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Population ecology and ETs based time series for climate smart pest management of *Spilosoma obliqua* (Walker)

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ABSTRACT: The two-sex pooled life table of *S. obliqua* (Walker) (Lepidoptera: Arctiidae) was constructed along with their population density and yield loss estimation to determine their economic thresholds (ETs) based time series on two different crops such as sesame (*S. indicum*; cv. Rama) and green gram (*V. radiata*; cv. KB-54) in 2019. The population ecology and ETs of *S. obliqua* were significantly (P<0.05) affected by the host phytoconstituents in terms of host suitability or susceptibility (sesame>green gram). Average EIL and ET for *S obliqua* was 26.388±1.627 and 24.230±2.412 pests/30 plants, respectively for sesame that were insignificantly ($F_{1,4}$=2.794-3.335; P≥0.142) differed from the green gram. For a single pest per m^2 (30±2 plants/m^2) the possible time that can be taken to reach EIL (Ti) and ET (Tt) were 38.246±1.157 and 37.246±1.157 days, respectively on sesame which were significantly ($F_{1,4}$=24.111; P=0.008) lower than green gram. Even, ETs based time series was also calculated to find the specific time (Tt days) to reach ET for any number of pest(s)on the selected crops for time based management. The benefit cost ratio (BCR/ha) of sesame and green gram was 0.478 and 0.390, respectively with significant (P<0.05) deviation. The carbon sequestration efficiency (CSE) of sesame (301.860 kg/ha) was significantly (P<0.05) higher than green gram (172.260 kg/ha) due to more biomass production. These findings will obviously help farmers to choose sesame as a suitable trap crop for green gram on the basis of pest attraction or susceptibility, ETs based time series, BCR values (sesame>green gram) as well as CSE for climate smart pest management (CSPM) by applying appropriate control measures judiciously if required within the time limit to reach the ETs as in time series for sustainable climate smart agriculture (CSA) of such crops in near future.

KEY WORDS: *Spilosoma obliqua*, *Sesamum indicum*, *Vigna radiata*, phytoconstituents, population ecology, ET, trap crop, carbon sequestration efficiency, climate smart pest management.

INTRODUCTION

Sesame (*Sesamum indicum* L., Family: Pedaliaceae) is the most important oilseed crop in tropical and subtropical regions of the world (Chongdar *et al*., 2015), while green gram (*Vigna radiata*, Family: Fabaceae) is an important short-season summer growing legumes and is also grown widely throughout tropic and sub tropic regions (Roy and Barik, 2010; Mobarak *et al*., 2019). In West Bengal, several cultivars of sesame (Rama, Savitri, Tillotama, Nirmala, Shubhra, Amrit, JLT-408, TKG-22, DSS-9, GT-2, etc.) and green gram (K-851, PDM-54, B-105, Pusa Baishakhi, Sonali, etc.)

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are cultivated (Chongdar *et al*., 2015; Mobarak *et al*., 2019). However, their productivity is extremely low due to several yield limiting factors like biotic and abiotic stresses with poor agronomic management practices (Adhikary *et al*., 2018). Among the insect pests, Bihar hairy caterpillar of *Spilosoma obliqua* (Walker) (Syn. *Diacrisia obliqua*) (Lepidoptera: Arctiidae) is one of the major generalist pests of different crops including sesame and green gram in India, Bangladesh, Bhutan, Srilanka, Pakistan and south-eastern Afghanistan (Nath, 1975; Mobarak *et al*., 2019). All the larval instars (I-VI) feed voraciously on their host leaves as well as pods and ultimately reduce crop productivity (Bhaduria *et al.,* 2001; Biswas, 2006; Roy and Barik, 2013; Mobarak *et al*., 2019). Today, the use of different high yielding varieties (Wolfenberg and Phifer, 2000; Mobarak *et al*., 2019), broad-spectrum synthetic pesticides like, triazophos, lambda cyahlothrin, indoxacarb, cypermethrin, deltamethrin**,** etc. (Nagia *et al.,* 1990; Mohapatra and Gupta, 2018), botanicals (Parui and Roy, 2016, Bhardwaj and Kumari, 2016), natural enemies (Damalas and Koutroubas, 2018), etc. are used for effective management of *S. obliqua*. But all the strategies are so far unable to manage the pest completely. So, farmers use more pesticides injudiciously for even a single pest observation without considering any economic threshold (ET) limit or irrespective of pest density to eradicate the pest population completely for better crop production (Nagia *et al.*, 1990; Jashvantbhai, 2015; Carvalho 2017; Mohapatra and Gupta, 2018). These create ecological imbalance in the agroecosystem and result into secondary pest outbreak, pest resurgence, development of pesticide resistance as well as emergence of pest biotypes (Kim *et al*., 2017).

