

## Research Article

# Diet source-dependent functional response of key parasitoids of *Spodoptera frugiperda* (J.E. Smith, 1797) (Lepidoptera, Noctuidae)

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**ABSTRACT:** Foods derived from plants are important sources of food for natural enemies and influence several functions of their existence, including reproduction. The objective of the current study was to assess the effect of different sources of food and host densities on the oviposition efficiency of key parasitoids of *Spodoptera frugiperda*. The experiment was set up under laboratory conditions in a completely randomized block design with three factors namely parasitoids (four), feeding (groundnut pollen, soybean nectar, honey, starved as control) and host densities (five), a total of 80 treatments. There were five replications for the experimental design while the experiment was repeated four times, a total of 20 replications for each treatment. Results showed that the functional response of adult parasitoids was influenced both by food sources and host densities. Soybean nectar worked the best like honey, followed by groundnut pollen. Soybeans and groundnut may therefore have agroecological interests beneficial for mass rearing to promote key parasitoids as biological agents to control *S. frugiperda*. As for the host densities, the minimum and maximum of the parasitized host were obtained respectively with the densities of 20 and 100 eggs per female for *T. remus*, 20 and 80 eggs for *Trichogramma* sp. and *C. insularis* and 5 to 50 larvae for *C. marginiventris*. Taking into account the interesting results obtained which would be favourable to the rapid multiplication of parasitoids, tests in real environments are necessary to test the influence of the main environmental factors on the performance of said parasitoids.

**KEY WORDS:** Adult parasitoids, diet source, functional response, *Spodoptera frugiperda*

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## INTRODUCTION

*Spodoptera frugiperda* is a devastating pest of many crops, which distribution is spread over different geographic zones and in the absence of effective alternatives requires various synthetic phytosanitary control methods despite their economic and environmental impacts (Fan *et al.*, 2020; Kumela, 2018). However, it has a diverse complex of natural enemies in Americas, the Caribbean basin and Africa with more than 53 species of parasitoids from 10 families which were not fully exploited for biological control (Molina-Ochoa *et al.*, 2003; Hoballah, 2004; Cokola, 2018). Despite various challenges linked to the success of conservation biological control, diversified farming systems with flowering vegetation are suitable ecosystems to a wide range of predators and parasitoids which feed on nectar and pollen to survive and reproduce (Winkler *et al.*, 2009). Functional response and consumption rate are key measurements

used to predict the natural enemy efficiency and success of biological control (Holling, 1959). Carbohydrates are crucial energy sources thereby highlighting the importance of the diet for the survival and fertility of many insect parasitoids (Wäckers, 2001; Fuchsberg *et al.*, 2007). Observations from studies in diverse contexts on the diet of natural enemies of Lepidoptera and others have shown that the primary sources of sugar-rich diet available for parasitoids in agroecosystems are honeydew and floral or extra floral nectar (Jervis and Kidd, 1986; Jervis *et al.*, 1993). A large part of adult parasitoids naturally feed on the sugar resources contained in flowers in fields (Desouhant *et al.*, 2010). The early studies provided useful information leading to the understanding and improvement of the effectiveness of biological control using parasitoids against target insect pests (Corbet, 2003; Heil *et al.*, 2000; Nicolson *et al.*, 2007). However, there are still gaps on quantitative and qualitative data to understand the effects of different natural diet sources on insect parasitoids.

This study aimed at evaluating the functional response of four major parasitoids of *Spodoptera frugiperda* (J. E. Smith, 1797) viz., *Trichogramma* sp. and *Telenomus remus* (Nixon, 1937) (egg parasitoids), *Cotesia marginiventris* (Cresson, 1865) (larval parasitoid) and *Chelonus insularis* (Cresson, 1865) (egg-larval parasitoid) to different sources of diets namely, honey, groundnut pollen and soybean nectar under laboratory conditions.

## MATERIALS AND METHODS

### *Spodoptera frugiperda* rearing

The eggs and larvae of *S. frugiperda* were obtained from mass rearing in the entomological laboratory of the International Institute of Tropical Agriculture (IITA), Benin station under  $26 \pm 1^\circ\text{C}$ , 70% Relative Humidity (RH) and 12:12 h (L:D) of photoperiod.

### Parasitoid rearing

The mass rearing of *Trichogramma* sp., *Telenomus remus*, *Cotesia marginiventris* and *Chelonus insularis* were obtained from a population of adults taken from a stock culture at the entomological laboratory of IITA-Benin between October 2019 to August 2020. The colonies of the parasitoids were fed with pure honey and maintained under constant laboratory conditions at  $26 \pm 1^\circ\text{C}$  and 70% RH with a photoperiod of 12:12 h (L:D).

*Trichogramma* sp. used for the experiment was reared in plastic tubes 4 cm in diameter and 5.5 cm deep with a lid and a ventilation space covered by the muslin. *Telenomus remus* was reared in Petri dishes 8.5 cm in diameter and 1.1 cm in depth. *Chelonus insularis* and *C. marginiventris* were reared in cubic cages of 15 cm per side and two sides of which are covered with a fine net for ventilation with an entrance with a sleeve on the main side of the cage for easy handlings. The rearing took into account parasitoids of both sexes fed on different diets from one food source to another to allow their mating. All four parasitoids were fed with groundnut pollen, soybean nectar, and honey and starved (as control). The pollen and nectar flowers were obtained from plants cultivated on the production sites of IITA-Benin without any chemical application. The soybean variety used was TGX 1987-62F and the groundnut variety, ICGV SM 85045, was developed in Benin while the honey was obtained from local production.

Besides the honey, two to three drops of which were deposited in thin layers on the internal upper surface of the cages, the flowers of groundnut and soybeans were placed in mini-boxes and directly exposed to the parasitoids inside the tubes, cages and Petri dishes that were initially disinfected with 90% ethanol. These flowers were renewed every morning

to maximize the foraging of the parasitoids which were kept in mass rearing for 72 hours to facilitate their mating.

