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Can trap color affect arthropod community attraction in agroecosystems? A test using yellow vane and colorless traps

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Abstract Vane trapping is one of the most effective methods for sampling flower-visiting arthropods. Despite its importance in pollinator studies, the effects of trap color on the abundance and richness of pollinators are less understood. To test this, we conducted a 3-season field experiment over 2 years with two types of vane traps: yellow and colorless. We set up twelve traps each in three field sites within the Lower Rio Grande Valley in south Texas, planted with *Vigna unguiculata*, *Crotalaria juncea*, *Raphanus raphanistrum*, and *Sorghum drummondii*. At each site, six colorless vane and six yellow vane traps were placed equidistant from each other. The experiment was replicated three times across three seasons, first during the pre-flowering season, when the crops were in full bloom, and when there was no crop on the field. In total, we collected 1912 insects, out of which 76.7% were pollinators. Generalized Linear Regression analyses showed that yellow traps consistently attracted significantly more arthropods and pollinators, but these differences were also season dependent. Furthermore, we noticed that Hymenoptera, followed by Coleoptera, were the most prevalent orders in both the yellow vane and colorless vane traps. Interestingly, although there was no significant difference in species richness of the arthropods in the yellow and colorless vane traps, our results suggest that trap color plays a significant role in capturing pollinators, including non-target arthropods. Our data add another line of evidence suggesting that trap color should be accounted for designing experiments that estimate pollinator and arthropod community diversity.

Keywords Arthropods · Traps · Pollinators · Color · Cover crop

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Introduction

Arthropods contribute significantly to biodiversity in agroecosystems by driving critical ecosystem processes such as pollination, herbivory, and multitrophic interactions (Meyer et al., 2011; Yang & Gratton, 2014). Both management and conservation practices in agroecosystems depend on reliable and consistent estimation of arthropods, both at species richness and diversity, and abundance (Kaur et al., 2020; Martinez et al., 2020; McLeod, 2000; Sane et al., 1999). In addition, estimating arthropods in the agroecosystems is essential in devising policy, conservation efforts, and monitoring arthropod decline over time (Karamaouna et al., 2021). However, the estimation of arthropods in the agroecosystems tends to be inconsistent and can vary due to many factors-including trap methodologies, an area that is poorly understood.

Various active or passive sampling techniques have been used to estimate and evaluate the population density and diversity of arthropods. Active sampling of arthropods involves using sweep nets and transect walks to estimate the population of arthropods in each area (Steffan-Dewenter & Schiele, 2008; Taki et al., 2018). However, this sampling technique is quite rigorous and time-consuming as accurate results entirely depend on the investigator's skill and experience (Prendergast et al., 2020). Passive sampling (e.g., trap) is easy to install and does not require the input of the investigator in collecting arthropod samples once the traps have been installed correctly (McCravy, 2018). They also allow for a more diverse range of arthropod collection through multiple time periods to eliminate investigator bias (McCravy, 2018). Examples include pan traps (Gonzalez et al., 2020; Shrestha et al., 2019; Sircom et al., 2018; Kariyat et al., 2018, sticky traps (Dimitrova et al., 2020; Kariyat et al., 2012), malaise traps (Srisuka et al., 2021; Volpato et al., 2020), pitfall traps (Umair Sial et al., 2022; Jiménez-Carmona et al., 2019; Kariyat et al., 2018, and colored vane traps (Hall & Reboud, 2019; Hall, 2018; Stephen & Rao, 2005). These traps are installed passively but actively use their colors to attract different arthropods belonging to various taxonomic groups (Acharya et al., 2021; Hall & Reboud, 2019; Moreira et al., 2016).

