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Evaluation of Low Temperatures and Gamma Radiations on Parasitization and Development of *Cotesia flavipes* (Cameron) Against *Chilo infuscatellus* (Snellen)

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Abstract. Laboratory studies were conducted to determine the effect of low temperatures and gamma radiation on parasitization of *Cotesia flavipes* (Cameron) on *Chilo infuscatellus* (Snellen). Five temperatures groups *i.e.*, 5.0, 7.5, 10.0, 12.5 and 15.0 °C along with control (25±1 °C) were maintained in separate incubators as ten larvae of 3rd, 4th and 5th instar *C. infuscatellus* were provided to coupled *C. flavipes* for parasitization. Cobalt-60 Telegraphy machine was used for gamma radiations of 20, 40, 60, 80 and 100Gy to fifty larvae of 3rd, 4th and 5th *C. infuscatellus* instars parasitized with *C. flavipes*. Results regarding number of *C. flavipes* cocoons, adult emergence, sex ratio and adult longevity indicated a declined trend with lowering temperatures as maximum parasitoid performance was recorded at control. Moreover, 75Gy was found more effective to support parasitization and development of *C. flavipes* and its preferred 5th instar *C. infuscatellus* larvae than 3rd and 4th instars. Therefore, 75Gy irradiated 5th instar *C. infuscatellus* larvae should be used for the laboratory rearing of *C. flavipes* at 25±1 °C.

Keywords: *Chilo infuscatellus*, *Cotesia flavipes*, radiation, sugarcane, temperature

Introduction

Chilo infuscatellus (Lepidoptera: Crambidae) is an important and destructive pest of sugarcane in Pakistan particularly in Sindh. *Chilo infuscatellus* plays a significant role in affects and yield of sugarcane in Sindh province. It reduces sugarcane yield from 30-70% (Nadeem and Hamid, 2011; Shahid *et al*., 2007). Among the four developmental stages of *C. infuscatellus*, larvae are the only damaging stage (Rachappa and Krishna, 2004) as they mainly remained active during March-November and hibernate in stubbles to over-winter. During germination phase of sugarcane, *C. infuscatellus* larvae damage parent shoot that become clumped and dry as in severe attack, the shoots become dried and the reddish streaks appear on the mid rib of leaves, having typical symptoms of dead heart (Sallam *et al*., 2010).

Despite heavy application of synthetic pesticides, they are not effective against *C. infuscatellus* due to the cryptic nature of the larvae (Sattar *et al*., 2016). Moreover, continuous and indiscriminate use of pesticides have led to developed insecticide resistance in *C. infuscatellus*, along with many human and environmental hazards (Mahmood *et al*., 2016; Gupta *et al*., 2014). Therefore, attention of growers and plant protection specialists has been shifted towards the use of biological control considering the environmental and biodiversity conservation (Goebel *et al*., 2010).

In biological control of sugarcane borers, predators, parasitoids and entomopathogenic micro-organisms are widely used in various regions of the world with variable success (Sattayawong *et al*., 2016; Nadeem and Hamed, 2011; Sétamou *et al*., 2005). Among such bio-control agents, *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) is a key, koinobiont parasitoid borers attacking on graminaceous crops (Alam *et al*., 1971). Particularly, it is found to be more effective against *Chilo partellus* by reducing the population upto 32-55%, as its populations are naturally available in the fields during the time of infestation of borers (Behera and Mishra, 2020; Divyal *et al*., 2009).

It is considered to be indigenous to south and south-east Asia (Mohyuddin, 1971) then introduced to Barbados against sugarcane borer, *Diatraea saccharalis*, where it has successfully established and found effective to reduce population of borer (Rao *et al*., 2019; Alam *et al*., 1971). Afterwards, it was introduced in more than forty countries of tropics and subtropics as classical and new association biological control programs of crambid stem borers (Dejen *et al.* 2013; Getu *et al*.,

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2001). However, in Pakistan in general and Sindh province in particular, there is problem for the laboratory mass production of *C. flavipes*. Therefore, the studies were undertaken to determine the impact of various low temperatures and gamma radiation in the mass rearing of *C. flavips* on *C. infuscatellus* in the laboratory.

Materials and Methods

Effect of various low temperatures on the parasitization of *C. flavipes* on *C. infuscatellus*. Studies were conducted at the Research Laboratory, Nuclear Institute of Agriculture, Tando Jam, Pakistan. Five temperature ranges *i.e.*, 5.0, 7.5, 10.0, 12.5 and 15.0 °C along with control (25±1 °C) were evaluated to determine their effect on the development of *C. flavipes* on 3rd, 4th and 5th instar larvae of *C. infuscatellus.* Ten *C. infuscatellus* larvae from each instar (3rd to 5th instar) were exposed to *C. flavipes* coupled adults for 24 h at the required temperatures in separate incubators to determine the impact of these low temperature regimes on the life parameters of *C. flavipes*. After the development of *C. flavipes* cocoons containing pupae were then confined in glass vials in sugarcane setts and placed in different incubators maintaining the required above mentioned temperatures till the completion of their development. The data was recorded for emergence of pupae and adults, sex ratio and longevity of adults. The experiment was arranged in a complete randomized design (CRD), where each treatment was replicated four times. Analysis of variance (ANOVA) and the least significant difference (LSD) at 5% probability were used to analyze the data using STATISTIX 8.1 software.

Effect of radiation on the parasitization of *C. flavipes* on *C. infuscatellus*. The experiment was conducted at NIMRA, Jamshoro using Cobalt-60 Telegraphy machine (Model GW × 580 NPIC China) that has capacity of irradiation of 2.62 Gy/sec as per 100=0.026 Gy/sec. In the experiment, fifty *C. flavipes* parasitized 3rd, 4th and 5th instar larvae of *C. infuscatellus* were placed in the petri dishes and then exposed to various doses of radiations *i.e.*, 20, 40, 60, 80 and 100 grey. Afterwards, irradiated larvae were kept between sugarcane setts under laboratory conditions to complete their development. Observations were taken on daily basis to record survival of *C. flavipes,* whereas sex ratios, adult emergence and adult longevity were recorded. The experiment was arranged in a CRD design where each treatment was replicated four times. ANOVA and LSD at 5% probability were used to analyze the data using STATISTIX 8.1 software.