To stop such creation of more ecological imbalance, pest population ecology based management strategy is necessary to combat with the pest (Chi and Su, 2006; Chen *et al.*, 2017; Roy and Barik, 2012; 2013; Roy, 2015a; 2015b; 2019; Mobarak *et al.*, 2019). Population dynamics and nutritional ecology based ET calculation for sustainable management of a pest are very crucial (Southwood 1978; Carey 1993; Dutta and Roy 2016; Chen *et al.*, 2017; Roy, 2015a, 2015b, 2017, 2019). Life table is a powerful tool to understanding the effect of different hosts on an insect pest as well as their management (Southwood, 1978; Carey, 2001; Kakde *et al*., 2014; Roy, 2019). The age-stage, two-sex life table is more powerful than traditional life table as it can eliminate many inherent errors due to sexual biasness (Chi and Su, 2006; Chen *et al*., 2017). There is a range of innet capacity for individual of a population (Roy, 2015b; Dutta and Roy, 2016) but the variation in available host plant quality always influence the growth, reproduction, longevity and survival of that population (Liu *et al*., 2004; Schoonhoven *et al*., 2005; Shobana *et al*., 2010; Win *et al*., 2011; Roy and Barik, 2012, 2013; Roy, 2019). Different host plants vary in the context of various physical and chemical characteristics (Schoonhoven *et al*., 2005; Shobana *et al*., 2010; Roy and Barik, 2012). Host phytoconstituents mediated defences against the herbivores are wide-ranging and highly dynamic in nature (Awmack and Leather, 2002; War *et al*., 2012). Secondary metabolites (polyphenols, terpenoids, alkaloids, etc.) either produced constitutively or in response to plant damage, and they affect feeding, growth, and survival of herbivores (Howe and Jander, 2008; War *et al.,* 2012). Moreover, host plant utilization is also influenced by the ability of insect to ingest, assimilate and convert food into their body tissues (Scriber and Slansky, 1981; Dadd, 1985; Nation, 2001). Thus, host plant quality during larval growth and development is the key determinant of adult longevity, fecundity, fertility and survivability (Awmack and Leather, 2002; Shobana *et al*., 2010; Roy and Barik, 2013; Roy, 2015a). The effect of different food sources on population parameters were observed in *Plutella xylostella* (Syed and Abro, 2003), *Helicoverpa armigera* (Liu *et al*., 2004), *Spodoptera litura* (Xue *et al*.,2010), *Papilio polytes* (Shobana *et al.,* 2010), *Diacrisia casignetum* (Roy and Barik, 2013), *Podontia quatuordecimpunctata* (Roy, 2015a), *Epilachna vigintioctopunctata* (Roy, 2017) and *Parallelia algira* (Munrswari *et al*., 2019) on different host plants. Variation between the results of this studies could be attributed to differences among nutritional and anti-nutritional factors present in the respective host plants (Awmack and Leather, 2002; Xue *et al*., 2010; Roy and Barik, 2013). Similarly, a number of biological studies have been reported for *S. obliqua* on sunflower (Varatharajan *et al.,* 1998), sesame (Biswas, 2006), jute (Gotyal *et al*., 2015), black gram (Mandal *et al*., 2013) and green gram (Mobarak *et al*., 2019). Even, there are few reports on carbon sequestration efficiencies (CSE) of different crops for climate smart agriculture (CSA) to mitigate the climate change (Albrecht and Kandji, 2003; Wang *et al*., 2016; Chhetri *et al*., 2017; Aryal *et al*., 2018; Anuga *et al*., 2019; Subedi *et al*., 2019). But, till date none of the studies has been performed with *S. obliqua* on sesame and green gram in a comparative manner by using population dynamics and nutritional ecology based ETs determination for their any sustainable management. Thus, my objectives of the present study were to (i) determine the host preference based on nutritional ecology and population dynamics of *S. obliqua* for ETs calculation, (ii) understand the pest density from the field and economic attributes beyond the field along with their population growth parameters on the selected crops to find the appropriate ETs of *S. obliqua* for time series calculation to apply any suitable control measures within the time limit (iii) and also determine the Carbon Sequestration Efficiency (CSE) of the selected crops to mitigate the climate change by climate smart pest management (CSPM) of *S. obliqua*as a part of CSA.

MATERIALS AND METHODS

Host plants: Two economic crops i.e., sesame (*S. indicum*; Pedaliaceae; cv. Rama) (Chongdar *et al*., 2015) and green gram (*V. radiata*; Fabaceae; cv. KB-54) (Roy and Barik, 2010) were cultivated and collected from a selected field situated near Chinsurah Rice Research Center (CRRC), Chinsurah, 22°53' N, 88°23' E, 13m above sea level, Hooghly, West Bengal, India, during summer season (February to June) in 2019. The plants were also identified and voucher specimens (Voucher No. ERU 23-24) were kept in Department of Zoology, Ecology Research Unit, M.U.C. Women's College, Burdwan, West Bengal, India. The selected crops (sesame and green gram) were separately germinated on moistened filter papers and each crop was grown in three side by side plots [plot size 10 m× 10 m; gap 0.5 m between two plots; soil organic matter 5.3 ± 0.2%, pH 7.7, photoperiod 13 L: 11 D at 30–35°C].All the plots were maintained without any insecticide for natural infestation of *S. obliqua* (Fig. 1 A & B). Intact mature leaves of 4-5 week old plants were collected separately from the respective crops for phytochemical analysis as well as for food of *S. obliqua* neonates for their population study.

Phytochemical analysis: The intact mature leaves of the crops were initially rinsed with distilled water and dried by paper towelling separately for phytochemical analysis. They were extracted in different solvents for extraction of different primary and secondary metabolites. The phytochemicals such as total carbohydrates, proteins, lipids, amino acids, phenols, flavonoids, tannins, saponin, alkaloid, phytate, oxalate, nitrogen and moisture content were estimated by various standard biochemical analysis protocols (Harborne, 1973; 1994) as in Roy (2015a; 2015b; 2017; 2019). Total alkanes, free fatty acids as well as free and bound amino acid content were also determined as in Roy (2018; 2019). Determination of each biochemical analysis was repeated for three times during 2019 and was expressed in dry or fresh weight basis accordingly.

Insect mass culture: The initial populations of *S obliqua* larvae were collected from each crop (sesame and green gram) separately from the cultivated fields in 2019. The larvae were incubated separately in the laboratory condition at 26±1°C, 60±5% RH and a photoperiodism of 12:12 (L:D) on intact mature leaves of the selected crops in glass jars (20 cm dia. × 30 cm ht.) until their pupation. After emergence of adults from the reared pupae six pairs of newly emerged male and female were placed in a glass jar (20 cm dia. × 30 cm ht.) containing the same mature leaves of each crop for their oviposition in an oviposition cage of fine nylon net (25×25×25 cm) containing a small cotton ball soaked with 10% honey solution for adults' feeding to obtain same aged eggs of *S obliqua* as described previously (Roy and Barik, 2013; 2014; Roy 2015a; 2015b; 2017). On each crop cultivar, newly laid eggs by the F_3 females were collected in order to obtain the same aged eggs of defined cohort (n=100) on each crop cultivar for stock culture of *S obliqua* up to three generations. The population data (developmental duration and survival) throughout their life cycle were recorded separately by using fourth generation (F_4) data (cohort size: n=100) on the selected crop cultivars with three replications in 2019 at same conditions [ten eggs in a glass jar (20 cm dia. × 30 cm ht.)] in a growth chamber as described previously (Chi and Su, 2006; Roy 2015a; 2015b; 2017; 2019).

