

Chemical Composition of Earthworm (*Eisenia fetida* Sav.) Biomass and Selected Determinants for its Production

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ABSTRACT

The study was designed to determine selected components of chemical composition in the body of earthworms cultivated on organic kitchen waste. It was shown that their biomass can be classified as protein-rich, succulent fodder. Notably, this work also specified the contents of 17 essential amino acids, as well as the profile of fatty acids. It also highlighted selected threats to the natural environment caused by food production and food wastage by man. Because of that, this paper also presents the determinants of earthworm biomass production. The possibilities of consuming alternative invertebrate protein were also discussed.

Keywords: food challenges, earthworm, *Eisenia fetida*, chemical composition, organic wastes, vermiculture.

INTRODUCTION

Food is now a special topic, provoking considerations in many directions. The production of food for humans raises many problems. On the one hand, it is the hunger and malnutrition of many people on Earth, and on the other, wastage of food produced at economic, environmental and even social costs. World food waste is enormous and varies both geographically and on the life stage of the food product. Various international and national institutions are making the attempts to estimate its scale, and it is advisable to undertake the research on standardizing the classification and methodology of collecting representative data. Such activities should be a priority for organizations participating in the debate on the problem of food waste. In the European Union, 88 million tonnes of food are wasted annually, including edible and inedible parts (About Food Waste), which can be a valuable biofraction resource used to regenerate soil and soil resources and for prevention of an earth-space battery discharging (Schramski et al., 2015; Kostecka et al., 2018). Per capita, an average of 173 kg is wasted,

which is the equivalent of 20% of total production, with losses amounting to EUR 143 billion annually (About Food Waste). This problem should be solved quickly and effectively, because by not doing so, huge amounts of greenhouse gases are unnecessarily emitted into the atmosphere (over 500 million tons of CO₂ per year in Europe alone), not to mention the moral dilemmas associated with throwing food away. The fact that people can now enjoy cheap food produced or imported from all over the world has its price. It is created in an energy-intensive system based on fossil fuels, exploiting natural resources and ecosystems at a faster pace than they can reproduce. Agriculture, food processing and transportation contribute to significant greenhouse gas emissions. The chemicals used in agriculture are destroying biodiversity and human health. Keeping vertebrates for meat has a negative impact on nature and the climate. Food production burdens ecosystems; it pollutes the air, water and soil. Depending on the country and the production system, 24000–49000 litres of water are required to produce 1 kg of beef, whereas 5800 to 12000 litres of water are required to produce 1 kg of pork.

In contrast, only 2000 to 4400 litres of water are needed to produce 1 kg of poultry meat (Gerbens-Leenes et al., 2013). The main responsibility for the phenomenon of food waste is now assigned to households. Therefore, it can be justified to take the steps to raise awareness of the importance of this link in the chain of organizational and economic activities. Educational programs aimed at consumers should be developed and implemented so that they understand and counteract the factors determining food waste.

The condition of ecosystems is now catastrophic for many reasons, but paradoxically, the greatest crisis is also the greatest chance for change. In which direction should science and the average person turn to be able to safely satisfy their food needs in the near future, thinking about their health and at the same time burden the environment less? Is pro-environmental thinking related to the familiarization of thoughts about the wide consumption of insects and earthworms present in such a large number of ecosystems? In the United States, following the example of the indigenous peoples of South America and Australia, insect and earthworm protein has been used for a long time (Gaddie & Douglas, 1977; Paoletti et al., 2003; Raloff, 2008; Zhenjun & Hao, 2017).

The present study was designed to determine the chemical composition of biomass of the *Eisenia fetida* (Sav.) earthworm. The conditions for production of earthworm biomass were also described and the prospects of potential benefits from the consumption of invertebrates on a much larger scale by humans of the future were presented.

