

The Black Cutworm as a Potential Human Food

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Abstract: Problem statement: The black cutworms (*Agrotis ipsilon*) were grown in an artificial medium to evaluate their potential as a human food. **Approach:** The culture was started from moths and the life cycle and culture structure were evaluated. There was an initial adjustment period of 3 days during which the growth of the larvae was very slow. The size of the larvae increased reaching maximum weight and length after 23 days and then declined as the larvae entered the pupation stage. For an efficient production system, the larvae should be harvested after 21 days. The moisture content of the medium may present an important management problem for commercial production. **Results:** A system in which the eggs are separated from the adults and hatched in separate cages would alleviate the danger of losing the new larvae due to fungal disease. The high moisture content of the larvae (60%) could also cause handling and storage problems. Drying and grinding the larvae would reduce them to easily manageable forms and would improve their marketability as novel food. The moisture, ash, carbohydrate, protein and fat contents were, 13.4, 12.1, 7.5, 53.1 and 13.9% (dry basis), respectively. The larval time index (time to produced one gram) was 3.20 d g⁻¹ weight. Considering the fact that a female moth produces 1200 eggs, the population time index is 3.90 min g⁻¹ weight. Because the larvae seem to be a promising source of protein for human consumption, further research is required to evaluate their growth characteristics on low substrates. **Conclusion:** The research should also evaluate the quality of larval protein (amino acid profile) and other nutritional values such as vitamins and minerals. The effects of environmental parameters, such as temperature, relative humidity and CO₂ and heat production on food consumption and protein yield, should also be investigated. This information will aid in the design of an optimal production system of insect protein.

Key words: Black cutworm, artificial feed, life cycle, growth rate, human food, protein, fat, moisture content

INTRODUCTION

The development of novel protein sources such as Fish Protein Concentrate (FPC)^[1,2], Single Cell Protein (SCP)^[3,4] and Soybean Protein (SBP)^[5,6] have made significant contributions toward the alleviation of the world's protein deficiency^[7]. However, there is still an estimated one billion people suffering from protein deficiency and malnutrition^[8]. It is, therefore, necessary that similar success be obtained by utilizing what seems to be an inexhaustible supply of insects as a protein source for human consumption. Insects make up (on the average) about two-thirds of the food of our common land birds and two-fifths of the food of fresh water fish. Turkeys, hogs and other domestic animals are often fattened on insects^[9].

Many cultures have been able to subsist on meagre rations during unproductive periods by supplementing their diets with insects while others consume insects all year long and would not be able to survive without

them^[10,11]. In Mexico, the eggs of certain large aquatic bugs are regularly sold in the city markets. The Mexicans sink sheets of matting under water upon which the eggs are laid by the millions and then dried, placed in sacks, sold by the kilogram and used for making cakes and other foods^[12]. In Jamaica, the local people consider a plate of crickets a compliment to the most distinguished of guests^[13]. In Australia, the natives collect quantities of the bugony moth (*Agrotis infusa*) in bags, roast and eat them and claim that they taste like nuts^[14]. The manna (surgery honey dew) excreted by aphids and scale insects is used as a sweet by peasants in Turkey, Iraq and Iran^[15]. Locusts are eaten with gusto (fried and seasoned with salt and pepper or in cakes) in Arabia, Persia, Madagascar, Africa and India boiled^[10,15,16]. Termites are the most popular insect food and in some regions of South America and Africa, termite colonies are often staked out as the private property of individuals or groups^[10]. The larvae of the palm weevil are extracted from the palm trees and eaten

Table 1: Nutritional value of selected food products and insects^[10,19,20]

Food product	Water (%)	Ash (%)	Carbohydrates (%)	Protein (%)	Fat (%)	kcal (100 g)
Beef (total edible, trimmed to retail level)	56.7-63.9	0.8-0.9	0.0	17.4-19.4	15.8-25.1	225-301
Lamb (legs, lean rib and shoulder, trimmed to retail level)	56.3-62.5	1.2-1.3	0.0	15.4-16.8	19.4-27.1	247-310
Pork (shoulder and spare ribs, trimmed to retail level)	52.6-59.5	1.0-1.2	0.0	14.6-23.4	22.7-31.4	276- 347
Chicken (broiler and rosters, light and dark meat without skin)	73.0	1.0	0.0	20.6-23.4	1.9-4.7	117-130
Fish (lake trout)	70.6	1.1	0.0	18.3	10.0	168
Fish (atlantic and Pacific Halibut)	76.5	1.4	0.0	20.9	1.2	100
Milk (whole)	87.2	0.7	4.9	3.5	3.7	66
Egg (whole)	73.7	1.0	0.9	12.9	11.5	163
Termites (<i>isoptera</i>)-fri	15.0	7.9	11.1	30.0	36.0	508
Grasshoppers (<i>orthoptera</i>)-dried	7.1	9.2	12.7	54.0	17.0	327
Butterflies (<i>lepidoptera</i>)-smoked	16.7	1.9	16.9	47.7	16.8	268
Beetles (<i>coleoptera</i>)-dried	15.1	3.6	2.3	53.1	25.9	464
Flies (<i>diptera</i>)-dried larvae	13.7	5.3	2.4	63.1	15.5	655
Bees (<i>hymenoptera</i>)-live	70.2	2.2	0.8	18.2	2.6	316
Spiders (<i>melopoensalbostratus</i>)-roasted	13.7	6.4	5.3	63.8	10.8	452