Feeding dynamics: Feeding ecology was conducted by taking the F_4 newly emerged larvae that had been reared in the same laboratory condition on the selected crop cultivars separately as in previous experiments (Roy 2015a; 2015b; 2017; 2019). Larvae were weighed initially and were placed in a glass jar (20 cm dia. × 30 cm ht.) containing leaves of a particular crop cultivar. The larvae were allowed to feed on the pre-weighed leaves from each cultivar for 24 h interval, and remaining leaves after 24 h of feeding were reweighed. Sample leaves from each crop cultivar initially and after 24 h were weighed, oven dried and reweighed to determine dry weight conversion factor (DWCF) for estimation of diet dry weight supplied to the larvae. Similarly leaf dry weight conversion factor (LDWCF) for the different instars and their faeces were also determined for estimation of the dry weight gain of the larvae after feeding. Food utilization indices were calculated by the formulae of Waldbauer (1968) with essential modifications as described elsewhere (Roy and Barik, 2013; Roy, 2015a, 2015b; 2017). All the feeding indices like, growth rate (GR), consumption rate (CR), relative growth rate (RGR), consumption index (CI), egestion rate (ER), host consumption rate (HCR), approximate digestibility (AD%), efficiency of conversion of ingested food (ECI%), efficiency of conversion of digested food (ECD%) and host utilization efficiency (HUE%) including feeding index (FI), growth index (GI) and pest susceptibility index (PSI) were estimated as in Roy (2015a; 2015b; 2017).

Life table study: The data on survival, developmental duration and oviposition of all individuals on the selected crops (sesame and green gram) cultivar were analysed separately based on age-stage and two-sex life table theory (Chi and Su, 2006; Chen *et al*., 2017; Roy, 2019). With the formulae of Southwood (1978), Carey (1993), Krebs (1994), Price (1998) and Kakde *et al*. (2014) to arrive the 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 total individuals at age x and beyond k (T_x), 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 (1993). 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), Hypothetical females in 2nd generation (HFF_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 (Southwood, 1978; Carey, 1993; Roy, 2019).

Field experiment: A field experiment was conducted in 2019 by growing selected crops (sesame and green gram) cultivar in randomized block design (RBD) to determine the economic threshold (ET) of BHCs of *S obliqua* as described by earlier workers with few modifications (Parui and Roy 2016, Roy, 2019). The experiment was carried out in 10 katha or 670 m^2 near CRRC, Chinsurah, 22°53' N, 88°23' E, 13m above sea level, West Bengal, India, with three replications for both control and treated plots (10 m× 10 m) as described above with average plant density of 30±2 plants/m^2 (Parui and Roy, 2016). The data from the selected crops were collected for determination of ETs of *S obliqua* for the crops. The yield potential of the selected crops was observed over a traditional synthetic pesticide, Triazophos 40 EC (@ 40g a.i/ha) along with control (without pesticide) side-by-side (Parui and Roy, 2016; Mohapatra and Gupta, 2018).

Yield loss and ET calculation: From seed sowing to harvest of the selected crops (sesame and green gram) cultivar, the occurrences of BHC(s) of *S obliqua* were recorded by random quadrat sampling (RQS) from each treated and control plots (Parui and Roy, 2016). Calculation of economic injury level (EIL) for *S. obliqua* according to the methodology proposed by Pedigo *et al*. (1986) expressed as numbers or injury equivalents and governed by four primary variables viz. cost of the management tactic per production unit (*C*), market value per production unit (V), D' = percent yield loss per pest and the proportional reduction in pest attack (*K*). If the relationship of these variables is linear or roughly so, the EIL can be given as EIL = C/VD'K (Pedigo *et al*., 1986; Pedigo and Buntin, 1994). The economic threshold (ET) is the population density at which control action should be determined (initiated) to prevent an increasing pest population (injury) from reaching the EIL (Pedigo and Higley,1992). The cost of control (C) includes cost of the insecticide plus application, although others could be added (Higley and Wintersteen 1992; Pedigo and Higley 1992). On the basis of BHC infestation and the efficacy of the traditional synthetic pesticide were determined in terms of yield damage reduction (%), proportion of insect controlled (%) and per cent yield loss per pest per plant (%) along with the management costs (CC) for the calculation of EIL, ET, time to reach the EIL and ET when a plant was infested by a single pest in the field (Roy, 2019). The management cost was calculated using the cost of the insecticide, Triazophos 40 EC (Mohapatra and Gupta, 2018). A time series was also calculated up to reach the ETL from population growth data. The benefit cost ratio (BCR) was also determined (Chongdar *et al*., 2015) to find the seed production efficiency as well as resistance of the selected crop (sesame and green gram) cultivars over BHC (s) of *S obliqua* as the sole pest infestation.

Determination of Carbon sequestration: The transfer of carbon (C) by sequestering carbon dioxide (CO_2) in the green biomass and its sink into the soils organic carbon (SOC) is one of the most important strategies to address the carbon sequestration efficiency (CSE) of any plant to mitigate climate change by reduced GHG emission (Anuga *et al*., 2019; Wang *et al*., 2016). To calculate the amount CO_2 sequestered by an annual crop (i.e., sesame) includes determination of total green weight, dry weight, C content and CO_2 sequestered by the crop plant as in standard IPCC protocol (Albrecht and Kandji, 2003; Wang *et al*., 2016). Determination of total green weight was based on the algorithm to calculate the weight (g) of average 30±2 plant (Plant density=30±2 plant/m^2) for both above and below-ground biomass of the crop plant. A dry weight conversion factor (DWCF) for the crop plant was determined by using their moisture content (%) to determine the dry weight (DW) in g/plant. The weight of C (CW) was determined through multiplying the DW of the crop plant (g/plant) by the average C content (46%) of the plant. The CO_2 sequestered was determined through multiply the CW in the crop plant by 3.67 (Ratio of CO_2 to C) (Albrecht and Kandji, 2003; Lal, 2008, 2011).

