Research Article

The Impact of Variation in Foliar Constituents of Sunflower on Development and Reproduction of *Diacrisia casignetum* Kollar (Lepidoptera: Arctiidae)

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Received 22 March 2012; Revised 18 May 2012; Accepted 24 May 2012

Academic Editor: G. B. Dunphy

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Effects of feeding on young, mature, and senescent sunflower leaves were studied under laboratory conditions ($27 \pm 0.5^\circ\text{C}$, 12L:12D, $65 \pm 5\%$ RH) to evaluate the impact of variation of nutrients on larval food utilization efficiency, larval and pupal development and survival, longevity, and fecundity of *Diacrisia casignetum* Kollar. The growth rate, which is the ratio between the dry weight gain of insect and duration of experimental period, of *D. casignetum* was in the order of mature leaf > young leaf > senescent leaf of sunflower. This was correlated with nutrient constituents of three kinds of sunflower leaves, which was measured by various biochemical analyses described elsewhere in the text. Total carbohydrates, proteins, lipids, nitrogen, amino acids, and water content are in greater amount in mature leaves when compared to young and senescent leaves, whereas phenol content was highest in young leaves than mature leaves. Hence, higher amount of total carbohydrates, proteins, lipids, nitrogen, amino acids including water and lower amount of total phenol content in mature leaves have influenced higher growth rate, less developmental time, and higher fecundity of *D. casignetum*.

1. Introduction

Diacrisia casignetum Kollar (Lepidoptera: Arctiidae) is an important economic pest in India and many other Asian countries [1]. The species is highly polyphagous, which is one of the major factors contributing to the pest status of this moth. Important agricultural crops such as sunflower, jute, sesame, and castor are among the host records in India. The occurrence of this arctiid moth has long been recorded in sunflower plant, and now it has been proved a serious defoliator in recent years [1]. The larvae of this arctiid moth feeds gregariously on sunflower leaves leaving mid ribs only and causes economic losses of this oil seed crop based on the crop stage and infestation level in the field [1].

Host plant quality is a key determinant of herbivorous insect which affects fecundity, growth rate, and development of insect [2]. Variation in development, survival, and fecundity of phytophagous insects is mainly due to variation

in qualitative and quantitative amounts of nutrients among host plants including change in the nutritional quality of leaves within a particular host plant during its different developmental stages [3]. Herbivores of polyphagous nature often show better development, survival, and reproduction on mature leaves than young leaves within a plant because of higher level of toxic secondary substances in young leaves [4, 5]. Hence, it will be interesting to observe whether mature leaves of sunflower are more nutritious to this arctiid moth than young and senescent sunflower leaves. The previous study on the biological parameters of *D. casignetum* on sunflower and hempweed leaves indicated influences of host plants, that is, a crop and a weed, on development of this insect pest [6]. But there are no reports on food utilization, development, and reproduction of *D. casignetum* by feeding on young, mature, and senescent sunflower leaves. So, in this study, we examined the role of sunflower leaves throughout its developmental stage on

food utilization efficiency, larval and pupal development and survival, longevity, and fecundity of the arctiid moth, *D. casignetum*.

2. Materials and Methods

2.1. Insect Rearing. *Diacrisia casignetum* adults (male and female) were originally collected from the field near Chin-surah Rice Research Center (22°53' N, 88°23' E), West Bengal, India and were subsequently reared in cages (50 cm × 50 cm × 50 cm) containing fresh young (1–2 weeks old), mature (2–4 weeks old) and senescent (5–7 weeks old) sunflower (cv. PAC-36) leaves separately for oviposition of *D. casignetum*. Two pairs of newly emerged adult males and females were released in sterilized glass jars (20 cm × 10 cm) covered with a fine nylon net at 27 ± 0.5°C, 12L: 12D, 65 ± 5% relative humidity. The adults were fed with 10% sucrose solution through a cotton ball in a small Petri dish (2 cm × 1 cm). The host plant leaves (i.e., young, mature and senescent leaf) used in this study were given for oviposition separately in different sterilized glass jars. To maintain natural condition of leaves, a moist piece of cotton was placed around the cut ends of leaves followed by wrapping with aluminum foil to prevent moisture loss. Fresh leaves were given daily by replacing the previous one until eggs were laid by the test insects, and the eggs with each kind of host plant leaves were placed in new sterilized glass jars separately. *Diacrisia casignetum* larvae developed from the eggs had been fed with the respective kind of sunflower leaf separately for three generations, and from the fourth generations, the comparative rate of development of this insect on each kind of sunflower leaf was enumerated depending on the total body weight and duration of postembryonic development. To study the duration of larval development, the fourth generation eggs were separated and reared separately in sterilized glass jars containing 20 larvae on each kind of leaf and observations were noted on their incubation period and duration of each larval stage during their respective development.

