Potential of Ethiopian mustard, Brassica carinata *as a trap crop for large white butterfly,* Pieris brassicae *infesting Indian mustard,* Brassica juncea

Sarwan Kumar

Journal of Pest Science

ISSN 1612-4758
Volume 90
Number 1

J Pest Sci (2017) 90:129-137
DOI 10.1007/s10340-016-0771-6

Springer

J Pest Sci (2017) 90:129–137
DOI 10.1007/s10340-016-0771-6

ORIGINAL PAPER

Potential of Ethiopian mustard, *Brassica carinata* as a trap crop for large white butterfly, *Pieris brassicae* infesting Indian mustard, *Brassica juncea*

Sarwan Kumar[1]

Received: 4 January 2016 / Revised: 19 April 2016 / Accepted: 19 April 2016 / Published online: 29 April 2016

Abstract The large white butterfly, *Pieris brassicae* (L.), is an important pest of Indian mustard, *Brassica juncea* (L.) Czern., and inflicts heavy damage to all the above ground plant parts with strong yield reducing impacts. Farmers have few practical options other than to spray insecticides to protect their crop. In this study, an attempt was made during 2012–2013 and 2013–2014 crop seasons at Ludhiana, India, to evaluate Ethiopian mustard, *Brassica carinata* A. Braun as a trap crop to manage this pest as an alternate pest management strategy. *B. carinata* borders surrounding *B. juncea* were compared to chemically protected *B. juncea* and control (without *B. carinata* borders) plots for their effects on *P. brassicae* infestation and grain yield. Oviposition preference of adult butterflies was studied in a two-choice test in field cages, while the effect of two host plants on larval performance was studied under laboratory conditions under no choice conditions. *B. juncea* plots bordered with *B. carinata* harbored significantly lower larval population compared to control *B. juncea* plots during both the seasons. The grain yield in the bordered plots was also significantly higher than that from control plots and was statistically non-significant from that obtained in chemically protected plots. Female butterflies showed distinct oviposition preference for *B. carinata* over *B. juncea* and the larvae reared on *B. carinata* completed development in shorter period and grew bigger and heavier than those reared on *B. juncea*. Results indicated that *B. carinata* has potential to be used as trap crop to manage *P. brassicae*.

Keywords *Brassica carinata* · *Brassica juncea* · Oviposition preference · *Pieris brassicae* · Push–pull strategy

Key message

- With the aim to provide environmentally sound "alternative" pest management strategy against *Pieris brassicae*, Ethiopian mustard was evaluated as a trap crop around Indian mustard.
- Ethiopian mustard is highly preferred for egg laying and feeding by adults and larvae, respectively, compared to Indian mustard and can be used as an effective trap crop against this pest.
- However, further research is required to optimize trap cropping system for maximum efficiency under field conditions.

Introduction

Oilseeds occupy an important position in the agricultural economy of India. These crops are second only to food grains in terms of acreage, production, and economic value. Among the nine oilseed crops cultivated in India, seven are of edible oils (soybean, groundnut, rapeseed-mustard, sunflower, sesame, safflower, and niger) and two are of non-edible oils (castor and linseed). Among the different edible oilseeds, rapeseed-mustard is the third most important oilseed crop in the world after soybean and palm oil. In the year 2012–2013, rapeseed-mustard contributed 26 % of

Communicated by J. J. Duan.

✉ Sarwan Kumar
sarwanent@pau.edu

[1] Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana 141 004, India

the total oilseeds production from seven edible oilseed crops (Singh 2014). In India, it is the second most important edible oilseed after groundnut sharing 27.8 % in the India's oilseeds economy. During the period from 2005–2006 to 2010–2011, the share of rapeseed-mustard to the total edible *rabi* (winter season) oilseeds production was 78.9 % (Kumar 2012). The country holds a premier position in rapeseed-mustard economy of the world with 2nd and 3rd ranks in area and production, respectively. However, the average productivity of India (1176 kg/ha) is still about two-thirds of world's average yield of 1695 kg/ha (Singh 2014). There are a number of factors responsible for this low yield, among which the losses caused by insect–pests are very important ones. The large white butterfly, *Pieris brassicae* (L.) (Lepidoptera: Pieridae), has emerged as an important pest of oilseed brassicas in addition to already prevalent turnip aphid, *Lipaphis erysimi* (Kaltenbach) (Kumar 2011), and is already a serious pest of vegetable brassicas. It is a cosmopolitan pest and is found wherever cruciferous plants are grown (Hill 1987). The pest has a Palearctic distribution from North Africa across Europe and Asia to the Himalayan Mountains (Raqib 2004; Jainulabdeen and Prasad 2004). It has been recorded as a serious pest of cabbage, cauliflower, broccoli, and Brussels sprouts in different parts of the world. In India, it is reported to cause about 40 % damage per annum to different cruciferous crops (Hasan and Ansari 2010a, b), particularly cabbage and cauliflower which are the two major vegetables produced and consumed in India particularly by smallholder farmers. Intensive cultivation of different cruciferous crops over the years has resulted in high pest infestation (Chaudhuri et al. 2001; Weinberger and Srinivasan 2009), and it has started damaging crop brassicas in serious proportions. The pest is a voracious feeder and feeds on all the above ground plant parts. In the event of lack of control measures, all the leaves, flowers, and developing pods are fed upon with only twigs left intact.

