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# Evaluation of the Functional Response of Seven Spotted Lady Bird Beetle Coccinella septumpunctata (Coleoptera: Coccinellidae) on Five Varying Densities of Bemisia tabaci (Homoptera: Aleyrodidae) Population under Controlled Laboratory Conditions

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**Abstract:** *Bemisia tabaci* is a cosmopolitan polyphagous insect undermining the productivity of a wide range of crops including but not limited to horticulture, ornamental and vegetable crops. The management of *B.tabaci* has been dominated by the use of broad-spectrum insecticides, though having the unique feature of reducing pest population below action threshold and economic injury level, their usage is however characterized with side effects including but not limited to environmental degradation and development of resistant genes in insects. The use of natural enemies (biological control) is considered more sustainable and viable option, environmentally friendly and poses no risk to users. Among the numerous biological control opportunities, the use of coccinellid beetles potentially proves to be quite promising and are abundantly found in insect infested vegetable fields. The ability of natural enemies as effective biological control agents is highly vested in their respond to density of preys density-dependent which can be measured in terms of their functional responses focusing on instantaneous search rates (a) and handling time (Th) as distinct and invaluable parameters. A bioassay cage experiment under laboratory conditions was carried out to evaluate the functional response of seven spotted lady bird beetle *C. septumpuntata* late 4$^{th}$ instars, male and female adults respectively on varying densities of *B. tabaci* eggs, 2$^{nd}$ and 3$^{rd}$ instars. The results were normalized and nature of response curves of C. septempartite on these prey densities were characterized and determined as Type II functional response. The response curves monotonically declined with increased in pest density for the 4$^{th}$ instars , female and male adults when fed on 2$^{nd}$ instar larvae with female adults showing the highest instantaneous search rate 0.54 and lowest handling time 0.19 and maximum consumption of 10.95 prey$^{-1}$hr$^{-1}$ strongly indicating that the female beetles showed potential attributes as ideal biological control candidate compare to the male and late 4$^{th}$ instar counterparts when fed on the 2$^{nd}$ and 3$^{rd}$ instars. However, when beetles were offered with *B. tabaci* eggs , the 4$^{th}$ instars demonstrated least handling time 0.73 and higher attack rate 2.57 than the female and male counterpart correspondingly showing the highest satiation threshold 32.87 prey$^{-1}$hr$^{-1}$.Though the beetle demonstrated promising potential as an ideal candidate based on current laboratory findings providing insight on the possibility for mass rearing and subsequent utilization in biological control programs of agricultural pests , there is however need for further investigation under greenhouse and field scenarios. Meanwhile, the prospect of *C. septumpunctata* as an ideal biological control candidate on *B. tabaci* population is discussed.

**Keywords:** Coccinellid beetles, Coccinellid septunpuntata, *Bemisia tabaci*, Biological Control, Functional response, Search rate, Handling time (Th).

## BACKGROUND

*Bemisia tabaci* is a cosmopolitan polyphagous insect affecting a wide range of crops including but not limited to horticultural and ornamental crops. More recently, *B. tabaci* has been described as a complex species comprising of different biotypes, new biotype due to evolution as a of result selective pressure and displacement of indigenous biotypes [1,2, 3]. The most predominant selective pressure according to [2] is the excessive and frequent use of insecticides. The first reported biotype is the A biotype which was displaced to B Biotype which is commonly referred to as Silverleaf whitefly mostly associated with the poinsettia host plant. This biotype is highly polyphagous and almost twice as fecund as biotype A , highly aggressive causing physiological disorders and stunted growth in plants and now commonly referred to as *B. argentifolli* [3, 4]), and the evolution of another type known as the Q biotypes due to more selection pressure as a result of excessive use of insecticides and subsequent development of resistance genes [2, 10]. More recently thorough the use of molecular tool has enable to unfold the complex nature of *B. tabaci* species and have been classified into three main types based on geographical locations by comparing their mitochondrial 16S ribosomal subunits- New World, India/Sudan and remaining Old World [5]. This revelation further points to the fact that *B. tabaci* is a pest globally distributed with diverse genetic diversity [2 ,6,7,8, 9]. The pest nature of *B. tabaci* cannot therefore be over-emphasized as it attacks wide range of crops causing economic losses due to direct feeding of the phloem sap with devastating effects leading physiological disorders, stunted growth and under severe infestation total collapse of the entire plant is evident. The pest status of *B. tabaci* is aggravated due to its ability to spread viral diseases with tendency of high economic losses [7]. The most common virus diseases spread by B. tabaci Cotton leaf curl disease, Cassava Mosaic Disease, Cassava Streak virus Disease, Tomato wilt virus diseases leading to annual production losses of billions of dollars [4,7].