The weight gain of insects, the weight of food consumed, and the weight of faeces produced were determined in a monopan balance (±0.01 mg). Fourth generation larvae of approximately same size were selected and weighed initially and were reared separately on young, mature, and senescent sunflower leaves into separate sterilized glass jars. They were allowed feeding on weighed quantity of each kind of leaf for 24 h separately as no-choice bioassay and were reweighed. The fresh weight gain during each instar was estimated by determining the differences in weight of larvae (by subtracting initial and final weight during the period of study). Ten larvae from each of the instar fed on each kind of leaf were weighed and dried in a hot air oven and weighed again to determine the percentage dry conversion value which was used to estimate dry weight of experimental larvae. The three kinds of sunflower leaves were left after 24 h of insect feeding and were oven dried, and weighed to determine dry weight gain of the diet given to the larvae. Sample leaves from the each kind of leaf were weighed,

oven dried and reweighed to estimate percent dry weight conversion values to allow estimation of the dry weight of the diet supplied to the larvae. The quantity of the food consumed was estimated by determining the difference between the dry weight of diet remaining at the end of each experiment and total dry weight of diet initially provided. Twenty larvae were used in each kind of sunflower leaf treatment for each instar, and each instar had five replicates with a particular type of leaf.

2.2. Oviposition Assay. This experiment was conducted by taking laboratory reared third generation male and female adults of same age that were reared on the three kinds of sunflower leaves separately. The adults were released into separate sterilized glass jars (20 cm × 10 cm) at a sex ratio of 1 : 1 to note their mating, egg laying behavior, and further developmental stages. The adults were fed with 10% sucrose solution through a cotton ball in a small glass Petri dish (2 cm × 1 cm). After mating, the females were allowed to oviposit for 48 h, and the number of eggs was recorded for each kind of leaf per female.

2.3. Food Utilization Indices. Food utilization indices (all based on dry weight) were calculated based on the formulas of Waldbauer [7] with slight modifications [8–11] to assess the feeding efficiencies of *D. casignetum* as follows:

$$\text{growth rate (GR)} = P/Q,$$

$$\text{consumption rate (CR)} = R/Q,$$

$$\text{relative growth rate (RGR)} = P/QS,$$

$$\text{consumption index (CI)} = R/QS,$$

$$\text{approximate digestibility (AD) (\%)} = 100 (R - T)/R,$$

$$\text{efficiency of conversion of ingested food (ECI) (\%)} = 100 P/R,$$

$$\text{efficiency of conversion of digested food (ECD) (\%)} = 100 P/(R - T),$$

$$\text{hatchability (\%)} = 100 A/B,$$

$$\text{larval survivability (LS) (\%)} = 100 N_b/N_a,$$

$$\text{effective rate of rearing (ERR) (\%)} = 100 C/D,$$

$$\text{moth emergence (ME) (\%)} = 100 E/C,$$

$$\text{feeding index (FI)} = F/G,$$

where *P*: dry weight gain of insect; *Q*: duration of experimental period; *R*: dry weight of food eaten; *S*: mean dry weight of insect during time *Q*; *T*: dry weight of faeces produced; *A*: number of eggs hatched; *B*: number of eggs laid by per female; *N_a*: number of larvae in beginning of instar; *N_b*: number of larvae in succeeding instar; *C*: number of cocoons harvested; *D*: number of larvae brushed (number of last instar larvae reached pupation); *E*: number of moths emerged; *F*: pupal weight; *G*: total weight of food consumed by the larvae.

TABLE 1: Life cycle of *D. casignetum* reared on young, mature, and senescent sunflower leaves.

Life cycle	Young	Mature	Senescent	$F_{2,12}$	P
Larval duration (days)					
I	3.16 ± 0.04^a	3.06 ± 0.15^a	3.36 ± 0.05^b	12.131	0.01
II	3.08 ± 0.04^a	3.06 ± 0.01^a	3.28 ± 0.07^b	5.331	0.05
III	3.94 ± 0.09	3.83 ± 0.01	4.05 ± 0.02	3.281	n.s.
IV	3.14 ± 0.07	3.00 ± 0.01^a	3.28 ± 0.07^b	5.297	0.05
V	3.01 ± 0.03	3.00 ± 0.01^a	3.16 ± 0.04^b	6.468	0.05
VI	4.91 ± 0.04	4.847 ± 0.01^a	5.08 ± 0.04^b	8.928	0.01
Total larval duration	21.25 ± 0.11^a	20.81 ± 0.02^b	22.22 ± 0.07^c	81.552	0.0001
Prepupal duration	1.83 ± 0.04	1.76 ± 0.01	1.97 ± 0.02	3.163	n.s.
Pupal duration	9.13 ± 0.05^a	9.00 ± 0.01^a	9.55 ± 0.02^b	46.380	0.0001
Male longevity	4.00 ± 0.04^a	4.01 ± 0.01^a	3.02 ± 0.02^b	318.056	0.0001
Female longevity	4.41 ± 0.17^a	4.66 ± 0.09^a	4.00 ± 0.04^b	10.243	0.01

Mean $\pm$ SE of five observations. Within the rows, means followed by different letters are significantly different.