At present, management of this pest relies on the use of toxic insecticidal chemicals which have their own adverse effects such as development of insecticide resistance in insect-pests, resurgence, pesticide residues in oil, and cake besides environment pollution. This necessitates the development of alternate management strategies. The use of trap crop offers one such option in pest management since it is an environmentally sound "alternative" pest management strategy. This approach may enable a reduction in the amount of insecticide required for pest management and in some cases may negate the need for insecticides altogether (Cook et al. 2007a, b). Trap crops are "plant stands that are, per se or via manipulation, deployed to attract, intercept, retain and/or reduce target insects…in order to reduce damage to the main crop" (Shelton and Badenes-Perez 2006). Several of these strategies exploit the differential host preference by many insects. In this strategy, the trap crop is planted near to main crop which results in the reduction in the number of insect–pests reaching main crop by concentrating them on the trap crop where they can be economically destroyed (Hokkanen 1991). Although this concept has received much research attention in recent years, there are relatively a few examples of successful trap cropping strategies in practice (Shelton and Badenes-Perez 2006). Stricter pesticide safety standards in many countries has resulted in withdrawal of a number of products used previously in pest management, which acted as a major driver for increased interest in trap cropping. Such product withdrawals may severely affect *Brassica* crops as there are often no alternative means of pest management (Wyman 2003). Further, using the products still available after withdrawals may be hampered as insect–pests develop resistance to them. Insecticide resistance to one or more insecticides has been reported in more than 500 insect–pest species (Altieri et al. 2004). The use of insecticides in trap cropping is either eliminated or significantly reduced since insect–pests concentrated on the trap crop can either be controlled with other control methods, when available such as cultural methods (Bensen and Temple 2008), biological pesticides or biocontrol agents (White et al. 1995), or with insecticides (Rea et al. 2002). The trap crop eliminates the need to spray the entire field and minimizes the negative effects on natural enemies in the main crop. The concept of trap cropping has been successfully tested with wheat stem sawfly (Seamans 1928), grasshoppers (Olfert 1986), wireworms (Vernon et al. 2000), and many other insects and crops around the world (Hokkanen 1991; Shelton and Badenes-Perez 2006), and has led to substantial reductions in pesticide use in many cropping systems. For example, planting alfalfa strips in cotton fields lowered lygus bug (*Lygus* spp.) (Hemiptera: Miridae) population levels significantly and eliminated the need for insecticide use on cotton crop in the United States (Stern et al. 1964, 1969; Godfrey and Leigh 1994). In north China, the use of mungbean is gradually being adopted as a trap crop for the control of *Apolygus lucorum* (Meyer-Dür) (Hemiptera: Miridae) on cotton crop (Lu et al. 2009). Despite many advantages, the application of trap cropping at commercial scale is still limited, partly due to initial cost of setting aside land for trap cropping, agronomic consideration associated with implementing trap crop, and potential for crop yield reductions if the trap crop fails (Hokkanen 1991; Shelton and Badenes-Perez 2006; Lin et al. 2015). Thus, there is a need to accelerate the use of trap cropping in insect–pest management.

The main aim of this study was to test whether Ethiopian mustard, *Brassica carinata* A. Braun can be used as a trap crop to attract *P. brassicae*. For this, the effectiveness of *B. carinata* as a trap crop was examined by comparing larval densities in Indian mustard, *Brassica juncea* (L.) Czern., crop bordered and unbordered with trap crop. The effectiveness of *B. carinata* in field cages and laboratory conditions was also examined.

Materials and methods

Insects and plant materials

Pieris brassicae larvae were collected from flowering turnip rape, *B. rapa* plants in the field (sown in September) during November, and brought to the laboratory. These larvae were reared in glass jars (10 cm length, 5 cm diameter) on cabbage heads till pupation. Adults emerging out of the pupae were paired in oviposition cages (30 × 30 × 30 cm) @ one pair per cage. The floor of the cage was lined with filter paper, and a few pieces of cabbage heads were placed at the bottom to act as oviposition substrate. Eggs thus obtained were kept in Biological Oxygen Demand (B.O.D.) incubator at 22 ± 1 °C, and the adults obtained from this generation were used for study of oviposition preference.

I used two hosts of *P. brassicae*, Ethiopian mustard, *Brassica carinata* A. Braun (cv. PC 5), and Indian mustard, *Brassica juncea* (L.) Czern. (cv. PBR 210), as experimental plants. *B. carinata* was assessed as trap crop around *B. juncea* main crop to attract *P. brassicae.* The selected *B. carinata* (cv. PC 5) was reported to be preferred by *P. brassicae* over *B. juncea* (Kular and Kumar 2011). The *B. juncea* cultivar (PBR 210) was susceptible to *P. brassicae* infestations under field conditions (Anonymous 2012).

Oviposition preference under choice conditions

The oviposition preference of *Pieris* female butterflies was determined under caged conditions in a two-choice test. For this, test plants of both the host species were sown in earthen pots (10 cm diameter). These potted plants were maintained under natural field conditions since previous experience with the potted plants under screen house conditions has shown that these tend to be more succulent and showed more luxurious growth than those grown under natural field conditions which may influence the natural host selection by female butterflies. When the plants were 60 days old, one potted plant of each *Brassica* species was placed in a field cage (1 × 1 × 3 m) covered with fine nylon mesh. Before this, whole plant was visually inspected for the presence of eggs/larvae which were removed. Two freshly emerged male and female butterflies were introduced in each cage and allowed to oviposit for 7 days which has been reported to be the period of maximum egg laying (Hasan and Ansari 2011). Data on the number of eggs laid on each plant were recorded after seven days of release. There were five biological replicates, and the experiment was repeated thrice.