MATERIAL AND METHODS

Material

The material used in the study consisted of the *Eisenia fetida* compost worms (Savigny 1826), obtained from long-term conservative breeding conducted at the Department of Natural Theories of Agriculture and Environmental Education (now at Department of the Basis of Agriculture and Waste Management) at the University of Rzeszów. The breeding population originated from the material bought in 1993 from a large-scale farm (“Vitahum”, 34-607 Szczawa 324), subsequently replenished with a purchase from the same source in 2005. *E. fetida* is a geopolitical

species, cultivated globally, and easily accepting varied properties of the habitat if constant access to organic waste is ensured. Its characteristic features include a high reproductive rate and the capacity to rapidly process organic waste. It tolerates a wide range of temperatures and occurs in waste with greatly varied moisture levels (Dominguez & Edwards, 2004; Edwards & Bohlen, 1996). There are two subspecies of compost worm: *E. fetida fetida* (Savigny 1826) and *E. fetida andrei* (Bouche, 1972). They are syntonic, i.e. they inhabit the same biocenoses, and their post-mating reproductive isolation is the evidence for their distinctness. In North European countries, worm farms mainly use *E. fetida fetida*.

Laboratory scale *E. fetida* biomass production

The laboratory experiment, with an adequate number of replicated observations ($n = 5$), was carried out in plastic test containers (vermireactors), with the dimensions of $20 \times 15 \times 15$ cm (length, width, height). Before starting the experiment, mature specimens (with a well-developed clitellum) were selected from the breeding beds and placed in the containers filled with garden soil and food for 7 days in order to acclimatize them. The bottom of each vermireactor was drained in the form of small holes to drain excess water. Each vermireactor was placed in a larger box, so that their bottoms were not touching. Earthworms were kept in vermireactors with soil and designed mixture of organic waste containing residues of boiled pasta, bread, potato and apple peelings (600 ml in total) mixed with 300 ml of cellulose (fragmented paperboard) (Table 1), which improved the vermicomposting conditions (Kostecka, 2000). The earthworms were secured from above against escape with a nylon mesh and the containers were covered with cardboard, which prevented the substrate from drying out. The development of the population took place in an air-conditioned chamber at a temperature of 20 ± 0.5 °C.

Determination of earthworm chemical composition

The worms feeding on kitchen waste (shown above) were examined for their chemical composition. After the contents were removed from their digestive tract, the bodies were assayed with the use of standard methods of fodder analysis (Kamiński et al., 1995), to identify the following parameters:

Table 1. Experimental design

Container	Medium	Earthworm <i>E. fetida</i>	Feeding
1–5	2 dm ³ of garden soil*	50 individuals of known biomass	5 times – per 600 ml of designed mixture of organic waste and cellulose (2:1)**

* universal substrate for ornament all plants Floro-hum: pH 5.5–6.5. Composition: highmoor peat, lowmoor peat, perlite, sand, microelements, mineral fertilizer NPK.

** 75 ml for each waste – which resulted in the administration of kitchen leftovers in a 2: 1 ratio (leftovers: cellulose).

- water content (according to PN-ISO1442, which involves drying the sample in an Eco-cell laboratory dryer from BMT, at a temperature of 103±2 °C to obtain dry matter),
- total ash (according to a method complying with PN-ISO936, which involves drying the analyzed sample, to be subsequently incinerated in a Snol muffle furnace at a temperature of 550±25 °C, and after cooling down the mass of the residue is determined),
- total nitrogen (with the Kjeldahl method in compliance with PN-75 A-04018, with conversion to protein),
- fat (with the Soxhlet method in Kjeltex 2200 apparatus manufactured by Boss, prior to this, the samples were subjected to hydrolysis with hydrochloric acid),
- contents of amino acids (by hydrolyzing the sample with 6M HCL for 24 hours at a temperature of 110 °C and rinsing with 0.1 molar solution of HCl and distilled water; the hydrolysate was then evaporated and the residue was dissolved in a buffer with pH 2.2; the contents of amino acids were determined with the use of AAA-400 amino acid analyzer, which performs an assay based on liquid chromatography – following the separation in the column, amino acids react with ninhydrin. The sulfur-containing amino acids were subjected to oxidizing hydrolysis with formic acid and hydrogen peroxide, and then examined with AAA-400).
- profile of fatty acids (the samples were prepared in accordance with the Folch method (extraction with chloroform-methanol (2:1) mixture, methylation BF₃/methanol). The profile was examined with a Varian 3400CX gas chromatograph, equipped with flame ionization

detector (FID), with the use of a CP-WAX column (length 50 m, diameter 0.53 mm); conditions of chromatograph operation: carrier gas - argon, temperature of the dispenser – 200 °C, temperature of the detector – 240 °C, temperature of the column – 60–220 °C).

