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The Use of Insects as Human Food in Zambia

A.E. Ghaly
Department of Process Engineering and Applied Science,
Faculty of Engineering, Dalhousie University, Halifax, Nova Scotia, Canada

Abstract: Problem statement: The life cycle and culture structure of two commonly eaten worms in Zambia (Isoberlinia paniculata and Miombo/Mopani) were evaluated. The worms were grown on an artificial medium to evaluate the potential of producing them on a commercial scale. **Approach:** An interesting characteristic of the worms studied was that they reached their maximum weight and maximum length at the same time. **Results:** The larvae started to decrease in weight soon after reaching their maximum size suggesting that they should be harvested shortly before reaching their maximum length (36 days old). Only 10% mortality was observed with the older larvae of the Miombo/Mopani worm. A system where eggs are separated from adults and hatched in separate chambers would alleviate the danger of losing the population due to microbial infection. The high moisture content of the live larvae (60.5-60.9%) could cause handling and storage problems. Drying and grinding the larvae would reduce them to easily manageable forms and would improve their marketability as a novel food. The results obtained from this study showed the potential of using these insects as a protein source for human consumption. They had structured animal protein that contained the essential amino acids, lipids, vitamins, minerals and energy required for human growth and their nutrition contents are comparable to those of conventional foods. These worms are harvested from trees in Africa but the industry is facing droughts and overexploitation that has lead to local extinctions in several areas. **Conclusion/Recommendations:** Therefore, further research is required to evaluate their growth on low substrates and to assess the effects of environmental parameters such as temperature, relative humidity, CO_2 and heat production on food consumption and protein yield and quality. This information will aid in the design of an optimal commercial insect production system. Appropriate processing and marketing procedures would also insure the sustainability of the industry.

Key words: Isoberlinia paniculata worm, Miombo/Mopani worm, growth rate, protein, fat, amino acids, essential elements, human food, artificial feed

INTRODUCTION

To alleviate the world protein deficiency and maintain the ever increasing human populations, attention has been directed over the past several decades to the development of new protein sources such as Fish Protein Concentrate (FPC)[1,2], Single Cell Protein (SCP)[3,4] and Soybean Protein (SBP)[5,6]. However, there is still an estimated one billion people suffering from protein deficiency[7]. 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 about two-thirds of the food of our common land birds and two-fifths of the food of adult fresh water fish. Turkeys, hogs and other domestic animals are often fattened on insects[8]. Mass rearing of insects has been practiced for years. Bees are grown in large quantities for distribution as colonies to honey producers[9]. Boll weevils have been mass reared for pest control[10-13]. Mealworms have been produced on a commercial scale as food for birds and reptiles[14]. Some efforts have also been made to produce flies from livestock waste for animal consumption[15-18]. Insects can, therefore, be reared on readily available low substrates to provide a sustainable and nutritional supply of protein for human consumption[9].

Several reports have been made on the eating of Isoberlinia paniculata worm and Miombo/Mopani worm in many African countries[19-21]. The Isoberlinia paniculata worms form a large part of the diet in Zambia (40% of the relishes during the period of November-January and 30% during the rest of the year) and are sold for good prices in urban centers including the capital Lusaka and the Copper Belt area[22]. The larvae of Miombo/Mopani worm have been reported to be sold and eaten in Namibia, Zambia, Zimbabwe and South Africa[19,21-24]. They are by far the most common

and of considerable commercial significance as a food in these countries as they are often sold by the sack in a roasted or dehydrated form. A fairly extensive trade in roasted Mopani caterpillars has been built up in the Northern Transvaal in Zambia. They are added to stews as they are preferred over fresh beef meat[22]. Quin[25] reported that the Pedi of South Africa prefer a quarter pound of these caterpillars to one pound of fresh beef. However, these worms are facing mass extinction due to drought and over harvesting. The local people are not familiar with the life cycle of the worms and the concept of sustainable harvest is not practiced[26]. Information on their reintroduction to these areas or on rearing them on artificial feed are paramount.

Objectives: Although many reports have been made on eating insects, very little information is available on the life cycles and nutritional qualities of Isoberlinia paniculata and Miombo/Mopani worms. The aim of this study was to rear these insects on a small scale in the laboratory on artificial diets in order to evaluate their potential as nutritional human food sources that can be produced at a commercial scale. The specific objectives of this study were: (a) to develop an artificial ration for production of a viable culture, (b) to establish a viable and strong culture of these worms, (c) to study the life cycles and culture structures of these insects, (d) to determine the growth rates and growth and time indices of these insects and (e) to evaluate the nutritional values of their larvae.

EXPERIMENTAL MATERIALS

Isoberlinia paniculata worm (*Anthoaera zambezina*): Isoberlinia paniculata caterpillars are close relatives of the wild silkworm. They are from the order *Lepidoptera* and the family *Suturniidae*[25,26]. They got their name from the Mutondo trees (Isoberlinia paniculata) which are found in Zambia in high to moderate rain fall areas. They are found in the Central, Copperbelt, Eastern, Northeastern, Luapula and Northern Provinces[20]. The life cycle includes four stages: egg, larva pupa and adult (Fig. 1)[23,27-29]. The larvae are bright green to yellowish in color. They are found between November and January and harvested as a food source by the local people. The adult is a fat bodied and feeble winged, creamy whitish or yellowish moth of about 50 mm across the open wings. The moths rarely fly or eat and live for 2-3 days. The female moth lays up to 500 yellowish white, semi spherical eggs, weighing about 1 mg. The larval stage moult at 6, 13, 17, 25 days after hatching. The larval stage lasts about 40 days, during which the larva increases in weight from 0.65 mg to 8 g, with a length of 78 mm. During this growth period, it consumes 90 g of the Mutondo tree leaves[22,25].