Trap color is an essential factor to consider while estimating arthropods and can influence arthropod diversity (Acharya et al., 2021; Cai et al., 2021; Hoback et al., 1999). The response of arthropods to trap color has also been found to vary significantly based on taxonomic group and ecology (Hall & Reboud, 2019; Skvarla & Dowling, 2017; Vrdoljak & Samways, 2012). For example, the commonly used colors for sampling pollinators are blue, white, and yellow (Abrahamczyk et al., 2010; McCravy, 2018). However, arthropods are more attracted to blue and yellow traps, although there is no consensus on which color is more appealing to a particular taxa or different habitat types (Abrahamczyk et al., 2010; Saunders & Luck, 2013). This has been linked to variations in reflectivity and vibrancy caused by a lack of uniform color and design quality (Shrestha et al., 2019). Dimitrova et al. (2020) compared the effectiveness of yellow and transparent sticky traps to evaluate arthropod diversity in an olive agroecosystem. They realized that the total number of arthropods captured in yellow traps exceeded the number trapped in transparent sticky traps. A similar experiment conducted in southern Australia tested the effectiveness of yellow and blue vane traps for sampling wild bees in both open and wooden habitats. They found that blue vane traps more effectively attracted wild bees than yellow vane traps (Hall, 2018). In an experiment to test the relative performance of different sampling methods for native bees, Prendergast et al. (2020) showed that the blue vane traps were more efficient than the yellow vane traps in sampling native bees. Taken together, these studies clearly demonstrate the importance of trap color for estimating arthropod diversity but also highlight the inconsistency in results.

There is no argument for the fact that pest and pollinator management needs a sound estimation of the prevailing arthropod community (Cai et al., 2021; Martinez et al., 2020). In addition to the odor of plant volatiles, arthropods employ visual cues, especially color, to locate their hosts for feeding and laying eggs (Schoonhoven et al., 2005). Some rely on vision and olfaction cues in locating their hosts, while others rely only on visual stimuli (Kerr et al., 2017; Kariyat et al., 2021). For example, an experiment that evaluated the population of *Lygus lineolaris* showed that both olfactory cues and visual stimuli played a vital role in their host selection (Prokopy et al., 1979). Arthropods such as *Empoasca fabae* and *Altica engstroemi* rely only on visual stimuli when they search for their host (Bullas-Appleton et al., 2004). In laboratory color-choice tests and field tests, Cai et al. (2021) showed that *Protaetia brevitarsis* adults (a major pest of many fruits and vegetable crops, including grapes and tomatoes) were more attracted to red traps. Clearly, the results from such experiments will improve the effectiveness of traps for capturing herbivores in integrated pest control programs.

Color is one of the most important visual characteristics utilized by pollinating insects (Kariyat et al., 2021; van der Kooi et al., 2019). The display of colorful flowers elicits various responses among pollinators (Renoult et al., 2014). For example, an experiment that assessed the most preferred cue used by pollinators showed that pollinators in two-choice bioassays showed a strong bias for visual cues over olfactory cues (Barragán-Fonseca et al., 2020). Also, the intensity of light and the reflectance of trap colors directly affect the population of pollinators that are attracted to the traps (Joshi et al., 2015; Vrdoljak & Samways, 2012). Pollinators such as bees can identify different colors and even discriminate against color textures, although this varies by species. Bees direct their attention to a source based on the color intensity and chromaticity of illumination (Koethe et al., 2018; Lotto & Chittka, 2005). Also, they use their olfactory signal if the source is at ~ 30 cm and their visual cues if they are close to flowers (Streinzer et al., 2009).

Taken together, agroecosystems can benefit from a better estimation of pollinators, and trapping methodologies, and should also explore whether non-target insects are disproportionately targeted by trap design, including their color. To test this, we used yellow and colorless vane traps to estimate the population of pollinators and non-target arthropods in three agroecological fields in the Lower Rio Grande Valley, Texas. The following questions were asked: (1) Can trap color affect arthropod diversity assessment? (2) If color affects trapping, will the traps differentially attract pollinators and non-pollinators?

Methods

Study sites

This experiment was conducted on three different agricultural fields in the Lower Rio Grande Valley. Our first site (26°18′12.2″N 97°50′13.1″W) had a mix of cowpea (*Vigna unguiculata* Fabaceae) and sunn hemp (*Crotalaria juncea* L.) (Fabaceae). The second site (26°24′35.1″N 98°27′52.8″W) also had a mix of cowpea (*Vigna unguiculata* Fabaceae) and radish (*Raphanus raphanistrum* Brassicaceae). Our third site (26°20′32.6″N 98°31′51.6″W) was planted with cowpea (*Vigna unguiculata* Fabaceae) and sorghum-sudangrass (*Sorghum drummondii* Poaceae).

