Acta Scientific AGRICULTURE (ISSN: 2581-365X)

Volume 6 Issue 11 November 2022

Research Article

Biology and Demographic Parameters of *Diaeretiella rapae* (McIntosh) against *Brevicoryne brassicae* (L.)

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DOI: 10.31080/ASAG.2022.06.1194

Received: May 23, 2022

Published: October 04, 2022

Abstract

The cabbage aphid, *Brevicoryne brassicae* (Hemiptera: Aphididae), is a cosmopolitan insect pest that attacks cruciferous crops. It causes plant deformities, stunting, or killing of young plants thereby resulting in 35-75 per cent yield losses. The present investigation was conducted during 2020-2021 at Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni Solan, Himachal Pradesh. The study reveals that *Diaeretiella rapae* parasitized all nymphal instars of *B. brassicae* with a preference for the third instar (42%) followed by the fourth instar (30%), second instar (24%), and first instar (13%). The mean period of parasitoid from egg to host mummification and mummification to adult emergence was 9.04 and 3.5 days on the third instar and 10.55 and 5 days on the fourth instar, respectively. The total time period from egg to adult emergence was 12.45 and 15.55 days with the third and fourth nymphal instars of the host, *B. brassicae*, respectively. The fecundity, pre-oviposition, and oviposition period of the parasitoid were 53.2 eggs/female, 1.0 day and 7.1 days on the third instar, and 45.7 eggs/female, 1.0 days and 6.4 days on the fourth instar, respectively. The gross reproductive rate (GRR), net reproductive rate (R0), true intrinsic rate of increase (rm), finite rate of increase (λ), mean generation time (T) and doubling time (DT) of third instar was 42.47 female progeny/female, 26.60 female progeny/female, 0.1943 females/female/day, 1.21 females/day, 16.89 days and 3.57 days, respectively and 28.65 female progeny/female, 22.85 female progeny/female, 0.1594 females/female/day, 1.17 females/day, 19.43 days and 4.30 days for the fourth instar, respectively. The age-stage survival rate (sxj), age-stage life expectancy (exj) and age-stage reproductive values (vxj) of *D. rapae* on the third instar of B. brassicae were 13- 15 d, 0.5 for males and 14 d, 0.51 for females, 19.75 days for eggs at age zero and 12.76 days for pupa at age seven, 31.59 d^{-1} on 13 d, respectively and 16- 20 d, 0.45 for male and 17-18 d, 0.5 for female, 22.65 days for eggs at age zero and 13.65 days for pupa at age nine, 31.49 d^{-1} on 16 d for the fourth instar, respectively. The present study revealed that the third instar nymphs of *B. brassicae* were most preferred by *D. rapae* for development. Therefore, the parasitoid, D. rapae can be utilized as one of the components in the integrated pest management programme of cabbage aphid (*B. brassicae*).

Keywords: Biology; Cabbage Aphid; Demographic Parameters; Fertility; Parasitoid

Abbreviations

DT: Doubling Time; e_{xj}: Age-Stage Life Expectancy; GRP: Gross Reproductive Rate; r_m: True Intrinsic Rate of Increase; R_o: Net Reproductive Rate; T: True Generation Time; v_{xj}: Age-Stage Reproductive Value; λ: Finite Rate of Natural Increase

Introduction

The cabbage aphid, *Brevicoryne brassicae* (Hemiptera: Aphididae), is a cosmopolitan insect pest that attacks cruciferous crops [1-5]. It causes plant deformities, stunting, or killing of young plants thereby resulting in 35-75 per cent yield losses [6-10]. Besides direct damage, it also causes indirect damage by spreading more than 20 viruses, including yellow mosaic virus, cauliflower mosaic virus, and cabbage black ring spot [3,8]. Chemical pesticides are the most common tool for controlling aphids, but their indiscriminate use causes environmental contamination, pest resurgence, secondary pest outbreaks, insecticide resistance, and toxicity to their natural enemies [11,12]. Aphid parasitoids of the subfamily Aphidiinae are very important control agents for various aphids in many crops [13-16]. There are various criteria for evaluating and selecting biological control agents, including parasitoids [17,18]. *B. brassicae* is suppressed by many natural enemies and among them, *Diaeretiella rapae* (McIntosh) (Hymenoptera: Braconidae) is the most abundant [19-23]. It is a koinobiont endoparasitoid [24] that feeds on the host's tissues in the early stages and host's organs in the later stages ensuing the host's death [25] and is also a potential bioagent for use in biological control strategies against many aphid species in different countries [26,27]. The parasitoid, *D. rapae* parasitizes about 98 species of aphids infesting more than 180 plant species belonging to 43 plant families distributed in 87 countries throughout the world [28]. *D. rapae* females lay a single egg in the host body. Parasitized hosts become mummies consisting of a hardened aphid exoskeleton. Parasitic larvae pupate inside the host body and emerge as adults [29]. *D. rapae* attacks and develops in all four nymphal instars of aphid hosts [30,31] at varying degrees due to different levels of host physiological suitability. The ecological and biological characteristics of natural enemies could be useful for predicting their value in a biological control system [32]. Studying life table parameters helps to better understand the biological control agent's effectiveness. However, before recommending any parasitoid for field release, its biotic potential must be investigated. As a result, demographic parameters are critical in determining a species population growth potential under specific conditions. These parameters are also used as population growth indices responding to selected conditions and as bioclimatic indices to assess the potential for pest population growth in a new area [33]. However, the information on the biology and fertility tables of this parasitoid on the cabbage aphid is scanty. Therefore, the present work aimed to study developmental biology and population growth parameters of *D. rapae* parasitizing *B. brassicae*.

