International Journal of Research in BioSciences
Vol. 2 Issue 2, pp. (54-62), April 2013
Available online at http://www.ijrbs.in
ISSN 2319-2844

Research Paper

Food metabolic efficiencies of the black blister beetle *Meloe proscarabaeus* (Coleoptera: Meloidae) as changed by feeding on different host plants

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(Received February 09, 2013, Accepted March 21, 2013)

Abstract

The black blister beetle *Meloe proscarabaeus* is firstly recorded in Egypt during the 1970s and then recorded as an agricultural pest on some crops and vegetables few years ago. The present study aimed to investigate the effects of some host plants, viz. faba bean *Vicia faba*, Egyptian clover *Trifolium alexandrinum*, pea *Pisum sativum*, and lettuce *Lactuca sativa*, on the food utilization efficiencies in the adults. The appropriate digestibility (AD) through the longevity of adult females and males were determined after feeding on the present host plants. Adult females exhibited the highest AD by feeding on *T. alexandrinum* but the lowest AD by feeding on *P. sativum*. The male congeners achieved the highest AD by feeding on *V. faba* but the lowest AD by feeding on *P. sativum*. The efficiency of conversion of ingested food into the biomass (ECI) was the highest in both sexes by feeding on *T. alexandrinum* but the lowest by feeding on *P. sativum*. The efficiency of conversion of digested food into the biomass (ECD) run in a parallel trend, regardless of the sex. An interrelationship between AD and ECI was appreciated for both sexes. Also, an interrelationship between AD and ECD of females or males was detected since ECD was higher than AD by feeding on *V. faba, T. alexandrinum* and *L. sativa* but the reverse was clearly found by feeding on *P. sativum*. Correlation between assimilation rate (AR), relative metabolic rate (RMR) and relative body weight (RBW) was estimated.

Keywords: Approximate digestibility, assimilation rate, efficiency of conversion of digested food, efficiency of conversion of ingested food, relative body weight, relative metabolic rate.

Introduction

Phytophagous insects may overcome nutritional unsuitability of the food plants through several ways, such as eating more quantities to compensate the limited nutritional requirements, changing the digestive and assimilatory efficiencies, mobilizing the reserves of limited stored nutrients or/and preferably selecting between the available sources of food [1, 2, 3, 4, 5]. Even under the best conditions, some insects must often eat poor-quality food in relation to nutritional needs. For example, grasshoppers maintain high levels of total nitrogen (protein) in body tissues [6, 7], but typically eat food containing much lower nitrogen concentrations. To make up for the differences in concentration between body requirements and food levels, individuals must eat and convert a significant amount of plant material relative to body size. However, the restricted gut volume available for holding food, coupled with the associated digestive constraints, limits the amount of food that ultimately can be eaten and digested [7, 8, 9], thus regulating the availability of resources to an individual.

For measuring the nutritional effects of the food plants and diets, Reese and Beck [10] and Slansky and Scriber [11] reported a number of methods to express the ratios of weight gain, food consumption and utilization. The approximate digestibility (AD) denotes the proportion of ingested food that is actually digested. Such efficiency depends on the sort of food and the insect species [12, 13]. The proportion of digested food that is actually absorbed and then transformed into net insect biomass is denoted by the efficiency of conversion of digested food (ECD). A parallel parameter indicates the efficiency of conversion of ingested food (ECI). It is well known that the degree of food utilization depends on the digestibility of food, and the efficiency with which digested food is converted into biomass [14]. These utilization efficiencies depend not only upon the insect species but also on the sort of food plant and some other environmental conditions [15, 16, 17]. However, ECI is a general index of an insect's ability to use the food consumed for growth and development, and ECD is an index of the efficiency of conversion of digested food into growth [18].