2.4. Biochemical Analysis of Leaves. The sunflower leaves were obtained from a 2.5×2.5 m plot of the sunflower field near Chinsurah Rice Research Centre ($22^\circ 53' N$, $88^\circ 23' E$), West Bengal, India that was free from insecticide or herbicide, but weeds were removed by hand-picking method. The variability of nutritional quality of three kinds of sunflower leaves (i.e., young, mature, and senescent) was estimated by subjecting the leaves to various biochemical analysis described elsewhere in the text, such as total carbohydrates [12], total proteins [13], total lipids [14], total amino acids [15], total nitrogen [16], and total phenol [17]. The determination of each biochemical analysis was repeated for five times.

2.5. Estimation of Moisture Content. One gram of each kind of leaf was placed separately in a hot-air oven at $50 \pm 1^\circ C$ temperature for 72 h, and materials that showed constant dry weight were removed from the oven and weighed in a monopan balance (± 0.01 mg). Differences in the fresh and dry weights were used to determine the percent water content of each kind of leaf. The moisture content was repeated for five times for each host leave.

2.6. Statistical Analysis. All the data on life history parameters of *D. casignetum* and biochemical analysis of three host leaves were analyzed using one-way analysis of variance (ANOVA). Means associated with all the data for each variable were separated using the Tukey test when significant values were obtained [18].

3. Results

3.1. Life Cycle of *Diacrisia casignetum* Reared on Young, Mature, and Senescent Sunflower Leaves. Data on life history parameters of *D. casignetum* reared on young, mature, and senescent leaves of *H. annuus* is presented in Table 1. The total larval developmental duration of *D. casignetum* was significantly affected by feeding on young, mature, and

FIGURE 1: Total eggs per female *D. casignetum* on young (Y), mature (M), and senescent (S) sunflower leaves. Means $\pm$ SE of five observations. The different letters over the three bars indicate that the means are significantly different at $P < 0.05$.

senescent sunflower leaves and was longest on senescent leaves and shortest on mature leaves ($F_{2,12} = 81.552$, $P < 0.0001$). Among the six instars, the developmental time of third instars did not vary significantly by feeding on young, mature, and senescent leaves ($F_{2,12} = 3.281$, $P > 0.05$), whereas the sixth instar took longer developmental time compared to other instars when reared with three kinds of sunflower leaves. Prepupal duration was not significantly different ($F_{2,12} = 3.163$, $P > 0.05$) when larvae were fed with three types of leaves, but pupal duration was significantly reduced in young and mature leaves than on senescent leaves ($F_{2,12} = 46.380$, $P < 0.0001$). The longevities of both male and female were significantly affected by three kinds of leaves on which their larva fed (male: $F_{2,12} = 318.056$, $P < 0.0001$; female: $F_{2,12} = 10.243$, $P < 0.01$) (Table 1). Both the male and female longevities were better in young and mature leaves than senescent leaves. Fecundity was highest in insects which were reared with mature leaves (number of eggs, 670 ± 20.13) and less on senescent leaves (number of eggs, 523 ± 33.65) ($F_{2,12} = 8.644$, $P < 0.01$) (Figure 1).

TABLE 2: Food utilization efficiency measures of first instar larva of *D. casignetum* reared on young, mature and senescent sunflower leaves.

Parameter	Young	Mature	Senescent	$F_{2,12}$	P
GR (mg/day)	0.06 ± 0.00^a	0.08 ± 0.02^b	0.04 ± 0.00^c	9.859	0.01
CR (mg/day)	15.17 ± 0.05^a	17.02 ± 0.12^b	13.26 ± 0.03^c	551.283	0.0001
RGR (mg/day)	0.38 ± 0.02^a	0.32 ± 0.01^b	0.31 ± 0.03^b	8.234	0.01
CI (mg/day)	84.46 ± 2.58^a	69.60 ± 1.48^b	83.13 ± 3.07^a	11.063	0.01
AD (%)	89.56 ± 0.15	89.61 ± 0.40	89.09 ± 0.19	1.048	n.s.
ECI (%)	0.46 ± 0.03^a	0.47 ± 0.02^a	0.37 ± 0.04^b	5.931	0.05
ECD (%)	0.51 ± 0.04^a	0.52 ± 0.03^a	0.42 ± 0.04^b	5.892	0.05
LS (%)	98.26 ± 0.97^a	98.29 ± 0.93^a	92.66 ± 1.89^b	5.834	0.05

Mean $\pm$ SE of five observations. Within the rows means followed by different letters are significantly different. Food utilization efficiency measures: GR: Growth rate, CR: Consumption rate, RGR: Relative growth rate, CI: Consumption index, AD: Approximate digestibility, ECI: Efficiency of conversion of ingested food, ECD: Efficiency of conversion of digested food, LS: Larval survivability.

TABLE 3: Food utilization efficiency measures of second instar larva of *D. casignetum* reared on young, mature, and senescent sunflower leaves.

