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Population studies of three stored grain pests on two common legumes, the common pea and the Indian pea

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Abstract

Callosobruchus maculatus, *Sitophilus oryzae* and *Tribolium castaneum* are capable of infesting various food grains, including legumes. Population studies of these stored grain pests were conducted on the common pea and the Indian pea. The primary and secondary phytochemicals present in the selected host grains were profiled, and correlations between host metabolites and the growth of the pest populations were drawn. On both hosts, the immature period was longest in *T. castaneum*, followed by *C. maculatus* and *S. granarius*. In contrast, *S. granarius* greatly outlived the other two in terms of adult longevity. Based on the population parameters such as gross reproductive rate (GRR), net reproductive rate (NRR), and population size of the 2nd generation (PF₂), the intrinsic rate of increase (r_m), the finite rate of increase (λ) and population growth rate (PGR), the susceptibility of both hosts to the pests has been classified in the order of: *S. oryzae* > *C. maculatus* > *T. castaneum*. *S. granarius* and *C. maculatus* thrive better on common pea than Indian pea, and *T. castaneum* thrives better on Indian pea. Nevertheless, both common pea and Indian pea require more control measures against *S. granarius* than *C. maculatus* or *T. castaneum*. An understanding of the degree of susceptibility of the grains to the pests may help in modifying grain phytochemical profiles for a more sustainable management of the pests.

Keywords: Legumes, phytochemicals, stored grain pests, population parameters, sustainable management

Introduction

Legumes (Family: Fabaceae) are a major source of affordable dietary nutrition globally. They also augment soil nitrogen by nitrogen fixation, constituting an integral component of the farming systems. India is the leading producer and consumer of legumes, contributing about 25-28% of the total global production (Naveen *et al.*, 2022) ^[36]. Common pea (*Pisum sativum* L.) is among the second most important legume crops in the world. Pea seeds contain high levels of amino acids, proteins, minerals and vitamins (Kalapchieva *et al.*, 2020) ^[26]. Indian pea (*Lathyrus sativus* L.) is another crop of immense economic significance as food, feed and fodder in India and many other countries. However, it produces a neurotoxin [β -N-oxalyl-L- α , β -diaminopropionic acid (ODAP)], prolonged consumption of which may lead to the neurological disorder lathyrism in humans and domestic animals (Dixit *et al.*, 2016) ^[18]. Despite the greater production of pulses, the production needs to be increased to attain the goal of self-sufficiency in India (Soumia *et al.*, 2015) ^[57]. Moreover, post-harvest losses result in a 10% decline in the stored crops, out of which 26% can be attributed to insect pests (Kalpna *et al.*, 2022) ^[27]. The cowpea weevil, *Callosobruchus maculatus* (Fabricius), is regarded as the most important and cosmopolitan storage pest of several species of pulse grains, such as cowpea, chickpea, garden pea and lentils (Osman *et al.*, 2015) ^[38]. The rice weevil, *Sitophilus oryzae* L. (Coleoptera: Curculionidae), is a major primary pest of stored rice worldwide. They are capable of infesting corn, wheat, barley, sorghum, oats, rye and dried beans (Zahir *et al.*, 2012) ^[61]. The red flour beetle, *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae), is a prevalent polyphagous secondary pest of stored grains with a worldwide distribution. This species has been recorded on 246 commodities, showing a preference for flours and amylaceous by-products (Duarte *et al.*, 2021) ^[19]. Insect feeding leads to extensive losses in the quality and quantity of nutritional and aesthetic values of products, weight losses, deterioration of seed viability and secondary infestations (Malaikozhundan and Vinodhini, 2018) ^[31].

Insect survival is influenced by the primary and secondary phytochemicals of hosts (Demissie *et al.*, 2015) [16]. The primary metabolites affect the growth and reproduction of herbivorous pests, while the secondary metabolites serve defensive roles against them (Chowdhury *et al.*, 2025) [13]. Stored grains provide shelter, security and abundant food to the pests. Grain transportation and marketing networks then pave the way for the local and global dispersal of these species (Nopsa *et al.*, 2015) [37]. However, farmers use broad-spectrum synthetic pesticides and biorational treatments to manage pest species, without considering the growth rates of pest populations (Carvalho, 2017) [10]. This leads to regulatory complications in the ecosystem (Kang, 2019) [28]. Therefore, it is necessary to identify how the characteristics of the host legumes are linked with their susceptibility (Murad and Batool, 2017) [34]. This is an important aspect of integrated pest management (IPM) that can reduce or eliminate the need for harmful insecticides (Quellhorst *et al.*, 2021) [41]. Thus, the objective of this research was to study and compare the biological characteristics of *C. maculatus*, *S. granarius* and *T. castaneum* when fed on common pea and Indian pea, under the same environmental conditions, and to assess the susceptibility of the pulses to the selected insect pests.

Material and Methods

Collection of the legumes and maintenance of insect cultures

Uninfested seeds of common pea (CV- Arka Priya) and Indian pea (CV- BioL-212 (Ratan)) and seeds infested with *C. maculatus*, *S. oryzae* and *T. castaneum* were collected from the FCI godown, Chinsurah, Hooghly (22°54' N, 88°23' E), different commercial stores of Purba Bardhaman (23°13' N, 87°51' E) and from farmers of Indas, Bankura (23.1504° N, 87.6318° E), West Bengal, India. We selected the uninfested seeds after separating the damaged seeds by physical inspection. Then we washed the seeds properly with distilled water, followed by heat drying (45°C) for 30 mins and UV-treatment (254 nm) for 20 mins. After the treatments, they were refrigerated (0°C) in airtight containers for further studies. To ensure disinfestation, a control set (with 100 seeds of each legume in separate containers) was also observed during the course of the population studies. The uninfested seeds of the selected legume cultivars, with a moisture content of 8-10%, were divided into two parts. One part of each legume cultivar served as host for each pest on which the population studies were conducted, and the other part was prepared for various phytochemical analyses. The stock cultures of the pests were initiated with adults (F₁) from the infested seeds in a growth chamber [30 eggs and 100 seeds in a glass jar (20 cm diameter × 30 cm height)]. The cultures were maintained from F₁ to F₄ generations separately on the selected legumes, and the F₄ generation was used for population studies with three replicates. All the culture sets were maintained under laboratory conditions (27 ± 1°C, 65 ± 5% RH, 12:12 [L: D] photoperiod and 1500 lux light intensity).

Phytochemical estimation of the legumes

Freshly collected uninfested seeds of common pea and Indian pea were initially rinsed with distilled water and dried with a paper towel. They were then dipped in different solvents for the extraction of various primary and secondary metabolites. The concentrations of each metabolite were

estimated by using standard procedures: carbohydrates (DuBois *et al.*, 1956) [20], total proteins (Miller, 1959) [32], lipids (Folch *et al.*, 1957) [22], amino acids (Moore and Stein, 1948) [33], nitrogen (Humphries, 1956) [24], moisture (Roy and Barik, 2013) [44], ash (Banerjee and Haque, 1984) [5], phenols (Bray and Thorpe, 1954) [7], flavonoids (Zhishen *et al.*, 1999) [64], tannin (Trease and Evans, 1983) [59], saponin (Trease and Evans, 1983) [59], alkaloids (Harborne, 1973) [23], phytates (Reddy and Love, 1999) [43] and oxalates (Day and Underwood, 1986). Total alkanes (Roy *et al.*, 2013b) [46], free fatty acids (Roy *et al.*, 2012) [47], and free and bound amino acids (Roy *et al.*, 2013a) [45] were also quantified. All the phytochemicals have been estimated using various protocols, as in Roy and Barik (2013) [44]. Each test was repeated three times and expressed on a dry or fresh weight basis (Roy, 2022; Chowdhury *et al.*, 2025) [50, 13].

Population growth of the insect pests

Ten pairs of freshly emerged males and females from the stock culture (F₃) were placed in an oviposition cage of fine nylon net [(25 × 25 × 25) cm³]. The pests were allowed to oviposit separately on each of the selected legumes. Newly laid eggs (n=30) from F₃ females, belonging to a defined cohort, were collected for the population studies. Therefore, the population studies began with the eggs of 3rd generation (F₃) females, i.e., the F₄ generation. Damaged seeds in the oviposition cage were replaced periodically with fresh ones. The larvae were placed in five glass jars [20 cm diameter × 30 cm height] containing the different seeds, and all the larval instars (I-V) were monitored. The mouths of the containers were covered with cotton cloths. Fresh seeds were again provided periodically. The pupae were then placed in separate glass jars [6 cm diameter × 10 cm height], covered with cotton cloth, until adult emergence. The males and females were differentiated based on their distinctive physical features. Adult females are larger than the adult males, and males have a more slender abdomen than females. Three replicates were maintained on each legume, and the experiments were repeated accordingly. Survival, mortality, fecundity and developmental durations from egg to adult were recorded separately on both hosts.

The data on survival, oviposition and developmental durations of all individuals on the selected legumes were subjected to stage-specific, two-sex life tables analyses (Chen *et al.*, 2017; Jaleel *et al.*, 2018) [11, 25]. The parameters included probability of survival from birth to age x (l_x), proportion dying at each stage (d_x), mortality (q_x), survival rate (s_x) per day per age class from egg to adult stages (Carey, 1993) [9]. Using these parameters the following statistics like total individuals at age x and beyond k (T_x), average population alive at each stage (L_x), life expectancy (e_x), exponential mortality or killing power (k_x), generation mortality (GM), generation survival (GS), gross reproductive rate (GRR), net reproductive rate (NRR or R₀), mean generation time (T_c), doubling time (DT), intrinsic rate of population increase (r_m), finite rate of population increase (λ), weekly multiplication rate (λ⁷), increase rate per generation (λ^{T_c}), which were computed by Carey's formulae (Price 1997) [40]. Some other demographic parameters like potential fecundity (P_f), total fertility rate (TFR), mortality coefficient (MC), population growth rate (PGR), effective population (N_e), population momentum factor of increase (PMF), number of individuals after time t (N_t), expected

population size in 2nd generation (PF_2), Hypothetical females in 2nd generation (HFF_2), general fertility rate (GFR), crude birth rate (CBR), reproductive value (RV), vital index (VI) and trend index (TI) were also analysed using various well-defined formulae (Southwood, 1978; Carey, 2001; Chowdhury *et al.*, 2025) [58, 8, 13].