### Experimental design

The tests were carried out in the isolation room at the entomological laboratory of IITA, Benin station. The experimental conditions in the laboratory were  $26 \pm 1^\circ\text{C}$ , 70% of relative humidity and a photophase of 12 hours. The experimental design was a Completely Randomized Bloc Design with three factors such as parasitoids, diet source and host densities. The experiment was replicated 10 times simultaneously within the same conditions and repeated twice.

The four parasitoids were two oophagous idiobionts (*Trichogramma* sp. and *Telenomus remus*) and two koinobionts (*Chelonus insularis* and *Cotesia marginiventris*) egg-larval and larval, respectively. Experimental female parasitoids were newly emerged without any experience of mating and reared in the isolation room of IITA-Benin. Out of *Trichogramma* sp. collected locally, the other three strains of parasitoids used during the experiment were exotic and imported from the United States of America under standard import permits.

### Functional response

The functional response was studied across parasitoids (*Chelonus insularis*, *Cotesia marginiventris*, *Telenomus remus* and *Trichogramma* sp.) with the variation of diet sources (groundnut pollen, soybean nectar, honey and starved as control) and the host density (eggs and larvae of *Spodoptera frugiperda*). After mass rearing and mating, the females of *Trichogramma* sp., *T. remus* and *C. insularis* were removed from the mass rearing and placed one by one in micro-Petri dishes disinfected with ethanol for the first two species (*Trichogramma* sp. and *T. remus*) and isolation mini dishes for the third (*C. insularis*). These boxes contained 1-3 day-old eggs of *S. frugiperda* at 5 different host densities (20, 40, 60, 80 and 100). These host eggs were obtained by their meticulous disaggregation from the egg-laying papers using a tin brush and counted under a binocular microscope. Experimental egg and egg-larval female parasitoids were carefully selected using a soft brush and transferred into separate boxes containing the different egg densities. The females were then kept for 24 hours after which they were removed. Besides, five different densities of three day-old instar larvae of *S. frugiperda* were exposed to *C. marginiventris*. Twenty-four hours after host larvae exposure, *C. marginiventris* females were removed from the mini-isolation boxes and the host larvae were transferred to the breeding boxes and fed ad libitum with germinated maize under the condition of rearing of *S. frugiperda* in the

laboratory. Fresh leaves of germinated maize were placed into the various boxes to serve as food for the host larvae as well as a roost for the parasitoids.

Concerning functional response evaluation of parasitoids, 72 hours after inoculation, the parasitized *S. frugiperda* eggs and larvae were checked. *Trichogramma* sp. and *T. remus* eggs were observed using a binocular microscope to assess their change in colour from light or dark green to dark black with a substance slightly sticky to the touch.

Regarding the larvae hatching from eggs parasitized by *C. insularis* and larvae parasitized by *C. marginiventris*, the parasitism parameters observed included change in colour, ability to move and parasitism rate. In larvae parasitized by *C. marginiventris* these parameters were recorded early enough. Parasitized and dead hosts were examined to determine parasitism rate.

Regarding the emergence rate of adult parasitoids, on average three days after inoculation, neonates emerged from *S. frugiperda* eggs not parasitized by *Trichogramma* sp. and *T. remus*. These neonates were removed from the trials and the parasitized eggs were followed over 15 days after inoculation. From the 12<sup>th</sup> day, the emergence of parasitoids took place until the fifteenth day during which a count of adults of parasitoids emerged was made. With the small size of the parasitoids and the risk of leaking from handling, it was necessary to cause their death by starving them. This strategy allowed us to count them accurately.

Concerning the eggs exposed to *C. insularis*, they were placed after the removal of the females on germinated maize in the mini-isolation boxes. When the eggs hatched, about three days after their exposure to the parasitoid, the young larvae (neonates) were transferred to breeding boxes with lids fitted with ventilation and secured. A layer of soft paper tissue was placed at the bottom of the boxes for larvae and pupation medium for parasitoids and pupated non-parasitized larva. Throughout the process, the host larvae were fed ad libitum with young leaves from pre-germinated maize and monitored under the host-rearing condition in the laboratory. During the test, the parasitized larvae were monitored as well as the development of *C. insularis* pupae formation. After 15 days, the different breeding boxes were checked to count the number of *C. insularis* pupae obtained. These pupae were followed until the emergence of adults.

For the larval parasitoid *C. marginiventris*, 24 hours after inoculation, the larvae were transferred from the mini-isolation boxes to the mass-rearing boxes under similar conditions as in *C. insularis*, the larvae being fed ad libitum. After 12 to 15 days, the different breeding boxes were verified

to count the number of *C. marginiventris* pupae obtained. These pupae were also followed until the emergence of adults.

## DATA ANALYSIS

To determine the normality of data concerning the mean and proportionate prey consumption by *Chelonus insularis*, *Cotesia marginiventris*, *Telenomus remus* and *Trichogramma* sp., the test of Shapiro-Wilk was used (Shapiro *et al.* 1965). The data were typically found to be non-normal ( $p < 0.05$ ). The data on average prey consumption were analyzed with a generalized linear model assuming negative binomial distribution due to over-dispersion and group means were separated with Tukey's Honestly Significant Difference (HSD) test ( $p < 0.05$ ). The data on proportionate prey consumption were subjected to the Kruskal-Wallis test (non-parametric ANOVA) for assessing significant effects, followed by Dunn's multiple comparison test to differentiate between group means ( $p < 0.05$ ). Eggs and larvae consumption rates by various parasitoids and different diet sources were assessed separately.