Miombo/Mopani worm (*Gonimbrasia belina*): The distribution of Miombo/Mopani caterpillar follows the Miombo/Mopani woodland which is found in the valleys of Luangura, Luano, as far north as Mofu in Kafue National Park and the Zambezi river west of Katima and the Mashite which is a low, open woodland with a deciduous canopy of 6-12 m high[30]. Miombo woodland trees cover about 70% of Zambia, 30% of the Democratic Republic of the Congo, western Malawi, much of Tanzania, Burundi and Angola. Mostly in elevations ranging from 800-1200 m above sea level[31]. The insect passes the winter as a dark brown collar like mass of egg securely attached to small twigs. The life cycle includes four stages: egg, larva pupa and adult (Fig. 1)[23,27-29]. The eggs mass measures about 18.6 mm long and 12.5 mm in diameter and contain 600 eggs of shiny varnished appearance. They hatch at the beginning of the summer. A colony is made from caterpillars hatching from several egg masses which gather in a new fork of the limbs. They become fully grown to a length of 50 mm in 4-6 weeks. They are black in color with various variations of spots of other colors (yellow, white and bluish-grey)[32]. The pupa is brown and later emerges as a reddish-brown moth with 2 whitish stripes running obliquely across each forewing. There is only one generation a year[23].

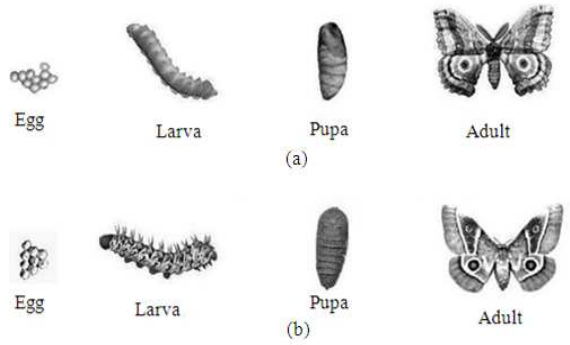

Fig.1: Life cycle of insects: (a): Isoberlinia paniculata (b): Miombo/Mopani[23,27-29]

Table 1: Chemical analyses of the diets used in the study

Constituent	Contents (%)	
	Starter diet	Mass rearing diet
Moisture	14.0	15.5
Ash	7.3	6.7
Carbohydrates	56.5	56.7
Protein	19.6	19.1
Fat	2.6	2.0

Growth medium: The proper consistency of the diet and provisions for an adequately balanced diet that contains the essential growth substance is necessary for the propagation of insects[33]. 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, (e) minerals, (f) water. In this study, two artificial diets (Table 1) were prepared: The first was used for rearing individual young insect caterpillars for the propagation of starter culture and the size and weight determination experiment and the second was used for mass rearing of insects for the determination of nutritional value of the larvae.

The starter diet was prepared according to the procedure described by Haydaks[34]. The diet was prepared 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.

The mass rearing diet 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 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.

Experimental procedure:

Rearing moths: Rearing moths was done 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. Old adult moths from each species were used for egg-laying. The starter medium was placed in each of oviposition cages (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. Ten seeding adults were placed over the medium and used to produce the next generation. Waxed paper sheets were provided for the moths to lay their eggs. The adults were removed from the oviposition containers after the desired egg range for the next generation was obtained during the egg laying period.

Hatching of eggs: The waxed paper with eggs was collected from the oviposition cages and the number of eggs per waxed paper sheet was estimated. The starter medium was placed in one of the egg hatching chambers (40 cm long × 40 cm wide × 25 cm deep plastic container with perforated sides and cover). Hundred eggs were added to the medium. The oviposition cages were 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 light and 14 h of darkness. Emerging larvae were isolated and 10 larvae were selected for the study of growth rates and life cycle while the rest were used as stock for mass rearing.

Rearing of larvae for growth rate determination: Ten larvae from each species were used for the size and weight measurements and growth rate determination. Each group of larvae were placed in separate rearing cages (60 cm long × 45 × wide × 25 × deep plastic containers with perforated plastic sides and cover) and reared on the prepared diet. The containers were 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 of each species were weighed as a group every 3 days. The length of the larvae was also measured and recorded. Any changes in the groups were observed and recorded.

Mass rearing of larvae: The larvae were taken from the starter culture and mass reared. They were all of similar age and reared to maturity. The mass rearing medium was placed in one of the rearing cages (65×45×45 cm deep plastic container with perforated sides and cover). The mass rearing cages were 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 photoperiodic regime of 10 h of light and 14 h of darkness. Two litter jars were provided for the larvae to pupate inside. The larvae were reared to maturity and the pupae were collected from the bottles and placed in special containers filled with medium and shredded paper until the emergence of the moths. Adults were allowed to emerge into the jars from which they were collected and placed in the oviposition cases.

Chemical analyses:

Moisture content: A sample of 30 mass reared larvae from each species representing a full range of weigh were used in the moisture content analysis. The oven dry method procedure described in APHA[35] 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 (%)
M_1 = The weight of the life sample (g)
M_2 = 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[35]. 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 on a dry basis as follows:

$$AC = \frac{M_3}{M_2} \times 100 \quad (2)$$

Where:
AC = The ash content (%)
M_3 = The weight of the material remaining after burning the dry sample (g)

