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Larvae of mealworm (*Tenebrio molitor* L.) as European novel food

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ABSTRACT

For centuries, insects have been used as food due to their availability and easiness in raising that is much less burdensome for environment than animal husbandry breeding. Mealworm (*Tenebrio molitor* L.) is a store-pest of which larvae are consumed by people. The aim of the work was to determine the nutritional value of larvae of mealworm (*Tenebrio molitor* L.). The material was a three-month-old mealworm larva 25 - 30 mm in length. Larvae were boiled for 3 min and next dried in 60˚C. Contents of water, ash, minerals, protein, fat and fat acids profile have been determined. Fresh larvae contained 56% of water, 18% of total protein, 22% of total fat and 1.55% of ash. High contents of minerals were found in the larvae: magnesium (87.5 mg/100g), zinc (4.2 mg/100g), iron (3.8 mg/100g), copper (0.78 mg/100g) and manganese (0.44 mg/100g). The proportion of n-6/n-3 fatty acids was very advantageous and amounted to 6.76. Larvae powder contained twice higher content of protein, fat, ash and minerals. Larva of mealworm is a valuable source of nutrients in amounts more profitable for human organism than traditional meat food. Powdered larva is a high-grade product to be applied as a supplement to traditional meals.

Keywords: Larvae *Tenobrio molitor* L.; Chemical Composition; Protein; Fat; Fatty Acid; Minerals

1. INTRODUCTION

For centuries, insects have been used as food [1]. Globally, about 1700 insect species are consumed [2,3], including 547 in Mexico [4]. The history of insect consumption is very rich, especially in Africa, Asia, Americas and Australia. Most insects are eaten in poor countries, where there is a shortage of nutritious food. The earliest information on insect consumption in Europe appeared in the early 20th century [5]. Despite the lapse of time since then, eating insects has not been popular among European nations. In Europe, insects make up 2% of the human foodstuff, whereas in America they reach 39% and in Africa 30% of the total food consumption [2]. The low consumption of insects by Europeans is due to the skeptical attitude to this kind of food. Most consumers perceive insects as "something disgusting", totally neglecting their high nutritive value. Very few people in Europe accept insects as food, but they consider eating insects as culinary curiosity rather than a source of proteins and other valuable nutrients in human diet, the fact that has been verified by the authors' own investigations (an article in preparation).

However, as the human population grows rapidly and the modern civilization continues to develop, the environment is exposed to degradation and the climate is becoming warmer. It is therefore worth considering an alternative food production that will not require huge energy input or generate large quantities of waste products and greenhouse gases, which is typical of such animal production as hog, cattle or poultry rearing. Growing insects for human food is less burdensome to the environment and cheaper, so the output offsets the effort.

Insect breeding has many advantages. It is more efficient than breeding large animals, needs much less space and generates less waste [6]. Moreover, insects have a better capacity for converting plant into animal biomass than large animals [7].

Experts from many sciences are devoting increasingly more time to this issue. The Food and Agriculture Organization of the UN predicts that the human population will have grown to 9 billion by 2050, and these people will need a source of valuable food. The rapid growth of the human population in the second half of the 21st century may lead to shortages of food, especially animal proteins [8-11]. At the meeting convened by the FAO in Rome in 2012 [12], possible solutions to this problem were suggested, including the use of insects as food. It was also planned to hold the first international scientific conference on the subject of using insects as food. Scientists work on developing insect processing technologies to obtain safe and wholesome food, which can be an alternative to the meat of farm animals. The European Union allocated high funds and has already spent 3 mln on studies on the nutritive value of insects.

