

Management of *Helicoverpa armigera* (Lepidoptera: Noctuidae) by Nutritional Indices and Botanical Extracts of *Millettia ferruginea* and *Azadirachta indica*

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Abstract

The development of hosts that are resistant and evaluation of botanical extracts to *H. armigera* Hübner (Lepidoptera: Noctuidae) is crucial for sustainable management, yet very limited in Ethiopia. Therefore, this study was done to identify alternative methods to insecticide control through host consumption study and botanical extracts. The performance of third-fifth larval stages of *H. armigera* on three host plant varieties including chickpea, tomato and faba bean and botanical extracts against the third larval instars and oviposition deterrence was studied under laboratory condition ($22^{\circ}\text{C} \pm 2^{\circ}\text{C}$, $55\% \pm 5\%$ RH, 12:12 L: D photoperiod). Significant differences were found in the efficiency of conversion of ingested food (ECI%) ($F = 80.06$; $df = 6, 2$; $p < 0.05$) and efficiency of conversion of digested food (ECD%) ($F = 175.91$; $df = 6, 2$; $p < 0.05$) values of *H. armigera* reared on the three host plant varieties of the whole larval instars. The minimum relative consumption rate (RCR) (11.271 ± 0.328) and maximum approximate digestibility (AD) (177.9 ± 1.928) values of the whole larval instars were on *Dagaga* and *Koshari*, respectively. The values of relative growth rate (RGR), ECI% and ECD% of the whole larval instars were highest on chickpea varieties and lowest on tomato *Koshari*. Among chickpea varieties, *Habru* was relatively resistant to larval instars of *H. armigera*. Botanical extracts at 50% neem oil (NO), 5% birbira seed extract (BSE) and 5% neem seed extract (NSE) (18.4%) resulted superior in larval mortality however, statistically not different. At both 5% and 2.5% concentra-

tion level of botanical extracts the minimum larval mortality was recorded from neem leaf extract (NLE). Maximum numbers of eggs were laid on control treatments and the minimum eggs were on 5% BSE. The deterrent effect of 50% neem oil was stronger (ODI = 17.66%) than that of 5% BSE (ODI = 14%) which is statistically similar value with 5% NSE (ODI = 13%). In conclusion, the result indicated that use of *Habru* chickpea variety with 50% NO was very effective in controlling both the larvae and deterring the adults of *H. armigera* from egg laying. These measures could be important in the wider managements of *H. armigera* by integrating host resistance and botanical extracts.

Keywords

Antibiosis, Botanicals, Insect Food Consumption, IPM, Oviposition

1. Introduction

Chickpea (*Cicer arietinum* L. (Family: Fabaceae) is one of the most important pulse crop grown in many parts of African and Asia. It is cheap source of proteins and maintains soil fertility through biological nitrogen fixation [1] [2] [3]. The crop has the ability to be grown in poor soil fertility at the minimum soil moisture having high moisture retention capacity [4] [5]. In Ethiopia it's considered as one among the major highland food crops grown. It ranks third in area coverage; among pulses grown in Ethiopia it preceded only by faba beans and haricot beans. The crop was considered as one of the most principal food legumes which have been widely grown in Ethiopia [6]. However, the production and productivity of chickpea is below the world average production due to various factors including both biotic factors like diseases [7] [8] [9], insects [10] [11] [12] and abiotic factors [4] [5]. *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) is a destructive pest of chickpea and many others crops causing a considerable loss in the world [13] [14]. The insect is highly polyphagous pest; attacking wide ranges of agricultural crops including beans, chickpea, peas, sorghum, cotton, tomato, Okra, Sesame, Corn, tobacco, pepper, sunflower, safflower and Niger seed [15] [16] [17] [18], high reproductive rate and dispersal ability [19] [20]. Yield losses due to *H. armigera* damage in chickpea range from 70 to 95% [21]. In Ethiopia, it's considered as the most prevalent insect pests on chickpea [22] [23]. Substantial proportions of chickpea in Ethiopia are lost to chickpea pod borer which causes up to 33% pod damage to chickpea [15] and 21% to faba bean [24]. Though, substantial proportions of chickpea in Ethiopia are lost to chickpea pod borer, current control methods by insecticides for the insect have been criticized for being expensive, environmental pollution, non-target, contamination and human exposure. Moreover, the insect has been developed resistance to most of the conventional insecticides in the world [25] [26]. Several researchers have used nutritional indices to study intake, digestibility and efficiency of food conversion to body matter by Lepidoptera larvae [27]

[28] [29] [30] [31]. Knowledge related to nutritional indices can lead to understanding of the behavioural and physiological basis of insect response to host plants [32]. The presence of secondary phytochemicals in some host plants or absence of primary nutrients necessary for growth and development of the target insect may alter the fitness of *H. armigera* [33]. The rate of developmental, survivorship, reproduction and life table parameters of *H. armigera* larvae could be influenced by the different nutritive values of host plants so that in turn affects the population dynamics of the target insect pests [19]. It has been postulated that using resistant varieties via nutritional indices study [13] [34] as strategic integrated pest management option. Botanicals have also received attention [35] [36] [37] due it's cheaper, environmentally friendly and effectiveness when integrated with other pest management options as natural alternatives to synthetic insecticides. Natural products and plant extracts have capable of deterring or inhibiting oviposition of lepidopteran insects [38] [39] [40] [41]. *Azadirachta indica* Juss. (Meliaceae) extracts from the seed, leaf and neem oil (Nimbecidine) have negative effect on the survival and feeding larvae of *H. armigera* and *Spodoptera eridania* [42]. Furthermore, *A. indica* products have been found to act as oviposition deterrents or repellents ovidal and antifeedant on various insect stages [43] [44]. Seed extract of *Millettia ferruginea* (Hochst.) has been observed to be effective in controlling storage insect pests such as *Callasobruchus chinensis* [45], *Sitophilus zeamais* [46], *Busseola fusca* [47] and *Zebrotres subfaciatus* [48]. However, synthetic insecticides are considered as sole option against *H. armigera* in chickpea production that need other pest management alternatives. Toxicity of *M. ferruginea* was not tested on oviposition deterrents of the moths and larvicidal against *H. armigera*. Moreover, information about development of chickpea pod borer resistant varieties and botanicals pesticides are limited for further development of IPM programme in chickpea against *H. armigera* in Ethiopia. Therefore, the objective of this study was to compare the nutritional indices of different varieties of chickpea, fababean and tomato on *H. armigera* larval instars and to evaluate the larvicidal and ovipositional deterrents of *A. indica* and *M. ferruginea*.

