Towards improved utilization of macimbi *Imbrasia belina* Linnaeus, 1758 as food and financial resource for people in the Gwanda district of Zimbabwe

S. Dube
Department of Applied Biology and Biochemistry
National University of Science and Technology P.O. Box AC 939 Ascot
BULAWAYO
Zimbabwe
shdube@nust.ac.zw

C. Dube
HTC Hillside Teachers College P. Bag 2 Hillside
BULAWAYO
cdube2022@nust.ac.zw

Abstract
Macimbi have two generations per annum one in November and the other in April. The November generation has a higher population per tree 206.9±56.7 than the April generation 100±25. The growth rate is the same for both generations. Each moth oviposits on one tree and the average distance between oviposited trees is 45.7±15 m. The protein and fat content of the larvae are 59% and 14% respectively. The mass of fresh full-grown 'worms' is 12g and they are 8-9cm long. The growth rate is increased when the relative humidity is above 75% and the temperature is 30±2°C. Worms harvested before maturity need evisceration whereas those gathered when fully grown need no evisceration. Spines begin to be effective as defense mechanism against predators after the fourth week. The pupa stage lasts 38±2 days for the November generation and 180±12 days for the April generation because of winter. It is suggested that persons be allocated woodlots as this could lead to responsible and sustainable harvesting and protection of the environment.

Key words: *Imbrasia belina,* life cycle, mopane tree, larvae, nutrition, Gwanda.

1. INTRODUCTION
Visits to the Zimbabwe food markets show that insects or their products are sold in more than 50% of these places. Entomophagy is a common practice among rural and urban Zimbabweans and also in many countries [1,2,3.4,5]. Generally, the insects eaten are those which can be collected in large numbers and meet the palate preferences of the consumers. In Zimbabwe a variety of insects are not only consumed in certain localities but they are also sold for money or exchanged for other necessities. By far the most consumed insect in Gwanda, Zimbabwe, is *Imbrasia belina* ***Linnaeus, 1758*** (mopane worm) – macimbi (Ndebele) and madora (Shona). This insect has a holometabolous life cycle, that is, it develops from the egg, to larva, to pupa, and to adult. The larva, which is the only feeding stage, is the one that makes popular dishes in Zimbabwean homes.
Studies showed that there is allozyme variation in two populations of *I. belina* sourced from different geographical locations in South Africa [6]. Allozyme variation has been used as an indicator of genetic variability for the species [7]. The poor flight ability of the moth stage

was apparently suggested as responsible for poor gene flow between populations, which could result in varied phenotypic expressions [8,9,10]. Such phenotypes could include mass, length, lifespan, and protein content among others.

In Makhulela area several thousands tones of the worms are harvested annually using methods that may not be sustainable [11]. Estimations are that a woodlot of 4000 hectares would support 19 million worms, which would translate to193 tones, and if this were sold in cities at the current price of US $10 per kilogram would yield $1,930,000.00 [12]. The life cycle of the first generation starts when the eggs hatch in October. The young caterpillars or larvae feed on the leaves of the tree where they hatch. This is usual host is the mopane tree (*Colophospermum mopane*), although other trees are also used. As the larvae grow, they moult 4 times (there are five larval stages) before they reach their maximum size [13,14,15]. This is also the stage where the most damage is done to future populations [10]. However, it is essential to harvest responsibly to ensure a good crop for the following season. Apart from humans, there are several other predators, such as baboons, birds and insect parasites that reduce the numbers of larvae [14,16,17]. They contain 65% crude protein and are rich in vitamins, fats, carbohydrates, and minerals such as phosphorus, iron and calcium [12,18].

When the larvae are fully-grown and have stored sufficient energy reserves for future development during the subsequent non-feeding stages, the survivors move down to the ground where they excavate a burrow in which they pupate. The pupa is a very important stage because it is in this stage that the Mopane Worm over winters for a period of 6 to 7 months [2,9,10,13].