Effect of host species on demographic parameters of larvae under laboratory conditions

The suitability of the two *Brassica* species as larval hosts was assessed under laboratory conditions. For this, 10 first instar larvae per replication were released in plastic Petri plate (2.5 cm height, 10 cm diameter) with the help of camel's hair brush and were provided with fresh leaves of each of the host species as larval food. The experiment was set up following completely randomized design with three biological replicates. The larvae were provided fresh food every other day till pre-pupation when they stopped feeding. Larval survival was recorded every alternate day, and the percent larval survival was worked out. The time taken from release of larvae till pupation was recorded as larval development time. Development time was recorded from the five surviving larvae in each replication. In addition, larval weight of five fully grown fifth instar larvae in each replication was recorded when they stopped feeding and aligned on the sides/top of the Petri plate for pupation.

Field experiments

The field experiments were conducted at Oilseeds Research Farm of Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana (30.9°N and 75.85°E, 244 m above msl), India during 2012–2013 and 2013–2014 crop seasons (November to April). This part of the country is characterized by sub-tropical and semi-arid climate with hot and dry spring–summer from April to June, and hot and humid summer from July to September. The crop season generally spans from October–November to April and is characterized by cold winters where the maximum temperature rises up to 31 °C and sometimes even more at the end of the season in March–April, while it falls to minimum of 1 °C and sometimes even lower than that during December–January, with RH ranging from 30.0 to more than 90.0 %. The average annual rainfall is about 705 mm, most of which is received during monsoon period from July to September, while a few showers are received during winter season from November to March. The treatments consisted of (1) *B. juncea* surrounded by rows of *B. carinata*, (2) a chemically protected *B. juncea* stand, and (3) an unprotected *B. juncea* stand as control. In total, nine *B. juncea* plots were sown in a randomized complete block design with a plot size of 6 × 5 m. Three plots were bordered by four rows of *B. carinata* (cv. PC 5), while the other three were sprayed with dichlorvos 85 SL @ 500 ml ha^{-1} against *P. brassicae* at the time of pest appearance since it is recommended insecticide for its management in this part of the country (Anonymous 2012). The remaining three plots were kept as unprotected pure *B. juncea* control. The plots and blocks were separated by 1.5 and 3 m of open space, respectively. Sowing was deliberately delayed than normal sowing in October and was done during November 14 and November 17 in 2012 and 2013, respectively, to ensure heavy population build up under natural conditions since late sown crop is attacked more by the pest (Kular and Kumar 2011; Kumar 2011). The row to row and plant to plant spacing was maintained at 30 × 15 cm, respectively. At the time of sowing a uniform dose of nitrogen and phosphorous was applied and about 20 days after sowing, manual weed removal method was advocated. All the recommended package of practices was followed for raising a good crop except spray of insecticides (Anonymous 2012).

Natural infestation was allowed to take place, and no pest control measures were applied except in the case of chemically protected *B. juncea* plots. At the time of pest appearance, 10 plants from middle six rows of each plot were selected at random, and weekly data on the larval density were recorded by counting total number of larvae present on each observed plant. Likewise data from the border rows of *B. carinata* were also recorded. At the time of harvesting, data on the grain yield were recorded from middle twelve rows of each plot.

Statistical analysis

In the field experiments and effect of host plants on demographic parameters of larvae under laboratory conditions and oviposition preference in field cages, data on the larval density, grain yield, larval survival, development time, larval weight, number of egg batches and number of eggs per plant were subjected to analysis of variance (ANOVA) using the statistical software SAS 9.1 (SAS Institute 2005). For the data on larval density, $\sqrt{n+1}$ transformation was used to stabilize variances. Whenever the F test was significant ($P < 0.05$), means among treatments were separated by LSD.

Results

Oviposition preference under field cages

Pieris brassicae females preferred to oviposit on *B. carinata* over *B. juncea* in a two-choice test. The number of egg batches (Experiment I: $F_{1,4} = 16.00$, $P = 0.016$; Experiment II: $F_{1,4} = 16.00$, $P = 0.016$; Experiment III: $F_{1,4} = 23.14$, $P = 0.008$; Pooled data of three experiments: $F_{1,4} = 123.66$, $P = 0.00037$) and total number of eggs per plant (Experiment I: $F_{1,4} = 67.83$, $P = 0.0011$, Experiment II: $F_{1,4} = 67.89$, $P = 0.0011$, Experiment III: $F_{1,4} = 96.92$, $P = 0.00059$, Pooled data of three experiments $F_{1,4} = 461.62$, $P = 0.000028$) were significantly higher on *B. carinata* than that on *B. juncea* (Table 1).

