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ORIGINAL ARTICLE

Influence of four host-plants on feeding, growth and reproduction of *Diacrisia casignetum* (Lepidoptera: Arctiidae)

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Abstract

Effects of four host-plants, sunflower, castor, jute and sesame, on feeding, growth and reproduction of *Diacrisia casignetum* Kollar (Lepidoptera: Arctiidae) were studied under laboratory conditions (27 ± 0.5°C, 12 h light : 12 h dark, 65 ± 5% RH). Total larval developmental time of *D. casignetum* was highest on sesame than the other three host-plants used in this study, but pupal duration was higher on sesame than sunflower but not for other dietary treatments. The longevity of females was generally longer than males. Male and female longevity was higher in sunflower than sesame ($P < 0.05$), but it did not differ significantly among other treatments. Fecundity was highest in sunflower followed by castor, jute and sesame. The growth and development of *D. casignetum* were related to nutrient and phenol contents of these four host-plants. Total carbohydrates and amino acids were present in rich quantities in sunflower when compared to other three host leaves, while nitrogen, protein and lipid contents were comparatively higher in sunflower and castor than jute and sesame. Phenol content was greatest in sesame, and least in castor and sunflower. Higher levels of total carbohydrates, proteins, lipids, nitrogen and amino acids including water content and lower phenol content of sunflower have influenced higher growth rate and fecundity of *D. casignetum*.

Key words: arctiid moth, castor, jute, sesame, sunflower.

INTRODUCTION

Selection of host-plants by several lepidopteran insects depends on chemical cues including nutritional requirements of insects (Schoonhoven *et al.* 2005) and to some extent on secondary metabolites of their host-plants (Harborne 1994). Fecundity of herbivorous insects also depends on host-plant quality, which influences growth rates, digestibility, utilization efficiencies and developmental time of herbivores (Shobana *et al.* 2010).

Diacrisia casignetum Kollar (Lepidoptera: Arctiidae) is a polyphagous pest, damaging numerous field crops in India and many other Asian countries (Banerjee & Haque 1985). The most effective strategy adapted by farmers is the application of insecticides for its proper control. Therefore, understanding of fundamental life history parameters of *D. casignetum* on different host-plants will enhance effective strategies to control this economic pest. The previous study on the biological parameters of *D. casignetum* on sunflower and hempweed leaves indicated influences of host-plants (i.e. between a crop and a weed) on development of this insect pest (Banerjee & Haque 1985). However, information on food utilization indices by different instars of this insect pest on sunflower *Helianthus annuus* (Asteraceae) is meager. Further, there are no reports on food utilization, growth, development and reproductive programming of *D. casignetum* on castor *Ricinus communis* (Euphorbiaceae), jute *Corchorus capsularis* (Malvaceae) and sesame *Sesamum indicum* (Pedaliaceae). So, in this report we summarize results of detailed studies of *D. casignetum* when reared on jute, sesame, castor and sunflower leaves, which will help in better understanding of host suitability of this insect species.

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MATERIALS AND METHODS

Mass rearing

Diacrisia casignetum adults (male and female) were originally collected from jute fields of the Hooghly district (22°53′N, 88°23′E), West Bengal, India and were subsequently reared in cages (50 cm × 50 cm × 50 cm) containing small branches of the respective host-plants for oviposition. From this, two pairs of adults (2 males and 2 females) of identical age were released in (10 cm × 20 cm) sterilized glass jars covered with fine mesh nylon net at 27 ± 0.5°C, under conditions of 12 h light : 12 h dark (LD 12:12) and 65 ± 5% RH. The adults were fed with 10% sucrose solution through a cotton ball in a small glass Petri dish (2 cm × 1 cm). The host-plants used in this study were given for oviposition separately in different sterilized glass jars. To maintain the 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 host-plant leaves were placed in new sterilized glass jars separately. *Diacrisia casignetum* larvae developed from the eggs had been fed with the leaves of respective host-plants (i.e. sunflower, castor, jute and sesame) separately for five generations and the comparative rate of development of this insect on these selected host-plant leaves were enumerated depending on the total body weight and duration of post-embryonic development on sixth generation. To study the duration of larval development, the eggs were separated and reared separately in sterilized glass jars containing 10 larvae on each kind of host-plant, and observations were noted on their incubation period and duration of each larval stage during their respective development. The larval duration experiment has five replicates for each host leaves.

