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Original Article

Performance and parasitism rate of *Diadegma insulare* (Cresson) (Hymenoptera: Ichneumonidae), a larval parasitoid of diamondback moth (*Plutella xylostella*) on brassica genotypes: a life table analysis

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Abstract

The performance, life history, and parasitism rate of *Diadegma insulare* **(**Cresson) (Hymenoptera: Ichneumonidae) on *Plutella xylostella* (Linnaeus, 1857) (Lepidoptera: Plutellidae) reared on six different cruciferous cultivars (Broccoli, Cabbage, Canola, Cauliflower, Chinese cabbage and PakChoi) was evaluated under controlled conditions (25±2 °C, 65±5% RH, and 16 L: 8 D photoperiod). The life history parameters were compared using the age-stage and two-sex life table theory. Significant variations were observed in different life stages of *D. insulare* on its host, *P. xylostella,* reared on different cruciferous genotypes. The adult duration of *D. insulare* ranges from 7.70 day on Pak Choi to 6.65 day on Cabbage. The maximum (19.83 offspring) and minimum (9.23 offspring) net reproductive rates of *D. insulare* were observed on cultivars Pak Choi and Cabbage, respectively. The increase in intrinsic rate ranged from the highest (0.1970 day-^{1}) on Broccoli to lowest (0.1471 day-^{1}) on Cabbage. The maximum (0.2814 host) finite predation rate was recorded on Broccoli, and was the minimum (0.2112 hosts) on Cabbage. The values of stable predation rate increased from 0.1824 (host/ parasitoid) to 0.2308 (host/ parasitoid) with changes in host diet. All tested brassica cultivars affected the life performance of *D. insulare*. The results confirmed that *D. insulare* showed better performance on Broccoli genotype when compared to other tested genotypes. Hence, Broccoli can be used for the rearing of *D. insulare* on a large scale for mass releases of this parasitoid in the brassica fields to get effective suppression in the population of *P. xylostella*.

Keywords: Biological control, *D. insulare*, Demography, Intrinsic rate of increase, Cruciferous plants.

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Introduction

Plutella xylostella (L.) known as the Diamondback moth (DBM) is the most damaging pest of brassica vegetables (Sarfraz et al., 2006) belonging to order Lepidoptera (Ahmed et al., 2018). This pest can cause up to 90% crop losses in different brassica-growing regions of Pakistan (Malik et al., 2020). The annual use of pesticides against *P. xylostella* costs around 4-5 billion US$ worldwide. According to FAO (2015), sixteen percent (16%) of all the pesticides applied to vegetables and fruits are being used only for the management of DBM. Most brassica vegetables are an important part of the human diet and the injudicious use of pesticides against DBM may cause serious repercussions. Despite the heavy use of insecticides, the farmers are sometimes unable to manage the DBM population and have to plough their crops and cultivate non-cruciferous crops (Syed et al., 2018). DBM has become a challenging pest to manage under field conditions mainly due to its multivoltine nature (Mubashir and Seram, 2022) and developed resistance to many broad-spectrum pesticides (Imran, 2018). Natural enemies particularly parasitoids are reported to play a crucial role for regulating the population of DBM on cruciferous crops (Löhr et al., 2007).

Diadegma insulare (Cresson) *is* an important host-specific, multivoltine parasitoid that parasitizes the DBM at the larval stage (Sarfraz et al., 2005). The affected larvae consume considerably less food (80%) than the healthy ones and eventually died due to starvation (Harcourt, 1960). Herbivore hosts of *D. insulare* are often influenced by the nutritional quality of their host plants (Sarfraz et al., 2009) from which they get their food (Ode et al., 2016).Herbivore food directly affects their key fitness parameters like growth, body size, generation time, survival, and biotic potential (Harvey et al., 2007; Gols et al., 2008). These demographic parameters are intrinsically linked to parasitoid performance (Othim et al., 2017).

