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Differential efficacy of edaphic traps for monitoring arthropods diversity in subtropical regions

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ABSTRACT

Installation of traps in the agricultural field is an economically important and cheaper technique to observe arthropods diversity. Cost-effective ecological monitoring of arthropods by traps has been gaining interest in the field of environmental entomology since last few decades. This study explains the effectiveness of four different types of traps (pitfall, yellow-sticky, pan and barrier traps) to monitor the arthropod diversity in summer and winter seasons. These traps were installed in different mango orchards located in Punjab, Pakistan. diversity of captured arthropods was 1.5 times higher in summer than in winter season. However, among the traps, pitfall traps were most effective than others for trapping edaphic arthropods in both seasons. The pan traps were found most effective in the summer season, while sticky traps in the winter season. The pitfall traps exhibited highest taxa richness index values (8.00 for summer and 5.00 for winter season), while the lowest values were recorded for barrier traps (5.00 for summer and 3.00 for winter season). Moreover, the pitfall were the most effective traps for the capture or collection of Arachnida, Coleoptera, Hymenoptera, Lepidoptera, Orthoptera and other arthropods. The PVC barrier and sticky traps were found most effective for Dipteran and Hemipteran's insects, respectively, and hence, are recommended for the ecological monitoring of these arthropod groups in future studies.

1. Introduction

Arthropods play a major role in the ecological functioning and are regarded as main global biodiversity components (Zwick and Mahon, 2017). The arthropods have been monitored by a range of traps including Pitfall, Yellow-sticky, Pan and PVC Barrier traps (Engel et al., 2017). A captivating and most obvious biological question to study arthropods' diversity is "how many species inhabit in a particular area?" (May 2011). Thus, this information regarding species diversity is important to understand the geographic range and abundance according to the environment

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(Bashir et al., 2019, Godfray et al., 2004, Khan et al., 2014). It is important to assess which sampling practice is wisest to adopt in collecting suitable target taxa (Nemésio and Vasconcelos, 2014). In usual, adopting several sampling methods for arthropod's diversity is perfect to evaluate community abundance with satisfaction. Unbiased and adequate assessment is important to examine the estimation of species diversity, affected by applied methodology and sampling effort (Vasconcelos et al., 2014).

The pitfall traps are best to estimate the diversity of edaphic insects (Pearce and Venier, 2005), and effective as it includes passive and continuous sampling and involves little environmental disturbance. Over the last 30 years, insects sampling via pitfall trap has been under keen investigations and previous studies confirmed that catches by this trap were subjected to many factors including the trap size or design, proper installation and time (Majeed et al., 2018; Perner and Schueler, 2004; Work et al., 2002). Pitfall traps are effectual practice, especially for the edaphic arthropods that are generally active at soil surface (Hansen and New, 2005). Likewise, a variety of colored pan traps (colored bowl or bee bowl trap) has been used to gather Hymenopteran insects (Abrahamczyk et al., 2010).

The pan traps considered the passive sampling approach with no bias collection which captures diverse arthropods samples. Color and interception are valuable features of pan traps (Vrdoljak and Samways, 2012). This trap is easily replicated and allows multiple transects sampling simultaneously Often the colored pan trap is known as cost-effective and alternative sampling practice (Campbell and Hanula, 2007; McCravy et al., 2016; Missa et al., 2009). Nevertheless, several arthropods catch depends on various factors such as trap color, length, species specialization and some gender traits and body sizes (Heneberg and Bogusch, 2014).

Another effective and quite easy to construct trap is a sticky trap, used to sample and monitor the population abundance of both beneficial and harmful arthropods (Wallis and Shaw, 2008). Measurable color spectrum affects the attraction of diurnal arthropods toward sticky traps. Usually, trap effectiveness is dependable on the response of arthropods to various colors being applied in various crops (Childers and Brecht, 1996; Gillespie and Vernon, 2014). Yellow sticky traps, for instance, has been considered a valuable tool for pest management and are commercially available to sample or monitor small and large insects including aphids, whiteflies, leafhoppers, leaf miners, thrips, fruit flies and common house flies (Hazir and Ulusoy, 2012). It is broadly used in a range of ecological studies, particularly for sucking insects in agroecosystems (Sridhar and Naik, 2015).