The weight gain of insects, weight of food consumed and weight of feces produced were determined with a monopan balance (±0.01 mg). Larvae of approximately the same size and weight were selected and weighed initially and were reared separately on four host-plants into separate sterilized glass jars. They were allowed to feed on weighed quantities of leaves of four host-plants for 24 h and were reweighed. The fresh weight gain during the period of study was estimated by determining the difference in weight of larvae (by subtracting initial and final weight during the period of study). Five individuals of each instar fed on each of four host-leaves 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 four host-leaves left after 24 h of insect feeding were oven dried and weighed to determine dry weight gain of the diet given to the larvae. Sample leaves from the four host-plants were weighed, oven dried and reweighed to estimate percent dry weight conversion 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. Feces was collected at 24 h intervals and weighed, and then placed in a hot air oven and reweighed to find the dry weight of excreta. One hundred larvae were used in each of the four host-plant leaves. Times needed to undergo pupation for the first and last larvae of a batch of 10 larvae from its hatching were noted to determine total larval duration, whereas pupal duration was noted as times required by first and last pupae to emerge into adults for a batch of 10 pupae. Further, times of death for first and last insects for a batch of ten insects were also recorded to calculate male and female longevity. Each batch of insects containing ten larvae or pupae or adults was replicated for five times for each kind of host-leaf to record total larval and pupal duration, and male and female longevity.

Oviposition assay

This experiment was conducted by taking laboratory reared male and female adults of the same age that were fed on the four host-plant leaves separately. The adults were released into separate sterilized glass jars (10 cm × 20 cm) at a sex ratio of 1:1 to note mating, egg laying behavior, larval survivability 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 egg masses and eggs in each egg mass was recorded for each host-leaf per female. The experiment was replicated five times.

Food utilization indices

Food utilization indices (all based on dry weight) were calculated based on the formulas of Waldbauer (1968) to assess the feeding efficiencies of *D. casignetum* as follows:

Growth rate (GR) = A/B

Consumption rate (CR) = C/B

Relative growth rate (RGR) = A/BD

Consumption index (CI) = C/BD

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Approximate digestibility (AD) (%) = 100(C – E)/C

Efficiency of conversion of ingested food (ECI) (%) = 100A/C

Efficiency of conversion of digested food (ECD) (%) = 100A/(C – E)

Larval survivability (LS) (%) = $100N_b/N_a$

Effective rate of rearing (ERR) (%) = 100F/G

Adult emergence (AE) (%) = 100H/F

where A, dry weight gain of insect; B, duration of experimental period; C, dry weight of food eaten; D, mean dry weight of insect during time B; E, dry weight of feces produced; N_a, number of larvae in beginning of instar; N_b, number of larvae in succeeding instar; F, number of cocoons harvested; G, number of caterpillars brushed; H, number of moths emerged.

Biochemical analysis of leaves

The variability in nutritional quality of four host-plants (sunflower, castor, jute and sesame) was estimated by subjecting the fresh undamaged leaves to various biochemical analyses: total carbohydrates (Dubios *et al*. 1958), total proteins (Lowry *et al*. 1951), total lipids (Folch *et al*. 1957), total nitrogen (Humphries 1956), total amino acids (Moore & Stein 1948) and total phenols (Bray & Thorpe 1954). Each biochemical analysis was repeated five times.

Estimation of moisture content

One gram of each kind of leaf was placed separately in a hot air oven at 50 ± 1°C for 72 h. Materials that showed constant dry weights were removed from the oven and weighed with 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 host-leaf. The moisture content was repeated five times for each host-leaf.

Statistical analysis

The ln-transformed data on growth duration (i.e. larval and pupal duration, male and female longevity, and fecundity) of *D. casignetum* reared on four host-plants were subjected to Bartlett's test for homogeneity of variances with respect to treatments. Following this, Kruskal–Wallis nonparametric one way analysis of variance (ANOVA) was conducted to compare the effects of the diet regimes. If found significant for the Kruskal–Wallis test, the data were subject to a Steel–Dwass–Critchlow–Flinger multiple pairwise comparisons test using XLSTAT software (Addinsoft 2010).