Effect of host plants on demographic parameters of larvae under laboratory conditions

The differences in larval survival on *B. carinata* and *B. juncea* were non-significant at all the observation intervals ($F_{1,4} = 0.25$, $P = 0.64$ one day after release (DAR), $F_{1,4} = 1.00$, $P = 0.37$ four DAR, $F_{1,4} = 0.50$, $P = 0.51$ seven DAR, $F_{1,4} = 1.50$, $P = 0.28$ ten DAR) (Table 2). However, significant differences in larval development time and weight were observed when reared on different host plants (Table 3). The larval development time when reared on *B. carinata* (14.93 days) was significantly lower than those reared on *B. juncea* (17.93 days) ($F_{1,4} = 253.12$, $P = 0.000091$). On the other hand, weight of larvae reared on *B. carinata* was significantly more than those reared on *B. juncea* ($F_{1,4} = 6948.18$, $P = 0.000000$).

Field experiments

Variations in the field incidence of *P. brassicae* larvae were observed among different treatments across different sampling intervals during both the seasons (Table 4). During 2012–2013 crop season, larval density in *B. juncea* plots bordered with *B. carinata* was significantly lower than unbordered/control *B. juncea* plots at all the observation intervals ($F_{3,2} = 58.73$, $P = 0.000077$ for mean larval density). However, it differed non-significantly from that in the chemically protected *B. juncea* plots. Interestingly, larval density on *B. carinata* border rows surrounding *B. juncea* plots was exceptionally high and remained significantly higher than that observed in the bordered, control, and chemically protected *B. juncea* plots throughout the observation period. During 2013–2014 cropping season, similar results were observed with larval density in *B. juncea* plots bordered with *B. carinata* being significantly lower than control *B. juncea* plots ($F_{3,2} = 42.69$, $P = 0.00019$ for mean larval density) and was non-significant from that recorded in chemically protected *B. juncea* plots. Mean larval density on *B. carinata* border rows surrounding *B. juncea* plots was exceptionally higher than the bordered, control, and chemically protected *B. juncea* plots.

Significant differences in grain yield were observed during both the years. *B. juncea* plots bordered with *B. carinata* and chemically protected *B. juncea* plots had

Table 1 Oviposition preference of *Pieris brassicae* under two-choice tests in field cages

Host plant	No. of egg batches/plant				No. of eggs/plant			
	Experiment I	Experiment II	Experiment III	Pooled data	Experiment I	Experiment II	Experiment III	Pooled data
Brassica juncea	1.00 ± 0.00 a	0.60 ± 0.24 a	0.60 ± 0.24 a	0.73 ± 0.12 a	16.00 ± 3.08 a	4.80 ± 2.57 a	5.20 ± 2.33 a	8.67 ± 1.05 a
B. carinata	1.80 ± 0.20 b	2.20 ± 0.20 b	2.40 ± 0.24 b	2.13 ± 0.07 b	78.20 ± 6.43 a	84.20 ± 8.03 a	92.00 ± 8.21 a	84.80 ± 3.14 b

Mean ± SE; means within a column without corresponding letters are significantly different (LSD test; $p \leq 0.05$)

significantly higher grain yield than control plots during both 2012–2013 ($F_{2,2} = 28.38$, $P = 0.0043$) and 2013–2014 ($F_{2,2} = 26.58$, $P = 0.0048$) crop seasons but differed non-significantly from each other.

Discussion

In response to visual, tactile, or olfactory cues, insects often demonstrate preference for a particular plant species, cultivar, or crop stage. These preferences can be exploited for pest management through the use of trap crops. The optimality theory suggests that ovipositing females should choose plant species that maximize larval fitness (Thompson and Pellmyr 1991). In two-choice oviposition test, *P. brassicae* females preferred to lay eggs on *B. carinata* plants over *B. juncea.* Compared with *B. juncea, B. carinata* was >10 times as attractive for oviposition in a two-choice test in field cages. The selection of host plants by female *Pieris* butterflies is initially guided by visual cues (Traynier 1979; Kolb and Scherer 1982; Renwick and Radke 1988); however, the final decision about acceptance or rejection of a host plant for oviposition is made after females drum the leaf surface with their tarsi and perceive the contact chemoreception (Ma and Schoonhoven 1973; Renwick and Radke 1988). The results from the present study show a distinct preference of *P. brassicae* for *B. carinata* as was reported in previous studies (Kular and Kumar 2011; Chahil and Kular 2013) which indicated the increased preference of *P. brassicae* for *B. carinata* over other Brassica hosts. Further, *B. carinata* also served as a better host for larvae compared to *B. juncea* since larvae reared on *B. carinata* completed development in comparatively shorter period and grew bigger and heavier. In another study at the same institute, Kaur (2015) has also reported shorter larval development period and significantly more larval weight of *P. brassicae* on *B. carinata* cv. PC 5 (the same cultivar used in the present study) over a range of other Brassicaceous hosts including brassica wild relatives. The basis of this differential preference for oviposition and suitability of *B. carinata* over *B. juncea* may possibly be linked to glucosinolates, the main cues used for host location, and feeding by adults and larvae, respectively. The concentration of total glucosinolates in leaf tissues was found to be significantly higher in *B. carinata* cv. PC 5 over *B. juncea* cv. PBR 210 (Kaur 2015). Adult females as well as larvae are known to exploit glucosinolates as token stimuli during selection of host plants for oviposition and feeding (David and Gardiner 1966; Renwick et al. 1992; van Loon et al. 1992; Moyes et al. 2000; Schoonhoven and van Loon 2002; Kumar and Singh 2015).

