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Population dynamics study for triple-e sustainable management of a major pest, *Leptocorisa oratorius* fabricius (Hemiptera: Alydidae)

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Abstract
In this modern era with increasing human population there is a need to increase rice (*Oryza sativa* L.) production per unit of land through sustainable strategies. A number of insect pests are the important limiting factor in rice fields throughout the world. Use of different broad spectrum synthetic insecticides or few botanicals are the general practices for their management without considering their population dynamics or their action threshold. Even their non judicious uses over the decades have high biomagnifications potential with adverse effects on food web. Life table study is a central theme in ecological research to understand the temporal and spatial patterns in population dynamics of any pest for their sustainable management. The host preference test of rice bug, *Leptocorisa oratorius* Fabricius (Hemiptera : Alydidae) in relation with phytochemical regime of rice (R) [*Oryza sativa* L.; Family: Poaceae, cv. Jamini (IET-12133)] and non-rice (NR) weed [*Cyperus rotundus*, common nut sedges, Family: Cyperaceae] were conducted in the laboratory condition. The different population growth parameters of *L. oratorius* on R were significantly differed (P< 0.005) from the NR system like higher intrinsic (r_m) and finite (λ) rate of increase through shorter generation time (T_c) and doubling time (DT). These differences were due to better nutritional quality relative to anti-nutritional factors in the respective host system. Thus, by knowing the host quality one can gain triple-E (ecological, environmental and economical) sustainability for management of this pest (*L. oratorius*) population or other such pests in any agro ecosystem in near future.

Keywords: *Leptocorisa oratorius*, population dynamics, *Oryza sativa*, *Cyperus rotundus*, phytoconstituents, triple-E sustainablity

1. Introduction

With the continued increases in the human population there is a need to increase rice (*Oryza sativa* L.) production per unit of land through development of their production strategies that are sustainable and are economically, environmentally, and socially acceptable [1-3]. Rice is the most economically important food crop in many developing countries, and has also become a major crop in many developed countries where its consumption has increased considerably due to food diversification and immigration [4, 5]. India is the second largest producer of rice in the world [4, 6-8]. However, insect pests and weeds are among the most important biological constraints limiting rice yield potential [9-13]. One of the most important rice pests in the subtropical and tropical rice areas belong to the genus *Leptocorisa* [1, 2, 14-22]. They are especially severe in tropical Asia and are increasing in Africa and South America[1,2,10,12,13,23]. Generally lowland rice crops of Asia are dominated by *L. oratorius* (Fabricius) [1-3, 10, 12, 13, 23-26]. Losses due to the insects reflect large scale reduction both in quality and quantity [1, 11, 15, 24]. When the bugs feed during the flowering stage, the grains become sterile, while feeding during the milk stage results in empty or half-filled discolored grains, thus a reduction in quantity[3, 17, 27]. The feeding habits of both adults and nymphs are similar [1, 10, 12, 13, 23]. They also can live on grasses but prefer flowering rice [10-14]. All growth stages, especially nymphs and adults, are generally present during the susceptible growth stage of the rice plant [10, 12, 13, 23]. In fact, the bugs are generally reproduced on certain grasses near or around rice cultivations, which makes it easy for both nymphs and adults to invade the rice crop during the reproductive growth phase [1, 10-13]. Growing rice bug nymphs are more active feeders than adults, but adults cause more damage because they feed for a longer period [11, 12, 14, 24]. Injury during the milk stage causes yield loss and damage during the dough stage impairs grain quality [11, 12, 24]. Control strategies in current use against the pest are largely based on chemical insecticides but intensive use creates an ecological imbalance through destruction of non-target beneficial insects, and accumulation of toxic residues in the environment [26, 28-33]. The effectiveness of the usual practised management like the use of resistant rice varieties, biorationals and natural enemies against this notorious pest is not so promising [3, 8,23, 27, 34-36]. Life table and population dynamics study is a central theme in ecological research to understand the temporal and spatial patterns in population growth for their sustainable management [37-45]. Today, the population dynamics along with limiting factors of this pest are very essential for timely adoption of different management techniques [42-47]. Though, only few studies have been made in the past related with ecology of the pest [12,18,19,23]. So there is an imperative need for alternative management of this deleterious insect pest through population dynamics based study on their preferred host plants in order to apply appropriate sustainable management strategies.