It has been reported that the development time of the herbivores extends due to the intake of inadequate nutrition from their host plants, consequently they are exposed for longer period to their natural enemies and abiotic stressors (Othim et al., 2019). Similarly, morphological features among different plant species and cultivars also affect the parasitism rate of the parasitoid (*D. semiclausim*) on different herbivore hosts (prey) (Kahuthia-Gathu et al., 2008). In addition, the performance of natural enemies has also been reported to be affected by the emission of secondary metabolites by their hosts (Gols et al., 2012). Parasitoids uses plant-emitted chemicals to find its herbivore prey (Rossbach et al., 2005). The vast number of allelochemicals found in the Brassicaceae family (Wittstock et al., 2003) can affect the performance of parasitoids and hyper-parasitoids, which are found in the third and fourth trophic ranks of the food chain, respectively (Karimzadeh and Wright, 2008). The fitness and performance of any insect pest or biocontrol agent can be better understood through life table analysis, because it provides a comprehensive detail about survival rate, development, and reproduction potential (Wittmeyer and Coudron, 2001) of the cohort of individuals under investigation. Life table studies can also serve as a foundational source of data for the development of an efficient pest management strategy (AmirMaafi and Chi, 2006; Talebi et al., 2008), which is based on the practical implementation of biological control (Farhadi et al., 2011). The present studies were conducted under laboratory conditions to test the hypothesis that different brassica species have significant effect on the fitness of DBM, which in turn can affect the performance of *D. insulare* as its specialist parasitoid.

Material and Methods

Plant culture

Highly cultivated genotypes of brassica were selected after consultation with local farmers. Six genotypes of Brassica were Canola (*B. napus* var. canola), Cauliflower (*B. oleracea* var.botrytis), Chinese cabbage (*B. rapa* L. subsp. pekinensis), Cabbage (*B. oleracea* var. capitata) Broccoli (*B. oleracea* var. italica) and Pakchoi (*B. chinensis* var. chinensis). Brassica plants were kept in 15cm in diameter plastic containers and plants of 45 days were used in our experiments.

Diamondback moth culture

Diamondback moth, *Plutella xylostella* was raised in the Biological Control Laboratory, Department of Entomology, Pir Mehr Ali Shah-Arid Agriculture University Rawalpindi, Pakistan. DBM caterpillars and eggs were randomly collected from brassica fields in the area of Chak Shahzad, Rawalpindi. They were kept at 25 ± 2ºC temperature and 65±5% R.H. with 16:8h (L:D). These caterpillars were raised on different tested six genotypes upto two generations prior to the experiment to eliminate previous host food effect on pest biology. After emergence from pupae, the adults were confined in plastic containers (16cm diameter/23cm height) for mating and oviposition on leaves (Sarfraz et al., 2009). The cruciferous leaves were replaced regularly after 24 hours. To preserve the turgidity of the leaf, its petiole was covered in moist cotton. The adults were fed on cotton balls soaked in a 20% w/w honey solution (Abbas et al., 2022).

Parasitoid culture and biological studies

Many of the collected larvae were found parasitized by the parasitoids in the filed before collection. Mouth aspirators were used to collect parasitoids and hyperparasitoids soon after they developed. Specimens were either placed in a glass vial with 70% alcohol or killed instantly in a bottle of potassium cyanide. Nikon microscope (SMS-1500, 30X-1-11.25X) and a set of identification keys was used to identify the *Diadegma insulare* specimens in the laboratory (Azidah et al., 2000).

For parasitoid studies, one hundred (100) 3rd instar larvae of DBM with leaves of host plants were confined in different cages. The DBM caterpillars were introduced to eight pairs of adult *D. insulare*, which were then kept in cages for 24 hours. The caterpillars were then shifted to the petri dishes individually and inspected daily. The egg and larval duration of the parasitoid were recorded together because it develops inside the body of DBM up to the pupal stage. After the emergence from pupae, the adults were mated and paired. Each pair (one female and one male) was placed in individual petri plates having cruciferous leaves and twenty 3rd instar DBM larvae. Cotton wool soaked in 20% honey solution was also provided in each petri plate as a feeding source for the adult parasitoids.

After 24 h, the adults were moved to a fresh container with a new group of 20 caterpillars (3rd instar) of DBM. Parasitoid pupae were collected, weighed, and stored separately in categorized see-through plastic jars in the growth chamber at 25 ± 2°C with 16h L: 8h D photoperiod till adult emergence. A daily log of pupal development and sex distribution was also maintained. Those DBM larvae changing into cocoons, despite the exposure to *D. insulare*, were deemed to have evaded parasitism.