A polynomial logistic regression equation was fitted for the proportion of eggs and larvae consumed on the different initial eggs and larvae densities, assuming a binomial distribution of data to determine the type of functional response (Juliano, 2001) (Equation 1).

$$\frac{Ne}{N_0} = \frac{\exp(P_0 + P_1 N_0 + P_2 N_0^2 + P_3 N_0^3)}{1 + \exp(P_0 + P_1 N_0 + P_2 N_0^2 + P_3 N_0^3)}$$

$Ne$  and  $N_0$  represent the number of eggs or larvae consumed and initial eggs or larvae densities respectively, and  $Ne/N_0$  is the proportion of eggs or larvae consumed. The regression parameters  $P_0$ ,  $P_1$ ,  $P_2$ , and  $P_3$  are the intercept, and the linear, quadratic and cubic coefficients, respectively. The coefficients were estimated by the maximum likelihood method. The signs of the linear and quadratic coefficients indicated the functional response type. When  $P_1 < 0$ , the functional response was type II, and if  $P_1 > 0$  and  $P_2 < 0$ , the response was type III (Juliano, 2001). The type II response indicated that the eggs and larvae consumption declined monotonically with eggs and larvae initial densities and a type III response indicated that the proportionate eggs and larvae consumption was positively density-dependent (Juliano, 2001).

Roger's random predator equation is appropriate for modelling predation or parasitism whenever predation or parasitism results in a significant reduction of eggs and larvae densities (Rogers, 1972) (Equation 2).

$$N_e = N_0 \left[ 1 - \exp(a(T_h N_e - T)) \right]$$

The simple type-I or linear functional response is helpful when the response is known (or suspected) to be handling time-independent. It is implemented as (Equation 3):

$$N_e = aN_{0T}$$

$N_e$  and  $N_0$  represent the number of consumed and eggs or larvae densities, respectively  $a$  is the instantaneous attack rate,  $T_h$  is the handling time,  $T$  is the duration of the experiment (24 h). We used the **glm** function to fit the logistic regression, and the **friar** (Pritchard *et al.* 2017) package to determine the coefficients of attack rate and handling time. All statistical analyses were done in R 4.2.0 (R Core Team, 2020). The theoretical maximum predation rate, given by the ratio of  $T/T_h$ , represents the maximal eggs or larvae consumption in the given time interval. We calculated the maximum predation rate from the estimates of  $T_h$  as determined above and subjected it to non-parametric ANOVA (Hassell, 2000).

## RESULTS

### Functional response of *Chelonus insularis*

The average number of eggs parasitized by *Chelonus insularis* varied significantly across densities with the same diet source. Also, there was a significant difference in terms of diet source under the same density (Table 1). The mean prey consumption rate increased with increasing the egg densities of *S. frugiperda* under both honey and soybean sources. The best mean rate of egg parasitism was observed with honey ( $42,66 \pm 2,88$ ), followed by groundnut ( $15,74 \pm 1,27$ ) and soybean ( $14,79 \pm 1,03$ ). The parasitoid starved (control) was ranked in the last position with an average of  $1,35 \pm 0,24$  (Table 1; Figure 1a). Concerning the coefficient of searching rate ( $a$ ) of attack (Table 5), results show better performance under honey (0.436) compared to groundnut (0.156), soybean (0.144) and control (0.019). For all diet sources and egg densities, the functional response data for the *C. marginiventris* over a 24 h period was a good fit to Type I functional response curves fitted by generic type-I (Equation 3) (Table 5; Figure 2a).

Means of the same line followed by the same letter (lower case) are not significantly different (Dunn Multiple Comparison Test,  $p < 0.05$ ). The mean of the same column followed by the same letter (upper case) is not significantly different (Dunn Multiple Comparison Test,  $p < 0.05$ ). \*The effect of density is non-significant (Kruskal-Wallis test  $p > 0.05$ ).

### Functional response of *Cotesia marginiventris*

The mean number of larvae parasitized by *Cotesia marginiventris* increase with the variation of the density irrespective of diet source. The results show that there was a significant difference in terms of diet source under the same density (Table 2). The highest mean rate of larval parasitism was observed in honey ( $56,74 \pm 1,96$ ), followed by soybean ( $30,28 \pm 2,11$ ), and groundnut ( $23,62 \pm 2,05$ ). (Table 2). Regarding the coefficient of searching rate ( $a$ ) of attack (Table 5; Figure 1b), the result shows a better performance under honey (0.666) compare to soybean (0.386), groundnut (0.364) and starved (0.103). Two types of functional response were globally observed. They were functional response type I (Equation 3) (Table 5; Figure 2b) for honey and functional response type II (Equation I) for soybean, groundnut and starved (Table 5; Figure 2b).

The highest handling time was noted on starved ( $0.164 \pm 0.080$  h) while the lowest handling time was recorded on soybean ( $0.023 \pm 0.007$  h) followed by groundnut ( $0.036 \pm 0.010$ h) (Table 6).

Means of the same line followed by the same letter (lower case) are not significantly different (Dunn Multiple Comparison Test,  $p < 0.05$ ). The mean of the same column followed by the same letter (upper case) is not significantly different (Dunn Multiple Comparison Test,  $p < 0.05$ ). \*The effect of density is non-significant (Kruskal-Wallis test  $p > 0.05$ ).