Table 2: Maximum permissible levels of insect infestation or damage^[21]

Product	Maximum level
Coffee beans	10% by count insect infested or insect damaged
Cherries (fresh, canned or frozen)	4% by count insect infested
Citrus fruit juices (canned)	5 per 250 mL <i>Drosophila</i> and other fly eggs or 1 maggot per 250 mL
Peanut butter	30 insect fragments per 100 g
Asparagus (canned or frozen)	10% of spears by count infested with 6 attached asparagus beetle eggs or egg sacs
Spinach (canned or frozen)	8 spinach leaf miners per 100 g or 4 leaf miners 3 mm or more in length per 100 g
Tomato puree	20 fruit fly eggs per 100 g, or 10 fruit fly eggs and 1 maggot per 100 g or 2 maggots per 100 g

in the West Indies under the name of “grugru”^[17]. The natives of many countries catch quantities of ants, grasshoppers, larvae and pupae of bees, moths, crane flies, wood boring beetles and eat them raw, dried or roasted^[10,15,16]. Thus, insects can be reared on readily available low substrates to provide a sustainable and nutritional supply of protein for human consumption^[7,11,12,17].

Although of small size, insects because of their prodigious numbers exceed in weight all other animal matter^[18]. This great mass of material possesses genuine food value. From the eating habits of wild animals and natives in many countries, it seems that much of the insects are palatable. Chemical analyses of many insects have also shown that they compare favourably with traditional foods (Table 1)^[10,19,20]. It would be difficult to give any sound reason why we should consume oysters, crabs and lobsters and disdain to eat equally clean, palatable and nutritious insects^[13]. Although consumers in western societies may look upon insects with disgust, they have ingested them on several occasions as insects are practically omnipresent within all consumed foods of plant origin as shown in Table 2^[21]. Also, insects are used as coloring agents in Smarties, Yoghurt and Campari^[22].

To alleviate the world protein deficiency and maintain the ever increasing human populations, we should turn our attention to the utilization of certain insects as human food.

Insects can be easily reared to efficiently convert low quality substrates to high quality proteins. Careful production, processing and marketing procedures would make insects as acceptable as the FPC, SCP and SBP. This will, however, require substantial innovation in food production and processing technologies^[19,22,23].

Objectives: Reports on eating black cutworms indicated that they taste like nuts^[11,24]. However, very little information is available on the nutritional quality of these worms. The ease with which this insect can be reared and handled makes it an ideal population to study on a small scale with the aim of developing an economically and technically feasible commercial larvae production system for use as a source of protein for human and/or animal consumption. The specific objectives of this study were: (a) to develop an artificial ration for production of a viable culture of the black cutworm *Agrotis ipsilon*, (b) to study the life cycle and culture structure of this insect, (c) to establish a viable and strong culture of larvae, (d) determine the growth rate of the larvae and (e) to evaluate the nutritional values of the larvae.

Black cutworm: The black cutworm (*Agrotis ipsilon*) belongs to the family of night flying moths and it is from the order *Lepidoptera* and the family *Noctuidae*. It is a cosmopolitan species with worldwide distribution and a restless pernicious habit of cutting off many plants while satisfying its appetite. The larvae attack

nearby plants including corn, alfalfa, beans, soybean, cabbage, cotton, sugar cane, tomatoes, tobacco and clover. The insect is found in Canada in all provinces in freshly cut plants or under soil clumps.

The life cycle of the black cutworm includes four stages: Egg, larva, pupa and adult (Fig. 1)^[25]. The female moths lay their eggs (1200-1500) singly or a few together (up to 30) on the leaves or stems of plants. The egg stage lasts from 2 days to 2 weeks depending on temperature. The larva has three pairs of true legs toward the front of their bodies, plus five pairs of fleshy prolegs towards the back. The larvae are greyish-black with a paler underside and no distinct markings on their bodies. The time to grow from newly hatched larvae of 2 mm to nearly 50 mm long varies from 2 weeks to 5 months depending on temperature and humidity. Under optimum conditions, only 30 days are required for the development from the egg stage to full adult caterpillar. The caterpillars remain below the surface of the ground during the day and feed at night. The caterpillars can dig down several centimetres in the soil where they make cells in which they pupate. The larvae do not overwinter in Canada, but are carried in from the south of the USA on strong southerly weather systems in April to May. Two to five generations can occur annually and the abundance of the species is affected by rainfall which can prevent the moths from laying eggs or by flooding the soil thereby, forcing the larvae up to the surface of the soil during the day to be destroyed by parasites^[9,26].