Statistical analysis

Correlation analysis has also been performed to demonstrate how variation in metabolites influences insect population growth (Zar, 1999) [62]. Experimental data on metabolites in the green gram cultivar and population parameters of the pests were homogeneous among treatments, as confirmed by Levene's homogeneity test. The data were normally distributed, as determined by Shapiro-Wilk tests, and were compared using one-way ANOVA (Zar, 1999) [62]. Means associated with all the data were separated using Tukey's (HSD) test when the values were significant (Zar, 1999) [62]. Statistical analyses have been performed using SPSS version 16.0.

Result

Host phytochemicals

The primary and secondary metabolites varied significantly

($F \geq 15.575$, $P < 0.004$) among the legumes (Fig 1(a) and Fig 1(b), Supplementary Table 1). Common pea contained higher levels of the primary and secondary metabolites than the Indian pea. The major primary metabolites ($\mu\text{g}/\text{mg}$ dwt), total carbohydrates, proteins and lipids in common pea were 57.589 ± 1.185 , 13.789 ± 1.105 and 12.389 ± 1.135 , respectively, and in Indian pea they were 50.310 ± 0.788 , 6.510 ± 0.708 and 5.110 ± 0.738 , respectively. Total amino acids and nitrogen (%) followed a similar order, with their higher concentrations in common pea than in Indian pea (Fig 1(a), Supplementary Table 1). The content of free amino acids was lower than that of alkanes, free fatty acids and bound amino acids in both the legumes, and they followed the same pattern as the major primary metabolites: common pea > Indian pea (Fig 1(b), Supplementary Table 1). The concentrations of phenols, saponins and alkaloids ($\mu\text{g}/\text{mg}$ dry weight) were also in the order of common pea (20.689 ± 0.993 , 19.829 ± 1.013 and 18.896 ± 0.655) > Indian pea (13.867 ± 0.667 , 12.673 ± 1.018 and 11.073 ± 1.068). All the other secondary metabolites followed the same pattern (Fig 1(a), Supplementary Table 1). Ultimately, the ratio of primary to secondary metabolites differed significantly in the selected legumes.

Table 1: Population parameters of *C. maculatus*, *S. granarius* and *T. castaneum* on common pea. Different alphabets within the rows indicate the means (Mean $\pm$ SE of 3 observations) are significantly different ($P < 0.05$, Tukey's HSD) while comparing one type of host grain with the others.

Stages	<i>Callosobruchus maculatus</i>	<i>Sitophilus granarius</i>	<i>Tribolium castaneum</i>	$F_{2,6}$	P
I_x					
Egg	1.000 $\pm$ 0.000 ^a	1.000 $\pm$ 0.000 ^a	1.000 $\pm$ 0.000 ^a	0.000	1.000
Instar-I	0.764 $\pm$ 0.008 ^a	0.691 $\pm$ 0.017 ^b	0.871 $\pm$ 0.010 ^c	53.656	0.000
Instar-II	0.607 $\pm$ 0.014 ^a	0.525 $\pm$ 0.014 ^b	0.793 $\pm$ 0.010 ^c	113.996	0.000
Instar-III	0.529 $\pm$ 0.017 ^a	0.425 $\pm$ 0.013 ^b	0.715 $\pm$ 0.010 ^c	116.971	0.000
Instar-IV	0.490 $\pm$ 0.018 ^a	0.358 $\pm$ 0.013 ^b	0.637 $\pm$ 0.010 ^c	98.389	0.000
Instar-V	-	-	0.559 $\pm$ 0.010	-	-
Instar-VI	-	-	0.507 $\pm$ 0.010	-	-
Prepupa	0.411 $\pm$ 0.021 ^a	0.292 $\pm$ 0.012 ^b	0.455 $\pm$ 0.010 ^c	30.605	0.001
Pupa	0.372 $\pm$ 0.023 ^a	0.192 $\pm$ 0.013 ^b	0.351 $\pm$ 0.010 ^c	37.785	0.000
Adult	0.293 $\pm$ 0.025 ^a	0.125 $\pm$ 0.013 ^b	0.221 $\pm$ 0.010 ^c	23.163	0.002
q_x					
Egg	0.236 $\pm$ 0.008 ^a	0.309 $\pm$ 0.017 ^b	0.107 $\pm$ 0.001 ^c	87.140	0.000
Instar-I	0.206 $\pm$ 0.010 ^a	0.241 $\pm$ 0.005 ^b	0.090 $\pm$ 0.001 ^c	152.610	<0.001
Instar-II	0.130 $\pm$ 0.008 ^a	0.191 $\pm$ 0.006 ^b	0.098 $\pm$ 0.001 ^c	72.279	0.000
Instar-III	0.075 $\pm$ 0.005 ^a	0.157 $\pm$ 0.006 ^b	0.109 $\pm$ 0.001 ^c	85.889	0.000
Instar-IV	0.161 $\pm$ 0.012 ^a	0.186 $\pm$ 0.008 ^b	0.122 $\pm$ 0.002 ^c	15.087	0.005
Instar-V	-	-	0.093 $\pm$ 0.002	-	-
Instar-VI	-	-	0.103 $\pm$ 0.002	-	-
Prepupa	0.096 $\pm$ 0.008 ^a	0.344 $\pm$ 0.018 ^b	0.229 $\pm$ 0.005 ^c	109.606	0.000
Pupa	1.000 $\pm$ 0.000 ^a	1.000 $\pm$ 0.000 ^a	0.370 $\pm$ 0.010 ^b	3736.793	<0.001
Adult	1.000 $\pm$ 0.000 ^a	1.000 $\pm$ 0.000 ^a	0.884 $\pm$ 0.039 ^b	8.806	0.016
L_x					
Egg	0.882 $\pm$ 0.004 ^a	0.846 $\pm$ 0.008 ^b	0.923 $\pm$ 0.010 ^c	23.987	0.001
Instar-I	0.686 $\pm$ 0.011 ^a	0.608 $\pm$ 0.015 ^b	0.832 $\pm$ 0.010 ^c	83.821	0.000
Instar-II	0.568 $\pm$ 0.016 ^a	0.475 $\pm$ 0.014 ^b	0.754 $\pm$ 0.010 ^c	116.244	0.000
Instar-III	0.509 $\pm$ 0.018 ^a	0.391 $\pm$ 0.013 ^b	0.676 $\pm$ 0.010 ^c	107.111	0.000
Instar-IV	0.450 $\pm$ 0.020 ^a	0.325 $\pm$ 0.012 ^b	0.598 $\pm$ 0.010 ^c	86.998	0.000
Instar-V	-	-	0.533 $\pm$ 0.010	-	-
Instar-VI	-	-	0.481 $\pm$ 0.010	-	-
Prepupa	0.391 $\pm$ 0.022 ^a	0.242 $\pm$ 0.013 ^b	0.403 $\pm$ 0.010 ^c	33.145	0.001
Pupa	0.186 $\pm$ 0.011 ^a	0.096 $\pm$ 0.006 ^b	0.286 $\pm$ 0.010 ^c	102.977	0.000
Adult	0.147 $\pm$ 0.013 ^a	0.062 $\pm$ 0.007 ^b	0.124 $\pm$ 0.010 ^c	18.803	<0.001
T_x					
Egg	3.487 $\pm$ 0.091 ^a	2.886 $\pm$ 0.072 ^b	5.608 $\pm$ 0.097 ^c	267.830	<0.001
Instar-I	2.791 $\pm$ 0.098 ^a	2.137 $\pm$ 0.070 ^b	4.686 $\pm$ 0.088 ^c	237.300	<0.001
Instar-II	2.105 $\pm$ 0.086 ^a	1.529 $\pm$ 0.056 ^b	3.854 $\pm$ 0.078 ^c	263.244	<0.001

Instar-III	1.537±0.071 ^a	1.054±0.044 ^b	3.100±0.068 ^c	296.881	<0.001
Instar-IV	1.027±0.053 ^a	0.662±0.031 ^b	2.425±0.058 ^c	359.949	<0.001
Instar-V	-	-	1.827±0.049	-	-
Instar-VI	-	-	1.294±0.039	-	-
Prepupa	0.577±0.033 ^a	0.337±0.019 ^b	0.813±0.029 ^c	73.152	0.000
Pupa	0.186±0.011 ^a	0.096±0.006 ^b	0.410±0.019 ^c	142.962	<0.001
Adult	0.147±0.013 ^a	0.062±0.007 ^b	0.124±0.010 ^c	18.803	0.003
e_x					
Egg	3.487±0.091 ^a	2.886±0.072 ^b	5.754±0.042 ^c	451.346	<0.001
Instar-I	3.649±0.087 ^a	3.090±0.054 ^b	5.381±0.041 ^c	353.776	<0.001
Instar-II	3.463±0.061 ^a	2.912±0.046 ^b	4.861±0.039 ^c	408.862	<0.001
Instar-III	2.903±0.041 ^a	2.479±0.037 ^b	4.337±0.036 ^c	658.741	<0.001
Instar-IV	2.097±0.030 ^a	1.847±0.028 ^b	3.807±0.034 ^c	1227.361	<0.001
Instar-V	-	-	3.268±0.030	-	-
Instar-VI	-	-	2.551±0.028	-	-
Prepupa	1.404±0.008 ^a	1.156±0.018 ^b	1.786±0.026 ^c	281.225	<0.001
Pupa	0.500±0.000 ^a	0.500±0.000 ^a	1.166±0.023 ^b	827.185	<0.001
Adult	0.500±0.000 ^a	0.500±0.000 ^a	0.558±0.020 ^b	8.806	0.016
k_x					
Egg	0.117±0.005 ^a	0.161±0.011 ^b	0.049±0.001 ^c	70.169	0.000
Instar-I	0.100±0.005 ^a	0.120±0.003 ^b	0.041±0.000 ^c	134.979	0.000
Instar-II	0.060±0.004 ^a	0.092±0.003 ^b	0.045±0.001 ^c	71.681	0.000
Instar-III	0.034±0.002 ^a	0.074±0.003 ^b	0.050±0.001 ^c	84.963	0.000
Instar-IV	0.076±0.006 ^a	0.090±0.004 ^b	0.057±0.001 ^c	14.602	0.005
Instar-V	-	-	0.042±0.001	-	-
Instar-VI	-	-	0.047±0.001	-	-
Prepupa	0.044±0.004 ^a	0.183±0.012 ^b	0.113±0.003 ^c	87.440	0.000
Pupa	0.105±0.011 ^a	0.189±0.019 ^b	0.201±0.007 ^c	15.448	0.004
Adult	0.201±0.000 ^a	0.201±0.000 ^a	0.998±0.175 ^c	20.836	0.002

