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Evaluation of the possibilities to use gastronomic by-products as feed for the yellow mealworm (*Tenerbio molitor*)

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Abstract: The gastronomic industry generates by-products, which could be used as insect feed. The objective of the experiment was to determine the potential of utilising post-gastronomic plant and animal products as a feed source for mealworm larvae. The insects were fed diets comprising of varying proportions of plant or animal fractions. The control group (Ctrl) received oatmeal with apples, while the experimental groups received oatmeal mixed with different proportions of the plant and meat fractions of restaurant leftovers. The plant fraction was incorporated into feed at 25, 50, and 75% (groups R25, R50 and R75), while the meat fraction was mixed at 25 and 50% (groups M25 and M50). The experiment lasted 48 days. The highest dry matter (DM) intake was observed in the M25 and R75 groups. Larvae in the experimental groups exhibited higher final body mass and total mass gain compared to the Ctrl group ($p < 0.01$). The survivability of larvae in the R50 and M25 groups was significantly higher than the Ctrl group ($p < 0.01$), while the lowest survivability was observed in the R25 group. The lowest feed conversion ratio (*FCR*) for dry matter was observed in the R50 and M50 groups, while the highest *FCR* was recorded in the M25 and Ctrl groups. The highest dry matter levels, crude protein, and crude fat were found in the M25 and groups ($p < 0.01$). Groups R25 and Ctrl exhibited the highest content of crude ash ($p < 0.05$). This suggests that mealworm larvae could be one of the potential solutions for the disposal of gastronomic by-products.

Keywords: animals, fat, forage, gastronomic by-products, protein, yellow mealworm

INTRODUCTION

As the global population continues to grow and access to food remains limited in many parts of the world, the scale of food loss and waste production remains unchanged. Approximately 33% of produced food is discarded, significantly contributing to pollution (Gustavsson, 2023). This waste includes approximately 30% of cereals, 40–50% of root crops, fruits and vegetables, 20% of oil seeds, meat and dairy products, and 35% of fish (FAO, 2018). The average European generates approximately 130 kg of food waste annually. As global food production increases, so does the quantity of food waste. In general, there are two methods for disposing of food waste. One method involves incineration, while the other, which is more environmentally friendly, encompasses composting.

Restaurants, food processing plants, and catering companies generate considerable amounts of food waste. In Europe, food processing plants are responsible for producing up to 9% of waste annually amounting to 12 kg per person (EC, 2023). Due to their specific composition, the waste cannot be reintroduced into human nutrition chain, and most are not suitable for direct us as farm animal feed. Gastronomic by-products have the potential to be a valuable resource; however, if not repurposed for human consumption, they are mostly discarded or composted. The by-products in question comprise meat scraps and fruit and vegetable leftovers. Nevertheless, due to their nutritional value and chemical composition, they are considered a potentially valuable supplementary feed to the diets of insects (Collavo *et al.*, 2005). Research conducted in collaboration with a gastronomy company revealed that the dry matter of the plant fraction may contain 11.43% crude protein, 2.36% crude fat, and 80.2% carbohydrates, indicating a high nutritional value. The animal fraction exhibited even higher protein and fat content.

A significant challenge facing the global community is the shrinking availability of farmland (Buczyńska and Szadkowska-Stańczyk, 2010). This trend may prompt further intensification in the agricultural sector to compensate for the loss of agricultural land. For several decades, it has been well-documented that European Union (EU) countries are heavily dependent on imported and non-European protein feedstuffs (Kowalska, 2019). Consequently, the EU is experiencing shortages of conventional protein sources for the nutrition of farm animals, leading to an increased demand and, subsequently, rising prices of feedstuff (Kowalska, 2019). That prompts the search for alternative protein sources, such as insect proteins.