2. Materials and Methods

2.1. Seed Sources

Seeds of the three chickpea (*Cicer arietinum* L.) varieties (Var. *Habru*, *Ararti* and *Natoli*), fababean (*Vicia faba* L.) varieties (Var. *Dagaga*, *Wolki* and *Moti*) and tomato (*Lycopersicon esculentum* Mill) variety (Var. *Kosharti*) were obtained from Debre Zeit, Hollota and Malkassa Agricultural Research Centres, Ethiopia, respectively. These varieties were selected based on their preference for productions among farmers. In some area chickpea was considered as double crop especially in West Showa zone; sown after harvesting the main crop from the field. The host plants were planted in the research field of Ambo University, Main campus in September 2017.

2.2. Laboratory Colony of *H. armigera*

H. armigera larvae were originally collected from chickpea unsprayed farm of Dandi district of West Showa zone, Oromiya region. The farm was located at 09°01. 303', latitude 038°07. 094' longitude and altitude 2285 m.a.s.l. The stock cultures were maintained under a laboratory condition (22°C ± 2°C, 55% ± 5% RH, 12:12 L: D photoperiod) on the leaves and pods of chickpea grown on the field for this purpose. Prior to the experiment the insect had been reared on respective natural hosts (chickpea, faba bean and tomato) for two generations under the above laboratory condition. The first and second larval instars of *H. armigera* were reared in groups of twenty onto a plastic container (17 cm diameter, 6 cm depth with ventilation windows), water-soaked cotton was fitted to ventilation window to avoid leaf drying of each host variety and the remaining third-fifth instar larvae were reared individually in a plastic vials (6 cm diameter, 6.5 cm depth) with the green pods of chickpea and faba beans and leaf/fruits of tomato varieties for a generation as previously reported procedures [17] [49] under laboratory condition. The host plant parts were changed every morning and rearing plastic containers and vials were cleaned every morning throughout the rearing period. The actual experiment was started when the leaves of the host plant varieties were reached the reproductive stage. For this experiment we used the F2 generations from the adult that fed on the natural respective host plants.

2.3. Experiment One: Food Utilization

2.3.1. Treatments

There were seven treatments. The experiment includes three varieties of chickpea, faba bean and a variety of tomato, described above. The experiment was conducted separately with third, fourth and fifth larval instars of *H. armigera* these larval instars were chosen because they are aggressive and can cause huge damage to the crops and they measurable than early instars. *H. armigera* larval instars were reared separately onto plastic vials as indicated above to prevent cannibalism. Each larval instar was provided separately with green pods of each chickpea and faba bean varieties, and fruit and leaves of tomato variety. The treatment was laid out using completely randomized design with three replications. There were 50 larvae per replication for each instar.

2.3.2. Data Collected

The data on food utilization, weight gain and feces produced were collected following the method of [50]. Daily weight of fresh larval foods was weighed prior to feeding them; and left over foods were weighed at the end of each day. Produced feces at the end of each day were measured until pre-pupal stage using sensitive balance. The weights of larvae before and after feeding until they cease feeding were taken daily. The amount of food ingested was estimated by subtracting the weight of food remained at the end from the weight of fresh food supplied for the larval instars. The dry weight of leftover food, faeces and larvae were also determined by drying them to a constant weight in an oven for 48hr, at

60°C. Finally, the nutritional indices were calculated on dry weight basis [50] as follows (Equation 1-5);

$$\text{Relative Consumption Rate (RCR)} = \frac{E}{A \times T} \quad (1)$$

$$\text{Relative Growth Rate (RGR)} = \frac{P}{A \times T} \quad (2)$$

$$\text{Approximate Digestibility (AD)} = \left(\frac{E - F}{E} \right) \times 100 \quad (3)$$

$$\text{Efficiency of Conversion of Digested Food (ECD)} = \left(\frac{P}{E - F} \right) \times 100 \quad (4)$$

$$\text{Efficiency of Conversion of Ingested Food (ECI)} = \left(\frac{P}{E} \right) \times 100 \quad (5)$$

where, A = mean dry weight of insect over unit time (mg), E = dry weight of food consumed (mg), F = dry weight of feces produced (mg), P = dry weight gain of insect (mg) and T = duration of feeding (days).

The data from the whole instar larvae were used to construct a dendrogram line for cluster comparison of the seven treatments.

2.4. Experiment Two: Evaluation of Botanical Extracts against Larvae and Ovipositional Deterrence

2.4.1. Collection and Processing of Botanicals

The seeds *A. indica* were collected from Malkassa Agricultural Research Center and leaves were collected from Adama town, 98 km from Addis Ababa. The seeds of *M. ferruginea* were collected from Ambo University. These collected plant materials were brought to Ambo Plant Science laboratory in December 2017. These botanicals were prepared following the procedures developed by [51] with slight modifications. *A. indica* seeds pulp were removed, cleaned and dried under shade for 2 weeks at room temperature. After removing seed coat, the seeds were powdered using an electric grinder machine. Neem leaves were also shade dried for five days before it was crushed to powder using an electric grinder. Similarly, the pods of *M. ferruginea* were shade dried for three weeks. The seeds were collected from pod coat and powdered separately as indicated above. All the seed and leaf powders were in an airtight container until they were used.

2.4.2. Preparations of Botanical Extracts

The extracted botanicals were prepared at 5% concentration by dissolving 5 kg of botanical seed or leaf powder in 100 liters of water to spray one hectare (Table 1). After mixing water and the powder, it was kept for 48 h while stirring periodically to mix the contents. After, 48 h the contents were filtered three times using muslin cloth. The filtrate was used for the treatment. For a comparison a commercial formulation of *A. indica*, 50% neem oil (Ariti Herbal product) was provided by Addis Ababa University, College of Natural Science, Addis Ababa, Ethiopia.

Table 1. Details of treatments used for bioassay.