Statistical Analysis: Experimental data of different phytoconstituents of the selected crop (sesame and green gram) cultivars and the pest (*S. obliqua*) population parameters along with their feeding indices were subjected to one-way Analysis of Variance (ANOVA) and correlation analysis (Zar, 1999). The field experiment (RBD) data of the selected crops and the RQS data from the field with ETL values of the pest were also analysed by using one-way ANOVA (Zar, 1999). Means of different phytoconstituents of the selected crops, demographic parameters and different feeding indices of the pest along with ET related values were compared by Tukey's test (HSD) when significant values were obtained (Roy, 2017). All the statistical analysis was performed by using SPSS, version 16.0 (Roy 2017, 2019).

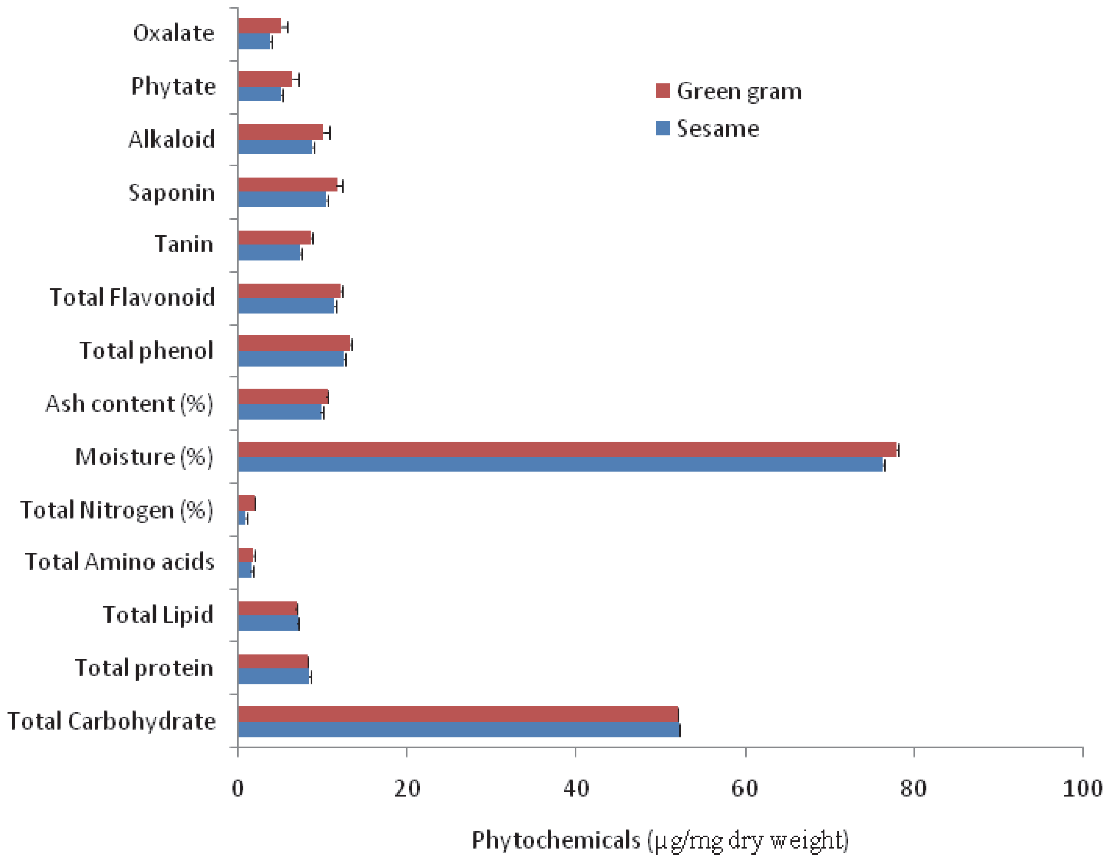
RESULTS

Host Phytochemicals: The biochemical constituents of the selected crop cultivars (sesame and green gram) are presented in fig. 1(A,B). The primary metabolites i.e., carbohydrates, proteins, lipids and amino acids (total, free and bound) including nitrogen, moisture content, alkanes and fatty acids varied significantly ($P < 0.05$) in the selected crop cultivars (sesame>green gram). Total carbohydrate, protein and lipid contents were 52.157±0.514, 8.357±0.334, 6.957±0.214 and 51.941±0.465, 8.141±0.246, 6.767±0.302 µg/mg dry weight, respectively, in the selected host cultivars (sesame>green gram). The secondary metabolites were almost reverse in the crops (sesame<green gram) cultivar with significant ($P < 0.05$) differences (Fig. 1A). Total phenol, flavonoid, tanin and phytate contents were12.387±0.654, 11.347±0.463, 7.227±0.343, 5.027±0.231 and 13.126±0.543, 12.086±0.542, 8.499±0.434, 6.299±0.354 µg/mg dry weight, respectively, in the selected crops (sesame<green gram) cultivar. Ultimately, the ratio of primary to secondary metabolites significantly ($P < 0.05$) varied in the selected crops cultivar.