Sampling

Sampling in each site was conducted three times over 2 years. The first was carried out during September 2021 (fall), when the crops were at the pre-flowering stage, the second sampling was conducted in during December 2021 (winter), when the crops were in full bloom, and finally during July 2022 (summer), post-harvesting when there no crops/plants on the fields. At each site, six yellow vane and six colorless vane traps (BanfieldBio INC Woodinville WA, USA; both traps had blue funnel and different in the color of the jar- yellow or colorless) were installed at 1.2–1.5 m above the ground on wooden sticks (Fig. 1A, B) and distanced 36 m from each other to prevent spatial autocorrelation (Greenleaf et al., 2007; Prendergast et al., 2020). The diameter and height of the traps used were 12 cm and 15 cm, respectively. The yellow and colorless vane traps were filled with a soap water solution to almost one-fourth of the traps to reduce surface tension (Kariyat et al., 2012, 2018) and were collected after four days of their setup in the field. Captured arthropods were transferred to containers containing 70% ethanol for identification. The sampled arthropods were classified into their orders and functional group (pollinators).

Shannon-Weiner diversity index

The Shannon-Weiner diversity index was used to test the diversity of arthropods in the yellow and colorless vane traps during different seasons (fall, winter, and

A B

Fig. 1 **A** Yellow vane trap. **B** Colorless vane trap summer). The diversity index was computed using the formula below:

$$H^{'} = -\sum Pi\ Ln\ Pi, \text{in which} \quad Pi = \frac{ni}{N}$$

Here,
H' = Shannon diversity index
Pi = Relative number of each species
ni = Species number i
N = total number of species

Statistical analysis

Since most of the data were insect count, we used Generalized Regression with Poisson distribution, and means were separated using the Tukey HSD test. All analyses were carried out using SAS JMP (JMP®, Version < 15 >. SAS Institute Inc., Cary, NC, 1989–2021), and plots were built using GraphPad Prism (GraphPad Software, version 9.0.0 for Windows, La Jolla, CA, USA, www.graphpad.com). The total number of arthropods was assessed and separated into different taxonomic orders and functional roles across different seasons. The mean numbers of total arthropods, pollinators, parasitoids, and taxonomic orders were included as response variables, while trap color, season, and their interactions were included as factors.

Results

General results on orders and families collected

We collected a total of 1912 arthropods, out of which 1466 were pollinators. The major orders found were Hymenoptera (76.7%) followed by Coleoptera (11.3%), Lepidoptera (5.6%), Diptera (2.2%), and Hemiptera (0.8%). A few insects of orders Collembola (0.49%), Blattodea (0.18%), Embioptera (0.06%), and Neuroptera (0.06%), were also found but in much fewer numbers. Most pollinators found were from Megachilidae, Xylocopidae, Vespidae, and Halictidae. Also, most of the Coleopterans found were from families Meloidae and Melyridae.

In general, yellow vane traps captured a higher number of total arthropods, which was ~ 68% of the total arthropods collected, compared to the colorless vane trap, which collected ~ 32% of the total arthropods. Furthermore, the yellow vane trap captured more pollinators (~ 70%) than the colorless vane traps (~ 30%).

Regression analyses

The total number of arthropods and pollinators collected differed between the yellow vane and colorless vane traps. The yellow vane trap was by far the most effective in sampling pollinators and lepidopterans. There was a significant difference in the total number of arthropods (Table 1; Fig. 2A; $P < 0.0001$) and pollinators (Table 1; Fig. 3A; $P < 0.0001$) caught in the yellow vane traps. Among the orders, Lepidopterans were significantly attracted to the yellow vane traps (Table 1; Fig. 4C; $P < 0.0001$). However, trap color did not significantly affect the attraction of insects belonging to the orders Coleoptera (Table 1; Fig. 4A; $P = 0.0921$), Diptera (Table 1; Fig. 4B; $P = 0.3038$), and Hemiptera (Table 1; Fig. 4D; $P = 0.5129$).