Similarly, an aerial passive barrier trap and a new form of malaise trap known as windowpane traps are specifically designed for flying insects belonging to orders Coleoptera, Hymenoptera and Diptera. These traps are omnidirectional and two-sided open to intercepts a variety of large flying insects (Bouget et al., 2008; Schmitz, 1984; Hakami et al., 2020). It is very effective with the added advantage of easy construction and installation designed to sample a variety of flying insects in different ecological zones (Grimbacher and Stork, 2009; Lamarre et al., 2012; Missa et al., 2009).

Moreover, chemical application for arthropods management is not environmentally safe and, thus, has a negative impact on naturally occurring biological control agent (Manzoor et al., 2016). Keeping in view the ecological and economic importance of arthropods, this study encompassed the evaluation of four different types of traps viz., Pitfall, Yellow-sticky, Pan and PVC Barrier for arthropods capturing and their monitoring in mango orchards of a subtropical area of Punjab, Pakistan. Secondary objectives included the impact of collection season and trap type on the captured population abundance of different arthropod groups.

2. Material and methods

2.1. Study

Installation of each trap was done at mango orchard 30.091°N, 71.264° E Multan, Punjab, Pakistan. Almost, 10–15 years old age mango orchards were selected for this study. Scheduled irrigation was applied through underground water via the tube well. In these orchards, no inter-cropping was done. Total four orchards were selected; soil samples were collected from each orchard and analyzed from the "Soil Testing Laboratory" of Bahauddin Zakariya University, Multan, Pakistan. Three different types of soils were found including clay loamy (nearby canals), sandy and sandy loam that varied from location to location.

2.2. Traps construction

2.2.1. Pitfall trap

The PVC cups were purchased from the market with an equal diameter of 90 mm. Two types of pitfall traps as cup and funnel traps have been used to monitor the insect diversity, but in this study, the funnel trap was selected to decrease the arrival of other arthropods (Lange et al., 2011). The funnel made of PVC was accurately fitted in cups, and the inner hole size was 22 mm in diameter. The funnel was fixed by using a glue gun to avoid its lower end disturbance from the bottom of the cup. While the length of the pitfall traps was kept 120 mm (Lange et al., 2011; Lasmar et al., 2017). The bottom of the trap was filled with 200 ml water including 0.4% salt and 0.6% soap to kill the insects for further taxonomic analysis and assessing the numbers involved from different orders (Harris et al., 2017). Particularly, PFT targets soil crawling insects, especially ants that belong to Hymenoptera (Majeed et al., 2018; Vieira et al., 2017).

2.2.2. Pan trap

Variety of color traps have been used to assess insect diversity but, in this study, yellow color was chosen because it preferably attracts more insects especially pollinators (Harris et al., 2017; Margatto and Gonçalves, 2017). Pan cups (60 × 80 mm) were purchased from the market and painted with sharp yellow color (Roulston et al., 2007). Each trap was filled with a soapy solution to reduce the surface tension of the insect's tarsus when they landed and to prevent insects from escaping and further analysis. The soapy liquid was refilled after every sampling (Harris et al., 2017).

2.2.3. Yellow sticky trap

The commercially available yellow sticky traps (300 × 210 mm) were purchased and used for small insects like aphids, whiteflies, leafhoppers, leaf miners, thrips etc. (Atakan and Canhilal, 2004; Zhao et al., 2016). The yellow sticky traps were hanged vertically at a different location by using a bamboo stick of 1524 mm length and height from the ground level was 1219 mm. The trap was checked and changed routinely, to sustain its adherence. The gummy material was dissolved with paint thinner to disengage insects easily, for proper identification at order levels (Atakan and Canhilal, 2004).