Management of *B. tabaci* has been dominated by the use of broad-spectrum insecticides , though having the inherent feature of reducing the pest population below the economic injury level and economic thresholds [1,11], the frequent and excessive use of pesticides have led to development of resistant genes in insects and importantly have served as selective pressure leading to speciation and subsequent development of biotypes which are more aggressive , destructive and adaptable nature [1]. The sole reliance of the use of insecticides is not only considered as unsustainable pest management efforts but have further exerted devastating effects on the environmental and production system, unequivocally justifying the practice of Integrated Pest Management (IPM) of which biological control is unarguably the cornerstone of IPM [11].

Among the numerous biological control strategies, the use of predators has been well recognized in the management of *B. tabaci* [12]. Ladybird beetles (family Coccinellidae) are well-documented as effective predators for the management of the whitefly *Bemisia tabaci* [13]. *Coccinella septumpuntata* is a predaceous lady bird beetle that is widely found on vegetable fields infested with aphids and whiteflies, the beetle is predaceous and goes through six developmental stages [13]. In Sierra Leone, Coccinellid beetles including seven spotted lady bird beetles are widely found on insect infested vegetable crops in the open fields and greenhouses. Coccinellid beetles generally are of great importance to the agro-ecosystems as they preyed upon many harmful insect pests [14]. Both larvae and adults are predacious in nature and feed on different kinds of pests notably aphids, thrips, and mites, whiteflies but some are microphagous and phytophagous in nature [15, 17]. The four developmental stages of ladybird beetles are the embryonic, larval, pupal, and adult stages. Before becoming adults, the larvae go through four instar stages and normally takes 1 week to complete one generation. Coccinellids are highly prolific with high fecundity rate further possessing unique features as ideal candidates for biological control program [13, 14].

Several studies have evaluated the functional responses of coccinellids, both individually ( [15] [18] and within guilds [21, 23,25, 27]. Most of the investigations that have been reported either a type II or a modified type II functional response or in most extreme case a type III functional response [24, 25,26]. Although predation under field conditions endeavours to shaping the community structure under natural settings, the need to thoroughly investigate the ideal nature of this biological control candidates cannot be over-emphasized. *C. septumpuntata* is commonly found on insect infested vegetable agroecosystem providing an assumption of demonstrating potential of biological control agent under biotic and biotic influence. There is however a need to evaluate the potential of C. septumpuntata to reinforce its potentials and understanding its behaviour in response to pest densities as an ideal biological control agent . This research work obviously provides a baseline information under controlled laboratory conditions as a preliminary study in the first instance , and the outcome of the study unequivocally served as insight on the prospect of C. *septumpunctata* as initial phase leading to a detailed field study to dissect more complex field predator-prey interactions within the guilds of vegetable agroecosystems as a trajectory to impact long term sustainable pest manage efforts in the face of resurged interest in organic crop production and environmental harmony.

## MATERIALS & METHODS

### Source and Rearing of *Bemisia tabaci*

*B. tabaci* adults were initially collected from vegetable crops in the Nursery Unit of Horticulture Department, School of Natural Resources Management, Njala University in southern part of Sierra Leone and maintained on poinsettia plants for five to six generation in bioassay cages 60 x 60 x 60 cm under standard laboratory conditions of 25±2° C and Relative Humidity of 70 ±10 as stock colony. Thereafter, the adult insects were inspirated after 5-6 generations and then transferred to cucumber plants as the main host plant for rearing of various developmental stages that were used in the investigation. To get the desired instars, the rearing and development periods are synchronized which are achieved by exposing clean host plants to whiteflies for 24-48 hours oviposition , thereafter adults whiteflies are removed, and the host plants bearing the eggs are maintained in bioassay cages for hatching and subsequent developments to preferred instars based on preliminary knowledge on rearing and development periods of immature.