Many insects are recognized as plant pests, which cause high losses, for example in agriculture. Owing to their high nutritional value they can be used for food [6, 13]. The mealworm (*Tenebrio molitor* L.) is one of the biggest beetles (ca 15 mm long) infesting stored food products. It forages on plant products and causes damage to their total mass and nutritive value. The mealworm not only eats stored food, but also contaminates it with exuviates, excrements and dead insects. *Tenebrio molitor* lays ovoid, elongated eggs, covered with some sticky substance with which it attaches eggs to the substrate. Small (about 3 mm long), whitish larvae hatch from the mealworm's eggs. After a few days, they turn yellowish and produce a hard, chitinous exoskeleton. An adult larva weighs about 0.2 g and is 25 - 35 mm long [14]. And it is the adult larvae that are used as human food in some parts of the world [14,15]. The pupa is a free-living creature, 12 - 18 mm long and of creamy white colour. Mealworms start to lay eggs 4 - 17 days after copulation. A single female may lay up to 500 eggs. The optimum incubation temperature is 25˚C - 27˚C, at which the embryonic development lasts 4 - 6 days. By slightly rising the temperature, the hatching can be accelerated. This species has a very long larval development, which at the optimum temperature and low moisture terminates after about half a year. Larvae forage deep in the products, avoiding the sunlight. Just before the end of this stage, larvae emerge onto the surface of food products and turn into pupae. The average duration of the pupal stage, at the optimum temperature, is 5 - 6 days.

The aim of the work was to determine the basic chemical composition of fresh and powdered larvae of mealworm (*Tenebrio molitor* L.) as a potential human novel-food.

2. MATERIAL AND METHODS

2.1. Material

Larvae of mealworm (*Tenebrio molitor* L.) were obtained from insect culture carried on at Chair of Phytopatology and Entomology, University of Warmia & Mazury in Olsztyn. Insects were kept in plastic containers (40 × 30 × 25 cm) in 25˚C, on feed of oat flakes with addition of vegetables as a source of water. Portion of about 0.5 kg of three-month-old larvae being 25 - 30 mm in length was taken for analysis. One part was placed into refrigerator (4˚C) making larvae sleeping, the other was submerged in boiling water bath for 3 min and dried in 60˚C (UFB 500, Memmert). Both, fresh and boiled and dried, larvae were milled (B-400, Büchi) for homogeneous mix. Materials were kept at 4˚C until used.

2.2. Chemical Analysis

The chemical analyses were performed at the Chair of Foundations of Safety of the Faculty of Technical Science and Chair of Dairy Science and Quality Management of the Faculty of Food Science at the University of Warmia and Mazury in Olsztyn using the techniques of the Association of Official Analytical Chemist [16]. Determinations: were performed for moisture content by oven drying a ca. 2-g test sample at 102˚C (AOAC No. 950.46B); ash content by igniting a ca. 3 - 5-g test sample in a muffle furnace at 550˚C until light grey ash results (AOCA No. 920.193); and lipid (crude) content by petroleum ether extraction using a Soxhlet apparatus (AOAC No. 960.39). Crude proteins were also determined using the Kejldahl method (AOAC No. 981.10), and the N conversion factor was 6.25. To determined water content and dry matter, a Memmert model UFB 500 oven was used. Fats were extracted with a Soxhlet flask and a Whatmann cartridge (B-411 Büchi Labortechnik AG), and fat contend was determined with Precisions Scientific Company Soxhlet (B-811 Büchi Labortechnik AG). Fat percentage was calculated by drying fats by extraction in Soxlet using petroleum, ether. Proteins were determined with a Digestion Systems (K-439 Büchi Labortechnik AG) and Büchi KjelFlex K-360. To determine ash 550˚C content, we used Phoenix (CEM Co., USA). Minerals elements were quantified by atomic absorption using a Pye Unicam spectrophotometer Model Unicam 939 Solar (Great Britain), equipped with an Optimus data station, background correction (deuterium discharge lamp) and an appropriate cathode lamp. Samples were mineralized in the microwave oven Phoenix (CEM Co., USA) at 450˚C. Residues

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were dissolved in 4 cm^3 of 6 M nitric acid (Suprapur Merck, Germany) and transferred into a 25 cm^3 volumetric flask adding ultra pure deionized water (Millipore, Baltimore, USA) to the 25 cm^3 mark.