### Functional response of *Telenomus remus*

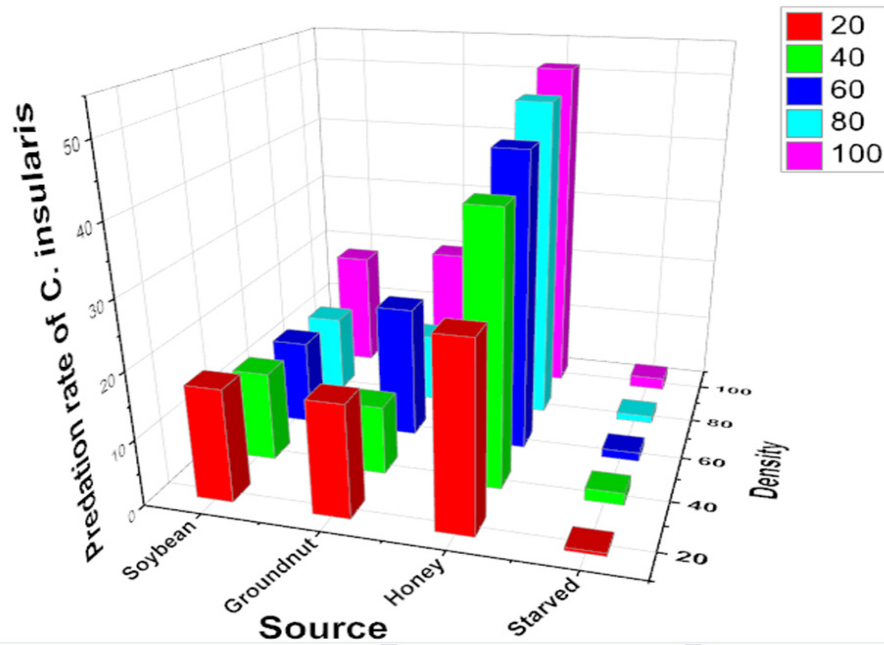
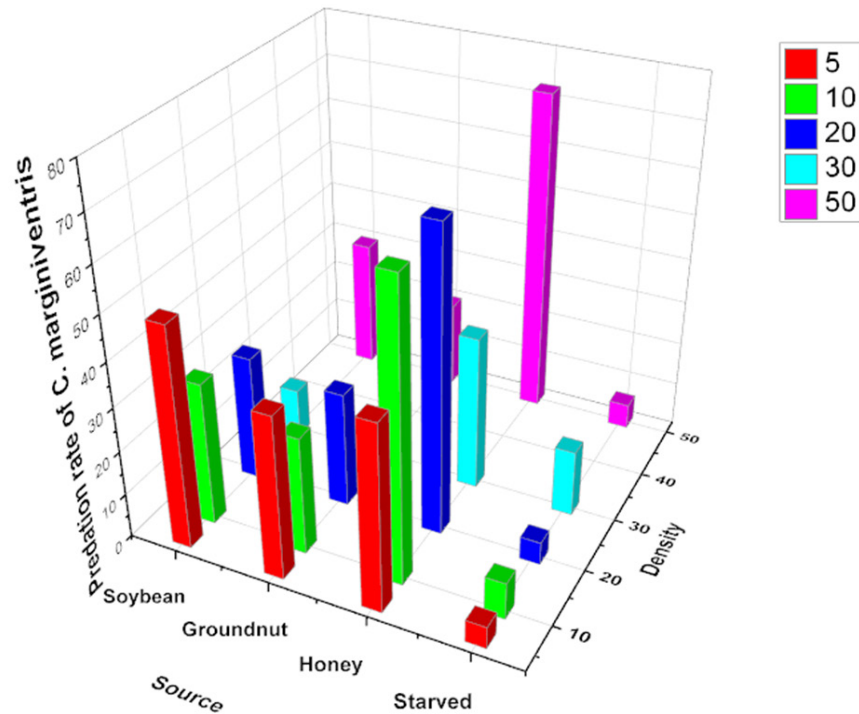
The mean number of eggs parasitized by *Telenomus remus* increased with the density irrespective of diet source. It was observed that there was a significant difference in terms of diet source under the same density (Table 3). The best mean rate of egg parasitism was observed on soybean ( $92,92 \pm 1,20$ ), followed by groundnut ( $83,23 \pm 2,24$ ), and honey ( $81,04 \pm 2,69$ ) and control  $60,63 \pm 3,54$  (Table 2). Regarding the coefficient of searching rate ( $a$ ) of attack (Table 5; Figure 1c), the result shows a better performance under soybean (2.941) compare to groundnut (1.516), honey (0.824) and starved (0.322). Two types of functional response were globally observed. They were functional response type I (Equation 3) (Table 5; Figure 2c) for groundnut and functional response type II (Equation I) for soybean, groundnut and starved (Table 5; Figure 2c).

The highest handling time was noted on starved ( $0.011 \pm 0.001$  h) while the lowest handling time was noted on soybean ( $0.003 \pm 0.001$  h) followed by honey ( $0.008 \pm 0.001$ h) (Table 6).



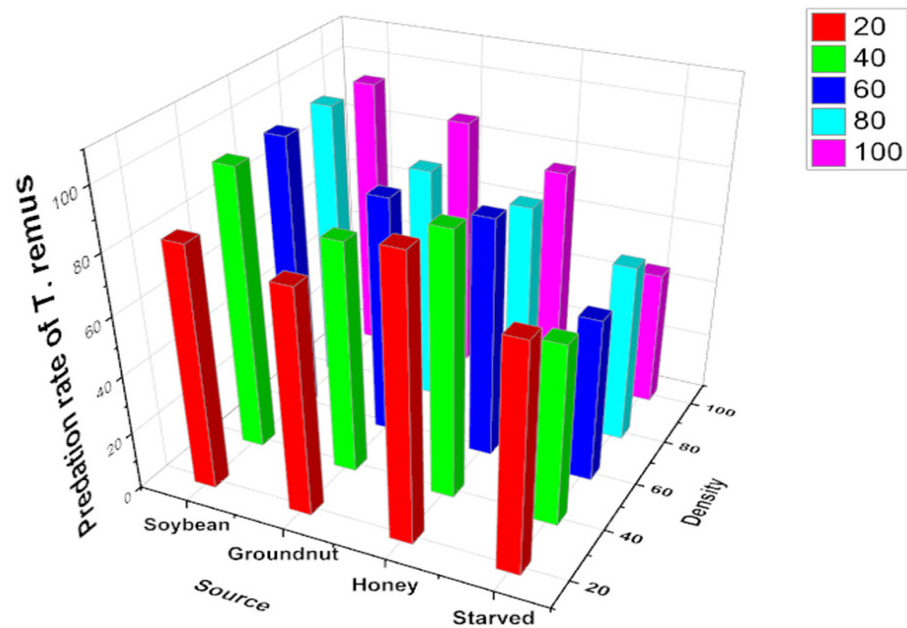
**Table 1.** Response-dose of *Chelonus insularis*