Protein content: The protein analysis was carried using 30 mass reared larvae from each species representing a full range of weights. The weight of each group (30 worms) was recorded using a Mettler scientific balance (AE 2005, Mettler Instruments, AG, Greifensee, Zurich, Switzerland). The worms were frozen and dried in a freeze dryer (Labconco FreeZone, Cat No. 10-271-16, Fisher Scientific, Montreal, Quebec) for 24 h. Each group was ground using a laboratory grinder (Waring Laboratory, Cat No. 14-509-18, Fisher Scientific, Montreal Quebec), placed in a plastic pouch and stored in a freezer until need for protein analysis. The total protein was determined using the Tecator Kjeltec Auto Analyzer (Model-1026, Fisher Scientific, Montreal, Quebec). The freeze dried worms were transferred to the macro 250 mL digestion tubes. One "Kjeltab" (containing 3.5 g K_2SO_4 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 on 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 tubes with 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 sample of live worms (g)

Fat content: The fat content was carried out using 30 mass reared larvae from each species representing a full range of weights. The weight of each group (30 worms) was recorded using a Mettler scientific balance (AE 2005, Mettler Instruments, AG, Greifensee, Zurich, Switzerland). The worms were frozen and dried in a freeze dryer (Labconco FreeZone, Cat No. 10-271-16, Fisher Scientific, Montreal, Quebec) for 24 h. Each group was 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[36]. Hot ether was percolated through a porous receptacle filled with the 30 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)

Amino acids: The amino acid content was carried out using 30 mass reared larvae from each species representing a full range of weights. The weight of each group (30 worms) was recorded using a Mettler scientific balance (AE 2005, Mettler Instruments, AG, Greifensee, Zurich, Switzerland). The amino acids (alanine, arginine, cysteine, glutamic, glycine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, serine, threonine, tryptophan, tyrosine and valine) were determined using the HFB-IBA (Heptafluorobutyric isobutyl esters of amino acids) Amino Acid derivatization Kit (Cat. No. 18094, Alltech Associates, Inc., Deerfield, Illinois). The worms were frozen and dried in a freeze dryer (Labconco FreeZone, Cat No. 10-271-16, Fisher Scientific, Montreal, Quebec) for 24 h. Each fFreeze dried sample was placed in a small reaction vial. An amount of 3 mL of 0.2 M HCl was added to each vial and the solutions were heated to approximately 110°C using a block heater (Model 16500-10, Hach Chemical Co., Loveland, CO) for 30 h. Then, the vials were removed from the heater and dried under a stream of dry nitrogen. About 1.25 mL of acetyl chloride (Cat. No. 18094B, Alltech Associates Inc. Deerfield, Illinois) was slowly added to 50 mL of isobutanol and the mixture was added to each vial, (which contained dry sample). The vials were capped and heated at 110°C for 45 min. The vials were uncapped and heated at 115°C under a stream of nitrogen to remove excess reagent. Then, the vials were removed from the heater and cooled in an ice bath (Microprocessor Controlled 280 Series Water Bath, Precision, City, State) for approximately 5 min. About 3 mL of methylene chloride and 2 mL of HFBA (Cat. No. 18094A, Alltech Associates Inc, Deerfield, Illinois) were added to each vial. The vials were then capped and heated at 100°C for 4 h. The vials were removed from the heater and after cooling to ambient temperature, excess reagent was evaporated under a stream of dry nitrogen. The dried samples were redissolved by adding 2 mL of ethyl acetate and injected into the gas chromatograph (Model-HP5890 Series II, Hewlett, Palo Alto, CA). The amino acids profile was determined from the output of the gas chromatograph.

Elemental analysis: The elemental analyses were performed in the Mineral Engineering Center of Dalhousie University, Halifax, Nova Scotia. All elements were determined by flame atomic absorption spectrometer (Spectr AA 55B, Varian Australia, Ply Ltd., Mulgrave, Australia) with a detlection limit of 1 ppm. Sulphur was determined with a Leco Sulphur Analyzer (Model 337-500, Leco Corporation, St. Joseph, MI, USA) along with an induction furnace (Leco HF_2O furnace, Leco Corporation, St. Joseph, MI, USA).

RESULTS

Life cycle and culture structure: The stages of the life cycle and the changes among the individuals in each group of insects were observed and recorded. These included the number of eggs, the weight of larvae, the length of larvae, the lengths of oviposition, pupal and adult stages, the mortality and 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 for each group. The results are shown in Table 2 and 3. The changes in the population structure are presented in Fig. 2.

There was no mortality among the larvae of the Isoberlinia paniculata worm and only one larva died (10%) from the Miombo/Mopani worm. Pupation started on day 33 for both worms and the emergence of adults started on day 48 and 45 for the Isoberlinia paniculata worm and Miombo/Mopani worm, respectively. The pupation stage lasted for 24 days for both worms and the adult stage lasted for 24 and 15 days for the Isoberlinia paniculata worm and Miombo/Mopani worm, respectively. The maximum length was 80 and 55 mm and the maximum weight was 7.8 and 7.1 g for the Isoberlinia paniculata worm and Miombo/Mopani worm, respectively.