Results and Discussion

Effect of low temperatures on the development of *C. flavipes* on 3rd instar *C. infuscatellus* larvae. Figure 1 showed the effect of low temperatures on the rate of parasitization of *C. flavipes* on 3rd instar *C. infuscatellus* as a significant difference (P < 0.05) was recorded on various parameters of its development. Results revealed that the comparatively a greater number of developed cocoons of *C. flavipes* (7.60±0.56 cocoons) along with maximum adult emergence (6.50±0.46 adults), highest number of emerged males and females (2.80±0.27 and 3.70±0.31, respectively) and longest longevity for both sexes (3.50±0.21 days for male and 4.55±0.21 days for female) were recorded when it was supplied with *C. infuscatellus* 3rd instar larvae at control temperature. Moreover, the lowest number of *C. flavipes* cocoons (0.45±0.15 cocoons) were recorded at 5 °C, whereas the adult emergence (0.45±0.05 adults, 0.45±0.08) along with least number of females (0.25±0.09 females) were observed at lowest temperatures of 5 °C and 7.5 °C. Accordingly, control (1.00: 0.76) was found most effective to support female based sex ratio, followed by 15 °C (1.00: 0.92), whereas 10 °C temperature was found to be less supportive in the female sex ratio (1.00: 1.06).

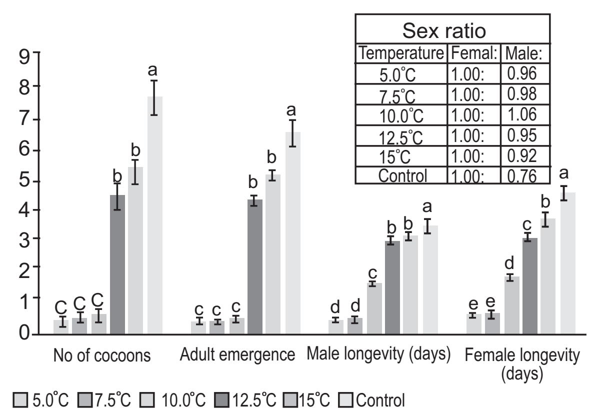

Fig. 1. Effect of low temperatures on the development of *C. flavipes* on 3rd instar larvae of *C. infuscatellus* during 2013 (mean ± SE). * = means followed by the same letters in same column are not significantly different (P < 0.05).

Almost similar trend in performance of *C. flavipes* was recorded on 3rd instar larvae of *C. flavipes* exposed to different temperature regimes as the maximum and minimum developmental parameters of parasitoid was recorded at control (25±1 °C) and 5 °C (Fig. 2). However, among lower temperatures applied, maximum number of cocoon production (7.00±0.46 cocoons) of *C. flavipes* on 3rd instar *C. infuscatellus* along with adult emergence (6.45±0.32) adults was obtained at 12.5 °C but the same was not significantly different (P > 0.05) from the cocoons produced (6.65±0.28) and adult emergence (6.35±0.14 adults) recorded at 12.5 °C. Moreover, after control temperature, the maximum adult longevity was observed at 15 °C (2.70±0.18 days for males and 2.85±0.21 days for females), however, male longevity recorded was also non-significant with that of 12.5 °C (2.55±0.13 days). The sex ratio results indicated that in comparison to 2013, 15 °C (1.00: 0.65) was found most effective to support female based sex ratio (F: M), followed by 5 °C (1.00: 0.80), whereas 10 °C temperature was found to be less supportive to produce females (1.00: 1.60).

Effect of low temperatures on the development of *C. flavipes* on 4th instar *C. infuscatellus* larvae. Figure 3 showed that a significant difference was recorded among various low temperatures on the rate of parasitization of *C. flavipes* on 4th instar *C. infuscatellus* larvae during both years of study. During 2013, control temperature range (25±1 °C) supported the maximum production of *C. flavipes* cocoons (8.70±0.62 cocoons), number of adults emerged (8.025±0.48 adults), number of males (3.70±0.22 males) and females (4.55±0.44 females) produced along with longest longevity of males (4.00±0.20 days) and females (4.25±0.30 days). Moreover, 5 °C was found the least supportive in the development of *C. flavipes* on 4th instar *C. infuscatellus* larvae with 0.77±0.21 cocoons, 0.40±0.07 adult emergence, along with shortest longevity of 0.25±0.05 days for males and 0.30±0.03 days for females. The sex ratio results indicated that control (1.00: 0.81) was found most effective to support female based sex ratio (F: M), followed by 7.5 °C (1.00: 0.83), respectively. Moreover, 10 °C temperature was found to be less supportive in the female sex ratio (1.00: 1.30), followed by 5.0 °C (1.00: 1.00).

As compared to 2013, relatively higher number of *C. flavipes* cocoons (9.25±0.95 cocoons) were recorded in control, whereas minimum cocoons (0.70±0.215 cocoons) were observed at 5.0 °C (Fig. 4). Among lower temperatures, 15 °C showed the maximum *C. flavipes* cocoons (7.10±0.55 cocoons) along with maximum adult emergence (6.25±0.38 adults) and longevity of both males (3.18±0.10 days) and females (3.44±0.19 days). The sex ratio results indicated that 5 °C (1.00: 0.82) was found most effective to support female based sex ratio, followed by 15 °C (1.00: 0.87). Moreover, 10 °C temperature was found to be less supportive in the female sex ratio (1.00: 1.08), followed by control (1.00: 0.91).