Diet Source	Density					Mean
	20	40	60	80	100	
Starved	0,5±0,34 a/A	1,87±0,72 ab/C	1,34±0,59 ab/A	1,14±0,37 ab/A	1,9±0,54 b/A	1,35±0,24
Honey	28±3,56 a/B	40,5±5,68 b/B	44,8±6,22 bc/B	48,71±6,97 c/B	51,3±8,13 c/*	42,66±2,88
Groundnut	17±3,23 a/B	10,45±2,10 a/B	20,17±3,07 b/C	10,77±1,27 b/B	20,3±3,40 b/*	15,74±1,27
Soybean	17±2,27 a/C	13,57±2,51 ab/A	13±2,08 b/D	12,09±1,52 c/C	18,3±2,85 c/*	14,79±1,03

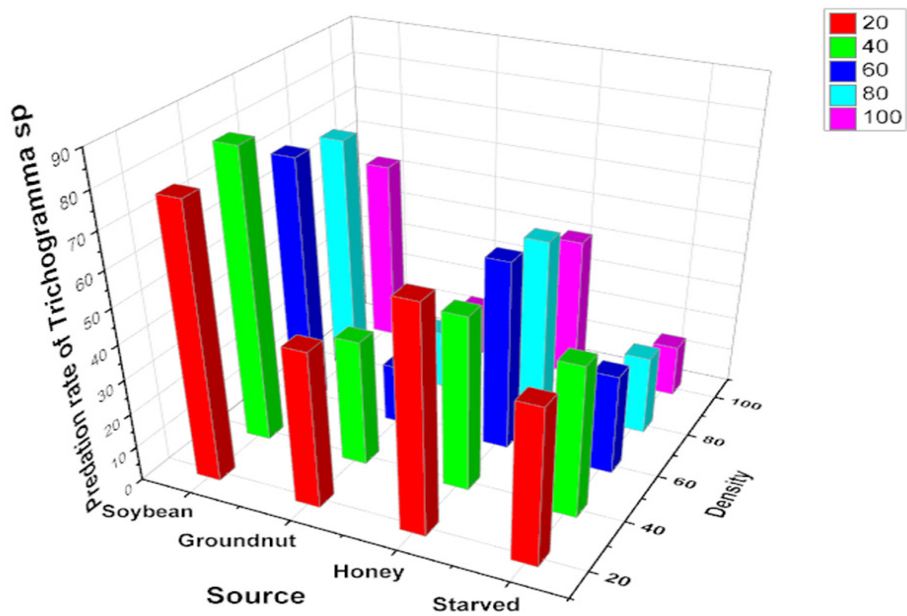
**Figure 1a.** Comparison of the theoretical maximum predation rates for *C. insularis*.**Figure 1b.** Comparison of the theoretical maximum predation rates for *C. marginiventris*.

**Table 2.** Response-dose of *Cotesia marginiventris*

Diet Source	Density					Mean
	5	10	20	30	50	
Starved	15±5,78*/*	5±1,99*/A	8,36±2,87*/A	5,17±1,84*/A	5,63±1,44*/C	7,83±1,45
Honey	35±3,20 a/A	42±3,81 b/*	66,25±2,54 c/C	67,84±1,61 d/C	72,6±2,29 e/B	56,74±1,96
Groundnut	9±3,39 a/*	37±5,29 b/*	26,75±3,35 c/B	26,17±4,74 c/B	19,51±3,73 c/A	23,68±2,05
Soybean	11±3,97 a/*	50±4,23 b/*	32,5±3,73 bc/B	28,51±3,33 c/B	29,4±4,07 d/A	30,28±2,11



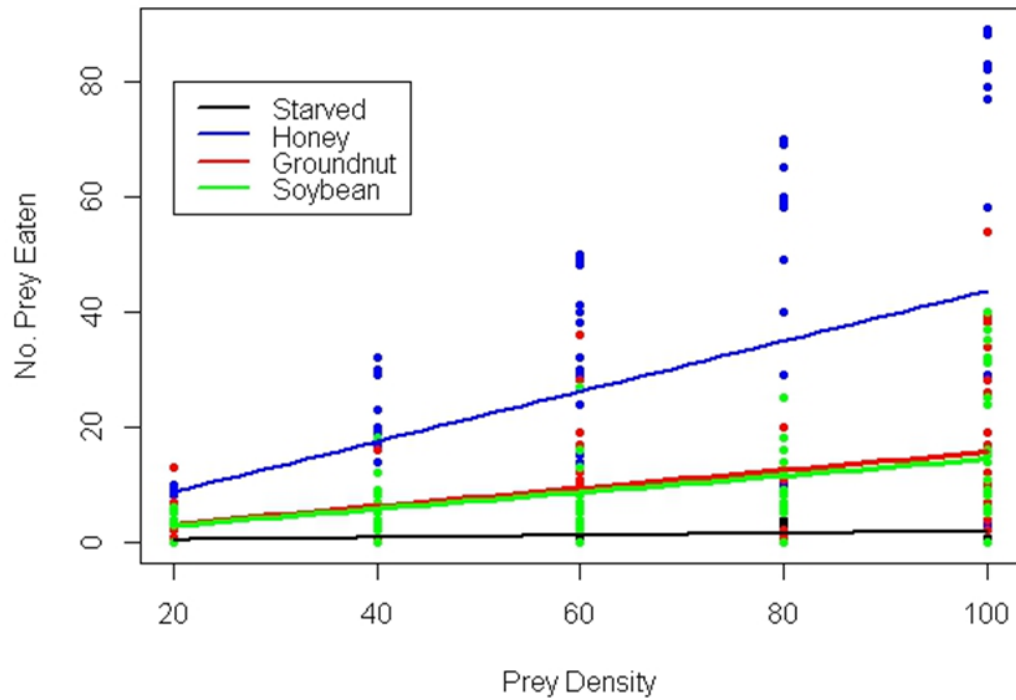
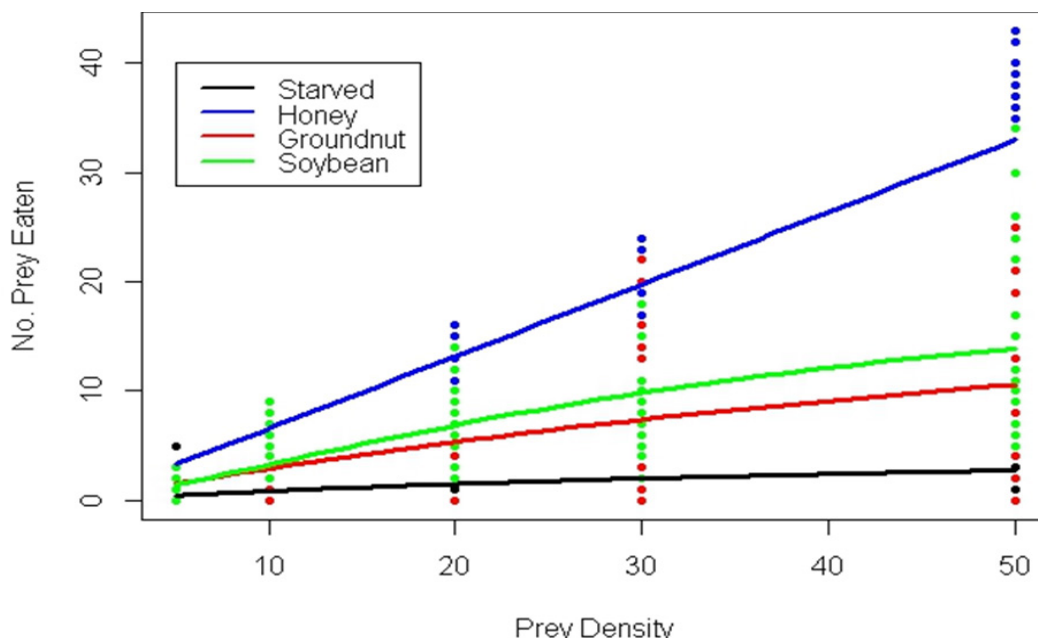
**Figure 1c.** Comparison of the theoretical maximum predation rates for *T. remus*.