### Source and Rearing of Rearing of *Coccinella septumtata*

The polyphagous predator *C. septumpuntata* was initially collected from smallholder vegetable gardens within the university vicinity and neighborhoods and then reared on eggplant and collard plants infested with aphids and whiteflies. The infested materials were maintained under abiotic conditions of 25±2°C, RH of 70 ±10 and photoperiod of L: H 12: 12 as stock colony in the laboratory in a wooden case 60 x 60 x 60 cm with ventilated nylon cloth at the top and sides to facilitate effective air circulation . The infested host plants were watered daily to ensure healthy growth, viability and development of both predator and prey. For experimental purpose,10-14-day old unmated females were selected to standardize size for uniformity whist females were isolated and maintained individually, and starved for 12-24 hours prior to testing to standardize hunger without causing stress.

### Experimental Design and Set Up

The experimental set up was designed to investigate the functional response of *C. septumpuntata* that is the search rate (a) and handling time ($T_h$) of *C. septumtata* on varying densities of *B. tabaci* eggs and immatures notably 2nd and 3rd instars. A complete randomized design of five varying prey densities: 50, 100, 150, 200 and 250 levels of *B. tabaci* eggs and and 10, 20 ,30 , 40 and 50 immatures for 2nd and 3rd instars were established and replicated 15 times per density to ensure adequate statistical inference. A size of 5-10cm host plant leaf bearing the immatures and eggs is excised and the number of immatures and eggs adjusted to the desired densities, and then placed in petri-dishes 10-15 cm in diameter and 1.5cm height lined with moist filter paper to maintain humidity. The top of petri-dishes is carefully cut and replaced with mosquito nylon cloth to permit air circulation, thereafter the petri-dishes were sealed with parafilm. The 2nd and 3rd nymphs were counted and adjusted to the required density on the leaves and allowed for 1-2 hrs for settling thereafter the beetles were introduced. The female, male and late 4th instars beetles were introduced to each density, and allow the beetles to forage for 24 hours as standard exposure time, thereafter the beetles were then removed and the number of surviving preys were counted under the microscope. The consumed nymphs are those considered missing, partially killed or consumed. A control is set up without beetle.

### Data Collection and Analysis

The functional response model of a predator is a key factor regulating the population dynamics of predator-prey system, the number of preys attacked per predator was used as an experimental measure of the functional response [25]. The assumption made in this investigation was that the predator search is random and the prey population was randomly distributed and homogenous [26] emphasized the need to discriminate the type of functional response by using the logistic linear regression approach in which the initial number of prey ($N_o$) introduced and the number of preys consumed after 24 hrs are counted and recorded [26]. The proportion of prey consumed per density ($N_o/N_e$) is linearly regressed against initial prey density ($N_o$):

$$N_e/N_o = \exp (Po + P_1No + P_2No^2 + P_3No^3$$

$$1 + \exp Po + P_1No + P_2No^2 + P_3No^3$$

The parameters for $P_0$, $P_1$, $P_2$ and $P_3$ were estimated using GLM / SAS PROC. A negative linear coefficient $P_1 < 0$ indicates type II decelerating whist negative quadratic $P_2$ indicate type III (sigmoid ) curve which is characteristic of type III functional response [26].

To determine the searching rate (a) and handling time (Th) for type II functional response, the Hollings Disc equation was employed using non-linear least square regression. The functional response curves were then differentiated by evaluating the parameters namely coefficient of instantaneous search rate and handling time. The coefficient of the instantaneous change estimates the steepness of increase with predation with increased intensity and handling time helped estimate the satiation threshold that is the maximum number of preys consumed in a unit time.

$$Pc = \frac{a^1NT}{1+a^1ThN}$$

Taking the inverse of the above equation becomes:

$$1/Pc = \frac{1+a^1ThN}{a^1NT}$$

In order to get the linear form Y = bX + c , the equation is rearranged as indicated: $1/Pc = (1/a^1T)(1/N) + (Th/T)$ , where the $(1/a^1T)$ is the slope and Th/T is the intercept, and 1/Pc is the proportion of preys consumed. Thus, the inverse values of the slope and intercept were quantified as the instantaneous search rate (a) and handling time (Th) respectively [28].

