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THE FUNCTIONAL APPROACH FOR THE STUDY OF CROP PEST PREDATORY ARTHROPODS

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Abstract

Crop pests represent the sole cause of pesticide use in agroecosystems, a practice linked to pollution and health problems. The use of natural enemies against crop pests can prove to be a solution to partially alleviate this anthropic pressure and reduce associated costs. Predatory arthropods, such as spiders and carnivorous ground beetles can be efficiently used to reduce harvest consumption by pests. The community structure and overall fitness of these natural enemies (and their efficacy in pest control) are inextricably linked to the functional traits of each comprising taxa. The trait-based approach proposes functional traits and functional diversity indices, as the common denominators between biotic communities instead of taxonomic diversity. This approach for the study of predatory arthropods in agricultural ecosystems, especially in the interest of mediating production losses, has recently increased in popularity due to its ease of use for biotic communities' assessments and for its convenience in predicating ecosystem interactions and fluxes. The scope of this research is to critically analyse the current state of knowledge on the use of the trait-based approach to study predatory arthropods in agroecosystems, in order to provide guidelines of how this framework can be efficiently used for scientific research and ecosystem management and to identify existing knowledge gaps, in order to support future scientific endeavours.

***Key words**: agricultural ecosystems, functional diversity, functional traits, natural enemies, predatory arthropods.*

INTRODUCTION

The imminent increase of worldwide human populations represents one of the main challenges for the continued existence of the current socio-economical system and for the actual functional stability of the ecosphere. The role of agriculture in maintaining social stability is expected to increase with the growing demand for food and so is the impact that it will have on the biodiversity of the world's terrestrial ecosystems. Aside from their main use for crop production, agricultural landscapes also host part of this biodiversity by providing habitat for multiple biotic communities, some of which provide beneficial ecosystem services, such as pollination (Lonsdorf, 2009) and pest control (Alexandridis et al., 2021) and which are usually affected by intensive agronomic practices (Bianchi et al., 2006; Deppe & Fischer, 2023).

Predatory arthropods inhabiting agricultural ecosystems, such as spiders and carnivorous ground beetles, represent a viable alternative to conventional pesticide use that can be used to control the populations of crop pests (Holland, 2002; Kromp, 1999; Marc et al., 1999; Sunderland, 1999). Agricultural practices and landscape management directly influences the habitat of natural enemies and their efficiency to provide the ecosystem service they are valued for (Kromp, 1999; Sunderland & Samu, 2000). Patch and landscape scale characteristics shape the communities of natural enemies in multiple ways, most of which are still not completely understood (Alexandridis, et al. 2021). The community structure, overall fitness and pest control efficiency of natural enemies are all inextricably linked to the functional characteristics of these organisms, termed functional traits or just traits (Deppe & Fischer, 2023; Maas et al., 2020). They represent generalizable properties of organisms that dictate how individuals interact with their environment and that apply for all species, thus bypassing taxonomic barriers (Moretti et al., 2017; Wong et al., 2019).

The trait-based approach utilizes traits as the common currency used to compare biotic communities, in their regard to environmental stimuli and to their effect over ecosystem processes and services. Since predatory arthropods inhabiting agricultural landscapes are associated with the pest control ecosystem service, it is clear that the study of this taxa is conducted primarily from a functional perspective. The use of functional traits and measures of functional diversity holds promise in helping researchers understand the effects of different agricultural practices on natural pest control services. This is achieved by observing the functional changes of natural enemy communities at various scales and from a unified perspective. The use of the trait-based approach promises to increase our knowledge and understanding of processes associated with crop pest predators and to help improve agricultural practices and ecosystem management, both locally and at the landscape level.

This review aims to: (1) identify the main traits and functional diversity components that shape the capacity of spiders and predatory ground beetles to control crop pests populations (response variables); (2) identify the main pressures that act at patch and landscape scales (predictor variables) and their effects on the functional traits and diversity components of the aforementioned communities; (3) highlight the impact of these effects on the pest control service and provide suggestions on how to ameliorate them and (4) suggest future research directions based on the identified knowledge gaps in this field of research.

