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Annual biomass production of two acridids (Orthoptera: Acrididae) as alternative food for poultry

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Abstract

Acridids could be an alternative nonconventional protein source for livestock industries like poultry farms. For a high acridid biomass production, selection of acridid species along with their suitable food plants is essential. The present experiment was conducted by rearing of two common Indian acridids, *Oxya hyla* and *Spathosternum prasiniferum,* to estimate which one could produce higher annual biomass when fed on three food plants, *Dactyloctenium aegyptium*, *Brachiaria mutica* and *Cynodon dactylon*, to determine the most favorable food plant. Fecundity, fertility, nymphal mortality and sex ratio of both acridid species fed with three different plants were estimated for the annual biomass production in terms of number. Annual biomass production in terms of wet weight, dry weight and energy content were also estimated. Among the two acridid species, *O. hyla* showed higher values for fecundity, fertility and both wet and dry body weight; and lower values for nymphal mortality in all the three food plant fed sets. Among the three food plants, *B. mutica* was found to be the most suitable for annual biomass production of both acridids. It was concluded that mass rearing of *O. hyla* fed on *B. mutica* could yield a high annual biomass in acridid farms.

Additional key words: acridid farm; *Brachiaria mutica*; fecundity; mass rearing; *Oxya hyla*.

Resumen

Producción de biomasa anual de dos acrídidos (Orthoptera: Acrididae) como alimento alternativo para aves de corral

Los acrídidos podrían ser una fuente de proteínas no convencional alternativa para las granjas de aves de corral. Para una producción masiva de biomasa de acrídidos, es esencial seleccionar las especies adecuadas, junto con las plantas que los alimenten adecuadamente. Se llevó a cabo un experimento para criar dos acrídidos comunes en la India, *Oxya hyla* y *Spathosternum prasiniferum* y estimar cuál de ellos puede producir una mayor biomasa anual cuando se alimentan de tres plantas, *Dactyloctenium aegyptium*, *Brachiaria mutica* y *Cynodon dactylon*, determinando cual de ellas es el alimento más favorable. Para la producción anual de biomasa, en términos de número, se estimaron las tasas de fecundidad, fertilidad, mortalidad de ninfas y el sexo de ambas especies de acrídidos alimentados con las tres diferentes plantas. También se estimaron la producción de biomasa anual, en términos de peso húmedo y seco, y el contenido de energía. Entre las dos especies, *O. hyla* mostró valores más altos de fecundidad, fertilidad y peso corporal, tanto húmedo como seco, y valores más bajos de mortalidad de ninfas para las tres plantas. Entre las tres plantas utilizadas como alimento, *B. mutica* fue la más adecuada para la producción anual de biomasa para ambos acrídidos. Se concluye que la cría masiva de *O. hyla* alimentándose de *B. mutica* puede producir una gran biomasa anual en las granjas de acrídidos.

Palabras clave adicionales: *Brachiaria mutica*; cría masiva; fecundidad; granja de acrídidos; *Oxya hyla.*

Introduction

Insects produce a significant biomass in nature and play a major role in animal nutrition, *e.g.* one attractive and important natural food source for birds are insects. McHargue (1917) reported that the wild bird diet consists almost entirely of insects during the season when they are present. Studier & Sevick (1992) published

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that insects are an excellent source of nitrogen, potassium, sodium, iron and magnesium and they fulfill the nutritional requirements for growth and reproduction of birds. Among insects, acridids (short horned grasshoppers under the family Acrididae of the order Orthoptera) which comprises locusts and grasshoppers are known to have a high nutritional value (De-Foliart *et al.*, 1982; Ramos-Elorduy, 1997), high reproductive potential (Haldar *et al.*, 1999; Lomer *et al.*, 2001), rapid life cycle (Ananthakrishnan *et al.*, 1985; Henry, 1985) and higher growth rate (Uvarov, 1966; Scoggan & Brusven, 1972; Muralirangan & Ananthakrishnan, 1977; Ananthakrishnan, 1986). Ramos-Elorduy (1997) reported that protein content of grasshopper varies from 52.1% to 77.1%. McHargue (1917) conducted a proximate analysis on dried *Melanoplus* spp. (Acrididae) showing 75.3% protein, 7.21% fat, 5.61% ash and high amount of lysine, stating that they might afford a new protein source for poultry and other livestock rations. DeFoliart *et al.* (1982) and Ramos-Elorduy (1997) estimated that acridids have a high nutritional value and can be used to formulate good quality feed for livestock. Moreover Wang *et al.* (2007) formulated high protein diets with the acridid *Acrida cineria* and proved that it is an acceptable feed for broiler without any adverse effect on weight gain, feed intake or gain: feed ratio.

