AN ENERGY BUDGET FOR THE GRANARY WEEVIL, SITOPHILUS GRANARIUS (L.)[1]

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ABSTRACT: To provide a theoretical basis for the commercial assessment of the energy loss of stored grain caused by an insect pest, an energy budget was determined for the developmental period of the granary weevil, *Sitophilus granarius* (L.) fed on wheat kernels. Caloric content was determined for weevil biomass, exuviae, feces and the food consumed. Peak energy biomass/individual reached 11.12 cal (ash-free) during the late fourth larval stadium. An average of 62.6% of a wheat kernel (12.6 cal) was consumed by an average *S. granarius* larva during its development from egg (0.062 cal) to adult (6.750 cal).

INTRODUCTION: Precise determination of actual and potential commercial loss of stored foods caused by stored-product insects has long been a central problem in stored-product entomology. Several authors [1,2] have used various criteria - weight loss, uric acid pollution, nutritional loss, loss in milling and baking quality, monetary loss, reputation loss etc. - to estimate the economic loss resulting from insect infestation. Despite the urgent need and continued search for a loss criterion caused by insect activity that would be both generally acceptable and scientifically defensible, no such criterion has emerged. Sinha [3] proposed that the problem of deterioration of stored grain should be considered in the bioenergetic context of modern ecology because there is an urgent need for developing energy budgets of individual pest species and energy-flow models of grain bulks. As a follow up to this proposal, our group in Winnipeg is presently working on the energy budgets of several major insect pests of stored grain. An interdisciplinary multivariate study of grain bulks infested by these insects is also being undertaken to assess changes in the abiotic, biotic (microorganisms and insects) and bioenergetic variables in small grain bulk ecosystems. Later we intend to use a computer to simulate insect energetics in these ecosystems. The results of this study will provide heretofore unavailable data on the energy loss caused by populations of each of these destructive insect

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species on a certain type of stored cereal. We hope that this information will form a realistic basis for the commercial assessment of actual and potential loss of stored grain by individual species of insects in various climatic and crop storing regions of the world.

As part of a series of reports on this project we present some preliminary data on the energy budget of the developmental period of the granary weevil, *Sitophilus granarius* (L.) reared on stored wheat. A more complete analysis of the energy budget of *S. granarius* will be published elsewhere.

MATERIALS AND METHODS: An energy budget can be expressed [4] by several equations using units of calories per unit time per average individual insect.

$$C = P + M + FU \quad - (i),$$

$$A = C - FU \quad - (ii),$$

$$M = A - P \quad - (iii), \text{ where:}$$

C = Consumption (total ingested food); P = Productive (body growth and exuviae); M = Metabolism (respiration or maintenance cost); FU = Rejecta (part of food ingested which is egested as feces (F) plus urinary and other excreted products (U); A = Assimilation (the sum of production and metabolism).

In this paper we measured C, P and FU and estimated A and M using the above equations. The energy budget thus calculated is cumulative [4], i.e. each value of the budget is calculated for each developmental age interval from egg to the specified insect age. Cumulative production according to [4] can be estimated by

$$P = (Bb)_t - (Bb)_o + {}_{k=o} (Bex)_k \quad - (iv) \text{ where:}$$

$(Bb)_t$ = Body biomass at time t; $(Bb)_o$ = Egg biomass;

Bex = Exuvia biomass.

Eggs of known age were obtained by placing 4-week old adults of *S. granarius* (from a stock culture reared on *Triticum aestivum* cv. 'Neepawa') for 1 day on whole wheat flour passed through a 100-mesh sieve. Over 2,400 eggs were collected using this method; half of these eggs were allowed to develop for 2 days and the other half for 4 days. The eggs were then cleaned in distilled water and the egg plugs removed. The eggs were then counted into groups of 20, dried and weighed.

Larvae and pupae of known age were obtained by the following method. One month old *S. granarius* adults were taken from the stock culture and were allowed to oviposit for two days in kernels of hard red spring wheat (*T. gestivum* cv. 'Neepawa') at 14% moisture content. The grain was stained with acid fuchin according to the methods of Frankenfeld [5] and Sharifi [6] and kernels with only one egg plug each were individually weighed and placed into numbered gelatin capsules (size 00). Thirteen groups, each containing 40 kernels with egg plugs and 10 pre-weighed kernels without egg plugs (controls), were placed in petri dishes and rearing cabinets. The insects were allowed to develop until 6 days after the mid-oviposition period when the first group of 50 kernels was removed from the rearing cabinet and stored at -18°C. Every 2 days thereafter, up to 30 days after oviposition, a group of kernels was removed and stored at -18°C. Processing each insect age group involved removing a group of kernels from cold-storage, dissecting each kernel and separating the insect, frass[1] and uneaten kernel. The larval instars were identified according to head capsule width [7]. The insects, frass and uneaten parts of each kernel were dried and weighed individually.

The dry weight of the consumed portion of each kernel was calculated by comparison with the weights of the control kernels. The weights of the exuvia were determined by dissecting and removing exuvia from additional infested kernels reared under the same conditions. The weight of the rejecta was estimated by subtracting the weight of the exuvia from the weight of the frass.

