EFFECT OF TRICALCIUM PHOSPHATE ON AN ENERGY BUDGET OF *TROGODERMA GRANARIUM* (COLEOPTERA: DERMESTIDAE)

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ABSTRACT

A sublethal concentration (2.5%) of tricalcium phosphate, a known insect suppressant, was used to investigate the effect of this salt on the energy budget of the khapra beetle, *Trogoderma granarium* Everts. Larvae fed tricalcium phosphate had a longer developmental period and one extra instar; they ingested more food and had a lower mean assimilation efficiency. *T. granarium* is relatively resistant to tricalcium phosphate and concentration only in excess of 2.5% will cause any appreciable population suppression. The higher mortality and longer development time of population treated with tricalcium phosphate were compensated for by a higher production of eggs. Greater numbers of progeny and living longer may even increase consumption. energy budgets of other stored product insects were compared with that of *T. granarium*.

INTRODUCTION

A promising alternative to conventional chemical pesticides in stored products pest management is the use of mineral food additives. For example, the United States approved the use of tricalcium phosphate as a component of the mineral mixture used in the blended cereals distributed in food donation programs. We know of no reports on the effect of mineral supplements on insects energy budgets. In this paper we present the results of effects of tricalcium phosphate on the energy budgets of the khapra beetle, *Trogoderma granarium* Everts.

MATERIALS AND METHODS

All *T. granarium* were from stock cultures that were maintained on whole wheat flour at 31±°C and 50% RH. In our tests wheat germ was substituted for whole wheat flour. The diet for the treated tests was obtained by thoroughly mixing for 1h, wheat germ with the tricalcium phosphate (Monsanto Chemical

Company, St.Louis Mo., USA) at 2.5% by weight. We selected a concentration of 2.5% to make the observed effects of the compound more distinct and at the same time to allow for full development of a population. Measurements of eggs and pupae were made daily and larvae every other day.

Observation on development, ingestion and egestion were made in small vials with screen openings. Screen allowed us to separate the feces from the diet. The tests were replicated 40 times; dead *T. granarium* were replaced with new individuals of the same age.

Preweighed wheat germs was put into each vial every second day and the uneaten food was removed and weighed. Dry weight of wheat germ was 93% of the fresh weight. The dry weight value was used throughout study. Feces collected during 48h intervals were dried under vacuum at 50°C for 48h and then weighed.

Biomass production and water content for each developmental stage was determined by weighing live insects, drying them under the same conditions as feces and reweighing. Eggs, pupae and adults were weighed in 30 replicates. The larval weight in each instar was replicated 100 times.

Oxygen consumption by the eggs and larvae up to day 15 of development was measured at 2-d intervals with Cartesian divers. Constant pressure respirometers were used for the older stages (Grodziński et al. 1975). Based on several authors we assumed the following values of the respiratory quotients: eggs and first four instars = 1; fifth instar = 0.95; sixth (sixth and seventh in the treated group) instar = 0.90; pupae = 0.70; adults = 0.80.

A modified Philipson microbomb calorimeter (Grodziński et al. 1975) was used to estimate energy values for the various stages of *T. granarium* they by-products and the food consumed.

The energy budgets were constructed following the methods described by Grodziński et al. (1975). Respiration of larvae (O_2 consumption) was performed with a calorimeter model MBC-3 and the results calculated as suggested by Ricker (1973) and Prus (1977).

Because female larvae consume more than males, unless otherwise stated, larvae refer to females only. The results obtained in this study are compared with the energy values observed by others working with stored product beetles. Where similarities are not found, the values are compared with other insects, beetles and moths.

RESULTS

Treated larvae had one more instar than controls and the entire larval developmental period was 4-d longer. The pupal period in the controls was 1-d longer. In both groups male larvae pupated earlier (only four molts) than females, but in the treated group they took 2-d longer.

In the control group, the metabolic rate increased remarkably in the middle of almost all larval instars. These increases were accompanied by the intense growth, which was particularly distinct between days 29 and 31 of development (Table 1). A similar relationship was not found in the experimental group.

Table 1. Dry weight and energy content of dry matter and dry organic matter of various life stages of *Trogoderma granarium* reared on wheat germs and wheat germs mixed with 2.5% of TCP at 30º, 50% RH.