Life table parameters

Life history characters were evaluated based on the age-stage, two-sex life table theory by Chi and Liu (1985) and Chi (1988). This type of life table is useful for illustrating stage differentiation, and determining an accurate representation of age-stage fecundity. This life table data includes both sexes (male and female), pre-adult mortality, the effect of sex ratio on population growth, stable age-stage distribution and establish solid relation among F and R°(Chi, 1988). This life table also establishes a link between predation or consumption with life table studies. For the life table and bootstrap analysis, TWOSEX-MS Chart (Chi, 2015) was used. One-way ANOVA was used to evaluate the obtained data followed by Tukey HSD post-hoc test (α=0.05) for comparing means of life history parameters. The age-stage specific survival rate (S_{xj}, where x = age and j = stage), the age-stage specific fecundity (f_{xj}), the age-specific survival rate (l_x), the age-specific fecundity (*mx*), and the population parameters (intrinsic rate of increase, finite rate of increase, net reproductive rate, mean generation time), the age-specific survival rate for the two-sex life table were calculated, following the protocol of Chi and Liu (1985). From these parameters, major demographic parameters like R_0: net reproductive rate; r: intrinsic rate of increase; λ: finite rate of increase; and T: mean generation time were calculated with the help of computer software TWOSEX-MS Chart (Chi, 2015). The Bootstrap technique (100,000) was employed to assess the variances as well as the standard errors of all these parameters (Tibshirani and Efron, 1993).

Following formula (Gharekhani et al., 2023) was used for calculation of net reproductive rate (R_0,):

$$R_0 = \sum_{x=0}^{\infty} l_x m_x$$

Euler-Lotka formula (age indexed from 0) was used for calculation of (r), intrinsic rate of increase by iterative bisection method (Goodman, 1982):

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1$$

The finite rate of increase (λ) was calculated by this formula:

$$\lambda = e^r$$

Mean generation time is the time span required by a population to increase R_0-fold of original population size at the stable age stage distribution, and is calculated as:

$$T = \ln R_0/r$$

Parasitism rate analysis

The finite parasitism rate can be used for the comparison of parasitism for the same parasitoid in different conditions. The finite parasitism rate (ω) was calculated as described by Chi et al. (2011).

$$\omega = \lambda\Psi = \lambda \sum_{x=0}^{\infty}\sum_{j=1}^{\beta} a_{xj}c_{xj}$$

The finite predation rate takes both the increase rate of parasitoid (λ) and the age-stage specific parasitism rate (c_{xj}) into consideration.

Stable parasitism rate (ψ) was calculated as (Chi et al., 2011; Yu et al., 2013)

$$\psi = \sum_{x=0}^{\infty}\sum_{j=1}^{\beta} a_{xj}c_{xj}$$

The transformation rate from host population to parasitoid offspring (Qp) was calculated as Chi et al. (2011) and Yu et al. (2013).

$$Q_p = \frac{C_0}{R_0}$$

This rate represents the total sum of host insects the parasitoids require to eat to yield an offspring.

Results

Development and fecundity of *D. insulare*

Our data revealed that cruciferous food of host insect had significant effect ($P \leq 0.05$) on the development period of the parasitoid from egg to pre-pupa (Table 1). Maximum developmental time was recorded when the host pest (*P. xylostella*) was reared on PakChoi (5.35 d) and minimum when on Cauliflower (4.85 d). Prepupal developmental period of parasitoid did not display any significant difference (Table 1).

There were observed shifts in the parasitoid's pupal period in response to shifts in the host food source. Longer pupal duration of the parasitoids was recorded when host pest was reared on Cabbage, Chinese cabbage, Broccoli and Canola as compared to those reared on PakChoi and Cauliflower. The shortest total immature developmental period (egg to pupa) of *D. insulare* was observed on Cauliflower which was statistically different than that recorded on all other cruciferous genotypes (Table 1). The maximum total longevity was observed on PakChoi (18.40 d) and minimum on Cauliflower (15.67 d). Total pre-adult oviposition period was longer on Pak Choi (12.85 d) and shorter on Cauliflower (12.01 d). Different host plants of *P. xylostella* had evident effect on oviposition period and fecundity of the parasitoid (Table 1). The oviposition period of *D. insulare* was considerably longer than that on other tested genotypes when the host pest was reared on PakChoi. Female fecundity was comparatively higher on *P. xylostella* reared on Broccoli (35.41 eggs per female) followed by that on Chinese Cabbage (27.52 eggs per female), Cauliflower (27.08 eggs per female) and PakChoi (26.94 eggs per female). Less parasitoid fecundity was observed when fed *P. xylostella* reared on Cabbage,(18.78 eggs per female) (Table 1).