S/N	Treatments	Treatment descriptions
1	5%NLE	5% water extract of <i>A. indica</i> leaf
2	5% NSE	5% water extract of <i>A. indica</i> seeds
3	50% NO	50% oil extract of <i>A. indica</i> seeds
4	5% BSE	5% water extract of <i>M. ferruginea</i> seeds
5	2.5% NLE	2.5% water extract of <i>A. indica</i> leaf
6	2.5% NSE	2.5% water extract of <i>A. indica</i> seeds
7	2.5% BSE	2.5% water extract of <i>M. ferruginea</i> seeds
8	UC	Untreated (control) treated with dH ₂ O
9	SCH	Control treated with the standard synthetic Deltamethrin 25% E C at recommended rate

The rates of crude botanical extracts were estimated by using the following formula (Equation 6);

$$C = \frac{W}{V} \times 100 \quad (6)$$

where; C = percent concentration of botanicals, W = Weight of solute (botanicals), V = Volume of solution (volume of botanical + volume of solvent (water))

2.5. Treatment Application

There were seven treatments and two controls, as described in **Table 1**. The treatments were at 5% and 2.5% water extract of *A. indica* leaf and seeds, 50% oil extract of *A. indica* seeds, 5% and 2.5% water extract of *M. ferruginea* seeds, and there were treated and untreated control. In untreated control distilled water was used; whilst in treated control the insecticide, Deltamethrin 25% EC was used. The treatment was arranged in completely randomized design with three replications. For this experiment, the larval rearing technique described above was used. Laboratory larval bioassay was conducted using larval immersion techniques described by [42] with slight modification. We used 50 larvae per replication. Each larva was immersed onto the botanical suspensions for 30 seconds then after, the larvae were placed on clean filter paper. When they started to crawl, they were transferred to plastic rearing vials (size indicated above) provided with fresh green chickpea pods daily.

2.6. Data Collected

Larval mortality was recorded starting immediately after treatment applications. Larvae are assumed to be dead when not responding to touch. Based up on the percent larval mortality of each treatment, four botanical extracts were selected to evaluate oviposition deterrence against adult moth of *H. armigera* via no-choice oviposition test. The treatments were 5% water extract of *A. indica* leaf, 5% water extract of *A. indica* seeds, 50% oil extract of *A. indica* seeds, 5%

water extract of *M. ferruginea* seeds, and untreated control. The treatment were arranged in completely randomized design and replicated three times. A newly hatched pair of moth, (one female and one male moth), from the stock populations were placed into oviposition cages (30 × 30 cm). A single planted chickpea (variety *Habru*) on plastic pot (20 cm top, 13.5 cm bottom and 20 cm length) 65 - 70 days old were sprayed with the help of hand pressurized sprayer with 30 ml of each treatment when they are at 25% flowered. The treated chickpea pot were kept at room temperature until the applied treatments be dried. Then, after we confirmed the confinement of the paired moths within the oviposition cages, each treated potted chickpea plant was placed inside the cages separately. After 24 h, evaluations on the number of eggs laid on each treatment were conducted and oviposition deterrent indices (ODI) were calculated following [52] as follows (Equation 7):

$$ODI = \frac{100(C - T)}{C + T} \quad (7)$$

where, *C* and *T* are the mean number of eggs laid on control and treated leaves, respectively.

2.7. Data Analysis

Prior to analysis, the nutritional indices parameters were checked for normality by Kolmogorov-Smirnov method. The parameters were analysed with one-way ANOVA using SAS statistical software to determine the similarities or differences. Statistical differences among the means were evaluated using the LSD test at 5% level of significance. The data of whole larval instars were used for cluster analysis which was done using SAS software by Ward's method. Data on percent larval mortality, number of eggs laid and oviposition deterrence were log-transformed before analysis and analysed with a one-way ANOVA. Differences among treatments were determined with a Tukey test.

3. Results

There were significant differences among values of the relative consumption rate ($F = 34.57$; $df = 6, 2$; $p < 0.0001$), relative growth rate ($F = 8.25$; $df = 6, 2$; $p < 0.0006$), efficiency of conversion of digested ($F = 485.21$; $df = 6, 2$; $p < 0.0001$) and ingested ($F = 310.85$; $df = 6, 2$; $p < 0.0001$) food, and approximate digestibility ($F = 47.39$; $df = 6, 2$; $p < 0.0001$) of different host varieties to nutritional indices of the third larval instars (**Table 2**). Maximum ($5.600\% \pm 0.264\%$) RCR% of the third larval instar was recorded from larvae fed on *Dagaga* which is on par with *Wolki* ($5.133\% \pm 0.185\%$) and minimum was obtained from chickpea varieties (*Ararti*, *Natoli*, *Habru*) and *Koshari* varieties.

With regard to RGR, higher values ($0.2233 \pm 6.66 - 0.21160 \pm 0.006$) were observed on chickpea varieties, whilst the lowest was recorded from larvae fed on *Koshari*, this was not significantly different with the values of *Wolki* and *Moti* faba bean varieties. Higher ($6.737 \pm 0.073 - 6.800\% \pm 0.115\%$) ECI value was

Table 2. Nutritional indices (mean \pm SE) of third instar larvae of *H. armigera* on different chickpea and faba bean varieties and tomato.

Hosts	Varieties	RCR	RGR	ECI (%)	ECD (%)	AD (%)
Chickpea	Ararti	3.450 \pm 0.05 ^c	0.2250 \pm 0.002 ^a	6.737 \pm 0.073 ^a	9.7 \pm 0.057 ^a	17.33 \pm 0.88 ^e
	Habru	3.420 \pm 0.06 ^c	0.21160 \pm 0.006 ^{ab}	6.800 \pm 0.115 ^a	9.0 \pm 0.057 ^b	22.67 \pm 1.45 ^{de}
	Natoli	3.403 \pm 0.146 ^c	0.2233 \pm 6.66 ^a	6.767 \pm 0.088 ^a	9.033 \pm 0.145 ^b	23.67 \pm 2.603 ^d
Faba bean	Dagaga	5.600 \pm 0.264 ^a	0.2007 \pm 0.005 ^{bc}	3.367 \pm 0.088 ^{bc}	4.167 \pm 0.088 ^d	38.33 \pm 2.401 ^b
	Wolki	5.133 \pm 0.185 ^{ab}	0.1847 \pm 0.003 ^{cd}	3.067 \pm 0.133 ^c	5.167 \pm 0.068 ^d	39.67 \pm 0.666 ^b
	Moti	4.990 \pm 0.105 ^b	0.1913 \pm 0.112 ^{cd}	3.600 \pm 0.057 ^b	5.167 \pm 0.240 ^c	31.67 \pm 2.026 ^c
Tomato	Koshari	3.567 \pm 0.22 ^c	0.1817 \pm 0.005 ^d	2.567 \pm 0.176 ^d	3.033 \pm 0.088 ^e	53.67 \pm 1.766 ^a