Statistical analysis

The results of earthworm population change assessment were presented as mean ± standard deviation (SD). The results were statistically analyzed in STATISTICA v. 10 using the Student's t-test.

RESULTS

Chemical composition of the *E. fetida* earthworm

The study determined selected components of chemical composition (dry mass, raw ash, total protein, and raw fat) of the body of worms cultivated in kitchen waste (Table 2). The factors examined also included 17 endogenous and exogenous essential amino acids and the profile of fatty acids (Table 3). The obtained data was compared with the data from the literature (Table 4).

Changes of earthworm number and biomass when breeding in the experiment

In the breeding experiment, the number and biomass of earthworms increased (Table 5). After three months, the population grew eight times in size, while the biomass grew over 70% during this time. Sexually mature earthworms multiplied, producing a variable number of cocoons per animal (Table 5).

Table 2. Chemical composition of the body of *E. fetida* worms cultivated in kitchen waste (% of fresh mass)

Name	Dry mass	Raw ash	Total protein	Raw fat
The earthworm's <i>E. fetida</i> body	17.790±0.480	0.745±0.019	61.288±2.112	1.586±0.053

Table 3. Contents of amino acids ($\text{mg}\cdot\text{g}^{-1}$) and profile of fatty acids (percentage in total acids) in *E. fetida* cultivated in kitchen waste

Contents of amino acids ($\text{mg}\cdot\text{g}^{-1}$)		Fatty Acids Profile (percentage in total acids)	
		Saturated fatty acids	
		Lauric acid C ₁₂	3.598±0.181
		Tridecanic acid C ₁₃	0.275±0.039
		Myristic acid C ₁₄	5.643±0.127
		Pentadecanoic acid C ₁₅	0.247±0.026
		Palmitic acid C ₁₆	17.061±0.121
		Heptadecanoic acid C ₁₇	0.500±0.021
		Stearic acid C ₁₈	6.476±0.613
Endogenous amino acids		Eikosan acid C ₂₀	0.118±0.009
Aspartic acid	10.238±2.029	Behenic acid C ₂₂	0.965±0.065
Serine	5.136±0.846	Lignoceric acid C ₂₄	0.123±0.012
Glutamic acid		Unsaturated fatty acids	
		Monosaturated fatty acid	
Proline	3.451±0.152	Myristoleic acid C _{14:1}	0.333±0.047
Glycine	4.601±0.692	C _{15:1}	0.135±0.011
Alanine	4.663±0.697	Palmitoleic acid C _{16:1}	5.605±0.764
Exogenous amino acids		C _{17:1}	0.795±0.050
Waline	4.016±0.637	Oleic acid C _{18:1}	31.055±0.482
Isoleucine	3.504±0.407	Eicosenoic acid C _{20:1}	1.880±0.316
Leucine	6.378±0.428	Euric acid C _{22:1}	0.561±0.327
Tyrosine		Polyunsaturated fatty acids	
		C _{14:2}	1.245±0.134
Phenylalanine	3.231±0.446	Linoleic acid C _{18:2}	9.776±0.421
Histidine	2.546±0.290	Linolenic acid C _{18:3}	1.121±0.172
Lysine	6.073±0.387	Eicosadienic acid C _{20:2}	0.772±0.076
Arginine	5.890±0.333	Arachidonic acid C _{20:4}	1.236±0.086
		Docosapentaenoic acid C _{22:5}	0.130±0.009
Cysteine	1.196±0.181	Clupandonic acid C _{22:6}	0.205±0.038
Methionine	2.008±0.049	Unmarked	9.645±1.025
Threonine	4.149±0.705		