2. Materials and Methods

2.1. Host Plants

Rice (R) [*Oryza sativa* L.; Family: Poaceae; cv. Jamini (IET-12133) [Aus season] [6-8] and Non-rice (NR) weed [*Cyperus rotundus*, Family: Cyperaceae] [48] were collected from the fields near Chinsurah Rice Research Centre (22°53' N, 88°23' E), Hooghly, West Bengal, India. The plant was identified by the help of plant taxonomist and voucher specimens (Voucher No. ERU8-9) were kept in Department of Zoology, Ecology Research Unit, MUC Women's College, Burdwan.

2.2. Phytochemical Analysis

The freshly harvested rice (R) and non-rice (NR) weed were collected randomly from the same fields near Chinsurah Rice Research Centre (22°53' N, 88°23' E), Hooghly, West Bengal, India. These were initially rinsed with distilled water and dried by paper toweling for phytochemical analysis. These were dipped in different solvents for extraction of different primary and secondary metabolites. The chemicals were estimated by various slandered biochemical analyses protocols as described by Roy [42, 43, 45, 49] (as well as Roy and Barik [50,51]. Determination of each biochemical analysis was repeated for three times and expressed in µg/mg dry weight basis.

2.3. Insect mass culture and development

The study on population dynamics and life table parameters of rice bug, *Leptocorisa oratorius* Fabricius (Hemiptera : Alydidae), was carried out in the laboratory condition (27±1°C, 65±5% RH and a photoperiodism of 12:12 [L:D]). The initial population of this notorious insect pest was collected from the field near Chinsurah Rice Research Centre (22°53' N, 88°23' E), Hooghly, West Bengal, India and was taken to the laboratory. Developmental time and survivability of *L. oratorius*, was determined on rice (R) plant and non-rice (NR) weed under the same laboratory condition as described by Dutta and Roy [17]. Duration and survival for each molt were recorded in the laboratory condition of three consecutive generations for construction of their stage-specific life table as described by Roy [42-45] as well as Dutta and Roy [17].

2.4. Life table parameters

The construction of life table includes several parameters which were calculated with the formulae of Southwood [37,52], Ricklefs and Miller [53], Carey [38,39], Krebs [54], Price [55], and Schowalter [56]. These parameters include probability of survival from birth to age x (l_x), proportion dying each age (d_x), mortality (q_x), survival rate (s_x) per day per age class from egg to adult stages. Using these parameters, the following statistics like, average population alive in each stage (L_x), life expectancy (e_x), exponential mortality or killing power (k_x), total generation mortality (K or GM), generation survival (GS), gross reproductive rate (GRR), net reproductive rate (NRR or R_0), mean generation time (T_c), doubling time (DT), intrinsic rate of population increase (r_m), Euler's corrected r (r_c), finite rate of population increase (λ), weekly multiplication rate (λ^7), increase rate per generation (λ^{Tc}), were also computed, using Carey's formulae [38]. Some other population parameters like potential fecundity (Pf), total fertility rate (F_x), mortality coefficient (MC), population growth rate (PGR), population momentum factor of increase (PMF), expected population size in 2nd generation (PF_2), expected females in 2nd generation (FF_2), general fertility rate (GFR), crude birth rate (CBR), reproductive value (RV), vital index (VI) and trend index (TI) were also determined by using well defined formulae [37,52,57,58].

