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RESEARCH ARTICLE

Strip intercropping of wheat and oilseed rape enhances biodiversity and biological pest control in a conventionally managed farm scenario

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Abstract

1. Conventional agriculture in the global north is typically characterized by large monocultures, commonly managed with high levels of pesticide or fertilizer input and mechanization. Strip intercropping, that is, diversifying cropland by growing strips of different crops using conventional machinery, may be a viable strategy to promote natural predator diversity and associated biological pest control in such conventional farming systems.
2. We tested the influence of strip intercropping of conventionally managed winter wheat with oilseed rape, using common machinery with 27–36 m broad strips, on arthropod predator diversity and biological pest control. We characterized spider and carabid beetle communities, calculated pest aphid and pollen beetle densities and recorded parasitism rates for both crops (number of mummified aphids on wheat and number of parasitized pollen beetle larvae on oilseed rape).
3. We observed a significant reduction in the densities of wheat aphids (50% decrease) and pollen beetle larvae (20% decrease) in strip intercropping areas compared to monocultures. Parasitism rates of wheat aphids increased significantly from 10% in monocultures to 25% in strip intercropping areas. The number of parasitized pollen beetle larvae did not show the same pattern but was higher towards the centre of the oilseed rape strip. Overall, the composition of predator communities benefited from the close neighbourhood of the two crop species in the strips, as carabid beetles were more abundant in oilseed rape and spiders were more abundant in wheat fields. Overall, strip intercropping reduced the dominance of one predator group and allowed for an equal representation of both spiders and carabid beetles in the mixture.
4. *Synthesis and applications*. Our study presents evidence of the benefits of adopting strip intercropping with relatively large strips (adapted to existing machinery) for natural predator diversity and biological pest control in a large-scale conventionally managed farm scenario. Wheat–oilseed rape strip intercropping reduced

pest densities, increased parasitism of wheat aphids and promoted equal representation of natural predator groups well beyond the areas of monoculture. Overall, by reducing the area dedicated to only one crop, the implementation of strip intercropping adapted to mechanized agricultural scenarios can be used to increase crop heterogeneity at regional scales and enhance biodiversity and biological control, even in simplified landscapes dominated by large-scale conventional agriculture.

KEYWORDS
agricultural diversification, biological pest control, conventional agriculture, crop heterogeneity, natural predator diversity, pollen beetle larvae, strip intercropping, wheat aphids

1 | INTRODUCTION

The biological regulation of pest populations in agricultural landscapes is a well-known ecosystem service (Dainese et al., 2019; Naylor & Ehrlich, 1997). The transition from a conventional, pesticide-based management strategy to a biodiversity-mediated ecosystem service approach often implies a redesign of the farming system (Wezel et al., 2014), as large monocultures can be hostile environments for predators, parasitoids or entomopathogens (Letourneau et al., 2011). Landscapes dominated by monocultures have led to a dramatic loss of biodiversity, with communities mostly composed of generalist species or species more resistant to disturbances (Dassou & Tixier, 2016). The spatial diversification of agroecosystems represents a viable strategy to improve biological pest control and promote biodiversity (Ang et al., 2018; Beillouin et al., 2019; Hatt et al., 2018; Iverson et al., 2014; Wan et al., 2020). Agricultural diversification is possible through the cultivation of (a) several crops (i.e. intercropping), (b) crop and non-crop plants (i.e. cover cropping) or (c) crops grown together with trees (i.e. agroforestry) on the same area of land (Kremen & Miles, 2012; Poveda et al., 2008). Strip intercropping is a type of agricultural diversification that involves the simultaneous cultivation of two or more crops in adjacent strips for at least part of their growing seasons (Brooker et al., 2015; Bybee-Finley & Ryan, 2018; Vandermeer, 1989). By increasing the complexity of the foraging environment (Landis et al., 2000), facilitating niche complementarity for predators (Snyder, 2019), reducing food resource concentration for pests (Malézieux et al., 2009) and optimizing plant nutrient use (Brooker et al., 2015), strip intercropping has the potential to promote biodiversity, biological pest control and stabilize yields (Kremen & Miles, 2012; Raseduzzaman & Jensen, 2017).