Blister beetles (family Meloidae) are widespread throughout the world except for New Zealand and Antarctic [19]. Diversity is greatest in arid and semiarid regions. The family has currently 120 genera and 3000 species[20]. Meloid adults are phytophagous and can be usually found on the plant families such as Asteraceae, Leguminosae, Compositae, Umbliferae and Solanaceae [21]. In Egypt, Alfieri[22] recorded the black blister beetle *Meloe proscarabaeus* Linnaeus among Meloidae and other families of Coleoptera. The first reference reporting this beetle as an agricultural pest attacking faba bean, peas, alfalfa, onion and wild weeds at El-Farafra oasis (in western desert of Egypt) was Ali et al.[23, 24]. However, Ghoneim [25] reviewed the agronomic impacts of blister beetles, in general, allover the world. In particular, Ghoneim et al.[26] studied the effect of food quality on the adult performance and Ghoneim et al.[27] investigated the adult preference and consumption on different host plants. Objective of the present paper was to determine the food efficiencies of *M. proscarabaeus* adults after feeding on some host plants, *viz*. faba bean *Vicia faba*, Egyptian clover *Trifolium alexandrinum*, pea *Pisum sativum*, and lettuce *Lactuca sativa*, under laboratory conditions.

Materials and Methods

Experimental Beetle

The Black Blister (Oil) Beetle, *Meloe proscarabaeus* Linnaeus 1758. (Coleoptera: Meloidae) was firstly recorded in Egypt by Alfieri [22]. Then, it was recorded as an agricultural pest on different Egyptian crops, particularly the faba bean (*Vicia faba*, Fabaceae) [23, 24] in El-farafra oasis, in western desert of Egypt near latitude 27.06º North and longitude 27.97º East, at 580 km from Cairo.

The adult beetles had been collected just after the emergence using pit-fall traps from the faba bean and Egyptian clover (*Trifolium alexandrinum* L., Leguminosae) fields in El-Farfra oasis for maintaining a continuous culture under the laboratory conditions (23±2ºC, 46±10% RH, 12L:12D photoperiod). Adult females and males were allowed to mate in cylindrical jars (20 cm height and 20 cm diameter) and the laid egg masses were kept at bottom of jars until hatching. The first instar larvae (triungulins) were provided with a diet containing bee honey and wax combs with clutches of honeybee, *Apis mellifera* (Hymenoptera: Apidae). Unfortunately, these triungulins did not exhibit an interest to the food but aggregated in clusters until death. Another trial had been carried out using some egg-pods of the desert locust *Schistocerca gregaria* (Orthoptera: Acrididae) and the same behaviour of triungulins had been observed until death [28]. Therefore, newly emerged adult beetles of both sexes (of 0-day old) were collected from the field and directly transferred to the laboratory and kept under the previously mentioned conditions. These adults were allowed to feed on different host plants, faba bean, Egyptian clover, pea *Pisum sativum* (Fabaceae) and lettuce *Lactuca sativa* (Asteraceae), separately.

Food Metabolic Parameters

Approximate digestibility (AD) was calculated as follows: AD = {weight of ingested food – weight of faeces / weight of ingested food} × 100. Efficiency of conversion of ingested food to the biomass (ECI) was calculated as follows: ECI = {weight gain / weight of ingested food} × 100. Efficiency of conversion of digested to the biomass (ECD) was calculated as follows: ECD = {weight gain / weight of ingested food – weight of faeces} × 100. Relative weight gain (RWG) was calculated according to Johnson and Mundel [29] as follows: RWG= mg weight gain during the adult life / days Assimilation rate (AR) was calculated according to Scriber and Slansky [1] as follows: AR = RCR × AD Relative

metabolic rate (RMR) was calculated according to Slansky [5] but corrected for fresh weight as follows: RMR = (mg weight of ingested food – weight of faeces) / g mean fresh body weight / day. These formulae and equations may help to clear the metabolic efficiencies [29, 30].

Statistical analysis of data

Data obtained were calculated as mean ±SD and analyzed using the Student *t*-distribution and were refined by Bessel's correction [31] for testing the significance of difference between means at probability 0.05, 0.01 and 0.001.