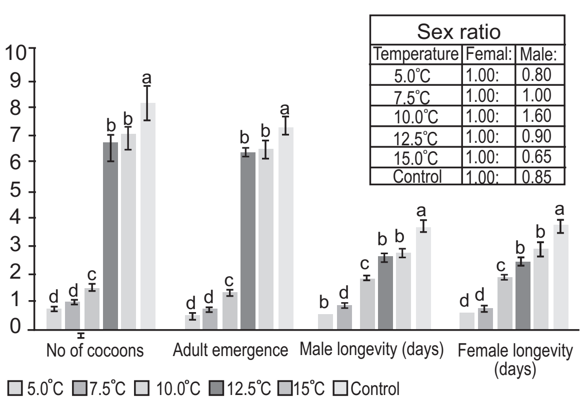

Fig. 2. Effect of low temperatures on the development of *C. flavipes* on 3rd instar larvae of *C. infuscatellus* during 2014 (mean ± SE). * = means followed by the same letters in same column are not significantly different (P < 0.05).

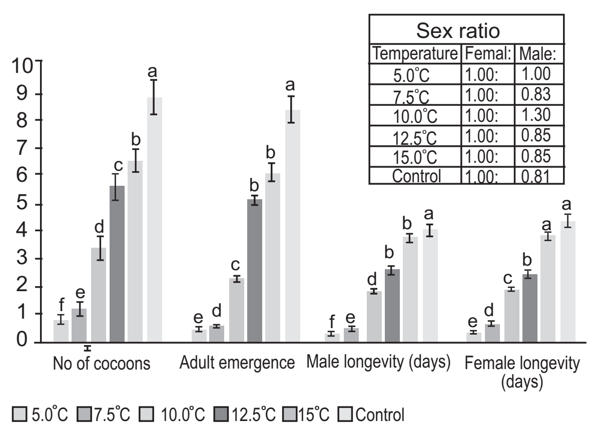

Fig. 3. Effect of low temperatures on the development of *C. flavipes* on 4th instar larvae of *C. infuscatellus* during 2013 (mean ± SE). * = means followed by the same letters in same column are not significantly different (P < 0.05).

Effect of low temperatures on the development of *C. flavipes* on 5th instar *C. infuscatellus* larvae. Similar to the previous results of 3rd and 4th instar *C. flavipes,* data in Fig. 5 also confirmed that optimum temperature (25±1 °C) supported the production of maximum number of cocoons (9.54±1.12 cocoons), higher number of emerged adults (8.64±0.48 adults), maximum male and female emergence (4.15±0.25 males and 4.50±0.35 females) and longest longevity for both male and female wasps (4.35±0.18 and 4.55±0.35 days, respectively).

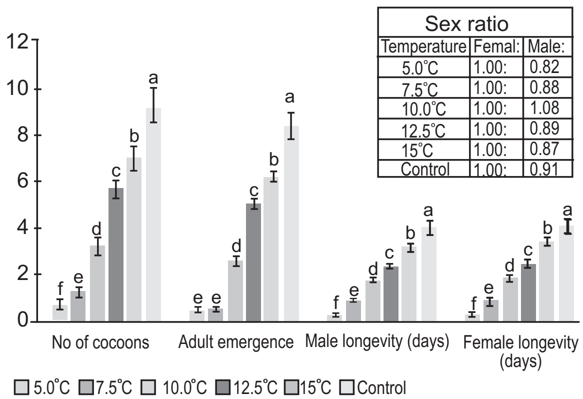

Fig. 4. Effect of low temperatures on the development of *C. flavipes* on 4th instar larvae of *C. infuscatellus* during 2014 (mean ± SE). * = mean followed by the same letters in same column are significantly different (LSD < 0.05).

Among the lower temperature ranges applied, 15 °C temperature supported the maximum parasitization of *C. flavipes* on 5th instar *C. infuscatellus* with production of maximum number of cocoons (7.85±0.75 cocoons) but not significantly different from the cocoons produced at 12.5 °C (6.70±0.40). Moreover, the minimum number of developed cocoons (1.25±0.12 cocoons), adult emergence (0.40±0.07 adults) and the shortest male and female longevity (0.25±0.05 and 0.30±0.03 days, respectively was recorded at 5 °C. Hence, overall data various parameters of *C. flavipes* on 5th instar *C. infuscatellus* showed a significant (P < 0.05) difference at various temperature ranges applied in (Fig. 5). The sex ratio results indicated that 7.5 °C (1.00: 0.83) was found most effective to support female based sex ratio (F: M), followed by 12.5 °C (1.00: 0.91). Moerover, 10 °C temperature was found to be less supportive in the female sex ratio (1.00: 1.30), followed by 15 °C (1.00: 0.95).

Data pertaining to the impact different temperature ranges on the development of *C. flavipes* on 5th instar larvae of *C. infuscatellus* under laboratory condition during 2014 is given in Fig. 6. The results exhibited that the significantly (P < 0.05) maximum number of developed cocoons of *C. flavipes* (9.50±1.08 cocoons), maximum adult emergence (8.35±0.88 adults), highest male and female population (4.15±0.32 males and 4.20±0.25 females) and longest longevity for male (4.11±0.17 days) and females (4.50±0.21 days) was recorded at control temperature. Moreover, the least

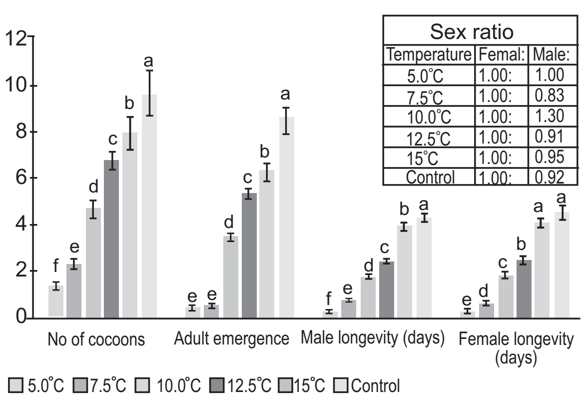

Fig. 5. Effect of low temperatures on the development of *C. flavipes* on 5th instar larvae of *C. infuscatellus* during 2013 (mean ± SE). * = means followed by the same letters in same column are not significantly different (P < 0.05).