All insects were reared at 30° ± 2% RH. The materials were oven-dried at 70°C for 48 h. A Cahn electrobalance (model g-2) was used for weighing the dry materials. The caloric content of the whole kernels, the germ, endosperm, eggs, larvae, teneral[2] adults, exuviae and rejecta were determined with a Phillipson Microbomb Calorimeter [8]. The ash values of all materials were determined using a muffle furnace at 550°C for 2 h. All caloric values shown are ash-free dry weight.

RESULTS AND DISCUSSION: Fifty samples (pellets) were burnt in the Phillipson microbomb calorimeter to determine the caloric values of the developmental stages of *S. granarius*. The mean caloric value of all stages of *S. granarius* was 6.012 cal/mg, fourth instar larvae had the highest value, 6.547 cal/mg; and teneral adults the least, 5.389 cal/mg.

The mean energy value for the exuvia was 5.399 cal/mg; rejecta, 4.540 cal/mg; the food - whole kernel, 4.348; germ, 5.563; endosperm, 4.183 cal/mg. The ash content of the developmental stages varied from 2.7 to 5.4%.

The mean caloric value per individual for all developmental stages is shown in Figure 1. The caloric value increased exponentially during larval growth, reaching a peak in the late fourth instar and pre-pupal period before declining during the pupal stage and then levelling off after emergence to the adult stage.

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[1]Frass = Feces + urinary products + exuviae (+ small particles of chewed but unconsumed kernel was negligible in this experiment).
[2]A teneral adult is a soft-bodied adult newly emerged from the pupa.

Comparing the calories per mg of the late larval stages and adults of *S. granarius* with similar stages of other stored-product beetles (Table 1) such as *Tenebrio molitor* (L.) and *Tribolium castaneum* (Herbst) two observations can be made: First, caloric values of corresponding stages of these 3 species are quite similar; second, variation in caloric content between insects may be attributed to differences in fat content [9] especially in the late larval stages where a high lipid content is required for pupal metabolism [4].

Figure 2 shows the amount of energy contributed by a kernel to insect development. The horizontal lines at the bottom of the figure show the general distribution of instar stages from the time of oviposition

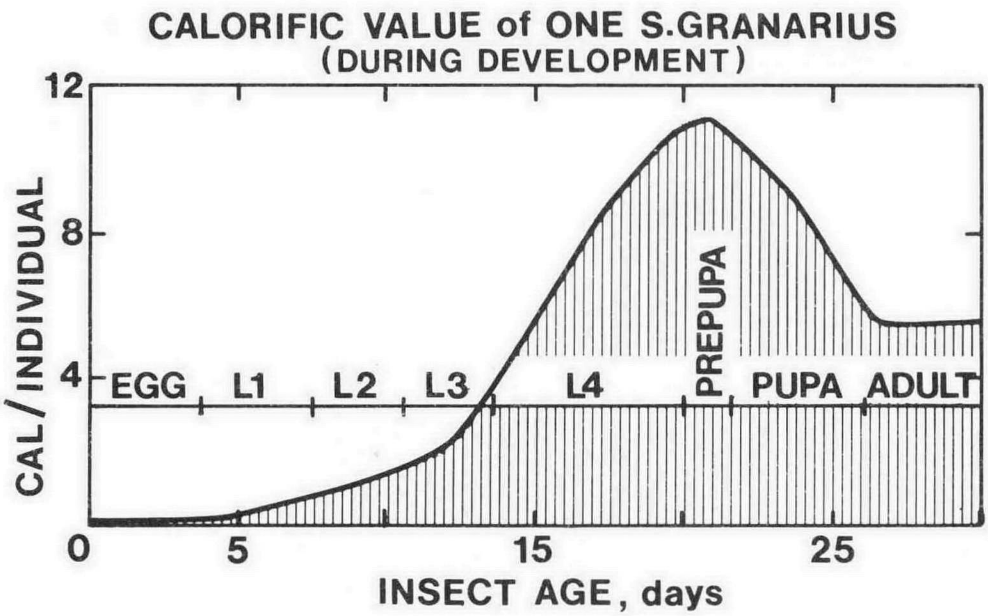

FIGURE 1. Growth curve of an average individual *S. granarius* in terms of energy content.

TABLE 1. Energy content of some stored-product beetles.

Reference No.	Species	Cal/mg (ash-free)
This study	*Sitophilus granarius* (L4)	6.500
"	*S. granarius* (Adult)	5.671
[10]	*Tenebrio molitor* (L4)	6.314
[9]	*T. molitor* (Adult)	5.000[a]
[4]	*Tribolium castaneum* (L7)	6.700
[4]	*T. castaneum* (Adult)	6.000

[a]Not known if ash-free

to emergence as teneral adults (n = 20 to 40). As the insect developed more of the kernel was consumed. By the time the larva was ready to pupate, at 20 days, as much as 60% of the total dry matter of the kernel was consumed. In many kernels almost all the germ and about three-quarters of the endosperm had been eaten by the time the insect had reached the pupal stage. *S. granarius* larvae preferred to eat the endosperm and germ of the wheat kernel; the bran was left intact and formed a protective case for the delicate larva or pupa. Thus only the caloric values of the endosperm and germ were used to show the actual energy consumed; the total energy in an average whole kernel, including bran, was determined as 126 cal (Fig. 2).