2.5. Field experiment

A field experiment was conducted for consecutive three years from 2015 to 2017 by growing the Rice (R) [*Oryza sativa*, cv. Jamini (IET-12133)], and Non-rice (NR) weed [*Cyperus rotundus*, Family: Cyperaceae] [6-8,48] in RDB to collect different life stages of *L. acuta* for laboratory mass culture as described earlier workers with few modifications [59,60]. The experiment was done by using a small land area (2 katha or 134 m^2) near CRRC, Chinsurah, 22°53' N, 88°23' E, 13m above sea level, West Bengal, India, with 3 replications for both R and NR plants side by side.

2.6. Statistical Analysis

Experimental data of different phytoconstituents of the host plants and the pest population parameters were subjected to one-way Analysis of Variance (ANOVA), regression analysis and correlation analysis [42-45, 49, 50\, 51, 60]. Effect of the host plants (R and NR) on the population dynamics of *L. oratorius* were analyzed using one-way ANOVA [42-45, 61, 62]. Means of different demographic parameters were compared by Tukey's test (HSD) when significant values were obtained [42-45, 61, 62]. All the statistical analysis was performed using the statistical program SPSS (version 13.0) [61-63].

3. Results

This study on *L. oratorius* on two host (R and NR) plants was carried out in the laboratory to understand their life table parameters and population dynamics of this notorious insect pest on two host (R and NR) plants. The biochemical constituents of the two types of host plants (R and NR) are presented in figure 1. The primary metabolites i.e., carbohydrates, proteins, lipids andamino acids including moisture content was varied significantly ($P < 0.0001$) in the host plants (Figure 1). Among the secondary metabolites, phenolics concentration was significantly ($P < 0.0001$) lower in R system than the NR system and differed significantly ($F_{1, 4}$=13.452, $P < 0.0001$) (Figure 1). Other secondary metabolites were also significantly differed ($F_{1, 4} \geq 12.211$, $P < 0.0001$) and higher in NR weed relative to R plants (Figure 1). Ultimately, the ratio of primary to secondary metabolites was always significantly ($P < 0.001$) higher in R system than NR weed systems. Thus, the nutritional factors (primary metabolites) along with the anti-nutritional factors (Secondary metabolites) were varied significantly ($P < 0.001$) in the two hosts and in terms of nutritional superiority R was much more superior than the NR system (Figure 1). The life table parameters of three cohorts of the pest, *L. oratorius*, on R and NR system for each developmental stage, from egg to five nymphal instars followed by adult, are presented in table 1 and 4, respectively. The developmental duration and relative survival of each stage from egg to adults were recorded as described by Roy [42-45] as well as Dutta and Roy [17]. It was observed that the incubation period from the time of egg laying to hatching lasted more on NR host than the R host. There were five nymphal stages where the insects molted between each stage and number of surviving nymphs present in each cohort was observed. Consequently, the total developmental period from egg to adult lasted more on NR host than the R host due to their respective host phytoconstituents. Adult females were laid eggs singly in clusters or in a linear fashion. The nymphs had green body with long black legs and antennae were brown with visible white bands. Well developed wings appeared after the final molt from the 5th instar nymph into adults. The adults were brownish-green in colour with more brown on the dorsal side, especially the wings. The ventro-lateral dark dots on the abdomen became visible at this stage as their key morphological feature. Both the nymphs and adults were slender but the adults were more slender and robust. The three cohorts containing 50 eggs in each were reared separately on R and NR weed systems, respectively to construct the life table of this notorious pest, *L. oratorius*, as described by Roy [42-45] as well as Dutta and Roy [17]. The average life span, overall survival from egg to the death of adults was significantly ($P < 0.0001$) higher on R system relative to the NR weed systems due to higher developmental duration (Table 7). Individual host have significant variation in their phytoconstituents and on population parameters of *L. oratorius* throughout the three consecutive cohorts (Table 6 and 8). ANOVA result of stage-specific pooled life table on the selected two hosts (R, NR) for the three cohorts each were differed significantly ($F_{6,42} \geq 15.862$, $P < 0.0001$) (Table 6). All the population parameters were significantly advandagious in R host system followed by NR weed system (Table 7) due to their respective phytoconstituents (Figure 1). The fecundity of *L. oratorius* was significantly higher ($P < 0.01$) on R system (93.697) relative to the NR weed system (84.685) (Table 7). Population dynamics and reproductive parameters of the six cohorts (3 cohorts on each host) of *L. oratorius* also show highly significant differences in individual ($F_{21,44} \geq 251.016$, $P < 0.0001$) and in combined host system ($F_{21,22} = 132.610$, $P < 0.0001$) (Table 8). The population parameters were positively and negatively correlated with the host (R and NR) primary and secondary metabolites, respectively. Thus, the population growth parameters of *L. oratorius* were significantly affected by the different host systems (Table 1, 4, 7) due to variation in their respective nutritional constituents (Figure 1).