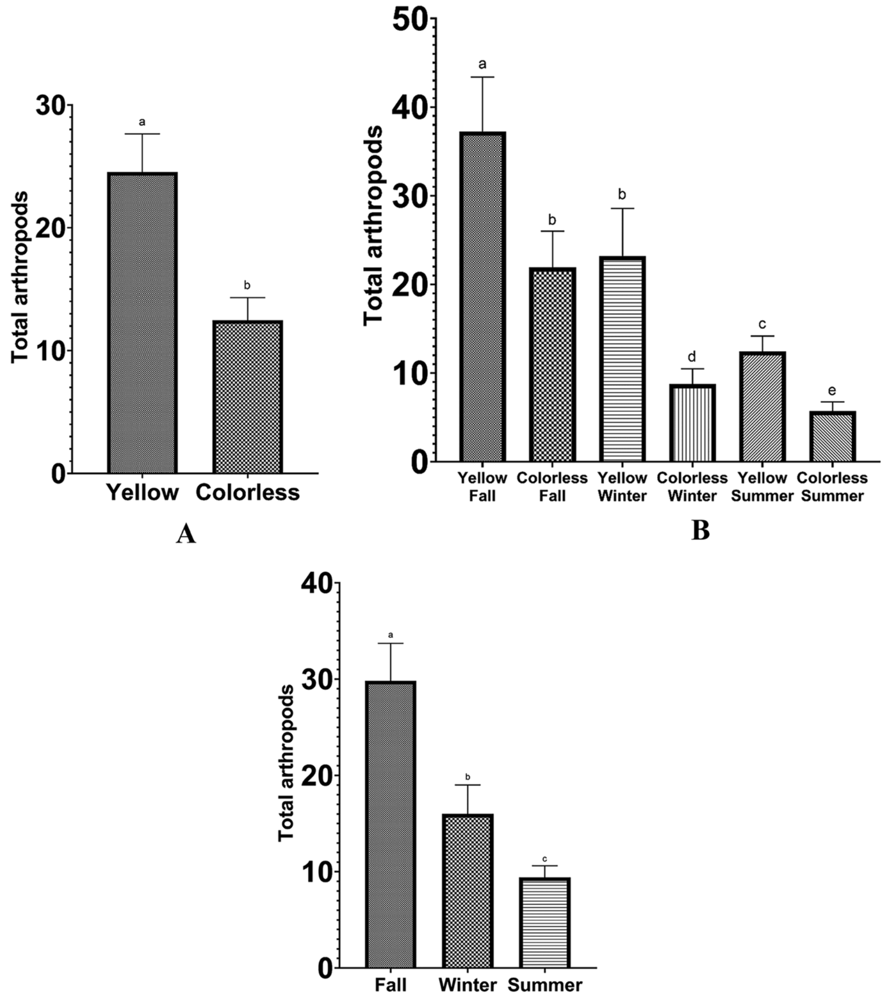
The season in which the sampling was carried out had a significant effect on the total number of arthropods (Table 2; Fig. 2C; $P < 0.0001$) and pollinators (Table 2; Fig. 3C; $P < 0.0001$) captured in the traps. There were significantly more arthropods and pollinators captured in the fall of 2021 in the yellow and colorless vane traps. However, the season had no significant effect on the population of the insect orders, even though their numbers were higher in the fall of 2021, except for the Dipterans. (Fig. 4C). There was a significant trap color x season interaction on the total number of arthropods (Table 3; Fig. 2B; $P = 0.0004$) and pollinators (Table 3; Fig. 3B; $P = 0.0001$). The yellow vane traps significantly captured more arthropods and pollinators than the colorless vane trap

Table 1 Results of Generalized Regression Analysis for the effect of trap color on the number of insects belonging to different orders and functional groups

Traits	Test statistic	*P* value
Total arthropods	|Z| = 10.81	**< 0.0001**
Pollinators	|Z| = 10.01	**< 0.0001**
Coleoptera	|Z| = 1.26	0.0921
Diptera	|Z| = 0.89	0.3038
Hemiptera	|Z| = 0.27	0.5129
Lepidoptera	|Z| = 1.4058	**< 0.0001**