Table 2 Percent larval survival of *Pieris brassicae* on test host plants at different observation times

Host plant	Larval survival (%)			
	1 DAR*	4 DAR	7 DAR	10 DAR
Brassica juncea	86.67 ± 3.33 a	70.00 ± 5.77 a	66.67 ± 8.82 a	60.00 ± 5.77 a
B. carinata	90.00 ± 5.77 a	76.67 ± 3.33 a	73.33 ± 3.33 a	70.00 ± 5.77 a

* DAR = days after release

Mean ± SE; means within a column without corresponding letters are significantly different (LSD test; $p \leq 0.05$)

Table 3 Larval development time and larval weight of *Pieris brassicae* on test host plants

Host plant	Development time (days)	Larval weight of fully grown fifth instar larvae (mg)*
Brassica juncea	17.93 ± 0.06 b	423.10 ± 0.45 a
B. carinata	14.93 ± 0.17 a	461.90 ± 0.13 b

Mean ± SE; means within a column without corresponding letters are significantly different (LSD test; $p \leq 0.05$)

* Larvae were weighed when they were fully grown, i.e., when they stopped feeding and alighted on the sides or top of the Petri plate for pupation

Table 4 Effect of different treatments on *Pieris brassicae* infestation and grain yield during the two seasons

Treatment	Larval density during different standard meteorological weeks (SMWs) (No. of larvae/plant)					Yield (kg/plot)
	10th SMW	11th SMW	12th SMW	13th SMW	Mean density	
2012–2013						
B. juncea plots bordered with *B. carinata*	0.00 ± 0.00 a	4.50 ± 1.21 a	0.00 ± 0.00 a	–	1.50 ± 0.40 a	5.35 ± 0.25 b
B. carinata border rows	33.7 ± 4.51 c	75.60 ± 13.14 c	41.80 ± 1.79 c	–	50.40 ± 5.89 c	–
Unbordered/control *B. juncea* plots	5.10 ± 1.50 b	21.10 ± 0.80 b	6.00 ± 0.52 b	–	10.70 ± 0.78 b	3.97 ± 0.12 a
Chemically protected *B. juncea* plots	0.00 ± 0.00 a	0.00 ± 0.00 a	0.00 ± 0.00 a	–	0.00 ± 0.00 a	5.49 ± 0.19 b
2013–2014						
B. juncea plots bordered with *B. carinata*	2.60 ± 0.55 a	4.00 ± 0.90 a	1.30 ± 0.63 a	0.00 ± 0.00 a	2.00 ± 0.20 a	5.31 ± 0.20 b
B. carinata border rows	73.80 ± 22.28 b	106.00 ± 4.60 c	44.20 ± 5.35 c	1.60 ± 0.56 b	56.40 ± 7.69 c	–
Unbordered/control *B. juncea* plots	56.40 ± 11.27 b	42.20 ± 9.06 b	18.40 ± 5.14 b	0.00 ± 0.00 a	29.30 ± 6.32 b	3.86 ± 0.08 a
Chemically protected *B. juncea* plots	0.00 ± 0.00 a	0.00 ± 0.00 a	0.00 ± 0.00 a	0.00 ± 0.00 a	0.00 ± 0.00 a	5.53 ± 0.17 b

Means within a column without corresponding letters are significantly different (LSD test; $p \leq 0.05$)

No incidence reported due to crop maturity

Brassica juncea plants bordered with *B. carinata* had lower larval density than control plots at different sampling intervals during both the seasons, which was statistically at par with the larval population in chemically protected plots. The reduction in larval density on bordered *B. juncea* plots over control plots was around 86 and 93 % in 2012–2013 and 2013–2014 crop seasons, respectively. Kular and Kumar (2011) has also reported higher incidence of *P. brassicae* on *B. carinata* compared to *B. juncea*, *B. napus*, *B. rapa*, and *Eruca sativa.* The differences in grain yield also varied significantly between *B. carinata* surrounded *B. juncea* plots and control *B. juncea* plots, and the yield obtained from bordered plots was statistically at par with that obtained from chemically protected plots. As per the available literature, there has been no comprehensive study to evaluate the effectiveness of *B. carinata* as trap crop for *P. brassicae* and the present study is the first attempt in India against this important pest of vegetable and oilseed brassicas.