The means followed by different letters in the same columns are significantly different (LSD, $P < 0.05$, LSD); RCR, relative consumption rate; RGR, relative growth rate; ECI (%), efficiency of conversion of ingested food; ECD (%), efficiency of conversion of digested food; AD (%), approximate digestibility.

recorded from the varieties of chickpeas and 9.7% \pm 0.057% was the maximum value of ECD recorded from *Ararti* followed by *Habru* and *Natoli*. Whereas, the lowest values of both ECI (2.567% \pm 0.176%) and ECD (3.033% \pm 0.088%) were on *Koshari*. The third instar larvae reared on *Koshari* had the highest (53.67% \pm 1.766%) AD value (**Table 2**). The result also reveals a significant difference on the values of RCR ($F = 71$; $df = 6, 2$; $p < 0.05$), ECI ($F = 39.66$; $df = 6, 2$; $p < 0.0001$), ECD ($F = 143.21$; $df = 6, 2$; $p < 0.0001$) and AD ($F = 615.20$; $df = 6, 2$; $p < 0.05$), however there was statistically no significant different values of RGR ($F = 2.54$; $df = 6, 2$; $p = 0.07$) of the fourth larval instars (**Table 3**). The highest (7.067 \pm 0.233) RCR value were obtained from instar larvae reared on *Koshari* whereas, the lowest (4.177 \pm 0.090) was from *Habru* which is statistically similar with the value of *Natoli* variety.

The highest values of ECI (7.550 \pm 0.149 - 7.797% \pm 0.118%) and ECD (38.40 \pm 0.737 - 40.33% \pm 1.766%) of the fourth instar of *H. armigera* were on *Ararti*, *Habru* and *Natoli* varieties, there was statistically no difference on these varieties with regard to the fourth larval instars. While, the lowest (4.973% \pm 0.188%) ECI and ECD (15.89% \pm 0.053%) was from *Koshari* variety. Maximum (66.73% \pm 0.733%) of AD were recorded from *Koshari* and the minimum (33.52% \pm 0.289%) was from *Moti* which is similar with the value of *Wolki* (**Table 3**).

There were significant difference with regard to RCR ($F = 57.96$; $df = 6, 2$; $p < 0.001$), RGR ($F = 3.10$; $df = 6, 2$; $p = 0.0451$), ECI ($F = 36.02$; $df = 6, 2$; $p < 0.001$), ECD ($F = 138.22$; $df = 6, 2$; $p < 0.001$) and AD ($F = 606.37$; $df = 6, 2$; $p < 0.0001$) values of the fifth larval instar of *H. armigera* (**Table 4**). The highest value of RCR (0.04717 \pm 0.0015) and RGR (0.5423 \pm 0.062) were recorded from the larvae reared on *Koshari* and lower values were from *Habru* and *Natoli* for RCR and chickpea and faba bean varieties for RGR values. Higher value of ECI (22.68 \pm 0.277 - 22.70% \pm 0.344%) and ECD (50.60 \pm 0.973 - 53.24% \pm 2.326%) values were obtained from larvae reared on varieties chickpea, followed by varieties of faba beans.

Table 3. Nutritional indices (mean \pm SE) of fourth instar larvae of *H. armigera* on different chickpea and fababean Varieties & tomato.

Hosts	Varieties	RCR	RGR	ECI (%)	ECD (%)	AD (%)
Chickpea	Ararti	4.587 \pm 0.059 ^d	0.7083 \pm 0.036 ^a	7.790 \pm 0.095 ^a	38.44 \pm 0.345 ^a	38.66 \pm 0.357 ^c
	Habru	4.177 \pm 0.090 ^e	0.6893 \pm 0.032 ^a	7.797 \pm 0.118 ^a	40.33 \pm 1.766 ^a	40.37 \pm 0.316 ^b
	Natoli	4.383 \pm 0.441 ^{de}	0.6303 \pm 0.057 ^a	7.550 \pm 0.149 ^a	38.40 \pm 0.737 ^a	39.22 \pm 0.276 ^{bc}
Faba bean	Dagaga	5.633 \pm 0.066 ^b	0.6800 \pm 0.055 ^a	6.300 \pm 0.115 ^{bc}	24.27 \pm 0.442 ^b	35.34 \pm 0.654 ^d
	Wolki	5.267 \pm 0.120 ^c	0.5903 \pm 0.047 ^{ab}	5.873 \pm 0.150 ^c	24.81 \pm 0.452 ^b	34.18 \pm 0.416 ^{de}
	Moti	5.133 \pm 0.088 ^c	0.6213 \pm 0.040 ^a	6.567 \pm 0.296 ^b	24.60 \pm 0.452 ^b	33.52 \pm 0.289 ^e
Tomato	Koshari	7.067 \pm 0.233 ^a	0.4807 \pm 0.062 ^b	4.973 \pm 0.188 ^d	15.89 \pm 0.053 ^c	66.73 \pm 0.733 ^a

The means followed by different letters in the same columns are significantly different (LSD, $P < 0.05$, LSD); RCR, relative consumption rate; RGR, relative growth rate; ECI (%), efficiency of conversion of ingested food; ECD (%), efficiency of conversion of digested food; AD (%), approximate digestibility.

Table 4. Nutritional indices (mean \pm SE) of fifth instar larvae of *H. armigera* on different chickpea and Fababean Varieties and tomato.