Stage	Age [Days]	Dry weight (µg) Control Mean	± SD	Dry weight (µg) Treatment Mean	± SD	Energy value (J/mg) Control n	Mean	± SD	Energy value (J/mg) Treatment n	Mean	± SD	Ash free (J/mg) Control	Ash free (J/mg) Treatment
Eggs	1	20.0	1.00	20.0	1.00	5	0.3	0.01	5	0.3	0.01		
	2	18.8	0.94	15.2	0.76								
	3	18.4	0.92	15.1	0.70								
	4	14.4	0.72	14.4	0.72								
	5	13.6	0.68	11.2	0.56								
	6	13.0	0.65	10.6	0.53								
Larvae	7	10.0	0.50	10.0	0.60	5	23.7	0.01	5	23.7	0.01	24.4	24.4
	9	10.7	0.54	8.2	0.41	5	23.5	0.12	5	23.9	0.12	24.2	24.5
	11	17.2	0.86	15.8	0.79	5	24.1	0.08	5	22.7	0.12	24.7	23.3
	13	13.0	0.65	21.0	1.05	5	24.2	0.24	5	22.5	0.08	24.7	23.2
	15	39.0	1.95	21.8	1.15	6	25.4	0.08	5	23.8	0.40	25.9	24.6
	17	47.0	2.35	27.0	1.35	6	25.4	0.04	6	24.9	0.12	25.9	25.9
	19	57.0	2.85	19.0	0.95	5	25.8	0.16	5	26.7	0.16	26.6	27.7
	21	88.9	4.45	41.9	2.10	5	30.2	0.30	5	25.9	0.16	31.1	27.0
	23	90.2	4.51	31.2	1.56	5	25.7	0.17	5	26.7	0.28	26.3	28.0
	25	326.8	16.34	28.2	1.41	5	25.7	0.10	5	27.7	0.12	26.4	29.0
	27	434.3	21.72	60.0	4.20	5	28.5	0.18	5	27.0	0.13	29.4	28.1
	29	466.3	23.32	248.1	12.41	5	28.5	0.28	5	27.2	0.17	29.4	28.3
	31	1538.4	76.92	526.9	26.35	5	28.5	0.09	5	29.4	0.32	29.4	30.6
	33	1169.1	58.46	307.5	15.38	5	27.8	0.16	5	27.2	0.20	28.6	28.2
	35	1550.9	79.05	401.5	20.00	6	28.1	0.20	5	27.9	0.16	29.1	28.9
	37	1928.2	96.45	1302.4	66.30	5	30.1	0.15	6	27.8	0.13	31.3	28.8
	39	-	-	2071.8	101.83	-	-	-	5	28.5	0.04	-	29.6
	41	-	-	1878.0	93.90	-	-	-	5	27.8	0.15	-	28.8
Prepupae	♀					5	29.2	0.14	5	29.5	0.24	30.4	30.7
	♂					5	29.6	0.03	5	29.6	0.20	30.8	30.8
Pupae ♀	38	1661.2	84.03			5	29.4	0.12				30.4	
	39	1628.8	81.44			5	28.8	0.16				29.8	
	40	1548.4	78.53			5	28.9	0.28				30.0	
	41	1490.9	70.63			5	28.5	0.09				29.5	
	42			1431.8	71.60				5	28.8	0.04		29.7
	43			1358.3	67.92				5	28.5	0.16		29.4
	44			1247.4	65.14				5	28.4	0.08		29.3
Pupae ♂	33	605.2	30.26			5	29.0	0.13				30.0	
	34	592.4	29.62			5	29.2	0.03				30.3	
	35	565.2	28.26	674.3	30.81	5	29.2	0.21	5	28.8	0.23	30.3	29.7
	36	506.0	26.83	540.5	27.15	5	29.2	0.09	5	29.2	0.20	30.3	30.1
	37			484.8	24.40				5	28.8	0.12		29.7
Adults ♀	42	1096.3	54.80			5	27.7	0.28				28.5	
	45			1339.6	65.34				5	27.9	0.08		28.8
	48	463.4	23.17			5	23.6	0.16				24.3	
	51			502.3	25.12				5	25.4	0.11		26.2
Adults ♂	37	421.9	20.57			5	28.5	0.25				29.3	
	38			461.2	23.06				5	28.7	0.20		29.6
	43	320.1	14.35			5	25.9	0.08				26.2	

44	310.2	13.06	1/	-	-	-

1/ Not enough material was collected for energy content determination.