Table-1. Developmental duration and fecundity of *Diadegma insulare* reared on *Plutella xylostella* using different cruciferous genotype as host plants

Immature duration (d)	Cruciferous Host Plants											
	n	Broccoli Mean±SEM	*n*	Cabbage Mean±SEM	*n*	Canola Mean±SEM	*n*	Cauliflower Mean±SEM	*n*	Chinese cabbage Mean±SEM	*n*	Pak choi Mean±SEM
Egg + Larva	124	5.00±0.07^{b}	124	4.91±0.07^{bc}	112	4.99±0.09^{bc}	121	4.85±0.07^{c}	119	5.02±0.07^{b}	124	5.35±0.06^{a}
Pre-pupa	89	1.00±0.00	90	1.00±0.00	69	1.00±0.00	91	1.00±0.00	69	1.00±0.00	96	1.00±0.00
Pupa	89	5.94±0.08^{a}	90	5.97±0.08^{a}	69	5.88±0.10^{a}	91	5.41±0.08^{b}	69	5.90±0.07^{a}	96	5.48±0.07^{b}
Pre-adult duration		11.99±0.13^{a}		11.97±0.12^{a}		11.96±0.15^{a}		11.33±0.11^{b}		11.94±0.13^{a}		11.89±0.09^{a}
Adult duration (d)												
Adult longevity	89	6.85±0.09^{b}	90	6.65±0.08^{c}	69	6.82±0.08^{bc}	91	6.74±0.08^{bc}	69	6.80±0.08^{b}	96	7.70±0.11^{a}
Total longevity	125	17.23±0.40^{bc}	125	16.18±0.49^{d}	125	16.46±0.48^{cd}	125	15.67±0.50^{d}	125	17.61±0.35^{b}	125	18.40±0.37^{a}
Reproduction												
APOP	80	1.00±0.00	76	1.00±0.00	63	1.00±0.00	80	1.00±0.00	55	1.00±0.00	58	1.00±0.00
TPOP	80	12.57±0.15^{b}	76	12.47±0.12^{b}	63	12.41±0.17^{b}	80	12.01±0.16^{c}	55	12.53±0.14^{b}	58	12.85±0.11^{a}
Reproductive days	80	4.41±0.08^{b}	76	4.35±0.09^{b}	63	4.04±0.09^{c}	80	4.44±0.08^{b}	55	4.32±0.07^{b}	58	5.64±0.14^{a}
	80	35.41±0.77^{a}	76	18.78±0.61^{d}	63	24.82±.006^{c}	80	27.08±0.59^{b}	55	27.52±0.66^{b}	58	26.94±0.74^{b}

Means having different letters in the same rows are significantly different at 5% level of significance using Tukey HSD test

APOP= Adult pre oviposition period

TPOP= Total pre oviposition period

Age specific survival rate (S_{xj}) of *Diadegma insulare* raised on *Plutella xylostella*

The age specific survival (S_{xj}) of parasitoid for egg-larva, pre-pupa, pupa, adult female and male stages described the possibility that a newly hatched insect lived on to age x and stage j (Figure 1). The curves showed clear overlaps for various stages of the parasitoid for different host genotypes, depicting variable developmental rates of the cohort members. The adult females showed higher peaks S_{xj} on Chinese cabbage and Pakchoi and lower peaks are formed on Cauliflower. On overall, the S_{xj} peaks for the adult females were higher on all the host plants as compared to the males.

Effect of host food on survival rate (*lx*) and fecundity (*mx*) of *Diadegma insulare*

Survival rate (*lx*) of new hatchlings of the parasitoid reduced sharply when the host insect was raised on Cauliflower as compared to the other host plants. The individual fecundity (*mx*) of the parasitoid showed high variations, with highest peaks for Broccoli and lowest for Pakchoi. Similar trend was observed in the curves of age specific reproductive value (*lxmx*), which depicted that Broccoli was the most suitable host food of *P. xylostella* for reproduction of *D. insulare* (Fig. 2).