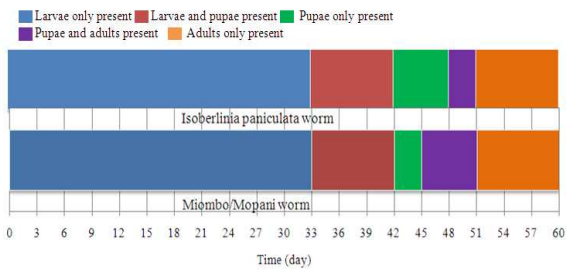

Fig. 2: Changes in population structure

Table 2: Larval growth, pupation and emergence of adults

	Isoberlina paniculata worm			Miombo/Mopani worm		
Day	Weight (g)	Length (mm)	Stage of growth	Weight (g)	Length (mm)	Stage of growth
0	1.00	15.00	10L	1.20	4.50	10L
3	1.08	17.00	10L	1.22	4.70	10L
6	1.27	18.00	10L	1.28	4.90	10L
9	1.65	24.00	10L	1.61	10.00	10L
12	2.20	30.00	10L	2.07	18.10	10L
15	2.80	36.00	10L	2.67	26.90	10L
18	3.50	42.50	10L	3.48	33.50	10L
21	4.30	49.50	10L	4.34	39.50	10L
24	5.35	57.00	10L	5.40	43.80	9L
27	6.25	66.50	10L	5.96	47.00	9L
30	7.00	69.50	10L	6.40	50.00	9L
33	7.50	78.00	8L+2P	6.80	53.00	8L+1P
36	7.80*	80.00*	8L+2P	7.10*	55.00*	6L+3P
39	7.50	76.00	6L+4P	6.90	49.00	2L+7P
42	7.15	74.00	10P	6.56	43.00	9P
45	6.65	70.00	10P	6.00	40.00	6P+3M
48	6.20	68.00	6P+4M	5.50	38.00	3P+6M
51	5.80	66.00	10M	5.20	36.00	9M
54			9M			9M
57			9M			9M
60			9M			8M

*: Maximum weight and length

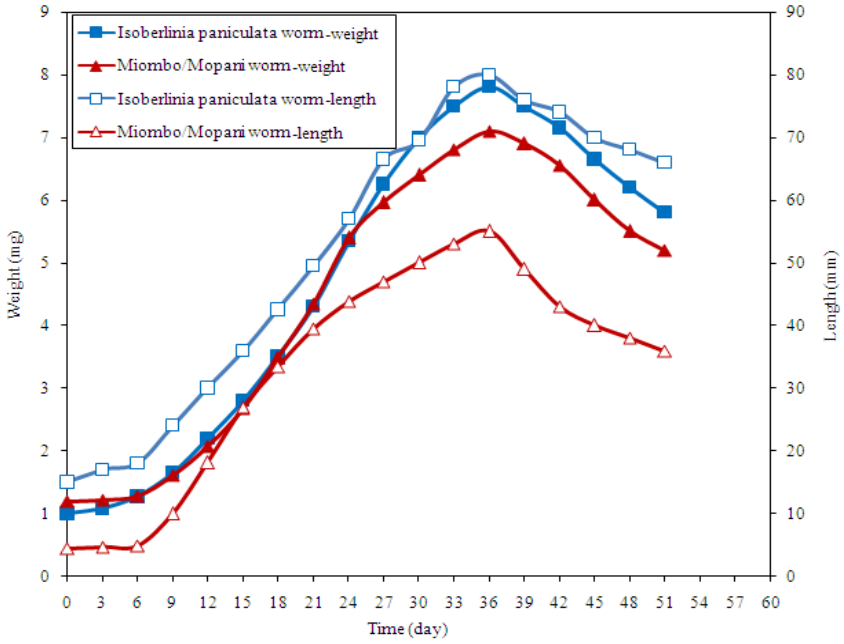

Fig. 3: Weight and length changes of the larvae

Growth rate: For each group of insects, the average total weight and average length were plotted against time as shown in Fig. 3. It was noticed that for the first 6 days the average weight did not show any significant increase. The weight of larva increased with time up to a maximum value and then began to decrease once the larva was preparing to enter the pupation stage. The growth rate (g day^{-1}) was determined by dividing the weight increase in a given period by the length of the period (3 day). The results are shown in Fig. 4. Initially, the growth rate increased and then decreased when the larvae were closer to the pupation stage. The negative values indicated weight loss.

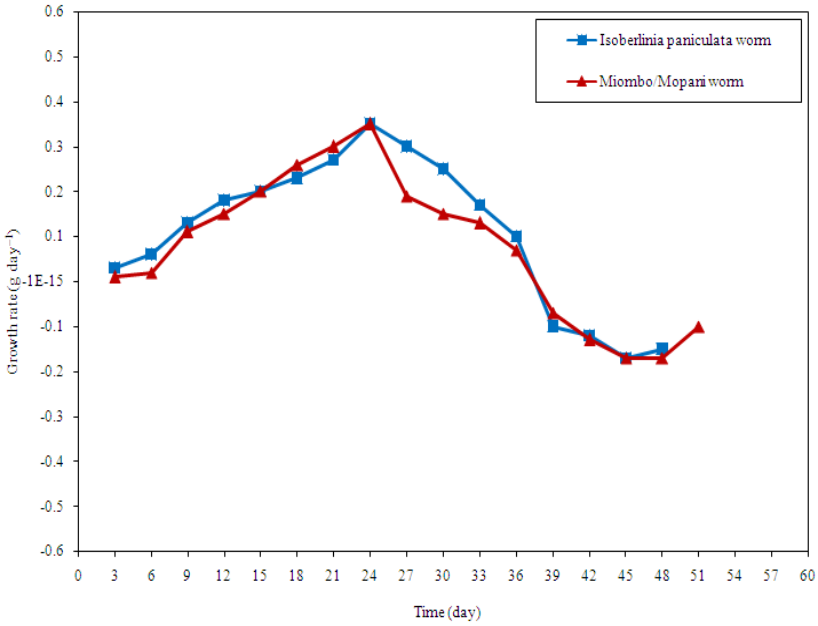

Fig. 4: Growth rate of worms

Table 3: Life cycle characteristics

Characteristics	Isoberlinia paniculata worm	Miombo/ Mopani worm
Number of eggs per sheet	40.0	70.0
Maximum weight (g)	7.8	7.1
Maximum length (mm)	80.0	55.0
Duration of egg stage (day)	3.0	5.0
Duration of larval stage (day)	30.0	30.0
Duration of pupal stage (day)	24.0	24.0
Duration of adult stage (day)	24.0	12.0
Larval mortality (%)	0.0	10.0
Color	Yellowish to greenish brown	Dark with variety of other colors

Table 4: Growth and time indices

Parameter	Isoberlinia paniculata worm	Miombo/ Mopani worm
Number of eggs produced by female moth	500.00	600.00
Maximum weight (g)	7.80	7.10
Time to reach maximum size (day)	36.00	36.00
Growth rate (g day^{-1})	0.20	0.23
Growth Index (g g^{-1} day^{-1})	4.60	5.26
Larval Time Index (day g^{-1})	4.62	5.07
Population Time Index (min g^{-1})	0.22	0.20

Growth index = (Maximum weight of larva)/(initial weight of larva time required for maximum growth)
Laval time index = (Time required for maximum growth)/(maximu weight of larva)
Population time index = (time required for maximum growth)/(maximum weight of larva x number of eggs)

Growth and time indices: The first 6 days were considered a period of slow or no growth and the period of pupation was associated with weight loss.