Materials and Methods

Rearing of the culture of *B. brassicae*

The cabbage aphid, *B. brassicae* was maintained on cauliflower seedlings raised in pots in the Biocontrol Research Laboratory of the Department of Entomology, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (Himachal Pradesh) India (30.85°;77.16°E). Cabbage aphids were collected from the field and released on cauliflower plants. For this purpose, naturally infested leaves of cauliflower were brought to the laboratory and released on potted cauliflower plants kept in screened cages. To maintain a constant supply of the cabbage aphid for the studies, the withered and dried cauliflower plants were periodically replaced with fresh seedlings/plants.

Rearing of the culture of *D. rapae*

Mummified aphids were collected from cauliflower plants and placed inside the glass tube for the emergence of parasitoid adults. On the sides of the glass tube, fine streak of honey was provided as food for the newly emerged parasitoid adults. These adults were then introduced into the wooden cage of 45×45×45 cm containing aphids-infested cauliflower plants in the pots. On the cotton swab, the honey streaks were provided as a food source for the parasitoid. After mummification, the parasitized aphids were gently removed and placed in the glass vials for adult emergence.

Relative preference of *D. rapae* to different stages of *B. brassicae*

For studying the relative preference of *D. rapae* to different nymphal instars of cabbage aphid, newly emerged parasitoid adults were offered with all the nymphal instars of cabbage aphid simultaneously. In the experiment, each pair of *D. rapae* was provided with twenty individuals of each instar (1st, 2nd, 3rd and 4th) of *B. brassicae* on a cauliflower seedling simultaneously in a glass chimney. These aphids were carefully transferred with a fine paintbrush and left for about 24h to settle down on the leaf. Then a pair of *D. rapae* was exposed to fixed numbers of aphids for 24h. After 24h the leaves containing aphids were removed and reared till mummification. Each set was replicated ten times. After the mummification of aphids, the mummies were counted, removed, and kept individually in the vial for the emergence of adults. The per cent parasitization was calculated by using the equation of [34]

Per cent parasitism = Parasitized aphids (mummified)/Total aphids × 100

Developmental Biology

The experiments were carried out by raising cauliflower seedlings in pots and covered with the glass chimney after the release of a female parasitoid from the stock culture and these were then kept at constant temperature (25 ± 0.5°C) and relative humidity (70 ± 5 per cent). The parasitoid was removed after 24h, and the aphids in the cage were reared for mummification. Mummified aphids were then transferred individually into small glass vials and checked every day for adult emergence. Upon emergence, the male and female parasitoids (0-1 day old) were sorted out, and a pair was introduced into a glass tube (150 × 25 mm) equipped with a honey droplet as food and cauliflower leaves infested with aphids for oviposition. After 24h, the old batch of aphids was replaced with a new one and the process was continued until all the parasitoids died. Data on the egg to adult emergence, pre-oviposition period, oviposition period, and fecundity (mummified aphids) was recorded.

Demographic parameters of D. rapae

Population growth parameters of *D. rapae* were studied on the third and fourth nymphal instars of *B. brassicae* by constructing fertility life tables separately. For this purpose, twenty nymphs of each instar were exposed to *D. rapae* for parasitism for 24h. Each set was replicated ten times. After 24h, aphids were reared for mummification and used for further rearing of the parasitoid. Adults who emerged from these parasitized nymphs were offered twenty host nymphs for parasitism for 24h. After 24h, the old batch of nymphs was replaced with a new one and the process was continued until all the parasitoids died.