Furthermore, the potential for industrial breeding of feed insects may become crucial to the feed market. This could help reduce the demand for high-protein feed imported from outside the EU, particularly soybean meal. Insect meals contain considerable high-quality protein and fat (Finke, 2002). The amino acid composition of insect protein is comparable to other animal proteins. Moreover, insect protein has a digestibility rate of approximately 77.9–98.9% (Bukkens, 1997). Several studies have demonstrated the potential for insect meals to be incorporated into the diets of pets and farm animals (Selaledi, Maake and Mabelebele, 2021; Hong and Kim, 2022; Kim *et al.*, 2022). One of the key advantages of rearing insects is their lower feed, water, and space requirements compared to farm animals (Gałęcki, 2021). Various commercially available by-products and waste products may be utilised by feed insects (Bordiean, Krzyżaniak and Stolarski, 2022). The by-products of gastronomic origin also can be utilised as a source of nutrition for insects, which could then be processed into a valuable feed source for animals. The potential for utilising domestic consumption/gastronomic residues in cricket feeding was investigated by Collavo *et al.* (2005). The study found that insects exhibited high efficiency in utilising such food sources, with a mass gain of 1 kg crickets from consuming 1.5 kg of by-products. Currently, EU legislation prohibits feeding food waste or leftovers to insects that will be used as feed for farm animals. However, this prohibition is likely be lifted due to growing environmental concerns, consumer pressure, and ongoing technological advancements.

Currently, the EU legislation permits the production and use of seven species of insects as feed for livestock such as poultry, swine, and aquaculture. Yellow mealworms (*Tenerbio molitor*) represent one of the most commonly produced and cosmopolitan beetles from the *Tenebrionidae* family. The adult form of the insect typically lives for approximately one month. The lifespan of an insect is contingent upon and correlated with the temperature of its environment. Even relatively minor fluctuations in environmental conditions, particularly temperature, may extend this period to three weeks (Gałęcki, 2021). While mealworms have long been considered an agricultural and storage pest, they can now contribute greatly to protecting and improving the environment through waste reduction (Kosewska, 2019).

This study aims to ascertain whether the abovementioned products can serve as a food source for feed insects, a topic of growing interest in the catering industry. Additionally, it explores the potential to reintroduce these by-products into the food chain, which is an essential issue for the future discussion on waste management and feed insect farming. The research objective was to assess the potential for utilising by-products from the food industry by feeding them to mealworm larvae and to evaluate the impact of these components on the insect production and chemical composition.

MATERIALS AND METHODS

The research material comprised of mealworm larvae introduced into the experiment within the first days after hatching. The experiment was conducted on six groups of larvae, each receiving a distinct variant of the food diet containing varying quantities of gastronomic waste, namely plant and animal by-products sourced from restaurants (Tab. 1). Each feeding group was maintained in duplicate, with an initial number of 100 larvae in each replicate.

Table 1. Scheme of experimental groups and composition of fresh matter of diets in individual groups

Feed component	Experimental group					
	Ctrl	R25	R50	R75	M25	M50
	% in feed					
Oatmeal	90	75	50	25	75	50
Apple	10	–	–	–	–	–
Vegetable by-products[1)]	–	25	50	75	–	–
Meat by-products[2)]	–	–	–	–	25	25

[1)] The average composition of the plant fraction of by-products for the entire experimental period is as follows: vegetable leaves and stems (55%), vegetable and fruit peels (30%), cores with seeds (10%), flour (3%), and breadcrumbs (2%).
[2)] The average composition of the animal fraction of by-products for the entire experimental period: poultry meat trimmings (50%), pork meat trimmings (50%).
Explanations: Ctrl = control group (the larvae were given oatmeal and an apple as a water source), R25, R50, R75 = experimental groups (the larvae were provided with varying proportions of oatmeal with the restaurant waste fraction, namely 25%, 50%, and 75% of the plant fraction in the diet, respectively), M25, M50 = experimental groups (the larvae received a diet comprising an oatmeal and meat fraction, i.e. 50% poultry meat and 50% pork meat, derived from restaurant waste, representing 25 or 50% of the diet's fresh mass.
Source: own elaboration.