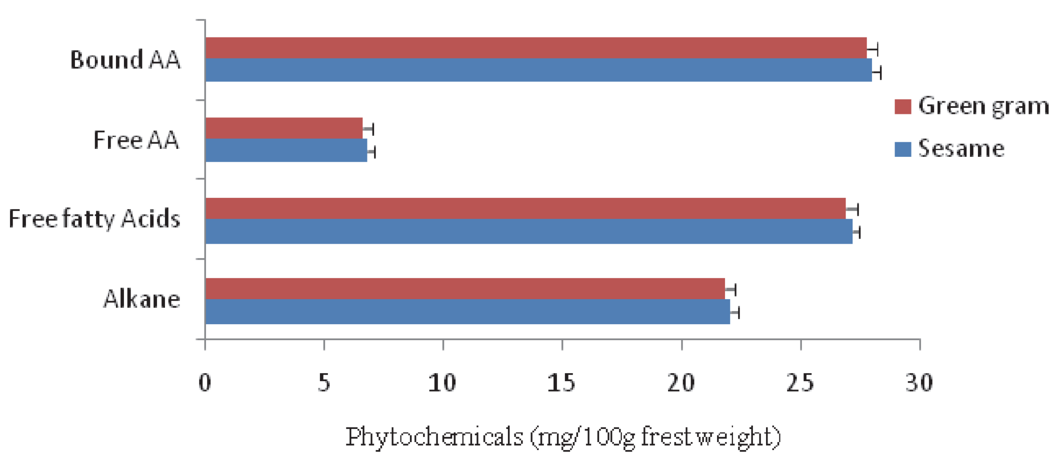
Feeding ecology: The food utilization indices were calculated only for the caterpillars of *S obliqua* as they only feed the plants and ultimately lead to the variation in their life history and other population parameters. The food utilisation efficiency of *S. obliqua* larvae significantly (P<0.05) varied on the selected crops cultivar. The average GR and CR were 7.148±4.722, 39.944±13.267 and 6.730±4.402, 33.484±11.429 mg/day, respectively, for the crops (sesame> green gram) cultivar which varied significantly ($F_{5,17}$≤72013.881; P<0.001). Whereas, the average AD and HUE were 72.355±6.639, 79.393±4.061 and 69.318±7.057, 77.627±4.117%, respectively, for the crops (sesame> green gram) (Table 1) which also varied significantly ($F_{5,17}$≤17049.041; P<0.001). Even, average GI and PSI (%) were 4.041±0.043, 62.838±2.904 and 3.405±0.073, 58.774±1.904%, respectively, for the crops (sesame> green gram) which varied significantly ($F_{1,4}$≤8.239; P<0.05) whereas FI on the selected host plants also varied similarly as GI. Thus, the feeding indices along with host susceptibility (PSI%) of *S. obliqua* represent biotic resistance to green gram relative compared to the sesame cultivar which might due to their respective phytoconstituents (Table 1).

Population dynamics: The stage-specific two-sex pooled life tables of *S. obliqua* were assessed in the laboratory with three replications on mature leaves of sesame and green gram during 2019.The pest exhibited four distinct stages (i.e., egg, larva, pupa and adult) with six larval instars on the selected crops.The demographic data of the cohorts (3×2=6; n=100 eggs) of *S. obliqua* represent similar pattern of development with significant variations (P<0.001) in different developmental stages on the crops (Table 2-5). The population parameters like, l_x, L_x, T_x and e_x of *S. obliqua* were higher throughout their developmental stages with significant ($F_{7,6}$ ≤170.784; P < 0.001) variations on sesame than green gram and they always produce type-III survivorship curve like most of the insects. However, the d_x, q_x and k_x varied in different developmental stages with significant (P < 0.001) variations and comparatively higher in egg and pupal stage with a rapid surge during adult stage on green gram than sesame. ANOVA results of the life table parameters on the selected crop cultivars revealed more or less same pattern on the host plants with significant variations ($F_{7,16}$=170.784-3876.337; P<0.0001) (Table 4).

The average Pf were 288.667±9.528 and 256.583 ± 8.513 eggs/female/generation, respectively for sesame and green gram. The Pf, GRR or m_x and NRR or R_0 of *S obliqua* were showed no significant variations. Whereas, average DT were 8.137±0.228 and 16.033±2.334, respectively (Table 5) for the crops (sesame< green gram) cultivar with significant variations ($F_{1,4}$=9.917; P=0.032). The r_m and ë were 0.085±0.002, 1.089±0.003 and 0.070±0.006,1.073±0.006, respectively (Table 5) for the crop cultivars (sesame>green gram) with significant variations ($F_{1,4}$=9.226-9.296; P=0.038). The average GM, GS, PGR, PMF, CBR, VI and TI of *S obliqua* were also without significant variations ($F_{1,4}$=0.071-0.99; P>0.05) like remaining other parameters (Table 5) on the selected crop.



(A)



(B)

Fig. 1 Phytochemical constituents of sesame (*S. indicum*; cv. Rama) and green gram (*V. radiata*; cv. KB-54). All the estimated chemicals (Mean ± SE of 3 observations) significantly differed at P< 0.05 by Tukey (HSD) test

Table 1. Growth parameters (Mean ± SE of 3 observations) of *S. obliqua* Walkar on sesame (*S. indicum*; cv. Rama) and green gram (*V. radiata*; cv. KB-54)

Parameter	Sesame	Green gram	$F_{5,17}$	Sig.
GR (mg/day)	7.148±4.722	6.730±4.402	72013.881	0.001
CR (mg/day)	39.944±13.267	33.484±11.429	85728.873	0.001
RGR (mg/day)	2.973±0.817	3.405±0.914	16220.850	0.001
CI (mg/day)	55.768±25.144	55.570±25.426	11854.754	0.001
AD (%)	72.355±6.639	69.318±7.057	17049.041	0.001
ECI (%)	10.711±5.163	12.143±5.681	10711.912	0.001
ECD (%)	16.644±7.829	20.074±9.239	40273.263	0.001
HUE (%)	79.393±4.061	77.627±4.117	17458.856	0.001
ER (mg/day)	15.254±8.666	17.458±10.065	56607.732	0.001
HCR (mg/day)	71.022±32.835	73.028±34.609	20122.187	0.001
Parameter	Sesame	Green gram	$F_{1,4}$	Sig.
FI	0.010±0.000	0.011±0.000	10.276	0.033
GI	4.041±0.043	3.405±0.073	13.857	0.020
PSI%	62.838±2.904	58.774±1.904	8.239	0.031

Within the rows means followed by same letter(s) are not significantly different at P<0.05 by Tukey (HSD) test along with *F* values (ANOVA).