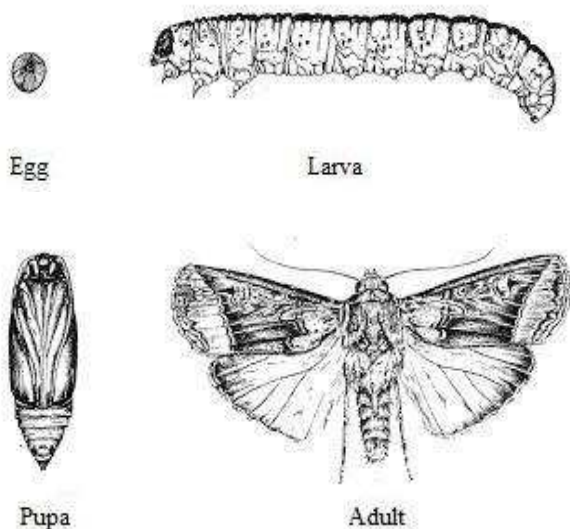


Fig. 1: Life cycle of black cutworm^[25]

MATERIALS AND METHODS

Growth medium: The proper consistency of the diets and provisions for an adequately balanced diet that contains the essential growth substance is necessary for the propagation of insects^[27]. A nutritionally complete diet for most insects must contain: (a) Protein or essential amino acids, (b) carbohydrates and (c) fat or fatty acids, (d) vitamins (ascorbic acid, α -tocopherol, folic acid, inositol, nicotinamide, pantothenic acid, riboflavin, thiamine or vitamin A), (e) minerals and (f) water. In this study, two artificial diets were prepared. The first diet was used for the propagation of starter culture for the determination of the changes in the size and weight of larvae. The second diet was used for mass rearing of insects for the determination of the nutritional value of the larvae. The chemical composition of these diets is shown in Table 3.

Starter diet: This diet was prepared according to the procedure described by Haydaks^[28] by mixing corn flour, whole wheat flour, wheat bran and dried yeast powder (3:3:3:1 ratio by weight). The dry mixture was combined with an equal part of fluid made of glycerine and honey (1:1 ratio by weight). The mixture was mixed thoroughly and then allowed to stand for 24 h before use.

Mass rearing diet: The diet used for mass rearing insects was made of corn flour, wheat bran, wheat germ, brewer's yeast, milk, castor oil, chicken mash and water. The corn flour, wheat germ, wheat bran and brewer's yeast (3:3:3:1 ration by weight) were mixed together, combined with an equal part of chicken mash and blended for 2 min. The dry mixture was combined with an equal part of fluid made of milk, castor oil and water (1:1:4 ration by weight), mixed thoroughly for 5 min and then allowed to stand for 24 h before use.

Starter culture:

Rearing moths: Three day old moths were obtained from the Nova Scotia Agricultural College in Truro. Ten months were used for egg-laying.

Table 3: Chemical analyses of the diets used in the study

Constituent	Content (%)	
	Starter diet	Mass rearing diet
Water	14.0	15.5
Ash	7.3	6.7
Carbohydrate	56.5	56.7
Protein	19.6	19.1
Fat	2.6	2.0

The starter medium was placed in the oviposition cage (60 cm long × 40 cm wide × 25 cm deep plastic container with perforated sides and cover) and arranged to provide the greatest surface area. Shredded filter papers were added to provide sufficient air exchange. The seeding moths were placed over the medium. Waxed paper sheets were provided for the moths to lay their eggs. The oviposition cage was placed in an environmentally controlled chamber (VWR Environmental Chamber, Model No. 2020, Shelden Manufacturing Company Inc., Cornelius, Oregon) at a temperature of 28°C, a relative humidity of 70% and a photoperiodic regime of 10 h of light and 14 h of darkness.

Hatching of eggs: The waxed papers (with eggs) were collected from the oviposition cages and the number of eggs per waxed paper sheet was estimated. The starter medium was placed in the egg hatching chamber (40 cm long × 40 cm wide × 25 cm deep plastic container with perforated sides and cover) and 100 eggs were added to the medium. The hatching chamber was placed in an environmentally controlled chamber (VWR Environmental Chamber, Model No. 2020, Shelden Manufacturing Company Inc., Cornelius, Oregon) at 28°C, 70% relative humidity and a photoperiodic regime of 10 h light and 14 h of darkness. Emerging larvae were isolated and 10 larvae were selected for the study of growth rate and life cycle while the rest were mass reared using the mass rearing medium for the determination of nutritional value.