DISCUSSION

Effective production of earthworm biomass in vermiculture

Vermiculture is a relatively new biotechnology enabling neutralization of organic waste. It involves farming of worm populations with increased density. A process may be classified as vermiculture if 1 dm³ of the substrate contains over 100 specimens of earthworms (Garg et al., 2006). A population of this density transforms organic waste into vermicompost, a fertilizer useful in farming (Edwards & Bohlen, 1996). Therefore, this is a valuable method for obtaining deficient nutrients needed for crop cultivation, even more so because vermicompost may be generated from

alternative and unconventional resources such as: sewage sludge, waste from crop processing, and harvesting, green waste, cotton waste, waste from coffee production, kitchen waste, waste from supermarkets and restaurants, slaughterhouse waste, bones and feather from poultry processing, excrement (from poultry, pigs, cattle, sheep, horses), excrement from furred animals (foxes, mink and rabbits), waste from mushroom cultivation, breweries and paper mills (Dominguez & Edwards, 2004; Garg et al., 2006; Pączka & Kostecka, 2012). The quality (in particular sanitary properties) of vermicompost and its usefulness result from the input material.

During the process of organic waste transformation, worms usually multiply rapidly, and they

Table 4. Amino acids composition of worm protein (g·100g⁻¹ of protein) [after Sabine 1983]

Name	McInroy (1971) [†]	Taboga (1980) ^{**}	Sabine (1981) [*]	Fish meal	Meat meal
Alanine	-	5.4	-	-	-
Arginine	6.1	7.3	6.8	6.7	6.5
Aspartic acid	-	10.5	-	-	-
Cysteine	1.8	1.8	3.8	1.1	1.3
Glutamic acid	-	13.2	-	14.8	13.8
Glycine	-	4.3	4.8	4.0	7.2
Histidine	2.2	3.8	2.6	2.0	2.5
Isoleucine	4.6	5.3	4.2	3.5	6.0
Leucine	8.1	6.2	7.9	6.4	8.4
Lysine	6.6	7.3	7.1	6.9	10.4
Methionine	1.5	2.0	3.6	1.5	3.0
Phenylalanine	4.0	5.1	3.7	3.5	4.2
Proline	-	5.3	-	-	-
Serine	-	5.8	4.7	-	-
Threonine	5.3	6.0	4.8	3.3	4.6
Tryptophan	-	2.1	-	0.5	1.1
Tyrosine	-	4.6	2.2	1.6	3.0
Valine	5.1	4.4	4.9	4.7	5.7

* *Eisenia fetida* ** *Eisenia fetida* and *Lumbricus rubellus* mixed.

Table 5. The dynamic of *E. fetida* population growth after 3 months

Time	Start of the experiment	1st month	2nd month	3rd month
Number (ind·container ⁻¹ ±SD)	50.0±0.0 ^a	239.8±23.3	320.6±27.6	400.0±39.0 ^b
Biomass (g·container ⁻¹ ±SD)	22.19±0.39 ^a	27.47±2.58	29.73±5.92	38.50±4.28 ^b
Mean cocoon production (cocoon·mature ind ⁻¹ ±SD)	-	2.2±0.6 ^a	5.2±1.5	4.6±2.1 ^b

ab – Statistically significant differences ($p < 0.05$).

constitute an additional source of biomass. The cultivation of earthworms can be carried out on a large or a small scale. Obtaining the biomass of earthworms in small containers may be demanding, because in small volume earthworms lose their growth dynamics faster. In addition, undesirable organisms can multiply in vermireactors, e.g. flies from the Sciaridae family, which can compete with earthworms for food (Garczyńska et al., 2020). This biotechnology is widely used in Germany, France, Spain, Canada, Sweden and the USA (Gaddie & Douglas, 1977; Pączka & Kostecka, 2012). The present study was designed to show selected factors facilitating the production of biomass of earthworms representing the species of *Eisenia fetida* (Sav.) but mainly to determine the chemical composition of their biomass. Semi-commercial farming of *E. fetida* to obtain biomass may be conducted, for example with the

use of cattle manure. Analysis of the population number in this substrate, taking into account the purpose of the culture, suggests a conclusion: when vermiculture is mainly designed to generate vermicompost, beds with a concrete base can be recommend, and if the purpose is to obtain biomass by increasing the number of worm specimens, better results can be achieved, with less work, in a more easily aerated bed with a mesh base (Kostecka, 2000) (Table 6). The properties of this type of site promote a good condition for the population of worms, as well as its increase.