Habitat diversification systems are effective integrated pest management tools for a number of insect–pests. In addition to reduction in the use of harmful pesticides, push–pull system is of particular interest to small holder farmers in a developing country like India, who invest little or no money to inputs required to control the pests. It is an appropriate system for resource poor farmers since it uses locally available plants rather than expensive imported inputs (Khan et al. 2014). However, trap crop requires land that would otherwise be used for growing main crop. Therefore, it requires a thorough economic and agronomic analysis of benefits and liabilities of using a trap crop. In field trials of the present study, four rows of *B. carinata* plants around *B. juncea* plots were grown, and there is a need to optimize this for obtaining maximum efficiency of trap crop. The economic value of trap crop is an important factor in its large scale use (Hokkanen 1991; Shelton and Badenes-Perez 2006; Khan et al. 2008, 2009). It is, therefore, important to develop an optimal planting pattern for *B. carinata* with strips either comprising the smallest possible percentage of the total field, or to offset commercial mustard losses by the grain yield obtained from *B. carinata*, though not equal to commercial mustard. Under the present market conditions in India, grains of both Indian and Ethiopian mustard fetch equal price; hence, the trap crop can get an economic value in its own right. However, there is a need of comprehensive study of economic value of Ethiopian mustard as a trap crop in Indian mustard. Further, the spatial and temporal pattern of trap crop deployment is needed to be worked out to ensure most effective trap crop system. For this, there is need to investigate not only the dispersal patterns of *P. brassicae* as it moves into the field but also its behavior within the field. The information generated through these studies about the movement patterns of *P. brassicae* will help in designing an effective trap cropping system for this important pest of vegetable and oilseed brassicas. Since trap crops are more attractive to a pest, thereby lowering the pest population levels in the main crop, they become resource habitats for the pest. Therefore, additional measures are necessary to suppress pest population within trap crops (Hokkanen 1991; Shelton and Badenes-Perez 2006). Faster larval development and increased oviposition preference on *B. carinata* suggest its potential of becoming source habitat for *P. brassicae*. Therefore, need-based suppression of pest population in trap crop is required which further requires regular population monitoring. A number of techniques such as trap harvesting, trap vacuuming, sticky traps, pheromones, natural enemies, or pesticides have been used for pest population suppression in trap crop (Shelton and Badenes-Perez 2006; Holden et al. 2012; Moreau and Isman 2012; Tillman and Cottrell 2012). Additional tactics could improve the effect of trap crop strips and targeted insecticide on resident pest populations, and bring about further reductions in pest population levels (Lin et al. 2015). The influence of *B. carinata* on disease control and secondary pest problem also requires further research, though no such problem was reported in the present study. Another advantage of use of trap crop is conservation of natural enemies of the pest. However, in the present study, I did not focus on whether trap crop can augment biocontrol of *P. brassicae* by its parasitoids, though some larval parasitization by *Cotesia glomerata* L. was reported. Further studies involving greater replications are required to investigate this question in greater detail.

It was confirmed from the study that trap crop plants should be highly acceptable to pest insect for oviposition, feeding, or both to function more effectively. When this does not happen, i.e., when the trap crop consists of relatively non-preferred host plants, it results in failure of pest management system (Rust 1977; Maguire 1984). Where trap crops have proved successful in managing insect–pests, they were grown as border rows surrounding the main crop or as strips running at right angle to the pests' entry route into the crop (Srinivasan and Krishna Moorthy 1991; Luther et al. 1996; Mitchell et al. 2000; Asman 2002; Rousse et al. 2003; Barari et al. 2005; Fearson et al. 2005).

Conclusion

It can be concluded from the present study that *B. carinata* has the potential to be used as trap crop in limiting the attack by *P. brassicae* on Indian mustard (*B. juncea*) by utilizing the pest's preference for these plants. *B. carinata* might make for attractive trap crop since it is longer duration crop and flowers very late compared to *B. juncea*. Further research will nevertheless be required to confirm these results under field conditions with large plot sizes representing the farmers' fields. In addition to crop brassicas, the attractiveness of *B. carinata* can also be exploited to serve as a trap crop in vegetable brassicas against this pest which has wider implications keeping in view the seriousness of the pest on brassica vegetables in many countries of the world.

Author contributions

S. K. designed and conducted experiments, collected and analyzed the data, and wrote the manuscript.

Acknowledgments The financial support from the Department of Biotechnology, Government of India in the form of International Travel Support (No. DBT/CTEP/02/201500680) to present the work at '14th International Rapeseed Congress' held from July 05–09, 2015 at Saskatoon, Saskatchewan, Canada, was duly acknowledged.

Compliance with ethical standards

Conflict of interest The author declares that he has no conflict of interest.

References

Altieri MA, Gurr GM, Wratten SD (2004) Genetic engineering and ecological engineering: a clash of paradigms or scope for synergy? In: Gurr GM, Wratten SD, Altieri MA (eds) Ecological engineering for pest management: advances in habitat manipulation for arthropods. CABI Publishing, Wallingford, pp 13–31

Anonymous (2012) Package of practices for crops of Punjab-Rabi. Directorate of Extension Education. Punjab Agricultural University, Ludhiana, pp 43–53

Asman K (2002) Trap cropping effect on oviposition behaviour of the leek moth *Acrolepiopsis assectella* and the diamondback moth *Plutella xylostella*. Entomol Exp Appl 105:153–164

Barari H, Cook S, Clark S, Williams I (2005) Effect of a turnip rape (*Brassica rapa*) trap crop on stem-mining pests and their parasitoids in winter oilseed rape (*Brassica napus*). BioControl 50:69–86

Bensen TA, Temple SR (2008) Trap cropping, planting date, and cowpea variety as potential elements of an integrated pest management strategy for *Lygus hesperus* in blackeyed cowpea. Crop Prot 27:1343–1352

Chahil GS, Kular JS (2013) Biology of *Pieris brassicae* (Linn.) on different *Brassica* species in the plains of Punjab. J Plant Prot Res 53:53–59

Chaudhuri N, Ghosh S, Ghosh J, Senapati SK (2001) Incidence of insect pests of cabbage in relation to prevailing climatic conditions of Terai region. Indian J Entomol 63:421–428

Cook SM, Khan ZR, Pickett JA (2007a) The use of push–pull strategies in integrated pest management. Annu Rev Entomol 52:375–400