Parameter	Young	Mature	Senescent	$F_{2,12}$	P
GR (mg/day)	0.43 ± 0.00^a	0.48 ± 0.02^b	0.38 ± 0.01^c	10.282	0.01
CR (mg/day)	29.74 ± 0.05	29.31 ± 0.73	28.59 ± 0.08	1.849	n.s.
RGR (mg/day)	0.43 ± 0.00^a	0.36 ± 0.10^b	0.45 ± 0.02^a	8.391	0.01
CI (mg/day)	30.04 ± 0.30^a	22.41 ± 0.53^b	29.79 ± 0.44^a	98.241	0.0001
AD (%)	84.94 ± 0.24^a	84.53 ± 0.47^a	82.88 ± 0.10^b	11.966	0.01
ECI (%)	1.44 ± 0.01^a	1.67 ± 0.01^b	1.50 ± 0.04^a	14.521	0.001
ECD (%)	1.70 ± 0.02^a	1.97 ± 0.01^b	1.81 ± 0.05^c	11.760	0.01
LS (%)	88.72 ± 1.45^a	91.62 ± 0.42^b	83.55 ± 0.79^c	9.064	0.01

Mean $\pm$ SE of five observations. Within the rows, means followed by different letters are significantly different. Food utilization efficiency measures: GR: growth rate, CR: consumption rate, RGR: relative growth rate, CI: consumption index, AD: approximate digestibility, ECI: efficiency of conversion of ingested food, ECD: efficiency of conversion of digested food, LS: larval survivability.

3.2. Food Utilization Efficiency Measures. Food utilization efficiency measures of first instar larvae of *D. casignetum* are given in Table 2. The GR was significantly higher in insects fed with mature leaves followed by young and senescent leaves ($F_{2,12} = 9.859$, $P < 0.01$). There were significant differences in CR between all the treatments ($F_{2,12} = 551.283$, $P < 0.0001$). CR was highest in mature leaves followed by young and senescent leaves, whereas RGR values were greater on young leaves than other two kinds of leaves ($F_{2,12} = 8.234$, $P < 0.01$). A higher value of CI was observed in insects when reared on young leaves, whereas mature-leaf-fed insects showed lower CI values ($F_{2,12} = 11.063$, $P < 0.01$). The AD was almost same when the insects were fed with three types of leaves ($F_{2,12} = 1.048$, $P > 0.05$). ECI ($F_{2,12} = 5.931$, $P < 0.05$) and ECD ($F_{2,12} = 5.892$, $P < 0.05$) values were higher on insects fed with young and mature leaves and lower on senescent leaves. The larval survivability was greater in insects that were fed with young and mature leaves rather than senescent leaves ($F_{2,12} = 5.834$, $P < 0.05$).

Table 3 presents food utilization measures for second instar larvae of *D. casignetum*. GR was greatest in insects fed with mature leaves and lowest in senescent leaves ($F_{2,12} = 10.282$, $P < 0.01$). The CR did not vary significantly between all the treatments ($F_{2,12} = 1.849$, $P > 0.05$). Higher values of RGR were recorded in young and senescent leaves than

mature leaves ($F_{2,12} = 8.391$, $P < 0.01$). CI was greater in young and senescent leaves, whereas it was lower in mature leaves ($F_{2,12} = 98.241$, $P < 0.0001$). Insects reared on young and mature leaves showed higher values of AD, whereas the value of this index was lower in senescent leaves ($F_{2,12} = 11.966$, $P < 0.01$). ECI ($F_{2,12} = 14.521$, $P < 0.001$) and ECD ($F_{2,12} = 11.760$, $P < 0.01$) values of mature-leaf-fed insects were greater than those of insects fed on young and senescent sunflower leaves. The LS index was higher on mature leaves followed by young and senescent sunflower leaves ($F_{2,12} = 9.064$, $P < 0.01$).

The data given on Table 4 provides food utilization efficiency measures of third instar larvae of *D. casignetum* reared on three kinds of sunflower leaves. Greater value of GR was recorded for insects fed on mature leaves and significantly lower in senescent leaves ($F_{2,12} = 6.940$, $P < 0.01$). Food consumption (CR) was greatest when insects were fed with mature leaves and least when fed with senescent leaves ($F_{2,12} = 1916.802$, $P < 0.0001$). Based on the value of AD index, three kinds of leaves can be arranged in order of food quality as mature > young > senescent leaves ($F_{2,12} = 515.709$, $P < 0.0001$). The value of ECI was greater in insects fed on young and senescent leaves, whereas it was reduced in case of mature-leaf-fed insects ($F_{2,12} = 57.141$, $P < 0.0001$). ECD values were higher on senescent leaves and

TABLE 4: Food utilization efficiency measures of third instar larva of *D. casignetum* reared on young, mature, and senescent sunflower leaves.