2.2.4. PVC barrier trap

A new or modified form of PVC Barrier trap was designed by previously used passive barrier trap of clear Plexiglas in 1984 and subsequent windowpane trap by many researchers specifically for flying insects (Lamarre et al., 2012; Schmitz, 1984). The good quality PVC sheets were purchased along with bamboo sticks of 1524 mm in length. The PVC sheets were bound between the two bamboo sticks to serve as a barrier. Therefore, insects unintentionally attract towards the barrier trap and fall. Below to this trap, a large tub like the pot was provided with soapy liquid to prevent the insect's escape. All constructed measurements are shown in (Fig. 1ABCD).

2.3. Installation of traps

One-acre area of each mango orchard was selected for installation of traps. There were 20 to 25 mango trees in one acre. Total 12 traps were used for each type of traps and randomly installed in the square form on each mango orchard. The distance between traps was 10 m (Margatto and Gonçalves, 2017). Traps were replaced weekly (Zhao et al., 2016). To achieve the best performance and maximum possible number of pollinators, traps were placed early in the morning (Bacandritsos et al., 2006).

2.4. Data collection

Data was recorded after week, started from September-December 2016. All the insect samples were collected with the help of flathead forceps. Specimens were transferred in clean plastic vials filled with ethanol (95%) for further processing like pinning, drying, labelling and identification in the laboratory. Specimens were identified by using published dichotomous keys (Huber, 1998).

2.5. Identification and description

All specimens were identified with the help of stereomicroscope (Labomed® CZM4-4X, Labo America Inc., CA, USA). All the collected specimens were identified up to a maximum possible extent. Description of the characters of all identified species has been provided in detail. Identification was carried out by running the different keys. The bees of the world studied by (Michener, 2007), Hymenoptera of the world by (Goulet and Huber, 1993) and Fauna of British India by (Bingham and Morley, 1897) along with color plates.

2.6. Data analysis

Data was analyzed statistically using Statistix® version 8.1 (Analytical Software). Apart from the graphical representation of arthropod capture rates and diversity, three types of diversity indices i.e. taxa richness index, taxa evenness index and ShannonWeiner diversity index were calculated for each trap type as described by Majeed et al. (2018). Moreover, the impact of different types of traps and of capturing season on the captured arthropod assemblages was determined by factorial ANOVA (at $\alpha = 0.05$).

3. Results

Pitfall traps were found more effective than other traps in both seasons, with highest Shannon Weiner's diversity index (1.65 for summer and 1.17 for winter captures). On the other hand, sticky traps had the lowest values of diversity index (1.08 for summer and 0.79 for winter) (Table 1). Pan and barrier traps were exhibited intermediate values of diversity index, i.e., 1.18 and 1.19 for summer and 1.06 and 0.91 for winter seasons, respectively as compared to a pitfall and sticky traps (Table 1). The highest number of the insect was captured in each trap type, a similar trend was observed with pitfall traps exhibiting highest taxa richness index values (8.00 for summer and 5.00 for winter seasons). In contrast, the lowest values of taxa richness index were found for barrier traps (5.00 for summer and 3.00 for winter season) followed by sticky traps. In case of taxa evenness index, maximum values were found for barrier traps (0.83 for winter season) followed by pitfall traps (0.80 for summer season) and pan traps (0.77 for winter season). By and large, minimum values of all three diversity indices were recorded for pan traps in both seasons, except for taxa evenness index of sticky traps (0.58) (Table 1).