Cook SM, Rasmussen HB, Birkett MA, Murray DA, Pye BJ, Watts NP, Williams IH (2007b) Behavioural and chemical ecology underlying the success of turnip rape (*Brassica rapa*) trap crops in protecting oilseed rape (*Brassica napus*) from the pollen beetle (*Meligethes aeneus*). Arthropod Plant Interact 1:57–67. doi:10.1007/s11829-007-9004-5

David WAL, Gardiner BO (1966) Mustard oil glucosides as feeding stimulants for *Pieris brassicae* larvae in a semi-synthetic diet. Entomol Exp Appl 9:247–255

Fearson DJT, Ferguson AW, Campbell JM, Williams IH (2005) The spatial dynamics of pollen beetles in relation to inflorescence growth stage of oilseed rape: implications for trap crop strategies. Entomol Exp Appl 116:21–29

Godfrey LD, Leigh TF (1994) Alfalfa harvest strategy effect on Lygus bug (Hemiptera: Miridae) and insect predator population density: implications for use as trap crop in cotton. Environ Entomol 23:1106–1118

Hasan F, Ansari MS (2010a) Effect of different cole crops on the biological parameters of *Pieris brassicae* (L.) (Lepidoptera: Pieridae) under laboratory condition. J Crop Sci Biotechnol 3:195–202

Hasan F, Ansari MS (2010b) Population growth of *Pieris brassicae* (L.) (Lepidoptera: Pieridae) on different cole crops under laboratory conditions. J Pest Sci. doi:10.1007/s10340-010-0339-9

Hasan F, Ansari MS (2011) Effects of different brassicaceous host plants on the fitness of *Pieris brassicae* (L.). Crop Prot 30:854–862

Hill DS (1987) Agricultural insect pests of temperate regions and their control. Cambridge University Press Archive, Cambridge

Hokkanen HMT (1991) Trap cropping in pest management. Annu Rev Entomol 36:119–138

Holden MH, Ellner SP, Lee D, Nyrop JP, Sanderson JP (2012) Designing an effective trap cropping strategy: the effects of attraction, retention and plant spatial distribution. J Appl Ecol 49:715–722

Jainulabdeen S, Prasad SK (2004) Severe infection of cabbage butterfly, *Pieris brassicae* (L.) on six species of brassica and effect of abiotic factors on its population dynamics. J Entmol Res 28:193–197

Kaur J (2015) Screening of *Brassica* germplasm for resistance against *Pieris brassicae* (L.). M.Sc. Thesis submitted to Punjab Agricultural University, Ludhiana, p. 81

Khan ZR, Midega CAO, Amudavi DM, Njuguna EM, Wanyama JW, Pickett JA (2008) Economic performance of the ‘push–pull’ technology for stem borer and striga control in small holder farming systems in western Kenya. Crop Prot 27:1084–1097

Khan ZR, Midega CAO, Wanyama JM, Amudavi DM, Hassanali A, Pittchar J, Pickett JA (2009) Integration of edible beans (*Phaseolus vulgaris* L.) into the push–pull technology developed for stem borer and striga control in maize-based cropping systems. Crop Prot 28:997–1006

Khan ZR, Midega CAO, Pittchar JO, Murage AW, Birkett MA, Bruce TJA, Pickett JA (2014) Achieving food security for one million sub-Saharan African poor through push-pull innovation by 2020. Philos Trans R Soc B 369:20120284

Kolb GK, Scherer C (1982) Experiments on wavelength-specific behavior of *Pieris brassicae* L. during drumming and egg-laying. J Comp Physiol 149:325–332

Kular JS, Kumar S (2011) Quantification of avoidable yield losses in oilseed *Brassica* caused by insect pests. J Plant Prot Res 51:38–43

Kumar S (2011) *Cotesia glomeratus*—a potential biocontrol agent for large white butterfly, *Pieris brassicae* in Indian Punjab. In: Proceedings of 13th international rapeseed congress, Prague, June 05–09, 2011, vol 13. pp 1141–1143

Kumar A (2012) Production barriers and technological options for sustainable production of rapeseed-mustard in India. J Oilseeds Brassica 3:67–77

Kumar S, Singh YP (2015) Insect Pests. In: Kumar A, Banga SS, Meena PD, Kumar PR (eds) Brassica oilseeds breeding and management. CABI Publishing, Wallingford, pp 193–232

Lin K, Lu Y, Wan P, Yang Y, Wyckhuys KAG, Wu K (2015) Simultaneous reduction in incidence of *Bemisia tabaci* (Hemiptera: Aleyrodidae) and *Sylepta derogata* (Lepidoptera: Pieridae) using velvetleaf, *Abutilon theophrasti* as a trap crop. J Pest Sci 88:49–56

Lu YH, Wu KM, Wyckhuys KAG, Guo YY (2009) Potential of mungbean, *Vigna radiatus* as a trap crop for managing *Apolygus lucorum* (Hemiptera: Miridae) on Bt cotton. Crop Prot 28:77–81

Luther GC, Valenzuela HR, Defrank J (1996) Impact of cruciferous trap crops on Lepidopteran pests of cabbage in Hawaii. Environ Entomol 25:39–47