2.3. Fatty Analysis

The samples were cooled at room temperature, and a 14% solution of BF3/MeOH was added, followed by further heating at 90˚C for another 30 min. Fatty acid methyl esters were extracted with hexane, taken to dryness, and resuspended again with 50 íL of isooctane. One microliter of each sample was analyzed by gas chromatography. Chromatography was performed with 6890N Agilent technologies gas chromatograph equipped with a FLD detector and a 30 m × 0.32 mm of column coated with a 0.25 µm film of SUPELCOWAX 10. Split injection was performed, with helium as carrier gas at a flow rate of 1.5 m/s. The column temperature was maintained at 195˚C by 30 min after injection. The injection port temperatures were 230˚C and the detector temperatures were 250˚C.

Chromatography was performed with 6890N Agilent Technologies gas chromatograph equipped with a FLD detector and a 30 m × 0.32 mm column coated with a 0.25 µm film of SUPELCOWAX 10. Split injection was performed, with helium as carrier gas at a flow rate of 1.5 m/s. The column temperature was maintained at 195˚C. The injection port temperature was 230˚C and the detector one—250˚C.

2.4. Statistical Analysis

Results are the mean of three determinations, and the standard deviation in reported. Results of fatty acid were compared to test t-student with the level of ($p > 0.05$).

3. RESULTS AND DISCUSSION

The basic compositions of fresh and powdered mealworm larvae and Polish conventional food are presented in **Table 1**. The fresh larvae contained more total protein, total fat and ash in comparison to traditional meats *i.e.* chicken, pork, beef, fish and eggs. Verkerk *et al.* [17] found content of nutrients in insects averaging to 45 - 55 g of total protein, 40 - 57 g of total fat and 1.4 - 2.3 g of as in 100 g of dry weight. Aguilar-Miranda *et al.* [14], Ramos-Elorduy *et al.* [4] confirmed that larvae and pupae of *T. molitor* contain a considerable amount of amino acids, essential vitamins and minerals. Moreover, mealworm larvae contain fibre, which helps digestion, and which cannot be obtained from meat of farm animals. The percentage content of the components of insect body depends on species, climate, habitation and feed.

Fresh and powdered larvae of mealworm are characterized by high content of minerals (**Table 2**) containing more phosphorus, magnesium, zinc, iron, cupper and manganese than Polish conventional meats of animals and eggs. High concentrations of such elements as Zn, Fe, Cu, Mg and Mn are particularly valuable. Also Ramos-Elordy *et al.* [18] found high minerals content in edible *Orthoptera* in Mexico. Noteworthy is also the content of mineral components and the most fatty acids in insects, which is several-fold higher than in traditional food.

Table 3 presents fatty acid contents in fresh and powder of *T. molitor* larvae. Fresh larvae contained significantly different amounts of palmitoleic acid (C16:0 n-7), sapienic acid (C16:1 n-10), elaidic acid (C18:1 n-9) and α-linoleic acid (C18:3 n-3) than the powdered one. It also contained more lauric acid (C12:0), mirystoleic acid (C14:0 n-5), sapienic acid (C16:1 n-10), elaidic acid (C18:1 n-9), linoleic acid (C18:2 n-6) and eicosapen-

Table 1. Proximal composition of larvae *Tenebrio molitor* end conventional food (%). Results are expressed as mean ± standard deviation, n = 3.

	Water	Proteins	Fats	Ash
	Larvae *Tenebrio molitor* L.			
Fresh	56.27 ± 0.127	17.92 ± 0.731	21.93 ± 0.577	1.55 ± 0.114
Powder	2.43 ± 0.157	44.72 ± 0.433	42.48 ± 0.808	3.69 ± 0.481
Conventional food [19]				
Chicken	75.2	17.8	6.0	1.0
Egg	76.2	12.5	9.7	1.0
Beff	75.4	20.1	0	1.0
Pork	74.2	22.0	1.6	1.0
Fish—rainbow trout	70.6	18.6	0.7	1.2

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Table 2. Content of minerals in larvae *Tenebrio molitor* end conventional food (mg/100g). Results are expressed as mean ± standard deviation, n = 3.