The moths emerge at the beginning of summer (November to December) but do not feed and live for only two to three days. Their single function is to mate and produce eggs. The male moth uses its feathery antennae to detect the chemical signals or sex pheromones released by the female so that he can find her. After the moths have mated, the female lays 50 to 200 eggs on leaves or branches of one tree. The eggs hatch in about ten days [3, 12, and 13].

Obviously there may be losses to the population in all stages. In order to preserve these insects and to optimize the industry, it is necessary to study and manage all four stages of the life cycle [10].

The aim of this study was to determine the life cycle and the effects of early harvesting on qualitative and quantitative nutritional productivity of *Imbrasia belina* in Gwanda.

2. MATERIALS AND METHODS

The larvae of *I. belina* occupying twenty randomly selected mopane trees in Gwanda District Buvuma Ward and four randomly selected mopane trees in Bulawayo NUST campus had morphometric data collected weekly until the whole life cycle was completed. When the larval stage came to an end, the worms were placed in containers of sand to allow them to excavate and bury themselves for pupation. The time for the completion of various stages was recorded for both the November and April generations. To determine the survival of worms safe from predators newly hatched larvae were transferred to indoor potted branches of mopane tree for four weeks.

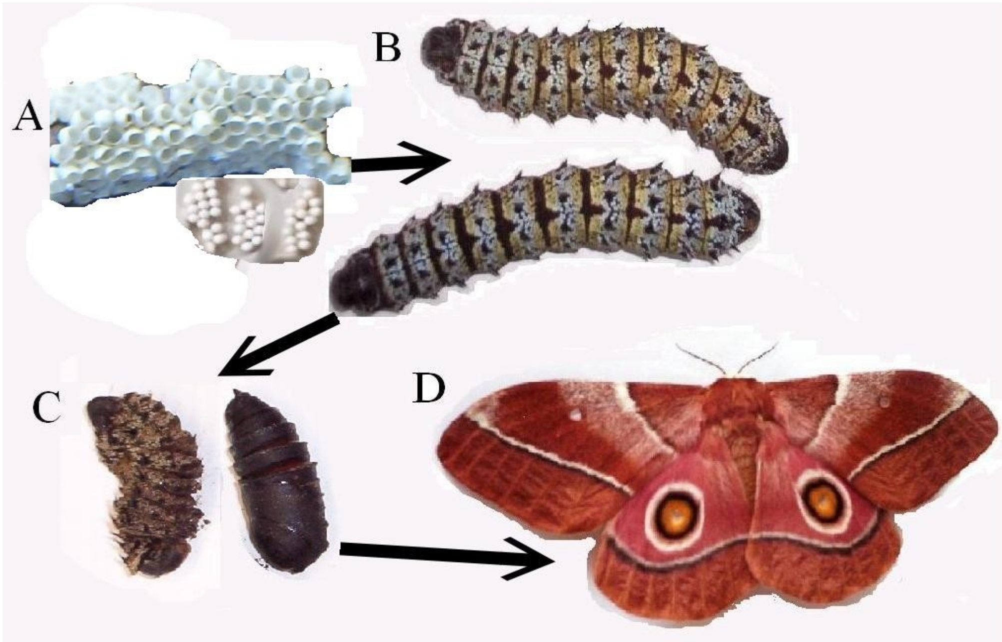

Figure 1: The life cycle of I. belina A) eggs B) larva C) pupa D) adult female.

The effects of various conditions, such as relative humidity, and temperature, on growth rate were also noted. After four weeks the worms reared indoors were transferred to outside trees because their spines were then sufficiently strong to protect them against most predators. Two weeks before the end of the larval stage worms were collected at regular intervals in order to determine their weight, length, thickness and amount of fat, proteins and Vitamin C. Vitamin C was determined by the DCCIP method. Fat was determined by the Soxhlet method while the protein was determined by the Kjeldahl digestion method. Data were collected weekly. Samples were also collected from the food markets and assayed for the above parameters. The market samples were either smoked or salted, and cooked. Other observations were made during regular visits to the occupied trees. The number of eggs on each tree was established by counting hatched egg shells. The intervals between the trees used for oviposition were determined by the transect method. The feeding rate was also determined by measurering the area of leaf consumed in minute.