## RESULTS

**Table 1a: Mean number (±SE) of eggs consumed by C. *septumpunctata* at varying *B. tabaci* egg densities maintained at laboratory condition of 25±2°C, 70±10 Relative Humidity and L:H (12:12)**

| Treatments | Prey (Egg) Densities | | | | |
|---|---|---|---|---|---|
| | 50 | 100 | 150 | 200 | 250 |
| 4th Instar | 27.89 (1.48) a | 87.34 (3.55) a | 132.26 (5.34) a | 133.47 (10.66) a | 129.23 (15.25) a |
| Female Beetle | 21.33 (2.09) a | 72.23 (7.89) b | 122.67 (10.89) b | 150.28 (15.34) b | 160.25 (16.21) b |
| Male Beetle | 19.88 (2.67) a | 70.34 (9.35) c | 100.29 (12.09) c | 115.37 (8.79) c | 133.28 (12.89) a |
| Ck | 02.21 (0.89) b | 03.21 (0.04) d | 2.09 (0.01) d | 02. 16 (0.09) d | 3.88 (0.23) d |

Mean number of eggs consumed by the predator C. septumpuntata at varying egg densities. Means are compared for each egg density by LSD at (p=0.05) level of significance. Means in the same column followed by the same letters are not significantly different .

**Table 1b: Mean Percentages of eggs consumed by C. *septumpunctata* at varying *B. tabaci* egg densities maintained at laboratory condition of 25±2°C, 70±10 Relative Humidity and L:H (12:12)**

| Treatments | Percentage consumption (predator-1day-1) | | | | |
|---|---|---|---|---|---|
| | 50 | 100 | 150 | 200 | 250 |
| Late 4th Instar | 53.00 | 74.34 | 83.17 | 66.73 | 51.69 |
| Female Beetle | 42.66 | 72.23 | 81.78 | 75.14 | 64.10 |
| Male Beetle | 39.76 | 70.34 | 66.16 | 57.68 | 53.31 |
| Ck (No predator) | 04.20 | 3.20 | 1.40 | 01.10 | 01.60 |

The mean predation rates and percentage consumption of *C. punsempuntata* developmental stages notably late $4^{th}$ instar larvae , male and female adults on five varying B. *tabaci* egg densities are presented in (Table 1a &1b). Results indicated that the predation or consumption rates monotonically decreased with increased in egg density. The maximum predation rates for the for late 4th instar larvae, female and male ducts were noted at a prey density density of 150 eggs, thereafter the predation rates dropped with further increased in egg density. At prey density of 150 , the predation rates for 4th instars was recorded as the highest with an average value of 132.26 eggs consumed per prey per day (24hrs) followed by female population 122.67 and 100.29 per prey per day respectively. The values for missing eggs in the control without predator for various densities were quite insignificant (Table 1a). The corresponding mean percentages egg consumptions were quite significant (P<0.05) as over 50% of the eggs were consumed irrespective of the densities (Table 1b). The highest percentage consumption was recoded as 83.17% at a density of 150 eggs/prey for the late 4th instar larvae, the female and male adults consumed 81.78 and 66.16% respectively, however no significance difference in percentage consumption (p>.0.05) whist the control which indicated the absence of predicator accounted for less than 5% in all the prey densities under investigation (Table 1b).

**Table2a: Mean Number (±SE) of 2nd Instars consumed by C. *septumpunctata* at varying *B*. density maintained at 25±2°C, 70±10 Relative Humidity and L:H (12:12)**

| C. septumpunctata | Second (2nd) Instars Densities | | | | |
|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 |
| 4th Instar | 6.18 (0.93) a | 13.4 (2.01) a | 19.73 (2.89) a | 24.3 (3.01) a | 26.88 (2.88) a |
| Female Beetle | 7.27(1.01) a | 17.31 (2.09) b | 23.9 (3.02) a | 26.34 (3.11) a | 28.56 (4.89) a |
| Male Beetle | 6.33(0.29) a | 15.54 (2.11) a | 20.21 (3.09) ab | 24.32 (3.92) a | 26.66 (3.09) a |
| Ck (No predator) | 0.28(0.03) b | 0.94 (0.01) b | 0.93 (0.02) c | 01.73 (0.04) b | 1.98 (0.01) b |

Mean number of 2nd Instars consumed b y the predator *C. septumpuntata* at varying density. Means are compared for each egg density by LSD at (p=0.05) level of significance. Means in the same column followed by the same letters are not significantly different.