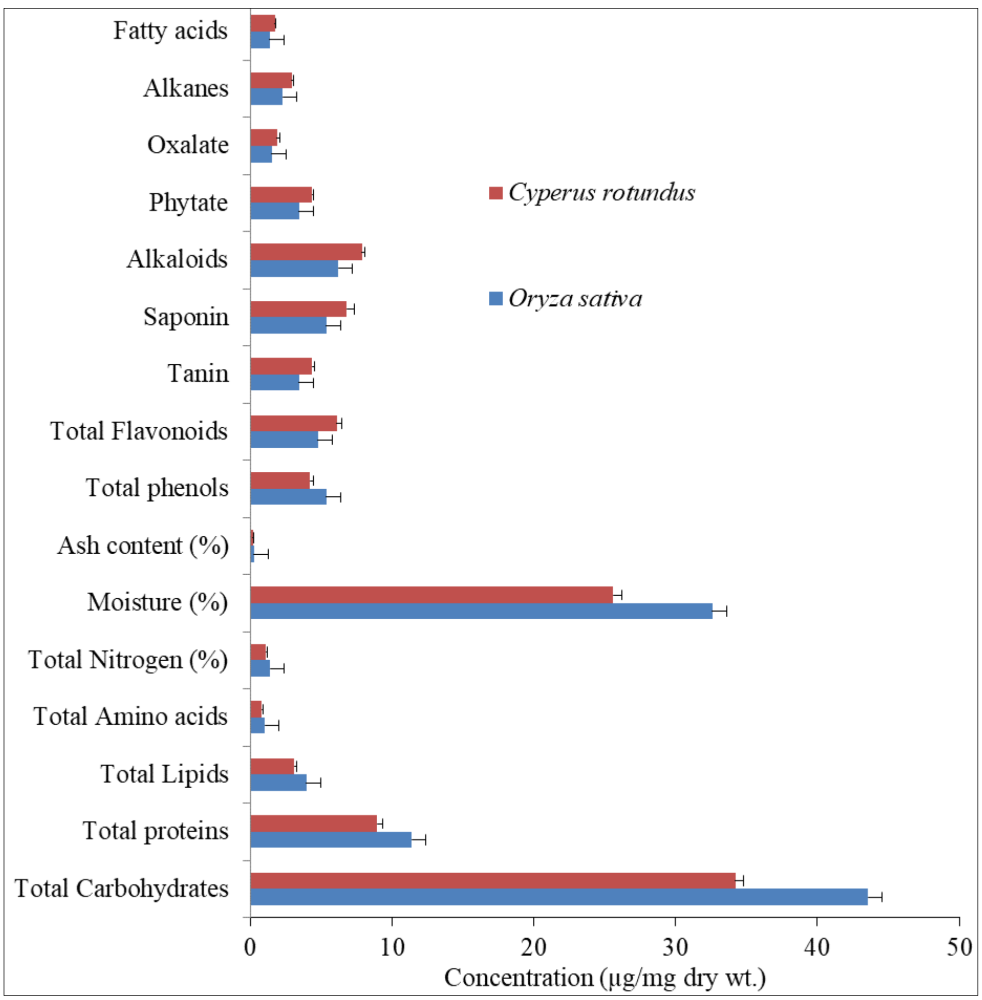

Fig 1: Phytochemical variations of rice [R](*Oryza sativa*, Family: Poaceae) and non-rice [NR] weed (*Cyperus rotundus*, Family: Cyperaceae) collected from pesticide free controlled agroecosystem during 2015-2017 (Mean ± SE of 3 observations).