Hosts	Varieties	RCR	RGR	ECI (%)	ECD (%)	AD (%)
Chickpea	Ararti	0.03144 \pm 4.058 ^c	0.3147 \pm 0.036 ^b	22.68 \pm 0.277 ^a	50.75 \pm 0.456 ^a	29.47 \pm 0.357 ^c
	Habru	0.02863 \pm 6.212 ^d	0.3337 \pm 0.032 ^b	22.70 \pm 0.344 ^a	53.24 \pm 2.326 ^a	31.18 \pm 0.316 ^b
	Natoli	0.03004 \pm 3.019 ^{cd}	0.3927 \pm 0.057 ^b	21.99 \pm 0.434 ^a	50.60 \pm 0.973 ^a	30.03 \pm 0.276 ^{bc}
Fababean	Dagaga	0.03760 \pm 4.451 ^b	0.3430 \pm 0.055 ^b	18.35 \pm 0.336 ^{bc}	32.04 \pm 0.584 ^b	26.15 \pm 0.654 ^d
	Wolki	0.03579 \pm 0.001 ^b	0.4327 \pm 0.049 ^b	17.10 \pm 0.438 ^c	32.74 \pm 0.562 ^b	24.99 \pm 0.416 ^{de}
	Moti	0.03518 \pm 6.045 ^b	0.4017 \pm 0.040 ^b	19.12 \pm 0.862 ^b	32.47 \pm 0.596 ^b	24.33 \pm 0.289 ^e
Tomato	Koshari	0.04717 \pm 0.0015 ^a	0.5423 \pm 0.062 ^a	14.48 \pm 0.547 ^d	20.98 \pm 0.070 ^c	57.55 \pm 0.733 ^a

The means followed by different letters in the same columns are significantly different (LSD, $P < 0.05$, LSD); RCR, relative consumption rate; RGR, relative growth rate; ECI (%), efficiency of conversion of ingested food; ECD (%), efficiency of conversion of digested food; AD (%), approximate digestibility.

Compared to other varieties the lowest (ECI; 14.48% \pm 0.547%, ECD; 20.98% \pm 0.070%) values were recorded on *Koshari* from which the highest (57.55% \pm 0.733%) value of AD was recorded (**Table 4**).

With regard to the value of nutritional indices of the whole larval instars (third to fifth) of *H. armigera* on the seven varieties, there were significant difference among the values ECD ($F = 175.91$; $df = 6, 2$; $p < 0.05$), ECI ($F = 80.06$; $df = 6, 2$; $p < 0.05$) and AD ($F = 215.2$; $df = 6, 2$; $p < 0.05$) (**Table 5**). The values for RCR were the highest (11.271 \pm 0.328) on *Dagaga* which is statistically similar value with *Koshari* (10.681 \pm 0.319) and lower (7.625 \pm 0.057 - 8.068 \pm 0.108) on chickpea varieties.

The highest (1.248% \pm 0.002%) was recorded on *Ararti* variety; statistically similar value with *Natoli* and *Habru* whereas, the lowest (1.205% \pm 0.005%) was from *Koshari* which is on par with *Moti* and *Wolki* values for RCR. Among the varieties tested, maximum (36.30 \pm 0.605 - 37.30% \pm 0.415%) for ECI and (98.13 \pm 1.772 - 102.57% \pm 4.053%) for ECD was recorded from larvae reared on *Habru/Ararti/Natoli* varieties and followed by faba bean varieties. The lowest (ECI = 22.02% \pm 0.887%; ECD = 39.91% \pm 0.072%) for *Koshari*. Furthermore,

Table 5. Nutritional indices (mean \pm SE) of whole instar larvae of *H. armigera*.

Hosts	Varieties	RCR	RGR	ECI (%)	ECD (%)	AD (%)
Chickpea	Ararti	8.068 \pm 0.108 ^c	1.248 \pm 0.002 ^a	37.21 \pm 0.443 ^a	98.89 \pm 0.857 ^a	85.5 \pm 1.391 ^e
	Habru	7.625 \pm 0.057 ^c	1.239 \pm 0.006 ^{ab}	37.30 \pm 0.415 ^a	102.57 \pm 4.053 ^a	94.2 \pm 0.951 ^{bcd}
	Natoli	7.817 \pm 0.102 ^c	1.246 \pm 6.639 ^a	36.30 \pm 0.605 ^a	98.13 \pm 1.772 ^a	92.9 \pm 2.754 ^{cd}
Faba bean	Dagaga	11.271 \pm 0.328 ^a	1.224 \pm 0.005 ^{bc}	28.01 \pm 0.430 ^{bc}	60.47 \pm 0.978 ^b	99.8 \pm 3.602 ^b
	Wolki	10.436 \pm 0.319 ^b	1.208 \pm 0.003 ^{cd}	26.04 \pm 0.486 ^c	62.69 \pm 1.050 ^b	98.8 \pm 1.246 ^{bc}
	Moti	10.159 \pm 0.062 ^b	1.214 \pm 0.011 ^{cd}	29.29 \pm 1.143 ^b	62.23 \pm 1.287 ^b	89.5 \pm 2.430 ^{de}
Tomato	Koshari	10.681 \pm 0.319 ^{ab}	1.205 \pm 0.005 ^d	22.02 \pm 0.887 ^d	39.91 \pm 0.072 ^c	177.9 \pm 1.928 ^a

The means followed by different letters in the same columns are significantly different (LSD, $P < 0.05$, LSD); RCR, relative consumption rate; RGR, relative growth rate; ECI (%), efficiency of conversion of ingested food; ECD (%), efficiency of conversion of digested food; AD (%), approximate digestibility.

the highest (177.9% \pm 1.928%) value of AD was determined from *Koshari* and the lowest (85.5% \pm 1.391%) was from *Ararti*, but similar value with *Moti* of the whole instar larvae of *H. armigera* (Table 5).

The result of the dendrogram showed three distinct clusters labelled as A (sub clusters A1 and A2), B (sub clusters B1 and B2) and line C. Cluster A included subclusters A1 (*Habru*); A2 (*Natoli* and *Ararti*), whereas cluster B included B1 (*Moti*); B2 (*Dagaga* and *Wolki*) and Line C consisted of *Koshari* (tomato) indicating that *Habru* (Chickpea) and *Moti* (Faba bean) as intermediate group, *Koshari* as partially resistant line to the larvae of *H. armigera* (Figure 1).

There were significant differences between treatments ($F = 11.45$, $df = 8$, $p < 0.0001$) in causing mortality to the third larval instar of *H. armigera* (Figure 2). Deltamethrin 25% EC (SCH) has resulted in 100% larval mortality.