The insects were maintained in shaded containers at 21°C with a relative humidity of 60%.

The plant and animal-origin leftovers were collected separately from the restaurant weekly. The percentage share of each fraction was determined on a fresh matter (FM) basis by weighing the individual ingredients of the plant and animal fractions. Subsequently, each diet sample was crushed separately and divided into small portions, which were subsequently frozen. On the day of feeding, the feed samples were thawed and, after reaching room temperature, mixed with oatmeal in appropriate proportions. They were then fed to the larvae in special containers that allowed for the measurement of the amount of consumed feed. The individual diets and feed remains from the previous feeding were weighed every three days, and a new batch of feed was added each time.

In the control group (Ctrl), the larvae were fed oatmeal with an apple as a water source. The experimental groups (R25, R50, R75) received diets containing varying proportions of oatmeal with restaurant waste, namely 25, 50, and 75% of the plant fraction, respectively. The vegetable fraction consisted of vegetable leaves and stems (55%), fruit and vegetable peels (30%), seed nests (10%), flour (3%), and breadcrumbs (2%). In groups M (M25 and M50), the larvae received a diet comprising an oatmeal and a meat fraction (50% poultry meat and 50% pork meat) derived from restaurant waste, representing 25 or 50% of the diet's fresh mass. Including 75% of the meat fraction would result in an excessive supply of protein and fat in the larvae's diet.

Samples were taken from individual diets before the feed mixture was administered to the larvae. These samples were then subjected to chemical analysis, and weekly average samples were created from them. A similar procedure was employed with the remaining uneaten food.

The research was conducted during the larval growth period, until the larvae entered their pupal stage after 48 days. During the rearing period, the body mass of the larvae was recorded weekly. At the outset of the study, it was decided that individual larvae would not be weighed due to their low mass (approximately 0.025 g). Instead, a collective sample of five larvae was weighed. The measurements were conducted in four repetitions (20 larvae) from each box. Eight sizes were performed for each feeding variant (four repeats × two boxes). From the fourth week onwards, body mass was measured for each of the 20 individual larvae from each box/replication. That was done for each feeding variant, with 80 larvae being measured.

Each experimental group's intake of fresh and dry matter was determined based on the amount of feed served and the remaining waste, as well as their chemical analyses. The feed conversion ratio (*FCR*) was calculated by dividing the feed consumed by the final insect mass.

During the entire larval rearing period, the number of dead larvae in each box was checked thrice weekly. This allowed the impact of individual feeding variants on their survival to be determined.

After rearing, the larvae were subjected to a cooling procedure at a freezer temperature of –20°C. Subsequently, the larvae were thawed, after which they were dried at 60°C for 6 h and homogenised by milling. The material was subsequently refrozen until further chemical analyses were performed. The elemental chemical composition of the larvae (dry matter, crude protein, crude fat, and crude ash) and the profile of fatty acids in the fat of the larval meal were determined. The chemical composition of the larvae and feed was determined according to the AOAC (2005) method. Moisture and dry matter contents were determined by drying at 105°C to constant mass. Crude ash content was determined by incineration at 550°C for 6 h. Crude protein (N · 6.25) was determined using the micro-Kjeldahl technique (Kjeltec System 1026 Distilling Unit, Foss Tecator, Sweden). Crude fat was extracted with petroleum ether and measured using the Soxhlet method. Crude fibre content was determined by the Henneberg–Stohman method.

The fatty acid composition of extracted fat samples from insects was analysed using gas chromatography flame ionisation detection (GC/FID) following the standards set out in ISO 12966-4, 2015. Helium (5N) was employed as the carrier gas, with the temperature maintained at 200°C. Prior to the analysis, the fats under investigation were derivatised using a 14% BF_3/methanol solution.

To calculate the potential amount of waste from the catering industry based on the EU values, it was assumed that 12 kg per person per year would be generated. Subsequently, the population figures for Poland and the entire European Union were used to calculate the total quantity of waste generated. This enabled to determine the total production of by-products in Poland and the EU.