Growth rate determination: Ten larvae were used for the size and weight measurements and growth rate determination. The larvae were placed in a separate rearing cage (60 cm long × 45× wide × 25 × deep plastic containers with perforated plastic sides and cover) and reared on the starter diet. The rearing cage was placed in the growth chamber (VWR Environmental Chamber, Model No. 2020, Shelden Manufacturing Company Inc., Cornelius, Oregon) at a temperature of 28°C, a relative humidity of 70% and a photoperiodic regime of 10 h day light and 14 h of darkness. The larvae were weighed as a group every 3 days. The average length of the larvae was also measured and recorded. The changes in the group were observed and recorded.

Mass rearing: The larvae were taken from the starter culture and used as stock for the mass rearing. They were all of similar age and reared to maturity. The mass rearing medium was placed in the rearing cage (65×45×45 cm deep plastic container with perforated

sides and cover) and the larvae were placed on the medium. One litter jar was provided for the larvae to pupate inside. The mass rearing cage was placed in an environmentally controlled chamber (VWR Environmental Chamber, Model No. 2020, Shelden Manufacturing Company Inc., Cornelius, Oregon) at a temperature of 28°C, relative humidity of 70% and photoperiodic regime of 10 h of light and 14 h of darkness. The pupae were collected from the bottle, placed in a special container (40 cm long × 40 cm wide × 25 cm deep plastic container with perforated cover) filled with medium and shredded paper and kept until the emergence of the moths. Adults were allowed to emerge into the one litter jar from which they were collected and placed in the oviposition cages.

Chemical analysis: The chemical analyses performed in this study included: Moisture, ash, protein and fat contents. The energy contents were then calculated from the carbohydrate, fat and protein contents.

Moisture content: A sample of thirty mass reared larvae representing a full range of weigh were chosen for moisture analysis. The oven dry method procedure described in APHA^[29] was followed. The samples were first weighted using a Mettler scientific balance (AE 2005, Mettler Instruments, AG, Greifensee, Zurich, Switzerland). The larvae were killed by freezing them alive for 24 h. They were then placed in a convection oven (Isotempoven, Model No. 655F, Fisher Scientific, Montreal, Quebec) for 24 h at 105°C. The dried samples were then removed from the oven, left to cool in a dessicator and weighed. The moisture content was calculated as follows:

$$MC = \frac{M_1 - M_2}{M_1} \times 100 \quad (1)$$

Where:

MC = The moisture content (%)

M₁ = The initial weight (g)

M₂ = The weight of the dried sample (g)

Ash content: The ash content was determined gravimetrically on the dried samples according to the procedure described in APHA^[29]. The dried samples were placed in a muffle furnace (Isotemp muffle furnace, Model No. 186A, Fisher Scientific, Montreal, Quebec) for 30 min at 550°C. They were removed from the muffle furnace, left to cool in a dessicator and then weighed using a Mettler scientific balance (AE 2005, Mettler Instruments, AG, Greifensee, Zurich, Switzerland). The ash content was calculated as follows:

$$AC = \frac{M_3}{M_1} \times 100 \quad (2)$$

Where:

AC = The ash content (%)

M₃ = The weight of the material remaining after burning the dry sample (g)

Protein content: The protein analysis was carried out using 30 mass reared larvae representing a full range of weights. The worms were subsequently frozen and dried in a freeze dryer (Labconco FreeZone, Cat No. 10-271-16, Fisher Scientific, Montreal, Quebec) for 24 h. The weight of the group (30 worms) was then recorded using a Mettler scientific balance (AE 2005, Mettler Instruments, AG, Greifensee, Zurich, Switzerland). The worms were ground using a laboratory grinder (Waring Laboratory, Cat No. 14-509-18, Fisher Scientific, Montreal Quebec). The total protein was determined using the Tecator Kjeltac Auto Analyzer (Model-1026, Fisher Scientific, Montreal, Quebec). The ground worms were transferred to the macro 250 mL digestion tubes. One "Kjeltab" (containing 3.5 g K₂SO₄ and 0.0035 g Se) and 3.0 mL of distilled water were added to the samples in the digestion tubes. The samples were digested at 420°C for 30 min in a digestion block heater (Tecator Digester System, 20 Model-1016, Fisher Scientific, Montreal, Quebec). The digestion tubes were removed and allowed to cool for 10 min. Then, 30 mL of distilled water was added to each of the digestion tubes. The test tubes and the digests were transferred to the Auto Analyzer. The constants A and B for the equipment were set at 0.00 and 1.862, respectively. The titrant acid and the predetermined blank sample were set at 0.2127 M and 0.01, respectively. Distillation, titration and calculation were performed automatically. The protein percentage was computed from the following equation:

$$PC = \frac{\text{Displayed result}}{W_s} \quad (3)$$

Where:

PC = The protein content (%)

W_s = The weight of the dried worms (g)

Fat content: The fat content was carried out using 30 mass reared larvae representing a full range of weights. The worms were then frozen and dried in a freeze dryer (Labconco FreeZone, Cat No. 10-271-16, Fisher Scientific, Montreal, Quebec) for 24 h. The total weight

of the group (30 worms) was then recorded using a Mettler scientific balance (AE 2005, Mettler Instruments, AG, Greifensee, Zurich, Switzerland). The worms were ground in a laboratory grinder (Cat No. 14-509-18, Waring Laboratory, Fisher Scientific, Montreal Quebec). The fat content was determined using an ether extraction technique according to the procedure described in the Official Method of the Association of Official Analytical Chemists^[30]. Hot ether was percolated through a porous receptacle filled with the dry ground meal worms for 24 h. The fat was released from the dry matter and collected in a flask at the bottom of the apparatus. The receptacle was removed, dried in a vacuum oven (Isotemp oven, Model No. 655F, Fisher Scientific, Montreal, Quebec) for 24 h at 105°C and then reweighed. The change in weight corresponded to the fat content of the original sample. The fat percentage was computed from the following equation:

$$FC = \frac{W_f}{W_s} \times 100 \quad (4)$$

Where:

FC = The fat content (%)

W_f = The weight of fat extracted (g)

RESULTS

Life cycle and culture structure: The stages of the life cycle and the changes among the individuals in the culture were observed and recorded. These included: The number of eggs per waxed sheet, the average weight of larvae, the average length of larvae, the average lengths of oviposition, pupal and adult stages, the mortality and the appearance. The changes were of three types: (a) Death of one or more of the worms, (b) pupation of one or more of the worms and (c) the emergence of adults from the pupal stage. The dead worms were counted and discarded. The number of worms to enter the pupal stage of their development and the number of adults emerging from the pupal stage were recorded. The results are shown in Table 4 and 5 and Fig. 2. There was no mortality among the larvae of the black cutworm. Pupation started on day 27 and emergence of adults started on day 51. The pupation stage lasted for 24 days and the adult stage lasted for 15. The maximum length was 51 mm and the maximum weight was 4.51 g.

Table 4: Larval growth, pupation and emergence of moths

Day	Weight (g)	Length (mm)	Stage of growth
0	0.80	0.63	10L
3	0.80	0.63	10L
6	0.80	0.67	10L
9	1.25	12.50	10L
12	1.75	19.00	10L
15	2.34	31.00	10L
18	2.97	38.00	10L
21	3.60	42.50	10L
24	4.09	47.00	10L
27	4.51*	51.00*	9L+1P
30	4.26	50.00	2L+8P
33	3.91	46.00	10P
36	3.50	38.00	10P
39	3.06	30.00	10P
42	2.59	25.00	10P
45			6P
48			6P
51			3P+3M
54			6M
57			6M
60			6M

*; Maximum weight and length; L: Larva; P: Pupa; M: Moth

Table 5: Life cycle characteristics

Characteristic	Value
Number of eggs per sheet	30.00
Maximum weight (g)	4.51
Maximum length (mm)	5.10
Duration of egg stage (d)	5.00
Duration of larval stage (d)	24.00
Duration of pupal stage (d)	24.00
Duration of adult stage (d)	15.00
Larval mortality (%)	0.00
Appearance	Shinny black

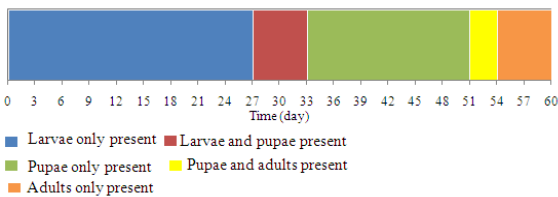


Fig. 2: Changes in population structure

Growth rate: The average weight and average length of the Larvae were plotted against time as shown in Fig. 3. It was noticed that for the first 6 days the average weight and length of the larvae did not show any significant increase. This initial period was required for the adjustment to the new environment and new medium. After the initial period, the weight of larva increased with time up to a maximum and then began to decrease once the larva was preparing for the pupation stage. The maximum weight and maximum length were reached at the same time. The change in the rate of growth (g day^{-1}) was determined by dividing the weight increase in a given period by the length of the period (3d). Figure 4 shows that the growth rate first increased and then decreased when the larvae were closer to the pupation stage. The negative values indicated weight loss.