Data on age-specific survival and fecundity (parasitized nymphs) was recorded. Population growth parameters of the parasitoid were calculated by using the TWOSEX-MS Chart computer programme [35,36]. Means and standard errors (SE) of population life table parameters were determined using 100,000 bootstrap replicates to obtain stable SE estimates [37,38]. The detailed procedure is as under

X = age of individuals in days (pivotal age)

l_x = proportion of individuals still alive at age X (survival value)

m_x = number of female off-springs produced per female in the age interval X (fecundity rate)

By using the above variables, the following population growth parameters were calculated

- **Gross reproductive rate (GRR):** It is the total number of female eggs laid per female and calculated as

$GRR = \sum m_x$

- **Net reproductive rate (Ro):** It is the rate of multiplication of the population in each generation and measured in terms of females produced per generation. It was calculated as

$R_o = \sum l_x m_x$

- **True intrinsic rate of increase (r_m):** It is the actual rate of increase of a population under specified environmental conditions in which space and food are unlimited. It was calculated by the equation, $\sum e^{-rmx} l_x m_x = 1$
- **True generation time (T):** It is the mean period elapsing from the birth of parents to the birth of off-springs. It was calculated by the formula

$T = \log_e R_o / r_m$

- **Finite rate of natural increase (λ):** It is the number of times the population increases per unit time. The value was calculated by the formula

$\lambda = \text{antilog}_e r_m$

- **Doubling time (DT):** It is the time taken by a species to double its population and was calculated by the formula

$DT = \log_e 2 / r_m$

- **Age-stage life expectancy (exj):** It is defined as the length of the duration or time that an individual or insect of x and j is predicted to live, calculated as follows

$e_{xj} = \sum \sum s_{iy}$

- **Age-stage reproductive value (vxj):** It is defined as the contribution of individuals of age x and stage j to the future population, calculated as follows

$V_{xj} = e^{r(x+1)} / s_{xj} \sum e^{-r(x+1)} \sum s_{iy} f_{iy}$

Statistical analysis

Data was analysed by using one-way analysis of variance (ANOVA) with a completely randomized design after appropriate transformation through the online OP-STAT software [39]. Different biological and demographic parameters were statistically evaluated using the TWOSEX-MS Chart computer program [35]. Means and standard errors (SE) of all biological and population life table parameters were determined using 100,000 bootstrap replicates to obtain stable SE estimates [37,38]. The age-stage-specific survival rate (s_{xj}), age-specific survival rate (l_x), age-specific fecundity (m_x), age-stage life expectancy (e_{xj}), age-stage reproductive value (v_{xj}), and life table parameters (r, intrinsic rate of increase; λ, finite rate of increase; R0, net reproductive rate; and T, the mean generation time), were designed in sequence according to previously described methods [40,41].

Results

Relative preference of *D. rapae* to different nymphal instars of *B. brassicae*

The relative preference of *D. rapae* to different nymphal instars i.e., first, second, third and fourth nymphal stages of *B. brassicae* was determined by offering 20 nymphs of each instar on cauliflower seedlings for 24 h in 10 replications. Significant differences were recorded in the parasitism (F = 42.98; df = 3; p < 0.001), rate of *D. rapae* to different nymphal instars of *B. brassicae.* When all the nymphal instars of *B. brassicae* were offered simultaneously in a random experiment, *D. rapae* parasitized all the stages of the aphid with preference to the third instar (42%) followed by 4th instar (31%) and 2nd instar nymphs (22%). First instar nymphs were the least preferred with 13 per cent parasitism (Table 1).

Larval instar	Number of aphids parasitized (per 10 aphids)	Parasitization (%)
1st instar	2.60^{d} ± 0.30	13.00
2nd instar	4.40^{c} ± 0.22	22.00
3rd instar	8.40^{a} ± 0.33	42.00
4th instar	6.20^{b} ± 0.21	31.00
CD $_{(p\ 0.05)}$	1.10	

Table 1: Relative preference of *D. rapae* to different nymphal instars of *B. brassicae.*

Mean values in a column superscripted with the same alphabet do not differ significantly at p = 0.05.

Developmental biology of *D. rapae* on *B. brassicae* third and fourth nymphal instars of *B. brassicae*

The parasitoid, *D. rapae* completed all developmental stages within the body of its host except the adult stage. The developmental period of the parasitoid from egg laying to host mummification was 9.05 days and from mummification to adult emergence was 3.4 days (Table 2). The total immature development from egg to adult emergence was completed in 12.45 days. The pre-oviposition and oviposition periods of the parasitoid were 1.0 and 7.1 days, respectively.