**Table2b: Mean Percentage of B. *tabaci* 2nd Instars consumed by C. *septumpunctata* at varying *B*. density maintained at 25±2°C, 70±10 Relative Humidity and L:H (12:12)**

| C. septumpunctata | Prey Density B. tabaci (2nd Instars) | | | | |
|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 |
| 4th Instar Beetle | 61.80a | 67.00a | 65.76a | 60.75a | 53.76a |
| Female Beetle | 72.70b | 86.55b | 79.66b | 65.85a | 57.12a |
| Male Beetle | 63.33a | 77.70c | 67.37a | 60.08a | 53.32a |
| Ck (No predator) | 02.80 | 04.70 | 03.00 | 04.32 | 03.39 |

Mean Percentage of *B.tabaci* 2nd Instars consumed by the predator *C. septumpuntata* at varying density. Means are compared for each 2nd Instar density by LSD at (p=0.05) level of significance. Means in the same column followed by the same letters are not significantly different.

The attack rate and % consumption of the predator C. *septumpunctata* fed on B. *tabaci* 2nd instars are presented in (Table 2a &2b). The attack rate and % consumptions displayed by the predator monotonically decreased with increased in prey density, the highest predation rates and % consumptions were observed at a prey density of 20, thereafter there consumption rate is a decreased in prey density (Table 2a & 2b). The consumption rate at this density were 66.80, 72.70 and 63.33 predator$^{-1}$ day$^{-1}$ (24hrs) for late 4$^{th}$ instar larvae, female and male adults respectively. The corresponding mean percentages were 67.00, 86.55 and 77.70 % for 4$^{th}$ Instars, the female and male beetles respectively ($p<0.05$). These values reflect the saturation or satiation threshold after which consumption gradually declined irrespective of increase in prey density. The control treatment which lacked the presence of the predator accounted for less than 5% in all the respective densities (Table 2b).

**Table 3a: Mean Number (±SE) of B. tabaci 3$^{rd}$ Instars consumed by C. *septumpunctata* att varying B. tabaci egg density maintained at 25±2ºC , 70±10 Relative Humidity and L:H (12:12)**

| C.septumpunctata | Prey Density | | | | |
|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 |
| 4$^{th}$ Instar Beetle | 5.79 (0.88) a | 14.57a (1.09) | 19.87 (2.98) a | 24.27 (2.71) | 29.53(3.44) |
| Female Beetle | 6.09 (0.54) a | 16.66 (1.34) a | 21.56 (2.55) | 25.31 (2.79) | 32.81 (3.09) |
| Male Beetle | 6.01 (0.33) a | 14.27a (1.29) a | 18.27 (2.11) | 24.0 (2.11) | 28.57 (2.91) |
| Ck (No predator) | 0.20 (0.01) c | 0.85 (0. 01) c | 0.25c (0.02) | 0.92 (0.03) | 0.90 (0.02) |

Mean number of 3$^{rd}$ Instars *of B. tabaci* consumed by the predator *C. septumpuntata* at varying egg density. Means are compared for each egg density by LSD at ($p=0.05$) level of significance. Means in the same column followed by the same letters are not significantly different.

**Table 2b: Percentage consumption of 3$^{rd}$ Instars consumed by C. *septumpunctata* at varying B. tabaci egg density maintained at 25±2ºC , 70±10 Relative Humidity and L:H (12:12)**

| Treatments | Prey Density | | | | |
|---|---|---|---|---|---|
| C. septumpunctata | 10 | 20 | 30 | 40 | 50 |
| 4$^{th}$ Instar Beetle | 57.90a | 72.85a | 66.23a | 60.00a | 59.06a |
| Female Beetle | 60.90a | 83.30b | 71.86a | 63.27a | 65.62a |
| Male Beetle | 60.01a | 71.35a | 60.90a | 60.00a | 57.14a |
| Ck (No predator) | 02.00 b | 04.25c | 00.85 | 00.23b | 01.80 b |

Mean Percentage of 3$^{rd}$ Instars of *B.tabaci* consumed by the predator *C. septumpuntata* at varying density. Means are compared for each instars density by LSD at ($p=0.05$) level of significance. Means in the same column followed by the same letters are not significantly different.