Boldface values represent statistically significant effects at $P < 0.05$

Fig. 2 **A** Results of the abundance of total arthropods pooled from yellow vane and colorless traps. Data was analyzed using generalized regression models and means were separated Tukey's post hoc tests at a *P* value of 0.05. Different letters denote statistical significance at $P<0.05$. **B** Results of the interaction of trap color and season on the total arthropods pooled from the yellow and colorless vane traps. Data was analyzed with generalized regression models and means were separated Tukey's post hoc tests at a *P* value of 0.05. Different letters denote statistical significance at $P<0.05$. **C** Results of the effect of season on total arthropods pooled from the yellow and colorless vane traps. Data was analyzed with generalized regression models and means were separated Tukey's post hoc tests at a *P* value of 0.05. Different letters denote statistical significance at $P<0.05$



across the seasons. There was no significant difference in the numbers of the insect orders captured in the yellow vane, and colorless vane traps across the seasons except for the Lepidopterans (Table 3; Fig. 4E; $P<0.0001$).

Shannon diversity index

The Shannon-Weiner diversity index estimate showed no significant difference in the diversity of arthropods in yellow or colorless vane traps across the seasons. However, the maximum diversity index equitability was 0.52 for the yellow traps during the fall of 2021. Therefore, we concluded that the trap color and season did not affect the species richness or the diversity of the arthropods in the yellow vane or colorless vane traps (Tables 4 and 5).

Discussion

This study demonstrates that trap color is essential in assessing arthropod community dynamics in agroecosystems, adding another line of evidence on how trap color must be accounted in field estimation of arthropods. Through 3 field seasons spread over 2 years, we demonstrate that the yellow vane traps captured significantly more arthropods than the colorless vane traps through repeated sampling. There was also a significant trap color x season interaction on the total number of arthropods and