When fourth instar nymphs of *B. brassicae* were offered to *D. rapae* for parasitization, the parasitoid took 10.55 days (range: 9-12 days) from egg laying to host mummification (Table 2). The development from mummification to adult emergence was completed in 5.0 days. The total duration to develop from egg to adult emergence was 15.55 days with a range of 15-18 days. The pre-oviposition and oviposition periods of the parasitoid were 1 and 6.4 days, respectively.

Parameter	Third instar (Mean ± SE)	Fourth instar (Mean ± SE)
Oviposition to mummification period (days)	9.05^{b} ± 0.25	10.55^{a} ± 0.23
Mummification to adult emergence period (days)	3.4^{b} ± 0.11	5.0^{a} ± 0.16
Total developmental period (days)	12.45^{b} ± 0.18	15.55^{a} ± 0.18
Pre-oviposition period (days)	1.0	1.0
Oviposition period (days)	7.1^{a} ± 0.92	6.4^{a} ± 0.73
Fecundity (eggs/female)	53.2^{a} ± 5.19	45.7^{a} ± 4.50

Table 2: Biological parameters of *D. rapae* on third and fourth instar nymphs of *B. brassiace.*

Mean values in a row superscripted with the same alphabet do not differ significantly at p=0.05 calculated by using TWOSEX-MS Chart programme.

Population growth parameters of the parasitoid, *D. rapae* on *B. brassicae*

The population growth parameters of *D. rapae* on *B. brassicae* were determined by constructing fertility tables. The data on age-specific survival and fecundity of the parasitoid were accumulated to develop the fertility tables and to determine the population growth parameters.

Population growth parameters of the parasitoid, *D. rapae* on third instar nymphs of *B. brassicae*

Diaeretiella rapae adult emergence occurred at the pivotal age of 11 days. There was no mortality until the 14th day of pivotal age. Thereafter, a gradual decrease in the survival rate of the parasitoid was observed and by the 25th day of the pivotal age, all parasitoids died. The parasitoid started egg laying at the pivotal age of 12 days and on average 0.5 female eggs/female were laid on that day. The age-specific fecundity increased gradually and was maximum (5 female eggs/female) on the 19th day of the pivotal age, which thereafter decreased. The age-specific life expectancy (ex) estimates the time individuals of age (X) are expected to live. The age-specific reproductive value (vx) indicates the contribution of individuals from age (X) to the future population. The reproductive value at age zero was lowest (1.21 per day) and increased to 12.5 per day at the age of 12 days with peak value of 14.58 per day at the age of 13 days and thereafter it follows a decreasing trend. Population growth parameters obtained from the data on the age-specific survival and fecundity are presented in Table 3 which showed that the GRR and R_0 were 42.42 ± 7.22 and 26.60 ± 6.45 females/parasitoid, respectively. The T was 16.89 ± 0.42 days. The parasitoid had r_m 0.1943 ± 0.015 females/parasitoid/day. The (λ) was estimated as 1.21 ± 0.019 times per day. The parasitoid had the capacity to double its population in 3.57 ± 0.04 days (Table 3).

Population growth parameters of the parasitoid, *D. rapae* on fourth instar nymphs of *B. brassicae*

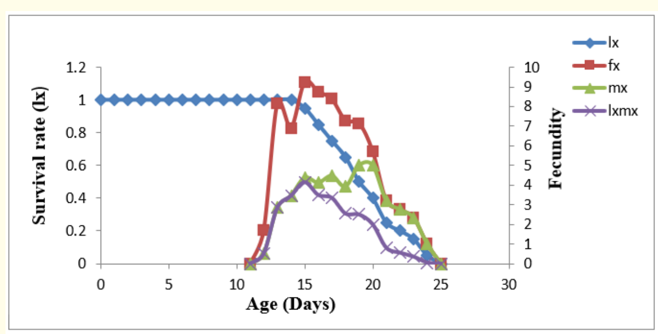
The adult emergence of *D. rapae* occurred at the pivotal age of 15 days. There was no mortality until the 17th day of pivotal age. Thereafter, a gradual decrease in the survival rate of the parasitoid was observed and by the 26th day of the pivotal age, all parasitoids died. The parasitoid started laying at the pivotal age of 16 days and on an average 2.65 female eggs/parasitoids were laid on that day. The age-specific fecundity increased gradually and was maximum (4.95 female eggs/parasitoid) on the 18th day of the pivotal age, which thereafter decreased. The age-specific life expectancy (ex) estimates the time of individuals of age (X) are expected to live. The age-specific reproductive value (vx) indicates the contribution of individuals from age (X) to the future population. When reproduction began, the values for reproduction increased and the reproductive values at age zero were the lowest (1.17 per day) and increased to the peak value of 15.45 per day at the age of 16 days. Population growth parameters of *D. rapae* on the fourth instar of *B. brassicae* obtained from the data on the age-specific survival and fecundity are presented in Table 3 which showed that the GRR and R_0 was 28.65 ± 6.42 and 22.85 ± 5.57 females/parasitoid, respectively. The T was 19.43 ± 0.24 days, respectively. The parasitoid had r_m 0.1594 ± 0.013 females/parasitoid/day. The λ was estimated as 1.17 ± 0.015 times per day. The parasitoid had the capacity to double its population in 4.30 ± 0.04 days.