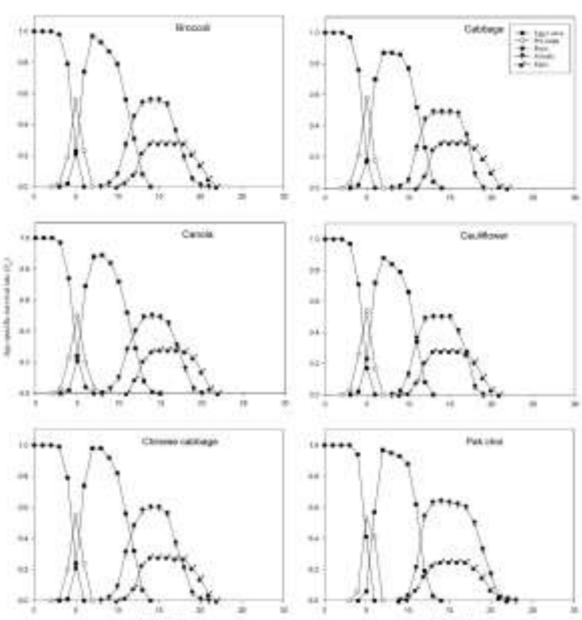

Figure-1. Age stage specific survival rate (S_{xj}) of *Diadegma insulare* reared on *Plutella xylostella* using different cruciferous host plants

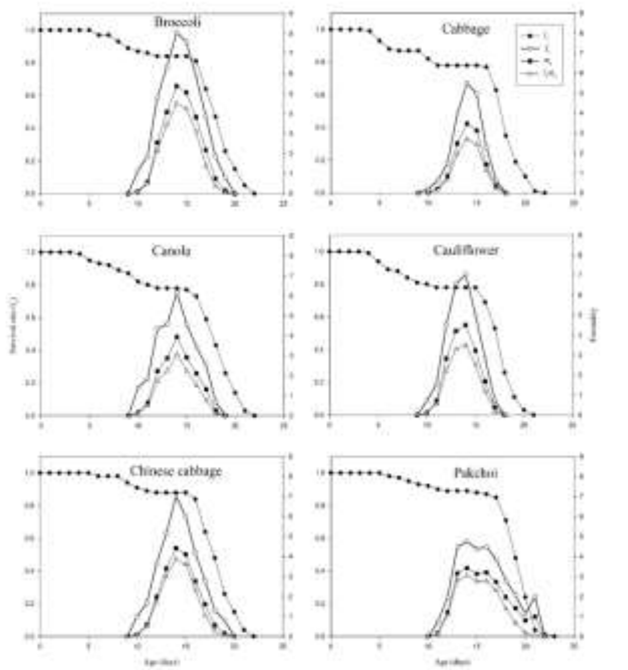

Figure-2. Survival rate (l_x) and maternity (l_xm_x) of *Diadegma insulare* reared on *Plutella xylostella* using different cruciferous host plants

Life table parameters of *D. insulare*

The life table parameters of *D. insulare* on *P. xylostella* nurtured on six different cruciferous host plants varied significantly (Table 2). Net reproductive rate (R_0) is the average number of young ones produced by an individual throughout its lifetime. R_0 of the parasitoid was higher on Broccoli (19.83) and lowest on Cabbage (9.23). Mean generation time (*T*) is the time span that an organism requires to grow its population equal to R_0 at stable age distribution and the stable increase rate. '*T*' of the parasitoid was shortest on Cauliflower (14.51 d) and longest on Pakchoi (15.83 d). Significantly higher intrinsic rate (*r*) and finite rate (λ), were noted on Broccoli (0.1970 and 1.2180 d^{-1}) as compared to Canola (0.1698 and 1.1851 d^{-1}), however, these parameters were at par between the two for Chinese Cabbage, Pakchoi, Cabbage and Cauliflower. The intrinsic rate of increase and finite rate of increase reflect the natural biotic potential of the population of a species in the absence of external limiting factors. Hence Canola can be considered the least suitable host plant for rearing *D. insulare.*

Parasitism rate analysis of *D. insulare*

Significant differences were found between host plants for transformation rate (Qp), finite parasitism rate (ω), and stable parasitism rate (ψ). The stable parasitism rate (ψ), is the full parasitism capability of a parasitoid population whose size is unity (Chi et al., 2011). The highest stable parasitism rate of *D. insulare* was recorded on Broccoli (0.2308 hosts/parasitoid), followed by Cauliflower (0.2176 hosts/parasitoid) and Chinese Cabbage (0.2161 hosts/parasitoid), while the lowest was observed on Cabbage (0.1824 hosts/parasitoid). The transformation rate (Qp) describes the conversion from the host population to the parasitoid offspring. The transformation rate for *D. insulare* ranged from 1.30 to 1.24 hosts/parasitoid. It was highest on Broccoli followed by both Chinese Cabbage and Cauliflower, while the lowest was observed on Cabbage.