Crop combinations play a crucial role in attracting predatory insects and promoting overall productivity (Wezel et al., 2014). Oilseed rape *Brassica napus* and winter wheat *Triticum aestivum* are major crops with high economic value for animal feed, biodiesel production and human consumption in the European Union (Eurostat, 2019). In Germany, wheat and oilseed rape are crops of major importance, generally cultivated as high input and conventionally managed monocultures (DESTATIS, 2019; UFOP, 2019). The main pests associated with winter wheat in Germany are three species of cereal aphids: *Sitobion avenae* (Fabricius), *Metopolophium dirhodum* (Walker) and *Rhopalosiphum padi* (Linnaeus) (Schmidt et al., 2003). Aphids suck plant nutrients, cause curling and twisting of shoots and a general weakening of the plant (Singh & Singh, 2016). In oilseed rape, pollen beetles (*Meligethes aeneus* Fabr. and *M. viridescens* Fabr., Coleoptera, Nitidulidae) are among the major pests responsible for significant yield losses (Williams, 2010). Carabid beetles and spiders have a high potential for biological pest control and are among the most abundant invertebrate predators on agricultural fields in Europe (Riechert & Lockley, 1984; Williams, 2010). Carabid beetles are omnivorous species, contributing to pest and weed control in various cereal crops (Williams et al., 2010). By predating on aphids that fall from the vegetation, carabids have been shown to significantly reduce wheat aphid abundance in cereal crop fields (Kromp, 1999). Spiders feed almost exclusively on insects, and reductions of crop pest damage through spider predation of herbivores such as green bugs, leaf flies and leafhoppers are well-documented (Li et al., 2018; Riechert & Lockley, 1984; Schmidt et al., 2003). Parasitism of wheat aphids may have a stronger effect on controlling aphid pest densities than predation by other natural enemies (Schmidt et al., 2003). Similarly, parasitism can account for economically significant suppressions of pollen beetles in oilseed rape (Büchi, 2002; Hanson et al., 2015; Vollhardt et al., 2008).

Higher predator diversity in diversified agricultural systems has been explained by the 'Natural Enemy Hypothesis' (Root, 1973; Russell, 1989), which predicts that crop diversification increases the local resource diversity attracting a higher number of predators than in monocultures. A wide range of intercropping combinations including vegetables (Ma et al., 2007; Qin et al., 2017), cereals (Arshad et al., 2018; Hatt et al., 2019; Lopes et al., 2016) or legumes (Cao et al., 2017) have been used to test the 'Natural Enemy Hypothesis'. The biocontrol success of intercropping is commonly related to the higher predator–prey ratios (Arshad et al., 2018; Bale et al., 2008; Liu et al., 2017). Nevertheless, most of the data on the effects of intercropping on biodiversity and pest suppression come from small-scale field studies. Even though the potential benefits of crop diversification are well-documented (Ditzler et al., 2021; Fahrig et al., 2011; Isbell, 2015; Risch et al., 1983; Sirami et al., 2019; Wan et al., 2020), data collected in the field on real-world farm scenarios, relevant for farmers' decisions, are largely missing.

In the present study, we tested the influence of strip intercropping on biodiversity and biological pest control in conventionally managed farms in Germany. We collected data on (a) predator diversity (carabid beetles and spiders), (b) pest densities of aphids on wheat and pollen beetle larvae on oilseed rape and (c) parasitism rates by specialist wasps of wheat aphids and of pollen beetle larvae. We surveyed wheat and oilseed rape monocultures and strip intercropping on each farm, comparing treatments with and without insecticides. We tested the hypothesis that strip intercropping supports (a) higher arthropod predator diversity than monocultures, (b) higher pest suppression in both crops and (c) higher benefits of strip intercropping without insecticide applications. Additionally, we tested for potential edge effects at the border between wheat and oilseed rape strips.

2 | MATERIALS AND METHODS

2.1 | Study area

We sampled data in three conventionally managed agricultural farms in the surroundings of the city of Goslar in the state of Lower Saxony, Germany (Figure 1). Farms represented a common German agricultural scenario, with fertile soils and large farm sizes. Farm size varied from 328 to 360 ha (339 ha ± 18.1; *M* ± *SD*). The total area covered by wheat per farm was 122 ± 84 ha (*M* ± *SD*), and the area of oilseed rape per farm was 134 ± 55 ha (*M* ± *SD*) (Table S1). Strip intercropping covered on average 10 ± 9.1 (*M* ± *SD*) hectares of the farms' arable land. Insecticides were applied during the growing period of both crops, and the type of insecticide applied was specific for each crop (Table S1). Monocultures and strips with the same crop were sprayed at the same time. Oilseed rape was sown in August 2018 and wheat in October of the same year. The flowering period of oilseed rape was during May, with a peak between the 10th and 20th of May. Wheat flowered in June, with a flowering peak between the 10th and 20th of the same month. Both crops were harvested in July 2019.

