Effect of food plants on nutritional ecology of two acridids (Orthoptera: Acrididae) to provide alternative protein supplement for poultry

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Abstract: A large annual acridid biomass should be produced on acridid farms to manufacture high-quality, low-cost feed for the poultry industry. A laboratory experiment was conducted to measure the nymphal mortality, nymphal developmental period, growth indices, and adult life span of 2 common acridids (Oxya hyla hyla and Spathosternum prasiniferum prasiniferum) on 3 food plants (Dactyloctenium aegyptium, Cynodon dactylon, and Brachiaria mutica). Among the 3 food plants, D. aegyptium was suitable only for 1st and 2nd instars of O. hyla hyla, and B. mutica was suitable for the remaining instars and the adult stages of O. hyla hyla and for all nymphal and adult stages of S. prasiniferum prasiniferum. Of the 2 selected acridids, O. hyla hyla gave better results for growth indices and other chosen parameters. It was concluded that on acridid farms, O. hyla hyla should be reared on D. aegyptium in early nymphal stages and on B. mutica in advanced nymphal and adult stages to obtain a high biomass.

Key words: Acridid farms, acridid biomass, Brachiaria mutica, Cynodon dactylon, Dactyloctenium aegyptium, low-cost feed, Oxya hyla hyla, Spathosternum prasiniferum prasiniferum

Introduction
The increasing human population, particularly in developing countries, is creating a rise in the demand for animal protein. Inability to meet this demand adversely affects the protein intake level of a population and results in malnutrition. Poultry meat contributes approximately 37% of the total animal protein supply, and there is a potential for growth and expansion of this industry (Ahmed and Islam, 1990; Khatun et al., 2003). However, production is hindered by cost, scarcity, and the fluctuating quantity and quality of feed ingredients. Generally, feed accounts for 75%-80% of the total cost of poultry production (Bhuiyan, 1998; Hassan, 2002). In light of this, the poultry industry is committed to finding alternative, nonconventional, economical, and high-quality renewable protein sources. One such source may include insects that can ultimately serve as a protein source for humans. The protein content of short-horned grasshoppers varies from 52.1% to 77.1% (Ramos-Elorduy, 1997). These were utilized in the formulation of a high-protein diet for poultry and are an acceptable feed that produced no adverse effects on weight gain, feed intake, or feed conversion ratio (FCR) (Wang et al., 2007). Ramos-Elorduy et al. (1988) reported that poultry performs better when reared on insect diets. According to Anand
et al. (2008b), *Oxya fuscovittata* and *Spathosternum prasiniferum prasiniferum* could be excellent sources of low-cost, protein-rich feed supplement for poultry. Moreover, the livestock industry needs a continuous and sustainable supply of acridids. In this context, Haldar et al. (1998) proposed establishing acridid farms for mass rearing of this protein source. Das et al. (2009) estimated the optimum space requirement for mass rearing of *Oxya fuscovittata* and *Spathosternum prasiniferum prasiniferum*. Anand et al. (2008a) reported that *Oxya fuscovittata* and *Spathosternum prasiniferum prasiniferum* could produce a huge biomass that would serve as a potential animal feed supplement. For worldwide livestock production enhancement, feed-producing companies could manufacture low-cost feed with protein-rich acridids. According to Das et al. (2002), to obtain a high amount of acridid biomass, studies on acridid growth rate and survival rate are essential as rapid growth and low mortality will directly influence mass culture and biomass production.

Nutrition is a factor of paramount importance that regulates growth and development (Rath, 2010). A quantitative nutritional approach measures the food consumed, digested, assimilated, excreted, metabolized, and converted into biomass (Waldbauer, 1968; Woodring et al., 1979). These rates are related to the growth of the organism during its feeding period, in order to assess how food properties affect insect performance (Scriber and Slansky, 1981). Food consumption and utilization influence metabolism, enzyme synthesis, nutrient storage, and other activities. Acridids are, without exception, phytophagous (Bernays and Bright, 1991), and the selection of food sources in acridids is governed by a complex series of factors, which include availability of the host plant as well as the behavior, physiology, and ecology of the insect (Gangwere, 1961; Mulkern, 1967; Otte and Joern, 1977). In addition, chemical composition of a plant is the main factor in host plant selection (Bernays and Chapman, 1978). In previous studies, adequate work has been done on food plant selection by grasshoppers (Sinoir, 1969; Bernays and Chapman, 1973; Campbell et al., 1974; Mulkern, 1967; Uvarov, 1977; Rowell, 1978; Parker, 1984; Hsiao, 1985; Chapman et al., 1988); however, the findings are largely associated with field observation at the level of population ecology, and studies were carried out in North and Central America and Africa. Works on acridid biology from India were limited to only a few species (Roonwal, 1945, 1976a, 1976b, 1978; Katiyar, 1957; Siddiqui, 1986, 1989). Food preferences of grasshoppers vary from place to place depending on the climate and ecological conditions of a region. Hence, there is a need for a detailed study of the effect of food plants on the growth rate of acridids from this region. With this in mind, a study was conducted with 2 highly nutritive common Indian acridids, *Oxya hyla hyla* and *Spathosternum prasiniferum prasiniferum*, to determine the effect of 3 types of food plants of the family Poaceae on nymphal development. In addition, detailed nymphal and adult growth rates and consumption indices were compiled in order to find a suitable plant species for biomass production on acridid farms.