All the data on food utilization index parameters of *D. casignetum* and biochemical analyses of four host leaves were analyzed using ANOVA. Means associated with all the data for each variable were separated using Tukey's test ("honestly significant difference test") when significant values were obtained (Zar 1999).

RESULTS

Growth duration of *D. casignetum* reared on four host-plants

Data on growth duration of *D. casignetum* reared on sunflower, castor, jute and sesame are presented in Table 1. The Bartlett's test for homogeneity indicated that the data set was homogenous conforming to application of Kruskal–Wallis (nonparametric). The χ^2 value of Bartlett's test were $\chi^2_{0.05,3} = 2.036$ ($P > 0.05$), $\chi^2_{0.05,3} = 6.409$ ($P > 0.05$), $\chi^2_{0.05,3} = 1.324$ ($P > 0.05$) and $\chi^2_{0.05,3} = 3.704$ ($P > 0.05$) for larval developmental time, pupal duration, male and female longevity, respectively. It was observed that the larval developmental time varied significantly with treatments through Kruskal–Wallis ANOVA ($\chi^2_{0.05,3} = 23.333$, $P < 0.0001$), and the Steel–Dwass–Critchlow–Flinger multiple pair wise comparisons test revealed that larval developmental time was

Table 1 Growth duration of *D. casignetum* reared on four host-plants

Lifecycle (days)	Sunflower	Castor	Jute	Sesame	$\chi^2_{0.05,3}$	*P*
Total larval duration	22.47 ± 0.22[a]	22.87 ± 0.19[a]	23.24 ± 0.23[a]	24.37 ± 0.16[b]	23.333	0.0001
Pupal duration	8.99 ± 0.06[a]	9.10 ± 0.14[ab]	9.13 ± 0.09[ab]	9.49 ± 0.10[b]	9.457	0.024
Male longevity	3.99 ± 0.11[a]	4.00 ± 0.16[ab]	3.99 ± 0.16[ab]	3.35 ± 0.11[b]	9.40	0.024
Female longevity	4.66 ± 0.09[a]	4.64 ± 0.12[ab]	4.54 ± 0.07[ab]	4.08 ± 0.12[b]	9.426	0.024
Fecundity (eggs/female)	670 ± 21.11[a]	560.8 ± 20.71[b]	439.4 ± 22.34[c]	332 ± 13.75[d]	17.857	0.0001

Mean ± SE of 5 observations. χ^2 value is for Kruskal–Wallis test. Within the row means followed by same letter(s) are not significantly different by Steel–Dwass–Critchlow–Flinger multiple pairwise comparisons test. Times of death for first and last insects for a batch of ten insects were recorded to calculate male and female longevity.

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Table 2 Food utilization efficiency measures of sixth instar larvae of *D. casignetum* ($n = 100$) reared on four host-plants

Growth parameters	Sunflower	Castor	Jute	Sesame	$F_{3,16}$	P
GR (mg/day)	21.41 ± 0.27[a]	17.79 ± 0.06[b]	16.16 ± 0.25[c]	15.51 ± 0.06[c]	191.309	0.0001
CR (mg/day)	166.1 ± 0.63[a]	126.1 ± 0.68[b]	121.60 ± 0.41[c]	113 ± 0.70[d]	1435.77	0.0001
RGR (mg/day)	0.12 ± 0.01[a]	0.11 ± 0.01[a]	0.10 ± 0.00[b]	0.10 ± 0.01[b]	3.90	0.05
CI (mg/day)	0.98 ± 0.02[a]	0.80 ± 0.01[b]	0.79 ± 0.01[b]	0.76 ± 0.01[b]	41.22	0.0001
AD (%)	45.12 ± 0.21[a]	47.29 ± 0.32[b]	43.65 ± 0.15[c]	39.48 ± 0.25[d]	119.61	0.0001
ECI (%)	12.25 ± 0.13[a]	14.16 ± 0.05[b]	13.98 ± 0.52[b]	15.13 ± 0.01[c]	18.19	0.0001
ECD (%)	27.71 ± 0.48[a]	30.86 ± 0.31[b]	31.18 ± 0.58[b]	37.81 ± 0.67[c]	63.25	0.0001
LS (%)	86.58 ± 0.38[a]	83.30 ± 0.48[b]	82.27 ± 0.59[b]	78.34 ± 0.46[c]	47.93	0.0001