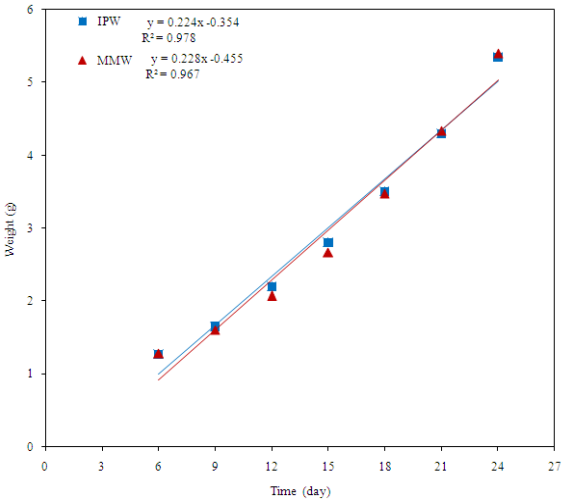

Fig. 5: Determination of average growth rate. (IPW = Isoberlinia Paniculata Worm, MMW = Miombo/Mopani Worm)

Thus, the period of increased weight was linearized as shown in Fig. 5. The slope of the linear line was divided by the initial weight to obtain the growth index. The time required to reach the maximum weight was divided by the maximum weight to obtain the larval time 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 × maximum weight

of larva) to obtain the population time index. The results are shown in Table 4. These results showed that the Miombo/Mopani worm had slightly higher growth rate (0.23 g day^{-1}) than the Isoberlinia paniculata worm (0.20 g day^{-1}). The time required to produce one gram of larva was 4.62 and 5.07 days for the Isoberlinia paniculata worm and Miombo/Mopani worm, respectively. When the population size (number of eggs produced be the female moth) was considered, the time required to produce one gram of insects was 0.22 and 0.20 for the Isoberlinia paniculata worm and Miombo/Mopani worm, respectively.

Larval composition: The results of moisture, ash, carbohydrate, protein and fat contents were calculated on dry weight basis when the larvae reached their maximum weights. The results are presented in Table 5. Although the two species were dried under the same conditions, the Miombo/Mopani worm had a slightly higher moisture content (12.7%) than the Isoberlinia paniculata worm (12.4%). The Isoberlinia paniculata had much higher ash, protein and fat content (12.5, 56.7 and 9.2%, respectively) than the Miombo/Mopani worm (7.6, 48.0 and 6.7%, respectively). The Miombo/Mopani worm had higher carbohydrate content (25.0%) than the Isoberlinia paniculata worm (9.2%).

The energy available in the carbohydrate, protein and fat in the larvae are shown in Table 6. A total of about 346 and 352 kcal/100 g larvae are provided by the carbohydrate, protein and fat contained in the Isoberlinia paniculata worm and the Miombo/Mopani worm, respectively. The female moths of the Isoberlinia paniculata worm produced 500 eggs while the female moth of the Miombo/Mopani worm produced 600 eggs. Therefore, about 13494 and 14995 kcal will be available in the larvae produced from the female moths of the Isoberlinia paniculata worm and Miombo/ Mopani worm, respectively.

The quality of the protein, and thus the nutritional value of the insects, is determined by the amino acid composition as reported by DeGuevara *et al.*[37]. The results of the amino acid profile are shown in Table 7. The larvae of both worms contain all the essential amino acids needed for human growth.

Table 5: Nutritional analyses of freeze dried larvae

	Content (%)	
Constituent	Isoberlinia paniculata worm	Miombo/Mopani worm
Moisture	12.4	12.7
Ash	12.5	7.6
Carbohydrate	9.2	25.0
Protein	56.7	48.0
Fat	9.2	6.7

Moisture content of live Isoberlinia paniculat larvae = 60.9%
Moisture content of live Miombo/Mopani larvae = 60.0%

Table 8 shows the profile of some of the essential elements found in the larvae. The total elemental composition was 316 and 214 mg g^{-1} dry matter for the Isoberlinia paniculata and Miombo/Mopani worm, respectively. The larvae of both worms contain most of the essential elements. However, the Isoberlinia paniculata worm has higher concentrations of all the elements compared to the Miombo/Mopani worm.