Parameter	Third instar (Mean ± SE)	Fourth instar (Mean ± SE)
Gross reproductive rate (GRR) (females/parasitoid)	42.47^a ± 7.22	28.65^a ± 6.42
Net reproductive rate ($R_{0)}$ (females/parasiitoid)	26.60^a ± 6.45	22.85^a ± 5.57
Intrinsic rate of increase (rm) females/parasitoid/day)	0.1943^a ± 0.015	0.1594^a ± 0.013
True generation time (T) (Days)	16.89^b ± 0.42	19.43^a ± 0.24
Finite rate of natural increase(λ) (females/day)	1.21^a ± 0.019	1.17^a ± 0.015
Doubling time (DT) (days)	3.57^a ± 0.04	4.30^a ± 0.04

Table 3: Population growth parameters of *D. rapae* on third and fourth larval instar of *B. brassicae*.

Mean values in a row superscripted with the same alphabet do not differ significantly at p = 0.05 calculated by using TWOSEX-MS Chart programme.

Figure 1 shows the age-specific survival rate (lx), the age-specific fecundity of total population (mx), age-stage specific fecundity (fx), and the age-specific maternity (lxmx) curves are plotted at different instar. Age-specific survival (lx) of the parasitoid on third and fourth larval instars of *B. brassicae*, reveals that the survival up to adult emergence was almost the same in the third and fourth instar. The age-specific fecundity (mx) of the parasitoid was highest on the third instar (5 female eggs/female) on the 19th day of pivotal age, whereas (4.95 female eggs/female on the fourth instar. The peak recorded values of age-stage specific fecundity (fx) were (9.2 eggs, 15 d) and (9.4 eggs, 18d) which appeared at the third and fourth instar, respectively.



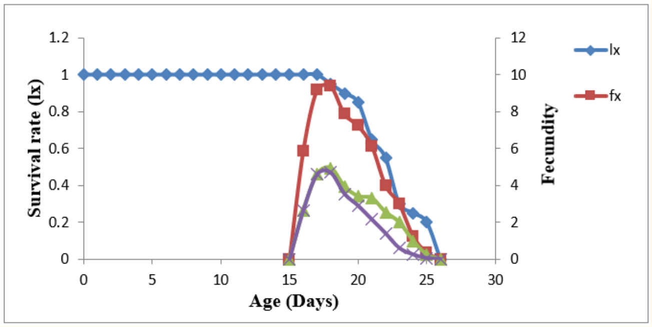


Figure 1: Age specific survival rate (lx), female age-stage specific fecundity (fx), age specific fecundity of total population (mx), and age-specific maternity (lxmx) of *D. rapae* on 3rd and 4th nymphal instars of *B. brassicae.*

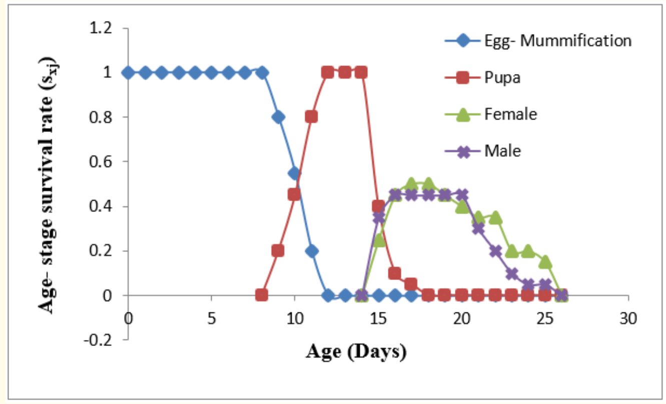
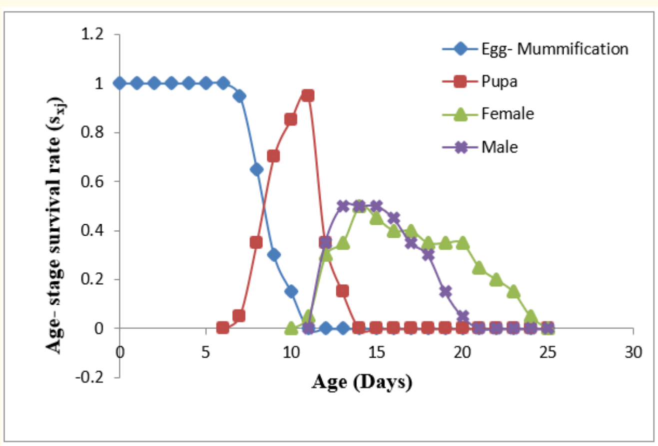