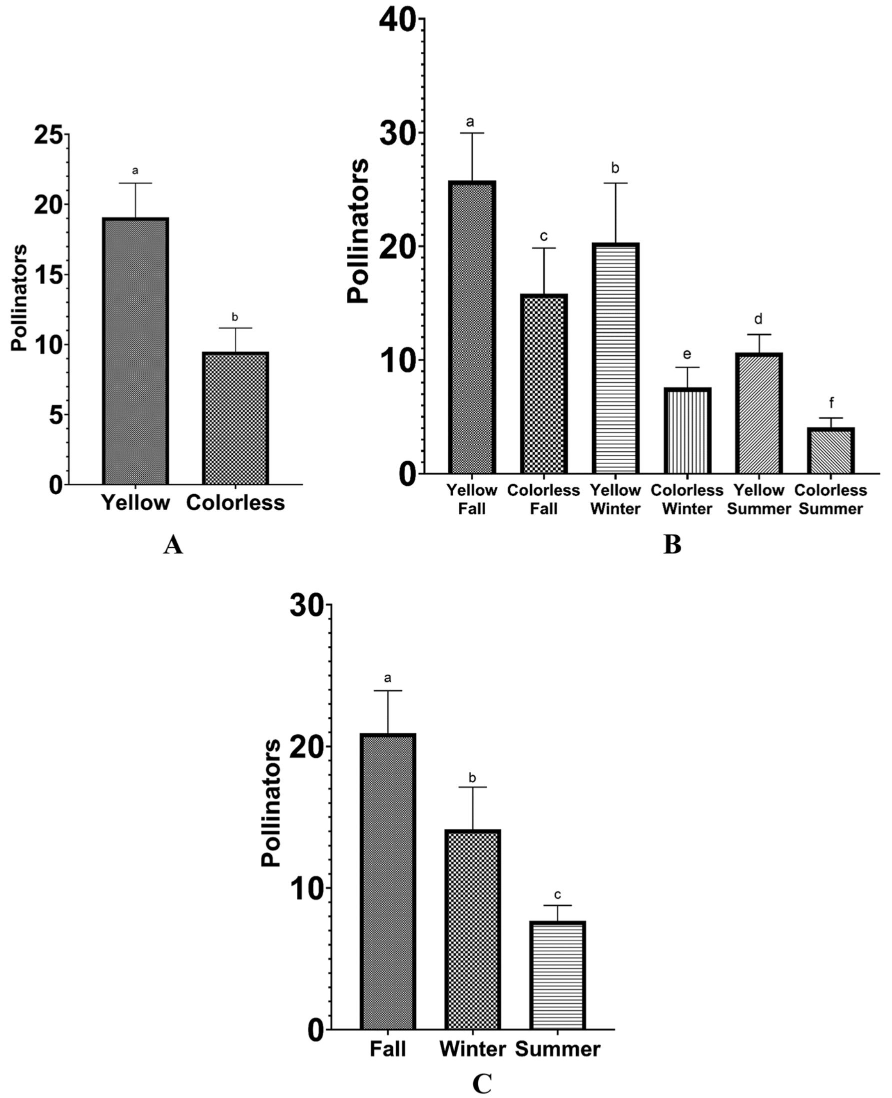


Fig. 3 **A** Results of the abundance of pollinators pooled from the yellow and colorless vane traps. Data was analyzed with generalized regression models means were separated Tukey's post hoc tests at a *P* value of 0.05. Different letters denote statistical significance at $P < 0.05$. **B** Results of the interaction of trap color and season on the pollinators pooled from the yellow and colorless vane traps. Data was analyzed with generalized regression models and means were separated Tukey's post hoc tests at a *P* value of 0.05. Different letters denote statistical significance at $P < 0.05$. **C** Results of the effect of season on pollinators pooled from the yellow and colorless vane traps. Data was analyzed with generalized regression models and means were separated Tukey's post hoc tests at a *P* value of 0.05. Different letters denote statistical significance at $P < 0.05$

even pollinators captured in the yellow vane and colorless vane traps. Arthropods, especially the pollinators and Lepidopterans, showed a marked preference for the yellow vane traps over the colorless vane traps across the seasons. A large number of arthropods were collected across the survey periods, particularly from certain families, mainly considered pollinators (Megachilidae, Xylocopidae, Vespidae, and Halictidae). Interestingly, lepidopterans displayed a marked color preference for yellow vane traps among the sampled orders. However, there was no significant difference in the species diversity of the arthropods in the yellow vane and the colorless vane trap. Our results indicate that trap color is an essential factor in understanding the distribution and demography of arthropods in the agroecosystem.

Our results that show a significantly higher number of pollinators in the yellow vane traps disagree with some other vane trap studies targeting arthropods in the agroecosystem (Stephen & Rao, 2005; Hall, 2018; Hall & Reboud, 2019) but is consistent with the results of Prokopy & Owens (1979), Dimitrova et al., 2020, which reported that arthropods are more attracted to yellow traps. The U.V. reflectance of traps has been reported as a factor responsible for arthropod attractiveness, especially bees and wasps, to the yellow vane traps (Acharya et al., 2022; Koski