Conventional protein source of poultry feed are mainly fishmeal and grains like maize and soybean which are also natural food for human beings. Nevertheless, resources of these food materials are limited, though their demand is very high. In this scenario these food materials are being overexploited. So, there is a need of alternative protein sources for poultry feed. Acridids may serve as alternative, nonconventional and protein rich, natural feed source for livestock industries like poultry farms, thus overexploitation of the conventional food sources could be controlled. But livestock industries need a constant supply of this alternative food source, which requires establishment of acridid farms that would produce huge biomass of acridids (Ganguly *et al.*, 2010).

Preliminary works on biomass production of *Oxya fuscovittata* and *Spathosternum prasiniferum* fed with a single type of food plant were done by Haldar *et al.* (1999) and Anand *et al*. (2008a) to utilise this acridid resource as an alternative feed for livestock. Haldar *et al*. (1999) established that these acridid species are very easy to grow and could produce a huge biomass according to their high reproductive ability and survival rate. Nutrient contents of both acridids gave satisfactory results (Anand *et al.*, 2008b). With this information in mind, the multivoltine acridid *Oxya hyla* (Serville) was chosen for the present study along with *Spathosternum prasiniferum* (Walker) that had been already used in preliminary studies.

Uvarov (1966) observed an increased fecundity of acridids that were fed on plants of Poaceae family. Haldar *et al.* (1995) also noticed that this plant family was mostly preferred by acridids. On another hand, commonly known plants under Poaceae family are mainly grain crops (rice, wheat, sorghum etc.). Hence it is inconvenient to use these grain crops as food plants for grasshoppers as this may increase the production cost of acridids due to a high expense in sowing and cropping and competition with human food. Although the three species chosen for this experiment belong to the family Poaceae, these are actually abundant weeds which could be easily harvested in grasslands in and around the area of the present study.

The aim of this study was then to determine the effect of three wild plant species of the Poaceae family on biomass production of the selected acridids, in order to find suitable plants and acridid species by which high biomass could be yielded in acridid farms.

Material and methods

Collection and rearing of acridids under laboratory conditions

Two grasshopper species, *O. hyla* and *S. prasiniferum,* were collected from nearby agricultural fields and grasslands of Santiniketan (23°39' N, 87°42' E), India, using an insect net of 30 cm diameter. Collected individuals were sent to the Orthoptera section of the Zoological Survey of India, Kolkata, for taxonomic identification. Then the acridid species selected for the present study were reared in the insectaria of the Entomology Research Unit, Dept. of Zoology, Visva-Bharati University, adopting the strategies proposed by Haldar *et al.* (1999). The collected insects were acclimatized in specially designed cages made of nylon net gauge on wooden frame measuring 75 × 52.5 × 30 cm^3 under laboratory conditions ranging from 30 °C to 35 °C temperature, 70 to 80% relative humidity, 500 ± 25 lux light intensity and 14L/10D photoperiod. Enamel trays measuring 10 × 10 × 4.5 cm^3 filled with fine, washed and sterilized moist-sand were kept inside the cages for insect oviposition. Eggs were collected every third day from the trays of oviposition and transferred to sterilized-sand filled plastic cups at the depth of 2.5-5 cm and incubated at 35 ± 2 °C. After hatching the hatchlings were used for the experimental purpose.

Nymphal mortality, sex ratio and body weight

The following description of the experimental setup is for single acridid species fed with single type of food plant. All the other experiments were carried out with similar setup. Two hundred and fifty newly hatched nymphs of the selected species were collected from insectaria and were kept in five transparent plastic jars measuring 20 × 20 × 35 cm^3 with 50 individuals in each. Then a selected species of food plant were offered in 5 replicates. On achieving the adult stage the number of individuals in each jar was counted to find out the nymphal mortality percentage. On the basis of newly emerged males and females, sex ratio was determined. Males and females of each species were weighed separately with a micro-analytical electro-balance (Sartorius, MC1, Analytic AC120S, Germany). To calculate their dry weight specimens were kept in thermo resistant glass vials and placed in a micro-oven at 45 °C for 72 h. The dried specimens were then reweighed to calculate the dry biomass.