Mean ± SE of 5 observations. Within the row means followed by same letter(s) are not significantly different by Tukey's test.
Food utilization efficiency measures: AD, approximate digestibility; CI, consumption index; CR, consumption rate; ECD, efficiency of conversion of digested food; ECI, efficiency of conversion of ingested food; GR, growth rate; LS, larval survivability; RGR, relative growth rate.

slowest in insects fed with sesame. Pupal duration varied significantly with treatments ($\chi^2_{0.05,3} = 9.457$, $P < 0.02$) and it was shorter in sunflower than sesame, but other pairs of dietary treatments did not indicate any significant differences. Male and female longevity showed significant differences (male longevity $\chi^2_{0.05,3} = 9.40$, $P < 0.024$; female longevity $\chi^2_{0.05,3} = 9.426$, $P < 0.024$) between sunflower and sesame but not for other pairs of dietary treatments. There were significant differences in the fecundity of *D. casignetum* between all the treatments ($\chi^2_{0.05,3} = 17.857$, $P < 0.0001$). Fecundity was greatest when the insects were fed on sunflower followed by castor and jute, and least when reared on sesame (Table 1).

Food utilization efficiency measures

Table 2 provides data of food utilization efficiency measures for sixth instar larvae of *D. casignetum* on the selected four host-plants. Higher GR values were recorded for insects fed on sunflower ($F_{3,16} = 191.309$, $P < 0.0001$), whereas greater RGR values were observed in sunflower and castor ($F_{3,16} = 3.90$, $P < 0.05$). Both GR and RGR values were lowest for jute and sesame. CR was significantly different between all the treatments ($F_{3,16} = 1435.77$, $P < 0.0001$). CR was highest when insects were reared with sunflower followed by castor, jute and sesame. CI was greatest in sunflower ($F_{3,16} = 41.22$, $P < 0.0001$), while this value did not differ significantly in other three host leaves. A higher value of AD was observed on castor followed by sunflower, and lower value of this index was recorded in insects fed with sesame ($F_{3,16} = 119.61$, $P < 0.0001$). Both ECI and ECD values were highest in sesame, lowest in sunflower, and intermediate in castor and jute (ECI: $F_{3,16} = 18.19$, $P < 0.0001$; ECD: $F_{3,16} = 63.25$, $P < 0.0001$). LS value was best in sunflower and worst in sesame-fed insects. ($F_{3,16} = 47.93$, $P < 0.0001$). Data

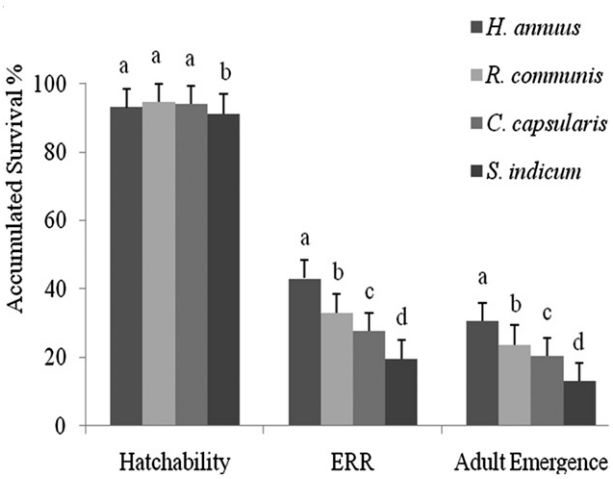

Figure 1 Accumulated survivals of *D. casignetum* on sunflower *H. annuus*, castor *R. communis*, jute *C. capsularis* and sesame *S. indicum* leaves. Mean ± SE of 5 observations. ERR, effective rate of rearing. Different letters over the bars indicate that the means are significantly different at $P < 0.05$.

on food utilization efficiency measures for the first five instars (Table S1–S5) are presented in Appendix S1 in Supporting Information.