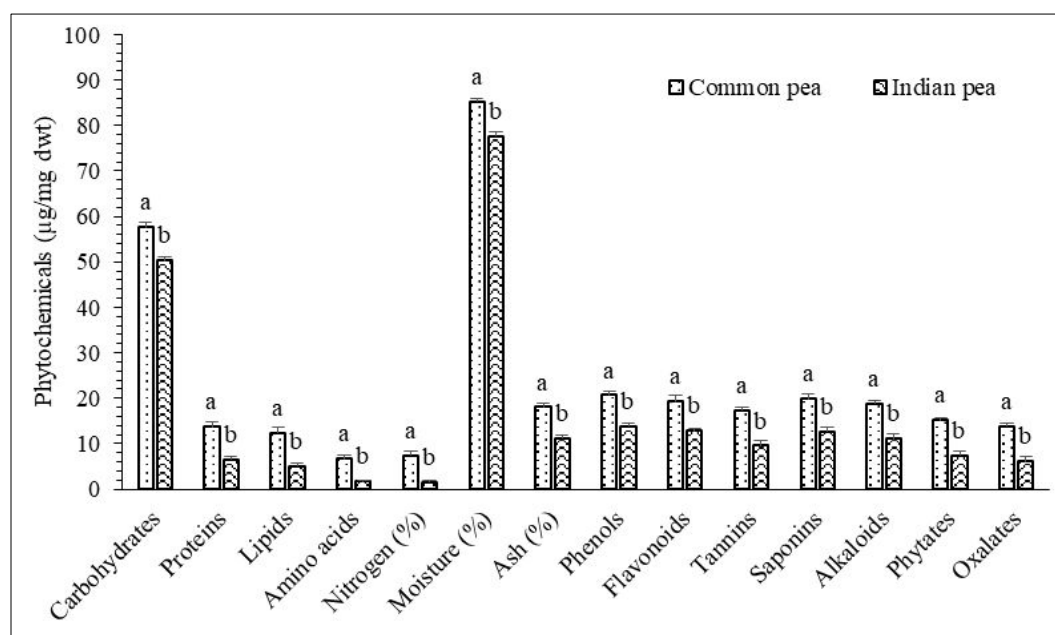


Fig 1(a): Phytochemical variations [Mean ± SE of 3 observations expressed in dry weight (µg /mg dwt)] in common pea and Indian pea. Means followed by the same alphabet above the error bars are not significantly different ($P \geq 0.05$) by Tukey's HSD test.

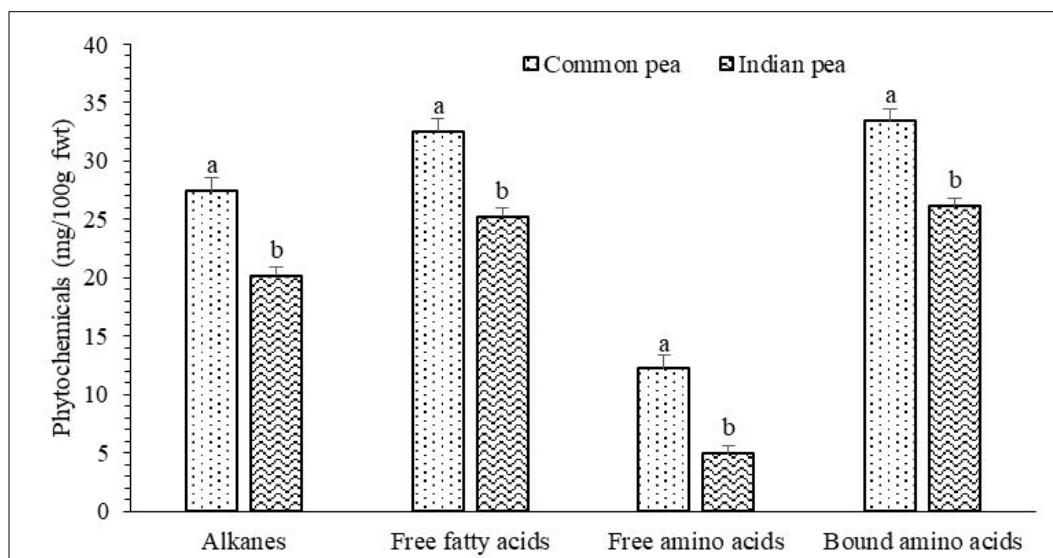


Fig 1(b): Phytochemical variations [Mean $\pm$ SE of 3 observations expressed in fresh weight (mg/100g fwt)] in common pea and Indian pea. Means followed by the same alphabet above the error bars are not significantly different ($P \geq 0.05$) by Tukey's HSD test.

Population growth of the insect pests

On common pea, the longest incubation period (days) was exhibited by *T. castaneum* (12.279 $\pm$ 0.386), followed by *C. maculatus* (6.375 $\pm$ 0.217) and *S. granarius* (5.375 $\pm$ 0.217). The total larval period (days) was also longest in *T. castaneum* (58.675), followed by *C. maculatus* (20.5) and *S. granarius* (19.5). Developmental periods (days) followed a similar order: *T. castaneum* (82.5125) > *C. maculatus*

(36.625) > *S. granarius* (32.625). The longest adult life span (days) was recorded in *S. granarius* (111 $\pm$ 4.359) and the shortest in *C. maculatus* (13.375 $\pm$ 0.217) (Fig 2). The patterns of the longest and shortest spans of all the developmental periods and adult lifespans were the same for the pests on Indian pea. The total developmental period also followed the order of *T. castaneum* (80.875) > *C. maculatus* (35.954) > *S. granarius* (31.954) (Fig 2).

Table 2: Population parameters of *C. maculatus*, *S. granarius* and *T. castaneum* on Indian pea. Different alphabets within the rows indicate the means (Mean $\pm$ SE of 3 observations) are significantly different ($P < 0.05$, Tukey's HSD) while comparing one type of host grain with the others.

Stages	<i>Callosobruchus maculatus</i>	<i>Sitophilus granarius</i>	<i>Tribolium castaneum</i>	<i>F</i> _{2,6}	<i>P</i>
I_x					
Egg	1.000 $\pm$ 0.000 ^a	1.000 $\pm$ 0.000 ^a	1.000 $\pm$ 0.000 ^a	0.000	1.000
Instar-I	0.739 $\pm$ 0.009 ^a	0.684 $\pm$ 0.026 ^b	0.909 $\pm$ 0.011 ^c	46.830	0.000
Instar-II	0.565 $\pm$ 0.014 ^a	0.509 $\pm$ 0.023 ^b	0.831 $\pm$ 0.011 ^c	106.346	0.000
Instar-III	0.478 $\pm$ 0.017 ^a	0.404 $\pm$ 0.021 ^b	0.753 $\pm$ 0.011 ^c	121.876	0.000
Instar-IV	0.434 $\pm$ 0.018 ^a	0.334 $\pm$ 0.019 ^b	0.675 $\pm$ 0.011 ^c	111.282	0.000
Instar-V	-	-	0.597 $\pm$ 0.011	-	-
Instar-VI	-	-	0.545 $\pm$ 0.011	-	-
Prepupa	0.347 $\pm$ 0.021 ^a	0.264 $\pm$ 0.018 ^b	0.493 $\pm$ 0.011 ^c	45.376	0.000
Pupa	0.304 $\pm$ 0.023 ^a	0.159 $\pm$ 0.016 ^b	0.389 $\pm$ 0.011 ^c	45.885	0.000
Adult	0.217 $\pm$ 0.026 ^a	0.088 $\pm$ 0.015 ^b	0.259 $\pm$ 0.011 ^c	24.000	0.001
q_x					
Egg	0.261 $\pm$ 0.009 ^a	0.316 $\pm$ 0.026 ^b	0.103 $\pm$ 0.001 ^c	48.257	0.000
Instar-I	0.236 $\pm$ 0.010 ^a	0.256 $\pm$ 0.005 ^b	0.086 $\pm$ 0.001 ^c	194.268	<0.001
Instar-II	0.154 $\pm$ 0.009 ^a	0.207 $\pm$ 0.005 ^b	0.094 $\pm$ 0.001 ^c	87.324	0.000
Instar-III	0.091 $\pm$ 0.006 ^a	0.174 $\pm$ 0.006 ^b	0.104 $\pm$ 0.001 ^c	80.888	0.000
Instar-IV	0.202 $\pm$ 0.015 ^a	0.211 $\pm$ 0.008 ^a	0.115 $\pm$ 0.002 ^c	27.267	0.001
Instar-V	-	-	0.087 $\pm$ 0.002	-	-
Instar-VI	-	-	0.095 $\pm$ 0.002	-	-
Prepupa	0.127 $\pm$ 0.012 ^a	0.401 $\pm$ 0.020 ^b	0.211 $\pm$ 0.005 ^c	104.173	0.000
Pupa	1.000 $\pm$ 0.000 ^a	1.000 $\pm$ 0.000 ^a	0.334 $\pm$ 0.009 ^b	5213.894	<0.001
Adult	1.000 $\pm$ 0.000 ^a	1.000 $\pm$ 0.000 ^a	0.753 $\pm$ 0.031 ^b	63.006	0.000
L_x					
Egg	0.869 $\pm$ 0.004 ^a	0.842 $\pm$ 0.013 ^b	0.961 $\pm$ 0.011 ^c	37.605	0.000
Instar-I	0.652 $\pm$ 0.011 ^a	0.596 $\pm$ 0.024 ^b	0.870 $\pm$ 0.011 ^c	74.090	0.000
Instar-II	0.521 $\pm$ 0.016 ^a	0.456 $\pm$ 0.022 ^b	0.792 $\pm$ 0.011 ^c	114.394	0.000
Instar-III	0.456 $\pm$ 0.018 ^a	0.369 $\pm$ 0.020 ^b	0.714 $\pm$ 0.011 ^c	116.454	0.000
Instar-IV	0.391 $\pm$ 0.020 ^a	0.299 $\pm$ 0.019 ^b	0.636 $\pm$ 0.011 ^c	106.287	0.000
Instar-V	-	-	0.571 $\pm$ 0.011	-	-
Instar-VI	-	-	0.519 $\pm$ 0.011	-	-
Prepupa	0.326 $\pm$ 0.022 ^a	0.211 $\pm$ 0.017 ^b	0.441 $\pm$ 0.011 ^c	44.682	0.000