Figure 2: Age stage survival rate (Sxj) of *D. rapae* on 3rd and 4th instar nymphs of *B. brassicae*

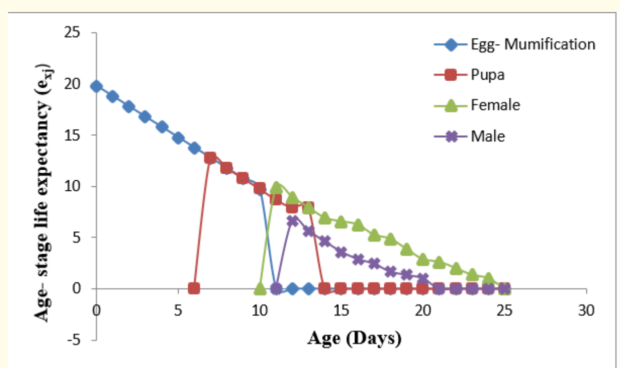
Survival rate

From the detailed age-stage survival rate (s_{xj}) of *D. rapae* on *B. brassicae* at different instars (Figure 2), the results indicated the probability of a parasitoid living to age x and stage j. As the age increased, the survival rate of individuals plummeted. The survival peak of *D. rapae* for males was 13- 15 d, 0.5 and for females was 14 d, 0.5 on third instar nymphs of *B. brassicae* and on fourth instar nymphs of *B. brassicae* it was 16- 20 d, 0.45 for male and 17-18 d, 0.5 for female.



Life expectancy

The life expectancy of *D. rapae* was studied on third and fourth instar nymphs of *B. brassicae* (Figure 3). The longevity of the eggs of *D. rapae* at age zero was 19.75 days on the third instar and 22.65 days on the fourth instar nymphs of *B. brassicae*, respectively. The maximum life expectancy of pupa was 12.76 days at age seven on the third instar and 13.65 days at age nine on the fourth instar nymphs. Female longevity was highest i.e., 9.9 days at age eleven and 8.2 days at age fifteen on the third and fourth instar, respectively. Whereas, the maximum life expectancy of males was 6.6 days at age twelve and 7.05 days at age fifteen on third and fourth instar, respectively. With variation in developmental stages, overall, the highest life expectancy was recorded in fourth instar nymphs of *B. brassicae.*



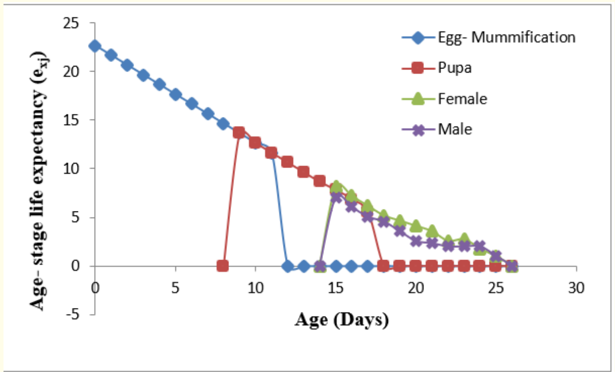


Figure 3: Age stage life expectancy (exj) of *D. rapae* on 3rd and 4th instar nymphs of *B. brassicae*

Reproductive value

The results from (Figure 4) reveal that reproductive values of *D. rapae* burgeoned and reached a peak i.e., 31.59 d^{-1} on 13 d and 31.49 d^{-1} on 16 d on the third and fourth instars of *B. brassicae*, respectively. The results reveal that reproductive value was higher on the third nymphal instar of *B. brassicae* and showed that it had a more positive effect on *D. rapae* reproduction.