Late 4$^{th}$ instar larvae , male and female adults of *C. septunpuntata beetles* were fed on 3$^{rd}$ instar *B. tabaci* for 24 hours and results on amount of prey consumed and percentage consumption are presented in (Table 3a &3b). Results indicated that amount of prey consumed initially increased with increased but monotonically decreased with increased in prey density with a maximum consumption of preys noted when the prey density was increased to 20 prey per predator. The number of preys consumed at this density were 72.85, 83.30, and 71.35 prey$^{-1}$ day$^{-1}$ (24hrs) for late 4$^{th}$ instar larvae, female and male adults respectively, thereafter the prey consumption declined irrespective of increased in prey density. The female adults indicated the highest amount of prey consumed whist the male adults exhibited the least prey consumption. The 4$^{th}$ instars beetles indicated a higher prey consumption than the male counterpart though results showed no significance difference

(P>0.05) (Table 3a & 3b). Corresponding values for mean percentage consumption indicated over 50% of prey were consumed at all densities, the highest percentage consumption 83.30% was exhibited by the female adults when the beetles were fed on a density of 3rd instars, whilst the least parentage consumption was recorded for male adult beetles when the density was increased to 50 (Table 3b). There was no significance difference in mean percentage consumption for densities under observation except at a density of 20 where the consumption rates were significant among the treatments (P<0.05) (Table 3b).

**<u>Table 3a</u>: Estimate of instantaneous Search rate (a) and Handling Time (Th) of predator Coccinella septumpuntata fed on *B. tabaci* eggs**

| C. septumpunctata | Functional Response Parameters | | | $r^2$ |
|---|---|---|---|---|
| | Search rate | Handling Time (Th) | T/Th Maximum consumption | |
| 4th Instars beetle | 2.57 | 0.73 | 32.87 | 0.892 |
| Female beetle | 1.44 | 0.88 | 27.27 | 0.887 |
| Male beetle | 1.41 | 1.08 | 22.22 | 0.873 |

Instantaneous search rate (a) expressed per day ; handling tine (Th) and maximum estimated amount of B. tabaci eggs consumed.

The instantaneous search rate (a) and handling time (Th) are critical features which are quantified to measure the response of predators to varying prey densities and can be used as empirical evidence to predict the effectiveness of biological control agents. Results on the instantaneous search rate , handling time and maximum consumption (T/Th) threshold or satiation point predator$^{-1}$ day$^{-1}$ for C. *septumpuctata* beetles fed on *B. tabaci* eggs, 2nd and 3rd instars are presented in (Table 3a, 3b & 3c) . The search rates for late 4th instar larvae , female and male beetles fed on eggs were computed as 2.57, 1.44 and 1.41 whilst the corresponding handling time (Th) were calculated as 0.73, 0.88 and 1.08 respectively. The maximum number of eggs consumed predator$^{-1}$ day$^{-1}$ (T/Th) for late 4th instar, female and male adults were computed as 32.87, 27. 23 and 22.22 which are considered the satiation thresholds per predator (Table 3a) . The late 4th instar larvae population exhibited strong functional response parameters to as features to consume more prey followed by female adult beetles and the least consumption was exhibited by male beetle population (Table 3a). Logistic regression of amount of prey consumed against prey density indicated strong relationship as highlighted by $r^2$ values (Table 3a).

**<u>Table 3b</u>: Estimate of instantaneous search rate and handling time of predator Coccinella septumpuntata fed on B. tabaci 2nd Instars at various densities :**

| C. septumpuntata | Functional Response Parameters | | | $r^2$ |
|---|---|---|---|---|
| | Search rate | Handling Time (Th) (24 Hrs) | (T/Th) Maximum prey consumption | |
| 4th Instars beetle | 0.52 | 2.49 | 9.64 | 0.881 |
| Female beetle | 0.54 | 2.19 | 10.95 | 0.901 |
| Male beetle | 0.49 | 3.91 | 6.13 | 0.791 |

Instantaneous search rate (a) expressed per day; handling tine (Th) and (T/Th) maximum estimated amount of B. tabaci eggs consumed per day per pray.