Pupa	0.152±0.011 ^a	0.079±0.008 ^b	0.324±0.011 ^c	152.866	<0.001
Adult	0.108±0.013 ^a	0.044±0.007 ^b	0.162±0.011 ^c	31.059	0.001
T_x					
Egg	3.215±0.091 ^a	2.772±0.114 ^b	5.991±0.109 ^c	275.207	<0.001
Instar-I	2.498±0.098 ^a	2.009±0.109 ^b	5.030±0.098 ^c	253.439	<0.001
Instar-II	1.846±0.087 ^a	1.413±0.085 ^b	4.160±0.087 ^c	293.640	<0.001
Instar-III	1.325±0.071 ^a	0.957±0.063 ^b	3.368±0.076 ^c	340.937	<0.001
Instar-IV	0.868±0.053 ^a	0.589±0.044 ^b	2.654±0.065 ^c	419.491	<0.001
Instar-V	-	-	2.018±0.054	-	-
Instar-VI	-	-	1.447±0.043	-	-
Prepupa	0.478±0.033 ^a	0.290±0.025 ^b	0.928±0.033 ^c	115.076	0.000
Pupa	0.152±0.011 ^a	0.079±0.008 ^b	0.486±0.022 ^c	212.708	<0.001
Adult	0.108±0.013 ^a	0.044±0.007 ^b	0.162±0.011 ^c	31.059	0.001
e_x					
Egg	3.215±0.091 ^a	2.772±0.114 ^b	5.915±0.044 ^c	372.945	<0.001
Instar-I	3.378±0.094 ^a	2.936±0.049 ^b	5.534±0.041 ^c	448.259	<0.001
Instar-II	3.264±0.072 ^a	2.776±0.045 ^b	5.006±0.039 ^c	478.100	<0.001
Instar-III	2.768±0.050 ^a	2.369±0.037 ^b	4.472±0.036 ^c	721.128	<0.001
Instar-IV	1.996±0.038 ^a	1.762±0.029 ^b	3.931±0.033 ^c	1253.490	<0.001
Instar-V	-	-	3.379±0.029	-	-
Instar-VI	-	-	2.653±0.027	-	-
Prepupa	1.373±0.012 ^a	1.099±0.020 ^b	1.880±0.024 ^c	410.857	<0.001
Pupa	0.500±0.000 ^a	0.500±0.000 ^a	1.248±0.021 ^b	1300.494	<0.001
Adult	0.500±0.000 ^a	0.500±0.000 ^a	0.623±0.016 ^b	63.006	0.000
k_x					
Egg	0.131±0.005 ^a	0.166±0.016 ^b	0.047±0.001 ^c	38.006	0.000
Instar-I	0.117±0.006 ^a	0.129±0.003 ^b	0.039±0.000 ^c	163.275	<0.001
Instar-II	0.073±0.005 ^a	0.101±0.003 ^b	0.043±0.001 ^c	83.717	0.000
Instar-III	0.042±0.003 ^a	0.083±0.003 ^b	0.047±0.001 ^c	81.695	0.000
Instar-IV	0.098±0.008 ^a	0.103±0.005 ^a	0.053±0.001 ^c	24.673	0.001
Instar-V	-	-	0.040±0.001	-	-
Instar-VI	-	-	0.044±0.001	-	-
Prepupa	0.059±0.006 ^a	0.223±0.015 ^b	0.103±0.003 ^c	84.630	0.000
Pupa	0.150±0.020 ^a	0.261±0.030 ^b	0.177±0.006 ^c	7.566	0.023
Adult	0.201±0.000 ^a	0.201±0.000 ^a	0.615±0.055 ^c	57.640	0.000

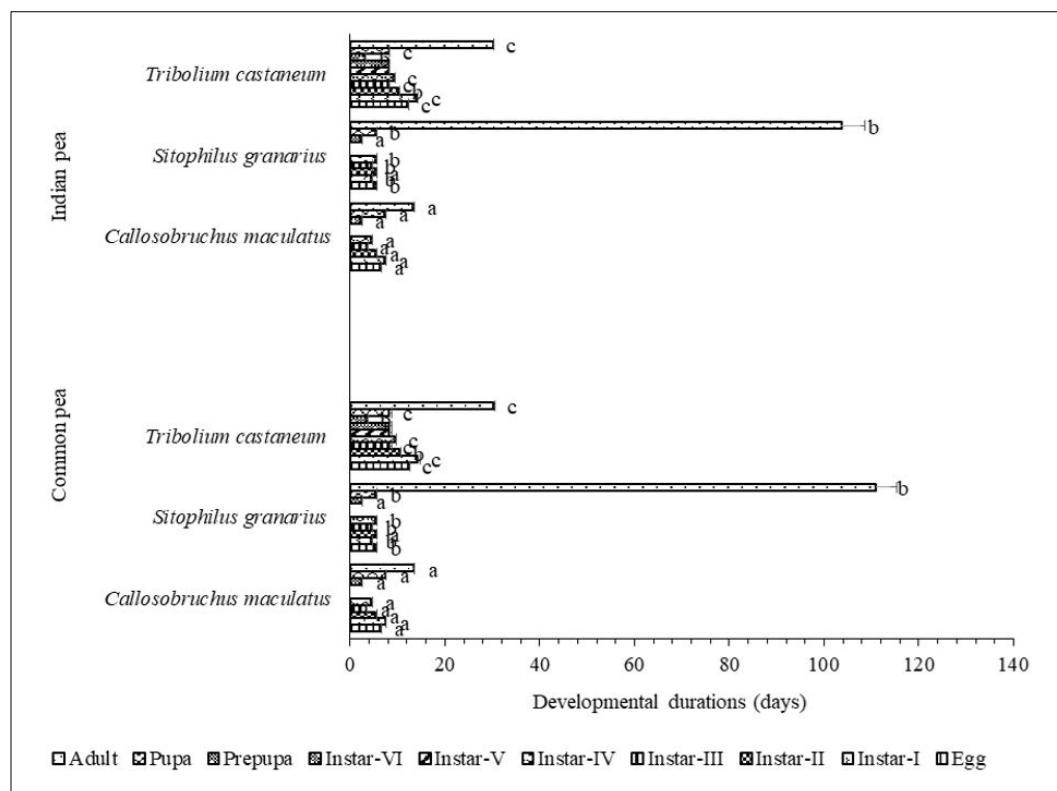


Fig 2: Developmental durations (days) of *C. maculatus*, *S. granarius* and *T. castaneum* on common pea and Indian pea. Means followed by the same alphabet above the error bars are not significantly different ($P \geq 0.05$) by Tukey's HSD test.

The stage-specific life tables of the pests were examined separately for each pest on both legumes. The values of l_x , L_x , T_x and e_x gradually decreased with the developmental stages. The l_x values were 0.293 ± 0.025 , 0.125 ± 0.013 and 0.221 ± 0.01 for the adults of *C. maculatus*, *S. granarius* and *T. castaneum*, respectively, on common pea; and 0.217 ± 0.026 , 0.088 ± 0.015 and 0.259 ± 0.011 on Indian pea. In our study, l_x dropped gradually from egg to advanced developmental stages in all pest species on both host legumes. Therefore, they exhibited Type III survivorship curves, like most other insects (Table 1 and Table 2, Fig 3). Similar to the l_x , the values of L_x and T_x also gradually decreased across the developmental stages; e_x increased from egg to instar-I, after which it decreased consistently; q_x and k_x followed a more random pattern. In both hosts, l_x , L_x , T_x , and e_x were in the order of *T. castaneum* > *C. maculatus* > *S. granarius*, with exceptions; q_x and k_x were in the order of *S. granarius* > *C. maculatus* > *T. castaneum*. The values of q_x , e_x and k_x for the adult *T. castaneum* were 0.884 ± 0.039 , 0.558 ± 0.02 and 0.998 ± 0.175 , respectively, on common pea; and 0.753 ± 0.031 , 0.623 ± 0.016 and 0.615 ± 0.055 on Indian pea. *C. maculatus* and *S. granarius* adults had the same values of q_x , e_x and k_x , 1.000 ± 0.000 , 0.500 ± 0.000 and 0.201 ± 0.000 , respectively, on both common pea and Indian pea. The population parameters presented in Tables 1 ($F_{2,6} \geq 8.806$; $P \leq 0.016$) and 2 ($F_{2,6} \geq 7.566$; $P \leq 0.023$) differed significantly among the pests. The P_f (eggs/female) was highest in *T. castaneum* (375.167 ± 3.753 and 389.889 ± 4.183 on common pea and Indian pea, respectively), followed by *S. granarius* (300.667 ± 8.667 and 285.944 ± 6.260 on common pea and Indian pea, respectively) and *C. maculatus* (127.667 ± 4.631 and 115.167 ± 3.753 on common pea and Indian pea,