Fecundity and fertility estimation

To find out the effect of food plants on fecundity, single pair of zero-day old adult male and female was kept in transparent experimental jars (25 cm height × 10 cm diameter) for copulation. Three sets of jars with three preferred food plants, *i.e. Dactyloctenium aegyptium* (L.) Willd., *Cynodon dactylon* Pers., and *Brachiaria mutica* (Forsk.) Stapf were maintained for each species. Each set had ten of such experimental jars. The floor of the jar was filled with fresh sterilized sand up to 5.0-7.6 cm from the base. One conical flask (Borosil, 50 mL) filled with water and specific fresh food plant was kept inside the jar and the opening of the jar was covered with nylon net. Sand from the experimental jars was examined every alternate day by sieving with fine mesh to count the egg-pods, if any. Collected egg-pods were counted and kept within moist tissue paper in petri dishes for 48 h to get the eggs swollen. Then the frothy material was removed with soft hair-brushes and forceps. Then the swollen eggs were separated out easily and the number of eggs per egg-pod was counted. Fecundity (total number of eggs laid per female) of each species was calculated by multiplying the number of egg-pods laid per female with the number of eggs per egg-pod. To calculate the fertility (total number of eggs hatched from each female), egg mortality percentage was deducted from fecundity.

Energy content

Deceased adult male and female individuals of both acridid species from the three different food plant fed sets were dried in a hot air oven at 45 °C for 72 h. The dried samples were powdered and mixed with fixed proportion of benzoic acid as burning agent prior to pellet formation. The sample pellets (sample powder + benzoic acid powder) of 1-g weight were charged with Oxygen at 20 kg cm^{-2} pressure and fired in the Digital Bomb Calorimeter (Model no. RSB-4, Instrumentation India Co., Calcutta, West Bengal) standardized with benzoic acid pellets. The increase in temperature was recorded and the energy content was calculated in terms of calories by following the formula mentioned in the user's manual:

$$W = (H \times T)/M$$

where W = the instrument value determined by calibration step, H = specific heat of combustion of benzoic acid, T = temperature increase of water and M = mass of sample.

Biomass production

For the annual biomass estimation only one fertilized female was considered as starting point and then biomass production in subsequent four generations (as both the acridids are tetra-voltine) that could be completed in a year, was estimated by the following procedure. Ten single pairs of a selected acridid were reared under laboratory condition for 1^{st} generation; with the obtained information the results of the subsequent generations were calculated. For the calculation only viable (on the basis of fertility) nymphs produced from one fertilized female (starting point) in her life span were counted. Then total number of individuals attained adulthood was recorded. In this way biomass of first generation in terms of number of males and females was obtained. Total number of individuals produced from a fertilized female in a year was calculated by adding the number of individuals produced in each of the four subsequent generations for males and females separately. Multiplying the numbers with the mean wet and dry body weight of the individuals of the respective species, biomass production per year in terms of wet weight and dry weight was calculated. Biomass in terms of energy was obtained by multiplying the energy content in kcal g^{-1} of dry tissue with the total dry biomass (in g) produced per year.

Statistical analysis

Data are presented as means ± SD. Five replicates were carried out for all the variables. For all the selected traits of the chosen acridid species, two-way analysis of variance (ANOVA) were carried out taking food plants and acridid species as factors. For egg-pods laid per female and nymphal mortality, though the factors individually showed significant effect ($p < 0.001$), their combined interaction did not show any significant variation ($p = 0.105$). Hence one way ANOVA were carried out for these above mentioned variables at different food plant or acridid species. For annual biomass estimation in terms of wet weight, dry weight and energy content, three way analysis of variance (ANOVA) were carried out taking food plants, acridid species and sex as factors. Duncan's multiple range tests (DMRT) were carried out for each case followed by ANOVA in order to separate the mean values according to significance. All of the analyses were carried out using Microsoft Excel 2000 and S-Plus version 4.0.

Results

The effect of different food plants on the reproductive performance and nymphal mortality of selected acridid species is shown in Table 1. In case of *O. hyla,* when reproductive variables and nymphal mortality were compared among food plants it was found that *B. mutica* fed sets produced significantly highest number of egg-pods and these egg-pods had high productivity. The same plant was also found to be the best for *S. prasiniferum.* On the contrary *D. aegyptium* fed acridid species showed significantly lower values for all the above mentioned reproductive variables except eggs per pod and fertile eggs per pod of *S. prasiniferum*, where both traits had insignificant variation between *D. aegyptium* and *C. dactylon* fed females. Nymphal mortality (Table 1) between food plants was significantly low in acridid species fed on *B. mutica* and high in *D. aegyptium* fed sets. When data were compared within food plants between the acridid species it was noted that *O. hyla* gave better results for all the mentioned traits except eggs per pod and fertile