Parameter	Young	Mature	Senescent	$F_{2,12}$	P
GR (mg/day)	0.85 ± 0.00^a	0.90 ± 0.01^b	0.78 ± 0.00^c	6.940	0.01
CR (mg/day)	74.81 ± 0.02^a	91.66 ± 0.41^b	72.16 ± 0.02^c	1916.802	0.0001
RGR (mg/day)	0.26 ± 0.00^a	0.24 ± 0.02^b	0.27 ± 0.00^c	139.082	0.0001
CI (mg/day)	21.52 ± 0.12^a	22.66 ± 0.54^{ab}	23.16 ± 0.14^b	6.282	0.05
AD (%)	56.59 ± 0.02^a	65.52 ± 0.61^b	49.39 ± 0.05^c	515.709	0.0001
ECI (%)	1.20 ± 0.01^a	0.96 ± 0.02^b	1.18 ± 0.01^a	57.141	0.0001
ECD (%)	2.13 ± 0.02^a	1.56 ± 0.02^b	2.40 ± 0.02^c	354.519	0.0001
LS (%)	87.60 ± 2.40	86.27 ± 0.49	84.85 ± 2.84	0.571	n.s.

Mean $\pm$ SE of five observations. Within the rows, means followed by different letters are significantly different. Food utilization efficiency measures: GR: growth rate, CR: consumption rate, RGR: relative growth rate, CI: consumption index, AD: approximate digestibility, ECI: efficiency of conversion of ingested food, ECD: efficiency of conversion of digested food, LS: larval survivability.

TABLE 5: Food utilization efficiency measures of fourth instar larva of *D. casignetum* reared on young, mature, and senescent sunflower leaves.

Parameter	Young	Mature	Senescent	$F_{2,12}$	P
GR (mg/day)	6.13 ± 0.01^a	6.69 ± 0.29^b	5.69 ± 0.01^c	6.069	0.05
CR (mg/day)	164.29 ± 0.02^a	175.50 ± 1.13^b	159.29 ± 0.02^c	160.278	0.0001
RGR (mg/day)	0.40 ± 0.00^a	0.34 ± 0.03^b	0.41 ± 0.00^a	158.179	0.0001
CI (mg/day)	10.84 ± 0.01^a	8.97 ± 0.08^b	11.23 ± 0.00^c	549.641	0.0001
AD (%)	70.09 ± 0.02^a	71.29 ± 0.58^a	67.34 ± 0.00^b	35.232	0.0001
ECI (%)	3.73 ± 0.00	3.82 ± 0.46	3.70 ± 0.00	0.053	n.s.
ECD (%)	5.32 ± 0.01	5.36 ± 0.16	5.49 ± 0.01	0.861	n.s.
LS (%)	92.74 ± 2.24^a	92.95 ± 0.08^a	85.85 ± 2.48^b	4.356	0.05

Mean $\pm$ SE of five observations. Within the rows, means followed by different letters are significantly different. Food utilization efficiency measures: GR: growth rate, CR: consumption rate, RGR: relative growth rate, CI: consumption index, AD: approximate digestibility, ECI: efficiency of conversion of ingested food, ECD: efficiency of conversion of digested food, LS: larval survivability.

lower on mature leaves ($F_{2,12} = 354.519$, $P < 0.0001$). The LS value did not vary significantly when the larvae were reared on three kinds of leaves ($F_{2,12} = 0.571$, $P > 0.05$).

Table 5 provides food utilization efficiency measures for fourth instar larvae of *D. casignetum* fed on young, mature, and senescent leaves. A higher GR was found for insects that were fed on mature leaves ($F_{2,12} = 6.069$, $P < 0.05$). Insects fed with mature leaves showed a higher value of food consumption (CR), whereas insects reared with senescent leaves showed a lower value of this index ($F_{2,12} = 160.278$, $P < 0.0001$). Higher RGR values were recorded on young and senescent leaves than mature leaves ($F_{2,12} = 158.179$, $P < 0.0001$). CI values were higher for insects given senescent leaves ($F_{2,12} = 549.641$, $P < 0.0001$). A higher value of AD was found in young and mature leaves, while AD was lower when the insects were fed with senescent leaves ($F_{2,12} = 35.232$, $P < 0.0001$). ECI ($F_{2,12} = 0.053$, $P > 0.05$) and ECD ($F_{2,12} = 0.861$, $P > 0.05$) values did not vary significantly when the larvae were reared with three kinds of leaves. LS was higher when the insects were fed with young and mature leaves, while a lower LS was recorded when fed with senescent leaves ($F_{2,12} = 4.356$, $P < 0.05$).

Food utilization measures for fifth instar larvae of *D. casignetum* are given in Table 6. Insects reared on mature leaves showed higher values of GR followed by young and senescent sunflower leaves ($F_{2,12} = 616.978$, $P < 0.0001$).

A higher value of CI was observed in young leaves, whereas mature-leaf-fed insects showed lower CI values ($F_{2,12} = 526.015$, $P < 0.0001$). Higher values of AD were observed on young and mature leaves ($F_{2,12} = 69.189$, $P < 0.0001$). Higher ECD ($F_{2,12} = 48.374$, $P < 0.0001$) and ECI ($F_{2,12} = 65.861$, $P < 0.0001$) values were evident on young and mature leaf than senescent leaves. LS values of young- and mature-leaf-fed insects were higher than those of insects fed on senescent leaf ($F_{2,12} = 5.234$, $P < 0.05$).