Fields dedicated to strip intercropping ranged in area from 2.1 to 13.4 ha (*M* = 6.18 ha ± 6.2 *SD*). Monocultures were on average

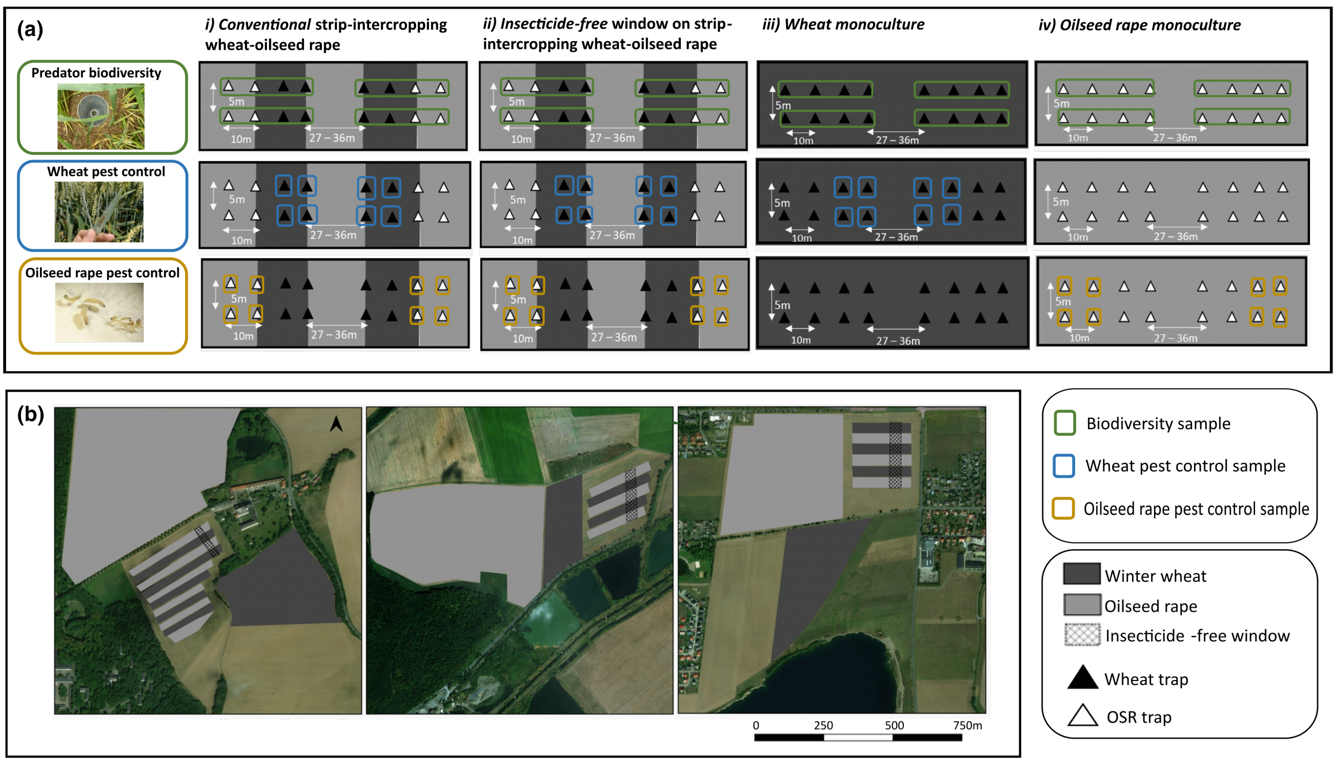

FIGURE 1 (a) Depiction of the spatial location of samples from one farm in our study. Green squares depict sampling points (four adjacent pitfall traps) used for our biodiversity models. Blue and yellow squares depict sampling points used for wheat aphid and pollen beetle larvae pest control analyses respectively. (b) Aerial photograph (1:10,000) depicting the three studied farms and the spatial arrangement of the four field types of our study. Continuously dark and continuously light grey areas represent winter wheat and oilseed rape monocultures respectively. Stripped area of dark and light grey represents the strip intercropping area. The squared dashed area depicts the insecticide-free window in the strip intercropping two to three times more extensive than the strip intercropping fields (mean wheat = 122.3 ± 84.5 *SD*, mean oilseed rape = 134.3 ± 55.07 *SD*). The insecticide-free area was relatively small (720 m^2) and was implemented only in the strip intercropping field (Figure 1). The strip width was adjusted to the machinery used on each farm. Two farms had a sown strip width of 36 m and one farm of 27 m. The strip length was at least 120 m. The same varieties of wheat and oilseed rape crops were used in monoculture and strip intercropped areas inside a single farm. However, crop varieties differed across farms (Table S1). Similar practices of soil tillage, drilling time and herbicide application were applied consistently across all farms. The owners of the sampled farms authorized data collection on the field.