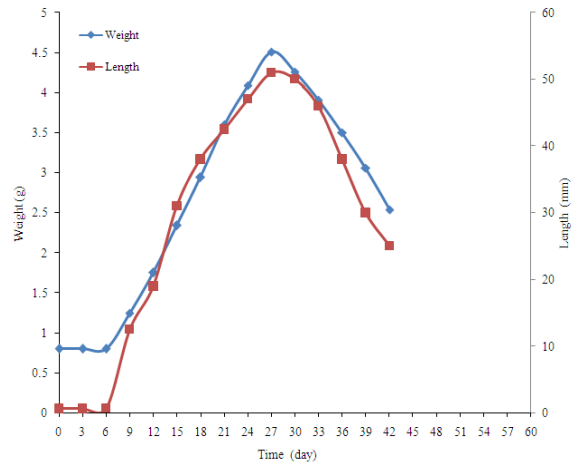


Fig. 3: Changes in the average weight and length of the larvae

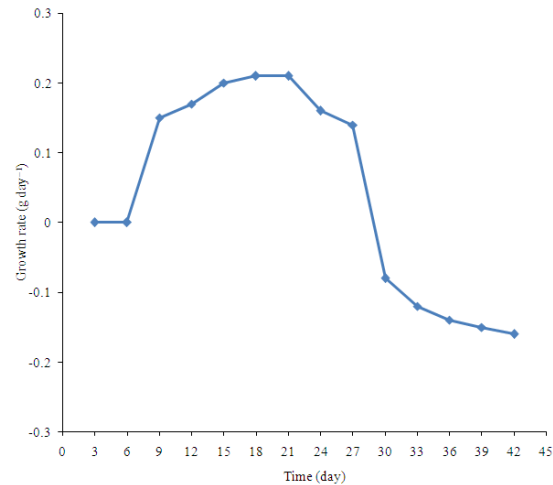


Fig. 4: Growth rate

Growth and time indices: The first 6 days were considered a period of adjustment to the new environment (slow or no growth) and the period of pupation was associated with weight loss. Thus, the period of accelerated larval growth (increased weight) was linearized as shown in Fig. 5. The slope of the linear line (average growth rate) was divided by the initial weight to obtain the larval growth index. The time required to reach the maximum weight was also divided by the total population weight (number of eggs produced by a female moth \times maximum weight) to obtain the population time index. The results are shown in Table 6. The average rate of growth, the time required to produce one gram of larva, the growth index, the larval time index and the population time index were 0.163 g day^{-1} , 24 days, $4.91 \text{ g}^{-1} \text{ day}^{-1}$, 3.20 day g^{-1} and 3.90 min g^{-1} , respectively.

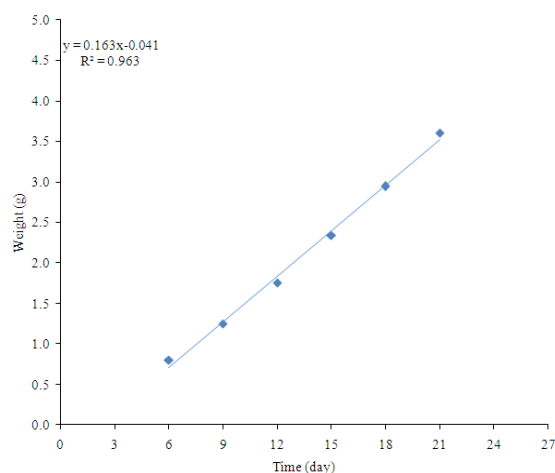


Fig. 5: Determination of the average growth rate

Table 6: Growth and time indices

Parameter	Value
Eggs produced by female moth	1200.00
Maximum weight (g)	4.51
Time to reach maximum weight (d)	24.00
Growth rate (g day ⁻¹)	1.63
Growth Index (g g ⁻¹ day ⁻¹)	4.91
Larvae Time Index (d g ⁻¹)	3.20
Population Time Index (min g ⁻¹)	3.90

Growth index: (Maximum weight of larva)/(Initial weight of larva × time required for maximum growth); Laval time index = (time required for maximum growth)/(maximum weight of larva); population time index: (Time required for maximum growth)/(maximum weight of larva × number of eggs)

Table 7: Nutritional analysis

Composition	Content (%)
Moisture	13.4
Ash	12.1
Carbohydrate	7.5
Protein	53.1
Fat	13.9

Moisture content of live larvae-60%

Table 8: Energy content

Source of energy	Contents (%)	kcal whole larva	100 g larva
Carbohydrate	7.5	0.62	30
Protein	53.1	4.35	212
Fat	13.9	2.56	125
Total		7.53	367