Table 1. Reproductive potential and nymphal mortality of acridids, fed on three preferred food plants

Food plants	Acridid species	Number of egg-pods laid/female	Number of eggs /pod	Number of fertile eggs/pod	Total number of eggs/ female	Total number of fertile eggs/ female	Nymphal mortality (%)
D. aegyptium	*O. hyla*	5.60 ± 0.56 b1a2	5.60 ± 0.56 a1a2	3.20 ± 0.45 a1a2	31.20 ± 2.68 b1a2	17.80 ± 0.71 b1a2	50.67 ± 1.49 b1c2
	S. prasiniferum	2.00 ± 0.00 a1a2	6.60 ± 0.89 a1a2	3.80 ± 0.45 a1a2	13.20 ± 1.79 a1a2	7.60 ± 0.89 a1a2	43.33 ± 0.93 a1c2
C. dactylon	*O. hyla*	8.20 ± 0.45 b1b2	9.80 ± 0.45 b1b2	7.40 ± 0.55 b1b2	80.20 ± 0.45 b1b2	60.60 ± 4.22 b1b2	37.96 ± 0.78 b1b2
	S. prasiniferum	3.40 ± 0.55 a1b2	7.20 ± 1.10 a1a2	4.60 ± 0.55 a1a2	24.20 ± 3.27 a1b2	15.40 ± 0.55 a1b2	32.50 ± 1.14 a1b2
B. mutica	*O. hyla*	10.40 ± 0.89 b1c2	14.80 ± 1.10 b1c2	13.20 ± 1.30 b1c2	153.20 ± 4.60 b1c2	136.40 ± 4.98 b1c2	27.56 ± 0.34 b1a2
	S. prasiniferum	6.60 ± 0.55 a1c2	9.40 ± 0.55 a1b2	8.00 ± 0.00 a1b2	61.80 ± 1.64 a1c2	52.80 ± 4.38 a1c2	21.61 ± 0.78 a1a2

Within a column a1, b1, c1 and a2, b2, c2 indicate significant differences between mean values within food plants between acridid species and within acridid species between food plants respectively. Two-way ANOVA were done for all variables except egg-pods laid per female and nymphal mortality, where only one way ANOVA were done. DMRT, $p < 0.001$.

eggs per pod of *D. aegyptium* fed females, where values did not show significant variation. Thus, *B. mutica* was recorded as the most preferable food plant and *O. hyla* was the most suitable acridid for better reproductive performance and nymphal mortality. Sex ratio was nearly 2 males: 3 females in *O. hyla*, whereas in *S. prasiniferum* males outnumbered females, as the ratio in this species was 4 males: 3 females.

Total number of acridid biomass produced in first generation fed on *D. aegyptium* is presented in Fig. 1a. In the case of males no significant variation was observed between the acridid species. Female biomass of the first generation was significantly higher in *O. hyla* than that of *S. prasiniferum*. In the other three generations (Figs. 1 and 2), both male and female biomass in terms of number followed a similar trend as noticed in female biomass of the first generation. For both acridid species, *B. mutica* fed sets always gave more number of individuals in all the four generations.

Taking one fertilized female as the starting point, total male and female annual biomass in terms of number produced by each species fed on three selected food plants is shown in Table 2. The trend of annual biomass in terms of numbers of both males and females followed a similar trend as found in each generation (except 1st), *i.e.* between the three different food plants, *B. mutica* fed acridids gave significantly higher biomass than the remaining two food plants. When the data were compared between the acridids, *O. hyla* fed on all of the three food plants showed significantly higher values.

The wet weight of acridids is summarized in Table 3. The results showed that among food plants in *O. hyla* male*, B. mutica* fed sets gave higher values of wet body weight. A similar trend was observed in *S. prasiniferum* male. Significantly lower wet weight values of *O. hyla* and *S. prasiniferum* were observed in *C. dactylon* and *D. aegyptium* fed sets respectively. Between acridids *O. hyla* gave higher values of wet body weight for all the cases of three food plants. Dry body weight of both acridids followed a similar trend as observed in wet body weight. The energy content of male acridid species was significantly higher in *B. mutica* fed sets and lower in *D. aegyptium* fed sets, when data were compared between food plants and within acridid species. On the other hand when the data were compared between acridids, energy content was higher in *O. hyla* when fed on all the three food plants.