respectively). The values of DT, GM and GFR followed the same pattern of: *T. castaneum* > *S. granarius* > *C. maculatus*. The values of r_m (individuals/female/day) followed the reverse order, i.e., *C. maculatus* (0.070 ± 0.001 and 0.066 ± 0.006 on common pea and Indian pea, respectively) > *S. granarius* (0.028 ± 0.001 and 0.028 ± 0.001 on common pea and Indian pea, respectively) > *T. castaneum* (0.011 ± 0.004 and 0.021 ± 0.001 on common pea and Indian pea, respectively). The values of λ , λ^T , MC, GS, PGR, N_e and VI followed the same order as r_m . GRR was highest in *S. granarius* (189.42 ± 5.460 and 180.145 ± 3.944 on common pea and Indian pea, respectively), followed by *C. maculatus* (80.430 ± 2.917 and 72.555 ± 2.364 on common pea and Indian pea, respectively) and *T. castaneum* (17.515 ± 6.032 and 38.557 ± 5.275 on common pea and Indian pea, respectively). The values of F_x , NRR, λ^{Tc} , PMF, PF_2 , HFF_2 , RFF_2 , CBR, RV and TI followed the same pattern of: *S. granarius* > *C. maculatus* > *T. castaneum*. T_c followed the order of: *S. granarius* > *T. castaneum* > *C. maculatus*. Thus, the population parameters presented in Tables 3 ($F_{2,6} \geq 2.148$; $P \leq 0.198$) and 4 ($F_{2,6} \geq 0.005$; $P \leq 0.996$) also varied significantly among the selected pests, with few exceptions. Therefore, we see that the reproductive and population growth parameters of the pests were significantly different. The overall population growth followed the order of *S. granarius* > *C. maculatus* > *T. castaneum*. Comparing the population parameters of each pest on the two hosts, it seems that the common pea was a more suitable host for *C. maculatus* and *S. granarius* than the Indian pea. In contrast, the Indian pea was a more suitable host for *T. castaneum* than the common pea (Supplementary Tables 2, 3 and 4).

Table 3: Population parameters of *C. maculatus*, *S. granarius* and *T. castaneum* on common pea. Different alphabets within the rows indicate the means (Mean $\pm$ SE of 3 observations) are significantly different ($P < 0.05$, Tukey's HSD) while comparing one type of host grain with the others.

Population parameters	<i>Callosobruchus maculatus</i>	<i>Sitophilus granarius</i>	<i>Tribolium castaneum</i>	$F_{2,6}$	P
Potential fecundity (P_f)	127.667 $\pm$ 4.631 ^a	300.667 $\pm$ 8.667 ^b	375.167 $\pm$ 3.753 ^c	437.168	<0.001
Total fertility rate (F_x)	3056.550 $\pm$ 485.422 ^a	7164.780 $\pm$ 1037.155 ^b	1536.944 $\pm$ 578.455 ^c	15.450	0.004
Gross reproductive rate (GRR or m_x)	80.430 $\pm$ 2.917 ^a	189.420 $\pm$ 5.460 ^b	17.515 $\pm$ 6.032 ^c	303.771	<0.001
Net reproductive rate (NRR or R_0)	33.180 $\pm$ 2.917 ^a	55.230 $\pm$ 2.917 ^b	3.992 $\pm$ 1.502 ^c	102.787	0.000
Generation time (T_c)	50.000 $\pm$ 1.732 ^a	143.625 $\pm$ 5.867 ^b	112.792 $\pm$ 3.862 ^c	130.501	<0.001
Doubling time (DT)	9.914 $\pm$ 0.095 ^a	24.816 $\pm$ 0.695 ^b	113.585 $\pm$ 66.239 ^c	2.148	0.198
Intrinsic rate of increase (r_m)	0.070 $\pm$ 0.001 ^a	0.028 $\pm$ 0.001 ^b	0.011 $\pm$ 0.004 ^c	140.683	<0.001
Finite rate of increase (λ)	1.072 $\pm$ 0.001 ^a	1.028 $\pm$ 0.001 ^b	1.011 $\pm$ 0.004 ^b	149.403	<0.001
Weekly multiplication rate (λ^T)	1.632 $\pm$ 0.008 ^a	1.216 $\pm$ 0.007 ^b	1.081 $\pm$ 0.032 ^c	214.941	<0.001
Increase rate per generation (λ^{Tc})	33.180 $\pm$ 2.917 ^a	55.23 $\pm$ 2.917 ^b	3.992 $\pm$ 1.502 ^c	102.787	0.000
Generation mortality (GM)	0.431 $\pm$ 0.026 ^a	0.720 $\pm$ 0.030 ^b	1.643 $\pm$ 0.189 ^c	32.104	0.001
Mortality coefficient (MC)	0.185 $\pm$ 0.016 ^a	0.079 $\pm$ 0.008 ^b	0.011 $\pm$ 0.004 ^c	67.096	0.000
Generation survival (GS)	0.537 $\pm$ 0.022 ^a	0.422 $\pm$ 0.013 ^b	0.254 $\pm$ 0.008 ^c	85.740	0.000
Population growth rate (PGR)	2.628 $\pm$ 0.299 ^a	1.047 $\pm$ 0.101 ^b	0.143 $\pm$ 0.082 ^c	44.724	0.000
Effective Population size (N_e)	35.120 $\pm$ 4.318 ^a	35.120 $\pm$ 4.318 ^a	9.760 $\pm$ 3.603 ^c	12.795	0.007
Population momentum factor of increase (PMF)	25.083 $\pm$ 0.056 ^a	32.985 $\pm$ 0.793 ^b	4.919 $\pm$ 1.032 ^c	370.459	<0.001
Population size in 2 nd generation (PF_2)	945.291 $\pm$ 118.284 ^a	1243.784 $\pm$ 164.520 ^b	57.715 $\pm$ 28.651 ^c	27.265	0.001
Hypothetical F_2 females (HFF_2)	1117.935 $\pm$ 195.602 ^a	3067.376 $\pm$ 324.189 ^b	20.451 $\pm$ 12.271 ^c	49.783	0.000
Realised F_2 females (RFF_2)	595.533 $\pm$ 74.519 ^a	783.584 $\pm$ 103.648 ^b	23.086 $\pm$ 11.460 ^c	28.654	0.001
General fertility rate (GFR)	5.497 $\pm$ 0.479 ^a	13.015 $\pm$ 1.482 ^b	133.623 $\pm$ 59.731 ^c	4.344	0.068
Crude birth rate (CBR)	1.895 $\pm$ 0.061 ^a	2.358 $\pm$ 0.074 ^b	1.744 $\pm$ 0.013 ^c	33.092	0.001
Reproductive value (RV)	160.860 $\pm$ 5.835 ^a	378.840 $\pm$ 10.92 ^b	35.030 $\pm$ 12.064 ^c	303.771	<0.001
Vital Index (VI)	0.293 $\pm$ 0.025 ^a	0.125 $\pm$ 0.013 ^b	0.027 $\pm$ 0.010 ^c	58.996	0.000
Trend index (TI)	40.421 $\pm$ 4.078 ^a	49.682 $\pm$ 6.197 ^b	5.087 $\pm$ 1.869 ^c	28.386	0.001

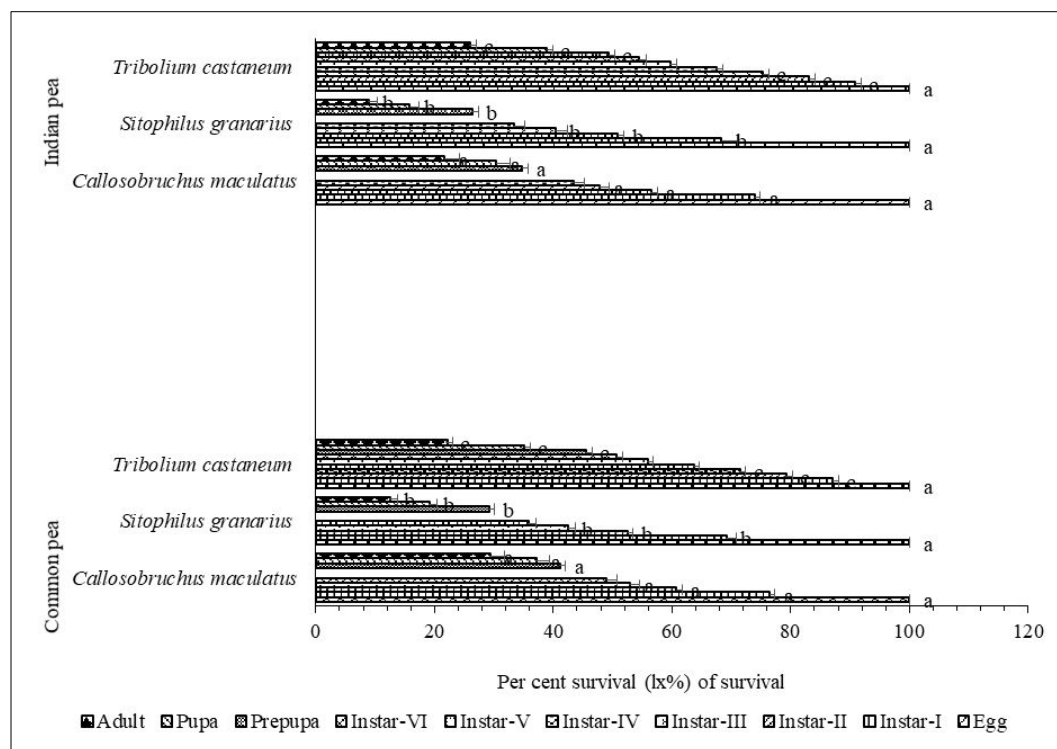


Fig 3: Per cent survival (lx%) of *C. maculatus*, *S. granarius* and *T. castaneum* on common pea and Indian pea. Means followed by the same alphabet above the error bars are not significantly different ($P \geq 0.05$) by Tukey's HSD test.

