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Research Article

Age, mating status and sex influence food consumption and utilization efficiency of *Parthenium* beetle, *Zygogramma bicolorata* Pallister

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ABSTRACT: A study was designed to evaluate the combined effects of age, mating status and sex on the feeding attributes of the *Parthenium* beetle, *Zygogramma bicolorata* Pallister when fed on *Parthenium hysterophorus* L., a serious weed of wastelands, pastures and agricultural fields. Newly emerged adult beetles were placed in two groups. Adults of the first group were kept unmated and their daily feeding and growth attributes were assessed for the following 20 days. By comparison, males and females of the second group were allowed to mate on the 11th day (attainment of sexual maturity) and mating pairs were kept individually to assess their daily feeding and growth attributes for the following 10 days. Results revealed higher consumption and growth rates of *Z. bicolorata* females than males. In contrast, males exhibited higher food conversion efficiencies than the females. However, food consumption and growth rates of unmated adults were higher than mated adults. Age-based regression graphs revealed decreased consumption rates, conversion efficiencies and growth rates of *Z. bicolorata* adults with increase in age. However, the mean body biomass of adults increased with increasing age. This further suggested compensatory feeding in *Z. bicolorata* adults as they age. The present findings may be helpful to mass-multiply *Z. bicolorata* in laboratories for the biocontrol of *Parthenium* weed in agricultural farms on the Indian subcontinent.

KEY WORDS: Conversion efficiency, energy budget, feeding attributes, weed

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INTRODUCTION

All living organisms are the 'transformers of energy'. They participate in conversion of energy from one form to another. Like other organisms, insects as well transform and/or store nutrients derived energy for their survival, growth and reproduction (Omkar and Afaq, 2011; Corcket *et al*., 2017). Since, phytophagous insects are the links in the chain of matter and energy transmission in terrestrial ecosystems; hence knowledge of their food intake, their efficiency of food utilization and their responses to food consumption may have wide ecological implications (Simpson and Simpson, 2017; Leather, 2017, 2018). Studies in phytophagous insects have shown that their developmental, survival and reproductive attributes depend on the quality and/or quantity of food they consume (Silva *et al*., 2017; Leather, 2017, 2018). In addition, abiotic factors like temperature and elevated CO_2 (Murray *et al*., 2013a, b; Zhang *et al*., 2018) also influence the food consumption, conversion and utilization efficiencies of phytophagous insects. Moreover, ageing is another factor that significantly alters their life attributes (Edward and Chapman, 2011).

While studies evaluating age-based food consumption and utilization efficiencies of males and females in phytophagous insects are in records (Chandravanshi *et al*., 2018), but those assessing twin effects of age and mating status on their food conversion and utilization are hardly any. To fill this gap, present study was designed using *Parthenium* beetle, *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae) as the experimental model. *Zygogramma bicolorata* was introduced to India from Mexico in 1983 by Indian Institute of Horticultural Research, Bengaluru, India, for the biocontrol of *Parthenium hysterophorus* Linnaeus (Family: Asteraceae), a serious weed of wastelands, pastures and agricultural fields (Jayanth and Nagarkatti, 1987). Studies assessing effects of food quality and quantity, temperature, photoperiod, crowding, and larval stages on the life attributes of *Z. bicolorata* are numerous (Omkar *et al.,* 2009; Hasan and Ansari, 2016; Chidawanyika *et al*., 2017; Cowie *et al*., 2018). However, studies on age-based food consumption and utilization by males and females of *Z. bicolorata* are still lacking. In this regard, the present study has been designed so that the results may be helpful in assessing energy budget

of *Z. bicolorata* for various biological activities and would improve our understandings of the feeding biology and nutritional ecology of *Z. bicolorata* on *Parthenium* weed.

MATERIALS AND METHODS

Stock maintenance

Adult males and females of *Zygogramma bicolorata* were collected from the agricultural fields of Varanasi, India (25°20'N, 83°0'E) and paired randomly in plastic beakers (9.0 x 6.5 cm^2). They were reared under constant abiotic conditions (27± 2°C; 65±5% relative humidity; 14:10 light: dark hours) in BOD Incubator (NSW-152; Narang Scientific Works Pvt. Ltd., New Delhi, India) on daily replenished supply of *Parthenium* leaves. Eggs laid were collected every 24 h and subsequent first instars were used for further experimentation.

Experimental design

First instar larvae of *Z. bicolorata* (n=100) were individually reared on *ad libitum* biomass of *Parthenium* inflorescence/leaves up to adult emergence under abiotic conditions similar to stock culture. Newly emerged adults were divided into two groups. The adults of first group were weighed (using Analytical Balance: RA-200, Roy Electronics, Varanasi, India) and reared individually on *ad libitum* biomass of food (=30 mg of leaves) daily for next 20 days. During this period food was replenished each day, and the weight of adults along with the biomass of leftover food were recorded every 24 h. While the adults were kept unmated throughout the experimental period; however, soon after the completion of experiment, they were allowed to mate and the data were analysed.