The wet weight of female *O. hyla* was significantly higher in *B. mutica* fed sets when data were compared

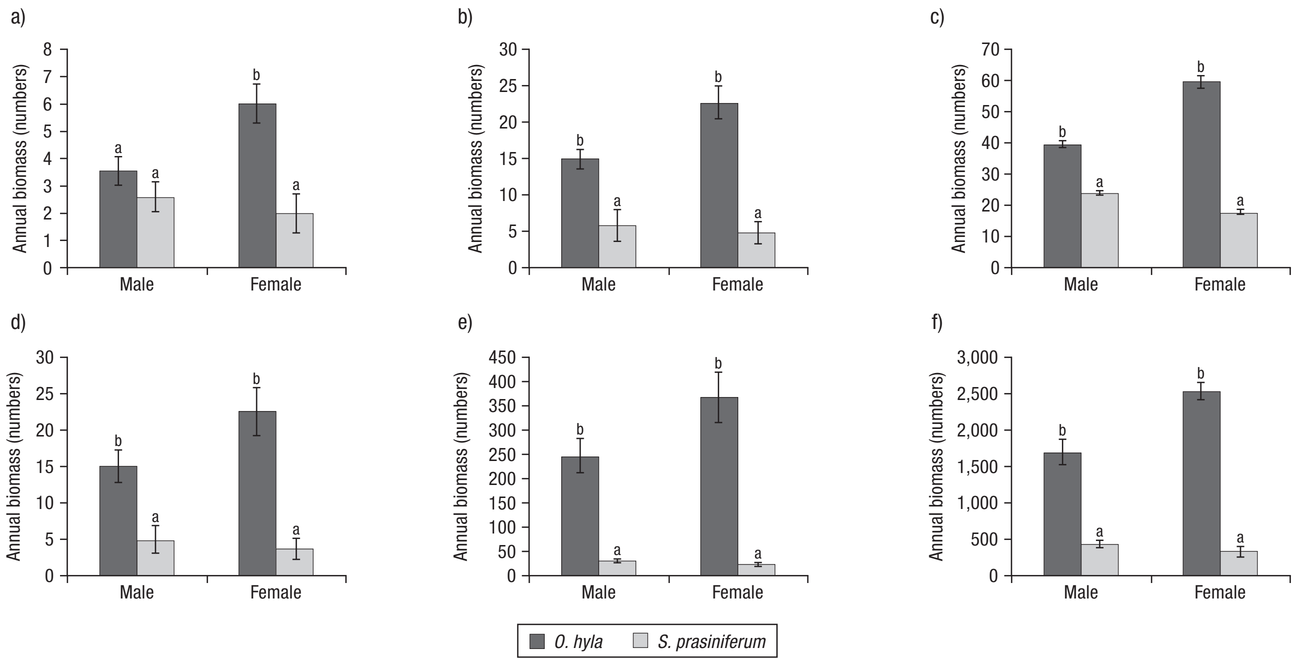

Figure 1. Annual biomass production in terms of numbers of 1st (a,b,c) and 2nd (d,e,f) generation of *Oxya hyla* and *Spathosternum prasiniferum* fed on three selected food plants (a,d: *D. aegyptium*; b,e: *C. dactylon*); c,f: *B. mutica*). Values are means ± SD. Bars with different letters within a male annual biomass and female annual biomass are significantly different ($p < 0.001$) using DMRT.

Table 2. Total number of individuals produced annually taking a single pair of male and female as starting point

Food plants	Males		Females	
	O. hyla	*S. prasiniferum*	*O. hyla*	*S. prasiniferum*
D. aegyptium	290.9 ± 67.6 a1b2	34.1 ± 14.4 a1a2	437.0 ± 102.3 a1b2	25.6 ± 11.4 a1a2
C. dactylon	68,571.0 ± 17,702.7 b1b2	730.8 ± 109.0 b1a2	102,856.8 ± 26,554.7 b1b2	548.5 ± 82.2 b1a2
B. mutica	3,094,607.0 ± 402,820.1 c1b2	143,527.9 ± 4,516.4 c1a2	4,641,911.0 ± 604,230.5 c1b2	107,645.7 ± 33,762.2 c1a2

Within a column a1, b1, c1 indicate significant differences between mean values within acridid species between food plants. Within a row a2, b2 indicate significant differences between mean values within food plants between acridid species. Three way ANOVA, DMRT, $p < 0.001$.

between food plants. In *S. prasiniferum*, it was higher in *C. dactylon* fed sets and lower in *D. aegyptium*. On the contrary, the values of *D. aegyptium* and *C. dactylon* fed *O. hyla* female varied insignificantly. The wet body weight of *O. hyla* was significantly higher than *S. prasiniferum*, when data were compared between acridids. Dry body weight and energy content of both the female acridids showed a similar trend as found in the results of male energy content *i.e.* between food plants within acridid species, *B. mutica* fed sets gave higher values and between acridid species within food plants, *O. hyla* showed higher values.