**Materials and methods**

**Collection and rearing of acridids under laboratory conditions**

The acridids of interest, *O. hyla hyla* and *S. pr. prasiniferum*, were collected from agricultural fields and grasslands in Santiniketan (23°39′N, 87°42′E), India, by a sweeping method using an insect net of 30 cm in diameter. The collected insects were acclimatized in specially designed cages made of nylon netting on a wooden frame (75 × 52.5 × 30 cm³) under laboratory conditions of 30-35 °C, 70%-80% relative humidity, 500 ± 25 lx light intensity, and a 12L/12D photoperiod. Enamel trays (10 × 10 × 4.5 cm³) filled with fine, washed, and sterilized moist sand were kept inside the cages for insect oviposition. Insects were reared in the insectariums of the Entomology Research Unit, Department of Zoology, Visva-Bharati University, where a huge biomass of the selected acridid species was maintained by mass culture, using the strategies proposed by Ewen and Hinks (1886) and Hinks and Erlandson (1994). Eggs were collected from the oviposition trays and transferred to sterilized sand-filled plastic cups at a depth of 2.5-5 cm and incubated at 35 ± 2 °C. Newly emerged nymphs were used for the experiment.

**Obtaining food plants to feed acridids**

*Cynodon dactylon* Pers. has a cyanogenic property that may be induced by herbivory or mechanical cutting
of the leaves. To avoid cyanogenic induction, leaves of *C. dactylon* were collected from different sites in the garden of the Department of Zoology, Visva-Bharati University, Santiniketan, West Bengal, India, where this grass is abundant. *Dactyloctenium aegyptium* (L.) Willd. and *Brachiaria mutica* (Forssk.) Stapf were grown outdoors at the Ecology and Entomology Experimental Plot of the Zoology Department, Visva-Bharati University. After the grasses were fully grown and spread over the plot area, young leaves with cut ends were immersed in water in 18-mL glass vials and offered to the experimental insects.

**Analysis of nutrient composition of food plants**

Nutrient composition of all 3 food plants was estimated by proximate analysis using a standard procedure (Association of Official Analytical Chemists, 2000). Analyses were performed with 5 replicates per plant.

**Experimental setup**

The following description of the experimental setup is for single acridid species fed with a single type of food plant. All other experiments were carried out with a similar setup. From the insectariums, 375 newly hatched nymphs of the selected species were collected. To reduce error, 25 individuals among the 375 were freeze-killed and dried in a hot air oven at 40 °C until the weight of the dried nymphs became constant; the dry weight of 1-day-old nymphs did not vary significantly. For the study of growth rate and consumption indices, 1 set was prepared with the remaining 350 nymphs, which were kept in 5 transparent plastic jars (20 × 20 × 35 cm³) containing 70 individuals each. One selected species of food plant was then offered in 5 replicates. From the selected acridid, 5 newly hatched nymphs of each instar were freeze-killed and dried in a hot air oven at 40 °C for 72 h to calculate the mean dry weight of each instar. Nymphs were observed daily to record molting, if any. Life spans of all intermediate instars were recorded.

For the experiment with newly hatched 0-day adult (fledglings), 3 sets were prepared: a 1st set with 25 male individuals, a 2nd set with 25 female individuals, and a 3rd set with 25 female and 10 male individuals. Each set had 3 replications, and all sets were fed with 1 type of food plant per replication, the same type fed to them in the nymphal stages. From each jar, 5 individuals (only mated females from the 3rd set) were freeze-killed weekly and dried in an oven to obtain the weekly mean dry weight gain of males, virgin females, and mated females. Acridids of interest were double-tagged on the pronotum and femur with marker pens of different colors for future identification. Adult duration was calculated in days after the individuals had died. Deceased adult individuals were put in the oven in order to obtain the final dry weight.

**Studied parameters**

Growth was measured in terms of growth rate (GR) and food consumption, and utilization was measured in terms of consumption index (CI), approximate digestibility (AD), efficiency of conversion of ingested food to body substance (ECI), and efficiency by which digested food is converted into body substance (ECD), as proposed by Waldbauer (1968). The parameters were calculated for nymphs, adult males, and virgin and mated females.

Dry weight of ingested food (F) was calculated following the method of Rahman (2001). Every morning, definite quantities of fresh washed leaves were provided to the insects, and aliquots of the same food were kept under the same conditions to calibrate water loss from the food provided. Every day, uneaten food was separated from the feces and weighed. This weight was used together with the initial and final weights of the aliquots to calibrate the approximate food consumed. The dry weight of the food consumed was calculated and recorded according to the following equation developed by Waldbauer (1968):

\[
\text{Dry weight of food consumed} = (1 - A/2) \times \left[ W - L(1 + B) \right],
\]

where \( W \) = fresh weight of food provided, \( L \) = dry weight of uneaten food, \( A \) = initial weight of the aliquot, and \( B \) = final weight of the aliquot.