Table 7 provides food utilization measures for sixth instar larvae of *D. casignetum*. A higher GR was found for insects, were fed on mature leaves ($F_{2,12} = 28.443$, $P < 0.0001$). Insects fed with mature leaf showed a higher rate of food consumption (CR) followed by young and senescent leaf ($F_{2,12} = 311.005$, $P < 0.0001$). CI was greater in senescent leaf than the other two kinds of leaves ($F_{2,12} = 15.203$, $P < 0.001$). Higher values of AD were observed in young and mature leaf, while it was lower when the insects were fed with senescent leaf ($F_{2,12} = 56.450$, $P < 0.0001$). The value of ECI was greater in insects that fed on young leaves ($F_{2,12} = 59.537$, $P < 0.0001$), whereas it was reduced in case of mature-leaf-fed insects. ECD values were higher on young and senescent leaves than on mature leaf ($F_{2,12} = 25.973$, $P < 0.0001$). LS values were higher in insects that were reared on young and mature leaves, while it was lower on senescent leaf-fed insects ($F_{2,12} = 5.121$, $P < 0.05$).

TABLE 6: Food utilization efficiency measures of fifth instar larva of *D. casignetum* reared on young, mature, and senescent sunflower leaves.

Parameter	Young	Mature	Senescent	$F_{2,12}$	P
GR (mg/day)	26.14 ± 0.01 ^a	28.15 ± 0.24 ^b	21.36 ± 0.01 ^c	616.978	0.0001
CR (mg/day)	216.44 ± 0.03 ^a	226.40 ± 1.51 ^b	202.46 ± 0.04 ^c	189.695	0.0001
RGR (mg/day)	0.41 ± 0.00 ^a	0.35 ± 0.01 ^b	0.34 ± 0.00 ^b	41.214	0.0001
CI (mg/day)	3.37 ± 0.00 ^a	2.79 ± 0.02 ^b	3.26 ± 0.00 ^c	526.015	0.0001
AD (%)	67.09 ± 0.01 ^a	67.60 ± 0.06 ^a	65.49 ± 0.00 ^b	69.189	0.0001
ECI (%)	12.07 ± 0.00 ^a	12.44 ± 0.21 ^a	10.55 ± 0.00 ^b	65.861	0.0001
ECD (%)	18.00 ± 0.00 ^a	18.62 ± 0.32 ^a	16.11 ± 0.00 ^b	48.374	0.0001
LS (%)	89.81 ± 2.02 ^a	90.02 ± 0.21 ^a	82.64 ± 3.25 ^b	5.234	0.05

Mean ± SE of five observations. Within the rows, means followed by different letters are significantly different. Food utilization efficiency measures: GR: growth rate, CR: consumption rate, RGR: relative growth rate, CI: consumption index, AD: approximate digestibility, ECI: efficiency of conversion of ingested food, ECD: efficiency of conversion of digested food, LS: larval survivability.

TABLE 7: Food utilization efficiency measures of sixth instar larva of *D. casignetum* reared on young, mature, and senescent sunflower leaves.

Parameter	Young	Mature	Senescent	$F_{2,12}$	P
GR (mg/day)	20.20 ± 0.015 ^a	21.41 ± 0.27 ^b	19.82 ± 0.01 ^c	28.443	0.0001
CR (mg/day)	158.86 ± 0.02 ^a	166.10 ± 0.63 ^b	153.15 ± 0.02 ^c	311.005	0.0001
RGR (mg/day)	0.13 ± 0.00	0.12 ± 0.01 ^a	0.14 ± 0.00 ^b	6.846	0.05
CI (mg/day)	0.97 ± 0.00 ^a	0.98 ± 0.02 ^a	1.08 ± 0.00 ^b	15.203	0.001
AD (%)	45.81 ± 0.02 ^a	45.12 ± 0.21 ^a	42.39 ± 0.01 ^b	56.450	0.0001
ECI (%)	13.47 ± 0.00 ^a	12.25 ± 0.13 ^b	12.94 ± 0.00 ^c	59.537	0.0001
ECD (%)	29.44 ± 0.02 ^a	27.71 ± 0.48 ^b	30.53 ± 0.02 ^a	25.973	0.0001
LS (%)	86.97 ± 2.80 ^a	86.58 ± 0.38 ^a	79.57 ± 1.97 ^b	5.121	0.05

Mean ± SE of five observations. Within the rows, means followed by different letters are significantly different. Food utilization efficiency measures: GR: growth rate, CR: consumption rate, RGR: relative growth rate, CI: consumption index, AD: approximate digestibility, ECI: efficiency of conversion of ingested food, ECD: efficiency of conversion of digested food, LS: larval survivability.