Results and Discussion

Efficiency of Absorption of Digested Food into the Biomass

The efficiency of absorption of digested food (or the approximate digestibility, AD) through the whole longevity of the adult female *M. proscarabaeus* beetles generally ranged from 9.59±2.33 to 23.60±8.33 Table 1). The AD values of male congeners generally ranged from 11.89±0.65 to 17.27±3.76 (Table 2). As seen in (Table 1) adult females exhibited the highest AD by feeding on *T. alexandrinum* but the lowest AD by feeding on *P. sativum*. The adult males achieved the highest AD (17.27±3.76) by feeding on *V. faba* but the lowest AD (11.39±0.65) by feeding on *P. sativum*. Thus, the lowest AD was determined by feeding on the latter food plant, regardless of the sex. Moreover, males exhibited a descending AD by feeding on *V. faba*, *T. alexandrinum*, *L. sativa* and *P. sativum*, respectively. The change% may be informative for investigating AD on the present food plants. On using *V. faba* as a base, change% s of AD were calculated for females as +11.69, -27.21 and -54.61, on *T. alexandrinum*, *L. sativa* and *P. sativum*, respectively (Table 1), as well as for males: -5.67, -27.62 and -34.05, on the same plants, respectively (Table 2).

Table 1: Daily food utilization of adult females black beetle*, Meloe proscarabaeus*, feeding on different plant hosts.

Host plants	AD	Change %	ECI	Change %	ECD	Change %
Vicia faba	21.13±6.64	-	5.54±2.63	-	22.53±7.10	-
Trifolium alexandrinum	23.60±8.33 a	11.69	7.99±3.14 c	44.22	31.18±5.36 d	38.39
Lactuca sativa	15.38±5.39 d	-27.21	3.46±1.81 c	-37.55	19.79±4.98 b	-12.16
Pisum sativum	9.59±2.33 d	-54.61	0.36±0.26 d	-93.50	6.84±2.22 d	-69.64

AD: Approximate digistibility, ECI: Efficiency of conversion of ingested food, ECD: Efficiency of conversion of digested food. Faba bean (*Vicia faba*) was used as standard host plant for the comparison purpose. No. of adult ♀♀ = 10. Mean ± SD followed with the letter (a): non-significantly different (P>0.05), (b): significantly different (P<0.05), (c): highly significantly different (P<0.01), (d): very highly significantly different (P<0.001).

Efficiency of Conversion of Ingested Food into the Biomass

Data assorted in (Table 1) evidently reveal the highest efficiency of conversion of ingested food (ECI) into the biomass of adult females by feeding on *T. alexandrinum* but their lowest ECI was determined by feeding on *P. sativum*. As obviously shown in (Table 2), males achieved a similar ECI by feeding on two food plants, respectively, although of *V. faba* was used as a base in the present study for only comparison purpose. A descending ECI was evidently achieved by females or males as feeding on *T. alexandrinum*, *V. faba*, *L. sativa* and *P. sativum*, respectively (For more details, see tables 1 and 2). These results can be expressed in change% using *V. faba* as a base as +44.22, -37.55 and -93.50 for females on *T. alexandrinum*, *L. sativa* and *P. sativum*, respectively. As well as the change% for males were calculated in +15.65, -48.54 and -72.68 on the same food plants, respectively.

Table 2: Daily food utilization of adult males black beetle*, Meloe proscarabaeus*, feeding on different plant hosts.

Host plants	AD	Change %	ECI	Change %	ECD	Change %
Vicia faba	17.27±3.76	-	3.77±1.22	-	20.45±3.2	-
Trifolium alexandrinum	16.29±4.94 a	-5.67	4.36±1.67 a	+15.65	23.53±6.52 d	+15.06
Lactuca sativa	12.50±4.49 d	-27.62	1.94±0.73 d	-48.54	14.50±2.93 d	-29.10
Pisum sativum	11.39±0.65 d	-34.05	1.03±0.55 d	-72.68	8.82±4.47 d	-56.87

AD: Approximate digistibility, ECI: Efficiency of conversion of ingested food, ECD: Efficiency of conversion of digested food. Faba bean (*Vicia faba*) was used as standard host plant for the comparison purpose. No. of adult ♂♂ = 10. Mean ± SD followed with the letter (a): non-significantly different (P>0.05), (b): significantly different (P<0.05), (c): highly significantly different (P<0.01), (d): very highly significantly different (P<0.001).