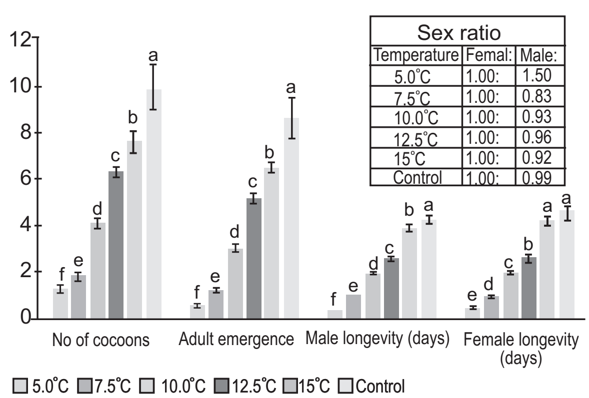

Fig. 6. Effect of low temperatures on the development of *C. flavipes* on 5th instar larvae of *C. infuscatellus* during 2014 (mean ± SE). * = means followed by the same letters in same column are not significantly different (P < 0.05).

number of developed cocoons (1.22±0.15 cocoons), emerged adult population (0.50±0.10 adults) along with lowest longevity for males (0.30±0.01 days) and females (0.40±0.03 days) was recorded at 5.0 °C. The sex ratio results indicated that 7.5 °C (1.00: 0.83) was found most effective to support female based sex ratio (F: M), followed by 15 °C (1.00: 0.92). Moreover, 5.0 °C temperature was found to be less supportive in the female sex ratio (1.00: 1.50), followed by control (1.00: 0.99) and 12.5 °C (1.00: 0.96).

Effect of gamma radiations on the development of *C. flavipes* on 3rd instar *C. infuscatellus* larvae. Results in Fig. 7 show the number of cocoons, adult emergence, number of emerged males and females, longevity of both sexes of *C. flavipes* recorded on different doses irradiated parasitoid 3rd instar *C. infuscatellus* larvae. According to results the maximum number of cocoon production (18.95±1.90) cocoons was recorded at 75Gy gamma radiation dose, followed by cocoons produced at 75Gy (15.65±1.02) cocoons, whereas the lowest cocoons (8.95±1.25) cocoons were produced at 25Gy. Moreover, although, the maximum adult emergence (17.50±1.70) adults was recorded at 75 Gy but the highest male (4.60±0.15 days) and female (4.75±0.17) days longevity was observed in the control treatment. The *C. flavipes* adult longevity of (3.40±0.35) days for males and (3.60±0.28) days for females was recorded at 75 Gy, whereas the lowest male (2.15±0.17) days and female (2.35±0.35) longevity of parasitoid was recorded at 25 Gy but the same was not significantly different from longevity (2.60±0.22) days for males and 2.75±0.25) days for females, recorded at 50 Gy (Fig. 7).

The sex ratio results indicated that 75Gy (1.00: 0.90) and 25Gy (1.00: 0.90) was found most effective to support female based sex ratio (F: M), followed by control (1.00: 0.98). Moerover, 100Gy was found to be less supportive in the female sex ratio (1.00: 1.07), followed by 50 °C (1.00: 1.04).

Similar trend in results was recorded for various developmental parameters of *C. flavipes* on 3rd instar *C. infuscatellus* larvae irradiated with different doses of gamma rays (Fig. 8). According to results, 75Gy irradiation supported the maximum cocoon development (18.95±1.90 cocoons) of *C. flavipes,* followed by 100Gy (15.65±1.02 cocoons) and control (11.95±0.66 cocoons). Moreover, the highest adult emergence (17.50±1.70 adults) was also noticed at 75Gy, whereas the lowest cocoon production (8.95±1.25 adults) and adult emergence (7.50±0.66 adults) was recorded when *C. flavipes* was provided with 3rd instar irradiated larvae of *C. infuscatellus.* The results also indicated that maximum (9.20±1.15 females) and minimum (3.95±0.55 females) female production was observed at 75Gy and 25Gy, respectively. Similar to females, maximum (8.30±0.77 males) and minimum (3.55±0.50 males) emergence of male *C. flavipes* was also recorded at 75Gy and 25Gy, respectively. However, the highest (4.60±0.15 days for males and 4.75±0.17 days for females) and lowest (2.15±0.17 days for males and 2.35±0.35 days for females) adult longevity of *C. flavipes* was recorded in control and 25Gy irradiation, respectively. Hence, analyzes of variance confirmed that exposure of gamma radiations

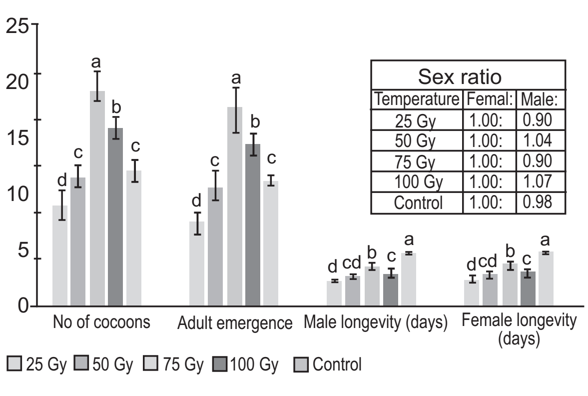

Fig. 7. Effect of gamma radiations on the development of *C. flavipes* on 3rd instar *C. infuscatellus* larvae during 2013 (mean ± SE). * = means followed by the same letters in same column are not significantly different (P < 0.05).