Number of eggs produced by female moth = 1200; Live weight of larva = 4.51 g; Dry weight of larva = 2.05 g; Live moisture content = 60%; Dried moisture content = 13.4%; Carbohydrate energy = 4 kcal g⁻¹; Protein energy = 4 kcal g⁻¹; Fat energy = 9 kcal g⁻¹

Larval composition: The average moisture content of live larvae was 60%. The results of moisture, ash, carbohydrate, protein and fat contents, calculated on a

dry weight basis when the larvae reached their maximum weights, are shown in Table 7. The moisture, ash, carbohydrate, protein and fat contents were 13.4, 12.1, 7.8, 51.1 and 13.9%, respectively. The energy available in the carbohydrate, protein and fat in the larvae is shown in Table 8. A total of 367 kcal/100 g larvae are contained in the carbohydrate, protein and fat. On the average, each female larva produces 1200 eggs and the hatched larvae reach their maximum weight after 23-24 days. Therefore, each female moth can produce about 4988 kcal in 23 days.

DISCUSSION

The high protein and fat contents of the black cutworm larvae and the fact that they are easy to rear and maintain make this insect a good potential source of human food. The growth rate of the youngest larvae was found to be the highest. The increase in the body weight during the initial growth period appeared to be linear. An interesting characteristic of the caterpillars studied is that they reach maximum weight and maximum length at the same time. After the initial accelerated growth period, the larvae started to decrease in weight as soon as they reached the maximum length. This suggests that for an efficient production system, the larvae should be harvested shortly before they reach the maximum length (21 days old) as they enter the pupation stage and began losing weight after reaching their maximum size.

The presence of material with high moisture content can encourage microbial growth leading to the loss of the entire population^[24]. Although there was no mortality observed among the larvae in this study, the moisture issue could present an important management problem for commercial production. A system where eggs are separated from adults and hatched in a separate chamber as done in this study would alleviate the danger of losing the population due to microbial infection. The high moisture content of the larvae (60%) could also cause handling and storage problems. Drying and grinding the larvae would reduce them to an easily manageable form that would improve their marketability as novel food.

Because the larvae seem to be a promising source of protein for human consumption, further research is required to evaluate their growth characteristics on low substrates. The research should also evaluate the quality of protein (amino acid profile) and other nutritional values such as vitamins and minerals. The effects of environmental parameters such as temperature, relative humidity and CO₂ heat generation on food consumption and protein yield should be investigated. This

information will aid in the design of an optimal economically viable production system. Handling and processing the insects is also of paramount importance.

The world is coming to recognize the grim truth that, ultimately the world population growth will outstrip food suppliers with apocalyptic results. In 2000, 36 million people died due to hunger or as a consequence of hunger^[31], with an estimated 60% of the 10.9 million deaths each year among children under the age of five in the developing world attributed to malnutrition^[32]. If the current birth rates continue, the earth's population will grow from the current 6.7-9.2 billion by the year 2050, most of which will be in the less developed countries of Latin America, Africa and Asia^[33], the countries least able to feed their children. If the world cannot feed those now living, it would be impossible to feed the next generation. Feeding 9.2 billion people at the current dietary levels presents the staggering necessity of increasing the earth's food producing capacity to a rate never seen before. Quite apart from whether we have the technology, manpower and the money to do it, the most ominous question is whether the ecosystem could survive such pressure; remembering that at the 2001-2003 dietary levels about 856.4 million people were malnourished^[34].

Although there is no simple unit for measuring the nutritional quality of a diet, protein content is a widely accepted indicator of nutritional quality. Most foods rich in protein are also comparatively good sources of many of the other required nutrients^[22]. Therefore, the greater the protein content of the food, generally the greater its nutritional value. However, the quality of the protein as well as the total amount is important. If animal protein supply a part of the total diet, the protein quality of the diet is generally enhanced because most animal proteins contain the essential amino acids (cysteine, histidine, isoleucine, methionine, leucine, lysine, phenylalanine, methionine, tryptophan, tyrosine and valine) humans require in the diet, whereas most plant proteins lack one or more of these essential amino acids. Also, in contrast to plants, animals contain a greater percentage of protein because of their lower water content, a fact which allows humans to consume a smaller quantity for the same food value^[23]. In addition to supplying the highest quality of protein, animal foods are rich sources of the B vitamins whereas some plant foods are deficient in these factors^[14]. Because the body's need for protein is related to its rate of growth, the need for protein is much greater in infants than in older children or adults^[23]. There seems to be little disagreement among scientists that protein malnutrition contributes to the high death rate among

infants and children of the less developed countries and causes among the survivors debilitating weakness, higher susceptibility to disease and irreversible brain damage^[20,23].