The finite parasitism rate (ω) is the parasitism potential of a parasitoid's population by combining its finite rate of increase (λ), parasitism rate (*cxj*), and stable age-stage structure (*axj*) (Chi et al., 2011). The highest finite parasitism rate was noted for Broccoli (0.2814 hosts/parasitoid/d) and the lowest on Cabbage (0.2114 hosts/parasitoid/d), while on Cauliflower, Canola, Chinese Cabbage and Pak Choi it was at par between Broccoli and Cabbage (Table 3). These results clearly advocate the comparative advantage of Broccoli for efficient biological control of the pest through *D. insulare* as compared to other host food plants.

Discussion

This primary objective of the current study was to understand the effects of various host plants (Brassica genotypes) of *P. xylostella* on the biology, demography, parasitism and efficiency of *D. insulare* as a biocontrol agent. The study reflected the significant differences among the duration of various stages (i.e. egg+larva, pupa, pre-adult, and adult longevity) of the parasitoid with different host plants of *P. xylostella*.

Table-2. Demographic parameters of *Diadegma insulare* reared on *Plutella xylostella* larvae using different cruciferous host plants

Parameters	Cruciferous Host Plants					
	Broccoli Mean± SEM	**Cabbage** Mean± SEM	**Canola** Mean± SEM	**Cauliflower** Mean± SEM	**Chinese cabbage** Mean± SEM	**Pak choi** Mean± SEM
Net reproductive rate (R_0) (offspring)	19.83± 2.34^{a}	9.23± 1.24^{c}	12.41± 1.70^{b}	13.54± 2.14^{b}	16.51± 2.12^{ab}	17.24± 2.32^{ab}
Generation time (T) (days)	15.08± 0.41^{ab}	15.04± 0.24^{b}	14.79± 0.34^{ab}	14.51± 0.28^{c}	15.01± 0.45^{ab}	15.83± 0.37^{a}
Intrinsic rate of increase (r) (days^{-1})	0.1970± 0.0124^{a}	0.1471± 0.0141^{ab}	0.1698± 0.0132^{b}	0.1792± 0.0112^{ab}	0.1864± 0.0120^{ab}	0.1796± 0.0120^{ab}
Finite rate of increase (λ) (days^{-1})	1.2180± 0.011^{a}	1.1584± 0.010^{ab}	1.1851± 0.020^{b}	1.1963± 0.022^{ab}	1.2050± 0.020^{ab}	1.1968± 0.021^{ab}

Means having different letters in the same rows are significantly different at 5% level of significance using Tukey HSD test

Table-3. Parasitism rate analysis of *Diadegma insulare* reared on *Plutella xylostella* using different cruciferous host plants

Parameters	Cruciferous Host Plants					
	Broccoli Mean± SEM	**Cabbage** Mean± SEM	**Canola** Mean± SEM	**Cauliflower** Mean± SEM	**Chinese cabbage** Mean± SEM	**Pak choi** Mean± SEM
Transformation rate, Qp (ratio)	1.3010± 0.0141^{a}	1.2404± 0.007^{c}	1.2503± 0.0072^{c}	1.2702± 0.0084^{b}	1.2703± 0.0087^{b}	1.2604± 0.0074^{b}
Stable parasitism rate(ψ) (preys)	0.2308± 0.0192^{a}	0.1824± 0.0172^{b}	0.2039± 0.0194^{ab}	0.2176± 0.0194^{ab}	0.2161± 0.0168^{ab}	0.2075± 0.0145^{ab}
Finite parasitism rate (ω) (preys)	0.2814± 0.0252^{a}	0.2114± 0.0215^{b}	0.2417± 0.0248^{ab}	0.2605± 0.0251^{ab}	0.2604± 0.0218^{ab}	0.2484± 0.0187^{ab}

Means having different letters in the same rows are significantly different at 5% level of significance using Tukey HSD test

The total longevity of the parasitoids was reduced significantly on both Cauliflower and Cabbage as compared to that on Pakchoi As the herbivore host continues to feed on plant species after being parasitized by *D. insulare*, the extended longevity may be attributed to the lack of necessary nutrients or allelochemicals in the host's diet (Turlings and Benrey, 1998). Earlier Ebon et al. (2000) and Sarfraz et al. (2008) have also documented the variation in the longevity of *D. insulare* (third trophic level) due to different host plants (first trophic level).