Results for the functional response parameters of *C.septumpuntata* fed on *B.tabaci* 2nd instars are presented in underscoring the instantaneous search rate (a) , the handling time (Th) and satiation threshold are presented (Table 3b). The search rate varied in values female beetle >4th instars > male adults , the corresponding handling time (Th) are 2.19 , 2.49 and 3.91 for the female adults , 4th instar beetles and male adults respectively (Table3b). The maximum prey consumption (T/Th) for 4th instars, female and male adults were 9.64 , 10.95 and 6.13 2nd instars predator$^{-1}$day$^{-1}$ respectively. The (T/Th) values indicated that female beetles consumed the highest number of preys whilst the male beetles showed least consumption threshold. Logistic regression analysis showed a strong relationship between prey density and amount of prey densities as $r^2$ values.

**Table 3c: Estimate of instantaneous search rate and handling time of predator C. septumpuntata fed on *B. tabaci* 3rd instars at various densities:**

| C. septumpunctata | Functional Response Parameters | | | $r^2$ |
|---|---|---|---|---|
| | Search rate (a) | Handling Time (Th) | Maximum Consumption (T/Th) prey$^{-1}$ day$^{-1}$ | |
| 4th Instars beetle | 1.69 | 1.59 | 15.09 | 0.820 |
| Female beetle | 2.57 | 1.29 | 18.60 | 0.911 |
| Male beetle | 1.33 | 2.88 | 08.33 | 0.856 |

Instantaneous search rate (a) expressed per day; handling tine (Th) and maximum estimated amount of *B. tabaci* 3rd instars consumed per predator per predator .

Table 3c shows the instantaneous search rate (a) and handling time (Th) of *C.septumpuntata* beetles fed on B. tabaci 3rd instars. The search rate (a) slightly varied in the treatment with highest search rate (2.57) noted for female adults followed by late 4th instar (1.69) whist the male adults exhibited least search rate (1.33) . Correspondingly the results on handling time (Th) varied in the trend male adult betels > late instar larvae > female adults . The shorter handling time is an ideal feature to subdue , kill and digest their preys a relative shorter (Table 3c). The satiation threshold (T/Th) signifying the maximum number of prey consumed per prey per day are indicated as 15.09, 18.60 and 8.33 for late 4th instars, female and male adults respectively (Table 3c). The female adults consumed more *B. tabaci* 3rd instars than the counterparts late instar larvae and male adults.

## DISCUSSION

The resurgence of interest for organic crop production coupled with environmental hazards connected with use of pesticides in the management of insect pests have necessitated the need to seek a viable sustainable option in the management of agricultural pests. The use of natural enemies as mortality agents has been recognized as a more sustainable and viable option where coccinellid beetles have been well recognized as effective biological control agents, their usage is considered more compatible with the environment and the ecological processes. These natural enemies play critical role in suppressing pest population as supported by [21, 22] who hypothesized that late instar and adult females coccinellids are quite voracious and have been often used for biological control programs [28] strongly suggested that, prior assessment of coccinellids for biological control efforts require a thorough laboratory evaluation to get a deeper understand of the efficacy of the control agents prior to release in the field. The author emphasized the need to understand the nature of functional responses of coccinellid which have been classified into three main types , the type I , II and III respectively based on the signs and coefficients of the logistic regressions as depicted by $P_0$, $P_1$, $P_2$ and $P_3$ [28]. Data generated from the current study was characterized as Type II functional response as the response of predator monotonically decreased in prey consumption as prey densities were increased. The type II functional response characteristics emphasized the use of Holling Disc equation to define the instantaneous search rate (a) and handling time (Th) which are valuable parameters to determine the efficiency of coccinellid beetles and natural enemies in general [28]