The relationship of the respiration rate (R) and "fresh" body weight (W) was described by the following regression equations :

$R = 0.006 \times W^{0.945}$ for the control

$R = 0.005 \times W^{0.947}$ for the treated group

Regressions were calculated using daily oxygen consumption only for larvae as they are the only feeding stage of *T. granarium*.

Treated larvae ingested much more than the control larvae. In both groups ingestion doubled between days 21 and 23 as larval development progressed from third to fourth larval instar and remained at the high level until pupation. Egestion (FU_C) increased irregularly and its correlation with ingestion (C) was described by the following regression equations:

$FU_C = -34.461 + 0.431C_C$ for the control

$FU_C = -7.872 + 0.367C_C$ for the treated group.

Energy values (J, Joules) of 1 mg dry weight (y) generally increased through development in both groups of larvae and were described satisfactorily by the following equations:

$y = 22.479 + 0.192x$ for control and $y = 23.067 + 0.174x$ for treatment

Although treated larvae took longer to reach an energy value equivalent to the controls, they finally did so and the prepupae had an energy content of about 57J/individual.

Changes in the cumulative energy transfer efficiencies during development were different for both groups (Fig. 1). All efficiencies in the control had a maximum on day 31 of the developmental cycle and regular small decreases in the middle of each larval instar. In the treated group there was a considerable decrease of assimilation and gross production efficiencies in the third instar and they remained at a very low level up to the fifth instar. However, in the control group an assimilation efficiency of 64.65 and a net production efficiency of 40.90 was observed.

Cumulative energy budgets show very distinct differences in ingestion by larvae from the two groups of *T. granarium* (Fig. 2). Ingestion increased regularly following a power curve. Finally it reached 226.3 J for the control and 311.0 J for the treated group, which indicated that treated larvae required 84.7 J to complete development. Production of eggs equaled 13.9 J for the control and 18.9 for the treated group.

DISCUSSION

Larvae of *T. granarium*, *Tribolium castaneum* and *Tenebrio molitor* grow by "jumping" from one weight to a higher one after a small decrease just before and after each moult (Burges 1960, Howe 1968). *T. granarium* weights during development that we observed, resembled those reported for *Sitophilus granarius* (Campbell et al. 1976), *T. castaneum* (Klekowski et al. 1970). Larvae grow slowly during the early instars and gain weight very rapidly during the last one or two instars,. Male larval development from our control was similar to the "jumping" model, but for all the others development was more continuous.

Mean metabolic rates of the control and treated larvae in our studies (4.11 and 3.87 µl O_2/mg/h, respectively) support the earlier findings of Burges (1960). These values are relatively high compared with those reported for other species of DERMESTIDAE.

We found that at the mid-point of almost all instars, the metabolism reached its maximal rate. The metabolic rate of pupae followed a U-shaped curve. This is characteristic of other species of insects (Slama 1960).

Generally the metabolism of *T. granarium* was not high as indicated by by the intercept (respiratory rate W^b) of the respiration regression. Metabolism in other stored product beetles is much higher, except for *Sitophilus oryzae* (Table 2). Respiration rates of *T. granarium* increased directly with weight, as indicated by value of slope and was close to 1 for both groups. When values of the slope approach 0.7, the expression Wb reflects body surface area (Grodziński et al. 1975) and is a major factor influencing metabolism (Table 2).

Table 2. Intercepts (a) and slopes (b) of regression equations of respiration and biomass relationship for several species of stored product beetles (a_{20} = intercept recorrelated for standard temperature 20°C) (Data from the literature).

Species	Temp. °C	Intercepts a	Intercepts a_{20}	b
Trogoderma granarium wheat germ	31	4.047	1.797	0.943
Trogoderma granarium wheat germ + 2.5 TCP	31	3.467	1.539	0.947
Tribolium castaneum[a]	29	13.840	6.653	0.844
Sitophilus granarius[b,c]	30	37.250	16.539	0.790
Sitophilus oryzae[b,d]	30	1.420	0.631	0.515
Cryptolestes ferrugineus[b,e]	30	10.990	4.880	0.539
Rhyzopertha dominica[b,e]	30	13.820	6.136	0.852
Tribolium confusum[f]		9.824	-	0.849

[a] Klekowski et al 1967
[b] Regression computed for dry matter
[c] Campbell et al. 1976
[d] Singh et al. 1976
[e] Campbell & Sinha 1978
[f] Bijok 1986

The energy value of the different stages of *T. granarium* varied, in the control group, from 23.5 J/mg to 30.0 J/mg of dry matter. Energy content equal to about 7.0 cal/mg is characteristic for organisms accumulating nutrients (Golley 1961). In *T. granarium* the larvae are only feeding stages and they accumulate energy for nonfeeding pupae and adults. 57 J/individual appears to be the energy content necessary for the larva to pupate. In the treated group, the tricalcium phosphate caused a delay in accumulating this amount of energy.