Formulas of the indices calculated are as follows:

1. \( \text{GR} = \frac{W_t}{TA} \) (where \( W_t \) = dry weight gained, \( T \) = duration of feeding period in days, and \( A \) = mean dry weight of the insect during feeding period).

2. \( \text{CI} = \frac{F}{TA} \) (where \( F \) = average dry weight of food ingested per individual).

3. \( \text{AD} = \frac{[(F - Fe)/F]}{100} \) (where \( Fe \) = average
4. ECI = (Wt/F) × 100.
5. ECD = [Wt/(F – Fe)] × 100.

Statistical analysis
Data are presented as mean ± standard deviation (SD). For all nymphal traits, 5 replicates were carried out, and 3 replicates were performed for all adult traits. For all selected traits of nymphs and adults, 2-way analysis of variance (ANOVA) was carried out, taking food plants and instar for nymphs or week intervals for adults as factors. ANOVA was followed by Duncan’s multiple range test (DMRT) in order to separate the mean values according to significance. All analyses were carried out using Microsoft Excel 2000 software.

Results
Nutrient composition of food plants
Nutrient composition of food plants is summarized in Table 1. The highest values for all estimated nutrients were observed in *B. mutica* and the lowest in *D. aegyptium*, with the exception of crude fat, which was lowest in *C. dactylon*.

Feeding experiment
The GR of *O. hyla hyla* is presented in Figure 1. Nymphal GR (Figure 1a) within instars among food plants was higher in *D. aegyptium*-fed sets for 1st and 2nd instars and in *B. mutica*-fed sets for the remaining instars except for the 6th instar, where *C. dactylon* - and *B. mutica*-fed sets did not show any significant variation (DMRT). Significantly lower results of nymphal GR were observed for the 1st instar in *B. mutica*-fed sets, the 2nd instar in *C. dactylon* - and *B. mutica*-fed sets, and the 3rd instar onwards in *D. aegyptium*-fed sets. The results of GR of adult males (Figure 1b) showed that the first 4 weeks had the highest results in *B. mutica*-fed sets compared to the last 3 weeks in *D. aegyptium*-fed sets. For the first 3 weeks, significantly lower results were noticed in *D. aegyptium*-fed sets, and for the remaining weeks, they were noticed in the *C. dactylon*-fed sets. The GR of virgin females (Figure 1c) was highest in *B. mutica*-fed sets for all weeks, except the 7th, when it was highest in the *D. aegyptium*-fed set. For the 1st and 2nd weeks, *D. aegyptium*-fed sets gave significantly lower results; for the remaining weeks, lower mean GR values were obtained in *C. dactylon*-fed sets. The GR of mated females (Figure 1d) was significantly higher in *B. mutica*-fed sets for all weeks except the 7th, when the values varied insignificantly among food plants. *D. aegyptium*-fed mated females showed a trend for lower GR, although in the 4th and 6th weeks values were insignificant when compared between *D. aegyptium* and *C. dactylon*. However, in these 2 cases the mean values of *D. aegyptium*-fed sets were lower than those produced by *C. dactylon*-fed sets.

The GR of *S. pr. prasiniferum* is shown in Figure 2. The trend in nymphal GR (Figure 2a) showed that the highest results were observed in *B. mutica*-fed sets and the lowest were observed in *D. aegyptium*-fed sets. Although in the 3rd instar no significant variation was obtained between *C. dactylon* - and *B. mutica*-fed sets, the mean value of *B. mutica*-fed sets was higher. The GR of males (Figure 2b), virgin females (Figure 2c), and mated females (Figure 2d) followed a pattern similar to the pattern observed in nymphs. However, in the case of the 2nd and 6th week of virgin females, significantly higher values were noticed in *C. dactylon*-fed sets. On the other hand, the GR of mated females showed insignificant variation for the 1st and 3rd weeks between *D. aegyptium* - and *C. dactylon*-fed sets. In the 6th week, insignificant variation was observed between *C. dactylon* - and *B. mutica*-fed sets.