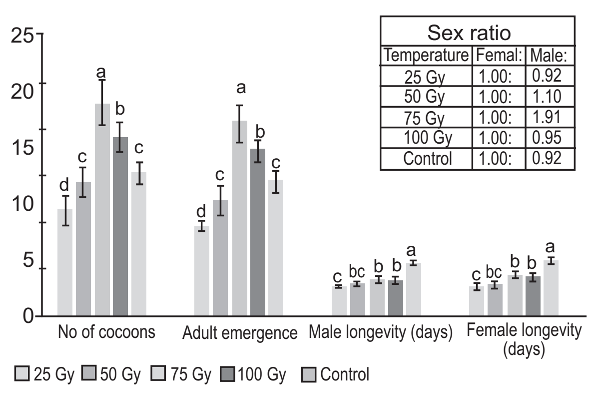

Fig. 8. Effect of gamma radiations on the development of *C. flavipes* on 3rd instar *C. infuscatellus* larvae during 2014 (mean ± SE). * = means followed by the same letters in same column are not significantly different (P < 0.05).

on 3rd instar *C. infuscatellus* significantly (P < 0.05) influenced on various life parameters of *C. flavipes*. The sex ratio results indicated that 75Gy (1.00: 0.91), followed by 25Gy and control (1.00: 0.92) was found most effective to support female based sex ratio (F: M). Moreover, 50Gy was found to be less supportive in the female sex ratio (1.00: 1.07), followed by 100 °C (1.00: 0.95).

Effect of gamma radiations on the development of *C. flavipes* on 4th instar *C. infuscatellus* larvae. The effect of different gamma irradiated 4th instar *C. infuscatellus* larvae on various life parameters of *C. flavipes* population are shown in (Fig. 9). Result revealed that significantly (P < 0.05) maximum *C. flavipes* cocoon development (29.97±3.81 cocoons), a greater number of adult emergence (25.57±1.77 adults), higher female and male population (13.10±1.15 females and 12.67± 1.03 males) was recorded at 75Gy dose. Moreover, the lowest number of cocoon production (14.65±1.11 cocoons), adult emergence (12.65±0.81 adults), minimum male and female emergence (6.10±0.54 males and 6.55±0.71 females) was recorded at 25Gy. The results also indicated that maximum and minimum adult longevity of *C. flavipes* (4.55±0.14 days for males and 4.57±0.18 days for females) was observed in control, followed by 75Gy irradiations (3.90±0.20 days for males and 4.05±0.19 days for females). Therefore, a highly significant difference (P < 0.001) was recorded in various parameters of *C. flavipes* when it was provided with irradiated 4th instar larvae of *C. infuscatellus*. The sex ratio results indicated that control (1.00: 0.91) was found to be most efficient to supported maximum number of females followed by 25Gy (1.00: 0.93) and 75Gy (1.00: 0.94). Moreover, 50Gy was found to be less supportive in the female sex ratio (1.00: 1.01) that was followed by 100 °C (1.00: 0.98).

Figure 10 indicated the results for various developmental parameters of *C. flavipes* when supplied with 4th instar irradiated larvae of *C. infuscatellus* that exhibited a significant (P < 0.05) variation. Observed data indicated similar trend as observed during the 2013 as maximum cocoon production (28.40±2.45 cocoons) along with adult emergence (24.90±1.35 adults) was recorded at 75Gy, followed by 50Gy irradiations (21.80±1.72 cocoons and 19.05±1.66 adults). Moreover, the longest male (4.45±0.22 days) and female (4.25± 0.20 days) longevity of *C. flavipes* was observed in control, whereas 25Gy irradiated 4th instar *C. infuscatellus* larvae showed minimum male (1.95±0.18 days) and female (1.98±0.11 days) longevity (Fig. 10). Similar to 2013, sex ratio results indicated that control (1.00: 0.87) was found most effective treatment to support female based sex ratio (F: M), followed by 50Gy (1.00: 0.96) and 75Gy (1.00: 0.99). Moreover, 25 (1.00: 1.04) and 100Gy (1.00: 1.03) were found to be less supportive in the female sex ratio.

Effect of gamma radiations on the development of *C. flavipes* on 5th instar *C. infuscatellus* larvae. A significant variation (P < 0.05) was recorded among different exposures of gamma rays on different developmental parameters of *C. flavipes*, while feeding on 5th instar *C. infuscatellus* larvae. According to results,

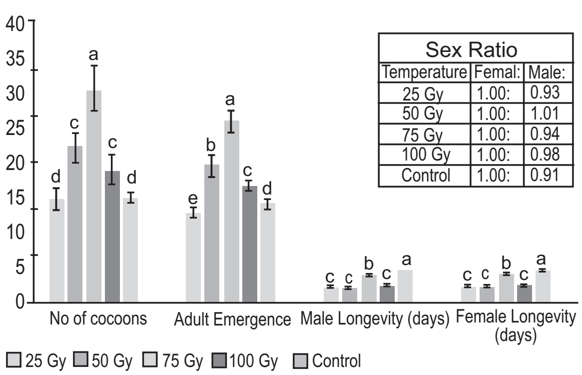

Fig. 9. Effect of gamma radiations on the development of *C. flavipes* on 4th instar *C. infuscatellus* larvae during 2013 (mean ± SE). * = means followed by the same letters in same column are not significantly different (P < 0.05).