The cumulative ingestion (226.3 J for the control group and 311.0 J for the treated group) by *T. granarium* larvae was relatively high as compared with ingestion by larvae of other stored product beetles, but low when compared with beetle species where the adults feed. For example *S. granarius* adults can ingest as much as 1189.0 J (Campbell et al. 1976) and *Rhyzopertha dominica* adult 2637.0 J (Campbell & Sinha 1978).

The way *T. granarium* uses ingested energy differs from other stored product pests. Most of the beetle species infesting stored products have fairly high assimilation efficiencies and rather low net production net production efficiencies during larval development. *T. granarium* is unique with an assimilation efficiency of nearly 65% and > 40% net production efficiency (Table 3).

T. granarium spends so much energy on production that allows the larva to become quiescent at almost any time during its development and survive >1 yr without food. Most probably accumulated energy is also used to survive other unfavorable conditions, such as very low humidity.

The total energy involved in egg production (13.9 J for control and 18.9 J for treated) constitutes about 6% of the total consumed energy by a *T. granarium* female larva. Most stored product insects that have been studied so far use a relatively small amount of consumed energy on reproduction. *Plodia interpunctella*, which like *T. granarium* does not feed as an adult, spends only 0.9% of its stored energy for that purpose (Imura & Sinha 1986).

The relatively high total energy involved in egg production in *T. granarium* results from the high energy value of the egg, which contains more energy (0.33 J/egg) than most other stored product beetles.

Very distinct differences were found between cumulated energy transfer efficiencies of the two groups. At the time when larvae usually stop feeding and prepare to molt, assimilation efficiency of the control larvae was higher. There was a large decline of assimilation during the third instar in the treated group. A destructive effect of tricalcium phosphate on the alimentary canal was described earlier (Bano & Majumder 1965). The inability to assimilate mostly affected production by treated larvae as indicated by their gross production efficiency, about twofold smaller than in the control (Table 3). The mean net production efficiency was the same in both groups.

Table 3. A comparison of cumulative energy budgets (in Jouls) and efficiencies for the developmental period of Trogoderma granarium reared on wheat germs and wheat germs with 2.5% TCP at 30ºC, 50% RH.

Condition	Control	Treatment
Age (days to pupation)	37	41
Consumption	226.01	310.97
Production	59.94	55.59
Respiration	86.62	70.66
Assimilation efficiency (A/C) 100	64.85	40.60
Gross production efficiency (P/C) 100	26.52	17.88
Net production efficiency (P/A) 100	40.90	44.03

Treated larvae as well as control ones spent 40% of assimilated energy on production. However, accumulated respiration of treated larvae was noticeably lower than in the control (Table 3). The incomplete digestion and low assimilation efficiency suggest a high egestion rate of treated insects. However, our studies did not confirm this. Earlier studies by Kraszpulski et al. (1987) have shown that 2.5% concentration by weight of tricalcium phosphate has no effect on population development of *T. granarium* , because higher mortality and longer developmental times of the treated population are compensated for by higher egg production. Our research indicated that tricalcium phosphate affected mainly the food assimilation of an individual. In the case of this species, this has practical advantages because larvae crawl into crevices where they are very difficult to reach with conventional contact pesticides.

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Figure 1. Cumulative energy transfer efficiencies during development in days of both groups of *T. granarium* (l, larvae; p, pupae; a, adults; A, assimilation; C, consumption; P, production).