Table 6: Energy content

	Contents (%)		kcal/whole	Larva	kcal/100 g	Larva
Source of energy	IPW	MMW	IPW	MMW	IPW	MMW
Carbohydrate	9.2	25.0	1.26	3.16	37	100
Protein	56.7	48.0	7.77	6.07	227	192
Fat	9.2	6.7	2.84	1.91	83	60
Total			11.87	11.14	347	352

IPW = Isoberlinia Paniculata worm
MMW = Miombo/Mopani Worm
Carbohydrate energy= 4 kcal g^{-1}
Protein energy= 4 kcal g^{-1}
Fat energy= 9 kcal g^{-1}
Live moisture content= 60.9% for IPW and 60.5% for MMW
Dried moisture content= 12.4% for IPW and 12.7% for MMW
Live weight of larva= 7.8 g for IPW and 7.1 g for MMW
Eggs produced by a female moth= 500 for IPW and 600 for MMW

Table 7: Amino acid profile

	g/100 g dry matter	
Amino acid	Isoberlinia paniculata worm	Miombo/Mopani worm
Alanine	4.6	5.2
Arginine	6.9	5.9
Cysteine	10.6	10.1
Glycine	9.2	7.5
Glutamic	10.3	10.3
Histidine	1.9	1.5
Isoleucine	4.8	4.2
Leucine	6.6	6.7
Lysine	7.8	8.3
Methionine	12.0	12.2
Phenylalanine	3.2	3.7
Serine	5.0	3.8
Threonine	3.7	3.9
Tryptophan	2.8	2.6
Tyrosine	13.6	10.9
Valine	4.8	6.7

Table 8: Mineral contents

	mg g^{-1} dry matter	
Mineral	Isoberlinia paniculata worm	Miombo/Mopani worm
K	52.5	35.2
Ca	18.9	16.0
P	25.4	14.7
S	27.9	25.9
Mg	14.7	4.1
Fe	12.9	12.7
Na	33.7	33.3
Zn	2.5	1.9
Cu	1.6	1.5
Mn	0.6	0.4
Others	125.3	68.3
Total	316.0	214.0

DISCUSSION

Growth and nutritional characteristics: An interesting characteristic of the worms studied was that they reach maximum weight and maximum length at the same time. The growth rate of the youngest larvae was found to be the highest. The increase in the body weight during the growth period appeared to be linear. 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 when they are 33 days old.

Only 10% mortality was observed with older larvae of the Miombo/Mopani worm. The moisture issue may present an important management problem for commercial production. A system where eggs are separated from adults and hatched in separate chambers would alleviate the danger of losing the population due to microbial infection. The high moisture content of the live larvae (60.5-60.9%) could also cause handling and storage problems. Drying and/or grinding the larvae would reduce them to easily manageable forms and 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 environmental parameters such as temperature, relative humidity, CO_2 and heat production on food consumption and protein yield. This information will aid in the design of an optimal production system that is economically sustainable. Handling and processing the insects is also of paramount importance.

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.

State of the industry in Africa: The most important types of woodlands in Zambia are the Miombo and Mopane woodlands. Miombo woodland is two storied woodland with a slightly closed canopy of semi-deciduous trees of up to 15-21 m in height. The dominant species are *Brachystegia*, *Isoberlinia*, *Julbernardia* and *Marquesia*. Usually more than one species is dominant. The Miombo woodland occurs on the main plateau, from Kabwe in the centre of the country towards Isoka in the northeast, on the southern plateau around Choma and Kalomo and in the Copperbelt region and west of it. The Mopane woodland is two stories of formations with the upper canopy between 6-18 m. The dominate species is the *Colophospernum mopane*[37,38].

Five caterpillar species dominate these woodlands: (a) *Cerina forda*, which is the most widely eaten caterpillar in Nigeria, Zaire, Zambia, Zimbabwe and South Africa, (b) *Gonibrasia belina*, which are packaged and sold in Botswana and South Africa, (c) *Bunaeopsis aurantiaca*, the most important species exported from Southern Zaire, (d) *Gynansis maia*, which is very popular in Malawi and (e) *mumpa* which is the most important species of caterpillar in Zambia[25,37,39-41].

The mopani worm (*Imbrasia belina)* is the most important insect in Southern Africa (Fig. 6. It is known as Mashonzha, Masonja or Amasonja[23]. It forms the basis of the multimillion dollar trade in edible insects. The nutritional value (protein and fat contents) are comparable to traditional foods (Table 9). The worms also contain all the essential amino acids and minerals required for human growth.

Fig. 6: Women selling Mopani worms at a market[23]

Table 9: Protein and fat contents of various food products

	Content (%)	
Product	Protein	Fat
Conventional food		
Beef	17.4-19.4	15.8-25.1
Lamb	15.4-16.8	19.4-27.1
Chicken	20.6-23.4	1.9-4.7
Pork	14.6-23.4	22.7-31.4
Fish	18.3-20.9	1.2-10.0
Milk	3.5-4.5	3.7-3.9
Eggs	12.9	11.5
Insects		
Isoberlinia aniculata worm	56.7	9.2
Miombo/Mopane worm	48.0	6.7

However, the industry is faced with several problems including droughts that have devastated the harvest on a regular basis and the over exploitation that had lead to local extinctions in several areas. This is further complicated by the fact that the local people are not familiar with the complex life cycle of the worms. The eggs are laid by a large and attractive moth. Small worms hatch from the eggs and moult a few times before they reach maturity. The worms that are not harvested leave the trees and pupate underground. The life cycle is completed when the adult moths emerge from the pupae, mate and lay eggs. If the cycle is broken at any point by excessive harvesting, it will not be possible to maintain a sustainable harvest. The concept of sustainable harvesting is not practised and traditional myths play a major role in determining harvesting strategies[23]. The locals believe that if the young worms are harvested, the older individuals will leave the area. They also believe that if the larvae leaves the trees and burrow into the ground they are going to die, not knowing the purpose of digging into the ground is to pupate which is essential to complete the life cycle.

Natural re-colonization of the areas that face extinction could be a slow and difficult process as the moths only live for 2-3 days and must complete their reproductive process in this short time, leaving little time for dispersal. The only stage of any dispersal potential is the worm stage. However, for natural dispersion to be effective it would need the assistance of the local communities who can place embargoes on harvesting in sensitive areas. Without this support, re-introduced worms will soon be harvested. Harvesting and relocation of eggs could also be tried. Collection of pupae from the field would be very expensive. Good management based on education and sound relationships with local harvesters, which allow for the removal of a controlled number of worms at the appropriate time, will ensure survival of these worms and a regular income from their harvest.