2.2 | Experimental design

We collected biodiversity and pest control data on three farms, each with four focal treatments: (a) wheat monoculture, (b) oilseed rape monoculture, (c) conventionally managed strip intercropping and (d) insecticide-free strip intercropping. Because of farm management practices, the insecticide-free window did not occur on a separated field but inside the conventionally strip intercropping field (Figure 1). For our biodiversity analysis, we installed 16 pitfall traps per treatment (Figure 1). Pitfall traps were separated by at least 10 m and located across wheat and oilseed rape strips in the strip intercropping area (Figure 1). We repeated the same spatial pattern for the pitfall traps in the monocultures. To capture the habitat heterogeneity of the strip intercropping areas, we pooled the data collected from four adjacent traps (two in oilseed rape and two in wheat) to calculate carabid and spider diversity (Figure 1). Pooled data from four pitfall traps were therefore considered in our biodiversity models as one sample. We carried out natural predator surveys at two points in time: (a) during the peak flowering time of oilseed rape (May 2019) and (b) during the peak flowering time of wheat (June 2019). We performed separate models of predator diversity for each survey time. Overall, the data for our biodiversity models were composed of 12 nested samples per treatment (4 samples per treatment ×3 farms) and 48 samples (12 samples per treatment ×4 treatments) per sampling period.

For our biological pest control analysis of wheat aphids, we counted the number of aphid and mummified aphids on 50 wheat shoots in plots adjacent to eight pitfall traps installed in wheat in the intercropping as well as in wheat monocultures. For the analysis of biological pest control of pollen beetles in oilseed rape, we counted and collected pollen beetle larvae on five oilseed rape branches at the height of *c*. 100 cm, adjacent to eight pitfall traps installed in oilseed rape-cultivated areas. Our calculations of pest density and parasitism rates of both wheat aphids and pollen beetle larvae were composed of eight samples per field and 24 nested samples per treatment (Figure 1).

2.3 | Carabid beetle and spider survey

We used pitfall traps to collect carabid beetles and spiders. Each pitfall trap was composed of a 300-ml plastic bottle filled with ~250 ml of 3% NaCl water solution and was buried with a funnel that reached precisely the surface of the soil. We added a squared roof 10 cm above each trap to prevent flooding by rain. The traps were exposed in the field for 72 hr. We collected all carabid and spider species from the traps and stored them in 90% ethanol; afterwards, single individuals were sorted by A.S.V. and sent for further identification to species level by expert taxonomists (see Acknowledgements section). Average temperature and rainfall conditions were similar across all farms on both sampling dates (Table S2).

2.4 | Wheat aphid density and parasitism rate survey

Alate aphid adults start colonizing cereal fields in May. After arrival in wheat fields, aphids reproduce for several generations and reach their peak in June, with sharp declines in abundance due to emigration or mortality on late June or early July (Honek et al., 2018; Singh & Singh, 2016). Several parasitoid species belonging to the families Braconidae (subfamily Aphidiinae) and Aphelinidae are specific to cereal aphids. Their population dynamics are spatially and temporarily linked to their host species (Singh & Singh, 2016). Higher aphid parasitism rates are frequently reported at the flowering time of the cereal crop when cereal aphids reach their abundance peak (Thies et al., 2008; Vollhardt et al., 2008; Yang et al., 2017).

We surveyed aphid densities and the number of parasitized aphids (mummies) on the same sampling locations at two points in time. Aphid density survey was carried out on 18 June 2019, while aphid mummies were counted on the first week of July of the same year. Around each wheat trap, we counted the number of wheat aphids encountered on 50 randomly selected wheat shoots and used the abundance of aphids as our measure of aphid density. On the second sampling date, we counted the number of aphids and mummified aphids encountered around the same trap (previously scanned for aphid abundance). We used the proportion of mummified aphids as our measure of parasitism rates of winter wheat.

2.5 | Density of pollen beetle larvae and oilseed rape biological control survey

Pollen beetles (*Meligethes aeneus* Fabricius, currently known as *Brassicogethes aeneus*) emerge from their overwintering sites in early spring (March). When the temperature exceeds 12°C, pollen beetles search for oilseed rape fields for mating and oviposition. Crop damage is caused by adults feeding on flower buds or larvae feeding on flower buds and pollen (Alford et al., 2003; Williams, 2010). Parasitoid species specialized in pollen beetle larvae such as *Phradis interstitialis*, *Phradis morionellus*, *Tersilochus heterocerus* and *Diospilus capito* spill over to oilseed rape fields when oilseed rape crop is in full bloom (Williams, 2010). After arriving on oilseed rape fields, parasitoid wasps lay their eggs inside pollen beetle larvae, causing significant increases in larvae mortality (Brandes et al., 2018). In May

2021, we counted and collected all pollen beetle larvae encountered on five branches (at a height of *c*. 100 cm) of oilseed rape plants in a 1-m^2 plot adjacent to eight pitfall traps installed in oilseed rape (Figure 1). We dissected the larvae in the laboratory and counted the number of parasitoid eggs inside each larva. The number of larvae with at least one parasitoid egg inside divided by the total number of larvae collected per plot was used as our measure of parasitism.