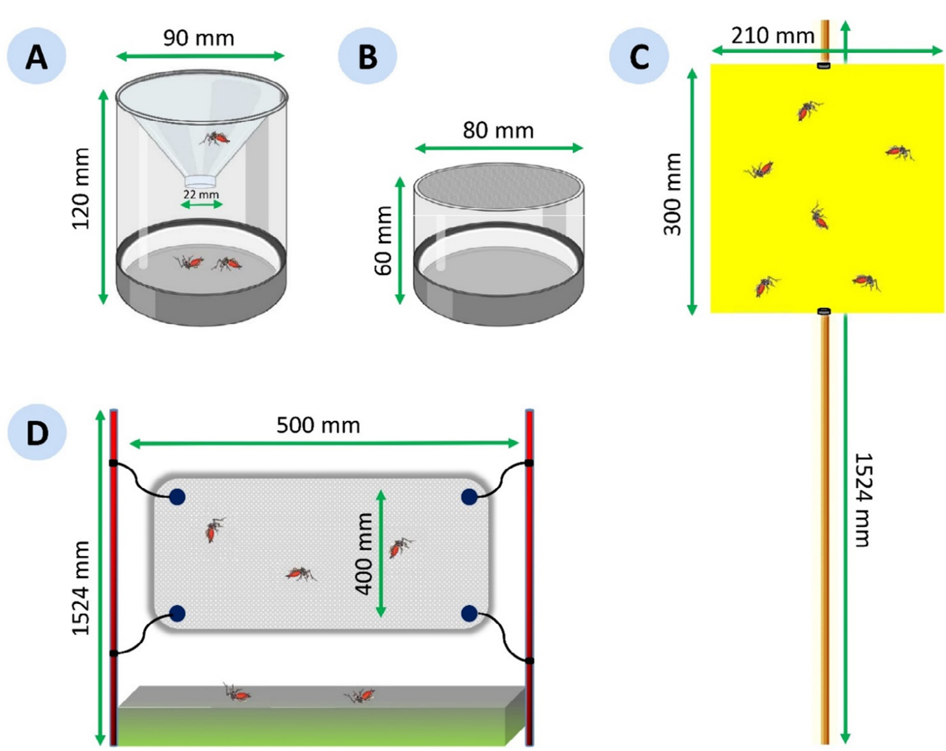

Fig. 1. Different types of traps (A; Pitfall, B; Pan, C; Yellow-sticky and D; PVC Barrier traps) used in the study.

Table 1
Diversity indices of different arthropod orders captured by different types of traps.

Trap Type Diversity Indices	Summer Season				Winter Season			
	Pan Trap	Pitfall Trap	Sticky Trap	Barrier Trap	Pan Trap	Pitfall Trap	Sticky Trap	Barrier Trap
Shannon Wiener's Diversity Index	1.18	1.65	1.08	1.19	1.06	1.17	0.79	0.91
Taxa (insect orders) Richness Index	6.00	8.00	5.00	5.00	4.00	5.00	4.00	3.00
Taxa (insect orders) Evenness Index	0.67	0.80	0.67	0.74	0.77	0.73	0.58	0.83

Table 2
Analysis of variance (factorial model) for the effects of different types of arthropod collection traps and collection seasons on population abundance of different arthropod orders captured.

Source	DF	F-value	P-value
Trap Type	3	43.18	0.001
Collection Season	1	163.38	0.001
Insect Order	8	166.89	0.000
Trap Type* Collection Season	3	1.57	0.195
Trap Type * Insect Order	24	108.33	0.000
Collection Season * Insect Order	8	12.06	0.000
Trap Type* Collection Season * Insect Order	24	6.56	0.001
Error	504		
Total	575		

Grand Mean: 5.36; Coefficient of Variation: 60.48

According to analysis of variance comparisons (Table 2), mean population abundance of all arthropod orders were significantly affected by trap type ($F_{3, 16}$ = 43.18; P = 0.001) and collection season ($F_{1, 8}$ = 163.38; P = 0.001). However, the interaction of trap type and collection season had no significant effect ($F_{5, 24}$ = 1.57; P = 0.195) on population abundance of arthropods. Insect orders and other interactions among insect orders, trap type, and the season also had a significant effect ($P \leq 0.001$) on the mean population abundance of arthropods (Table 2).

During summer season, pitfall type was found most effective traps for Arachnida (F = 28.77; P < 0.001), Coleoptera (F = 84.23; P < 0.001), Hymenoptera (F = 40.91; P < 0.001), Lepidoptera (F = 12.96; P < 0.001), Orthoptera (F = 7.21; P = 0.001) and other arthropods (F = 127.93; P < 0.001), while barrier (F = 50.62; P < 0.001) and sticky (F = 28.77;117.51; P < 0.001) traps were most effective for Diptera and Hemiptera orders, respectively (Table 3). Pan trap type was most effective for the capture of Odonata order (F = 1.89; P = 0.085). Winter season captures also exhibited the same trend of effectiveness.