<table>
<thead>
<tr>
<th>Food plants</th>
<th>Crude protein (%)</th>
<th>Crude fat (%)</th>
<th>Carbohydrate (%)</th>
<th>Total ash (%)</th>
<th>Crude fiber (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>D. aegyptium</em></td>
<td>8.6 ± 0.84</td>
<td>2.37 ± 0.48</td>
<td>72.09 ± 0.57</td>
<td>7.75 ± 0.58</td>
<td>21.11 ± 0.83</td>
</tr>
<tr>
<td><em>C. dactylon</em></td>
<td>9.5 ± 0.55</td>
<td>2.19 ± 0.55</td>
<td>75.95 ± 0.52</td>
<td>10.4 ± 0.26</td>
<td>25.85 ± 0.97</td>
</tr>
<tr>
<td><em>B. mutica</em></td>
<td>13.1 ± 1.25</td>
<td>3.21 ± 0.77</td>
<td>79.22 ± 0.99</td>
<td>13.85 ± 0.55</td>
<td>28.35 ± 0.66</td>
</tr>
</tbody>
</table>
The CI of *O. hyla hyla* is shown in Figure 3. Nymphal CI (Figure 3a) of all instars was significantly lower in *B. mutica*-fed sets and higher in *D. aegyptium*-fed sets, except in the 1st instar, where data varied insignificantly between *D. aegyptium* and *C. dactylon*-fed sets; however, the mean value was higher in *D. aegyptium*-fed sets. Similar trends were found in males (Figure 3b) for all weeks and in virgin females (Figure 3c) for the 2nd, 3rd, and 4th weeks. For the remaining weeks, virgin females gave significantly lower values in *B. mutica*-fed sets, and the values of *D. aegyptium* and *C. dactylon*-fed sets varied insignificantly. A type of result similar to that observed in males was found in the CI of mated females of the 1st, 2nd, and 3rd weeks. In the 4th and 7th weeks, insignificant variation was notice between *D. aegyptium* and *C. dactylon*-fed sets. On the other hand, in the 5th and 6th weeks, significantly higher results were noticed in *C. dactylon*-fed sets.

Figure 4 shows the CI of *S. pr. prasiniferum*. Nymphal CI (Figure 4a) of the 1st, 3rd, and 4th instars showed a result similar to the type observed in *O. hyla hyla*, and 2nd instars of *S. pr. prasiniferum* gave results reciprocal to those of the 1st instars. In 5th and 6th instars, the CI was significantly higher in *C. dactylon*-fed sets and lower in *B. mutica*-fed sets. The CI of males (Figure 4b), virgin females (Figure 4c), and mated females (Figure 4d) of *S. pr.
prasiniferum showed a pattern similar to that found in the CI of O. hyla hyla males, with the exception of results from the 4th week of males and the 3rd week of virgin females; in the case of mated females in the 1st, 2nd, and 6th weeks, insignificant variations were found between D. aegyptium- and C. dactylon-fed sets.

The AD of O. hyla hyla is presented in Figure 5. A gradual increase in the mean value of nymphal AD (Figure 5a) was obtained in D. aegyptium-, C. dactylon-, and B. mutica-fed sets, respectively; B. mutica-fed sets always gave significantly higher values. A similar trend emerged in adult males (Figure 5b), virgin females (Figure 5c), and mated females (Figure 5d). The AD of S. pr. prasiniferum (Figure 6) showed a trend similar to the one observed in O. hyla hyla.
A significantly higher value of nymphal ECI (Figure 7a) of *O. hyla hyla* for the 1st and 2nd instars was observed in *D. aegyptium*-fed sets; for the 3rd, 4th, and 6th instars in *B. mutica*-fed sets; and for the 5th instar in *C. dactylon*-fed sets. The ECI of adult males (Figure 7b) of *O. hyla hyla* was significantly higher in *B. mutica*-fed sets and lower in *D. aegyptium*-fed sets for the first 3 weeks; from the 4th instars onward the ECI was significantly lower in *C. dactylon*-fed sets. The ECI of virgin females (Figure 7c) showed higher values in *B. mutica*-fed sets through the 6th week; in the 7th week, the values of *D. aegyptium*- and *B. mutica*-fed sets showed insignificant variation, and the lowest values were obtained in *C. dactylon*-fed sets. The ECI values of mated females (Figure 7d) of *O. hyla hyla* showed a trend of gradual increase in the mean values of *D. aegyptium*- , *C. dactylon*- , and *B. mutica*-fed sets, respectively; *B. mutica*-fed sets always showed significantly higher values in all cases. However, from the 4th to the 7th week, the ECI

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**Figure 3.** Consumption index (CI) in *O. hyla hyla* fed on 3 food plants: a) nymphs, b) adult males, c) virgin females, d) mated females. Values are mean ± SD. Bars with different letters within a growth stage are significantly different (P < 0.001) using DMRT.
values of $D. \text{aegyptium}$- and $C. \text{dactylon}$-fed sets did not vary significantly.

The nymphal ECI (Figure 8a) of $S. \text{pr. prasiniferum}$ was significantly lower in $B. \text{mutica}$-fed sets for 1st, 2nd, and 6th instars, and in $D. \text{aegyptium}$-fed sets for 3rd and 4th instars. Significantly higher nymphal ECI values were observed in $D. \text{aegyptium}$-fed sets for the 1st, 5th, and 6th instars; in $C. \text{dactylon}$-fed sets for 2nd instars; and in $B. \text{mutica}$-fed sets for 3rd instars. In the case of 4th instars, $C. \text{dactylon}$- and $B. \text{mutica}$-fed sets did not show any significant variation. The mean value of ECI in adult males (Figure 8b) gradually increased when they were fed $D. \text{aegyptium}$, $C. \text{dactylon}$, and $B. \text{mutica}$, respectively. However, in the 4th week, no significant variation was observed among the selected sets. A similar trend was also observed in virgin females (Figure 8c) and mated females (Figure 8d).