2.6 | Statistical analysis

We conducted separate generalized linear mixed-effects models (GLMM) for each of our hypotheses. To account for the spatial non-independence of our samples (due to nesting of traps inside farms), we included a random effect for farm identity. For predator diversity analysis, we ran the models separately for each of our sampling dates (Table S3). We used predator (carabid beetles or spider species) abundance and richness as our response variable in our predator diversity models and aphid or pollen beetle larvae density as our pest density response variable. We used parasitism rates of wheat aphids (number of mummified aphids) and parasitism rates of pollen beetle larvae (number of parasitized larvae) as our response variables in our biological pest control models.

We used the packages LME4 (Bates et al., 2015) and glmmTMB (Magnusson et al., 2019) for our statistical analysis. Carabid beetle and spider abundance and pest densities were modelled using a negative binomial error distribution specified using the glmmTMB function and the nbinom2 (link = "log") family. Species richness for both arthropod groups followed a Poisson distribution and were modelled using the glmer() function from the LME4 R package. The proportion of mummified aphids and parasitized larvae were modelled following a binomial error distribution using the glmer (cbind(), family = "binomial") function. We used the glht(linfct = mcp(tr = "Tukey") function from the MULTCOMP R package (Hothorn et al., 2008) to explore post hoc multiple comparisons among treatment levels. Model coefficients and estimates were evaluated using summary (Bates et al., 2015), Anova (Fox & Weisberg, 2019) or drop1 (Hartig, 2019) functions. Plots were created using DPLYR (Wickham, François, et al., 2019) and GGPLOT2 (Wickham, Chang, et al., 2019) R packages. We tested the effects of insecticide application and trap location only with data from traps located on the strip intercropping areas. None of our explanatory or response variables was transformed. All statistical analyses were performed with R version 3.6.1 (R Core Team, 2021).

3 | RESULTS

3.1 | Arthropod predator biodiversity

We recorded 2,640 individuals of 45 carabid beetle species (Table S4) and 654 individuals of 47 spider species during the whole study period (Table S5). By characterizing the natural predator community composition associated with each crop during the complete growing season of both crops, we found temporal and spatial differences in predator diversity responses to strip intercropping. Carabid beetles were more diverse in oilseed rape monocultures than any other sampled land use in early July (during the flowering peak of winter wheat), whereas spiders were more diverse on wheat monocultures during the flowering period of oilseed rape. We found intermediate values of species richness and abundance for both arthropod predator groups in strip intercropping (Figure 2) and no effect of trap location (edge or interior of the strips) or insecticide application on natural predator diversity.

3.2 | Biological pest control

We counted 1,294 aphids across farms (13.47 ± 13.57; mean per plot ± *SD*). Wheat aphid densities were higher in wheat monocultures than insecticide-free or conventional wheat strips (Figure 3a). The proportion of mummified aphids was significantly lower in wheat monocultures than in conventionally managed wheat strips (Figure 3c). We found no influence of insecticide use or edge effects on wheat aphid abundance or parasitism rates. Further, we also found higher densities of pollen beetle larvae in monocultures than in oilseed rape strips (Figure 3b). Parasitism rates of pollen beetle larvae did not differ among treatments, and we found no influence of insecticide use or edge effects on larvae density or parasitism rates (Table S6).

4 | DISCUSSION

We analysed the influence of strip intercropping with relatively large strips (adapted to existing machinery) on arthropod predator diversity and biological pest control in conventionally managed farms in Germany. We found that strip intercropping of winter wheat and oilseed rape enhanced biological pest control and reduced pest pressure compared with monocultures. Pest densities of wheat aphids and pollen beetle larvae decreased *c*. 50% on wheat strips and *c*. 20% on oilseed rape strips. Parasitism rates of wheat aphids were much higher in strip intercropping areas. Carabid beetles were more abundant in oilseed rape strips, while spiders were more abundant in wheat strips in the strip intercropping area. Nevertheless, strip intercropping maintained intermediate values of diversity for both predator groups compared with monocultures.