Efficiency of Conversion of Digested Food into the Biomass

Recalling data of (Table 1) and (Table 2), females and males exhibited an efficiency of conversion of digested food (ECD) into the biomass similarly as achieved ECI. For some details, the highest ECD was estimated (31.18±5.36) for females by feeding on *T. alexandrinum* but the lowest ECD was estimated (6.84±2.22) by feeding on *P. sativum*. On comparison with *V. faba*, the change% in ECD were calculated in +38.39, -12.16 and -69.64 by feeding on *T. alexandrinum*, *L. sativa* and *P. sativum*, respectively. As seen in (Table 1), males' ECDs could be expressed in the change% s: +15.06, -29.10 and -56.87 by feeding on *T. alexandrinum, L. sativa* and *P. sativum*, respectively.

Is there an interrelationship between AD and ECI of females or males? Depending on data arranged in (Table 1), there is an inverse interrelationship between these two metabolic efficiencies, regardless of the food plant. Is there an interrelationship between AD and ECD of females or males? Data of (Table 1), again, show the higher ECD than AD by feeding on *V. faba, T. alexandrinum*, and *L. sativa* but the reverse was clearly found by feeding on *P. sativum* because AD appeared in lower value than ECD value. With regard to the male congeners, data given in (Table 2) generally indicate the higher values of ECD than AD values, whatever the food plant.

Correlation between assimilation and relative metabolic rates and relative body weight

Dealing with the daily mean of the food assimilation rate (AR) for the adult females on the present host plants, data distributed in (Table 3) show the highest rate (6581.62±1475.80) by feeding on *P. sativum* but the lowest rate (1714.69±819.59) by feeding on *L. sativa* which did not significantly differ from that AR on *V. faba* (1937.76±1392.05, P>0.05). There is a sexual difference in this rate since adult males attained the highest AR (7206.31±586.62, P<0.001) by feeding on *P. sativum* but the lowest AR (1918.57±818.33) by feeding on *V. faba* (Table 4). Estimated AR for males by feeding on *T. alexandrinum* or *L. sativa* was insignificantly higher than that achieved by feeding on *V. faba* (P >0.05).

Relative metabolic rate (RMR) is another metabolic parameter indicating the beetle capability for food metabolism. As obviously shown by the data of (Table **3**), RMR of adult females reached the lowest value by feeding on *T. alexandrinum* but the highest by feeding on *P. sativum*. Male congeners had different RMR because data of (Table 4) indicate the highest rate by feeding on *T. alexandrinum* and the lowest one by feeding on *V. faba*.

Table 3: Daily mean correlation of AR and RMR to RWG of adult females black beetle, *Meloe proscarabaeus*, feeding on different plant hosts.

Host plants	AR	RMR	RWG
Vicia faba	1937.76 ±1392.5	581.33 ±417.74	78.86 ±57.16
Trifolium alexandrinum	2136.63 ±861.88 a	463.74 ±214.94 d	111.88 ±72.86 a
Lactuca sativa	1714.69 ±819.59 a	552.14 ±267.68 a	80.50 ±70.44 a
Pisum sativum	623.61 ±1475.8 d	612.16 ±139.37 a	2.53 ±1.35 c

AR: assimilation rate, RMR: relative metabolic rarte (x100), RWG: relative weight gain. Faba bean (*Vicia faba*) was used as a standard host plant for the comparison purpose. No. of adult ♀♀ = 10. Mean ± SD followed with the letter (a): non-significantly different (P>0.05), (b): significantly different (P<0.05), (c): highly significantly different (P<0.01), (d): very highly significantly different (P<0.001).

Table 4: Daily mean correlation of AR and RMR to RWG of adult males black beetle, *Meloe proscarabaeus*, feeding on different plant hosts.

Host plants	AR	RMR	RWG
Vicia faba	1918.57±818.33	498.83 ±212.77	36.00 ±18.70
Trifolium alexandrinum	2623.8±1675.2 a	524.77 ±335.05 a	49.53 ±26.79 a
Lactuca sativa	2162.93±1063.5 a	605.62 ±297.79 a	29.23 ±19.48 d
Pisum sativum	7206.31±568.62 d	576.50 ±45.49 a	03.66 ±1.8 d

AR: assimilation rate, RMR: relative metabolic rarte (x100), RWG: relative weight gain. Faba bean (*Vicia faba*) was used as standard host plant for the comparison purpose. No. of adult ♂♂ = 10. Mean ± SD followed with the letter (a): non-significantly different (P>0.05), (b): significantly different (P<0.05), (c): highly significantly different (P<0.01), (d): very highly significantly different (P<0.001).