To calculate the amount of feed production for mealworms with different percentages of by-products in the dose, the following formula was employed:

$$IFP = \frac{12N}{UF} \tag{1}$$

where: *IFP* = potential insects feed production (kg), *N* = number of citizens, 12 = estimated amount of by-products from gastronomy (kg), *UF* = utilisation factor (% of by-products in the diet).

Based on the data obtained, a system was employed to calculate the potential effects of this feed on larvae. The results of the larvae's use of this feed were also considered.

$$MLP = \frac{IFP}{FCR} \tag{2}$$

where: *MLP* = potential mealworm larvae production, *FCR* = feed conversion ratio.

The final body mass, final body gain, final survivability, and chemical composition were analysed using the Statistica version 13 program (Tulsa, Oklahoma, USA). A one-way ANOVA was performed on the final body mass, final body gain, and chemical composition of the larvae in conjunction with the preceding analyses and Tukey's post-hoc test. The chi-square test was employed to assess larval survival.

RESULTS AND DISCUSSION

THE CHEMICAL COMPOSITION OF DIETS AND THEIR UPTAKE BY LARVAE

Table 2 presents the content of nutrients expressed in kilograms of dry matter. The diets in the R50 and R75 groups exhibited the lowest dry matter content of 56.32 and 48.88%, respectively. The diet of the M50 group (62.89%) exhibited a lower dry matter content than that of the Ctrl (65.25%), R25 (73.46%), and M25 (76.99%) groups. There are notable differences in the protein and fat content in individual diets. The diets with the highest protein content were those containing 25 and 50% meat, with proteins levels of 23.10 and 16.90%, respectively.

In contrast, the diets with the lowest protein content of 12.70% were those which included a 25% plant fraction. The highest crude fat content was observed in the M50 group (8.84%), while the lowest was in the R25 group (3.44%). In the case of diets containing the plant fraction of waste, an increase in the proportion of this fraction was accompanied by an increase in the protein content expressed as a percentage of dry matter. This regularity was not observed concerning fat, which exhibited an equal content in all individual groups with the plant fraction. The

Table 2. Mean (± *SD*) chemical composition (% DM) of the diets used in the experiment for the entire experimental period

Factor	Experimental group					
	Ctrl	R25	R50	R75	M25	M50
	g·kg^{-1}					
Dry matter	65.25 ±4.60	73.46 ±5.24	56.32 ±4.38	48.88 ±5.02	76.99 ±3.21	62.89 ±2.98
Content in dry matter:						
– crude protein	12.90 ±0.87	12.70 ±1.03	13.10 ±1.17	14.00 ±1.38	16.90 ±0.98	23.10 ±1.05
– crude fat	4.40 ±0.60	3.44 ±0.44	5.27 ±0.49	6.05 ±0.85	4.39 ±0.62	8.84 ±0.98
– crude fibre	2.70 ±0.45	1.49 ±0.18	2.84 ±0.25	4.68 ±0.47	1.18 ±0.11	1.00 ±0.09
– crude ash	2.16 ±0.16	2.09 ±0.21	2.50 ±0.17	2.90 ±0.26	2.16 ±0.41	2.38 ±0.29

Explanations: Ctrl, R25, R50, R75, M25 and M50 as in Tab. 1.
Source: own study.

diet with the highest proportion of the plant fraction exhibited the highest levels of crude fibre (2.29%) and crude ash (2.90%).

During the study, food intake was controlled in individual groups. The larvae willingly and eagerly consumed feed with varying amounts of fresh restaurant plant and meat by-products.

Figure 1 depicts the total fresh and dry matter intake for each experimental group during the entire experimental period. The highest fresh matter intake was observed in groups M50 (114.69 g), R75 (95.33 g) and R50 (94.02 g).