MATERIALS AND METHODS

In order to find relevant articles related to the topic, the Web of Science Core Collection database was queried. The search sting used included a combination of terms related to the taxa (spiders and predatory ground beetles), habitat types (agricultural ecosystems and landscapes) and functional assessment metrics (functional traits and functional diversity components) of interest. The initial results of the query returned 865 articles, which were further screened in order to select only the studies that addressed the functional traits or functional diversity components of predatory arthropods in agricultural ecosystems.

The results sections were structured based on the functional traits and diversity components assessed, the level of the research (patch and landscape scale) and on the type of acting pressures (soil preparation; crop selection and rotation, pesticide use and landscape management). Firstly, the effect of the acting pressures on each trait was described, followed by discussions regarding possible improvement methods and, finally, possible future research directions were suggested, in order to further develop the field of research.

Table 1. Literature search sting

TOPIC: "predatory arthropod*" OR spider* OR beetle* OR arachnid* OR carabid*
AND
TOPIC: functional* OR trait*
AND
TOPIC: agricultur* OR agro*

RESULTS AND DISCUSSIONS

General findings

Based on the scientific literature screening, the most commonly used traits for the research of arthropod natural enemies were: feeding preference, body size and dispersal capacity. In most cases, these traits were studied together, with the first two being addressed based on their importance in pest control, while the latter due to its relevance for recolonization from adjacent habitats. Hunting strategy, fecundity and activity period were also studied, but to a lesser degree, prompting the current study to focus more on the three most addressed traits. Although the use of functional diversity is relatively novel, some valuable studies do exist. Based on the literature screening, the main pressures affecting the communities of natural enemies in agricultural landscapes are pesticide use (conventional vs. organic agriculture), soil preparation practices, such as tillage and winter cover crops and most importantly, the reduction of natural and seminatural habitat patches.

The overall findings suggest that the functional traits, functional diversity and capacity for pest control of natural enemies often varies between spiders and ground beetles and between habitat and landscape characteristics. More than often, research shows that multiple interacting factors at multiple scales act, in order to shape the functionality of the studied communities.

Furthermore, it is important to point out that research of many traits is still underdeveloped and that most of the research takes place in temperate climates (in Europe and North America), while the most drastic landscape changes caused by agriculture take place in the least studied tropical zones.

Pesticide use

Pesticide use associated with conventional agricultural practices is documented to reduce the body size of spiders and the abundance of web hunters within cropland communities (Michalko and Kosulic, 2020), while having the opposite effect in vineyards (Caprio et al., 2015). These findings underline the importance in understanding how different pesticides act in different agricultural habitat types. However, the body size of ground beetles was shown to decrease in organic orchards, as their dispersal capacity increased (Caprio et al., 2015; Mickael et al., 2015), a discovery which also shows the response variability among different taxa (reinforcing the need for multitaxon studies). In opposition to ground beetles, spiders decreased in body size in conventional orchards and increased in organic ones (Mazzia et al., 2015). Opposite to spiders from the same type of agricultural habitat, carabid body size was documented to increase in crops with reduced pesticide use (Galle et al., 2018; Rusch et al., 2013). The hunting strategy of natural enemies was shown to change with pesticide application from active hunters to web and ambush hunters (Caprio et al., 2015). Furthermore, conventional pesticide use was further documented to have daunting sublethal effects on spider assemblages, such as reducing predatory rate in both web hunters and ground hunters (Boyd et al., 2022; Deng et al., 2007; Deng et al., 2008) and causing a reduction in dispersal capacity and even paralysis of multiple spider taxa (Shaw et al., 2006). Interestingly enough, another recent study showed the increase in killing neonicotinoids contaminated prey by spiders, but without consumption (Korenco et al., 2019) This is a factor which can prompt short term increase in pest control, but a long-term reduction of this service, due to useless energy waste of the predators which could indirectly affect their overall fitness. Though no direct link between pesticide uses and body size of spiders was found, it can be argued that reduced mobility and hunting can slow down the development of spiders in agricultural landscapes, leading to a reduction in body size and highlighting their pest control efficiency.