An earlier experiment on the cattle manure (Kostecka, 2000) also examined the influence of the volume of manure substrate on the growth of worm populations and the findings showed that, after six months, the populations cultivated in a manure substrate of greater volume (the examined substrates differed in terms of volume at the

Table 6. Comparison of vermiculture assumptions to produce vermicompost or earthworm biomass (after Kostecka 2000)

Purpose of vermicomposting	Indications for preferential method of conducting	The effects of favorable target	Accompanying threat
Production of vermicompost	On concrete base, hollow brick side	1. Less “escape” of mineral elements available for plants 2. Possibility of recycling eluates which contain mineral elements available for plants 3. Longer lasting bed	1. In spite of appropriate slope of base excess rainwater remains in bed, so it is necessary to aerate manure substrate more frequently because it improves the pace of vermicomposting 2. No possibility of recycling eluates
Production of earthworm biomass	On metal net with small mesh, wooden sides	1. Natural outflow of water resulting in better ventilation of bed which promotes earthworms 2. Earthworms are easy to keep in good condition, individuals are firm and alive	1. “Escape” of mineral elements and increased growth of weeds in neighbourhood where mole mounds e.g., can hide 2. Base less permanent, more frequent replacement and repairs of beds necessary

rate 1:2) were characterized by a greater number of specimens and their higher total biomass. The greater volume of manure also resulted in a higher number of cocoons produced by the worms. The identified differences were statistically highly significant ($p < 0.001$). In the substrates of higher volume (and consequently lower population density) the number of newly hatched specimens was three times larger.

The above-mentioned tendency was confirmed by examining the size and biomass of the population resulting from the applied vermicomposting technology (focusing on the effects of worm culture), which involved a monthly procedure of dividing the substrate and the population of earthworms that were vermicomposting kitchen waste (Kostecka & Pączka 2011). Significant differences in relation to the population with unchanged density were observed after as little as four months. The findings showed that in the containers in which the applied technology involved monthly dividing of the vermicomposted substrate and the worm population (D) – the number of worms reached the value of 404 ± 111 specimens \cdot dm^{-3} with the mean total biomass of 69.792 ± 13.610 g \cdot dm^{-3} ; while in the containers cultivated without dividing the earthworm population (ND), the mean number of the specimens amounted to only 142 ± 42 specimens \cdot dm^{-3} (mean total biomass of 30.333 ± 7.746 g \cdot dm^{-3}) ($p < 0.05$). In terms of the examined properties, the differences between containers (D) and (ND) also related to the number and biomass of cocoons produced by the worms (Kostecka & Pączka 2011). Neuhauser et al. (1980) and Rodriguez Garcia et al. (2019) supported the above-mentioned findings that the technology, involving frequent reduction

in the density of worms, is effective both in waste utilization as well as in increasing the number and biomass of specimens obtained. The above-mentioned data contain significant suggestions for those who apply the method of organic waste vermicomposting designed to produce worm biomass to be used as cost-effective and highly nutritious fodder in numerous situations (e.g. at a large scale for various animals in Zoos, and at a small scale for feeding animals kept at home). High contents of such essential amino acids as lysine, methionine, cysteine, tryptophan and threonine in worm body were pointed out by Sabine (1983) (Table 5). Gaddie and Douglas (1977) demonstrated that *Lumbricus terrestris* deliver 24056 kJ kg^{-1} and *Eisenia fetida* – 23000 kJ kg^{-1} .

It has been observed that in the natural environment earthworms are a source of food for various animal species (including large mammals), e.g. red fox (*Vulpes vulpes*), raccoon (*Procyon lotor*), European badger (*Meles meles*) and brown bear (*Ursus arctos*). Consequently, research has been conducted worldwide to investigate the possible use of worm biomass as fodder or as feed supplement for various groups of livestock animals: fish, chickens, pigs and rabbits (Edwards & Bohlen, 1996). In Poland, the research of this type was conducted e.g. by Popek et al. (1996), Kostecka & Pączka (2006). Potential industrial application of worm biomass for feeding livestock was for the first time discussed during the FAO Conference held in 1976 in Bangkok. The body of these animals has high nutritional value, so they are attractive for dietary purposes. Researchers also explore the options of alternative food for livestock and for people (Lowe et al., 2014). Earthworms contain very little dry mass,

so they are classified as succulent fodder. Borowiec *et al.* (2001) reported dry mass at the level of 18.25% in the *E. fetida* fed on cattle manure. The present study also focused on this species, but the culture was based on organic kitchen waste (leftovers such as pasta, bread, apple and potato peels, mixed with cellulose). In this case, the identified dry mass amounted to $17.79 \pm 0.48\%$. Because of the high protein contents (Table 3), worm meal is classified among high-protein feeds and is comparable to fishmeal or meat and bone meal (Table 4).