3. RESULTS

The mean number of eggs deposited on a single tree was 206.9±56.7 for the November generation and 100±25 for the April generation. The distance between trees on which eggs had been deposited was 45.7±15.0m.The mean height of trees used for oviposition was 7±2.5m. The mean number of eggs successfully hatched per tree was 193±50.8 for the November generation and 93±13 for the April generation.

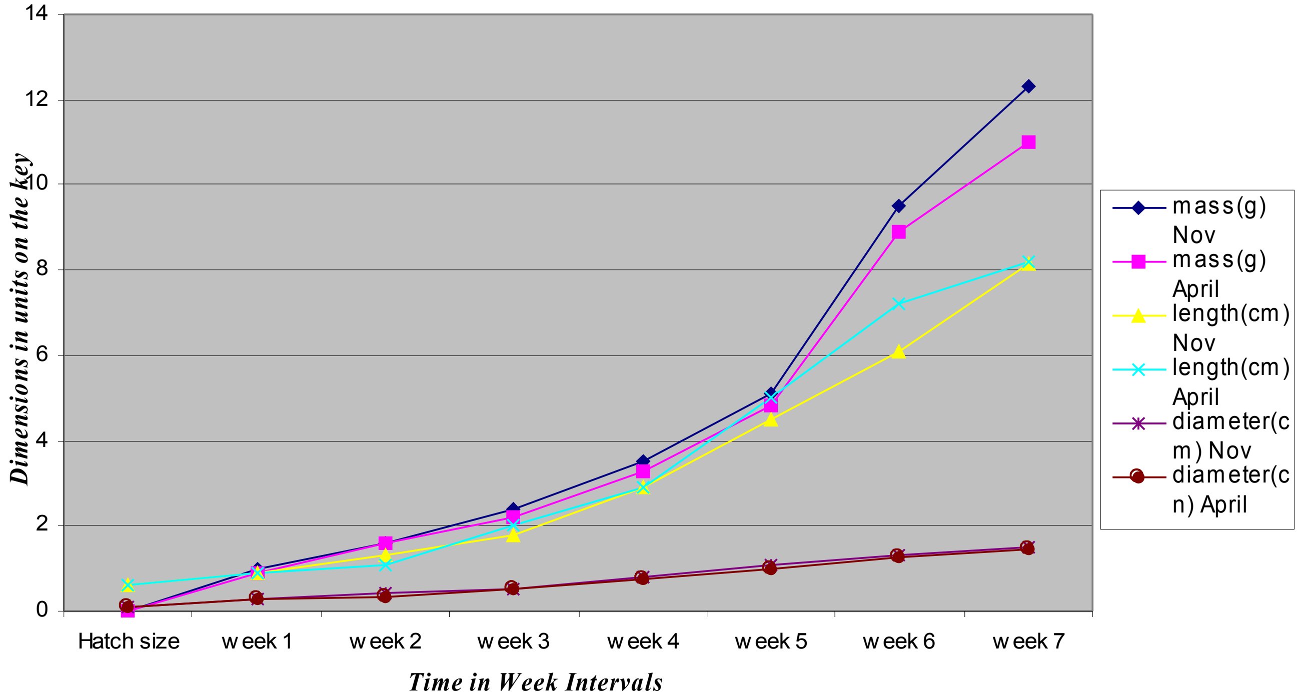

Figure 2: Increase in growth parameters for I. belina per week.

The eggs of *I. belina* are very small and hard structures. Each measures 3.14±0.26mm by 1.84±0.15mm and resembles a short sausage. The white eggshell provides a protective covering for embryonic development. It remains white until hatching takes place.