Table 3. Wet weight, dry weight and energy content of *Oxya hyla* and *Spathosternum prasiniferum*

Food plants	Acridid species	Sex	Wet weight (g)	Dry weight (g)	Energy (kcal g^{-1})
D. aegyptium	*O. hyla*	Male	0.257 ± 0.006 b1b2	0.084 ± 0.002 b1b2	3.017 ± 0.021 a1b2
		Female	0.476 ± 0.002 a1b2	0.160 ± 0.001 a1b2	6.030 ± 0.026 a1b2
	S. prasiniferum	Male	0.083 ± 0.001 a1a2	0.027 ± 0.001 a1a2	4.550 ± 0.025 a1a2
		Female	0.151 ± 0.001 a1a2	0.050 ± 0.001 a1a2	6.310 ± 0.006 a1a2
C. dactylon	*O. hyla*	Male	0.238 ± 0.001 a1b2	0.078 ± 0.002 a1b2	3.097 ± 0.012 b1b2
		Female	0.480 ± 0.003 a1b2	0.162 ± 0.001 b1b2	6.150 ± 0.025 b1b2
	S prasiniferum	Male	0.086 ± 0.0015 b1a2	0.028 ± 0.001 b1a2	4.630 ± 0.015 b1a2
		Female	0.158 ± 0.001 c1a2	0.050 ± 0.001 b1a2	6.360 ± 0.006 b1a2
B. mutica	*O. hyla*	Male	0.290 ± 0.003 c1b2	0.096 ± 0.001 c1b2	3.200 ± 0.015 c1b2
		Female	0.542 ± 0.001 b1b2	0.184 ± 0.001 c1b2	6.240 ± 0.030 c1b2
	S. prasiniferum	Male	0.088 ± 0.001 c1a2	0.029 ± 0.001 c1a2	4.730 ± 0.025 c1a2
		Female	0.153 ± 0.001 b1a2	0.051 ± 0.001 c1a2	6.430 ± 0.015 c1a2

Within a column a1, b1, c1 and a2, b2, c2 indicate significant differences between mean values within acridid species between food plants and within food plants between acridid species respectively. Two way ANOVA, DMRT, $p < 0.001$.