Compared to botanical extracts, high larval mortality was achieved when treated with *A. indica* oil extract at 50% (50%NO), *M. ferruginea* at 5% (5% BSE) and *A. indica* seed extract gave similar results, followed by leave extracts of *A. indica* at 5%. Similarly, there were significant differences between treatments ($F = 7.88$, $df = 4$, $p = 0.0059$) in affecting number of eggs laid by the female moths (Figure 3). The least number of eggs was laid by the moth when chickpea was sprayed with 5% *M. ferruginea* (5% BSE) seed extract followed by 50% *A. indica* oil extract (50% NO) compared to the other treatments. *A. indica* seed and leaf extract at 5% concentration gave similar results in affecting egg lying.

In no choice experiment there were significant differences between treatments ($F = 45.21$, $df = 4$, $p = 0.0001$) in deterring the oviposition of *H. armigera* moth adults (Figure 4).

The deterrent effect of 50% *A. indica* oil extract (50% NO) was stronger (ODI = 17.66%), followed by 5% *M. ferruginea* (5% BSE) seed extract (ODI = 14%) and *A. indica* seed and leaf extract at 5% concentration (5%NSE) (ODI = 13%). The least deterrent effect was when treated by 5% *A. indica* leaf extracts (Figure 4).

4. Discussion

H. armigera is a highly polyphagous destructive pest insect of many economically crucial crops [14] [18] [53]. Applying resistant cultivars plays a key role in

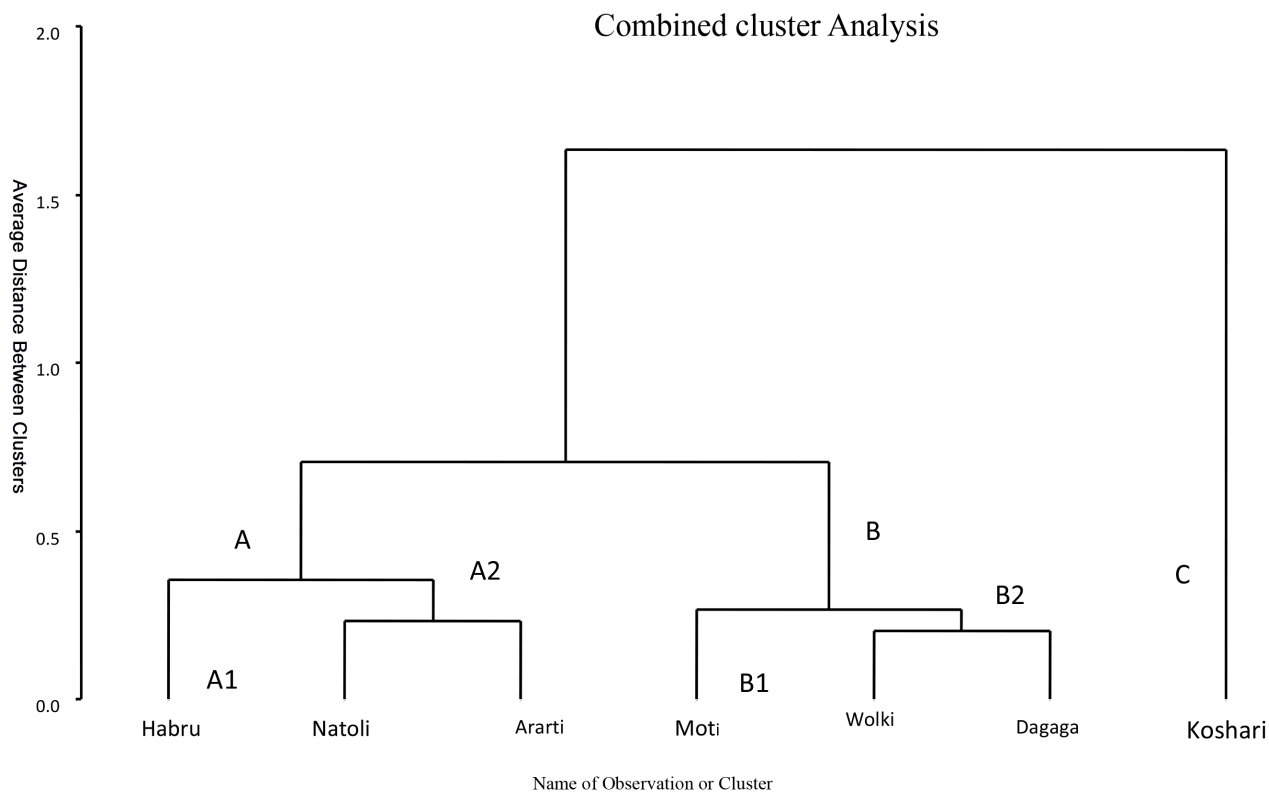


Figure 1. Dendrogram of nutritional indices of *H. armigera* reared on different varieties of chickpeas, Fababean and tomato.

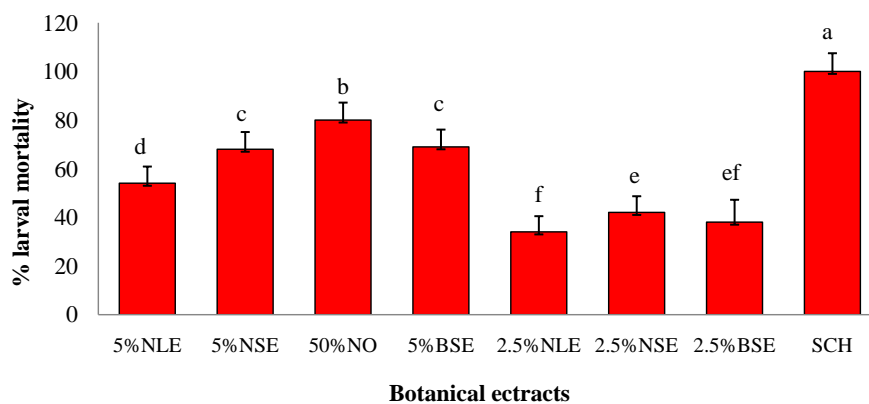


Figure 2. Mean (\pm SE) percent larval mortality of the 3rd larval instars of *H. armigera* to various concentrations of botanical products. Bars with the same letters are not significantly different (ANOVA; Tukey test; $\alpha = 0.05$). Note: 5%NLE, 5% water extract of neem leaf; 5% NSE, 5% water extract of neem seeds; 50%NO, 50% oil extract of neem seeds; 5%BSE, 5% water extract of birbira seeds; 2.5% NLE, 2.5% water extract of neem leaf; 2.5% NSE, 2.5% water extract of neem seeds; 2.5% BSE, 2.5% water extract of birbira seeds; UC, Untreated (control) treated with dH₂O; SCH, Control treated with the standard synthetic Deltamethrin 35% EC at recommended rate.