Ma WC, Schoonhoven LM (1973) Tarsal contact chemosensory hairs of the large white butterfly *Pieris brassicae* and their possible role in oviposition behaviour. Entomol Exp Appl 16:343–357

Maguire LA (1984) Influence of surrounding plants on densities of *Pieris rapae* (L.) eggs and larvae (Lepidoptera: Pieridae) on collards. Environ Entomol 13:464–468

Mitchell ER, Hu G, Johanowicz D (2000) Management of diamondback moth (Lepidoptera: Plutellidae) in cabbage using collard as a trap crop. HortScience 35:875–879

Moreau TL, Isman MB (2012) Combining reduced risk products, trap crops and yellow sticky traps for greenhouse whitefly (*Trialeurodes vaporariorum*) management on sweet pepper (*Capsicum annum*). Crop Prot 34:42–46

Moyes CL, Collin HA, Britton G, Raybould AF (2000) Glucosinolates and differential herbivory in wild populations of *Brassica oleracea*. J Chem Ecol 26:2633–2641

Olfert OO (1986) Evaluation of trap strips for grasshopper (Orthoptera: Acrididae) control in Saskatchewan. Can Entomol 118:133–140

Raqib A (2004) Population dynamics of cabbage butterfly and cabbage aphid on five cultivars of cauliflower at Peshawar. Asian J Plant Sci 3:391–393

Rea JH, Wratten SD, Sedcole R, Cameron PJ, Davis SI, Chapman RB (2002) Trap cropping to manage green vegetable bug *Nezara viridula* (L.) (Heteroptera: Pentatomidae) in sweet corn in New Zealand. Agric For Entomol 4:101–107

Renwick JAA, Radke CD (1988) Sensory cues in the host selection for oviposition by the cabbage butterfly, *Pieris rapae*. J Insect Physiol 34:251–257

Renwick JAA, Radke CD, Sachdev-Gupta K, Städler E (1992) Leaf surface chemicals stimulating oviposition by *Pieris rapae* (Lepidoptera: Pieridae) on cabbage. Chemoecology 3:33–38

Rousse P, Fournet S, Porteneuve C, Brunel E (2003) Trap cropping to control *Delia radicum* populations in cruciferous crops: first results and future applications. Entomol Exp Appl 109:133–138

Rust RW (1977) Evaluation of trap crop procedures for control of Mexican bean beetle in soybeans and lima beans. J Econ Entomol 70:630–632

SAS Institute (2005) SAS/Stat software: version 9.1. SAS Institute, Cary

Schoonhoven LM, van Loon JJA (2002) An inventory of taste in caterpillars: each species its own key. Acta Zool Acad Sci Hung 48(Suppl. 1):215–263

Seamans HL (1928) The value of trap crops in the control of the wheat stem sawfly in Alberta. Annual report entomological society of Ontario. pp 59–64

Shelton AM, Badenes-Perez FR (2006) Concepts and applications of trap cropping in pest management. Annu Rev Entomol 51:285–308

Singh D (2014) Genetic enhancement of mustard for seed yield and its sustainability. In: Kumar V, Meena PD, Singh D, Banga S, Sardana V, Banga SS (eds) Abstracts, 2nd national Brassica conference on brassicas for addressing edible oil and nutritional security, Punjab Agricultural University, Ludhiana, 14–16 Feb 2014. p 18

Srinivasan K, Krishna Moorthy PN (1991) Indian mustard as a trap crop for management of major lepidopterous pests on cabbage. Trop Pest Manag 37:26–32

Stern VM, van den Bosch R, Leigh TF (1964) Strip cutting alfalfa for lygus bug control. Calif Agric 18:4–6

Stern VM, Mueller A, Sevacherian V, Way M (1969) Lygus bug control in cotton through alfalfa interplanting. Calif Agric 23:8–10

Thompson JN, Pellmyr O (1991) Evolution of oviposition behavior and host preference in Lepidoptera. Ann Rev Entomol 36:65–89

Tillman PG, Cottrell TE (2012) Case study: trap crop with pheromone traps for suppressing *Euschistus servus* (Heteroptera: Pentatomidae) in cotton. Psyche. doi:10.1155/2012/401703

Traynier RMM (1979) Long term changes in the oviposition behavior of the cabbage butterfly *Pieris rapae* induced by contact with plants. Physiol Entomol 4:87–96

van Loon JJA, Blaakmeer A, Griepink FC, van Beek TA, Schoonhoven LM, de Groot A (1992) Leaf surface compound from *Brassica oleracea* (Cruciferae) induces oviposition by *Pieris brassicae* (Lepidoptera: Pieridae). Chemoecology 3:39–44

Vernon RS, Kabaluk R, Behringer A (2000) Movement of *Agriotes obscurus* (Coleoptera: Elateridae) in strawberry (Rosaceae) plantings with wheat (Gramineae) as a trap crop. Can Entomol 132:231–241

Weinberger K, Srinivasan R (2009) Farmers' management of cabbage and cauliflower pests in India and their approaches to crop protection. J Asia Pac Entomol 12:253–259

White AJ, Wratten SD, Berry NA, Weigmann U (1995) Habitat manipulation to enhance biological control of *Brassica* pests by hover flies (Diptera: Syrphidae). J Econ Entomol 88:1171–1176

Wyman V (2003) Pesticide withdrawals threaten crop supplies. Food Manuf (August): 4