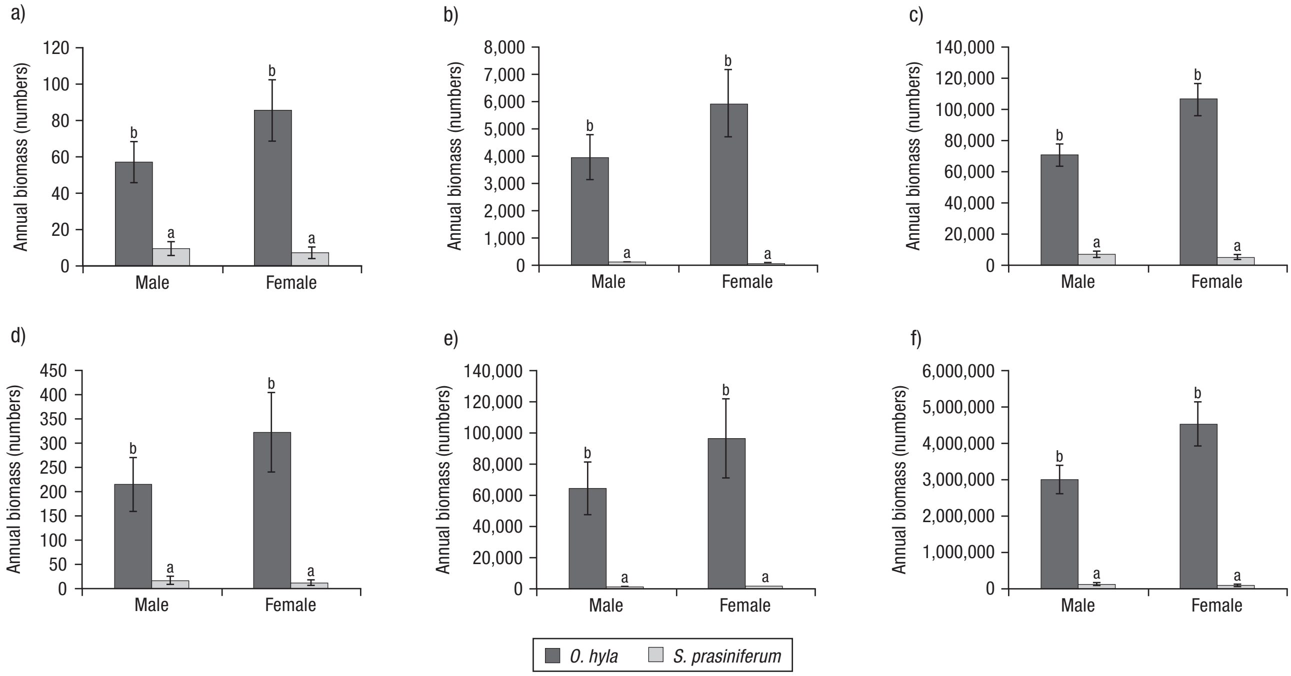

Figure 2. Annual biomass production in terms of numbers of 3rd (a,b,c) and 4th (d,e,f) generation of *Oxya hyla* and *Spathosternum prasiniferum* fed on three selected food plants (a,d: *D. aegyptium*; b,e: *C. dactylon*); c,f: *B. mutica*). Values are means ± SD. Bars with different letters within a male annual biomass and female annual biomass are significantly different ($p < 0.001$) using DMRT.

The effect of different food plants on annual biomass production in terms of wet weight, dry weight and energy content of both acridids fed on the three food plants, is shown in Table 4. Biomass productions in all the above mentioned variables per year in both males and females of the selected acridids were al-

Table 4. Annual biomass production (mean ± SE) of of both acridids males and females in terms of weight and energy

Food plants	Wet biomass (kg yr^{-1})		Dry biomass (kg yr^{-1})		Biomass (kcal yr^{-1})	
	O. hyla	***S. prasiniferum***	***O. hyla***	***S. prasiniferum***	***O. hyla***	***S. prasiniferum***
Males						
D. aegyptium	0.075 ± 0.002 a1b2	0.003 ± 0.001 a1a2	0.024 ± 0.001 a1b2	0.001 ± 0.001 a1a2	73.794 ± 1.411 a1b2	4.108 ± 0.021 a1a2
C. dactylon	16.320 ± 0.363 b1b2	0.063 ± 0.001 b1a2	5.358 ± 0.128 b1b2	0.020 ± 0.001 b1a2	16,592.054 ± 423.484 b1b2	93.382 ± 0.583 b1a2
B. mutica	901.253 ± 10.819 c1b2	12.693 ± 0.008 c1a1	298.114 ± 3.573 c1b2	4.136 ± 0.081 c1a2	954,964.774 ± 13,099.400 c1b2	19,496.002 ± 340.047 c1a2
Females						
D. aegyptium	0.208 ± 0.001 a1b2	0.004 ± 0.001 a1a2	0.070 ± 0.001 a1b2	0.001 ± 0.001 a1a2	422.101 ± 0.877 a1b2	8.081 ± 0.112 a1a2
C. dactylon	49.337 ± 0.331 b1b2	0.087 ± 0.001 b1a2	16.679 ± 0.110 b1b2	0.028 ± 0.001 b1a2	102,521.738 ± 1,089.580 b1b2	177.275 ± 0.313 b1a2
B. mutica	2,514.680 ± 0.536 c1b2	16.484 ± 0.003 c1a2	854.576 ± 0.464 c1b2	5.514 ± 0.015 c1a2	5,332,562.370 ± 28,533.800 c1b2	35,399.741 ± 130.445 c1a2

Within columns a1, b1, c1 indicate significant differences between mean values within acridid species between food plants. Within rows a2, b2 indicate significant differences between mean values within food plants between acridid species. Three way ANOVA, DMRT, $p < 0.001$

ways higher in *B. mutica* fed sets, when data were compared between food plants and within acridids; whereas between acridids, it was always higher in *O. hyla.* When selected species of acridids were fed on *B. mutica,* following results were obtained: biomass production in terms of wet weight per year was estimated for *O. hyla* to be nearly 901.25 kg and 2,514.68 kg in males and females respectively and for *S. prasiniferum* it was 12.69 kg in males and 16.48 kg in females. Near about 298.22 kg and 854.58 kg of dry biomass of *O. hyla* could be observed annually in case of males and females respectively. Total dry biomass (males + females) was 9.65 kg for *S. prasiniferum*, which was much less than that of *O. hyla* (1152.8 kg). Annual biomass in terms of energy (kcal) was 954,964.77 and 5,332,562 for *O. hyla* and 19,496 and 35,400 for *S. prasiniferum* (males and females respectively). Results showed that *O. hyla* fed on *B. mutica* produced a huge biomass in terms of wet weight, dry weight and energy content per year. Annual dry biomass of *O. hyla* was approximately 120 times higher than that of *S. prasiniferum*, when fed on the same food plant.