The nymphal ECD of the 1st instar (Figure 9a) of $O. \text{hyla hyla}$ gradually decreased when fed on $D. \text{aegyptium}$, $C. \text{dactylon}$, and $B. \text{mutica}$, respectively, and in the 4th instar reciprocal results were noticed. In 2nd instars, $C. \text{dactylon}$-fed sets showed significantly lower values, and the other 2 plants did not show any
significant variation. On the other hand, in 3rd instars, a lower value was found in *D. aegyptium*-fed sets, and the other 2 plants did not show any significant variation. For 5th and 6th instars, *C. dactylon*-fed sets showed higher values. The ECD values of adult males (Figure 9b) in the first 3 weeks showed a trend similar to that of the 4th instars' nymphal ECD, i.e., a gradual increase from *D. aegyptium*- to *B. mutica*-fed sets. From the 4th week onwards, ECD was lower in *C. dactylon*-fed sets, and from the 5th week, ECD was higher in *D. aegyptium*-fed sets. The ECD of the first 2 weeks in virgin females (Figure 9c) showed a trend similar to that found in the first 3 weeks in adult males. From the 3rd to the 6th week, ECD was significantly lower in *C. dactylon*-fed sets and higher in *B. mutica*-fed sets. However, in the 7th week, the highest values were obtained in *D. aegyptium*-fed sets. The ECD of the

Figure 5. Approximate digestibility (AD) in *O. hyla hyla* fed on 3 food plants: a) nymphs, b) adult males, c) virgin females, d) mated females. Values are mean ± SD. Bars with different letters within a growth stage are significantly different (P < 0.001) using DMRT.
variation. In the 7th week, insignificant results were obtained for all 3 food plants.

The ECD of *S. pr. prasiniferum* is shown in Figure 10. In all cases, the values of nymphal ECD (Figure 10a) were significantly lower in *B. mutica*-fed sets. For the 1st, 5th, and 6th instars, a gradual decrease was noticed in *D. aegyptium*- and *C. dactylon*-fed sets, respectively. In the remaining instars, insignificant variations were observed in *D. aegyptium*- and *C. dactylon*-fed sets. The ECD of adult males (Figure 10b) was significantly higher in *B. mutica*-fed sets for every week except the 5th, when insignificant variations were obtained for all 3 food plants. In all studied weeks except the 3rd, insignificant variation was observed between *D. aegyptium* and *C. dactylon*-fed sets. The ECD of virgin females (Figure 10c) and mated females (Figure 10d) showed a trend of gradual increase in mean value for the 3 food plants; the ECD values of mated females varied insignificantly in the first 4 weeks when they were fed on *D. aegyptium* and *C. dactylon*.

The results of nymphal mortality percentage are summarized in Table 2. When data were compared
among food plants within *O. hyla hyla*, it was observed that in the 1st and 2nd instars, nymphal mortality percentages were significantly higher in *B. mutica*-fed sets and lower in *D. aegyptium*-fed sets; the remaining instars gave reciprocal results. In *S. pr. prasiniferum* 1st and 2nd instars, significantly higher values for nymphal mortality were found in *D. aegyptium*-fed sets; for 3rd and 4th instars, it was significantly higher in *C. dactylon*-fed sets. Nymphal mortality was significantly lower in *B. mutica*-fed sets. When data were compared between selected acridids within food plants, it was observed that for *D. aegyptium*-fed sets, nymphal mortality percentages were lower in *S. pr. prasiniferum* except in the 1st and 2nd instars; for *B. mutica*-fed sets, an opposite trend was found. In *C. dactylon*-fed sets, significantly higher nymphal mortality percentages were noticed in *O. hyla hyla*.

Table 3 shows the results for the nymphal developmental period (NDP). When data were compared between food plants within acridid

Figure 7. Efficiency of conversion of ingested food to body substance (ECI) in *O. hyla hyla* fed on 3 food plants: a) nymphs, b) adult males, c) virgin females, d) mated females. Values are mean ± SD. Bars with different letters within a growth stage are significantly different (P < 0.001) using DMRT.
species, in *O. hyla hyla* it was observed that the NDP of the 1st instar was significantly longer in *B. mutica*-fed sets. For the 2nd instars, no significant variation was observed when data were compared among food plants. However, from the 3rd instar onwards, significantly lower values were obtained in *B. mutica*-fed sets. In *S. pr. prasiniferum* 1st, 2nd, and 3rd instars, the NDP did not vary significantly when results were compared among food plants. For the remaining instars, however, it was significantly lower in *B. mutica*-fed sets. When data were compared between acridids within a single food plant, in *D. aegyptium*-fed sets the NDP was significantly shorter in *O. hyla hyla* for the 1st and 3rd instars and higher in the 5th and 6th instars; for the 2nd and 4th instars, there was no significant variation. In *C. dactylon*-fed sets, significantly lower NDP values were observed in *O. hyla hyla* for the 1st and 4th instars and in *S. pr. prasiniferum* for the 2nd and 6th instars. *B. mutica*-fed sets showed shorter NDPs in *O. hyla hyla* for the 2nd, 3rd, 4th, and 6th instars, and the other 2 instars did not show any significant variation between selected acridids.