The functional diversity and evenness of spider communities was recorded to increase in organic orchards (Mazzia et al., 2015). Pesticide use was documented to decrease the functional diversity of ground beetles (Galle et al., 2018) along with intensive tillage and bare soil practices (Muneret et al., 2002) and along with the reduction in habitat diversity at landscape scale (Gayer et al., 2019). Though much research is still needed, organic research seems to increase the functional diversity and pest control services standalone by also helping increase the diversity of adjacent natural and seminatural habitats (Caprio et al., 2015). These findings reaffirm the importance of habitat diversity in agricultural landscapes and the idea that the effect of different agricultural practices should be assessed in broader scale perspectives. Further search on pesticide use can focus on the nonlethal effect over the functional traits of natural enemies and of their prey. Furthermore, studies comparatively addressing the effect of various stimuli on agricultural habitats with conventional and organic agriculture could be very important to understand local and large-scale interactions between natural enemies and their environment in dynamic landscapes. More research on better biopesticides is needed. Overall, pesticides (even biopesticides) should be examined in regard to their morphological and behavioural effects on nontarget beneficial taxa and to their interacting trophic links, including natural enemies and pollinators (Cappa et al., 2022).

Tillage practices

A number of studies have shown that the body size of carabids seems to decrease with tillage intensity (Hanson et al., 2016; Jacobsen et al., 2022). However, the dispersal capacity of carabids was documented to increase in intensively managed crops, probably as an adaptation measure to the reduced body size and preying efficiency (Hanson et al., 2016). One research study points out that the effect of tillage on carabid body size and dispersal capacity seems to be season dependent and that lower intensity tillage (Non-Inversion Tillage) seems to favour capable dispersal taxa (Kosewska, 2016). Though less studied than ground beetles, spiders were also documented to respond to tillage, by an increase in the number of cursorial dispersers (Topa et al., 2021). The activity of spiders was documented to decrease with land management intensity in landscapes rich in natural and seminatural habitat patches and, conversely, to decrease in vineyards with natural management type (Pfingstmann, 2019). This aspect further solidifies the need for multiscale studies in the functional ecology of natural enemies.

The functional diversity and density of spiders were found to be lower in no-tillage fields, thus reducing aphid effectives (Tahir & Mukhtar, 2012). The effect of tillage on the functional diversity of ground beetles was found to be similar to spiders, with the highest functional diversity recorded in non-tillage sites (Jacobsen et al., 2022; Muneret et al., 2002). Tillage needn't be bad as some research found that reduced intensity tillage seems to reduce the effect of urbanization al landscape scales in comparison to conventional tillage, by harbouring more functionally diverse ground beetle communities in agricultural patches and surrounding habitats (Tamburini et al., 2016). Based on the last result, future research endeavours should focus on (1) the effect of low impact tillage in promoting biodiversity across landscapes and (2) the response of natural enemy communities from these habitats to other possibly acting pressures. Additionally, further research should focus on the impact of seasonal changes and predicted climatic changes on different crop management systems, in order to improve the conservation of beneficial invertebrates, such as natural enemies and pollinators and of the ecosystem services they provide.

Landscape management

Based on the literature screening, landscape management is by far the most addressed pressure analysed in the functional ecology research of natural enemies. Increased natural and seminatural habitats cover within agricultural catchments was documented to increase overall pest predation (Zamberletti et al., 2021). Habitat diversity is connected to different hunting strategies and better pest control efficiency. Web hunting spider were documented to be efficient against flying pest, ambushing pests against flower visiting pests, while active ground predators are inclined to prey on pest with developmental stages in and on the ground. (Benhadi-Marin et al., 2019). Multiple research document body size as an important trait related to pest control at landscape level, both in spider and ground beetles (DeLong & Uiterwaal, 2022). Increased body size of natural enemies was observed to be linked to habitat size (DeLong & Uiterwaal, 2022; Gale et al., 2020) and place within the filed (Gale et al., 2020). The availability of natural and seminatural habitat patches increased carabid and spider body size (Plath et al., 2021) and active hunting species (Maas et al., 2021). Furthermore, the body size of multiple natural enemies was recorded to increase in proximity to natural and seminatural habitats (Zhang et al., 2019; Zhang et al., 2020).