The higher quality of animal protein, as compared to plant protein^[23], justifies man's efforts to maintain animal production as a source of protein for human consumption. However, since livestock lose over 90% of the protein and calories in the feed material they eat, we should shift our emphasis to those animals (insects) that are most efficient in the conversion of their food into nutritional meat^[14]. By such shift, more animal protein would be produced from a given quantity of feed. It is, therefore, conceivable that insect farming will be a part of a new agricultural system. It will be possible in the near future to construct small but efficient insect farms that have high volumetric production rate of protein. Insects are in size between SCP and farm animals, they yield structured animal protein, require much less energy for processing than SCP and less space than farm animals, still large enough to be reared and harvested using automated systems. Insects contain proteins (essential amino acids), lipids, minerals, vitamins (E and B2) and energy^[14,19,35].

The results obtained from this study show the potential of using insects as a protein source for human consumption to alleviate protein deficiency in many parts of the world, especially in Africa and Asia. Governments in these countries should embark on using these inexhaustible nutritional resources to feed their people. A number of insects show good taste and flavour (Table 9)^[11,16,17]. The species that have been proven to be high in protein and nutritional contents and show the economics of energy conversation of feed to insect protein such as the one used in this study are good candidates for mass rearing. The inexhaustible supply of low substrates (waste materials) can be used as a feed source because the insects feed conversion efficiency is quite high.

Table 9: Taste of commonly used insects^[11,16,17]

Insect	Taste
Fried ants	Described as insipid because they lacked distinct taste
Fried agave worm	Were compared to slightly burned French fries
Fried caterpillars	Provided such comments as putrid and horrible
Dried predaceous diving beetle	Quite good and compared to clams, sunflower seeds and shrimp
Fried grasshopper	Taste like sardines or fish
Dried bees	Strong disagreeable flavour and too mushy
Fried silkworms	Likened to rotten meat
Fried butterflies	Taste like the pier smells
Fresh grasshoppers	Pleasant taste and delicious
Fresh cockchafer worms	Acceptable
Termites	Taste like lobsters or snail with a faint smell of mushrooms

Since wide varieties of these substrates are available, materials which are not edible can be converted into human food by insects such as black cutworms. In addition, insects are very efficient feed converters to protein (more than five times that of beef) and fast growing organisms^[14], two characteristics that allow the design of a farm system that can respond to changes in demand. The integration of insects into the current agricultural production system will increase the complexity of the systems by creating symbiotic relationships with other species which will improve the system efficiency and insure its sustainability.

In addition to addressing the nutritional, biological and economical issues of mass rearing of insects, the issues of social acceptance of food fortified with insect protein need to be addressed. The fact is that insects are a source of animal protein that can play a major role in eliminating or reducing protein deficiency in many parts of the world. The following necessary steps must be taken for successful marketing of a novel food such as insects^[36]: (a) obtaining knowledge of the existing patterns of the consumers, (b) developing and standardizing suitable recipes for utilising the novel food, (c) testing the standardized new recipes and ensuring their acceptability, (d) imparting nutrition education to the public on the benefits of the novel food and (e) advertising the novel food through the press, radio, TV and other media.

CONCLUSION

The high protein and fat contents of the back cutworm larvae and the fact that they are easy to rear and maintain make the results of this study very interesting. The growth rate of the youngest larvae was found to be the highest. The increase in the body weight during the initial growth period appeared to be linear. An interesting characteristic of the caterpillars studied is that they reached maximum weight and length at the same time. After the initial accelerated growth period, the larvae started to decrease in weight as soon as they reached the maximum size. This suggests that for efficient production systems the larvae should be harvested shortly before they reach the maximum length (21 days); i.e., before they enter the pupation stage and began losing weight after reaching their maximum size.

The presence of material with high moisture content can encourage microbial growth leading to the loss of larval population. A system where eggs are separated from adults and hatched in a separate chamber as done in this study would alleviate the danger of losing the population due to microbial

infection. The high moisture content of the larvae (60%) could also cause handling and storage problems. Drying and grinding the larvae would reduce them to easily manageable forms and would improve their marketability as novel food.

The dry larvae contained 13.4, 12.1, 7.5, 53.1 and 13.9% moisture, ash, carbohydrate, protein and fat contents, respectively. The time required to produce one gram larva was 3.20 days. Considering the fact that each female moth produced 1200 eggs, the time required to produce one gram would be 3.9 min. Because the larvae seem to be a promising source of protein for human consumption, further research is required to evaluate their growth characteristics on low substrates. The research should also evaluate the quality of protein (amino acid profile) and other nutritional values such as vitamins and minerals. The effects of environmental parameters, such as temperature, relative humidity and CO₂ and heat generation on food consumption and protein yield, should be investigated. This information will aid in the design of an optimal production system. Handling, processing and marketing the insects are also of paramount importance.

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