Table 2. Stage-specific pooled life table (Mean ± SE of 3 observations) for 3 cohorts (n=100) of *S. obliqua* Walker on sesame (*S. indicum*; cv. Rama)

Stage	l_x	d_x	q_x	s_x	L_x	T_x	k_x	e_x
Egg-0	1.000±0.000	0.125±0.004	0.125±0.004	0.875±0.004	0.938±0.002	6.955±0.101	0.058±0.002	6.955±0.101
Inst- I -1	0.875±0.004	0.038±0.001[a]	0.044±0.002[a]	0.956±0.002[a]	0.856±0.005	6.018±0.099	0.019±0.001[a]	6.877±0.080
Inst- II-2	0.837±0.005	0.038±0.001[a]	0.046±0.002[a]	0.954±0.002[a]	0.818±0.006	5.162±0.094	0.020±0.001[a]	6.167±0.073
Inst- III-3	0.799±0.007	0.049±0.002	0.061±0.003[b]	0.939±0.003[b]	0.774±0.007	4.344±0.088	0.027±0.001[b]	5.438±0.065
Inst- IV-4	0.750±0.008	0.052±0.002	0.070±0.003	0.930±0.003	0.724±0.009	3.570±0.080	0.031±0.001	4.758±0.055
Inst- V-5	0.698±0.010	0.042±0.001	0.060±0.003[b]	0.940±0.003[b]	0.677±0.011	2.846±0.071	0.027±0.001[b]	4.076±0.044
Inst- VI-6	0.656±0.011	0.066±0.002	0.101±0.005	0.899±0.005	0.623±0.012	2.169±0.061	0.046±0.002	3.303±0.035
Prepup-7	0.590±0.014	0.014±0.000	0.024±0.001	0.976±0.001	0.583±0.014	1.545±0.048	0.010±0.001	2.617±0.022
Pup-8	0.576±0.014	0.076±0.003	0.133±0.008	0.867±0.008	0.538±0.015	0.962±0.034	0.062±0.004	1.668±0.019
Adult-9	0.500±0.017	0.153±0.005	0.307±0.020	0.693±0.020	0.424±0.019	0.424±0.019	0.160±0.013	0.847±0.010

Within the column means followed by same letter(s) are not significantly different at P<0.05 by Tukey (HSD) test

Thus, all the 25 selected population parameters of *S. obliqua* were showed more or less insignificant (*P*>0.05) variations with few deviations on the selected crops (sesame> green gram) cultivar (Table 5). Thus, host superiority or susceptibility (sesame> green gram) in respect to their phytoconstituents (Fig. 1A,B) also influence the notorious pest in their population growth and reproductive parameters.

Yield loss and Crop productivity parameters: Yield loss in sesame and green gram and ET for *S obliqua* were assessed in the field condition against a traditional synthetic pesticide (Triazophos 40 EC) over control (without any pesticide) during summer season (February to June) in 2019 (Table 6). The damage (D%) per pest (*S obliqua*) per plant were 5.392±0.443 and 4.619±0.028%, respectively on the cultivars(sesame>green gram) without significant

($F_{1,4}$=2.894; P=0.169) differences (Table 6). Average EIL and ET were 26.388±1.627, 24.230±2.412 and 29.907±1.917, 27.930±1.841 pest/30 plants, respectively for the selected crops (sesame< green gram) cultivar without any significant ($F_{1,4}$=2.794-3.335; P≤0.142) variation (Table 6). For a single pest/m^2 (30±2 plants/m^2) observation the possible time that can be taken to reach EIL (Ti) and ET (Tt) were arrived as 38.246±1.157, 37.246±1.157 and 50.132±2.746, 49.132±2.746 days, respectively on the selected crops (sesame< green gram) cultivar with significant ($F_{1,4}$=24.111; P=0.008) variation (Table 6). Even, ET based time series was also calculated to find the specific time (Tt days) to reach ET for any number of pest(s)on the selected crops The maximum tolerance levels of the pests were 22.200 and 25.800 insects per m^2 (30±2 plants/m^2), respectively on sesame and green gram (Table 7). The benefit cost ratio (BCR/ha) of sesame and green gram were 0.478 and 0.390, respectively with significant (P<0.05) deviation (Table 6).Thus, the yield loss and ET calculation also represent similar biotic resistance (sesame<green gram) and or susceptibility (sesame>green gram) of the host plants as in feeding as well as in population dynamics

Table 3. Stage-specific pooled life table (Mean ± SE of 3 observations) for 3 cohorts (n=100) of *S. obliqua* Walker on green gram (*V. radiata*; cv. KB-54)

Stage	l_x	d_x	q_x	s_x	L_x	T_x	k_x	e_x
Egg-0	1.000±0.000	0.151±0.003	0.151±0.003	0.849±0.003	0.924±0.001	6.349±0.073	0.072±0.001^a	6.349±0.073
Inst- I -1	0.849±0.003	0.046±0.001^a	0.055±0.001^a	0.945±0.001^a	0.826±0.003	5.424±0.072	0.025±0.001^b	6.347±0.056
Inst- II-2	0.803±0.004	0.046±0.001^a	0.059±0.001^a	0.941±0.001^a	0.780±0.004	4.598±0.068	0.027±0.001^b	5.673±0.050
Inst- III-3	0.756±0.005	0.059±0.001	0.081±0.002^b	0.919±0.002^b	0.727±0.005	3.819±0.064	0.037±0.001	4.981±0.044
Inst- IV-4	0.698±0.006	0.063±0.001	0.095±0.002	0.905±0.002	0.666±0.007	3.092±0.058	0.044±0.001^c	4.351±0.036
Inst- V-5	0.635±0.007	0.050±0.001	0.086±0.002^b	0.914±0.002^b	0.609±0.008	2.426±0.052	0.040±0.001^c	3.732±0.028
Inst- VI-6	0.584±0.008	0.080±0.002	0.154±0.003	0.846±0.003	0.544±0.009	1.816±0.044	0.075±0.002^a	3.016±0.022
Prepup-7	0.504±0.010	0.017±0.000	0.041±0.001	0.959±0.001	0.496±0.010	1.272±0.035	0.018±0.000	2.443±0.013
Pup-8	0.488±0.010	0.092±0.002	0.242±0.005	0.758±0.005	0.441±0.011	0.776±0.025	0.143±0.002	1.519±0.011
Adult-9	0.395±0.012	0.122±0.004	0.301±0.011	0.699±0.011	0.334±0.014	0.334±0.014	0.178±0.006	0.850±0.006

