in comparison to native or already available ones) needs to be a step in the final assessment. As a result of this process, the approved use of IBCA will help to increase the safety and acceptability of biological control by natural enemies in the future. This would ensure legal certainty in the selection, production and use of IBCA. Overall, such a regulation might not just help in plant protection, but also in environmental and nature conservation. It would also allow developing a “pre-emptive biological control approach” meaning that potential biological control agents of invasive pest species not yet established will be evaluated in advance, best in a joint effort between countries (Avila et al. 2023).

Conclusion

Biological control using IBCA is a reliable and essential method in the production of cultivated plants in Germany. This option is highly needed to contribute to further pesticide reduction in agriculture. Farmers are well trained to use IBCA and they are highly interested in this method, also to combat serious new pests and in open field. Biocontrol agent manufacturers and researchers are constantly contributing with new IBCA candidates and innovations for their high-quality production and application. To deal with invasive pests, the option of classical biological control should not be neglected.

The authorization of new IBCA candidates in biocontrol needs to be implemented in such a way that both perspectives, that of nature conservation and that of environmentally friendly plant protection, are considered in the decision-making process. Here, the current legal framework offers the possibility of creating an approval procedure under the PflSchG in addition to the provisions given by the BNatSchG, which could be performed by relevant authorities. The (eventually updated) list of organisms published in Table 1, which are already in use—most of them for decades with no adverse effects—or which even are on the EPPO “Positive List”, could serve as the baseline for a "German Positive List" of recognized species. Such a list would ensure legal certainty in the manufacture and use of IBCA and thus contribute to improve plant protection, but also environmental and nature conservation.

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Declarations

Conflict of interest None.

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