The present study, conducted with the use of kitchen waste, showed that the bodies of *E. fetida* contained $61.3 \pm 2.1\%$ of total protein in fresh matter. The body of earthworms (*E. fetida*) is considered an integral feed product and has high crude protein content (60 to 70% dry weight) (Rezaeipour *et al.*, 2014; Ncobela & Chimonyo, 2015). It can supplement the current deficiency of essential amino acids in many plant feeds commonly used in livestock diets (such as lysine, threonine, arginine and valine). In addition, the presence of biologically important fatty acids such as octadecanoic acid (C18: 0), linoleic acid (C18: 2) and linolenic acid (C18: 3) was detected in the body of earthworms (Tiroesele & Moreki, 2012; Gunya *et al.*, 2016). Other nutrients, such as copper, iron, manganese, zinc and phosphorus have also been found in significant amounts (Gunya *et al.*, 2016). Koreleski *et al.* (1994) and Borowiec *et al.* (2001) reported similar protein contents in this worm species (ranging from 596 to 610 g·kg⁻¹s.m). As mentioned before, the value of worm protein is a result of the beneficial composition of amino acids. The ratio of essential amino acids, such as lysine, methionine, cysteine and phenylalanine, is of particular importance in determining the nutritional doses for animals. For example in the case of fattening pigs, the dietary requirement for such essential amino acid as lysine, depending on the stage of the fattening process, ranges from 0.66 g·kg⁻¹ to 0.77g·kg⁻¹ of fodder dry matter (Jamróz & Podkański, 2004).

The worm body also contains a wealth of mineral salts and vitamins (particularly A, B and D), 100 g of worm biomass comprises approx. 0.25 mg of vitamin B₁, and 2.3 mg of vitamin B₂ (Kangmin, 2005). The high content of lysine in the body of *E. fetida* suggests its usefulness as a dietary supplement for the animals feeding on grains. It can also be used as food in pisciculture (Kangmin, 2005). Fish, unlike other animals (poultry and pigs), have good ability to digest and assimilate protein. This leads to high costs of production,

because the fodder designed for fish must contain at the least 55% of proteins, while for chicken 25% of this component is sufficient. The protein level in fodder promoting maximum growth depends on the specimens' weight, age, and fish species as well as temperature of water. The factors significantly impacting the dietary requirement for proteins include the species-specific rate of growth: the higher it is, the greater the requirement for proteins. Like in other animals, some amino acids, known as essential amino acids, are not produced by fish. Research has shown that the growth of fish is most frequently limited by such amino acids as methionine, lysine and tryptophan. Adequate dietary supplement improves nutritional results. Popek *et al.* (1996) explored the effects of using the *E. fetida* worms in feeding goldfish (*Carassius auratus*) and demonstrated that by supplementing the fodder with worm biomass at a rate of 10%, it was possible to significantly speed up the growth of fish, in comparison to a control group. Upon conclusion, the experimental specimens were nearly twice as heavy as the fish receiving standard fodder. He also showed that the goldfish whose food included worms, tended to mature earlier and had heavier gonads.