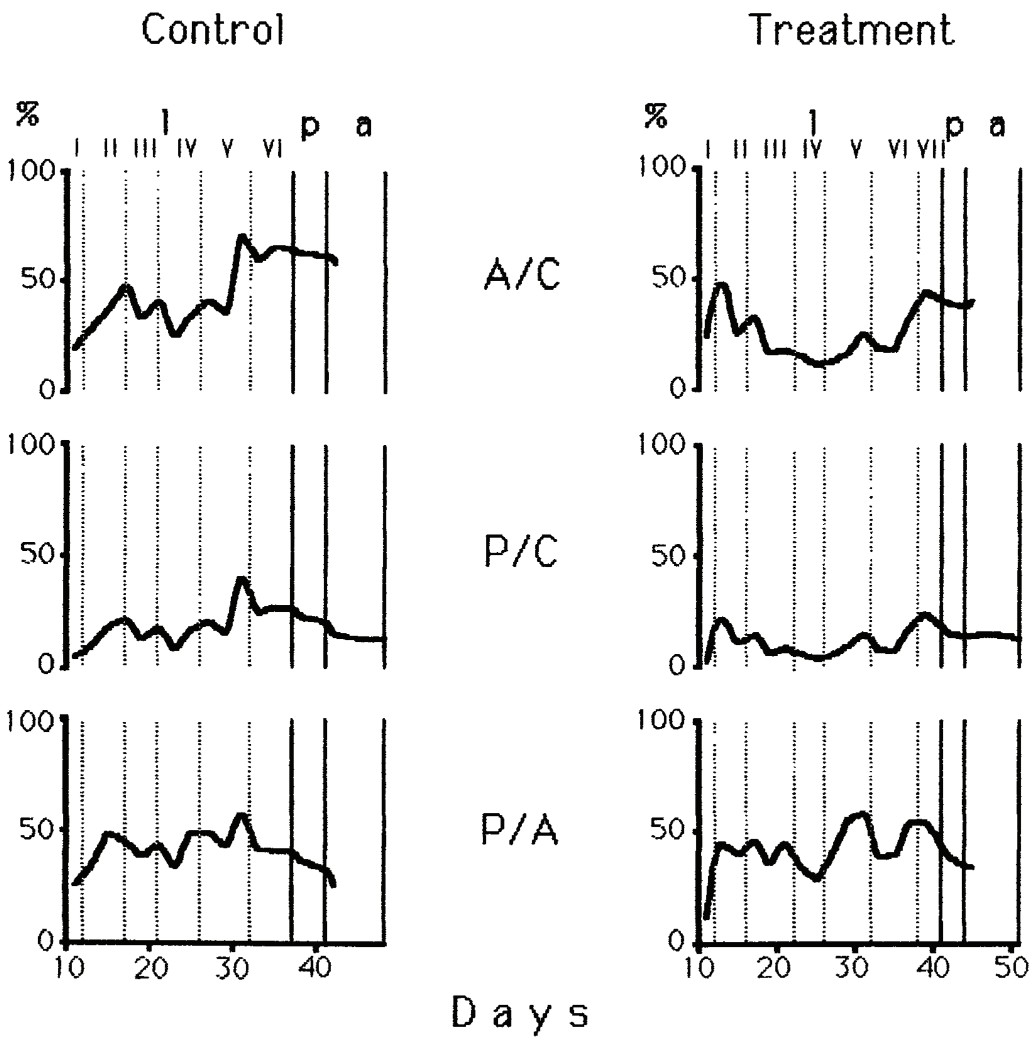
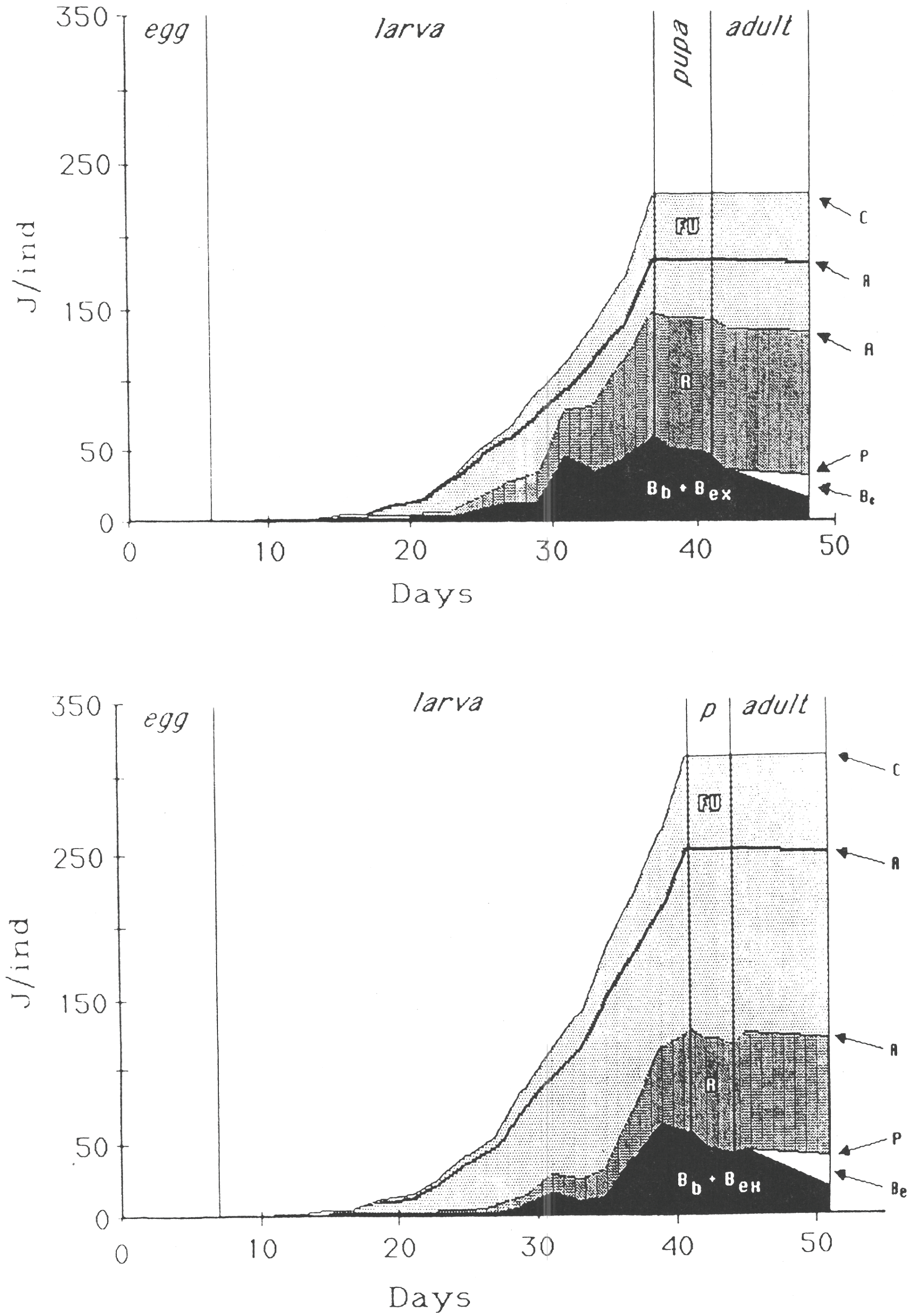