In general, population abundance of arthropods was 2 times higher in summer than in winter seasons. Moreover, pan traps were 1.4 and 1.7 times less than total arthropod numbers than barrier traps in summer and winter seasons, respectively. While, about 2.0 and 2.7 times, fewer arthropods were captured in pan traps than both pitfall and sticky traps for summer and seasons, respectively (Figs. 2 and 3).

According to the taxonomic composition of different arthropods captured during summer season (Fig. 2), pitfall and sticky traps captured a higher number of arthropods than a barrier and pan ones. The most abundant arthropod order captured by sticky, pan, barrier and pitfall trap types was Hemiptera (63%), Hymenoptera (54%), Diptera and Hymenoptera (40% each) and Hymenoptera (38%), respectively (Fig. 2). In the winter season, the most abundant arthropod order captured by sticky, pitfall, barrier and pan trap types was Hemiptera (72%), Hymenoptera (50%), Hymenoptera (47%) and Hymenoptera (45%), respectively (Fig. 3). Furthermore, Pitfall traps showed most diverse arthropod community assemblage in both seasons, followed by pan traps in summer and sticky traps in the winter season (Figs. 2 and 3). By and large, Orthoptera was the least captured arthropod order in both seasons followed by Odonata. At the same time, Hymenoptera was the most abundant arthropod order in both seasons, followed by Hemiptera and Diptera.

4. Discussion

We studied the effectiveness of different cost-effective traps, i.e., pitfall trap, yellow sticky trap, pan trap and PVC barrier trap, to assess the diversity of insects in the tropical area, especially in a mango orchard. The number of insects caught by different sampling methods were examined both in summer and wintertime. Prodigious variations among insect populations were found in all sampling traps during the experiment that exhibits traps effectiveness. Although, results revealed that 54% hymenopteran captures by yellow pan trap during summertime, while the number was substantially decreased to 45% in winter. Generally, in Hymenopterans, the captures were frequent flower visitors and bees (Margatto and Gonçalves, 2017), moreover, the highest number of captures were found Hymenopterans by pan traps. Several insects captured by pan trap have been reported higher in summer or flowering season (Banaszak et al., 2014). The weekly interval sampling by traps is considered more effective as also suggested through the previous studies (Banaszak et al., 2014; Schirmel et al., 2010). Yellow sticky traps are the best physical approach to sample jassid, thrips, whiteflies and other small bugs (Atakan

Table 3
Analysis of variance comparisons of four arthropod collection traps for different arthropod orders captured during summer and winter seasons.

Arthropod orders	Summer Season			Winter Season		
	F-value	P-value	Most effective trap	F-value	P-value	Most effective trap
Arachnida	28.77	< 0.001	Pitfall Trap	5.35	0.0048	Pitfall and Sticky Traps
Coleoptera	84.23	< 0.001	Pitfall Trap	16.09	< 0.001	Pitfall Trap
Diptera	50.62	< 0.001	Barrier Trap	12.33	< 0.001	Barrier and Barrier Traps
Hemiptera	117.51	< 0.001	Sticky Trap	61.37	< 0.001	Sticky Trap
Hymenoptera	40.91	< 0.001	Pitfall and Pan Traps	33.41	< 0.001	Pitfall Trap
Lepidoptera	12.96	< 0.001	Pitfall and Barrier Traps	23.55	< 0.001	Pitfall Trap
Odonata	1.89	0.0847	Pan Trap	21.00	< 0.001	Pan Trap
Orthoptera	7.21	0.0010	Barrier and Pitfall Traps	2.33	0.0955	Pitfall Trap
Other arthropods	127.93	< 0.001	Pitfall Trap	3.80	0.0211	Pitfall Trap