Findings of the studies conducted by Kostecka & Pączka (2006) provide the evidence for beneficial influence of worm biomass on reproduction of aquarium fish. It was shown that female guppy (*Poecilia reticulata*) fed with earthworms produced offspring in three larger broods, while the fish receiving standard food produced two smaller broods. Perez-Corria *et al.* (2019) experimented with feed for animals based on the biomass of the *E. fetida* earthworms obtained by culturing them using bovine manure. To evaluate the chemical composition of the earthworm (EW) as animal feed ingredients, they co-dried them with vegetable meals (VM). The blends were mixed with wheat bran (WB), rice powder (RP), corn meal (CM) and soy cake meal (SCM) in proportions of 85:15; 75:25 and 65:35. The dry matter (DM), crude protein (CP), crude fat (CFA), crude fiber (CF), ashes and nitrogen-free extract (NFE) of the ingredients and final mixtures were determined. All the mixtures resulted with a high content of DM ($\geq 90.00\%$). No significant differences among the proportions were revealed ($p > 0.05$). In addition, the higher inclusion of the earthworm in the proportions (85:15) increased ($p < 0.05$) the CP (54.70%), CFA (7.28%), and ashes (10.20%), mainly when mixed with SCM, CM, and RP,

respectively. However, the use of vegetable meals proportionally increased the CF (7.31%), and NFE (52.62%), mainly with the proportion of 65:35 and with RP and CM, respectively ($p < 0.05$), the results showed that the vegetable meals (WB, RP, CM, and SCM) are useful to co-dry the earthworm to be used for animal feed. It was concluded that the most appropriate proportion (VM:EW) will depend on the animal species, productive stage and market requirement.

The body of earthworms may also be an unconventional source of food for people. According to Paoletti et al. (2000), mean consumption of the *Andiorrhinus kuru* earthworms, for instance, among Indians of Venezuela amounts to 1.7–2 kg per person. The diet enriched with these annelids is beneficial for people, because they contain plenty of proteins, calcium, iron and selenium (the diet is also suitable for children and pregnant women, as it prevents iron deficiency). The fatty acids occurring in the body of these annelids include particularly high content of arachidonic acid (Paoletti et al., 2003). More common consumption of earthworms is prevented, among others, by cultural barriers, even though, according to Raloff (2008) people from approx. 113 countries (e.g. in Asia, Africa, Latin America, New Zealand and North America as well as Australian Aborigines) regularly consume equally unconventional insects. It seems that the food obtained from invertebrates may be a dietary perspective in the context of sustainable development of the world. The varied nutritional contents of biomass of earthworms, depending on the culture substrate, suggest it is necessary to continue monitoring of their chemical composition. This may hinder the possible use of such material as animal fodder because chemical assays are costly and time-consuming. Important problems connected with applying worm biomass in animal fodder include parasitology-related control measures designed to ensure safe application of such feedstuff (raw or processed) as nutrition for animals.

Moreover, worms are an important source of nutrition because of their high energy value. Borowiec et al. (2001) reported very high content of raw fat, 19.2% of fresh matter, in the *E. fetida* raised in cattle manure. In the case of the *E. fetida* vermiculture based on kitchen waste, the analyses showed significantly lower contents of this component ($1.6 \pm 0.1\%$ of fresh matter). Furthermore, the dietary value of fodder also depends on fatty acids, the deficiencies of which lead to numerous

disorders in animals (cardiovascular diseases, impaired immunity, skin cancer) (Bartnikowska & Kulasek, 1994). Fatty acids, saturated and unsaturated, regulate activity of enzyme responsible for cholesterol synthesis. The present findings show that the body of earthworms contains mainly long-chain fatty acids. These cannot be synthesized by non-ruminant mammals; therefore, according to Bartnikowska & Kulasek (1994) earthworms may be a valuable dietary supplement for such animals.

Prospects for the consumption of invertebrates

Hunger still threatens millions of people around the world. The number of people starving has been growing. In 2020, between 720 and 811 million people faced it. This makes ending hunger by 2030 very difficult to achieve (The State of Food, 2021) and there is no single good solution. These problems require global and interdisciplinary approach. Owing to the Novel food regulation of the European Union, insects for instance are known in Europe as a nutritious and ecological food source, and supermarkets or online-traders offer a small selection of products such as protein bars or insect pasta. Over 2,100 species of edible insects are consumed, mostly beetles, hymenoptera (bees, wasps, and ants), grasshoppers and butterflies. The value of insects as food source lies in their protein content, which is as high as in conventional meat products, including all essential amino acids, in addition to various micronutrients and vitamins. Their production also comes along with environmental advantages, as it has high food conversion rates, needs little space and water, and emits comparatively low levels of CO_2 – especially in the places where the temperatures meet their natural habitats of a warm climate. One approach to benefit from edible insects while avoiding the disadvantages of wild harvesting is to encourage rearing them (Nischalke & Forneck, 2020). Humans have been eating insects for millennia and, even today, the practice remains far more widespread than is generally believed. Although modern society has largely shunned insects from the dinner table, entomophagy – the practice of eating insects – is receiving renewed attention from nutritionists, food security experts, environmentalists and rural development specialists. On the basis of contributions from some of the world's leading experts on entomophagy, Durst et al. (2010), highlighted