Table 1: Stage-specific pooled life table for 3 cohorts each (Mean of 3 observations) of *L. oratorius* on rice [R] (*Oryza sativa*, Family: Poaceae) collected from pesticide free controlled agroecosystem during 2015-2017.

Stage	l_x	d_x	q_x	s_x	L_x	e_x	k_x
Egg 0	1.000	0.136	0.136	0.864	0.932	5.864	0.064
Nymph 1	0.864	0.170	0.197	0.803	0.778	5.711	0.095
Nymph 2	0.693	0.045	0.066	0.934	0.670	5.992	0.029
Nymph 3	0.648	0.068	0.105	0.895	0.614	5.377	0.048
Nymph 4	0.580	0.148	0.255	0.745	0.506	1.951	0.128
Nymph 5	0.432	0.136	0.316	0.684	0.364	1.447	0.165
Adult 6	0.295	0.068	0.231	0.769	0.261	0.885	0.114
Stage	l_x	d_x	q_x	s_x	L_x	e_x	k_x
Egg 0	1.000	0.136	0.136	0.864	0.932	5.862	0.064
Nymph 1	0.864	0.170	0.197	0.803	0.778	5.708	0.095
Nymph 2	0.693	0.045	0.066	0.934	0.670	5.989	0.029
Nymph 3	0.648	0.068	0.105	0.895	0.614	5.374	0.048
Nymph 4	0.580	0.148	0.255	0.745	0.506	1.948	0.128
Nymph 5	0.432	0.136	0.316	0.684	0.364	1.443	0.165
Adult 6	0.295	0.072	0.244	0.756	0.259	0.878	0.121
Stage	l_x	d_x	q_x	s_x	L_x	e_x	k_x
Egg 0	1.000	0.136	0.136	0.864	0.932	5.860	0.064
Nymph 1	0.864	0.170	0.197	0.803	0.778	5.706	0.095
Nymph 2	0.693	0.045	0.066	0.934	0.670	5.986	0.029
Nymph 3	0.648	0.068	0.105	0.895	0.614	5.371	0.048
Nymph 4	0.580	0.148	0.255	0.745	0.506	1.944	0.128
Nymph 5	0.432	0.136	0.316	0.684	0.364	1.438	0.165
Adult 6	0.295	0.076	0.258	0.742	0.257	0.871	0.130

Table 2: Stage-specific pooled life table for 3 cohorts each (Mean of 3 observations) of *L. oratorius* on non-rice [NR] weed (*Cyperus rotundus*, Family: Cyperaceae) collected from pesticide free controlled agroecosystem during 2015-2017.

Stage	l_x	d_x	q_x	s_x	L_x	e_x	k_x
Egg 0	1.000	0.136	0.136	0.864	0.932	5.867	0.064
Nymph 1	0.864	0.170	0.197	0.803	0.778	5.714	0.095
Nymph 2	0.693	0.045	0.066	0.934	0.670	5.997	0.029
Nymph 3	0.648	0.068	0.105	0.895	0.614	5.382	0.048
Nymph 4	0.580	0.148	0.255	0.745	0.506	1.957	0.128
Nymph 5	0.432	0.136	0.316	0.684	0.364	1.455	0.165
Adult 6	0.295	0.061	0.208	0.792	0.265	0.896	0.101
Stage	l_x	d_x	q_x	s_x	L_x	e_x	k_x
Egg 0	1.000	0.136	0.136	0.864	0.932	5.863	0.064
Nymph 1	0.864	0.170	0.197	0.803	0.778	5.710	0.095
Nymph 2	0.693	0.045	0.066	0.934	0.670	5.991	0.029
Nymph 3	0.648	0.068	0.105	0.895	0.614	5.376	0.048
Nymph 4	0.580	0.148	0.255	0.745	0.506	1.950	0.128
Nymph 5	0.432	0.136	0.316	0.684	0.364	1.446	0.165
Adult 6	0.295	0.070	0.236	0.764	0.261	0.882	0.117
Stage	l_x	d_x	q_x	s_x	L_x	e_x	k_x
Egg 0	1.000	0.136	0.136	0.864	0.932	5.865	0.064
Nymph 1	0.864	0.170	0.197	0.803	0.778	5.712	0.095
Nymph 2	0.693	0.045	0.066	0.934	0.670	5.994	0.029
Nymph 3	0.648	0.068	0.105	0.895	0.614	5.380	0.048
Nymph 4	0.580	0.148	0.255	0.745	0.506	1.954	0.128
Nymph 5	0.432	0.136	0.316	0.684	0.364	1.451	0.165
Adult 6	0.295	0.065	0.220	0.780	0.263	0.890	0.108