Figure 2. Cumulative energy budget of the control (upper graph) and treated (lower graph) groups of *T. granarium* (C, cumulative consumption; FU, cumulative egestion; A`, assimilation as a difference between C and FU; A``, assimilation as a sum of P and R; R, cumulative respiration; P, cumulative total production; B_e, cumulative production of eggs; B_b, cumulative body production; B_{ex}, cumulative production of exuviae).



EFFETS D'UNE ALIMENTATION EN PHOSPHATE TRICALCIQUE SUR LA BALANCE ENERGETIQUE DE *TROGODERMA GRANARIUM* (EVERTS) COLEOPTERA DERMESTIDAE

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RESUME

Nous avons utilisé une concentration sublétale (2,5 %) de phosphate tricalcique (TCP), un insecticide connu, pour rechercher les effets de ce sel sur la balance énergétique du coléoptère khapra, *Trogoderma granarium* Everts. Les larves nourries au TCP ont présenté une période de développement plus longue, une mue extra larvaire, ont ingéré plus de nourriture et ont vu leur capacité d'assimilation moyenne diminuer. Le *T. granarium* est relativement résistant au TCP et seules des concentrations de plus de 2,5 % pourraient causer une diminution appréciable de la population. La mortalité plus élevée et la durée de développement plus longue des populations traitées au TCP ont été compensées par une augmentation de la production d'oeufs. Une descendance plus nombreuse et de plus longue durée de vie peut même accroître la consommation. Nous avons comparé la balance énergétique de *T. granarium* avec celle d'autres insectes des denrées.