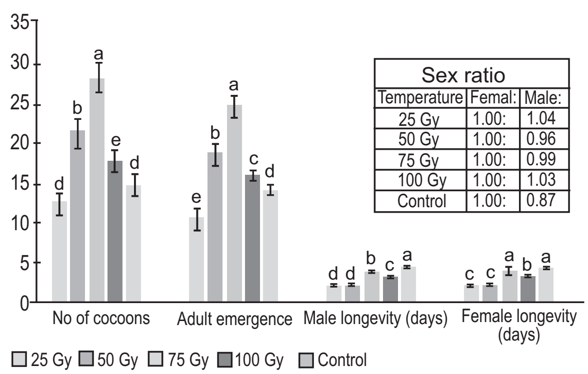

Fig. 10. Effect of gamma radiations on the development of *C. flavipes* on 4th instar *C. infuscatellus* larvae during 2014 (mean ± SE). * = means followed by the same letters in same column are not significantly different (P < 0.05).

maximum cocoon production of *C. flavipes* (26.30±2.04 cocoons) was recorded when it was provided with 75Gy irradiated 5th instar *C. infuscatellus* larvae, followed by 50Gy (20.40±2.69 cocoons), whereas minimum cocoons were produced in control (11.20±0.65 cocoons), followed by 25Gy (13.20±1.34 cocoons). Moreover, 75Gy irradiated 5th instar *C. infuscatellus* also produced maximum number of adults (23.15±1.97 adults), males (11.50±0.97 males) and female (11.65±0.90 females) *C. flavipes*. However, the highest male (4.42±0.19 days) and female (4.35±0.18 days) longevity of *C. flavipes* was recorded in control, whereas the minimum longevity of 1.85±0.10 days and 1.90±0.20 days for males and females, respectively was recorded at 25Gy irradiations (Fig. 11). The sex ratio results indicated that control (1.00: 0.89) was found to be most efficient to supported maximum number of females followed by 100Gy (1.00: 0.93) and 75Gy (1.00: 0.99). Moreover, 50Gy was found to be less supportive in the female sex ratio (1.00: 1.09) that was followed by 100 °C (1.00: 1.03).

During 2014, similar trend was recorded for the various parameters of *C. flavipes* parasitization on irradiated 5th instar *C. infuscatellus* larvae as maximum (27.90±2.04 cocoons) and minimum (12.45±0.55 cocoons) cocoon production was recorded at 75Gy dose and control, respectively (Fig. 12). Moreover, 75Gy irradiated 5th instar *C. infuscatellus* larvae also supported the maximum adult (25.75±1.25 adults) and female (12.70±0.97) emergence, however, maximum male (4.85±0.40 days) and female (4.75±0.40) longevity of *C. flavipes* was 38 days recorded in control. Overall, a highly significant (P < 0.001) difference was recorded among various parasitization parameters of *C. flavipes* when provided with 5th instar irradiated larvae of *C. flavipes*. Similar to 2013, The sex ratio results for 2014 indicated that control (1.00: 0.95) was found to be most efficient to supported maximum number of females followed by 75Gy (1.00: 0.97). The lowest female-based ration was recorded in 100Gy (1.00: 1.04) followed by 25 and 50Gy treatments (1.00: 0.99).

Effect of low temperature on the development of *C. flavipes* on *C. infuscatellus* larvae. It has been observed in the study undertaken that no significant impact of the lower temperatures was recorded on various parasitization parameters of *C. flavipes* on 3rd, 4th and 5th instar larvae of *C. infuscatellus.* Instead, the controlled optimum temperature (25±1 °C) supported the maximum cocoon production, adult emergence along with males and females and longevity of both male and female adults. The findings of our studies are supported by the studies of (Mbapila and Overholt, 2001) who also recorded the inverse relationship of temperature with the development of *Cotesia* spp. as lower temperature were found less supportive. Moreover, an increase in female-based sex ratio was also observed in *C. flavipes* with the increasing temperature by (Jiang *et al*., 2004). Another study suggested that none of the population of *C. flavipes* was found tolerant to low temperatures as mortality increased with lowering the temperatures (Tanwar, 2004). However, (Manjoo and Bajpai, 2012) reported that the storage of cocoons for 10 and 15 days at 5, 10, 15 and 20 °C did not affect the adult emergence,

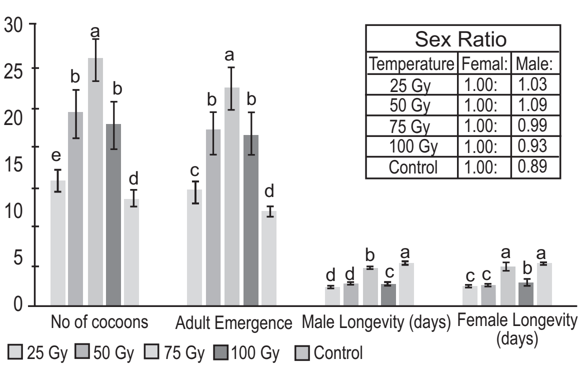

Fig. 11. Effect of gamma radiations on the development of *C. flavipes* on 5th instar *C. infuscatellus* larvae during 2013 (mean ± SE). * = means followed by the same letters in same column are not significantly different (P < 0.05).

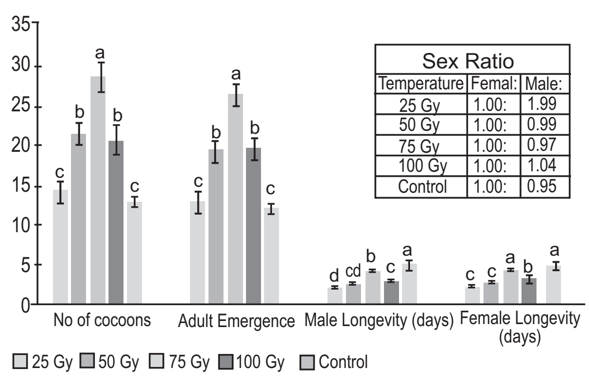

Fig. 12. Effect of gamma radiations on the development of *C. flavipes* on 5th instar *C. infuscatellus* larvae during 2014 (mean ± SE). * = means followed by the same letters in same column are not significantly different (P < 0.05).

but, the lowest temperature of 5 °C significantly affected the female emergence. Moreover, they recorded maximum female emergence when cocoons were stored for 10 days at 20 °C. Accordingly, in this study, 5 °C was to be less supportive for the growth and development of *C. flavipes* as the lowest number of cocoons developed at this temperature.