The ecological benefits of agricultural diversification by intercropping are well-studied (Dainese et al., 2019; Iverson et al., 2014; Letourneau et al., 2011; Yin et al., 2017), while neutral or even negative effects of intercropping on predator diversity in cereal crop mixtures have also been reported (Lopes et al., 2016; Sarwar, 2011). We did not find higher predator diversity in strip intercropping treatments than in monoculture areas. Nevertheless, we found that strip intercropping supported intermediate values of the diversity of carabid beetles and spiders, thereby enhancing the potential

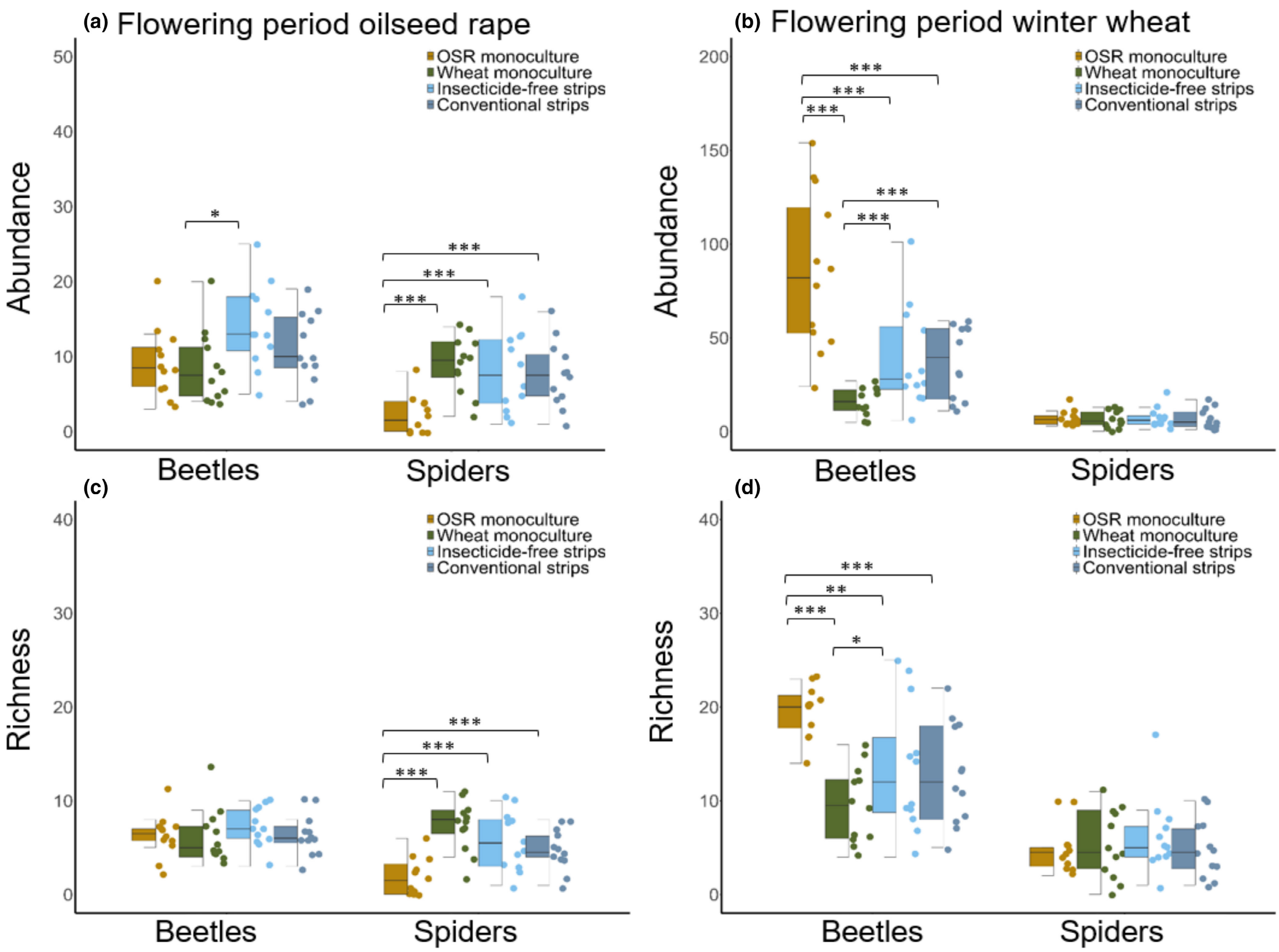

FIGURE 2 Data points and confidence interval of carabid beetle and spider abundance (a–b) and richness (c–d) on each cultivation type per sampling event. (a, c) Data recorded on the first sampling event –– flowering period of oilseed rape (mid-May 2019). (b, d) Data recorded on the second sampling event –– flowering period of wheat (mid-June 2019). Asterisk symbols denote statistically significant differences between the groups; (*) $p \leq 0.05$, (**) $p \leq 0.01$ and (***) $p \leq 0.001$