integrated pest management programs for any crop plant resistance to pests [34] [54] [55]. As paramount measurement of host plant resistance, the ability of insect larvae to utilize the host plants was crucial. Insect fitness was determined by different nutritional values of the host plants [56] [57] [58]. The current result

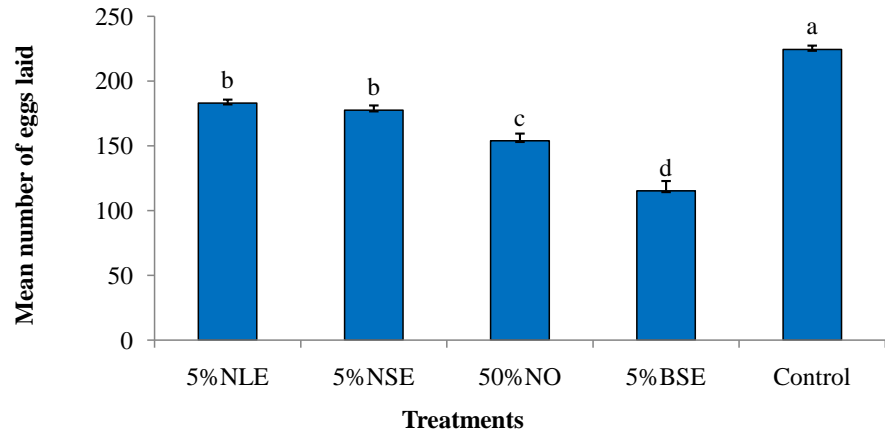


Figure 3. Mean (\pm SE) number of eggs laid by adult moths of *H. armigera* on botanically treated chickpea plants. Bars with the same letters are not significantly different (ANOVA; Tukey test; $\alpha = 0.05$). Note: 5%NLE, 5% water extract of neem leaf; 5% NSE, 5% water extract of neem seeds; 50%NO, 50% oil extract of neem seeds, 5%BSE, 5% water extract of birbira seeds.

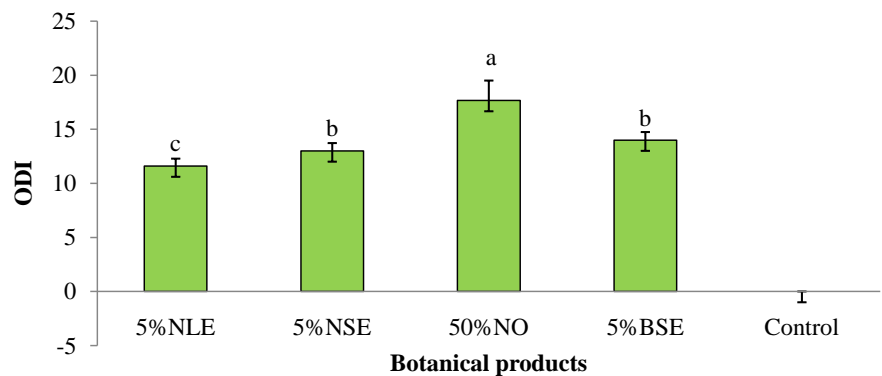


Figure 4. Mean (\pm SE) number of oviposition deterrent indices to adult moths of *H. armigera* as affected by botanically treated chickpea plants. Bars with the same letters are not significantly different (ANOVA; Tukey test; $\alpha = 0.05$). Note: ODI = Oviposition deterrence index. 5%NLE, 5% water extract of neem leaf; 5% NSE, 5% water extract of neem seeds; 50%NO, 50% oil extract of neem seeds, 5%BSE, 5% water extract of birbira seeds.

demonstrated that, there was a difference among the nutritional indices parameters of the different varieties tested on larval instars of *H. armigera*. The variation in the value of nutritional indices observed among varieties in the present finding may dependent on the durations of larval feeding periods and protein content of the host plants used for the experiment. Previously research output stated, low protein content in host plants/diet can cause an increase in the rate at which the larvae feed [30] [59] [60]. Legumes such as pigeon pea, pea and chickpea had the highest protein content and tomato had very low protein content [61]. Particularly, the efficiency of conversion of ingested food and efficiency of conversion of digested food values were different among the host plant varieties which suggests the intrinsic variations among the host plant varieties; different nutritional values [56] [57] [58] and chemical composition of the hosts

such as allelochemicals [62] could be the reason for the variation.

It has been postulated that ECI is a general index of an insect's ability to use the food consumed and may vary with the digestibility of food and the proportional amount of the digestible portion of food which is converted to body mass and metabolized for energy needed for vital activity like growth and development [63] [64]. ECI is an index of the efficiency of conversion of digested food into growth [65]. Therefore, change in ECI is an indication of the overall increase or decrease of the proportion of digested food metabolized for energy [17], whereas, no change in ECI or ECD% values indicate that ingested secondary biochemicals do not exhibit any chronic toxicity to the insects [62] [63]. Such difference or variation between host plant varieties can affect an insect development and growth. Third instar larvae fed on *Koshari* had the highest AD and almost the lowest ECI and ECD values. In line with our result, [30] found the highest AD and lowest ECD of the third instar *H. armigera* larvae when reared on chickpea *Hashem*. Higher value of ECI and ECD was recorded on chickpea varieties, followed by faba bean varieties in instar larvae of *H. armigera*. It's reported that the physiological, metabolic and behavioural changes in the nervous system among penultimate and ultimate instar larvae reared on different host plants are perhaps partially responsible for the differences in such increases/or/and decreases in the values of ECD and ECI [30] [66]. In addition, to the above reason there could be a result of changes at the level of digestive enzymes, for instance the midgut proteinase levels of *H. armigera* reached its maximum in the penultimate instar and were decreased in the ultimate instar [30] [67]. Also effected by the host plants/diet they fed on [19] [31] [61] [68].