The present study revealed that the mature-leaf-fed caterpillars demonstrated greater growth rate (GR) throughout all the instars. Except for second instar, where consumption rate (CR) did not vary significantly among the three kinds of leaves, CR was higher in all the instars of mature-leaf-fed caterpillars. Relative growth rate (RGR) values displayed different patterns throughout all instars, when the insects were offered three kinds of leaves. The approximate digestibility (AD) was greater in young- and mature-leaf-fed insects during the second and last three instars, whereas AD was higher in mature-leaf-fed third instar caterpillars. Both the ECI and ECD values for the first instar were higher for young and mature leaves, whereas second instar indicated greater ECI and ECD values on mature leaf. ECI values were higher for third instar on young and mature leaves than senescent leaf, while ECD value was higher on senescent-leaf-fed insects. ECI and ECD values did not differ significantly, when fourth instar caterpillars were reared on three kinds of leaves. Fifth instar larvae showed greater ECI and ECD on young and mature leaves. ECI value for the sixth instar larvae was higher when they were given young leaves, whereas higher ECD values were recorded on young and senescent leaves. Larval survivability (LS) was higher in young and mature leaves for all the instars except for second and third instars. LS did not differ significantly in third instar larvae among three kinds of sunflower leaves, whereas second instar larvae indicated better survivability on mature leaves.

FIGURE 2: Accumulated survivals of *D. casignetum* on young (Y), mature (M) and senescent (S) sunflower leaves. Means ± SE of five observations. The different letters over the bars indicate that the means are significantly different at $P < 0.05$.

The hatchability percent from *D. casignetum* eggs ($F_{2,12} = 6.468$, $P < 0.05$) was highest in mature leaves and lowest in senescent leaves (Figure 2). The overall accumulated survival rate in all the larval stages was greatest when the insects were fed with mature leaves followed by young leaves and

FIGURE 3: Feeding index of *D. casignetum* when reared with young (Y), mature (M), and senescent (S) sunflower leaves. Means $\pm$ SE of five observations. The different letters over the three bars indicate that the means are significantly different at $P < 0.05$.

FIGURE 4: Biochemical compositions of young (Y), mature (M), and senescent (S) sunflower leaves. Means $\pm$ SE of five observations. The different letters over the three bars indicate that the means are significantly different at $P < 0.05$.

senescent leaves ($F_{2,87} = 5.545$, $P < 0.05$) (Figure 2). The ERR was comparatively higher in mature leaves followed by young and senescent leaves ($F_{2,12} = 6.176$, $P < 0.05$) (Figure 2). The emergence of adult moths from the hatched eggs was greatest when the larvae were reared on mature leaves followed by young leaves and senescent leaves ($F_{2,87} = 7.131$, $P < 0.01$). The feeding index value of mature-leaf-fed insects was higher than those of insects fed on young and senescent sunflower leaves ($F_{2,12} = 30.692$, $P < 0.0001$) (Figure 3).

3.3. Biochemical Components in Three Kinds of Leaves. Figure 4 provides variation in biochemical compositions of the three kinds of leaves. Total carbohydrate ($F_{2,12} = 544.244$, $P < 0.0001$) and protein ($F_{2,12} = 17.120$, $P < 0.001$) content

varied significantly between the leaf stages and can be placed in the order of mature leaf > young leaf > senescent leaf. Lipid content was greatest in mature leaf and least in senescent leaf ($F_{2,12} = 343.125$, $P < 0.0001$). Total nitrogen ($F_{2,12} = 73.921$, $P < 0.0001$) and amino acid ($F_{2,12} = 56.611$, $P < 0.0001$) were highest in mature leaf and lowest in senescent leaf. Total phenol content was greatest in young leaf followed by mature leaf and least in senescent leaf ($F_{2,12} = 480.903$, $P < 0.0001$). Water content varied significantly between the leaves ($F_{2,12} = 146.008$, $P < 0.0001$). Mature leaf of sunflower plant had highest water content followed by young and senescent leaf.

4. Discussion

The concentration and proportion of nutrients vary considerably within a particular species throughout its different developmental stages, which influences food utilization, development, and reproduction of herbivorous insects [3, 5]. Herbivorous insects are adapted to the nutrient composition of host leaves within a particular species, so it would be expected that development and reproduction will be better on leaves which are rich in nutrients. The biochemical components, that is, carbohydrates, proteins, lipids, amino acids, nitrogen, and phenols play an important role for host selection of phytophagous insects [5, 19–22]. Host plant utilization is also influenced by the ability of insect to ingest, assimilate, and convert food into body tissues [23]. In the present study, it was observed that *D. casignetum* showed significant differences in growth rate, consumption rate, utilization efficiency, developmental time, and fecundity when they were reared on young, mature, and senescent sunflower leaves, separately.