Daily means of relative body weight gain (RWG) by females and males are assorted in Tables 3 and 4, respectively. The RWG of females on *V. faba* was found as 78.86±57.16 which insignificantly increased by feeding on *T. alexandrinum* or *L. sativa* but elaborately declined (P<0.01) by feeding on *P. sativum*. Male congeners gained different RWG because they gained 36.00±18.70 by feeding on *V. faba* but larger RWG by feeding on *T. alexandrinum* and lower RWG by feeding on *L. sativa*. Furthermore, RWG of males feeding on *P. sativum* was severely declined (3.66±1.8, in comparison with 36.00±18.70 on *V. faba*, P<0.001).

Is there an interrelationship between RWG and AR of females or males? For females, data of (Table 3) prevail some interrelationship since the higher AR was reflected on higher RWG in the case of *V. faba, T. alexandrinum* and *L. sativa* but the interrelationship was unfortunately strange by feeding on *P. sativum* because RWG was only 2.53±1.35 in spite of the largest AR!! As shown in (Table 4), such interrelationship was obviously observed by male congeners. Considering the interrelationship between RWG and RMR, no certain trend could be conceived for females or males.

Adult females of *M. proscarabaeus* in the present study exhibited the highest value of efficiency of absorption of digested food (approximate digestibility, AD) by feeding on *T. alexandrinum* but the lowest AD by feeding on *P. sativum* while male congeners exhibited the highest AD by feeding on *V.*

faba and the lowest AD by feeding on *P. sativum*. Thus, both sexes had the lowest AD after feeding on *P. sativum*. The current results may be supported by a number of studies, although the direct comparison of these data is difficult because different host plants, insect species, and environmental conditions were used. However, adult males of the grasshopper *Dociostaurus brevicollis* exhibited AD 44-66% of food consumed during 24 h, but female adults exhibited AD 28-62% during the same period on the same host plants[32]. Adult females and males of the grasshopper *Euprepocnemis plorans* exhibited very low AD by feeding on *Zea mays* but pronouncedly higher AD by feeding on *T. alexandrinum*, compared to their AD by feeding on *V. faba*. Also, adult males exhibited similar AD on the same host plants[33]. Some authors reported a tendency of decreasing AD throughout the adult life [34, 35, 36, 37] while others reported a gradual decrease or increase depending on the host plant [33]. No such tendency could be distinguished in the present beetle *M. proscarabaeus* because the AD values were calculated as means along the whole life of adults. It may be worthy to mention that AD of the treated larvae of rice leaffolder *Cnaphalocrocis medinalis* with various concentrations of *Dysoxylum* triterpenes, significantly increased as a result of treatment (in particular 6 and 12 ppm) [38].

On the contrary, Treatment of larvae of the elm leaf beetle *Xanthogaleruca luteola* Mull. with methanolic extract of *Artemisia annua* L., a weed collected around paddy fields in north of Iran, resulted in significantly decreasing AD in adults[39]. However, the lowest AD of both sexes of *M. proscarabaeus* fed on *P. sativum*, in the present study, can be understood in the view of a previous study[27] where the lowest consumption rate of food was determined for both sexes by feeding on *P. sativum.*