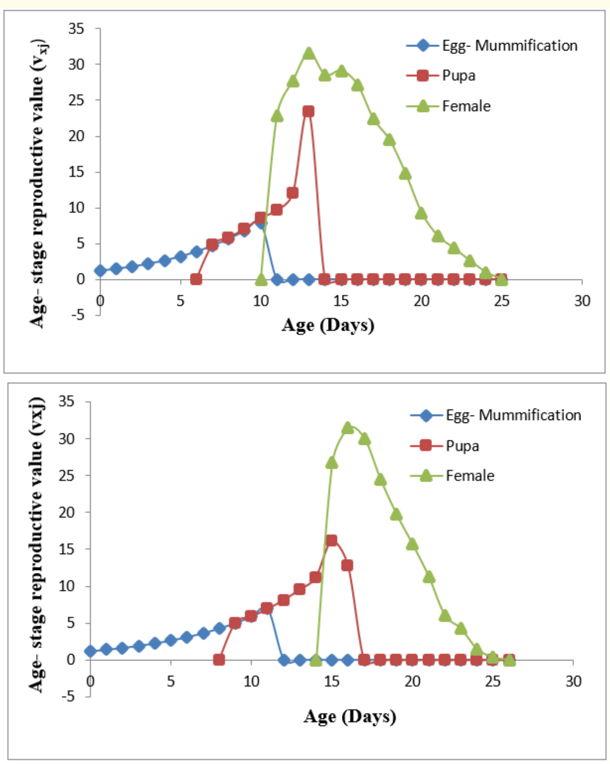


Figure 4: Age-stage reproductive value (vxj) of *D. rapae* on 3rd and 4th instar nymphs of *B. brassicae.*

Age-specific reproductive value (vx)

The age-specific reproductive value of *D. rapae* on third and fourth instar nymphs of *B. brassicae* reveals that the curve for a reproductive value significantly increased to 14.58 on 13 day and 15.45 on 16 day on third and fourth nymphal instars of *B. brassicae,* respectively (Figure 5).

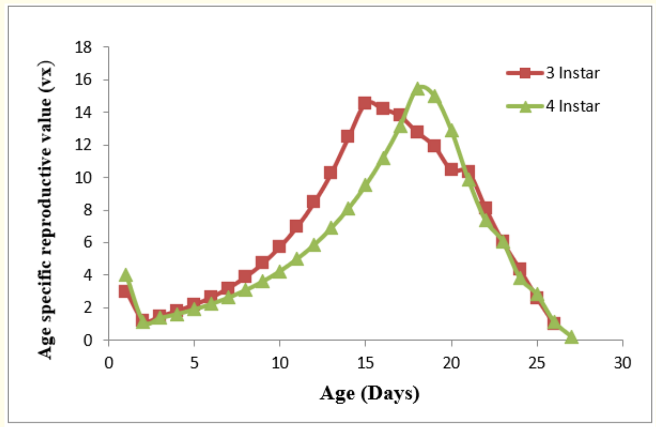


Figure 5: Age-specific reproductive value (vx) of *D. rapae* on 3rd and 4th instar nymphs of *B. brassicae.*

Discussion

In the present study, the developmental period from egg to adult emergence of the parasitoid in the third and fourth instars of *B. brassicae* varied from 12.45 and 15.55 days, respectively (Table 2). The pre-oviposition period on both (third and fourth) nymphal instars was equal (1 day). While oviposition period of the third instar (7.1 days) and fourth instar (6.4 days) were statistically at par. These results suggest that the third instar of the cabbage aphid was a more suitable stage than the fourth instar for the development of *D. rapae.* The present findings are in accordance with the findings of [42] who reported that its development from egg to adult ranged from 9 to 15 days. [43] also reported that the total developmental duration of *D. rapae* (egg to adult emergence) on *B. brassicae* was 15.58 days. The present findings also find support the findings of [44] who reported that the total developmental time of *D. rapae* on *B. brassicae* was 13.4-14.2 days. The present findings differed from the findings of [45] who reported that the total life cycle duration of the parasitoid was completed in 19.3, 20.1, and 17.2 days when reared on 48, 72, and 96 h old nymphs of *B. brassicae*, respectively, whereas in the present study, third and fourth instar nymphs were exposed for 24 h for parasitization The difference in total life cycle duration may be due to the influence of the host stage. According to [46] several interrelated factors determine the impact of a parasitoid on its hosts. The most important factors that determine the effectiveness of the parasitoid depend upon the net fecundity rates of the aphid and its parasitoid [47]. In the present study, the net fecundity rate of *D. rapae* was 53.2 and 45.7 eggs/female on the third and fourth instar of *B. brassicae* on cauliflower, respectively. The present study indicated that parasitoid development was faster when reared on the older host nymphs than on the younger ones. The present findings were in line with the findings of [45] who reported that the fecundity of *D. rapae* was 120-140 eggs per female and the life cycle parameters of parasitoid varied with the age of host insect. The total life cycle of the parasitoid was completed in 19.3, 20.1, and 17.2 days when reared on 48, 72, and 96 h old nymph of *B. brassicae,* respectively, which indicated that the days required to form mummy, pupal period, and duration from egg to adult emergence was comparatively shorter when *D. rapae* was reared on 96h old *B. brassicae* nymphs.