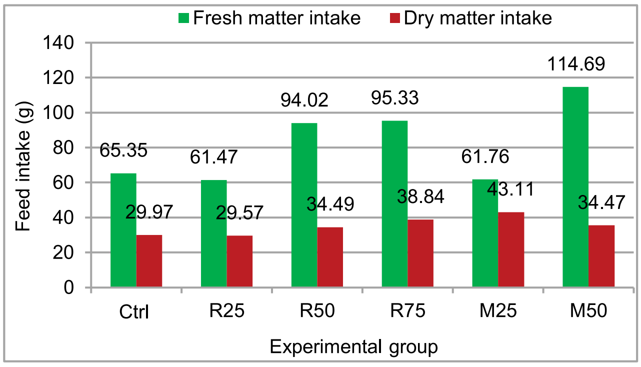

Fig. 1. Feed intake throughout the experiment depending on the experimental group; Ctrl, R25, R50, R75, M25 and M50 as in Tab. 1; source: own study

Analysis of the dry matter intake revealed that the group receiving 25% animal fraction by-products (43.11 g) had the highest intake. Conversely, the lowest dry matter intake was observed in the group fed with 25% plant fraction (29.57 g), with the highest dry matter content. In addition to the R25 group, all experimental diets exhibited a higher dry matter intake compared to the control diet.

The higher dry matter intake observed in the experimental diets may indicate an increased feed palatability for the larvae. Mealworms are omnivorous, which means they may be fed with any plant and animal-origin feed (Grau, Vilcinskas and Joop, 2017). The traditional commercial mealworm feed is cereal bran or protein-fortified flour (Makkar *et al.*, 2014). Research indicates the potential for utilising by-products such as chicken feed residues, rapeseed meal, wheat bran, and blue sunflower seeds to feed mealworms (Bordiean, Krzyżaniak and Stolarski, 2022).

THE PROCESS OF LARVAL DEVELOPMENT AND THE UTILISATION OF DIETARY RESOURCES

The results in Table 3 demonstrate that higher feed consumption was associated with the final mass of the reared insects. The larvae fed the experimental diets were heavier than those fed the control dose (0.105 g). At the end of the experiment, the heaviest single larvae specimen was observed in the M50 group (0.210 g), followed by the M25 group (0.179 g), the R50 group (0.165 g), the R75 group (0.161 g), and the R25 group (0.144 g). In terms of the final mass of all larvae, the highest combined mass was observed in larvae from the M50 group (30.30 g), followed by R50 (28.58 g), R75 (23.90 g), R25 (21.93 g), M25 (19.77 g), and Ctrl (15.98 g).

The development of larvae is influenced by the intake of dry matter and the chemical composition of the dose. After the experiment, the highest final mass of all larvae was observed in the M50 (30.30 g) and R50 (28.88 g) groups. However, this is the

Table 3. Mean (± *SD*) mass of single larva and total mass of larvae in experimental groups

Parameter	Mass (g) in group					
	Ctrl	R25	R50	R75	M25	M50
Mass of single larva (g)	0.105 ±0.011 F	0.144 ±0.009 E	0.165 ±0.012 C	0.161 ±0.010 D	0.179 ±0.024 B	0.210 ±0.033 A
Total mass of all larvae (g)	15.98	21.93	28.58	29.90	19.77	30.30

Explanations: Ctrl, R25, R50, R75, M25, and M50 as in Tab. 1, A, B, C, D, E, F = significant values for $p \leq 0.01$.
Source: own study.

mass of all larvae that survived until the time of the investigation. Consequently, the number of larvae present in each of the groups differed as well.

A more precise parameter for evaluating rearing success is the larvae's mass at the completion of the experiment. Group M50 (30.30 g) exhibited the highest final mass of larvae, while Ctrl group (15.98 g) exhibited the lowest. The M50 diet exhibited the highest protein and fat content of all the diets. Notably, as the proportion of the plant fraction increased, the percentage of crude protein and crude fat in the diet's dry matter also increased.