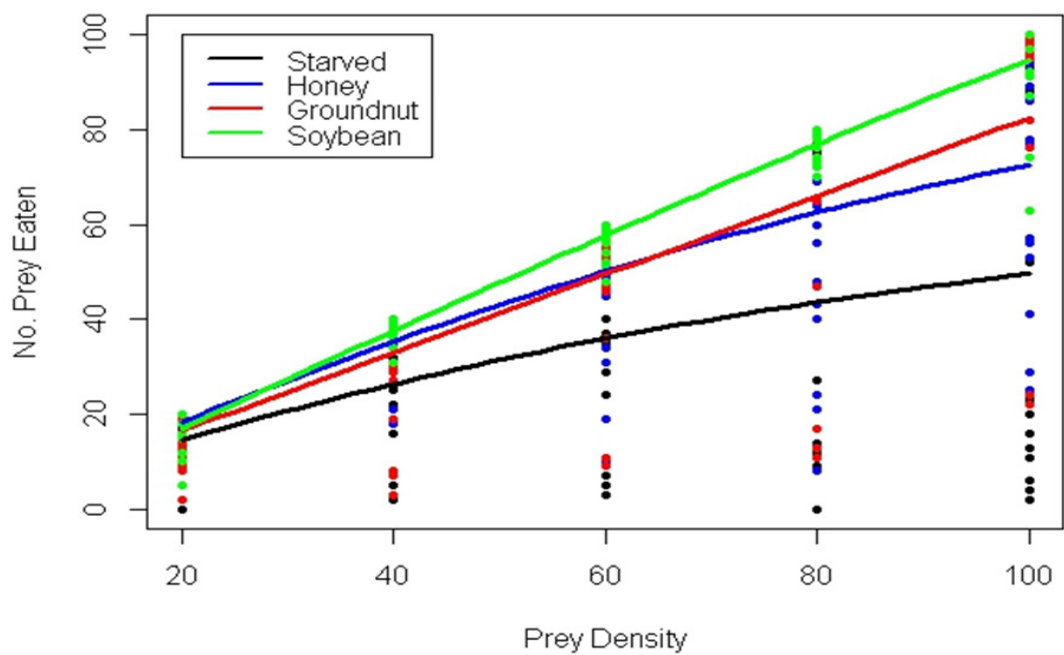


**Figure 1d.** Comparison of the theoretical maximum predation rates for *Trichogramma sp.*

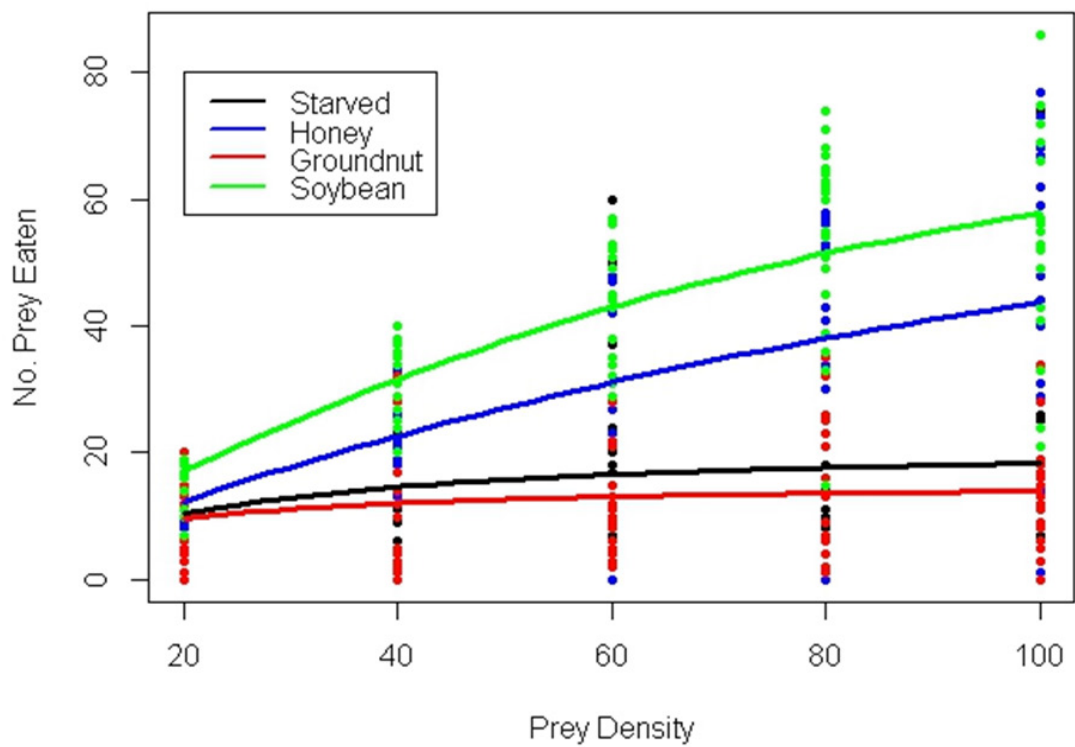
**Table 3.** Response-dose of *Telenomus remus*