Another way of developing the mopani worm resource is to investigate the possibility of a silk worm like industry by raising them on harvested leaves or artificial feed as was done in this study. One of the advantages of moving in this direction is to make the industry less unpredictable, because it is now strongly affected by environmental conditions such as drought. However, for a domesticated industry to succeed on a small scale and be accessible to the poorest of the poor, the cost of production of artificial media have to be compared to the cost of wild worms. The information gained in this study is potentially useful in optimizing domesticated crops in areas where re-introductions are needed. The knowledge about rearing and sustaining the larvae will be of great value in keeping them alive during capture, transportation and subsequent release.

Commercial production of these insects on artificial media seems to be the most practical approach. However, further research is required to evaluate their growth characteristics on low substrates and to assess the effect of various operating parameters on protein yield and quality. These insects are in size between SCP and farm animals, they yield structured animal protein (containing essential amino acids, lipids, minerals, vitamins and energy), 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[42-44]. It will, therefore, be possible in the near future to construct small but efficient insect farms that have high volumetric production rate of protein. Careful production, processing and marketing procedures would make insects as acceptable as the FPC, SCP and SBP. This will require substantial innovation in the areas of food production and processing technologies[43,45,46].

CONCLUSION

The high protein and fat content of these insects 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 worms studied is that they reach maximum weight and maximum length at the same time. The larvae started to decrease in weight soon after reaching their maximum size. Therefore, the larvae should be harvested shortly before they reach the maximum size as they enter the pupation stage and begins losing weight.

Only 10% mortality was observed with older larvae of the Miombo/Mopani worm. The moisture issue may present an important management problem for commercial production. A system where eggs are separated from adults and hatched in separate chambers would alleviate the danger of losing the population due to microbial infection. The high moisture content of the live larvae (60.5-60.9%) could also cause handling and storage problems. Drying and/or grinding the larvae would reduce them to easily manageable forms and would improve their marketability as novel food.

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. Effort should be made to reintroduce the worms to the area that is faced with extinction and develop harvesting guidelines for the resources. Another solution is to embark on commercial production of the insects on artificial medium. However, further research is required to evaluate their growth characteristics on low substrates as well as to assess the effects of environmental parameters such as temperature, relative humidity, CO_2 and heat production on food consumption and protein yield and quality. This information will aid in the design of an optimal production system that is economically sustainable.

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REFERENCES

1. Pariser, E.R., M.B. Wallerstein, C.J. Corkery and N.L. Brown, 1978. Fish Protein Concentrate: Panacea for Protein Malnutrition. The MIT Press, Boston, Massachusetts, ISBN: 10: 0262160692, pp: 256.
2. Sikka, K.C., R. Singh, D.P. Gupta and S.K. Duggal, 1979. Comparative nutritive values of Fish Protein Concentrate (FPC) from different species of fish. J. Agric. Food Chem., 27: 946-949. http://www.ncbi.nlm.nih.gov/pubmed/546956
3. Tannenbaum, S.R. and D.K. Wang, 1975. Single Cell Protein Production. The MIT Press, Boston, Massachusetts.
4. Ferrianti, M.P. and A. Fiechter, 1983. Production and Feeding of Single Cell Protein. Applied Science Publications, London, ISBN: 10: 0853342431.
5. Mendez, M.A., M.S. Anthony and L. Arab, 2002. Soy-based formula and infant growth and development: A review. J. Nat., 132: 2127-2130. http://jn.nutrition.org/cgi/content/full/132/8/2127
6. Bhatia, J. and F. Greer, 2008. Use of soy protein based formulas in infant feeding. Pediatrics, 121: 1062-1068. http://pediatrics.aappublications.org/cgi/reprint/121/5/1062
7. WHO/FAO., 2007. Protein and Amino Acid Requirements for Human Nutrition. World Health Organization/Food and Agricultural Organization of the United Nations WHO Press, New York. http://whqlibdoc.who.int/trs/WHO_TRS_935_eng.pdf
8. Metcalf, C.L. and W.P. Flint, 1962. Destructive and Useful Insects. 4th Edn., McGraw Hill, Beck Company, Toronto, ISBN: 10: 0070416583, pp: 1099.
9. Kok, R., U.S. Shivhare and K. Lomaliza, 1991. Mass and component balances for insect production. Can. Agric. Eng., 33: 185-192.
10. Miller, J.A., C.D. Schmidt and J.L. Eschle, 1975 Systems for large scale rearing of hornfly *Haematobia irritans*. ASAE Technical paper No. 75.415 ASAE, St. Joseph Illinois.
11. Harrel, E.A., W.D. Perkins and A.N. Sparks, 1980. Improved equipment and techniques for mechanizing the boll weevil larval rearing system. Trans. ASAE., 23: 1554-1556.
12. Garth, C.W. and W.E.G. King, 1981. Diet dispenser for a multiple insect species rearing program. Trans. ASAE., 24: 194-196.
13. Webb, J.C., H.R. Agee, N.C. Leppla and C.O. Calkins, 1981. Monitoring insect quality. Trans. ASAE., 24: 476-479.
14. Ebeling, W., 1975. Urban entomology, pests of stored food products. http://www.entomology.ucr.edu/ebeling/
15. Morgan, N.O. and H.J. Eby, 1975. Fly protein production from mechanically mixed animal wastes Israel. J. Entomol., 10: 73-81.
16. Booram, C.V., G.L. Norton, R.W. Baker and O.M. Hale, 1976. The value of *Hermetia illucens* as an alternative protein source. ASAE Technical Paper No. 75-4563 ASAE, St. Joseph, Illonois
17. Eby, I.T. and W.L. Dandy, 1962. An attempt to mechanized nutrient recovery from animal waste by the use of house fly larvae. Technical Report No. 20705 Beltsville Agricultural Research Center, Beltsville, Maryland.
18. Burchell, R.L., 1989. Production of a protein substrate from poultry manure through the intensive production of insects final design project report. Technical University of Nova Scotia, Halifax, Nova Scotia.
19. Richards, A.L., 1939. Land labor and diet in Northern Rhodesia, an Economic Study of the Bemba Tribe. Oxford University Press, London, pp: 423.
20. Thomson, B.P., 1954. Two studies in African nutrition. An urban and a rural community in Northern Rhodesia. Rhodes-Livingstone Papers, 24: 1-57.
21. Taylor, R.L., 1975. Butterflies in my Stomach: Insects in Human Nutrition. Woodbridge Press Publishing Company, London, ISBN: 10: 0912800186.