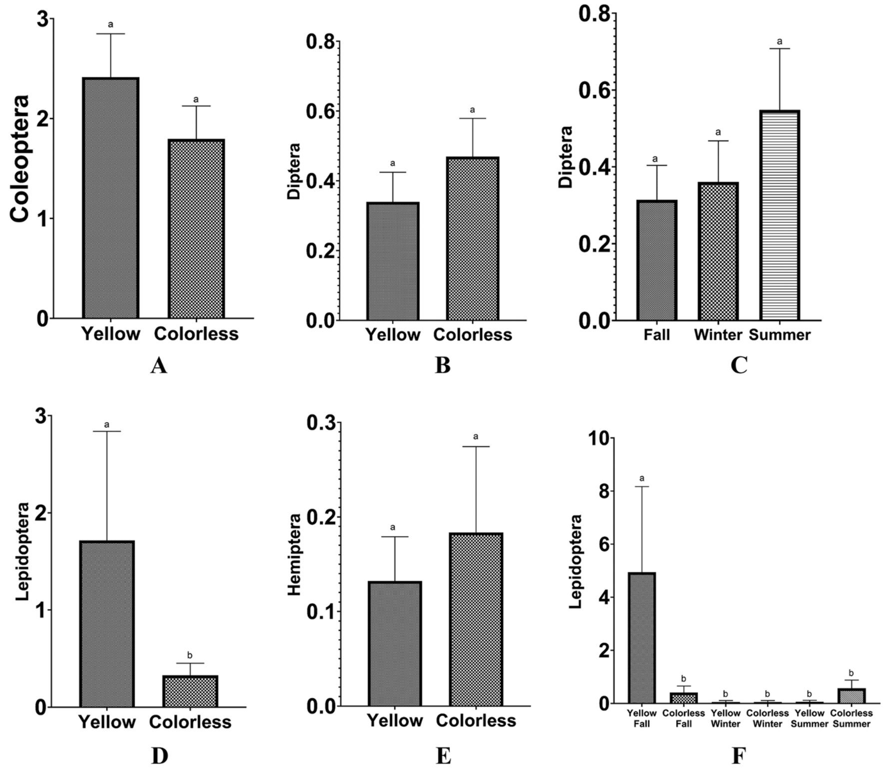


Fig. 4 **A** Results of the abundance of the total Coleoptera pooled from the yellow and colorless vane traps. Data was analyzed with generalized regression model means and were separated Tukey's post hoc tests at a *P* value of 0.05. Different letters denote statistical significance at $P<0.05$. **B** Results of the abundance of the total Diptera pooled from the yellow and colorless vane traps. Data was analyzed with generalized regression models and means were separated Tukey's post hoc tests at a *P* value of 0.05. Different letters denote statistical significance at $P<0.05$. **C** Results of the effect of season on Dipterans pooled from the yellow and colorless vane traps. Data was analyzed with generalized regression models and means were separated Tukey's post hoc tests at a *P* value of 0.05. Different letters denote statistical significance at $P<0.05$. **D** Results of the abundance of the total Lepidoptera pooled from the yellow and colorless vane traps. Data was analyzed with generalized regression models and means were separated Tukey's post hoc tests at a *P* value of 0.05. Different letters denote statistical significance at $P<0.05$. **E** Results of the abundance of the total Hemipterans pooled from the yellow and colorless vane traps. Data was analyzed with generalized regression models and means were separated Tukey's post hoc tests at a *P* value of 0.05. Different letters denote statistical significance at $P<0.05$. **F** Results of the interaction of trap color and season on the Lepidopterans pooled from the yellow and colorless vane traps. Data was analyzed with generalized regression models and means were separated Tukey's post hoc tests at a *P* value of 0.05. Different letters denote statistical significance at $P<0.05$

& Ashman, 2014). However, there was no significant difference in the number of insects from the orders: Diptera, Hemiptera, and Coleoptera in the yellow or colorless vane traps.

Habitat type, together with trap color, can influence arthropod trapping in agroecosystems (Saunders & Luck, 2013). Although most pollinators are considered generalist foragers, the composition of pollinators assemblages is believed to have evolved in response to environmental characteristics like habitat shape, plant diversity, or the dominant floral resource color (Bates et al., 2011; Wenninger & Inouye, 2008). Therefore, pollinator assemblages may respond to colored traps differently depending on their habitat. The fields sampled in this study differ in some ways. The fields comprised different cover crops like cowpea, radish, sorghum-sudangrass, and sunflower. Although each cover crops have different growth patterns and floral resources (Martinez et al., 2020). We found that pollinators and Lepidopterans were caught in yellow vane traps more often than in the colorless vane traps across the three fields. Furthermore, the

Table 2 Result of generalized regression analysis of the effect of season on insects belonging to different orders and functional groups

Traits	Test statistic	*P* value
Total arthropods	|Z| = 11.67	**< 0.0001**
Pollinators	|Z| = 6.35	**< 0.0001**
Coleoptera	|Z| = 30.97	**< 0.0001**
Diptera	|Z| = 1.04	0.3031
Hemiptera	|Z| = 1.86	0.8839
Lepidoptera	|Z| = 2.24	**< 0.0001**

Boldface values represent statistically significant effects at $P < 0.05$

Table 3 Result of Generalized Regression Analysis of the interaction between trap color and season on insects belonging to different orders and functional group