At the egg stage the factors that contributed to failure to hatch were: 1) high temperatures, >35ºC which lead to dehydration of some eggs; 2) brown ants (species not determined) which ate some of the eggs; 3) some egg cases were too tough for the larvae to emerge from, or the larvae were too weak to emerge from the egg casing; and 4) undetermined factors. For five trees considered 7±2% was the failure rate of eggs hatching in this study. Remains of the hatched eggs show that only one moth lays eggs on a mopane tree.

The larva is the vegetative stage where growth takes place. The larvae were host specific to mopane tree. The larvae moulted 4 times. Newly hatched larvae fasted for the first 7-8 hours before beginning to feed and weighed 38.75±3.28mg.They were 5.5±0.97mm long and 1.0±0.36mm in breadth. [They kept moving continuously until all the eggs in the same batch had hatched]. They then aggregated and began to feed on the same leaf? 20% died in the first week for those exposed to natural conditions but only 1% of those indoors died. At temperatures above 35ºC and relative humidity below 40% the death rate was 60%. The complete life cycle of I. Belina is shown in (Fig.1). The first moulting (ecdysis) took place on day 8±2 after hatching. In the second instar they changed from being hairy grey to yellow with dark spots where the spines would later grow.

They still continued their gregarious behaviour. To prevent falling off the tree

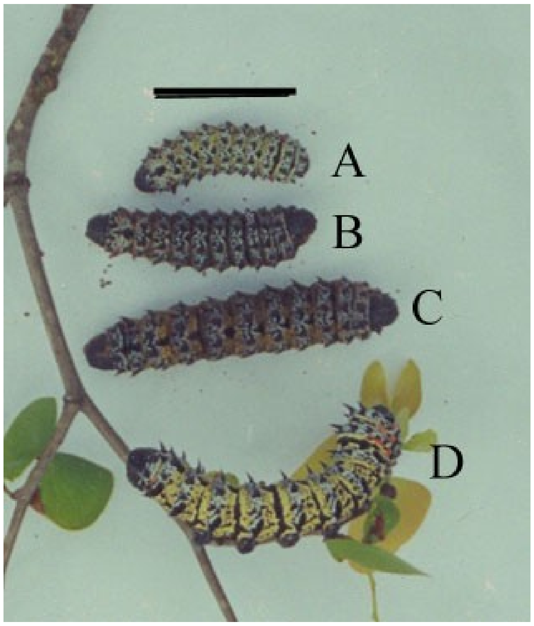

Figure 3: Imbrasia belina at different stages of development. A= worm 5 weeks after hatching. B= worm 6 weeks after hatching. C= full grown worm ready to bury itself underground. D= worm 7 weeks after hatching. Scale bar= 6cm.

during moulting they weaved a silk web, which glues them to the leaf during this vulnerable period. A few failed to release themselves from this web. The second ecdysis occurs 16±2 days after hatching, the larva now assumes a black and white colour, which is maintained until the end of the larval stage. In this instar the spines are sharp, about 2mm long, and repellent to predators. The increase in mass, length and diameter of the larvae with time are shown in (Fig.2). Day 25±2 after hatching marks the beginning of the third ecdysis. At this point early human harvesters begin to remove the worms from the trees; they now weigh 6gm fresh or 1gm dry mass. The mean number of fully mature worms per tree at this stage was 80±18.9. Evisceration or disemboweling is necessary as the worm still contains a lot of matter in their gut but the sharp spines injure the harvester in the process. They are harvested from this point on until the end of the larval stage.

There was no significant difference in the protein content between the early harvested and late harvested worms which is 59% ($p < 0.001$). The fat content which is 14% of the total mass did not change significantly with time ($p < 0.001$). But the mass increased from 6g to 12g fresh mass (Fig. 3) or 1.18g to 3.13g dry mass. A single worm at this stage consumes 0.75 cm^2 leaf area per minute. The fourth ecdysis takes place 31±2 days after hatching. On day 35±2, feeding stops. The worms pass brown droppings and spend their day with either the anterior or posterior body end hanging downwards. They loosely grip onto the tree such that a slight shaking of the tree will dislodge them to the ground. No evisceration or disemboweling, which normally injures the harvester, is necessary if harvesting is done at this stage. The harvested worms are cooked in salt or are roasted in charcoal heated river sand and then sun dried. Excess harvest is sold at about US$10 per kilogram dry mass. Some individuals gather as much as 100 kg dry mass per harvesting period. Traditionally harvesters are supposed to leave a few worms on the tree as this augurs well for future generations but this is not well observed at the moment.