22. Chipeleme, A.C. 1981. An evaluation of some locally available worms as human protein source. Technical Report, University of Zambia, Lusaka, Zambia.
23. Toms, R.B., M.P. Thagwana and K.D. Lithole, 2003. The mopane worm-indigenous knowledge in the classroom. Science in Africa. http://www.scienceinafrica.co.za/2003/june/mopane.htm
24. Halliday, J., 2007. Crunchy delights: Snacks on Mopani worms. Tourism Zimbabwa, Herary, Zimbabwa. http://www.pilotguides.com/destination_guide/africa/zimbabwe-botswana-namibia/mopani_worms.php
25. Quin, P. J. 1959. Foods and Feeding Habits of the Pedi. Wits University Press, Johannesburg, South Africa, ISBN: 10: 0854940553, pp: 278.
26. Illgner, P. and E. Nel, 2000. The geography of edible insects in Sub-Saharan Africa: A study of the mopane caterpillar. Department of Geography, Rhodes University, South Africa. http://www.encyclopedia.com/doc/1G1-70649095.html
27. UNL., 2006. Silkworm life stages. Department of Entomology, University of Nebraska-Lincoln. http://entomology.unl.edu/images/silkworm/silkworm.htm
28. SANParks, 2007. Competition in the Mopani Valy. South African National Parks. http://www.parks-sa.co.za/about/news/2007/december/moths2.php?PHPSESSID=mnucpk41n4ug7ko3n2h3b78vp7
29. National Museums Liverpool, 2008. Mopane worm stew. http://www.liverpoolmuseums.org.uk/wml/naturalworld/bughouse/mopanewormstew.aspx
30. McGinley, M., 2007. Central Zambezian Miombo Woodlands (ATO704). Encyclopedia of Earth, Environmental Information Coalition, National Council for Science and the Environment, Washington DC. http://www.nationalgeographic.com/wildworld/profiles/terrestrial/at/at0704.html
31. McGinley, M., 2007. Zambezian Cryptosepalum dry forests. World Wildlife Fund, Encyclopedia of Earth. http://www.eoearth.org/article/Zambezian_Cryptosepalum_dry_forests
32. Morris, B., 2005. Insects and Human Life. Berg Publishers, New York, ISBN: 10: 1845200756, pp: 320.
33. Lipke, H., 1957. Nutritional considerations for rearing insects. Proc. Entomol. Soc. Am., 12: 90-91.
34. Haydaks, H.H., 1936. A food for rearing laboratory insects. J. Ecol. Entomol., 29: 1026-1028.
35. APHA., 1990. Standard Methods for Examination of Water and Wastewater. American Public Health Association, Washington DC.
36. AOAC., 1975. Official Methods of Analysis of the Association of Official Agricultural Chemistry. Washington, DC., pp: 1015.
37. Holden, S., 1991. Edible caterpillars-a potential agroforestry resource? Food Insects Newslet., 4: 3-4.
38. Mickels-Kokwe, 2006. Small-scale woodland-based enterprises with outstanding economic potential, the case of honey in Zambia. Center for International Forestry Research, Bogor, Indonesia, ISBN: 979-24-4673-7, pp: 82.
39. Brandon, H., 1987. The snack that crawls. Int. Wildlife, 17: 16-21.
40. Mkanda, F.X. and S.M. Munthali, 1994. Public attitudes and needs around Kasungu National Park, Malawi. Biodiver. Conserv., 3: 29-44. DOI: 10.1007/BF00115331
41. DeFoliart, G.R., 1995. Edible insects as minilivestock. Biodiver. Conser., 4: 306-321. DOI: 10.1007/BF00055976
42. DeGuevara, L.O., P. Padilla, L. Garcia, J.M. Pino and J. Ramos-Elorduy, 1995. Amino acid determination in some edible Mexican insects. Amino Acids, 9: 161-173. DOI: 10.1007/BF00805837
43. Bukkens, S.G.F., 1997. The nutritional value of edible insects. Ecol. Food Nutr., 36: 287-319. http://cat.inist.fr/?aModele=afficheN&cpsidt=2097512
44. DeFoliart, G.R., 1992. Insects as human food: Gene DeFoliart discusses some nutritional and economical aspects. Crop Prod., 11: 395-399. DOI: 10.1016/0261-2194(92)90020-6
45. DeFoliart, G.R., 1999. Insects as food: Why the western attitude is important. Ann. Rev. Entomol., 44: 21-50. http://www.ncbi.nlm.nih.gov/pubmed/9990715
46. Verkerk, M.C., J. Tramper, J.C.M. Van Trijp and D.E. Marlens, 2007. Insect cells for human food. Biotechnol. Adv., 25: 198-202. DOI: 10.1016/j.biotechadv.2006.11.004