Within the column means followed by same letter(s) are not significantly different at P<0.05 by Tukey (HSD) test

Table 4. Stage-specific pooled life table for the six cohorts (n=100) of *S. obliqua* Walkar on sesame (*S. indicum*; cv. Rama) and green gram (*V. radiata*; cv. KB-54)

Developmental stages	Sesame	Green gram	*Sig.*
	$F_{7,16}$	$F_{7,16}$	
Egg-0	3540.022	3051.643	0.0001
Inst- I -1	3876.337	3326.806	0.0001
Inst- II-2	3411.683	2919.135	0.0001
Inst- III-3	2963.365	2527.338	0.0001
Inst- IV-4	2664.170	2266.508	0.0001
Inst- V-5	2456.039	2087.538	0.0001
Inst- VI-6	2067.495	1752.255	0.0001
Prepup-7	2102.920	1799.046	0.0001
Pup-8	1148.710	963.127	0.0001
Adult-9	221.232	170.784	0.0001

Table 5. Population dynamics and reproductive parameters (Mean ± SE of 3 observations) of *S. obliqua* Walker on sesame (*S. indicum*; cv. Rama) and green gram (*V. radiata*; cv. KB-54)

Population parameters	Sesame	Green gram	$F_{1,4}$	Sig.
Potential fecundity (Pf)	288.667±9.528	256.583±8.513	6.047	0.070
Total fertility rate (F_x)	11696.267±1482.325	9529.233±1276.552	6.085	0.069
Gross reproductive rate (GRR) m_x	80.193±5.349	71.924±5.947	5.715	0.075
Net reproductive rate (NRR) R_0	40.267±3.811	31.644±3.801	6.047	0.070
Generation time (T_c)	43.215±0.101	44.206±0.248	1.648	0.269
Doubling time (DT)	8.137±0.228	16.033±2.334	9.917	0.032
Intrinsic rate of increase (r_m)	0.085±0.002	0.070±0.006	9.226	0.038
Euler's corrected r (r_c)	0.037±0.003	0.059±0.009	3.858	0.121
Finite rate of increase (ë)	1.089±0.003	1.073±0.006	9.296	0.038
Weelkly multiplication rate (ë^{7})	1.817±0.030	1.655±0.058	9.685	0.036
Annual rate of increase (ARI) (ë^{365})	6.02E+13	7.91E+14±2.6E+14	2.415	0.195
Increase rate per generation (ë^{Tc})	40.267±3.811	31.644±3.801	6.047	0.070
Generation mortality (GM)	0.461±0.027	0.659±0.098	4.582	0.099
Mortality coefficient (MC)	0.139±0.010	0.109±0.012	5.686	0.076
Generation survival (GS)	0.571±0.016	0.456±0.029	5.593	0.077
Population growth rate (PGR) (r_mN)	8.633±1.046	6.727±0.884	7.072	0.056
Population momentum factor of increase (PMF)	14.695±0.637	16.327±1.239	6.086	0.069
Population size in 2nd generation (PMF_xN)	1491.388±203.564	1281.499±189.710	6.344	0.065
Hypothetical F_2 females (HNf_2)	1650.453±251.697	1470.311±241.114	5.915	0.072
Realised F2 females (RNf_2)	596.555±81.425	512.599±75.884	6.344	0.065
General fertility rate (GFR)	7.255±0.458	17.523±7.311	3.366	0.140
Crude birth rate (CBR)	1.433±0.025	1.626±0.052	5.368	0.081
Reproductive value (RV)	160.387±9.970	143.848±11.947	5.715	0.075
Vital Indwx (VI)	0.347±0.022	0.273±0.030	5.686	0.076
Trend index (TI)	52.504±4.485	41.415±4.874	5.980	0.071

Within the rows means followed by same letter(s) are not significantly different at P<0.05 by Tukey (HSD) test along with *F* values (ANOVA).

of *S. obliqua* due to variation in their respective phytoconstituents (Fig. 1A,B).The carbon sequestration efficiency of sesame (301.860kg/ha) was significantly (P<0.05) higher than green gram (172.260 kg/ha) due to more biomass production (Table 6). It will also support climate smart pest management (CSPM) strategy of the crops.

DISCUSSION

In the modern era of climate smart agriculture (CSA) as well as CSPM,use of irradiated sterile insects (male), genetically engineered pests (mutant male) and pest pheromones (lure for male) in mating disruption are most effective pest management strategy other than use of pest resistant crop cultivars to avoid or reduce the adverse effects of broad spectrum synthetic pesticides (Alphey, 2007; Witzgall *et al*., 2010; Heeb *et al*., 209; Kang, 2019), while population ecology based ETs determination and time series calculation is also a widely useful technique for ecological pest management (EPM) as a part of IPM (Southwood, 1978; Carey, 2001; Kakde *et al*., 2014; Chávez *et al*., 2018; Roy, 2019).