The hatchability percent from *D. casignetum* eggs was lower for sesame leaves than the other three host-leaves used in this study ($F_{3,16} = 9.425$, $P < 0.001$) (Fig. 1). The overall accumulated survival rates of all larval stages on four host-plants varied significantly ($F_{3,16} = 666.948$, $P < 0.0001$) (Fig. 1) and was highest in sunflower (53.27%) followed by castor (42.15%), jute (35.48%) and sesame (27.79%). The ERR varied significantly between all the treatments ($F_{3,16} = 398.083$, $P < 0.0001$), which could be placed in the order of sunflower > castor > jute > sesame (Fig. 1). The emergence of adult moths from the hatched eggs was greatest when the larvae were reared on sunflower followed by castor, jute and sesame ($F_{3,16} = 234.515$, $P < 0.0001$).

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Table 3 Biochemical analyses of four host-plants

Biochemical parameters	Sunflower	Castor	Jute	Sesame	$F_{3,16}$	P
Carbohydrate (mg/g)	104.10 ± 1.13[a]	98.77 ± 1.22[b]	55.17 ± 1.03[c]	43.51 ± 0.30[d]	945.67	0.0001
Protein (mg/g)	12.14 ± 0.16[a]	12.42 ± 0.18[a]	11.35 ± 0.13[b]	10.07 ± 0.06[c]	41.29	0.0001
Lipid (mg/g)	12.17 ± 0.14[a]	11.96 ± 0.10[a]	10.60 ± 0.22[b]	9.83 ± 0.17[c]	44.07	0.0001
Nitrogen (%)	4.39 ± 0.07[a]	4.51 ± 0.07[a]	3.95 ± 0.05[b]	2.94 ± 0.06[c]	112.09	0.0001
Amino acid (mg/g)	2.77 ± 0.08[a]	2.21 ± 0.05[b]	1.97 ± 0.06[c]	1.98 ± 0.07[c]	28.41	0.0001
Phenol (mg/g)	7.25 ± 0.24[a]	7.30 ± 0.22[a]	9.60 ± 0.23[b]	10.69 ± 0.12[c]	64.77	0.0001
Moisture content (%)	78.53 ± 0.21[a]	76.77 ± 0.20[b]	73.33 ± 0.53[c]	77.50 ± 0.16[d]	13.18	0.001

Mean ± SE of 5 observations. Within the row means followed by same letter(s) are not significantly different by Tukey's test.

Biochemical analysis and moisture content of host-plants

The biochemical analyses of the four host-plants are presented in Table 3. Total carbohydrates varied significantly among the four host-plants, which can be arranged in order of sunflower > castor > jute > sesame ($F_{3,16} = 945.67$, $P < 0.0001$). Total nitrogen and proteins were highest in sunflower and castor followed by jute and sesame (nitrogen $F_{3,16} = 112.09$, $P < 0.0001$; protein $F_{3,16} = 41.29$, $P < 0.0001$). Lipid content was greater in sunflower and castor, and lower in sesame ($F_{3,16} = 44.07$, $P < 0.001$). Total amino acid content was highest in sunflower, least in jute and sesame, and intermediate in castor ($F_{3,16} = 28.41$, $P < 0.001$). Phenol concentration was highest in sesame and lowest in sunflower and castor ($F_{3,16} = 64.77$, $P < 0.0001$). Sunflower had the highest water content among the four host-plants ($F_{3,16} = 13.18$, $P < 0.001$).

DISCUSSION

The role of host-plant is an important factor in regulating insect populations as the concentrations and proportion of nutrients differ greatly among species (Schoonhoven *et al*. 2005). The growth duration and rate, consumption rate, utilization efficiency, developmental time, longevity, fecundity and survival of *D. casignetum* showed significant differences among the four host-plants tested with respect to their food quality (Awmack & Leather 2002; Shobana *et al*. 2010). Low water content acts as limiting factor for the growth rate reduction of plant-fed caterpillars (Mattson & Scriber 1987; Shobana *et al*. 2010). This study demonstrated the water content in the order of sunflower > sesame > castor > jute, which has probably influenced the higher growth rate (GR) of *D. casignetum* when fed with sunflower leaves.