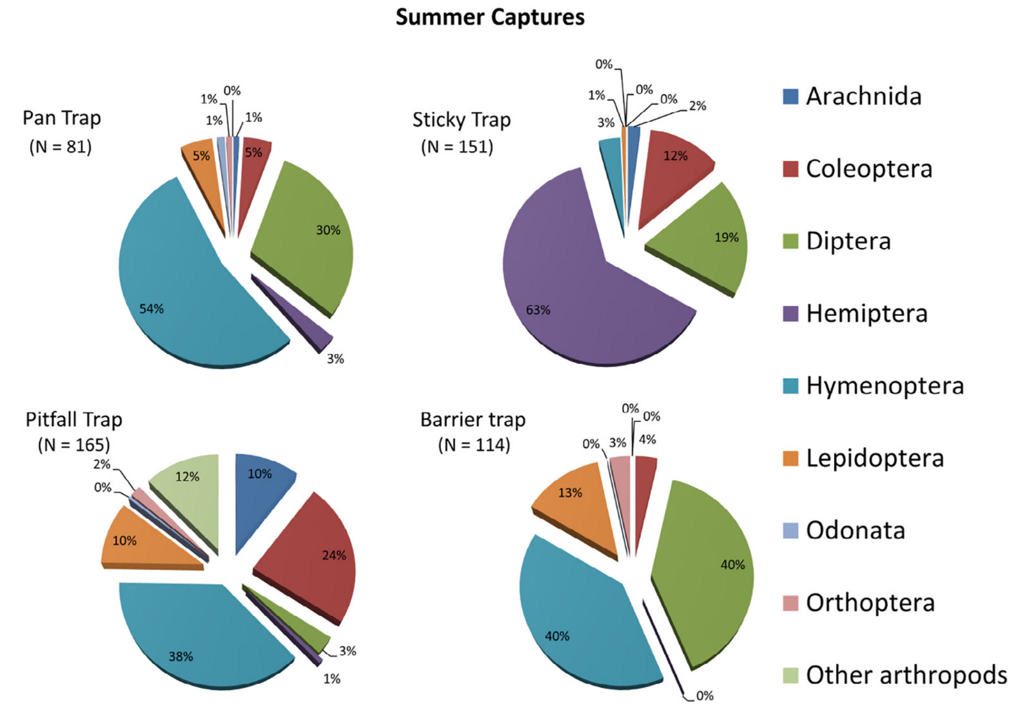

Fig. 2. Pie-charts are representing the taxonomic composition of different arthropod groups captured during summer season using four different types of collection traps. For each type of collection trap, values represent the mean (%) proportion of each arthropod group and "N" represents the total number of arthropod individuals encountered.