Carbohydrate deficiency results in reduction of general vitality, activity, and growth rate of phytophagous insects even though proteins and lipids serve as an alternative source of energy [5, 24, 25]. Higher level of carbohydrate content was observed in mature sunflower leaves, and insects fed on this kind of leaf exhibited a higher growth rate. During diapause, lipids serve as primary source of energy [26]. Furthermore, lipid is an essential component of insect diet, which acts as precursors of ecdysteroid moulting hormone and provides structural role in cellular membranes and transport of lipoproteins [27]. More growth rate was observed in *D. casignetum* fed with mature leaves of sunflower plant where lipid content was also higher than young and senescent leaves.

The protein content of host leaves is generally a limiting factor for the optimal growth of phytophagous insects [5, 20]. Insects feeding on nitrogen-rich leaves had a higher growth rate than those which consume leaves containing less nitrogen [20, 22]. Mature leaves are rich in protein and nitrogen when compared to young and senescent leaves, suggesting that insects feeding on mature sunflower leaves will develop more quickly. Further, growth and reproduction of insects could be explained in part in relation to amino acid composition of diet [5, 25]. Higher level of amino acids in mature leaves would probably explain better growth and reproduction of *D. casignetum*.

Water content in host leaves plays an important role in growth rate of plant-fed caterpillars [21, 22, 28]. The mature leaves of sunflower plant had higher water content than young and senescent leaves which might have influenced the higher growth rate of *D. casignetum* feeding on them. Decreased water content in senescent leaves reduced the growth rate of *D. casignetum* than when fed with young leaves.

Phenols induce resistance in hosts against herbivory. Consumption of greater amount of phenols was found to significantly reduce adult longevity, fecundity, and retardation of larval growth [5, 25]. In this study, phenol concentration was higher in young leaves than mature leaves, suggesting that insects feeding on mature leaves will develop more quickly and will be more successful which supports the hypothesis that polyphagous species prefer mature leaves [5]. However, despite high level of phenols in mature leaves than senescent leaves, growth rate and development of *D. casignetum* were fastest when fed on mature leaves. This could possibly be attributed to the proportionately high level of readily utilizable primary substances, that is, carbohydrates, proteins, and lipids in mature leaves than senescent leaves [5].

In the present study, all nutritional indices varied when *D. casignetum* fed on three kinds of sunflower leaves. The growth rate (GR) of insects depends on efficiency of conversion of digested food; whereas a reduction in ECD indicates higher metabolic maintenance cost [11, 20, 23]. The current data reveal that all the larval instars of *D. casignetum* had higher GR on mature leaves, which would explain shorter developmental time of mature-leaf-fed caterpillars. The consumption rate (CR) of all the instars was lower when feeding on senescent leaves compared with those of mature and young leaves. The approximate digestibility (AD) is affected by water content of host leaves and decreased water content in senescent leaves caused reduction in the efficiency of nutrient digestion or absorption because the lower water level interfered with feeding and nutritional process. Though, third, fourth, and sixth instar caterpillars were efficiently converting senescent leaf tissues into their biomass as shown by larvae fed on senescent sunflower leaf tissues having lowest approximate digestibility and the maximum efficiency of conversion of digested food. This might be due to homeostatic adjustment of consumption rates and efficiency parameters of the insect which can approach ideal growth rate even though with foods of different quality [29].

In the present study, three kinds of sunflower leaves influenced survival of *D. casignetum* in the larval, pupal, and adult stage. Egg survival (percentage hatch) was the highest (93.01%) in mature leaf followed by young leaf (91.06%) and senescent leaf (88.12%). High survival rates and shorter developmental time indicate better nutritional quality of their larval food in relation to greater amount of carbohydrates, proteins, lipids, and amino acids [20]. These results of this study would probably indicate the greater survival and shorter developmental time of *D. casignetum* when they were reared on mature leaves followed by young and senescent leaves. Furthermore, the feeding index was

higher in mature leaf than the other two kinds of leaves, which indicates lesser amounts of mature leaf are consumed by *D. casignetum* to produce better quality of pupal weight.

The caterpillars reared on mature leaves show more fecundity when compared to young and senescent sunflower leaves. Host plant quality is a key determinant of the fecundity of herbivorous insects. Herbivorous insects feeding on protein-rich leaves will be more successful when compared to leaves less rich in proteins. Larval dietary nitrogen and adult carbohydrate diets influence the development of male and female reproductive system of lepidopteran insects [30]. In the present study, *D. casignetum* feeding on mature leaves allocated more nutrients to egg production than when feeding on young and senescent leaves. Nutrient accumulated during larval feeding including quality and quantity of adult food influences the number of eggs laid and its quality [19]. Hence, a reduction in larval consumption may result in longer developmental time, smaller size of the adult, and ultimately the lower fecundity [20]. Therefore, we conclude that mature leaves of sunflower plant provide the best food quality of *D. casignetum*, senescent leaves the worst, and young leaves of intermediate quality.

Acknowledgments

The authors are thankful to retired Professor T. C. Banerjee of this university for identification of this insect. The financial assistance provided by University Grants Commission (F. NO. 37/615/2009), New Delhi, Government of India is gratefully acknowledged.

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