The ECI and ECD values showed an increased trend from third to fifth instar in most cases. An increasing of ECI and ECD values from the third to fifth larval instar indicated a higher efficiency of the conversion of ingested and digested food to body biomass. Increases in ECD from early to late instars were reported by [30] [68]. Maximum food intake was recorded during fourth-fifth larval instars of *H. armigera*. Hence, this instar could potentially cause damage on the host plants. Therefore, control of *H. armigera* should be considered before fourth instar. In *H. armigera*, maximum food intake occurs during the penultimate instar, and feeding slows down or stops in the ultimate instar [30]. For the whole larval instars, the highest ECI and ECD values were on chickpea varieties suggesting that the larvae were more efficient at conversion of ingested and digested food to body biomass with a high increase in larval weight when they reared on varieties of chickpea in this experiment. The slight variation observed among the same host of different varieties on the value of ECI and ECD may be due to the difference in nutritional quality, contents of secondary metabolic products of the varieties or/and other factors. Accordingly the report of [69] a lepidopteran larva fed on high nutrient food increase growth rates and complete the development period faster than larvae fed on low nutrient food. Highest AD% value of the whole larval instars of *H. armigera* was on *Koshari*, indicating that the rate of intake relative to the mean larval dry weight gained during the

feeding period was lower than other host varieties and an indication for the larvae feeding on this host were less effective in converting ingested and digested food to biomass. Possibly due to the lack of nutritional components and presence of some secondary chemicals which confirms that tomato *Koshari* was not suitable host for rearing of the *H. armigera* larvae. [70] reported that the degree of food utilization depends on the digestibility of food and the efficiency with which digested food is converted into biomass. Unsuitability, of potato germplasm (*Morene*) when fed to *Phthorimaea operculella* was also reported by [30] and [31] also found minimum ECD and ECI values when *H. armigera* reared on tomato *Meshkin*. Furthermore, tomato itself is not a fine host plant for *H. armigera* larvae, as previous works have shown [16]. Tomato acidity/orthodihydroxy phenols may be negatively correlated with larval feeding [33] [71]. In addition, this value was similar to the report by [28] on varieties of tomato, [72] on *Sorghum vulgare* (69.33%) and *Gossypium hirsutum* var. NIAB-98 (66.15%).

The cluster analysis represented here indicated that grouping within each cluster might be due to a high level of physiological similarity of different varieties of the same host plants or due to variability in physiological characters of the varieties clustered. Line C (*Koshari*) was the least suitable and subcluster A₂ which consists of *Natoli* and *Ararti* was the most suitable varieties for *H. armigera* and followed by A₁ (as an intermediate for chickpea variety; *Habru*), B₂ (*Wolki* and *Dagaga*) and B₁ (as an intermediate for fababean variety; *Moti*). This result is related to the finding of [16] who reported that the suitability of host plants is classified as follows (descending in suitability): cotton, corn, legume, tobacco, tomato, and hot pepper. In our case we found that varieties of chickpea, fababean and tomato were clustered accordingly their suitability for *H. armigera*. [30] also reported the unsuitability of tomato *Meshkin* as a host for *H. armigera*.

This study demonstrates that *A. indica* oil extract at 50% (50%NO) is effective in causing high larval mortality. The high larval mortality in oil (50%) could be due to high concentration of azadirachtin in the seeds of *A. indica*. High larval mortality of *H. armigera* due to seed extracts of *A. indica* was reported by [42] when treated at high concentration. *M. ferruginea* at 5% (5%BSE) were effective in reducing/inhibiting egg laying by adult moth of *H. armigera*. This indicates that the active principles present in the botanical extracts had altered or deterred the oviposition of adult moths of *H. armigera*. It was previously reported that, the toxicity of *M. ferruginea* can be attributed due to rotenone which is one of the dominant compounds found in the seed and stem bark of *M. ferruginea* and is a well-known botanical insecticide through contact and stomach poisoning [73] [74] [75]. In line to the present finding, high toxicity of *M. ferruginea* seeds to *Sitophilus zeamais* [73], *Callisobruchus chinunesis* [15] was reported. In study by [76] fewer eggs were oviposited by *Plutella xylostella* on the plants that had been treated with leaf extracts of *Melia azedarach* under laboratory and glass-house trials. Rotenone has been found to deter the oviposition of *Monochamus alternates* Hope [77] and *C. maculatus* [78]. [45] also reported that oils of *M. ferruginea* and *A. indica* was able to effectively control *C. chinunesis* from stored

faba bean preventing egg laying (antioviposition properties). Recently, [40] reported that Yam bean seed extract and coumarin showed a deterrent effect to *P. xylostella* adult.

5. Conclusion

In conclusion studying nutritional indices of insects leads to better understanding of insect behaviour and physiological activities, in turn host variations, host suitability, resistance and it gives direction towards development of integrated pest management of *H. armigera*. ECI and ECD values of the *H. armigera* larval instars were the highest on chickpea followed by faba bean varieties. The larvae fed on the tomato *Koshari* variety had the lowest value of ECI and ECD, which suggests that these larvae were apparently not as efficient in turning digested food into biomass. The result for cluster analysis indicated chickpea variety *Habru* as an intermediate for resistance against *H. armigera*. Incorporation of botanical extracts either locally extracted or commercially available *M. ferruginea* at 5% seeds and *A. indica* oil extract at 50% (50%NO) extracts were effective in causing larval mortality and deterring the oviposition capacity of the adult by altering the subsequent population of *H. armigera*. Hence, the use of *Habru* chickpea variety with 50% (50%NO) extracts were effective in managing the larval and adult stages of *H. armigera*. This finding can be applied to design a comprehensive IPM strategy to *H. armigera* in major hosts. Future research has to focus on the use of host plant resistant and botanical extracts as it has receiving emphasise as a part of integrated pest management tools due to its economic feasibility, eco-friendly and social acceptance of the tactic.

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Disclosure Statement

No potential conflict of interest was reported by the authors.

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