In the end the larva disembarks from the tree (Fig 4) and then burrows into the ground where it turns into the pupa in 7±1 days for the November generation and 11±2days for the April generation. The silky cocoon made underground serves as protection for the pupa. Cocoons are interwoven with soil particles. After the final moult inside the cocoon, the larva develops into a chitin covered black pupa. For the November generation this lasts for 38±2days where as in the April generation this lasts for 180±12days, and metamorphic changes in the pupa result in a moth emerging. Of all the worms that go underground only 60% emerged as moths. Some are malformed and others were dug out and eaten by jackals. Some just failed to emerge. The relative humidity must be around 75% and the temperature of between 25ºC and 28ºC for the moths to emerge.

The adult stage, which completes the life cycle of *I. belina*, is the reproductive stage where adults mate and females lay eggs. Moths are poor fliers and lack functional mouthparts, so are unable to feed. The expected dates for each stage are shown in Table 1.

Table 1: The time frame of the life cycle of Imbrasia belina Linnaeus, 1758 studied in Gwanda / Bulawayo for the year 2004.

	Early	Late	Std. deviation
Moths emerge from cocoon	22nd October	13th November	±5 days
Eggs laid	27th October	17th November	±5 days
Eggs hatched	10th November	1st December	±3 days
Larval stage ends	20th December	12th January	±7 days
Pupa formed	24th December	19th January	±2 days
Moths emerge	1st February	21st February	±10days
Eggs laid	6th February	26th February	±7days
Eggs hatched	18th February	17th March	±5 days
Larval stage ends	10th April	25th May	±10 days

The worms in Gwanda communal areas are regarded as communally owned if the nearest homestead is more than 50m from the tree on which they grow. On the other hand if they grow less than 50m from the nearest homestead they are said to belong to the owner of the homestead. When people find young hatchlings on ‘no man’s land’ they cut the branch on which these grow and place on a tree less than 50m from the homestead. These are usually harvested when they have reached maximum growth size. On the other hand those which remain on ‘no man’s land’ are harvested on a first-come-first-served basis which results in people harvesting them before they are fully mature usually as early as two and half weeks before the end of the larval stage.

4. DISCUSSION

The life cycle of *I. belina* in Gwanda matches that of the same species studied elsewhere [9,15]. A lot of variation in the worms, which were obtained from separate geographical areas, has been documented [6]. This variation, which manifests itself in a number of ways such as average mass, length and protein content, makes it important to study the biology of *I. belina* in different geographical locations.

Figure 4: A Fully grown Imbrasia belina disembarking from mopane tree. Note the sharp spines on each segment. Scale bar= 4cm.

For example the average mass of each worm for a given place is critical for estimating the tonnage of worms that can be harvested in that area [4,5,12]. For commercial purposes it may be necessary to replace stunted varieties through selective breeding with robust ones to maximize on output. The variety we studied in Gwanda seems to be one of those that yield high mass. Both the November and April generations had the highest mass and nutritional value when harvested at the end of the larval stage. The determination of the dates, when the various stages of the worms begin, is a milestone towards the commercial management of the worms as a food and financial resource. Gwanda district, which has a high *I. belina* population occupies 4500km^2 hectares. The high protein content of these worms will go a long way to supplement the low protein content in the food consumed in this area.