In second group, the newly emerged adults were weighed and reared individually on *ad libitum* biomass of food daily for next 10 days. However, on eleventh day (i.e., attainment of sexual maturity by adults), the adults were allowed to mate and mating pairs were separated. Males (n=10) and females (n=10) of each mating pair were reared individually on *ad libitum* biomass of *Parthenium* leaves for next 10 days. During this period the food was replenished daily, adults were allowed to mate once, and their weight along with the biomass of leftover food were recorded every 24 h.

Feeding attributes, viz. consumption rate, conversion efficiency and growth rate of the adults were calculated using the following formulae (Patel *et al*., 2018):

1. Consumption rate ($mg\text{-}day^{-1}$) =

$$\frac{\text{Leaf biomass consumed by the adult (mg)}}{\text{Feeding duration of the adult (days)}}$$

2. Conversion efficiency =

$$\frac{\text{Increased biomass of the adult (mg)}}{\text{Leaf biomass consumed by the adult (mg)}}$$

3. Growth rate (day^{-1}) =

$$\frac{\text{Fresh mass gain of adult (mg)}}{[(\text{Feeding duration (days)})\times \text{Mean biomass of adult (mg)})]}$$

Where, mean body biomass is average of the initial (prior to experimentation) and final (after experimentation) biomass.

Statistical analysis

Data were checked for normal distribution using Kolmogorov–Smirnov test for normality and Bartlett's test for homogeneity of variances prior to further analysis. Feeding attributes (dependent factors) that were recorded each day, *viz*. consumption rate, conversion efficiency, growth rate and mean body biomass of adults, were subjected to three-way ANOVA followed by Tukey's *post hoc* comparison of means, considering age (from day 1 till day 20), mating status (unmated/ mated), sex (males/females) and their interaction as independent factors during the analysis. Feeding attributes were further regressed with age and the graphs were extrapolated. All statistical analyses were performed using MINITAB 16 (Minitab Inc., State College, Pennsylvania, United States of America) on PC.

RESULTS AND DISCUSSION

Three-way ANOVA revealed significant influence of age, mating status, sex and their interaction on the consumption rates of *Zygogramma bicolorata* adults (Table 1). Age-specific regression graphs revealed increased consumption rates of *Z. bicolorata* adults with increase in age, but up to a certain age, thereafter their consumption rates declined with further increase in age. However, unmated adults had higher consumption rates than the mated ones; being higher in females than in males (Fig. 1).

Further, the growth rates of *Z. bicolorata* adults were significantly affected by the three independent factors, but not by their interaction (Table 1). Age-specific regression graphs revealed decreased growth rates in *Z. bicolorata* adults with increase in age. Comparison of means further revealed higher growth rates of unmated adults than the mated ones, being higher for females than the males (Fig. 2).

While the conversion efficiencies and mean body biomasses of *Z. bicolorata* adults were significantly affected by their age and sex. However, neither mating status nor the interaction amongst the three independent factors significantly influenced their conversion efficiencies and

Table 1. General ANOVA table showing the effects of age, mating status, sex and their interaction on feeding attributes of *Zygogramma bicolorata* (F-values significant at P<0.05)

Independent variables	Dependent variables			
	Consumption rate	Conversion efficiency	Growth rate	Mean body biomass
Age (1 day-20 days)	F=192.48; P<0.0001; df=19, 799	F=4.51; P<0.0001; df=19, 799	F=214.67; P<0.0001; df=19, 799	F=14.60; P<0.0001; df=19, 799
Mating status (Mated/ Unmated)	F=3204.48; P<0.0001; df=1, 799	F=0.97; P=0.325; df=1, 799	F=2286.85; P<0.0001; df=1, 799	F=1.02; P=0.313; df=1, 799
Sex (Male/ female)	F=57.49; P<0.0001; df=1, 799	F=4.87; P=0.028; df=1, 799	F=63.44; P<0.0001; df=1, 799	F=319.62; P<0.0001; df=1, 799
Interaction (Age × Mating status × Sex)	F=1.76; P=0.024; df=19, 799	F=1.16; P=0.289; df=19, 799	F=0.49; P=0.967; df=19, 799	F=0.69; P=0.833; df=19, 799

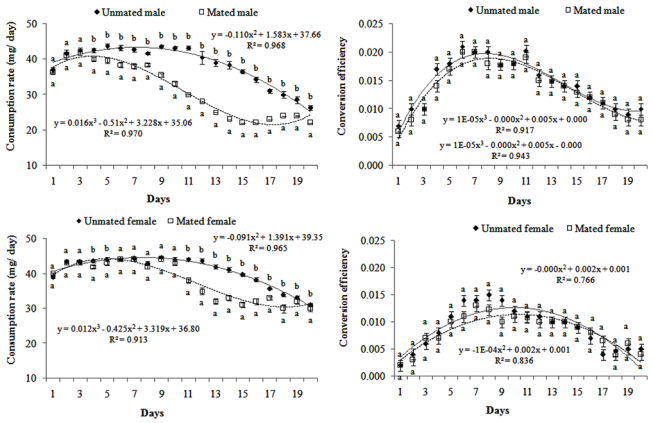

Fig. 1. Regression graphs showing the effect of age and mating status on consumption rates and conversion efficiencies of males and females of *Zygogramma bicolorata.* Note: Small letters represent comparison of mean values between mated and unmated individuals based on Tukey's post-hoc comparison of means.