Pest ecology and host preference based studies are common to cope with the pest infestation in IPM or rather EPM for better crop production (Dicke, 2000; Schoonhoven *et al*., 2005; Roy and Barik, 2013; Roy, 2019). Host plant availability and quality in terms of their phytochemicals play a vital role in pest feeding preference as well as population dynamics by affecting immature and adult performance (Shobana *et al*., 2010; Roy and Barik, 2012). Variation in the results of this study could be attributed to differences among nutritional and anti-nutritional factors present in the respective crops (sesame and green gram) cultivar directly affect host preference and population parameters of *S. obliqua* as in other findings (Awmack and Leather, 2002; Syed and Abro, 2003; Xue *et al*., 2010; Roy and Barik, 2013; Dutta and Roy, 2016).The overall survival rate of *S. obliqua* on sesame leaves was higher than on green gram leaves and the result suggest type III survivourship curve like most other insect pests (Price, 1998; Roy, 2015b; Dutta and Roy, 2016). The GRR, R0, rm, Tc, DT and λ are fundamental ecological parameters to predict the pest population growth to evaluate the performance of an insect on different host plants as well as their resistance or susceptibility (Southwood and Henderson, 2000; Win *et al*., 2011; Roy, 2015b; Dutta and Roy, 2016; Roy, 207). In my current study, the variations in life table parameters of *S. Obliqua* is due to variation in primary and

Table 6. Yield loss and crop productivity parameters of sesame (*S. indicum*; cv. Rama) and green gram (*V. radiata*; cv. KB-54) due to *S. obliqua* infestation

Crop Parameter	Sesame	Green gram	$F_{1,4}$	Sig.
Yield damage without treatment (Yd %)	22.585±2.661	23.897±0.049	0.262	0.636
Proportion of insect controlled (PC %)	75.000±4.811	80.300±0.449	1.008	0.372
Yield damage reduction after treatment (Yr %)	17.193±3.104	19.279±0.022	0.461	0.535
Damage per pest per plant (D%)	5.392±0.443	4.619±0.028	2.814	0.169
EIL (pests/30 plants)	26.388±1.627	29.907±1.917	2.794	0.170
ETL (pests/30 plants)	24.230±2.412	27.930±1.841	3.335	0.142
EEIL(pests/30 plants)	26.415±2.630	29.938±1.919	2.794	0.170
Time to reach EIL/pests/30 plants (Ti days)	38.246±1.157	50.132±2.746	24.111	0.008
Time to reach ETL/pests/ 30 plants (Tt days)	37.246±1.157	49.132±2.746	24.111	0.008
Production values				
Seed Yield [SY] (kg/ha)	788.172	741.471	-	-
Production cost [C] (Rs/ha)	22400.000	22400.000	-	-
Economic yield [EY](Rs/ha)	33103.205	31141.767	-	-
Net Profit [NP] (Rs/ha)	10703.205	8741.767	-	-
Benefit cost ratio (BCR/ha)	0.478	0.390	-	-
Carbon sequestration efficiencies				
Plant density (number/m^2)	30±2	30±2	-	-
Biomass produced (kg dry wt/ m^2)	0.060	0.034	-	-
Carbon sequestration (kg/ m^2)	0.030	0.017	-	-
Equivalent CO2 sequestration (kg/ m^2)	0.111	0.063	-	-
Carbon sequestration (kg/ha)	301.860	172.260	-	-
Equivalent CO2 sequestration (kg/ ha)	1106.820	631.620	-	-
Equivalent CO2 sequestration (Tons/ ha)	13.423	7.660	-	-

Within the column means followed by same letter(s) are not significantly different at P<0.05 by Tukey (HSD) test along with *F* values (ANOVA).

Table 7. Time Series assessment of ET at varied pest density (*S. obliqua*) on sesame (*S. indicum*; cv. Rama) and green gram (*V. radiata*; cv. KB-54)

Pest(s)/m^2	Tt (days) for Sesame	Tt (days) for Green gram
0.025	80.653	99.613
0.05	72.523	89.775
0.1	64.393	79.938
0.2	56.264	70.100
0.3	51.508	64.345
0.4	48.134	60.262
0.5	45.517	57.095
0.6	43.378	54.508
0.7	41.570	52.320
0.8	40.004	50.425
0.9	38.623	48.753
1	37.387	47.258
....up to ETLe"1 day remain for manage the pest		
MTL (Pests/m^2)	22.200	25.800

MTL (Maximum tolerance level)

secondary metabolites of respective host plants which is also supported by host preference or resistance or vice versa.

Pest population ecology and their ETs for any appropriate pest management strategy is a part of IPM or EPM (Pedigo and Higley, 1992; Roy, 2019). The EIL and ET is generally calculated by linear regression model (y= ax+c) based on yield loss, degree of pest infestation, Pest population growth, cost of protection and market price of the crop (Pedigo and Higley, 1992). A low EIL and ET of *S. obliqua* was found in sesame than green gram due to high damage potential of the pest on their respective preferred host plantsas in other findings (Pedigo and Higley, 1992; Roy, 2019). Thus, this study suggests that sesame possessed relatively rich food quality for *S. obliqua* than green gram leading to higher level of leaf consumption and crop damage resulting in more susceptibility or less resistance indicating the chance of utilization of sesame as a trap crop for green gram. Even, ETs based time series for judicious application of any sustainable control measures against this pest under the arena of CSPM as well as carbon sequestration efficiency of the crops will reduce ecological imbalance to promote CSA of such crops in near future.

There is a worldwide growing awareness for promoting environmentally benign and ecosystem service (ESS) based CSPM practices for CSA. Even ecological engineering (EE) by tailoring ESS manipulation is crucial for better production of any crop. These approaches would bring down the pest load below ETL by judicial use of any control measures including broad-spectrum pesticides for sustainable agriculture. In respect to the phytochemical regime, sesame leaves had the lowest antibiosis resistance than green gram against *S. obliqua* as indicated by the short developmental time and high survival of their immature stages which will enable growers to use sesame as a trap crop for green gram along with their respective ETs for most appropriate control tactics towards CSPM. Even, it will also supportE^3 (Ecosystem service based Ecological engineering for Ecological pest management [ESS-EE-EPM]) pest management strategy with Triple-E (ecological, environmental and economical) sustainability for the generalist pest, *S obliqua*, to promote CSPM for better cultivation of such crops in near future.

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