When the adult life span data (Table 4) were compared among food plants within selected acridids, it was observed that adult males, virgin females, and mated females of both acridid species gave significantly better results in *B. mutica*-fed sets.
It was also observed that the life spans of adult males, virgin females, and mated females of *O. hyla hyla* were significantly longer than those of *S. pr. prasiniferum*.

**Discussion**

The present study showed that food plants have a significant effect on the growth parameters, nymphal mortality, nymphal developmental period, and adult life span of acridids. Moreover, quality of food is important for the fitness and survival of insects (Price et al., 1980). This finding agrees with those of Ganguly et al. (2010), Das et al. (2002), Riffat and Muhammad (2007), and Sanjayan and Murugan (1987). Chin et al. (1957) and Uvarov (1966) observed that growth indices were at a maximum and mortality percentages at a minimum in locusts fed plants belonging to the family Poaceae. Haldar et al. (1995) also noticed that plants of the family Poaceae were mostly preferred by acridids. As a result, in the present experiment all plants chosen were from Poaceae.

As established by Haldar et al. (1998), *C. dactylon* is used as a standard food plant for *Oxya fuscovittata* in insectariums. Ganguly et al. (2010) also observed...
that *C. dactylon*-fed *Oxya fuscovittata* showed moderate results for growth parameters. In the present study, in most cases, *C. dactylon*-fed acridids showed moderate growth.

That nymphal growth, developmental periods, and survival percentages of grasshoppers were influenced by different food plants supports the views of Ananthakrishnan et al. (1985) and Olert et al. (1990). *D. aegyptium*-fed sets gave better results for nymphal mortality, nymphal developmental period, and growth parameters for the 1st and 2nd instars of *O. hyla hyla*. As a result, during the rearing process for the 1st and 2nd instars of *O. hyla hyla*, *D. aegyptium* was recorded as the most suitable food plant. Similarly, for the other instars of this species and for all nymphal stages of *S. prasiniferum*, *B. mutica* was the most favorable food plant. Maximum CI was observed for both selected acridids when they were fed with *D. aegyptium*. This may be due to its lower nutrient content; the acridids were required to consume a greater amount to maintain their development. Relatively lower amounts of *B. mutica* were consumed. It had greater digestibility as it contained high amounts of fiber and low amounts of antifeedant chemicals. The observed results also agreed with those of Zheng et al. (1993) and Ganguly et al. (2010), who reported that food type could influence larval growth and development.
of grasshoppers. The present study also supports the view of Nzekwu and Akingbohungbe (2002), who wrote that variable developmental periods can occur in nature depending on the preponderance of particular food plants in various localities. In nature, mixed diets are available in particular areas. As a result, grasshoppers can choose their diet; in most cases, they prefer to eat a mixed diet, and this provides better growth and reproductive performance. This may be due to consumption of sufficient nutritive elements from various food plants (Westcott et al., 1972; Rice and Panchoy, 1973) or higher tissue growth efficiency of insects (Phillipson, 1966; Latheef and Harcourt, 1972; Fanny et al., 1999). Various authors including McFarlane and Thorsteinson (1980) reported that mixed plant diets are better for Melanoplus bivittatus (Say), because they promote higher growth indices, larger adults, and a higher survival rate than any single plant-based diet. Bernays and Bright (1991) reported that individual polyphagous grasshoppers switch between different food plants and consume mixed food. According to Ganguly et al. (2010), Oxya fuscovittata displayed better growth indices and reproductive ability when reared on Sorghum halepense. Fanny et al. (1999) obtained the shortest nymphal periods in acridids reared on a definite food plant. On the other hand, Ganguly et al. (2010) reported worse results in the