Traits	Test statistic	*P* value
Total arthropods	|Z| = 0.65	**< 0.0001**
Pollinators	|Z| = 0.37	**0.0001**
Coleoptera	|Z| = 13.12	0.6590
Diptera	|Z| = 0.85	0.3963
Hemiptera	|Z| = 1.25	0.7518
Lepidoptera	|Z| = 2.03	**< 0.0001**

Boldface values represent statistically significant effects at $P < 0.05$

Table 4 The sum of all arthropods and taxonomic diversity caught by the yellow vane and colorless vane traps

	Yellow vane trap	Colorless vane trap
Total arthropods	1301	611
Pollinators	1011	455
Taxonomic units	247	136
Coleoptera	113	82
Diptera	10	14
Hemiptera	5	9
Lepidoptera	92	8

yellow vane traps caught more pollinators and total arthropods than the colorless vane traps. This could be due to the yellow vane traps' high reflectivity and the contrast between trap color and the predominant colors of the plants in the field (green) (Abrahamczyk et al., 2010; Joshi et al., 2015).

Pollinating insects require two essential habitats to perform ecosystem services: nesting habitat and foraging habitat (Olsson et al., 2015). However, the proximity of these habitats to the pollinators is essential for pollination (Kline & Joshi, 2020). Therefore, landscape structure characteristics such as the shape of patches, availability of flowers, plant arrangement, and type of plants significantly affect the population and visitation of pollinators (Turley et al., 2022; Syrbe & Walz, 2012). Additionally, the availability of floral resources and pollinators' foraging behavior could also be impacted by variations in seasonal weather patterns and extreme weather patterns (Straka et al., 2014). We surveyed the fields three times, the first few days after germination of the plants (fall 2021; no flowers), when the plants were in full bloom (winter 2021) and when there were no plants on the fields (summer 2022). We noticed that there were significantly greater numbers of pollinators in the fall and winter of 2021 across the three fields. This could, however, be because pollinators such as bees are more abundant in mild to moderately warm weather conditions than in harsh or extremely hot conditions, which is associated with fewer flowering plants (Abrahamczyk et al., 2011; Koch, 2002). Furthermore, the abundance and diversity of pollinators such as bees and wasps are influenced by a variety in the number of flower and food plant species which were more abundant during the fall and winter seasons (Abrahamczyk et al., 2011).

In 2018, we developed (Kariyat et al., 2018) a comprehensive and inexpensive trapping technique to quantify the field arthropod community that uses both volatile and contact cues for trapping. Therefore, a combination of this trapping technique together with

Table 5 Diversity indices of different arthropods captured by yellow and colorless vane traps

	Fall		Winter		Summer	
Trap type diversity indices	Yellow	Colorless	Yellow	Colorless	Yellow	Colorless
Shannon-Winer's diversity index	0.84	0.77	0.33	0.61	0.55	0.86
Equitability	0.52	0.48	0.21	0.38	0.30	0.48

the vane traps can be used for the complete quantification of arthropod diversity in agroecosystems. Previous studies have also confirmed that trap color is a significant factor in the survey of pollinators and non-bee pollinators in agroecosystems. However, here we show and confirm that trap color is a significant factor in estimating arthropods in the agroecosystem. The vane traps (yellow and colorless) are best suited for estimating pollinators alone because no single trap can be efficiently used to capture all arthropods in every habitat in the agroecosystem.

Conclusions

The study revealed four vital findings: (1) Trap color is a significant factor in estimating the population of arthropods in the agroecosystem. (2) Season is an essential factor to consider when estimating the population of arthropods in the agroecosystem. (3) The yellow vane trap significantly captured more arthropods, especially pollinators and Lepidopterans, than the colorless vane traps. (4) The yellow vane trap is best suited for the estimation of pollinators in the agroecosystem.

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Author contribution AF, RK, and AR designed the study. AF, SK, and AV collected and analysed the data. AF wrote the first draft and RK edited it. All authors contributed to revisions.

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Data availability All raw data will be made available on request.

Declarations

Ethics approval All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.

Competing interests The authors declare no competing interests.

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