Table 3: ANOVA result of stage-specific pooled life table for the three cohorts each (Mean of 3 observations) of *L. oratorius* on rice [R] (*Oryza sativa*, Family: Poaceae) and non-rice [NR] weed (*Cyperus rotundus*, Family: Cyperaceae) collected from pesticide free controlled agroecosystem during 2015-2017.

Cohorts	SS	df	MS	F	P-value	F crit
R1	76.240	6,42	12.707	15.982	0.0001	2.324
R2	76.062	6,42	12.677	15.924	0.0001	2.324
R3	75.868	6,42	12.645	15.862	0.0001	2.324
NR1	76.552	6,42	12.759	16.081	0.0001	2.324
NR2	76.422	6,42	12.695	15.960	0.0001	2.324
NR3	76.388	6,42	12.731	16.029	0.0001	2.324

Table 4: Population dynamics and reproductive table of the six cohorts (Average of 3 observations on each host) of *L. oratorius* on rice [R] (*Oryza sativa*, Family: Poaceae) and non-rice [NR] weed (*Cyperus rotundus*, Family: Cyperaceae) collected from pesticide free controlled agroecosystem during 2015-2017.

Population Parameters	R	NR	Averae	Variance
Potential fecundity (Pf)	93.697	84.685	89.191	40.608
Total fertility rate (F_x)	785.03	660.651	722.8 7	7734.092
Gross reproductive rate (GRR)	28.304	26.363	27.333	1.884
Net reproductive rate (NRR)	8.362	7.789	8.076	0.164
Intrinsic rate of increase (r_m)	0.043	0.044	0.044	0.000
Euler's corrected r (r_c)	0.102	0.106	0.104	0.000
Finite rate of increase (λ)	1.044	1.045	1.044	0.000
Generation time (T_c)	49.557	46.584	48.070	4.419
Doubling time (DT)	16.171	15.727	15.949	0.099
Increase rate per generation (λ^{Tc})	8.362	7.789	8.076	0.164
Generation mortality (GM)	0.651	0.638	0.645	0.000
Mortality coefficient (MC)	0.089	0.092	0.091	0.000
Generation survival (GS)	0.342	0.342	0.342	0.000
General fertility rate (GFR)	11.198	10.867	11.033	0.055
Crude birth rate (CBR)	1.725	1.725	1.725	0.000
Population momentum factor of increase (PMF)	9.409	9.195	9.302	0.023
F_2 Population size (PF_2)	196.78	179.109	187.93	156.096
Probable F_2 females (FF_2)	78.711	71.644	75.177	24.975
Reproductive value (RV)	56.608	52.726	54.667	7.535
Population growth rate (PGR)	0.896	0.859	0.877	0.001
Vital Indwx (VI)	0.223	0.230	0.227	0.000
Trend index (TI)	11.212	10.443	10.827	0.296

Table 5: ANOVA result of different population parameters for nine cohorts (Average of 3 observations on each host) of *L. oratorius* on rice [R] (*Oryza sativa*, Family: Poaceae) and non-rice [NR] weed (*Cyperus rotundus*, Family: Cyperaceae) collected from pesticide free controlled agroecosystem during 2015-2017.