The primary metabolites (such as carbohydrates, proteins, lipids, alkanes and fatty acids) of the hosts were positively correlated with the population parameters of the pests, except for r_m , λ and MC. In contrast, the secondary metabolites (ash (%), phenols, flavonoids, tannins, saponins,

alkaloids and phytates) showed negative correlations with GRR, NRR, T_c , r_m , λ , PGR, PF_2 and HFF_2 of the pests (Supplementary Table 5). The correlation coefficients (r) for individual metabolites and population parameters (i.e., along rows and columns) of the pests varied considerably.

Table 4: Population parameters of *C. maculatus*, *S. granarius* and *T. castaneum* on Indian pea. Different alphabets within the rows indicate the means (Mean $\pm$ SE of 3 observations) are significantly different ($P < 0.05$, Tukey's HSD) while comparing one type of host grain with the others.

Population parameters	<i>Callosobruchus maculatus</i>	<i>Sitophilus granarius</i>	<i>Tribolium castaneum</i>	$F_{2,6}$	P
Potential fecundity (P_i)	115.167 $\pm$ 3.753 ^a	285.944 $\pm$ 6.260 ^b	389.889 $\pm$ 4.183 ^c	815.665	<0.001
Total fertility rate (F_x)	1843.713 $\pm$ 331.902 ^a	4513.629 $\pm$ 603.762 ^b	3895.556 $\pm$ 696.942 ^c	6.102	0.036
Gross reproductive rate (GRR or m_x)	72.555 $\pm$ 2.364 ^a	180.145 $\pm$ 3.944 ^b	38.557 $\pm$ 5.275 ^c	334.652	<0.001
Net reproductive rate (NRR or R_0)	25.304 $\pm$ 2.364 ^a	47.355 $\pm$ 2.364 ^b	10.118 $\pm$ 1.810 ^c	72.747	0.000
Generation time (T_c)	49.233 $\pm$ 3.089 ^a	135.621 $\pm$ 2.862 ^b	110.972 $\pm$ 2.788 ^c	232.890	<0.001
Doubling time (DT)	10.647 $\pm$ 0.982 ^a	24.388 $\pm$ 0.497 ^b	33.977 $\pm$ 1.785 ^c	93.830	0.000
Intrinsic rate of increase (r_m)	0.066 $\pm$ 0.006 ^a	0.028 $\pm$ 0.001 ^b	0.021 $\pm$ 0.001 ^c	51.813	0.000
Finite rate of increase (λ)	1.068 $\pm$ 0.006 ^a	1.029 $\pm$ 0.001 ^b	1.021 $\pm$ 0.001 ^b	50.064	0.000
Weekly multiplication rate (λ^7)	1.592 $\pm$ 0.063 ^a	1.220 $\pm$ 0.005 ^b	1.155 $\pm$ 0.009 ^c	40.821	0.000
Increase rate per generation (λ^{T_c})	25.304 $\pm$ 2.364 ^a	47.355 $\pm$ 2.364 ^b	10.118 $\pm$ 1.810 ^c	72.747	0.000
Generation mortality (GM)	0.520 $\pm$ 0.033 ^a	0.804 $\pm$ 0.043 ^b	1.207 $\pm$ 0.068 ^c	47.323	0.000
Mortality coefficient (MC)	0.137 $\pm$ 0.016 ^a	0.056 $\pm$ 0.009 ^b	0.025 $\pm$ 0.004 ^c	27.368	0.001
Generation survival (GS)	0.470 $\pm$ 0.023 ^a	0.385 $\pm$ 0.012 ^b	0.285 $\pm$ 0.009 ^c	33.495	0.001
Population growth rate (PGR)	1.707 $\pm$ 0.384 ^a	0.717 $\pm$ 0.114 ^b	0.520 $\pm$ 0.115 ^c	6.975	0.027
Effective Population size (N_e)	23.465 $\pm$ 3.499 ^a	23.465 $\pm$ 3.499 ^a	23.893 $\pm$ 4.015 ^b	0.005	0.996
Population momentum factor of increase (PMF)	24.629 $\pm$ 0.455 ^a	32.134 $\pm$ 0.776 ^b	7.943 $\pm$ 0.625 ^c	383.291	<0.001
Population size in 2 nd generation (PF_2)	623.207 $\pm$ 103.477 ^a	804.039 $\pm$ 104.124 ^b	202.904 $\pm$ 49.771 ^c	11.877	0.008
Hypothetical F_2 females (HFF_2)	651.485 $\pm$ 119.779 ^a	2253.644 $\pm$ 224.001 ^b	108.934 $\pm$ 38.221 ^c	56.537	0.000
Realised F_2 females (RFF_2)	392.621 $\pm$ 65.191 ^a	506.545 $\pm$ 65.598 ^b	81.162 $\pm$ 19.908 ^c	16.255	0.004
General fertility rate (GFR)	7.534 $\pm$ 0.917 ^a	18.966 $\pm$ 3.126 ^b	41.254 $\pm$ 6.305 ^c	17.516	0.003
Crude birth rate (CBR)	2.098 $\pm$ 0.075 ^a	2.490 $\pm$ 0.122 ^b	1.696 $\pm$ 0.013 ^c	22.786	0.002
Reproductive value (RV)	145.110 $\pm$ 4.728 ^a	360.29 $\pm$ 7.888 ^b	77.115 $\pm$ 10.551 ^c	334.652	<0.001
Vital Index (VI)	0.217 $\pm$ 0.026 ^a	0.088 $\pm$ 0.015 ^b	0.064 $\pm$ 0.010 ^c	20.875	0.002
Trend index (TI)	28.859 $\pm$ 3.668 ^a	33.541 $\pm$ 3.010 ^b	12.353 $\pm$ 2.045 ^c	13.921	0.006

Discussion

Insects seek hosts that can provide optimal nutrition and a suitable mating and oviposition site (Scriber and Slansky,

1981; Anukiruthika *et al.*, 2021) [53, 1]. Conversely, the hosts have developed complex networks to regulate a balance between growth and defence (Kessler and Baldwin, 2002)

[30]. Therefore, to devise pest control strategies, it was necessary to correlate the host nutritional profile and population dynamics of insect pests (Awmack and Leather 2002; Roy, 2020) [4, 49]. We studied the developmental patterns and life tables of *C. maculatus*, *S. granarius* and *T. castaneum* on common pea and Indian pea. The pests exhibited similar developmental and population patterns on both legumes. *C. maculatus* and *S. granarius* exhibited four larval instars and *T. castaneum* six, all with distinct prepupal stages. The immature period was longest in *T. castaneum*, followed by *C. maculatus* and *S. zeamais* on both pulses. In contrast, *S. granarius* outlived the other two in terms of adult longevity. Our findings on the developmental durations and lifespans of these pests differ greatly from previous reports. Devi *et al.* (2017) [17] observed adult longevities for *S. zeamais* on wheat (105.90±8.81 days for females and 67.40±5.59 days for males) that are comparable to our study, but the immature periods they reported were longer than our findings. The total developmental period of *C. chinensis* was 30.90 ± 4.28 days, and the adult male and female longevities were 8.30 ± 1.25 and 9.50 ± 1.58 days, respectively, on cowpea (DC-15) (Augustine and Balikai, 2019) [3]. The developmental periods and adult longevities of two strains of *T. confusum* on cracked barley were much longer than our results on the selected legumes (Kavallieratos *et al.*, 2020) [29].

Life table studies are a key in understanding the temporal and spatial patterns in population dynamics of insects (Southwood, 1978; Chen *et al.*, 2025) [58, 12]. The r_m is an effective tool for comparing the survival rate and reproduction of the insect (Carey, 1993; Price, 1997; Roy, 2021) [9, 40, 48], while R_0 and GRR represent the reproductive potentials (Zeinalzadeh *et al.*, 2016). In the current investigation on both legumes, the F_x , GRR, R_0 , λ^{T_c} , PF_2 and HFF_2 were highest in *S. granarius*; These growth parameters were observed to be lowest in *T. castaneum*. Meanwhile, r_m , λ , λ^7 and GS were highest in *C. maculatus*, and accordingly, the T_c and DT were lowest in *C. maculatus*. Considering the population parameters, we classify the susceptibility of common pea and Indian pea in the order of *S. granarius* > *C. maculatus* > *T. castaneum*. Even a single host phytochemical had different effects on different pests due to the variations in nutrition utilisation patterns (Roy, 2020, 2021) [49, 48]. The correlation coefficients between host phytochemicals and pest population parameters also varied significantly. The value of r_m (individuals/female/day) that Singh *et al.* (2022) [56] found for *C. chinensis* on cowpea was 0.130 ± 0.010, which was significantly higher than the r_m for *C. maculatus* in our findings. Meanwhile, the lowest r_m value we observed (for *T. castaneum*) was comparable to the r_m reported by Kavallieratos *et al.* (2020) [29] for two strains of *T. confusum* on cracked barley (0.014 and 0.025). Singh *et al.* (2022) [56] found the range of T_c (days) for *C. chinensis* on pulses to be between 25.59 ± 0.37 and 28.640 ± 0.410, much lower than the lowest T_c we recorded for *C. maculatus* (45.000±1.732 on common pea and 44.233±3.089 on Indian pea). All these data emphasise the role of host metabolites in the physiology of insect pests. The physico-chemical properties of the hosts affect the development, reproductive performance and survivorship of pests (Perez-Mendoza *et al.*, 2016) [39].