Discussion

High biomass production of acridids in terms of wet weight, dry weight and energy content is a critical factor in establishment of acridid farms in order to mass scale production. Thus the present study was carried out to estimate the ability of acridid biomass production through mass rearing, fed with various food plants.

In India, Iqbal & Aziz (1974) found that acridid species normally feed on some field crops, a few garden plants and weeds. The same authors later reported (Iqbal & Aziz, 1976) the food preference of *S. prasiniferum* and stated that it selects food plants which are favorable for development and the food preference changes with its age. They also opined that food plants have pronounced effects on development and reproductive potential of *S. prasiniferum* (Iqbal & Aziz, 1977). Likewise, Fanny *et al.* (1999) found significant effects on the nymphal period and survival in *Oxya nitidula*. Ganguly *et al.* (2010) demonstrated optimum consumption, utilization and development of *Oxya fuscovittata* when fed on *Sorghum halepense.* In another species from the genus *Oxya, i.e. Oxya japonica* Lee & Wong (1978) got significant effects of food plants on the reproductive potential.

Fecundity and fertility are one of the key determinants of mass production. Various authors like Awmack & Leather (2002) and Branson (2003, 2006) found that host plant quality has an important role in the fecundity of herbivorous insects at both individual and population level. Sanjayan & Murugan (1987) also reported that food plants had pronounced effect on fecundity of Orthoptera. Food quality was a necessary pre-requisite for the development and egg production of acridids (Joern & Behmer, 1997). According to Nezkwu & Akingbohungbe (2002) nymphal development and egg production of acridids are dependent on food plant. The present study also supports the view that food plants exert a great influence on reproductive traits of acridid species. This might be because food plants have significant effects on oocyte development in acridids (Lee & Wong, 1978).

Branson (2008) cited that body size of acridids has also an influence on fecundity and fertility, and consequently on their biomass production. Katiyar (1957) reported that among *Acrida gigantea* and *Hieroglyphus assamensis,* higher fecundity, fertility and adult emergence were observed in the large species in comparison to the smaller one. Such type of results was also observed in *Melanoplus sanguinipes* and *Melanoplus bivittatus* by Smith (1966). Branson (2008) and Anand *et al.* (2008a) found that fecundity in acridids is positively correlated with body weight and structural size. In the present study body weight of *O. hyla* was nearly two times higher than that of *S. prasiniferum* and fecundity and fertility were consequently higher in *O. hyla.* When the acridids were fed on *B. mutica*, large numbers of nymphs were produced. According to Ganguly *et al.* (2010) nymphal mortality is significantly dependent on food plants. Our results were in concert with this finding because here also food plants and acridid species individually exerted significant effect on nymphal mortality. But their combined interaction did not show significant variation between the two grasshopper species, however, number of viable nymphs was quite high in *O. hyla* due to their higher fecundity. When starting with a pair of male and female, it was observed that in a year huge numbers of individuals would be produced by *B. mutica* fed *O. hyla* due to their high fecundity and fertility. Biomass production (in terms of wet weight) per year was highest in *O. hyla* (3,415.93 kg) when fed on *B. mutica*.

To calculate yearly biomass production in terms of energy the calorie content of both males and females was estimated. Results showed that in the females of both species, energy was higher than that of males might be due to retention of more energy for reproductive purposes in female. Anand *et al.* (2008a) also reported that female individual of acridids had higher calorie content than male individuals; they also stated that acridid species of smaller body size had more energy than those of large sized species. A similar trend was observed in our experiment where the smaller species, *S. prasiniferum*, showed higher energy. However the yearly biomass production in terms of energy was higher in *O. hyla* (total: males + females = 6,287,527.14 kcal) as they had higher body weight and produced large number of acridid biomass.

Results of the present experiment on two common Indian acridid species fed on three different preferable food plants clearly establishes that among the three food plants *B. mutica* is the most suitable one, and *O. hyla* could produce a higher annual biomass in terms of wet weight, dry weight and energy content. This information supports the view of establishing acridid farms where *O. hyla* would be produced in mass scale to provide alternative protein source for poultry and other livestock. However, there exist lacunae in knowledge regarding economic assessment for acridid farm establishment. Hence, it is a must for biologists and economists to come to a single platform for this kind of studies; then only this unconventional protein source could be effectively supplied for livestock feed development.

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