Source of Variation	df	MS	F	P-value	F crit
Oryza sativa (R)	21, 44	84753.736	251.016	0.0001	1.801
Cyperus rotundus (NR)	21, 44	60421.848	299.201	0.0001	1.801
COMB	21,22	48043.541	132.610	0.0001	2.059

4. Discussions

In this study life table data along with all the stages of *L. oratorius* development will make easy to identify this notorious pest for effective management in the field to reduce yield loss of rice. Adult females of *L. oratorius* generally oviposit from the booting to milky stage of rice development as described by several researchers [1, 2, 11, 12, 14, 24]. They are generally laid eggs in single or double rows on the leaf and occasionally on the panicle of rice [1, 10, 12, 13, 18, 23]. *L. oratorius* has also been reported to reproduce on a number of weeds, although as food plants weeds were inferior to rice [9, 10-13, 64]. They have only one well-timed generation per rice crop, except when alternative food plants are present early in the season [1, 18, 64, 65]. Adults and nymphs pierce developing rice spikelets and feed on the ovary, liquid endosperm or solid endosperm [1, 2, 18, 64,65]. The study can describe duration and survival at each life stage which allow prediction of the population size and age structure of a pest insect at any time. It is very helpful to determine the different mortality stage as well as pattern of population growth on both R and NR hosts. There is a range of innet capacity for individual of a population but the variation in available food quality along with environmental factors [42-45, 49, 57, 55, 66]. Even, the host plant quality traits are the key determinants of the insect reproductive strategies [42-45, 66]. The effect of different food sources on population parameters were also observed on different host plants [42-46, 66]. In this study, the overall difference in the determined population parameters could be due to the variation in nutritional and anti-nutritional factors of the respective host plants [42-45, 66]. Similar findings with few variations were reported by Domingo *et al*. [20], Morrill *et al*. [24], Berg and Soehardi [1], Begum *et al*. [10] and Hosamani *et al*. [5]. The variation of these findings can be as a result of several factors and some of them may beyond our control. With this understanding, the population dynamics of *L. oratorius* is highly supported by R plants due to high nutritional quality relative to the NR weeds. But it is also predicted that, NR weeds are the alternative source of their population growth in absence of R plants. So the removal of NR weeds is of course a way to control the pest in field condition. Even, this study also informs the complete picture along with vulnerable stage(s) of the pest for their sustainable management in the field condition.

5. Conclusions

Recent advancement in IPM has employed molecular techniques including better breeding programmes, genetically modified crops (GMOs), expressing resistant traits and use of synthetic and natural semiochemicals around the world for pest control. It is an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices. Once monitoring, identification, and action thresholds (ETs) indicate that pest control is required, and then less risky sustainable pest controls are chosen first. Sighting a single pest does not always mean control is needed which actually the first step to remove the possibility of injudicious use of pesticides. The injudicious application of pesticides always leads to the destruction of ecological biodiversity including beneficial natural enemies, essential pollinators and foragers. These also result into secondary pest outbreak and development of pesticide resistance in insect pests and emergence of pest biotypes. At this point population dynamics based eco-friendly approaches would obviously help in the conservation of natural enemies which would bring down the pest load below ET and eventually lower broad spectrum pesticides use which generally brings pest resurgence and pest resistant problems. The life table study of *L. oratorius* on R and NR hosts showed three distinct stages with five nymphs and represent similar pattern of development with significant variations ($P< 0.001$). These differences in the demographic parameters are due to the variation in their nutritional quality of respective kind of host plants. But it is also predicted that, NR weed is an alternative source of their population growth in absence of R plants. So the removal of NR weed is of course a way to control the pest in field condition. Their further management strategies may include different ecofriendly control strategies following their population parameters. There may be few limitations in the methodical scientific study but this particular study somehow has triple- E (Environmental, Ecological and Economical) sustainability for any kind of pest management in near future.

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