complementarity effects of these two important predator groups. This result adds to the growing knowledge of the benefits of combining two or more plant crops in the same area to attract predator species that would otherwise not be present (Brooker et al., 2015; Kremen & Miles, 2012; Lichtenberg et al., 2017; Qian et al., 2018). Spiders or carabid beetles that are more abundant in one crop can spill over to the second crop and promote ecological benefits. Therefore, having spiders and carabid beetles equally and their potentially complementary activity may enhance biological control more than the dominance of just one predator group. A similar effect has been observed in strip intercropping of peanuts and maize, where 90% of the predators were collected in maize-grown areas, but upon analysis of their gut contents, were found to prey mainly on peanut aphids (Ju et al., 2019). Ground-dwelling arthropod predators alone can often not account for controlling crop pests (Thies et al., 2011; Williams, 2010). Wasp parasitoids are often key in complementing biological pest control in cereal crops such as winter wheat and oilseed rape (Brandes et al., 2018; Vollhardt et al., 2008; Yang et al., 2017). We did not measure predation rates and did not experimentally manipulate predation or parasitism rates, so we can only speculate on the enhancement of potential control by these predators. However, we found much higher parasitism rates in strip intercropping than monocultures, similar to effects otherwise usually only found through the influence of nearby semi-natural habitat (Thies et al., 2005; Tscharntke, 2000).

Even though we found significantly higher parasitism rates of cereal aphids in strip intercropping than in monocultures, we did not find higher parasitism rates of pollen beetles in strip intercropping. The benefits of agricultural diversification on biodiversity have often been shown to be greatest when combined with reduced chemical inputs (Bourguet & Guillemaud, 2020; Chèze et al., 2020; Devine & Furlong, 2007; Wilson & Tisdell, 2001). However, we did not find increased biodiversity or biological pest control in the insecticide-free strip intercropping. This result may be due to the relatively small insecticide-free area or a potential spillover of insecticides. Our data were collected in a conventionally managed farm and large-scale agricultural landscape (see Table S1 for further farm management details). Wheat fields were sprayed to control aphid densities when