A number of research studies associated the community wide shift of dispersal capacity with both local and landscape drivers (Gale et al., 2020; Saquib et al., 2022). For spiders, the proximity to natural habitats such as forests (Saquib et al., 2022) and wildflower strips (Gale et al., 2020) was shown to increase ballooning propensity. Ballooning propensity also increased in the central parts of crop fields and the choice of structurally complex plant crops was shown to increase ballooning propensity. The community wide dispersal capacity of ground beetles increased in relation with patches of natural and seminatural habitats (Pecheur et al., 2020). The activity of both spiders and ground beetles was linked to increase with proximity to seminatural habitats (Jacobsen, 2022; Maas et al., 2021; Pecheur et al., 2020) and with their increased availability at the landscape level (Maas et al., 2021).

The availability of varied seminatural habitats (such as forest, meadows) at the level of agricultural landscapes is documented to further aid in natural pest control, by providing shelter for natural enemies. The necessity of integrating diverse natural and seminatural habitats at larger scales is important due to the functional differences exhibited by each type of natural enemy community (Michalko & Birkhofer, 2021). Recently, the importance of

these habitats was further demonstrated to vary seasonally depending on the type of migrating taxa and the type of habitat (Robinson et al., 2021), further reinforcing the need for large scale multi-seasonal studies in agricultural landscapes. Furthermore, with respect to seasonality, it was documented the cover winter crops along agricultural landscapes provide additional food resources for natural predators, thus enhancing their effectives, fitness and the overall pest control service they provide (Boweres et al., 2021). Aside from harbouring functionally distinct communities, natural and seminatural habitat patches were documented to also support other invertebrate taxa (Snyder, 2019). An analysis of how these types of habitats should be used requires more research in order to gain further improvement. Aside from landscape structure, the functionality of natural enemies is also influenced by the agricultural practices carried at patch scale influence. Predatory activity in agricultural landscapes with tree lines was recorded to decrease in conventional farming patches. In opposition, this activity increased in organic farming patches, underlining once again the importance of the local and large scales interactions (Bonoit et al., 2020).
Functional diversity of carabids was found to be sensitive to various factors throughout seasons, at the landscape level. Reducing the use of pesticide, avoiding bare soils all along the year, keeping pesticide use intensity below the identified thresholds and adopting a wide diversity of tillage strategies at the landscape scale should all contribute to enhance in-field carabid occurrences and richness (Muneret et al., 2002). Additionally, the functional redundancy of spiders and ground beetle communities was documented to increase in response to a reduction in agricultural practices intensity and to an increase in natural and seminatural habitats availability at landscape level (Rusch et al., 2014). Interestingly enough, in large scale experiments, functional diversity of predators was not sufficient to explain the overall pest control, thus further reinforcing the need for concomitant multiscale approaches in the research of natural enemies. (Alhadidi et al., 2019). Future research should focus on the influence that different habitat combinations across landscape exert on balancing crop productivity and ecosystem services provided by useful taxa. Furthermore, in the context of the environmental changes taking place, more research should assess the contribution of agricultural landscape in large scale ecosystem processes, by analysing their insect communities and on how these communities increase the ecosystem resilience against different pressures, such as pest invasion and others.

CONCLUSIONS

Most of the research focused predominantly on three major functional traits (body size, dispersal capacity and feeding preference) and to a lesser degree on functional diversity. Addressing the effect exerted by other traits is important for developing our understanding of natural pest control efficiency.
Most of the research was carried out in Europe and developed countries. In continuing this trend, it is also highly important to address the effect of local and landscape changes on the communities of natural enemies from other geographic zones, where agricultural impact is steeply rising.
The functional traits and functional diversity of natural enemies seems to be shaped by multiple interacting variables from different scales. Furthermore, the responses are usually taxa specific and depend on the characteristics of the habitats and landscapes analysed. Further research should account for these ideas, in order to help develop our knowledge on the inner working of pest control provided by natural enemies and to help preserve this valuable communities and ecosystem service.

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