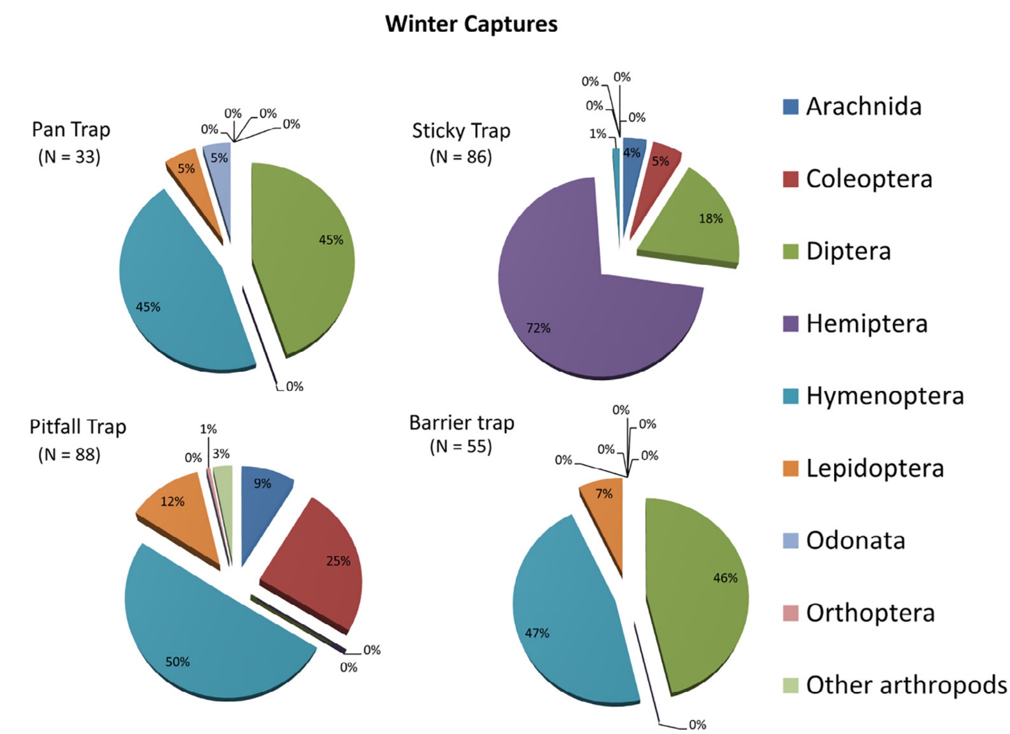

Fig. 3. Pie-charts representing taxonomic composition of different arthropod groups captured during winter season using four different types of collection traps. For each type of collection trap, values represent mean percent proportion of each arthropod group and "N" represents total number of arthropod individuals encountered.

and Canhilal, 2004; Zhao et al., 2016). To sample small insect's diversity, the yellow sticky trap was used, and significant captures of Hemiptera were resulted, i.e., 63% and 72%, both in summer and winter capture, respectively. Studies reported for yellow sticky trap captured Hemipterans (39.08%) in a large population than any other order, which indicates the efficacy of yellow sticky trap for hemipterans as also reported by our study.

To assess the soil surface or soil-dwelling insects, pitfall trap is quite a suitable sampling method to determine insect diversity (Pearce and Venier, 2005). However, some population of other arthropods was found in pitfall trap (12% in summer and 3% in winter) and could be minimized by using a funnel for pitfall trapping instead of a cup (Work et al., 2002). In pitfall traps, spiders and tods were frequently observed, other than insects which are not new in this study as also linked to previous studies (Ward et al., 2001). Hymenopteran, especially ants, were captured in the highest number during the summer as well as winter sampling by pitfall trap which agrees on the recent research (Mahon et al., 2017). It has been widely studied that ants are taken as environmental monitoring due to their high abundance, sensitivity and rapid response to ecosystem changes (Mahon et al., 2017). Likewise, next to this order, Coleopterans abundance was more as also reported (Lange et al., 2011), who used pitfall trap for ground beetles and spiders. Classification for the range of arthropods population into dominant and seldom ones is a vital tool in ecology to assess relationship and functions among the population. By using a pitfall trap, a sampling of non-insects is also suitable (Lange et al., 2011). In 1984, a passive omnidirectional barrier trap of clear Plexiglas was used for flying insects by Schmitz. Subsequently, a new windowpane trap was designed by many scientists to sample the arthropods usually in forest zones which are closely related to our PVC barrier (Bouget et al., 2008; Carrel, 2009; Grimbacher and Stork, 2009; Lamarre et al., 2012; Missa et al., 2009). We used a PVC barrier trap, a modified form of the previously used trap with more easy construction and installation designed for flying insects. Both in summer and winter captures, more insect's catches by barrier traps were hymenopteran followed by dipterans which support the study of (Lamarre et al., 2012; Schmitz, 1984), in which highest number collected by the barrier trap was Coleopteran, Hymenopteran and dipteran.

Our outcomes demonstrate the effectiveness of all traps which are inexpensive and easy to construct and install, to assess the insect diversity on any land either agricultural farm, orchards, grasslands and forest zones etc. The results disclosed the great prevalence of insects in all traps for ecological monitoring and biodiversity conservation perspectives. Though, in the monitoring plan, the abundance of non-arthropods should be minimized by improving the quality of the trap. Besides all this, future experiments could be conducted to explore the efficacy of all used traps, especially PVC barrier traps in different ecological zones to determine our outcomes as also support in other areas.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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