It is well known that, after absorption of the digested food, some of the compounds are used for metabolic energy and a certain portion is converted into the biomass. The current data on the blister beetle *M. proscarabaeus* reveal the highest efficiency of conversion of ingested food into the biomass (ECI) of adult females and males by feeding on *T. alexandrinum* but lowest ECI by feeding on *P. sativum*. Generally, the beetle's ECI on the present tested host plants can be ranked in *T. alexandrinum*, *V. faba*, *L. sativa*, and *P. sativum*, respectively. No published information exists in the literature on the ECI of *M. proscarabaeus* fed on host plants, however, some related studies have been done for investigating the influence of food plants on feeding indices, such as the grasshopper *E. plorans* in which adult females exhibited slightly higher ECI by feeding on *Z. mays* than that recorded by feeding on *T. alexandrinum* while feeding on *V. faba* prohibited such efficiency in adult grasshopper to appear in remarkably decreased value during the ovarian maturation period[33]. After feeding on different host plants by the grasshopper *Melanoplus bivittatus* and *Melanoplus femurrubrum*, ECI varied from 15 to 18% in *M. bivittatus*, and from 15 to 19% in *M. femurrubrum* [35]. After feeding of the beetle *Henosepilachna septima* on food plants *Memordica charantia*, *Luffa acutangula*, and *Trichosanthus anguina*, the ECI were higher in *T. anguina* fed beetles[40]. Outside of the assessment of different host plants, ECI of treated larvae of the rice leaffolder *Cnaphalocrocis medinalis* significantly decreased as a result of treatment with *Dysoxylum* triterpenes (in particular 6 and 12 ppm)[38]. Also, treatment of larvae of the elm leaf beetle *X. luteola* with methanolic extract of *A. annua* resulted in significantly decreasing ECI in adults [39].

After feeding of the black blister beetle adults, in the present study, on four food plants, the mean efficiency of conversion of digested food into the biomass (ECD) was determined throughout their life. Adult females exerted the highest ECD by feeding on *T. alexandrinum* and the lowest ECD by feeding on *P. sativum*. A significant sexual difference in ECD could not be detected for *M. proscarabaeus*. This finding disagreed with some reported observations on the sexual difference for several insect species fed on various food plants [33, 41, 42, 43, 44]. After feeding of the beetle *Henosepilachna septima* on food plants *Memordica charantia*, *Luffa acutangula*, and *Trichosanthus anguina*, The ECD were higher in *T. anguina* fed beetles[40]. Outside of the assessment of different host plants, ECD of treated larvae of the rice leaffolder *Cnaphalocrocis medinalis* significantly decreased as a result of treatment with various concentrations of *Dysoxylum* triterpenes, (in particular 6 and 12 ppm)[38]. Also, treatment of larvae of the elm leaf beetle *X. luteola* with methanolic extract of *A. annua* resulted in significantly decreasing ECD in adults[39]. Otherwise, the decreasing ECD of the present blister beetle adults after feeding on some of the tested food plants can be attributed to the nutritional deficiency of them that cause the digested protein of food to be poorly utilized resulting in a lower ECD [33, 35].

Depending on the obtained results, higher ECD than AD was estimated for females fed on *V. faba*, *T. alexandrinum* or *L. sativa* but the reverse was clearly found by feeding on P. sativum. With regard to the male congeners, higher values of ECD than AD values were observed, whatever the food plant.

An understanding of the commonly observed inverse interrelationship between ECD and AD is pending until a distinction is made between the components of metabolism [10, 45, 46] associated with 1) tissue maintenance (Basal metabolic rate), 2) activity, including feeding and digestion/assimilation, and 3) growth [47, 48].

The current results demonstrated a correlation between the assimilation rate (AR), relative metabolic rate (RMR) and relative weight gain (RWG) in the *M. proscarabaeus* adults. The higher AR was reflected on higher RWG in the case of *V. faba*, *T. alexandrinum* and *L. sativa*, while such correlation was strangely detected by feeding on *P. sativum*. A reliable interpretation to this diverged correlation cannot be provided now which, also, absent in the available literature.

Conclusion

In conclusion, both sexes of *M. proscarabaeus* adults exhibited the lowest AD by feeding on *P. sativum* but there was a sexual difference regarding the highest AD since was it was achieved by female feeding on *T. alexandrinum* but by male feeding on *V. faba*. A significantly sexual difference could not be detected for each of ECI or ECD. Generally, the beetle's ECI on the present tested host plants can be ranked in *T. alexandrinum*, *V. faba*, *L. sativa*, and *P. sativum*, respectively. Thus the food utilization efficiencies of *M. proscarabaeus* depended on the food type.

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