The two-sex life table is the best technique for basic and vital research in ecological studies compared with traditional life tables [48,49]. In the present findings, age-specific survival (lx) of the parasitoid on the third and fourth larval instars of *B. brassicae*, reveals that the survival up to adult emergence was almost the same in the third and fourth instar. Life expectancy (ex) of females was highest (9.9 days) at age eleven and 8.2 days at age fifteen on the third and fourth instar, respectively. Whereas, the maximum life expectancy of males was 6.6 days at age twelve and 7.05 days at age fifteen on the third and fourth instar, respectively. Overall, the highest life expectancy was recorded on fourth instar nymphs of *B. brassicae.* Similar observations were also recorded by [50]. The survival rates (lx) and the life expectancy (ex) at the beginning of adult emergence were 100 per cent and 7.36 days for *D. rapae,* respectively. The intrinsic rate of natural increase is the most important factor for evaluating the efficiency of natural enemies in the control of their host [51]. Different factors affect the rm-value like host and parasitoid species [52], host and parasitoid size [53,52], host plant and temperature [54], and experimental conditions. In the present investigation, the life table and reproductive parameters of *D. rapae* differed from the results of the other authors which may be due to variations in experimental conditions whereas [55] reported that it may be due to intrinsic differences between the geographical populations. While many workers have reported differences in biological attributes among populations of aphid parasitoids [56-58].

When the population growth parameters of *D. rapae* on the third and fourth larval instar of *B. brassicae* were compared, no significant differences were observed in GRR, R_0, r_m, λ, DT (Table 3). The true generation time of *D. rapae*, however, differed significantly; being lesser on the third host instar (16.89 ± 0.42 days) than on the fourth instar (19.43 ± 0.24 days). In the present study, net reproductive rate was 26.60 ± 6.45 females/parasitoid with the third instar whereas it was 22.85 ± 5.57 females/parasitoid with fourth instar. The doubling time was 3.57 days and 4.30 days with the third and fourth nymphal instar of cabbage aphid, respectively. This indicates that the parasitoid population would develop faster when third instar nymphs of *B. brassicae* were offered for parasitism and also indicated that the third nymphal instars of cabbage aphid were the suitable stage for the growth and development of *D. rapae.* The present findings are in agreement with the findings of [59] who reported that the rm-values for aphid and parasitoid were 0.22 ± 0.002 and 0.19 ± 0.003 per day, respectively. The R_0-value of *D. rapae* was 18.07 ± 0.761 females/female/generation and the gross reproductive rate was 32.825 ± 0.972. The fertility table summarizes the information on the biological performance of a given species. It takes into account the age-specific survival and fecundity of the species to determine the net reproductive rate, intrinsic rate of increase, and true generation time. Intrinsic rate of natural increase is the measure of biotic potential of the species and the advantage of using this measure is that it integrates the effect of survival, reproduction, and development time into a single value. Generally species with a high intrinsic rate of increase have high fecundity, high survival, and shorter generation time. Hence, instead of comparing characteristics such as developmental time, longevity, sex ratio, etc. among a population, a single comparison based on i rate of increase can be applied [60].

Conclusion

The result of this research extend our knowledge of one of the most important parasitoid of *B. brassicae* and reveal a better understanding of host parasitoid interactions. Relative preference, biological parameters, and demographic parameters of the parasitoid, *D. rapae* parasitising third and fourth nymphal instars of cabbage aphid, *B. brassicae* were studied. All the biological and demographic parameters of *D. rapae* were better on 3rd nymphal instar of *B. brassicae.* Therefore, the results can be used in mass rearing and mass release programmes and moreover, the parasitoid can be successfully utilised in the integrated pest management of the cabbage aphid.

Declarations

Conflicts of Interest/Competing Interests

The authors foresee and have no conflict of interest or competing interest.

Consent to Participate

All authors had consented to participate in this multidisciplinary research.

Consent for Publication

The corresponding author has consent of all participating authors to submit the research for publication.

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