Common pea possessed higher concentrations (µg/mg dwt) of the major primary metabolites like carbohydrates

(57.589±1.185), proteins (13.789±1.105) and lipids (12.389±1.135) than Indian pea (50.31±0.788, 6.51±0.708 and 5.11±0.738, respectively). Similarly, secondary metabolite content was significantly higher in common pea than in Indian pea. Secondary metabolites like phenols, flavonoids, tannins, saponins, alkaloids, etc., constitute the most widespread group of defensive chemicals utilised by plants (Simmonds, 2003; Schoonhoven *et al.*, 2005) [55, 52]. A diet with high protein or carbohydrate content resulted in the complete absence of *T. castaneum* offspring, and a protein level below 10% prolonged the development period and reduced the number of offspring (Đukić *et al.*, 2022) [21]. Higher phenol and amylose contents in host cultivars reduced *S. oryzae* and *S. cerealella* infestation (Ramputh *et al.*, 1999; Ashamo, 2010; Muthukumar *et al.*, 2015; Demissie *et al.* 2015) [42, 2, 35, 16]. Saponin causes moulting inhibition in *T. castaneum* and acts as a feeding deterrent or repellent for *S. oryzae* (Shakeel *et al.*, 2025) [54]. In the present investigation, common pea was found to be a more suitable host for *S. granarius* and *C. maculatus* than Indian pea based on population studies, despite the higher content of phenols, saponins and alkaloids in common pea than in Indian pea. This is because nutrition utilisation is also influenced by the ability of insects to ingest, assimilate and incorporate the food into their body tissues (Roy, 2022) [50]. Correlation analysis shows that the population parameters of the pest species and host metabolites are directly (both positively and negatively) correlated. The degrees of susceptibility of the common pea and Indian pea were different towards different pests. *S. granarius* and *C. maculatus* thrived better on common pea than Indian pea, and *T. castaneum* thrived better on Indian pea. Nevertheless, both common pea and Indian pea were more susceptible to and hence require more control measures against *S. granarius* than *C. maculatus* or *T. castaneum*.

Conclusion

Common pea contained higher levels of the primary and secondary metabolites than the Indian pea. Despite this, *S. granarius* and *C. maculatus* thrived better on common pea than Indian pea; *T. castaneum* thrived better on Indian pea. However, both common pea and Indian pea were more susceptible to and hence require more control measures against *S. granarius* than *C. maculatus* or *T. castaneum*. The population growth of insect pests may also change in response to a myriad of biotic and abiotic factors and geographical locations. Future work can further substantiate these with population studies on intra- and interspecific interactions of the pests. That may lead to solutions regarding the sustainable management of the pests.

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Supplementary Table 1: Phytochemical variations (Mean $\pm$ SE of 3 observations, expressed in dry weight ($\mu\text{g}/\text{mg}$ dwt) or fresh weight ($\text{mg}/100\text{g}$ fwt)) in common pea and Indian pea. Different alphabets within the rows indicate the means (Mean $\pm$ SE of 3 observations) are significantly different ($P < 0.05$, Tukey's HSD) while comparing one type of host grain with the others.

Phytochemicals ($\mu\text{g}/\text{mg}$ dwt)	Common pea	Indian pea	$F_{1,4}$	P
Carbohydrates	57.589 $\pm$ 1.185	50.31 $\pm$ 0.788	22.341	0.002
Proteins	13.789 $\pm$ 1.105	6.51 $\pm$ 0.708	22.341	0.002
Lipids	12.389 $\pm$ 1.135	5.11 $\pm$ 0.738	22.341	0.002
Amino acids	6.709 $\pm$ 0.907	1.707 $\pm$ 0.285	19.999	0.002
Nitrogen (%)	7.456 $\pm$ 0.943	1.6 $\pm$ 0.365	24.837	0.001
Moisture (%)	85.229 $\pm$ 0.805	77.707 $\pm$ 0.827	54.879	0.000
Ash (%)	18.049 $\pm$ 1.003	11.227 $\pm$ 0.677	25.659	0.001
Phenols	20.689 $\pm$ 0.993	13.867 $\pm$ 0.667	25.659	0.001
Flavonoids	19.316 $\pm$ 1.252	12.827 $\pm$ 0.647	15.575	0.004
Tannins	17.396 $\pm$ 0.625	9.573 $\pm$ 1.038	29.777	0.001
Saponins	19.829 $\pm$ 1.013	12.673 $\pm$ 1.018	16.878	0.003
Alkaloids	18.896 $\pm$ 0.655	11.073 $\pm$ 1.068	29.777	0.001
Phytates	15.196 $\pm$ 0.615	7.373 $\pm$ 1.028	29.777	0.001
Oxalates	13.936 $\pm$ 0.685	6.113 $\pm$ 1.098	29.777	0.001
Phytochemicals ($\text{mg}/100\text{g}$ fwt)				
Alkanes	27.449 $\pm$ 1.175	20.17 $\pm$ 0.778	22.341	0.002
Free fatty acids	32.529 $\pm$ 1.145	25.25 $\pm$ 0.748	22.341	0.002
Free amino acids	12.219 $\pm$ 1.115	4.94 $\pm$ 0.718	22.341	0.002
Bound amino acids	33.409 $\pm$ 1.085	26.13 $\pm$ 0.688	22.341	0.002

Supplementary Table 2: Population parameters of *Callosobruchus maculatus* on common pea and Indian pea. Different alphabets within the rows indicate the means (Mean $\pm$ SE of 3 observations) are significantly different ($P < 0.05$, Tukey's HSD) while comparing one type of host grain with the others.

Population parameters	<i>Callosobruchus maculatus</i> on common pea	<i>Callosobruchus maculatus</i> on Indian pea	$F_{1,4}$	P
Potential fecundity (P_f)	127.667 $\pm$ 4.631	115.167 $\pm$ 3.753	2.932	0.162
Total fertility rate (F_x)	3056.55 $\pm$ 485.422	1843.713 $\pm$ 331.902	2.836	0.167
Gross reproductive rate (GRR or m_x)	80.43 $\pm$ 2.917	72.555 $\pm$ 2.364	2.932	0.162
Net reproductive rate (NRR or R_0)	33.18 $\pm$ 2.917	25.304 $\pm$ 2.364	2.933	0.162
Generation time (T_c)	50.000 $\pm$ 1.732	49.233 $\pm$ 3.089	0.031	0.868
Doubling time (DT)	9.914 $\pm$ 0.095	10.647 $\pm$ 0.982	0.368	0.577
Intrinsic rate of increase (r_m)	0.070 $\pm$ 0.001	0.066 $\pm$ 0.006	0.284	0.622
Finite rate of increase (λ)	1.072 $\pm$ 0.001	1.068 $\pm$ 0.006	0.282	0.624
Weekly multiplication rate (λ^7)	1.632 $\pm$ 0.008	1.592 $\pm$ 0.063	0.264	0.634
Increase rate per generation (λ^{T_c})	33.18 $\pm$ 2.917	25.304 $\pm$ 2.364	2.933	0.162
Generation mortality (GM)	0.431 $\pm$ 0.026	0.520 $\pm$ 0.033	2.929	0.162
Mortality coefficient (MC)	0.185 $\pm$ 0.016	0.137 $\pm$ 0.016	2.981	0.159
Generation survival (GS)	0.537 $\pm$ 0.022	0.470 $\pm$ 0.023	2.976	0.160
Population growth rate (PGR)	2.628 $\pm$ 0.299	1.707 $\pm$ 0.384	2.385	0.197
Effective Population size (N_e)	35.120 $\pm$ 4.318	23.465 $\pm$ 3.499	2.932	0.162
Population momentum factor of increase (PMF)	25.083 $\pm$ 0.056	24.629 $\pm$ 0.455	0.654	0.464
Population size in 2 nd generation (PF_2)	945.291 $\pm$ 118.284	623.207 $\pm$ 103.477	2.800	0.170
Hypothetical F_2 females (HFF ₂)	1117.935 $\pm$ 195.602	651.485 $\pm$ 119.779	2.757	0.172
Realised F_2 females (RFF ₂)	595.533 $\pm$ 74.519	392.621 $\pm$ 65.191	2.800	0.170
General fertility rate (GFR)	5.497 $\pm$ 0.479	7.534 $\pm$ 0.917	2.586	0.183
Crude birth rate (CBR)	1.895 $\pm$ 0.061	2.098 $\pm$ 0.075	2.934	0.162
Reproductive value (RV)	160.86 $\pm$ 5.835	145.11 $\pm$ 4.728	2.932	0.162
Vital Index (VI)	0.293 $\pm$ 0.025	0.217 $\pm$ 0.026	2.981	0.159
Trend index (TI)	40.421 $\pm$ 4.078	28.859 $\pm$ 3.668	2.962	0.160

Supplementary Table 3: Population parameters of *Sitophilus granarius* on common pea and Indian pea. Different alphabets within the rows indicate the means (Mean $\pm$ SE of 3 observations) are significantly different ($P < 0.05$, Tukey's HSD) while comparing one type of host grain with the others.

Population parameters	<i>Sitophilus granarius</i> on common pea	<i>Sitophilus granarius</i> on Indian pea	$F_{1,4}$	P
Potential fecundity (P_f)	300.667 $\pm$ 8.667	285.944 $\pm$ 6.26	1.264	0.324
Total fertility rate (F_x)	7164.78 $\pm$ 1037.155	4513.629 $\pm$ 603.762	3.253	0.146
Gross reproductive rate (GRR or m_x)	189.42 $\pm$ 5.46	180.145 $\pm$ 3.944	1.264	0.324
Net reproductive rate (NRR or R_0)	55.23 $\pm$ 2.917	47.355 $\pm$ 2.364	2.932	0.162
Generation time (T_c)	143.625 $\pm$ 5.867	135.621 $\pm$ 2.862	1.002	0.373
Doubling time (DT)	24.816 $\pm$ 0.695	24.388 $\pm$ 0.497	0.168	0.703
Intrinsic rate of increase (r_m)	0.028 $\pm$ 0.001	0.028 $\pm$ 0.001	0.154	0.715
Finite rate of increase (λ)	1.028 $\pm$ 0.001	1.029 $\pm$ 0.001	0.153	0.715
Weekly multiplication rate (λ^7)	1.216 $\pm$ 0.007	1.22 $\pm$ 0.005	0.152	0.716

Increase rate per generation (λ^{Tc})	55.23±2.917	47.355±2.364	2.932	0.162
Generation mortality (GM)	0.72±0.03	0.804±0.043	1.732	0.258
Mortality coefficient (MC)	0.079±0.008	0.056±0.009	2.238	0.209
Generation survival (GS)	0.422±0.013	0.385±0.012	2.973	0.160
Population growth rate (PGR)	1.047±0.101	0.717±0.114	3.123	0.152
Effective Population size (N_e)	35.12±4.318	23.465±3.499	2.932	0.162
Population momentum factor of increase (PMF)	32.985±0.793	32.134±0.776	0.392	0.565
Population size in 2 nd generation (PF ₂)	1243.784±164.52	804.039±104.124	3.401	0.139
Hypothetical F ₂ females (HFF ₂)	3067.376±324.189	2253.644±224.001	2.843	0.167
Realised F ₂ females (RFF ₂)	783.584±103.648	506.545±65.598	3.401	0.139
General fertility rate (GFR)	13.015±1.482	18.966±3.126	1.972	0.233
Crude birth rate (CBR)	2.358±0.074	2.49±0.122	0.570	0.492
Reproductive value (RV)	378.84±10.92	360.29±7.888	1.264	0.324
Vital Index (VI)	0.125±0.013	0.088±0.015	2.238	0.209
Trend index (TI)	49.682±6.197	33.541±3.01	3.659	0.128

Supplementary Table 4: Population parameters of *Tribolium castaneum* on common pea and Indian pea. Different alphabets within the rows indicate the means (Mean ± SE of 3 observations) are significantly different ($P < 0.05$, Tukey's HSD) while comparing one type of host grain with the others.