the potential of edible forest insects as a current and future food source, documented their contribution to rural livelihoods as well as highlighted important linkages between edible forest insects and forest management.

Are similar food applications of earthworm biomass possible? The consumption of earthworm biomass is known similarly. According to Gaddie & Douglas (1977), there are recipes for meals using earthworms in the USA. In the book of these authors, the reader is able to find the descriptions of cooking with earthworm biomass. In the national earthworm recipe contest sponsored by North American Bait Farm and judged by faculty of Nutrition Department of the School of Agriculture at California State Polytechnic University at Pomona, the judges rated each recipe for economy of ingredients, ease of preparation, as well as potential eye and taste appeal; for instance, the “applesauce surprise cake”, “earthworm patties supreme”, “earthworm omelette”, “curried ver de terre and pea souffle” recipes have won. Taking into account the presented results of own and other authors’ research (table 3 and 4) over chemical composition of the body of worms cultivated in good quality sorted kitchen waste, as well as endo- and exogenous essential amino acids and the profile of fatty acids of their biomass, the advantages and disadvantages of using earthworms as a food for humans can be considered. As it is important for creating the conditions of sustainable development, the considerations will concern the social, economic and natural plane.

On a social scale, the fact that humans will be able to use a relatively inexpensive solution to malnutrition can be mentioned among the advantages. Earthworm biomass can be alternative source of food, rich of proteins, fat (and thus, energy), vitamins and minerals. It will also be an occasion for the employment growth (supplementary workplaces in the vermicomposting business). Most of the disadvantages of eating earthworms are the results of prejudice and stereotypes, such as phobia of eating invertebrates in western societies (Kostecka et al., 2017). Economical advantages are also connected with the fact that earthworm biomass is a relatively inexpensive solution which will be able to provide food at low price, and increase profits for a lot of people growing a new business (supplementary workplaces, e.g. restaurants or breeding farms). Disadvantages may be related to the politically and artificially picking up prices of this food (as it

can be treated e.g. as new original trend in Western civilization). The most important advantages of using biomass of these invertebrates can be found on an ecological scale (which of course is very much connected with social and economical scales). This mini-livestock is now emerging in animal husbandry as an ecologically sound concept, and a more environmentally friendly alternative to traditional animal livestocking. It needs a smaller breeding area and gives food protein from the perspective of lower CO₂ and NH₃ emissions. Importantly, breeding earthworm biomass will neutralize some of organic waste, and produce vermicompost, the fertilizer so needed to improve soil properties. As disadvantages, some imbalance in the ecosystem may be considered. Industrial agriculture systems of cultivation use large amounts of labour and capital relative to land area. Large amounts of labour and capital are necessary for the application of fertilizer, insecticides, fungicides, and herbicides to grow crops, and capital is particularly important to the acquisition and maintenance of high-efficiency machinery for planting, cultivating, and harvesting, as well as irrigation equipment where it is required. It has a great impact on the landscape (depending on the perspectives of the argument: for or against)

According to research, part of the culture of earthworms could be spent on food for places such as zoos. In the future, however, the current researchers would like to enter the western market with process food produced from earthworms for humans.

CONCLUSIONS

Currently, researchers focus on various aspects of environmental stress resulting from inadequate management of waste (including organic waste) and intensive systems of livestock production. Vermicomposting is not only an option which may be applied to neutralize organic waste (the method is used to transform this type of waste into a fertilizer, i.e. vermicompost), but it also enables production of highly nutritious worm biomass (animal fodder and possibly also food for people). Identifying the conditions for effective production of biomass of these invertebrates and its chemical composition is important in terms of economy and organization as well as in line with sustainable development.

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