Nutritional requirements for insect growth and reproduction depend on the ability of the insect to ingest, assimilate and convert food into body tissue (Dadd 1985; Nation 2001). Clear variation was observed in food consumption and development of *D. casignetum* when fed with these four host-plants. The possible explanation for variation in food consumption and development of this insect is due to significant differences in carbohydrates, proteins and lipids. This study indicated highest growth rate of *D. casignetum* when fed with sunflower, and insects reared on sesame exhibited the lowest growth rate, which may be due to the highest and lowest carbohydrate contents in sunflower and sesame, respectively. Sunflower and castor are richer in proteins than jute and sesame, which suggests that growth of the insects will be fastest by feeding on the former two species of host-plants. Amino acid content was highest in sunflower, which would probably explain the higher growth rate of *D. casignetum* fed on sunflower host-plants. Lipid content was higher in leaves of sunflower and castor. Deficiency of lipids in lepidopteran species results in defective wing formation and also their scales adhere to the pupal case on emergence (Turunen 1990; Nation 2001; Genc & Nation 2004).

Phenols determine the suitability of the substrate for exploitation by the herbivores and thus govern host preferences and acceptability (Harborne 1994; Schoonhoven *et al*. 2005). Further, an increase in phenol content indicates reduction in adult longevity and fecundity, and retardation of larval growth (Harborne 1994). Higher phenol content was observed in sesame, which probably indicates greater resistance in this plant against herbivory. Further, greater content of phenol in sesame probably caused reduction in fecundity and retardation of larval growth of *D. casignetum* when compared to the other three host-plants used in this study, even though sesame possessed higher amounts of water than castor.

The ECD values indicate the allocation of assimilated food to growth, hence a decreased ECD proves as an indicator of higher metabolic maintenance costs (Slansky & Scriber 1985). However, the larvae of *D. casignetum* reared on sesame were more efficiently converting these tissues into biomass than other plant

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tissues as having lowest AD and highest efficiency of conversion of digested and ingested food. This might be due to homeostatic adjustment of consumption rates and efficiency parameters of an insect to achieve ideal growth rate even with foods of different quality (Xue *et al*. 2010). This suggests that sesame-fed *D. casignetum* larvae are able to compensate by more efficiently utilizing their limited sesame tissue than other host-leaf tissue (Zhu *et al*. 2005). In this study, higher levels of carbohydrates, proteins, lipids and nitrogen including amino acids, and lower levels of phenol in sunflower might be the possible explanation for relatively higher consumption index (CI) shown by *D. casignetum*, and fastest larval development when the insects were fed with sunflower. Lower levels of carbohydrates, amino acids and water in castor than sunflower probably would explain the lower consumption index by *D. casignetum*.

The fecundity of *D. casignetum* adults is in the order of feeding on sunflower > castor > jute > sesame. This suggests that sunflower has the best nutritional quality of these four host-plants (Shobana *et al*. 2010). Host-plant affected survival of *D. casignetum* on the larval stages. Higher larval survival rates and shorter developmental time of *D. casignetum* fed on sunflower indicates better food quality. Since the development of the lepidopteran reproductive system is dependent on nutrients acquired during their lifetime (Johansson 1964), increasing allocation of nutrients to egg production was displayed by *D. casignetum* feeding on sunflower. Hence, this study suggests that the relatively low food quality of sesame for *D. casignetum* requires longer feeding than other crops such as sunflower, castor and jute, and consequently leads to higher level of leaf consumption and crop damage.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Appendix S1 Food utilization efficiency measures from first to fifth instar larvae of *D. casignetum* reared on four host-plants.
Table S1 Food utilization efficiency measures of first instar larvae of *D. casignetum* ($n = 100$) reared on four host-plants.
Table S2 Food utilization efficiency measures of second instar larvae of *D. casignetum* ($n = 100$) reared on four host-plants.
Table S3 Food utilization efficiency measures of third instar larvae of *D. casignetum* ($n = 100$) reared on four host-plants.
Table S4 Food utilization efficiency measures of fourth instar larvae of *D. casignetum* ($n = 100$) reared on four host-plants.
Table S5 Food utilization efficiency measures of fifth instar larvae of *D. casignetum* ($n = 100$) reared on four host-plants.

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