Population parameters	<i>Tribolium castaneum</i> on common pea	<i>Tribolium castaneum</i> on Indian pea	$F_{1,4}$	P
Potential fecundity (P_f)	375.167±3.753	389.889±4.183	4.576	0.099
Total fertility rate (F_x)	1536.944±578.455	3895.556±696.942	4.521	0.101
Gross reproductive rate (GRR or m_x)	17.515±6.032	38.557±5.275	4.597	0.099
Net reproductive rate (NRR or R_0)	3.992±1.502	10.118±1.81	4.521	0.101
Generation time (T_c)	112.792±3.862	110.972±2.788	0.097	0.771
Doubling time (DT)	113.585±66.239	33.977±1.785	0.962	0.382
Intrinsic rate of increase (r_m)	0.011±0.004	0.021±0.001	3.089	0.154
Finite rate of increase (λ)	1.011±0.004	1.021±0.001	3.110	0.153
Weekly multiplication rate (λ^7)	1.081±0.032	1.155±0.009	3.240	0.146
Increase rate per generation (λ^{Tc})	3.992±1.502	10.118±1.81	4.521	0.101
Generation mortality (GM)	1.643±0.189	1.207±0.068	3.132	0.151
Mortality coefficient (MC)	0.011±0.004	0.025±0.004	4.614	0.098
Generation survival (GS)	0.254±0.008	0.285±0.009	4.617	0.098
Population growth rate (PGR)	0.143±0.082	0.520±0.115	4.754	0.095
Effective Population size (N_e)	9.760±3.603	23.893±4.015	4.576	0.099
Population momentum factor of increase (PMF)	4.919±1.032	7.943±0.625	4.187	0.110
Population size in 2 nd generation (PF ₂)	57.715±28.651	202.904±49.771	4.261	0.108
Hypothetical F ₂ females (HFF ₂)	20.451±12.271	108.934±38.221	3.239	0.146
Realised F ₂ females (RFF ₂)	23.086±11.460	81.162±19.908	4.261	0.108
General fertility rate (GFR)	133.623±59.731	41.254±6.305	1.577	0.278
Crude birth rate (CBR)	1.744±0.013	1.696±0.013	4.625	0.098
Reproductive value (RV)	35.03±12.064	77.115±10.551	4.597	0.099
Vital Index (VI)	0.027±0.010	0.064±0.010	4.614	0.098
Trend index (TI)	5.087±1.869	12.353±2.045	4.586	0.099

Supplementary Table 5: Correlation analysis between host phytochemicals and the pest population parameters.

	Carbohydrates	Proteins	Lipids	Amino acids	Nitrogen (%)	Moisture (%)	Ash (%)	Phenols	Flavonoids	Tannins	Saponins	Alkaloids	Phytates	Oxalates	Alkanes	Free Fatty Acids	Free Amino Acids	Bound Amino Acids
Potential fecundity (P_f)	0.020	0.020	0.020	-0.192	-0.213	-0.274	0.316	0.316	-0.316	0.358	0.358	-0.358	-0.358	-0.358	0.020	0.020	0.020	0.020
Total fertility rate (F_x)	0.356	0.356	0.356	-0.075	-0.140	-0.228	0.611	0.611	-0.611	0.650	0.650	-0.650	-0.650	-0.650	0.356	0.356	0.356	0.356
Gross reproductive rate (GRR or m_x)	0.095	0.095	0.095	-0.180	-0.187	-0.204	0.492	0.492	-0.492	0.470	0.470	-0.470	-0.470	-0.470	0.095	0.095	0.095	0.095
Net reproductive rate (NRR or R_0)	0.206	0.206	0.206	-0.027	-0.040	-0.056	0.360	0.360	-0.360	0.343	0.343	-0.343	-0.343	-0.343	0.206	0.206	0.206	0.206
Generation time (T_c)	0.084	0.084	0.084	-0.255	-0.268	-0.325	0.542	0.542	-0.542	0.561	0.561	-0.561	-0.561	-0.561	0.084	0.084	0.084	0.084
Doubling time (DT)	0.163	0.163	0.163	0.246	0.289	0.294	0.334	0.334	0.334	0.320	0.320	0.320	0.320	0.320	0.163	0.163	0.163	0.163
Intrinsic rate of increase (r_m)	-0.007	-0.007	-0.007	0.202	0.205	0.252	0.317	0.317	0.317	0.344	0.344	0.344	0.344	0.344	-0.007	-0.007	-0.007	-0.007
Finite rate of increase (λ)	-0.005	-	-	0.206	0.209	0.256	0.320	0.320	0.322	0.349	0.349	0.349	0.349	0.349	-0.005	-0.005	-0.005	-0.005

		0.00 5	0.0 05				2	2		9								
Weekly multiplication rate (λ^7)	0.002	0.00 2	0.0 02	0.225	0.229	0.278	0.35 0	0.35 0	0.350	0.37 7	0.377	0.377	0.377	0.377	0.002	0.002	0.002	0.002
Increase rate per generation (λ^{Tc})	0.206	0.20 6	0.2 06	-0.027	-0.040	-0.056	0.36 0	0.36 0	-0.360	0.34 3	0.343	0.343	-0.343	-0.343	0.206	0.206	0.206	0.206
Generation mortality (GM)	-0.027	0.02 7	0.0 27	-0.028	-0.011	-0.028	0.06 3	0.06 3	0.063	0.03 8	0.038	0.038	0.038	0.038	-0.027	-0.027	-0.027	-0.027
Mortality coefficient (MC)	0.206	0.20 6	0.2 06	0.374	0.369	0.400	0.37 0	0.37 0	0.370	0.38 2	0.382	0.382	0.382	0.382	0.206	0.206	0.206	0.206
Generation survival (GS)	0.200	0.20 0	0.2 00	0.286	0.280	0.305	0.20 8	0.20 8	0.208	0.22 6	0.226	0.226	0.226	0.226	0.200	0.200	0.200	0.200
Population growth rate (PGR)	0.241	0.24 1	0.2 41	0.413	0.399	0.422	0.39 9	0.39 9	0.399	0.40 1	0.401	0.401	0.401	0.401	0.241	0.241	0.241	0.241
Effective Population size (N _e)	0.413	0.41 3	0.4 13	0.229	0.160	0.105	0.16 1	0.16 1	-0.161	0.19 6	0.196	0.196	-0.196	-0.196	0.413	0.413	0.413	0.413
Population momentum factor of increase (PMF)	0.069	0.06 9	0.0 69	-0.077	-0.076	-0.066	0.29 2	0.29 2	-0.292	0.25 5	0.255	0.255	-0.255	-0.255	0.069	0.069	0.069	0.069
Population size in 2 nd generation (PF ₂)	0.394	0.39 4	0.3 94	0.199	0.172	0.146	0.18 7	0.18 7	-0.187	0.18 8	0.188	0.188	-0.188	-0.188	0.394	0.394	0.394	0.394
Hypothetical F ₂ females (HFF ₂)	0.293	0.29 3	0.2 93	-0.004	-0.020	-0.053	0.41 3	0.41 3	-0.413	0.40 6	0.406	0.406	-0.406	-0.406	0.293	0.293	0.293	0.293
Realised F ₂ females (RFF ₂)	0.391	0.39 1	0.3 91	0.209	0.187	0.166	0.16 3	0.16 3	-0.163	0.16 0	0.160	0.160	-0.160	-0.160	0.391	0.391	0.391	0.391
General fertility rate (GFR)	0.104	0.10 4	0.1 04	0.218	0.259	0.268	0.35 6	0.35 6	0.356	0.34 2	0.342	0.342	0.342	0.342	0.104	0.104	0.104	0.104
Crude birth rate (CBR)	-0.122	0.12 2	0.1 22	-0.319	-0.295	-0.276	0.47 6	0.47 6	-0.476	0.42 2	0.422	0.422	-0.422	-0.422	-0.122	-0.122	-0.122	-0.122
Reproductive value (RV)	0.095	0.09 5	0.0 95	-0.180	-0.187	-0.204	0.49 2	0.49 2	-0.492	0.47 0	0.470	0.470	-0.470	-0.470	0.095	0.095	0.095	0.095
Vital Index (VI)	0.199	0.19 9	0.1 99	0.372	0.362	0.389	0.37 4	0.37 4	0.374	0.38 3	0.383	0.383	0.383	0.383	0.199	0.199	0.199	0.199
Trend index (TI)	0.372	0.37 2	0.3 72	0.189	0.160	0.136	0.18 1	0.18 1	-0.181	0.18 1	0.181	0.181	-0.181	-0.181	0.372	0.372	0.372	0.372