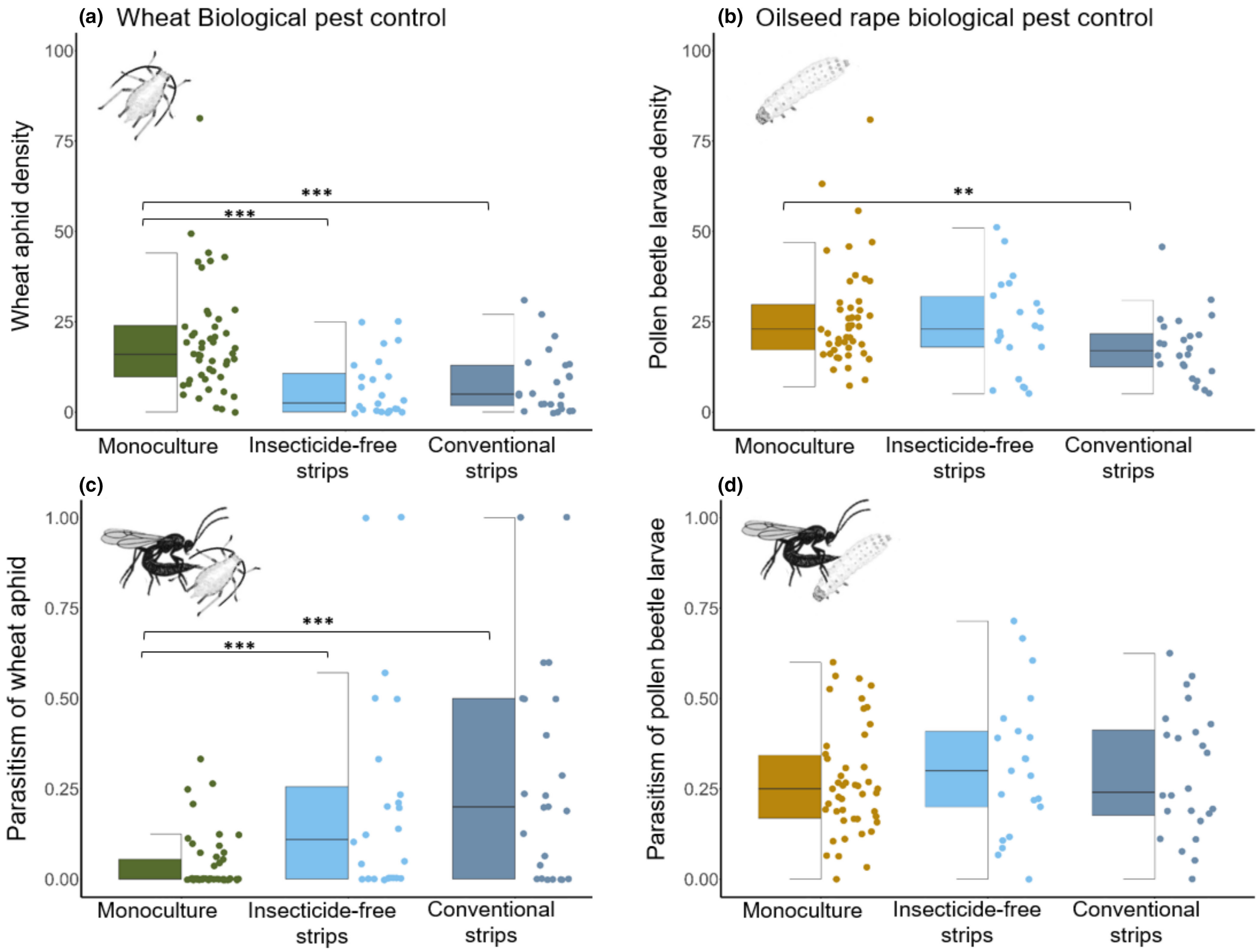

FIGURE 3 Data points, confidence interval and mean values of: (a) number of aphids counted per plot (50 shoots of wheat) on wheat-cultivated areas. (b) Number of pollen beetle larvae collected per plot (five branches of OSR) on OSR-cultivated areas. (c) Proportion of mummified aphids collected per plot, and (d) proportion of pollen beetle infested larvae per plot. (*) denote significant differences between the groups; $p \leq 0.05$

the threshold of four aphids per wheat leaf was exceeded, while oilseed rape fields were sprayed when more than six pollen beetles per oilseed rape plant were found (Planzenschutz Im Ackerbau, 2021). Even with such rules of insecticide applications, wheat and oilseed rape monocultures were not devoid of pests, and strip intercropping helped reduce the remaining level of pest infestations. On the other hand, the reduction of pest densities through strip intercropping may not be the result of increased predation or parasitism rates but of the direct responses of the pest population to the reduced resource concentration. Insect pests are less likely to localize and colonize their host plant and build up large populations in sparsely distributed patches of their food resources (Smith & McSorley, 2000; Vandermeer, 1989). Therefore, by disrupting the availability of large-scale homogeneous resources for pests, strip intercropping has the potential to reduce the probability of pest colonization.

Strip intercropping can provide yield benefits for farmers beyond supporting reductions in resource concentration, enhanced natural predator communities and higher biological pest control (Liang et al., 2016; Ning et al., 2017). Economic benefits of strip intercropping are commonly measured in terms of land use efficiency or harvested yields (Noman et al., 2013; Tajmiri et al., 2017b; Yu et al., 2015; Zhou et al., 2013), and reports of yield losses for one of the crops involved are frequent (Noman et al., 2013; Ramalho et al., 2012; Tajmiri et al., 2017a, 2017b). Noteworthy, yield data for all crops used in the mixture are rarely reported or considered in intercropping studies. We obtained complete data of harvested yields separated by field for one farm only (see Table S7). From these data, we found that only marginal yield losses occurred in wheat and oilseed rape, indicating that strip intercropping systems applied to large-scale agriculture may be an economically viable option. Strip intercropping with wider strips can also be seen as a way to reduce field size and increase crop heterogeneity, not only at the field level but also at the landscape level, a process that has been shown to greatly enhance biodiversity in agricultural fields (Sirami et al., 2019). Small-scale strip intercropping with narrow strips also increases habitat heterogeneity and promotes potential spillover between crop types which may benefit biodiversity and reduce pest levels. We emphasize the importance of further testing the role of strip width for biodiversity, pest control and yield to find synergies or ecological-economic trade-offs of strip intercropping.

Our study provides evidence of the biodiversity and biocontrol benefits of implementing strip intercropping with large machinery in large-scale, conventionally managed agricultural landscapes. We found reduced pest densities, enhanced parasitism of pests and balanced predator communities, well beyond the levels found in monocultures. We show how strip intercropping can increase small-scale crop heterogeneity, farm-level biodiversity and ecosystem service provision. We advocate strip intercropping as a promising and feasible strategy to promote sustainability of cropping systems, which conventional as well as organic farms can apply.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

AUTHORS' CONTRIBUTIONS

T.T., G.B. and I.G. conceived the ideas and designed the methodology; V.A.-S. collected the data; V.A.-S. analysed the data; V.A.-S., T.T. and I.G. led the writing of the manuscript; G.B. and M.R. contributed to the manuscript revisions for submission. All authors contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Data available via OSF repository https://doi.org/10.17605/OSF.IO/ZK48Y (Alarcon-Segura et al., 2022).

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