Diet Source	Density					Mean
	20	40	60	80	100	
Starved	76,75±6,60 a/*	61,88±7,78 b/A	56,33±7,56 b/A	61,4±8,63 b/A	46,8±8,16 b/A	60,63±3,54
Honey	77±6,36 a/*	79±6,96 b/B	81,91±5,46 c/B	80,34±6,44 d/A	86,95±5,12 e/B	81,04±2,69
Groundnut	94,75±1,56 a/*	89,5±3,53 b/B	81,76±5,42 c/B	74,46±6,37 c/A	75,7±5,43 d/B	83,23±2,24
Soybean	82,75±4,62 a/*	95,63±1,45 b/B	95,34±1,28 c/B	96,07±0,91 d/B	94,8±2,23 e/C	92,92±1,20

**Figure 2a.** Type I functional response curves fitted by generic type-I (linear) response of *C. insularis*.**Figure 2b.** Type I and Type II functional response curves fitted by generic type-I (linear) of *C. marginiventris*.



**Figure 2c.** Type I and Type II functional response curves fitted by generic type-I (linear) response of *T. remus*.



**Figure 2d.** Type II functional response of *Trichogramma* sp.



Means of the same line followed by the same letter (lower case) are not significantly different (Dunn Multiple Comparison Test,  $p < 0.05$ ). The mean of the same column followed by the same letter (upper case) is not significantly different (Dunn Multiple Comparison Test,  $p < 0.05$ ). \*The effect of density is non-significant (Kruskal-Wallis test  $p > 0.05$ ).

#### Functional response of *Trichogramma* sp.

The average number of eggs parasitized by *Trichogramma* sp. increased with the density. There was a significant difference regarding the diet source under the same density (Table 4). The best mean rate of eggs parasitism was observed on soybean ( $71.1 \pm 1.89$ ), followed by honey ( $52.34 \pm 2.58$ ), control ( $31.13 \pm 2.80$ ) groundnut ( $26.09 \pm 2.48$ ) (Table 4). Concerning the coefficient of searching rate (a) of attack (Table 5; Figure 1d), a better performance was

recorded under soybean (2.395) compare to honey (1.687), starved (1.434) and groundnut (1.112). For all diet sources, the functional response type I (Equation 3) was noted (Table 5; Figure 2d).

The highest handling time was noted on groundnut ( $0.065 \pm 0.003$  h) follow by starved ( $0.047 \pm 0.002$  h), soybean ( $0.011 \pm 0.001$  h) and honey ( $0.011 \pm 0.001$  h) (Table 6).

Means of the same line followed by the same letter (lower case) are not significantly different (Dunn Multiple Comparison Test,  $p < 0.05$ ). The mean of the same column followed by the same letter (upper case) is not significantly different (Dunn Multiple Comparison Test,  $p < 0.05$ ). \*The effect of density is non-significant (Kruskal-Wallis test  $p > 0.05$ ).

**Table 4.** Response-dose of *Trichogramma* sp.

Diet Source	Density					Mean
	20	40	60	80	100	
Starved	45±6,48*/A	43,75±7,27*/A	29±5,68*/A	22,83±5,38*/A	15,05±3,42*/A	31,13±2,80
Honey	64,5±5,32 a/AB	50,25±4,95 b/A	54,75±5,66 c/B	50,89±6,36 c/B	41,35±5,76 c/B	52,34±2,58
Groundnut	45±7,50*/A	36,5±6,71*/A	17,17±2,66*/A	17,22±2,89*/A	14,55±2,03*/A	26,09±2,48
Soybean	78±3,78 a/B	82,87±3,16 b/B	72,08±3,31 c/C	68,97±4,25 d/C	53,55±3,70 d/B	71,1±1,89

**Table 5.** Coefficients of attack rate (mean  $\pm$  SE) of *C. insularis*, *T. remus*, *C. marginiventus* and *Trichogramma* sp. at predatory feed with various diet sources, preying upon *frugipeda* eggs and larvae

Parasitoids	Diet Source	a	SE	CI Lower	CI Upper	Z values	p
<i>C. insularis</i>	Starved	0.019	0.0017	0.013	0.029	10.683	< 2.2e-16
	Honey	0.436	0.0064	0.364	0.504	68.104	< 2.2e-16
	Groundnut	0.156	0.0047	0.132	0.188	33.302	< 2.2e-16
	Soybean	0.144	0.0045	0.123	0.168	31.749	< 2.2e-16
<i>C. marginiventus</i>	Starved	0.103	0.0249	0.058	0.39	4.1401	3.47e-05
	Honey	0.666	0.0099	0.631	0.688	66.754	< 2.2e-16
	Groundnut	0.364	0.174	-0.12	2.932	2.092	0.0365
	Soybean	0.386	0.042	0.285	0.585	9.308	< 2.2e-16
<i>T. remus</i>	Starved	0.322	0.104	0	0.005	3.0921	0.001987
	Honey	0.824	0.005	0.758	0.874	167.89	< 2.2e-16
	Groundnut	1.516	0.090	0.899	2.525	16.799	< 2.2e-16
	Soybean	2.941	0.154	1.997	4.176	19.054	< 2.2e-16
<i>Trichogramma</i> sp.	Starved	1.434	0.181	0.719	3.23	7.9378	2.057e-15
	Honey	1.687	0.337	0.636	16.331	5.0097	5.451e-07
	Groundnut	1.112	0.070	0.765	1.616	16.0378	< 2.2e-16
	Soybean	2.395	0.124	1.822	2.986	19.275	< 2.2e-16
a = Coefficients of attack rate ; SE = Standard Error, CI = Confidence Interval							

**Table 6.** Coefficients of handling time (mean<sub>SE</sub>) of *C. insularis*, *T. remus*, *C. marginiventris* and *Trichogramma* sp.