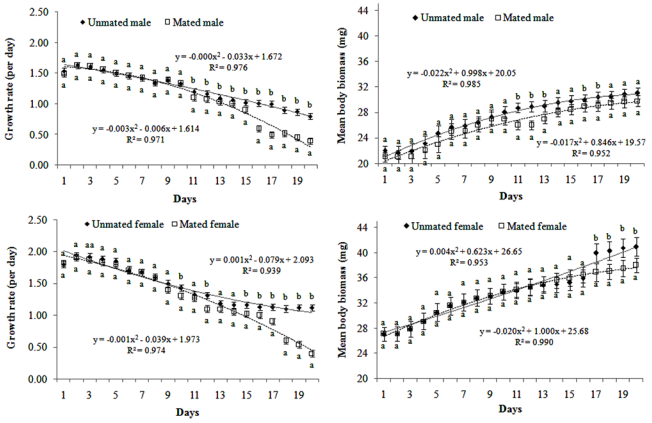

Fig. 2. Regression graphs showing the effect of age and mating status on growth rates and mean body biomasses of males and females of *Zygogramma bicolorata.* Note: Small letters represent comparison of mean values between mated and unmated individuals based on Tukey's post-hoc comparison of means.

mean body biomasses (Table 1). Age-specific regression graphs revealed an increase in conversion efficiency of *Z. bicolorata* adults with increase in their age, but till a certain age. Thereafter their conversion efficiency declined with further increase in age. In contrast, mean body biomass of *Z. bicolorata* adults increased with increase in age. While males had higher conversion efficiencies than the females, however, females exhibited higher mean body biomass than the males (Fig. 1 and 2).

In the present study, age-specific graphs revealed an increase in consumption rates of *Z. bicolorata* adults with increase in their age, but up to a certain age; thereafter their consumption rates declined with further increase in age. The increased food consumption by adults at early ages may be ascribed to their high energy requirements for gonadal development and to attain sexual maturity, since quantity of food influences the rates of development, reproductive output and the fitness (Chidawanyika *et al*., 2017; Patel *et al*., 2017). The process of senescence may be another factor that can lead to decline in food consumption by adult males and females, characterised by decline in fertility, assimilation and speed of locomotion with age (Dixon and Agarwala, 2002; Mishra *et al*., 2012). However, the higher consumption rates of unmated adults of *Z. bicolorata* over their mated ones are in conformity with the findings of Rhamhalinghan (1987) in seven-spotted coccinellid beetle, *Coccinella septempunctata* Linnaeus.

Higher consumption rates of females than the males may be attributed to: (i) their higher nutrient and energy requirements for ovarian development and egg production, and (ii) their larger size which has greater food nutrient requirements owing to possible high-energy expenditures for sustenance. The present findings are in agreement with those reported earlier (Moeser and Vidal, 2005; Omkar and Afaq, 2011).

In the present study, the decreased growth rates in males and females of *Z. bicolorata* with increase in age may probably be owing to the physiological effects of senescence leading to decreased consumption rates. However, the higher growth rates of females than the males may be owing to their large size and high consumption rates, as the females need high amount of energy for reproduction and oviposition.

Age-specific graphs further revealed an increase in conversion efficiency of adults with increase in their age, but up to a certain age. Thereafter a declining pattern in conversion efficiency was recorded for the adults of *Z. bicolorata* with further increase in age. This may possibly be owing to the physiological effects of ageing. In contrast, mean body biomass of *Z. bicolorata* adults increased with increase in age. This further suggests that males and females of *Z. bicolorata* increase their digestive capabilities as they age, so as to compensate for their increased nutritional needs. Similar results were reported earlier in coccinellid beetles by Dixon and Agarwala (2002) and Mishra *et al*., (2012). In the present study, the small size of male may possibly be responsible for its higher conversion efficiency than the female. Higher conversion efficiencies in insects due to small size have also been reported earlier (Omkar and Afaq, 2011; Mishra *et al*., 2011, 2012).

In brief, the present study shows that: (i) females consume more food and exhibit higher growth rates than the males. In contrast males have higher food conversion efficiencies than the females. (ii) Both the food consumption and growth rates are higher for the unmated adults than the mated ones. (iii) While the age-specific graphs revealed decreased consumption rates, conversion efficiencies and growth rates of *Z. bicolorata* adults with increase in age, but their mean body biomasses increased with further increase in age. This further suggests that the adults of *Z. bicolorata* exhibit compensatory feeding as they age. The results of present study may be helpful in developing strategies to suppress *P. hysterophorus* by *Z. bicolorata* in agricultural farms on the Indian subcontinent.

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