Between 70 and 80% of the food consumed was assimilated by larvae during development; the remaining 30-20% was eliminated as feces or other waste products (Fig. 2). As the larvae developed

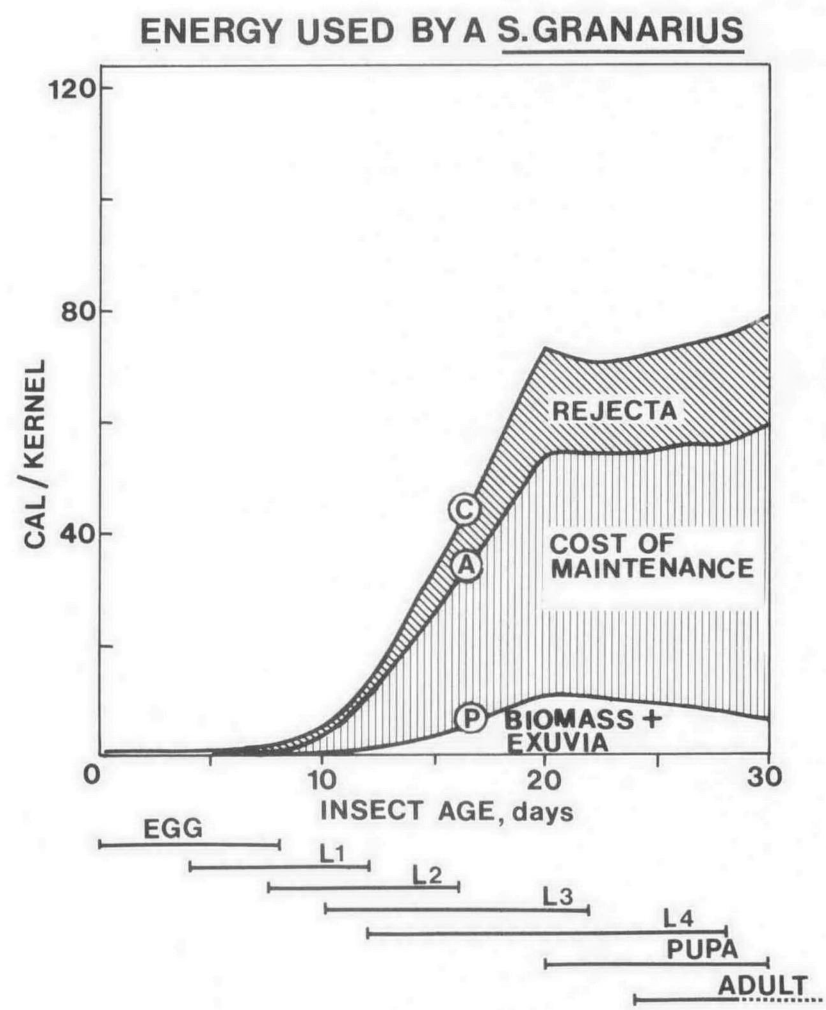

FIGURE 2. A cumulative energy budget of an average population of *S. granarius* during development. Means of 20 to 40 larvae developing in individual wheat kernels of an average energy content of 126 cal.

production increased reaching the highest cumulated production recorded just prior to pupation. During the pupal state production decreased because there was no energy intake and only energy stored in the body was used for metabolism. Prior to pupation out of the total 72 cal consumed only 55 cal was assimilated; 79% of the assimilated energy, however, was used up in metabolism resulting in only 11.7 cal of insect biomass production. Of the total energy consumed for development only 16% went into biomass production which is equivalent to the gross production efficiency ($\frac{P}{C} \times 100$).

The net production efficiency ($\frac{P}{A} \times 100$) was 21% up to the end of the larval stage (Fig. 2). This is lower than the 29% recorded for the prepupal stages of *Tribolium castaneum* (reared on wheat flour and Brewer's yeast) by Klekowski et al. [4].

The low efficiency of *S. granarius* larvae feeding on wheat kernels probably was a result of the high cumulated metabolism required to convert carbohydrates into lipids prior to pupation.

This study demonstrates that the calculation of energy loss of wheat kernels caused by insect infestation can be quantified in terms of caloric units. We hope that in the future the values derived from energy budget studies of individual insect species and the type of food they infest can be converted into monetary values; thus providing a more precise measure of the actual and potential loss of stored-products caused by insects.

ACKNOWLEDGEMENTS: We thank Drs. C. G. Bailey, N. B. Singh, and F. L. Watters for helpful suggestions and critically reading the manuscript. The work was supported in part by an operating grant from the National Research Council of Canada to R. N. Sinha.

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