Parasitoids	Diet Source	h	SE	CI Lower	CI Upper	Z value	P value
<i>C. insularis</i>	Starved	X	X	X	X	X	X
	Honey	X	X	X	X	X	X
	Groundnut	X	X	X	X	X	X
	Soybean	X	X	X	X	X	X
<i>C. marginiventris</i>	Starved	0.164	0.080	0	0.568	2.045	0.041
	Honey	X	X	X	X	X	X
	Groundnut	0.036	0.010	0	0.082	3.7444	0.0002
	Soybean	0.023	0.007	0	0.057	3.513	0.000
<i>T. remus</i>	Starved	0.011	0.001	0	0.02	13.132	< 2.2e-16
	Honey	0.008	0.001	0.003	0.012	15.934	< 2.2e-16
	Groundnut	X	X	X	X	X	X
	Soybean	0.003	0.001	0.057	1.583	12.5943	< 2.2e-16
<i>Trichogramma</i> sp.	Starved	0.047	0.002	0.028	0.063	20.7074	< 2.2e-16
	Honey	0.011	0.001	0.002	0.02	9.9854	< 2.2e-16
	Groundnut	0.065	0.003	0.046	0.084	19.6579	< 2.2e-16
	Soybean	0.011	0.001	0.008	0.014	20.839	< 2.2e-16
h = Coefficients of handling time; SE = Standard Error; CI = Confidence interval							

X = Functional response type I with no handling time

## DISCUSSION

The functional response of *Chelonus insularis*, *Cotesia marginiventris*, *Telenomus remus* and *Trichogramma* sp. varied significantly in terms of diet sources and host densities. The performances obtained at the level of the parasitoids fed with honey and soybean nectar showed, whatever the density of the host (eggs or larvae of *S. frugiperda*), better results for all diet sources tested. However, in *T. remus*, almost identical performance was noted for all food sources namely honey, groundnut pollen and soybean nectar. Regarding the global trend of functional response by diet source, soybean and groundnut were recorded as the best performances in terms of predation for *C. insularis*. Concerning *C. marginiventris*, and *T. remus*, honey and soybean performed better attack rates with the highest handling time. However, parasitoids starved show a better attack rate and handling time specifically for *T. remus*. While honey and soybean performed better for *Trichogramma* sp. Those results were in accordance with the finding of G. Benelli *et al.* (2017) who demonstrated that diet source is one of the most important influences more common on the reproductive traits of parasitoids, their lifespan, their mating capacity, fecundity and fertility. In addition, these authors have come to the evidence that in the field, Hemiptera parasitoids can rely on different hosts and non-host diet sources, such as floral and extrafloral nectar, honeydew and

pollen. Likewise, Chang *et al.* (2007) carried out similar studies in which, the number of eggs laid by a female natural enemy is related to the composition and quality of the different nutrient media supplied to her diet. Many predatory insects and parasitoids that play a role in pest control require foods other than prey such as nectar or pollen in adulthood (Wäckers and Van Rijn, 2012). Since parasitoids live in nature, they can forage on several plants' flowers including soybeans and groundnuts to use up their diet reserves. This postulate joins that of Wäckers, (2001) who demonstrated that in nature, adult parasitoids can feed directly on nectar, pollen and honeydew as sources of carbohydrates to ensure their survival and their reproductive function. Along the same lines, Jervis *et al.*, (1986) conducted research on plant nectar (both floral and extrafloral), by demonstrating their roles in functional response while improving their longevity. The importance of pollen as a source of sugar to promote the health of parasitoids was also discussed by Zhang *et al.* (2004) who showed, for example, that females of *Trichogramma brassicae* Bezdenko (Hymenoptera: Trichogrammatidae) fed on maize pollen prolonged their lifespan compared to unpowered ones. Haslett (1989) and Laubertie *et al.* (2012) also showed for some species of Aphidophagous predators that protein-rich pollen is necessary for sexual maturation and reproductive activity. A 2013 study by Segoli & Rosenheim on the effects of Spatio-temporal variation in sugar availability for

parasitoids in agricultural fields revealed the consequences of low concentrations of sugar feed sources on the reproductive potential of plants. Female parasitoids. These authors showed that the reproductive potential of parasitoids was negatively influenced by the availability of sugar; suggesting that sugar increases egg-laying success, although causal role arguments for other specific factors cannot be ruled out.

## CONCLUSION

Diet source and host densities influence the functional response of parasitoids. Soybean nectar displays almost similar performance to honey. Moreover, honey and soybean diet sources generated interesting results for all of the parasitoids tested. Overall, the functional response type I was observed for *Chelonus insularis* while a type II functional was observed for *Cotesia marginiventris*, *Telenomus remus* and *Trichogramma* sp.

Those results should be improved in the control environment and the natural fields for the purpose of evaluation of the different parameters of lifespans of parasitoids studies, this facilitates the promotion of biological control of *Spodoptera frugiperda*.

## CONTRIBUTIONS FROM AUTHORS

AMA followed the trials, collected, processed, analyzed the data and wrote the manuscript. GTY supervised the overall monitoring of the trials, participated in data analysis and drafting of the manuscript. AA supervised the work and contributed to the correction of the manuscript.

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