In Sierra Leone, the Seven spotted lady bird beetle C. *septumpuntata* beetle is widely distributed on insect infested vegetable crops in diverse agro-ecosystems (personal observation) invariably enhancing natural mortality of the pests under natural field conditions. Despite the existence of this natural mortality biotic agents providing natural control situation that can be exploited for pest management purposes , there is however no research record or documentation of the functional response of this beetle in Sierra Leone. This has warranted a laboratory investigation on the functional response of this beetle as preliminary effort to explore the opportunity that can lead to mass rearing of the beetle for biological control programs. The current investigation endeavoured to determine the instantaneous search rate (a) and handling time (Th) of the late 4$^{th}$ instars, the female and male adults respectively fed on *B. tabaci* eggs, 2$^{nd}$ and 3$^{rd}$ instars. Findings indicated that the beetle population exhibited the type II functional response underscoring the female adults indicated the highest instantaneous search rate (a) and the lowest handling (Th) time as compared to the late 4$^{th}$ instars and counterparts male adults. However , investigation showed that when the beetles were fed on eggs, the late 4$^{th}$ instars showed higher attack rate (a) and lowest handling time (Th) than the male and female adults counterparts. This simply implies that the 4$^{th}$ instar population empirically displayed more effective features in managing *B.tabaci* at the initial infestation stage. It is worth noting however that under real natural field conditions, there is a mosaic of different B. *tabaci* developmental stages affecting crops under real time. Findings in this current study provide empirical information strongly indicating that the late 4$^{th}$ instar and female adults can potentially provide synergistic ability in managing *B. tabaci* infestation under field and greenhouse conditions. Though functional response of male adults was not as pronounced as those of the late 4$^{th}$ instars and female counterparts based on empirical findings in this study, their release along side the female adults would be considered realistic to ensure the numerical response of the female adults particularly when the strategy of biological program is centred around inoculative biological control in which the control efficiency is highly dependent on the number of offsprings that would be produced (numerical response).

[28] stated that high attack rate (a) and short handling time (Th) potentially lead to highest consumption of prey. Findings in this investigation underscored parallel view on the opinion of [27, 25] in which the female adults indicated the highest search rate and lowest handling time with a resultant outcome of highest consumption potential strongly

underscoring that the female beetle population can serve as better candidates for biological program as compared to the male counterpart. In addition, [21, 27] proposed the hypothesis that the female beetles and late 4$^{th}$ instar larvae have an innate energy accumulation threshold that are required to reach under limited prey availability by investing less time in attacking and consuming compared to usual predation rate that are displayed under optimal and abundant prey availability. The current results indicated that the late 4$^{th}$ instar larvae exhibited higher attack rate (a) and less handling time *(Th*) for egg consumption in support of the hypothesis that larvae might have an innate energy accumulation threshold that they try to reach under limited prey availability by investing less time in attacking and consuming the prey compared to their usual predation rates that are displayed under optimal or abundant prey availability. Because environmental unpredictability encourages behavioural flexibility in insects [27], the individuals that fed poorly during their early larval stages might accumulate fewer reserves– presumably in the form of stored fat to carry through pupation into adulthood [27]. As a result, they might feed more aggressively during their late-larval stages or as adults, as demonstrated by higher attack rates and lower prey-handling times. These results of the current study are in support with views of [22,27] based on the predation rate and handling time of late 4$^{th}$ instar larvae more specifically that consumed more eggs than the counterpart male and female adults.

## CONCLUSION

The use of beetles as predators or biological control agents in the management of whiteflies, thrips aphids which are common pests of vegetable crops is quite a promising one particularly when these natural enemies can be easily sourced from smallholders' vegetable fields, evaluating their functional responses both laboratory and field conditions, validate their feasibility and efficiency under field conditions, and final applications in farmers' fields. This unique pest management effort can be easily realized in Sierra Leonean context as the climatic conditions are quite ideal for the beetle population to thrive under natural conditions as evidence on their availability on vegetable growers' gardens. The result derived from the current investigation is a wake call to usher pest management efforts, a paradigm shift from the use of broad-spectrum chemical pesticides to the use of beetles specifically for pest management of vegetable crops which has been dominated by the use of broad-spectrum synthetic pesticides over the years. This current investigation is an initial effort, much information is however required with respect to functional response of the *C. septumpuntata* under greenhouse and open field conditions dictating the real biotic and abiotic factors that are at interplay, and results that would be derived under such natural circumstances would provide concrete and realistic information to guide in mass rearing and their utilization as potential biological control candidates.

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**Author Contribution**

The authors equally contribute their expertise in experimental design , collection and analysis of data and developing the manuscript to completion .

**Conflict of Interest**

No conflict of interest in the publication of this work , both authors equally consented to the publication of this research article.

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