<table>
<thead>
<tr>
<th>Food plants</th>
<th>Acridid species</th>
<th>1st instar</th>
<th>2nd instar</th>
<th>3rd instar</th>
<th>4th instar</th>
<th>5th instar</th>
<th>6th instar</th>
</tr>
</thead>
<tbody>
<tr>
<td>D. aegyptium</td>
<td>O. hyla hyla</td>
<td>6 ± 1</td>
<td>9 ± 1</td>
<td>6.33 ± 0.58</td>
<td>10 ± 1</td>
<td>15 ± 1</td>
<td>17.67 ± 1.53</td>
</tr>
<tr>
<td>S. pr. prasiniferum</td>
<td>O. hyla hyla</td>
<td>10 ± 1</td>
<td>9 ± 1</td>
<td>8 ± 1</td>
<td>10 ± 1</td>
<td>10.67 ± 1.15</td>
<td>14 ± 1</td>
</tr>
<tr>
<td>C. dactylon</td>
<td>O. hyla hyla</td>
<td>7.33 ± 0.58</td>
<td>10 ± 1</td>
<td>8 ± 1</td>
<td>8 ± 1</td>
<td>8.67 ± 1.15</td>
<td>14.67 ± 0.58</td>
</tr>
<tr>
<td>S. pr. prasiniferum</td>
<td>O. hyla hyla</td>
<td>10.33 ± 0.58</td>
<td>8.33 ± 0.58</td>
<td>9 ± 1</td>
<td>10.67 ± 0.58</td>
<td>8.33 ± 0.58</td>
<td>11.33 ± 1.15</td>
</tr>
<tr>
<td>B. mutica</td>
<td>S. pr. prasiniferum</td>
<td>10 ± 1</td>
<td>8 ± 1</td>
<td>1 ± 1</td>
<td>5 ± 1</td>
<td>5.33 ± 1.15</td>
<td>3 ± 1</td>
</tr>
</tbody>
</table>

Table 2. Nymphal mortality percentage of acridids fed on 3 food plants. Within a column, a1, b1, c1 and a2, b2 indicate significant differences between mean values within acridids and within food plants, respectively; 2-way ANOVA, DMRT, P < 0.05.

Table 3. Nymphal developmental period of acridids fed on 3 food plants. Within a column a1, b1, c1 and a2, b2 indicate significant differences between mean values within acridids and within food plants, respectively; 2-way ANOVA, DMRT, P < 0.05.
Effect of food plants on nutritional ecology of two acridids (Orthoptera: Acrididae) to provide alternative protein supplement for poultry

above parameters in *Oxya fuscovittata* when they were fed only *Oryza sativa* throughout their lifespan, although they are known as a paddy pest. In this context, the authors opined that *Oryza sativa* is not a suitable food plant in the initial stages of this species, when it tends to prefer soft grasses only. Idowu and Sonde (2003) also reported that the early instars of *Zonocerus variegatus* did not eat cassava in the field, although they might roost on it; the later instars preferred to eat cassava and showed higher growth and rapid development. In the present study, newly hatched nymphs of *O. hyla hyla* preferred to feed on soft green grasses (*D. aegyptium*) and consumed the less soft *B. mutica* only after reaching the 3rd instar stage. As the individuals in the experimental sets were offered *B. mutica* from the 1st day, nutrition may have been inadequate, resulting in high mortality, growth retardation, late maturation, and a very short adult life span. Thus, it could be said that the 1st and 2nd instar should be reared with *D. aegyptium* and the rest with *B. mutica* for more favorable results.

In adult *O. hyla hyla*, higher CI, AD, and GR values were observed in the 2nd week, probably due to higher metabolism and development. In male *S. pr. prasiniferum*, all of these parameters showed higher values in the 3rd week. On the other hand, in virgin and mated females, GR and AD values were at a maximum in the 3rd week, while the highest CI was noted in the 5th week. Higher CI and lower AD values could be explained as individuals consumed more food in the 5th week but produced more fecal matter as well. The highest ECI and ECD values were observed mostly in the 1st and 2nd weeks as the acridids had maximum dry weight gain in these periods. From the 2nd week onwards, the ECI decrease may be due to the use of food energy for increased reproductive performance as opposed to weight gain. Lower ECD values were found from the 2nd through the 4th week in the case of mated *O. hyla hyla* females. This may be due to an increase in fecal matter production and lower weight gain as the bulk of energy was utilized for egg pod production. When the 2 selected acridids were compared, lower ECD was observed in the 3rd week of male *S. pr. prasiniferum*. This may be due to the utilization of energy to mate with females. Relatively higher ECD values were obtained for male specimens of *O. hyla hyla*, and this may be due to less physical activity used to mate with female counterparts. The higher protein content of *B. mutica* may have led to lower consumption and maximum growth in both acridid species.

The results revealed that acridids fed with a food plant with relatively lower moisture content (*B. mutica*) grew better and had lower nymphal mortality. The nature of this finding was also supported by the work of Bernays and Chapman (1973), Bernays and Chamberlin (1980), and McKinlay (1981). Ali (1982) also reported that grasshopper metabolism was possibly affected by the water content of food, which may influence the quality of food consumed and therefore the rate of growth. The endocrine system plays a major role in grasshopper growth. According to Hill et al. (1966), activity within the endocrine system is generated by the stimulation of foregut stretch receptors during optimum feeding. In

### Table 4. Adult life span of acridids fed on 3 food plants. Within a column, a1, b1, c1 and a2, b2 indicate significant differences between mean values within acridids and within food plants, respectively; 2-way ANOVA, DMRT, P < 0.05.