It has been evident that among weather parameters, the effect of temperature on life history parameters of insects is more significant than remaining factors (relative humidity, rain etc.) as temperature significantly affected the longevity, fecundity and fertility among insects (Getu *et al*., 2004). Moreover, temperature regimes at different geographical locations also exhibited variations in longevity and fecundity of variable population of *C. flavipes* from Pakistan and India. Studies on survival, development, and body growth patterns of *C. flavipes* on 3rd and 4th instar larvae of *C. partellus* at 22, 26 and 30 °C temperatures showed that non-parasitized hosts, larval mortality was highest at lowest temperatures (Jiang *et al*., 2004). Development time of *C. flavipes* immature significantly decreased with host instar and with temperature. Sex ratio of *C. flavipes* varied from male to female-based with increase in temperature. Therefore, it has been suggested that the duration of *C. flapives* life cycle completely depends on temperature as no development of *C. flavipes* was noted at 10, 15 and 32 °C temperature ranges, whereas at optimum temperature range of 25-38 °C, the maximum success in life cycle of parasitoid was observed (Smaniotto *et al*., 2019).

Effect of gamma radiations on the development of *C. flavipes* on *C. infuscatellus* larvae. The biological parameters of *C. flavipes* were significantly affected when supplied with gamma irradiated 3rd, 4th and 5th instars of *C. infuscatellus* applied at various doses. Among the doses, 75Gy dose of gamma radiations was found the most effective to produce maximum numbers of cocoons and accordingly, the highest adults (both males and females) were also emerged at 75Gy. Moreover, 50Gy and 100Gy doses of radiations also produced more cocoons with higher adult emergence of *C. flavipes* than control treatment. However, maximum longevity of *C. flavipes* was recorded in control treatments instead of those when supplied with 3rd, 4th and 5th instar irradiated larvae of *C. infuscatellus* at various doses of gamma radiations. It has been also recorded in the study that in comparison to 3rd and 4th instar *C. infuscatellus* larvae, 5th instar larvae produced significantly a greater number of *C. flavipes* cocoons showing maximum adult emergence, along with male and female population emergence. Therefore, our results are supported by the findings of (Fatima *et al*., 2009), who reported that gamma radiation doses *i.e*., 60-80 Gy improved the suitability of *C. infuscatellus* larvae for parasitism by *C. flavipes,* allowing normally unsuitable fourth and fifth instar larvae of *C. infuscatellus* to be successfully parasitized. The sex ratio of parasitoids reared on irradiated larvae was skewed in favour of females. Irradiation also slowed immature development of *C. flavipes* and the combination of irradiation and low temperature (10 °C) proved effective for prolonged storage of the parasitoids. Their findings also evident that the pupae of *C. flavipes* irradiated at 20 Gy gamma radiation dose could be stored for 2 months at 10 °C without apparent loss of quality and deferred emergence by 29-30 days. Furthermore, (Abdel-Hameid *et al*., 2019) observed the effect of gamma radiation doses on the development of *Trichogramma evanescens* and stated that the parasitism percentages were relatively reduced to (97.1, 96.1, 93.03 and 92.7%) after irradiating the *S. cerealella* eggs at 40, 60, 80 and 100 Gy, respectively than the control (97.3% emergence). Moreover, the percentages of emergence and females' percent were slightly decreased by gamma irradiation doses, while equal preferred by the F_1 generation of parasitoid that produced from irradiated *S. cerealella* eggs. Among other parasitoids, *Trybliographa daci* (Weld) (Hymenoptera: Eucoilidae) also showed improved parasitization on peach fruit-fly, *Bactrocera zonata* (Saunders) (Diptera: Tephritidae), when they were provided with 15Gy irradiated fruit flies as it has been suggested that irradiated prey showed no negative repercussions on parasitoid development. The same study also suggested that overall, parasitism by *T. daci* increased with age of the host larvae of fruit flies as significantly higher parasitism occurred on 4 days old, irradiated larvae of *B. zonata* than 5 days old larvae. Moreover, as female parasitoids preferred the irradiated larvae and significantly higher numbers of larvae were parasitized compared with non-irradiated larvae. There was no significant difference in adult parasitoid emergence with respect to the sex of the host.

Conclusion

The performance of *C. flavipes* against *C. infuscatellus* showed a declined trend as the temperature was reduced, with minimum parasitism parameters recorded at 5 °C. Significant impact of gamma irradiations were recorded on the biological parameters of *C. flavipes* on 3rd, 4th and 5th instar larvae of *C. infuscatellus* with best results obtained at 75Gy radiations. *Cotesia flavipes* showed comparatively more parasitism performance when provided with 5th instar larvae of *C. infuscatellus* than 3rd and 4th instars.

Conflict of Interest. The authors declare that they have no conflict of interest.

References

Abdel-Hameid, N.F., Elzoghby, I.R.M., Mehany, A.L., Sayed, W.A.A. 2019. Cold storage and gamma irradiation of *Sitotroga cerealella* Olivier eggs (Lepidoptera: Gelechiidae) in relation to the success of parasitism by *Trichogramma evanescens* westwood (Hymenoptera: Trichogrammatidae). *Egyptian Journal of Biological Pest Control*, **29:** 1-5.

Alam, M.M., Bennett, F.D., Carl, K.P. 1971. Biological control of *Diatraea saccharalis* (F.) in Barbados by *Apanteles flavipes* Cam. and *Lixophaga diatraea* TT. *Entomophaga*, **16:** 151-158.

Behera, P., Mishra, B.K. 2020. Biological control of maize stem borer, *Chilo partellus* (Swinhoe) in Kharif maize through combined releases of *Trichogramma chilonis* (Ishii) and *Cotesia flavipes* (Cameron) in Odisha. *Journal of Entomology and Zoology Studies*, **8:** 1647-1651.