The fecundity of the parasitoid (offspring or female) was observed significantly higher in Broccoli as compared to the other host plants. Similarly, higher peaks of age-specific maternity curves (*lxmx*) were observed on the 14^{th} day for Broccoli as compared to all other host plants which indicates the comparatively higher potential of this genotype in the biological control of *P. xylostella*. High fecundity reflects more synchronization of the parasitoid with its host and adaptation to the environment and may be regarded as one of the important predictors of parasitoid fitness (Van Lenteren and Woets, 1988). The evident overlaps were observed between the curves of age-stage-specific survival rate (*Sxj*) of different stages and sexes of the parasitoid, which provided a comprehensive description of the variable growth rates of the individuals of the cohorts. It also reflects more usefulness of the age-stage two-sex life table over traditional female-based life tables, which ignore such details about the life history of the insect (Ebrahimi et al., 2013). Numerous studies have discussed the problems in the results using female-specific life tables Chi (1988), Yu et al. (2005), Chi and Su (2006), and Huang and Chi (2012).

The life table parameters of *D. insulare* on the host grown on different cruciferous genotypes had substantial effects on its performance. Higher numerical values of the parasitoids intrinsic rate of increase (*r*) and finite rate of increase (λ) of the parasitoids were observed for Broccoli, which was statistically comparable to Chinese Cabbage, Pak Choi, and Cauliflower, however, lower for Cabbage. As the computation of the value of the intrinsic rate of increase (*r*) involves many important factors like survival rate, fecundity, and mean generation time: so it could be used as an appropriate index to evaluate the performance of a parasitoid against its host (Safuraie-Parizi et al., 2014).

The present study indicated Cabbage as the least favored food plant for the host; however, Broccoli, Chinese Cabbage, and PakChoi proved as better host plants, while considering the performance and fitness of the parasitoid. The differences in the performance of the parasitoid may be due to the variation in the nutritional quality of the herbivore food (Sarfraz et al., 2009), the presence of plant allelochemicals inside the host insect, or compromised host quality due to suboptimal plant food (Harvey et al., 2007; Ode, 2006). The present findings also highlight the need to incorporate a thorough analysis of the tri-trophic relationship while devising pest management programs for cruciferous crops, because we investigated the evident link between the plant genotypes used for rearing the host insect and the fitness correlates of the parasitoid.

A comprehensive comparison of the parasitoid's parasitism potential is not possible just through the estimation of population parameters, that's why it is proposed to combine the finite rate of increase (λ), age-stage parasitism rate (*cxj*), and stable age-stage structure (*axj*) to get the finite parasitism rate (ω) (Chi et al., 2011). The finite parasitism rate can be considered a standard parameter to relate the potential of the same parasitoid in diverse host environments. In the current studies, the transformation rate (Qp) from the host population to parasitoid offspring was higher on Broccoli and lowest on both Cabbage and Canola. The stable parasitism rate (ψ), the total parasitism ability of a population whose size is unity, and the finite parasitism rate (ω) of parasitoids were also observed highest on Broccoli and lowest on Cabbage.

These findings agree with those of Idris and Grafius (1996), who reported considerably greater parasitism (87%) of *D. insulare* on *P. xyllostela* when reared on Broccoli than on other brassica host plants. The higher finite parasitism rate of *D. insulare* on *P. xyllostela* reared on Broccoli corroborates its success as a biological control agent on this specific host plant.

For the effective management of *P. xylostella* (through biological control agent i.e. *D. insulare*) Canola and Cabbage growers should consider Broccoli as an alternate genotype. Such interventions in brassica cropping systems may improve the genotype's compensatory ability with respect to the performance of *P. xylostella.*

Conclusion

D. insulare significantly suppresses the *P. xylostella* populations fed on all the tested genotypes. However, among the six brassica cultivars, the high performance (Intrinsic rate of increase) of *D. insulare* was noted on Broccoli under controlled conditions. Based on the controlled experiments, it is suggested that broccoli may be utilized in the field to manage the *P. xylostella* populations, and to obtain favorable growth dynamics for *D. insulare.*

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Contribution of Authors

Khaliq S: Conducted the experiments, performed analysis and wrote manuscript.
Aziz MA: Conceptualized the experiments, helped in analysis and preparation of manuscript.
Mohsin AU & Hafiz IA: Assisted in experiments and reviewed and edited the manuscript.

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