<table>
<thead>
<tr>
<th>Food plants</th>
<th>Acridid species</th>
<th>Males</th>
<th>Females</th>
<th>Mated females</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>D. aegyptium</em></td>
<td><em>O. hyla hyla</em></td>
<td>63.33 ± 2.31 a1b2</td>
<td>70.67 ± 2.89 a1b2</td>
<td>58 ± 1.73 a1b2</td>
</tr>
<tr>
<td></td>
<td><em>S. pr. prasiniferum</em></td>
<td>46.67 ± 2.31 a1a2</td>
<td>50 ± 1.73 a1a2</td>
<td>43.67 ± 2.89 a1a2</td>
</tr>
<tr>
<td><em>C. dactylon</em></td>
<td><em>O. hyla hyla</em></td>
<td>71.67 ± 1.15 b1b2</td>
<td>77.33 ± 2.08 b1b2</td>
<td>65.67 ± 2.89 b1b2</td>
</tr>
<tr>
<td></td>
<td><em>S. pr. prasiniferum</em></td>
<td>52.33 ± 1.15 b1a2</td>
<td>57 ± 1.73 b1a2</td>
<td>52.33 ± 2.89 b1a2</td>
</tr>
<tr>
<td><em>B. mutica</em></td>
<td><em>O. hyla hyla</em></td>
<td>77 ± 1.73 c1b2</td>
<td>86.33 ± 2.52 c1b2</td>
<td>74.33 ± 1.53 c1b2</td>
</tr>
<tr>
<td></td>
<td><em>S. pr. prasiniferum</em></td>
<td>67 ± 5.65 c1a2</td>
<td>74.67 ± 2.52 c1a2</td>
<td>59.33 ± 1.15 c1a2</td>
</tr>
</tbody>
</table>
this context, Mordue and Hill (1970) reported that somatic growth in grasshoppers was activated by the ingestion of more nutritious food and optimum amounts of food. Furthermore, the authors stated that this condition might be responsible for fat synthesis up to the point at which vitellogenin protein synthesis could begin. Therefore, the optimum amount and quality of food were necessary prerequisites for the growth and fecundity of acridids (Mulkern, 1967; Campbell et al., 1974; Uvarov, 1977; Parker, 1984; Hsiao, 1985; Riffat and Muhammad, 2007; Riffat and Wagan, 2007). Some previous studies also stated that food plants that facilitated increased growth, body weight, and survival in grasshoppers also led to greater fecundity (Pickford, 1962; Mulkern, 1967; Hewitt, 1968), as the nutritive value of food plants had a significant effect on oocyte development in acridids (Lee and Wong, 1978; Riffat and Muhammad, 2007).

Adult life spans of the studied acridids were mostly longer than 7 weeks, although growth indices were only estimated up to the 7th week because negative values were obtained after that period. This observation was supported by Garcia-Garcia et al. (2008), who reported that adult acridids did not grow after a certain period and that their weight also declined slightly. Apart from this, longer adult life span was related to the fact that they received a greater number of chances to copulate; as a result, more egg pods were laid. Evidently, a shorter nymphal duration and a longer adult life span could produce a huge amount of biomass. It is also notable that low consumption means less food provided on acridid farms. It was safely concluded that B. mutica is a suitable grass species for acridid rearing. Furthermore, not all of the acceptable food plants of grasshopper were adequate for their growth and survival. For higher growth and survival of acridids, species-specific food plants that provide sufficient nutrients and will ultimately lead to a huge acridid biomass should be selected. Previous studies in Oxya fuscovittata (Ganguly et al., 2010), Hieroglyphus banian (Das et al., 2002), Hieroglyphus nigrorepletus (Riffat and Muhammad, 2007), and Aiolopus thallassinus and Gesonula punctifrons (Sanjayan and Murugan, 1987) also support this view.

When nymphal mortality and nymphal duration were taken into consideration, B. mutica was determined to be the most suitable food plant for S. pr. prasiniferum. For the 1st and 2nd instars of O. hyla hyla, both of the above-mentioned parameters produced better results in D. aegyptium-fed sets, and for the remaining instars, in B. mutica-fed sets.

Statistical comparison between selected acridids revealed that, in most cases, O. hyla hyla produced suitable growth index results due to higher consumption, digestion, dry weight gain, and metabolism. In light of these findings, O. hyla hyla could be the most acceptable acridid for mass production.

Conclusion

D. aegyptium for the 1st and 2nd instars of O. hyla hyla and B. mutica for the remaining acridid nymphs and adults may be potential food plants; additionally, O. hyla hyla may be a suitable species for mass production in acridid farms as nymphal mortality was minimal, nymphal duration was lower, and growth indices gave acceptable results. Rearing the suitable acridid with the appropriate food plant will ultimately lead to a large amount of grasshopper biomass in acridid farms. This huge biomass could be supplied to the poultry feed-producing companies in order to allow for the manufacture of a high-protein, low-cost alternative feed for poultry and other livestock.

In addition, because the acridids may perform better feeding on a combination of mixed food plants, further experiments are required to explore a mixed diet using B. mutica as a supplementary food in order to obtain a clear idea of how suitable this food plant is.

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Effect of food plants on nutritional ecology of two acridids (Orthoptera: Acrididae) to provide alternative protein supplement for poultry