The drying of these worms prolongs their shelf life to almost a year therefore maintaining a steady supply of protein in the diet of the people in the area. However the rush to harvest the worms results in high losses to both the individual and the community as this action lowers the mass harvested as only the caterpillars can convert the mopane leaf protein to an edible form. This calls for community organized harvesting. For example if there were harvesting rights for specified areas shared equally among the residents of the area there would be no need for the rush harvest, which is a result of the first-come-first-harvest system currently practiced. Harvesters can wait until the worms have attained full size before starting to harvest. This is both nutritionally and economically sustainable and prevents the elimination of advantageous genes in future generations. Eggs can be placed on one woodlot from where they can be propagated. A community or individuals can then manage their own woodlots. This would reduce people walking long distances to harvest worms and the risk of veld fires started during the gathering period.

5. REFERENCES

[1] Ene J.C. (1963) Insects and man in West Africa. University Press, Ibadan pp 7-52.

[2] Glew R.H., Jackson D., Sena L., Vander Jagt D.J. and M. Milson. *Gonimbrasia belina* (Lepidoptera: Saturniidae): a nutritional food source rich in protein, fatty acids and minerals: *American Entomologist*. 45, 250-253, 1999.

[3] Allotey J. and S. Mpuchane. (2003).Utilization of useful insects as a food source: *African Journal of Food Agriculture Nutrition and Development* Vol.3 No.2 *ISSN1684*-5378

[4] Latham P. (1997) Edible caterpillar programme, Bas Zaire. *Bull. Amateur Entomol. Soc.* 56**:** 54–56.

[5] Ashipala J., Garoes T.M. and C.A. Flower. Mopane caterpillar resource utilisation and marketing in Namibia. In Flower, C., Wardell-Johnson, G. and Jamieson, A. (eds.) Management of mopane in Southern Africa. Ch.13, 72-78. 1996.

[6] Greyling M., Van D.E.R., Grobler J.P. and D.C.J. Wessels (2001) Allozyme variation in two populations of the Mopane worm, Imbrasia belina (Saturniidae), and the effect of developmental stage and staggered generations: *South African Journal of Animal Science* 31:15-24.

[7] Weeden, F.N. (1989) Application of isozymes in plant breeding. In Jannick, J. (ed.) *Plant Breeding Reviews.* 6:11-39.

[8] Oberprieler R. G. (1997) Classification of the African Saturniidae: The quest for natural groups and relationships. Abstracts of the Inaugural Conference on African Lepidoptera, Nairobi & Kakamega, Kenya, 1–8 May 1997.

[9] Oberprieler R. G. (1995) The Emperor Moths of Namibia. Sigma Press, Pretoria.

[10] Campfire Zimbabwe. Management and utilization of mopane worms: Fact sheet number 10 2002.

[11] Dube, S., Chandra P. and W. Muzungu. (2000) Aerobic sporeformers in Madora, an edible caterpillar in sold in Zimbabwean markets. *Zimbabwe Journal of Science and Technology* 2: 5-9.

[12] Barlett E. (1996) Hold the Turkey. *New Scientist* 21/28 Dec: 58-59.

[13] Toms R.B. (2001) The mopane worm and the wonder of metamorphosis. *Easy Science* 4:6-8.

[14] Timberlake J. A review of the ecology and management of *Colophospermum mopane*. In Flower, C., Wardell-Johnson, G. and Jamieson, A. (eds.) Management of mopane in southern Africa. Ch.1, 10-16. 1996.

[15] Wiggins D. A. (1997) Fluctuating asymmetry in *Colophospermum mopane* leaves and oviposition preference in an African silk moth *Imbrasia belina*. *Oikos* 79**:** 484–488.

[16] Styles C. V. and J. D. Skinner (1996) Possible factors contributing to the exclusion of saturniid caterpillars (mopane worms) from a protected area in Botswana. *African J. Ecology* 34: 276–283.

[17] Roberts C. (1998) Long-term costs of the mopane worm harvest. *Oryx*, 32: 6-8.

[18] Styles C. (1995) The mopane worm - too profitable for its own good? *Our Living World Magazine*.