Dejen, A., Getu, E., Azerefegne, F., Ayalew, A. 2013. Distribution and extent of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) parasitism in north-eastern Ethiopia. *International Journal of Insect Science*, **5:** 9-19. http://doi:10.4137/IJIS.S11009

Divya, K., Marulasiddesha, K.N., Krupanidhi, K., Sankar, M. 2009. Population dynamics of spotted stem borer, *Chilo partellus* (Swinhoe) and its interaction with natural enemies in sorghum. *Indian Journal of Science and Technology*, **3:** 70-74.

Fatima, B., Ahmed, N., Memon, R.M., Bux, M., Ahmad, Q. 2009. Enhancing biological control of sugarcane shoot borer, *Chilo infuscatellus* (Lepidoptera: Pyralidae), through use of radiation to improve laboratory rearing and field augmentation of egg and larval parasitoids. *Biocontrol Science and Technology*, **19:** 277-290.

Getu, E., Overholt, W.A., Kairu, E. 2004. Comparative studies on the influence of relative humidity and temperature on life table parameters of two populations of *Cotesia flavipes* (Hymenoptera: Braconidae). *Biocontrol Science and Technology*, **14:** 595-605.

Getu, E., Overholt, W.A., Kairu, E. 2001. Distribution and species composition of stemborers and their natural enemies in maize and sorghum in Ethiopia. *International Journal of Tropical Insect Science*, **21:** 353-359.

Goebel, F.R., Achadian, E., Kristini, A., Sochib, M., Adi, H. 2010. Investigation of crop losses due to moth borers in Indonesia. In: *Proceedings of the Australian Society of Sugar Cane Technologists*, **33:** pp 9.

Gupta, S., Gupta, R., Sharma, S. 2014. Impact of pesticides on plant growth promotion of *Vigna radiata* and non-target microbes: comparison between chemical and bio-pesticides. *Ecotoxicology*, **23:** 1015-1021.

Jiang, N.Q., Setamou, M., Ngi-Song, A.J., Omwega, C.O. 2004. Performance of *Cotesia flavipes* (Hymenoptera: Braconidae) in parasitizing *Chilo partellus* (Lepidoptera: Crambidae) as affected by temperature and host stage. *Biological Control*, **31:** 155-164.

Mahmood, I., Imadi, S.R., Shazadi, K., Gul, A., Hakeem, K.R. 2016. Effects of pesticides on environment. In: *Plant, Soil and Microbes*, pp. 253-269.

Manjoo, S., Bajpai, N.K. 2012. Effect of storage at different temperatures on the biological parameters of *Cotesia flavipes* Cameron. *Journal of Biological Control*, **26:** 157-161.

Mbapila, J.C., Overholt, W.A. 2001. Comparative development, longevity and population growth of exotic and native parasitoids of lepidopteran cereal stemborers in Kenya. *Bulletin of Entomological Research*, **91:** 347-353.

Mohyuddin, A.I. 1971. Comparative biology and ecology of *Apanteles flavipes* Cam. and *Apanteles sessamiae* Cam.as parasites of graminaceous borers. *Bulletin of Entomological Research*, **61:** 33-39.

Nadeem, S., Hamed, M. 2011. Biological control of sugarcane borers with inundative releases of *Trichogramma chilonis* (Ishii) (Hymenoptera: Trichogrammatidae) in farmer fields. *Pakistan Journal of Agricultural Sciences*, **48:** 71-74.

Rachappa, V., Krishna, N.L. 2004. Integrated management of early shoot borer, *Chilo infuscatellus* (Snellen) in sugarcane. *Annals of Plant Protection Sciences*, **12:** 71-73.

Rao, G.M.V.P., Ramani, S., Singh, S.P. 2019. Studies on *Cotesia flavipes* and *Tetrastichus howardi* parasitoids of the maize stem borer *Chilo partellus*

(Swinhoe). *Insect Environment*, **7:** 112-113.

Sallam, N., Achadian, E., Kristini, A., Sochib, M., Adi, H. 2010. Monitoring sugarcane moth borers in Indonesia: towards better preparedness for exotic incursions. In: *Proceedings of the Australian Society of Sugar Cane Technologists*, **32:** 181-192.

Sattar, M., Mehmood, S.S., Khan, M.R., Ahmad, S. 2016. Influence of egg parasitoid *Trichogramma chilonis* Ishii on sugarcane stem borer (*Chilo infuscatellus* Snellen) in Pakistan. *Pakistan Journal of Zoology*, **8:** 989-994.

Sattayawong, C., Uraichuen, S., Suasa-ard, W. 2016. Larval preference and performance of the green lacewing, *Plesiochrysa ramburi* (Schneider) (Neuroptera: Chrysopidae) on three species of cassava mealybugs (Hemiptera: Pseudococcidae). *Agriculture and Natural Resources*, **50:** 460-464.

Sétamou, M., Jiang, N., Schulthess, F. 2005. Effect of the host plant on the survivorship of parasitized *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) larvae and performance of its larval parasitoid *Cotesia flavipes* Cameron (Hymenoptera: Braconidae). *Biological Control*, **32:** 183-190.

Shahid, M.R., Anjum, S., Muhammad, J.A., Muhammad, D.G., Shahzad, M.A., Hussain, S. 2007. Effectiveness of *Trichogramma chilonis* (Ishii) (Trichogrammatidae: Hymenoptera) against Sugarcane stem borer *Chilo infuscatellus* (Lepidoptera: Pyralidae). *Pakistan Journal of Entomology*, **29:** 141-46.

Smaniotto, G., Filho, R.C.B., Bernadi, D., Rodriguez, G.I., Rosa, A.P., Nava, D.E. 2019. Biology of *Cotesia flavipes* (Hymenoptera: Braconidae) strains at different temperatures. *Environmental Entomology*, **48:** 649-654.

Tanwar, R.K. 2004. Variability and reproductive compatibility among populations of *Cotesia flavipes* from different agroclimatic regions. *Annals of Plant Protection Sciences*, **12:** 16-20.