	P	K	Na	Mg	Ca	Zn	Fe	Cu	Mn
Larvae *Tenebrio molitor* L.									
Fresh	319.4 ± 16.53	373.7 ± 19.07	40.4 ± 2.57	87.5 ± 5.34	16.8 ± 0.95	4.2 ± 0.21	3.79 ± 1.362	0.78 ± 0.039	0.44 ± 0.019
Powder	700.2 ± 40.29	726.6 ± 41.86	81.1 ± 4.66	144.6 ± 4.65	31.5 ± 0.51	8.2 ± 0.38	4.10 ± 0.198	1.19 ± 0.088	0.82 ± 0.093
Conventional food [19]									
Chicken	215	334	91	26	8	1.40	0.7	0.08	0.01
Eggs	204	133	141	12	47	1.75	2.2	0.06	0.03
Beff	212	382	52	26	4	2.93	3.1	0.10	0.04
Pork	208	343	42	24	15	1.93	1.0	0.06	0.04
Fish—rainbow trout	245	420	52	25	18	0.48	0.4	0.05	0.02

Table 3. Fatty acid composition in total lipid (% of total identified fatty acid). Results are expressed as mean ± standard deviation, n = 3. Means in rows with like superscripts do not differ (p > 0.05) test t-student.

IUPAC name	C:D	Larvae *Tenebrio molitor* L.		Pigs [22]	*Pangasius Hypophthalmus* Boiled [23]
		Fresh	Powder		
Σ SFA[A]		33.46	35.05	20.92	47.15
Lauric acid	C 12:0	0.36 ± 0.009[a]	0.36 ± 0.003[a]	0.01	0.14
Mirystoleic acid	C 14:0 n-5	4.22 ± 0.127[a]	4.26 ± 0.106[a]	0.16	3.77
Palmitoleic acid	C 16:0 n-7	21.53 ± 1.108[a]	23.02 ± 0.348[b]	16.66	32.60
Oleic acid	C 18:0 n-9	6.89 ± 0.446[a]	6.89 ± 0.024[a]	3.16	9.14
Arachidic acid	C 20:0 n-6	0.46 ± 0.061[a]	0.52 ± 0.094[a]	0.55	0.15
Σ MUFA[B]		53.600	51.45	24.16	40.41
Sapienic acid	C 16:1 n-10	1.86 ± 0.036[a]	1.40 ± 0.015[b]	0.12	1.10
Elaidic acid	C 18:1 n-9	51.74 ± 0.488[a]	50.05 ± 0.394[b]	0.48	37.59
Σ PUFA[C]		12.95	11.76	47.44	12.45
Linoleic acid	C 18:2 n-6	12.09 ± 1.610[a]	10.97 ± 0.694[a]	-	7.53
α-linoleic acid	C 18:3 n-3	0.12 ± 0.027[a]	0.10 ± 0.010[b]	1.12	-
Eicosapentaenoic acid	C 20:5 n-3	0.74 ± 0.109[a]	0.69 ± 0.098[a]	0.06	0.21
	n-6	12.55 ± 1.671	11.49 ± 0.788	47.44	8.84
	n-3	1.86 ± 0.136	0.79 ± 0.108	1.18	3.64
	n-6/n-3	6.76	14.49	40.31	2.46

[A]SFA—saturated fatty acids. [B]MUFA—mono unsaturated fatty acids. [C]PUFA—poli unsaturated fatty acids.

taenoic acid (C20:5 n-3) in comparison to boiled panga (*Pangasius hypophthalmus*). The results were considerably higher than those obtained for powder of *T. molitor* cultured on corn flakes feed [14]. The high content of fatty acids in insects has been well documented in the scientific literature [3,4,14,18,20,21].

T. molitor larvae were characterized by favourable proportion of n-6/n-3 fatty acids in comparison to pork meat. A very good ratio of n-6/n-3 acids (6.76) in mealworm larvae may be taken as another determinant of their high quality and nutritive value. The high content of fatty acids in diet affects its antioxidant activity, which is

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highly desirable in the human diet [24].

A convenient form of insects as human food, and at the same time the most easily accepted, is insect powder containing twice higher content of protein, fat and ash as fresh larvae and can easily be used as an additive to traditional foods. The fact that consumers accept dishes containing powdered larvae suggests that mealworm larvae can be used as a source of wholesome novel food [14].

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