Other research by the authors has demonstrated that an increase in protein diets (from 12.9 to 21.9%) shortens larvae's development time, reduces mortality, and increases body mass gain (Broekhoven van *et al.*, 2015; Oonincx *et al.*, 2015).

Figure 2 illustrates the total growth of larvae over the entire experimental period. The greatest increase in larval body mass was observed in groups fed diets containing 50% and 25% meat fraction (M50 and M25), with an increase of 0.185 g and 0.145 g, respectively. The increase in the groups fed with plant fractions (R50, R25, and R75) was as follows: 0.137 g, 0.133 g, and 0.121 g. The Ctrl group exhibited the lowest mass gain, averaging 0.084 g per larva. The protein content of the ration may have influenced the growth rate of the larvae. The greatest gains were observed in larvae fed diets comprising the M50 and M25 meat fractions, which exhibited the highest protein and fat content, respectively (Tab. 2). In the groups receiving plant by-products, the greatest increase in the average crude protein, crude fat, and crude fibre contents was observed in the R50 group. Notably, the slowest growth rate was observed in the Ctrl group, which diet had a lower crude protein content than the diets containing meat fractions (M25 and M50) yet a similar nutritive value to the diets with plant fractions (R25 and R50). The conversion of feed protein to insect protein is relatively high, ranging from 22 to 55%. The conversion rate increases significantly when high-protein and high-fat diets are used for the larvae (Oonincx *et al.*, 2015). This factor is considerably higher for mealworm larvae than ruminant animals and is comparable to monogastric animals (12% for cattle, 23% for pigs, 33% for chickens) (Wilkinson, 2011).

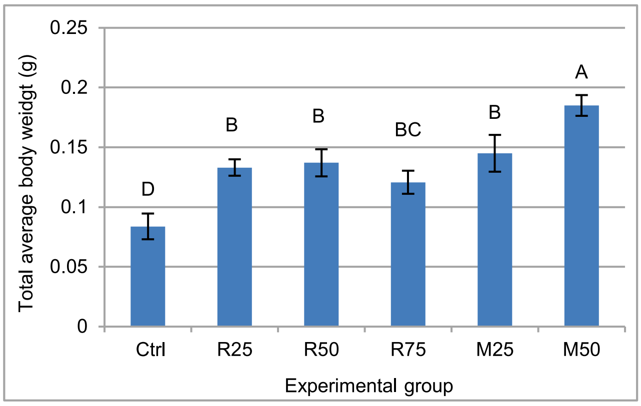

Fig. 2. Total average body mass gain of the larvae for the entire experimental period; A, B, C, D, E, F = significant values for $p \leq 0.01$, Ctrl, R25, R50, R75, M25 and M50 as in Tab. 1; source: own study

Figure 3 presents the feed conversion ratio during the experiment in all groups. Regarding the calculated consumption of fresh diet mass per unit of larval growth, the highest value was observed in the Ctrl group (4.09 g·g^{-1}), while the lowest was

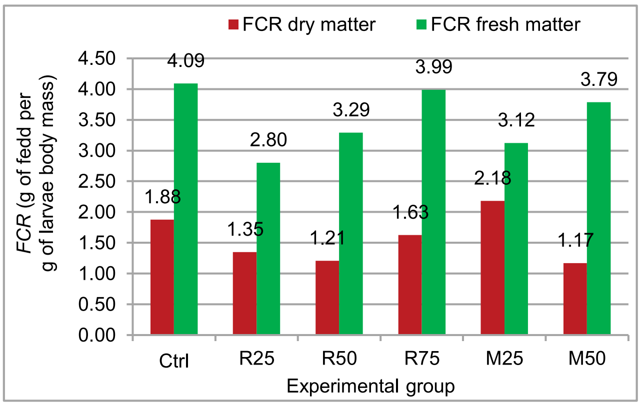

Fig. 3. Feed conversion ratio (*FCR*) for dry and fresh matter; Ctrl, R25, R50, R75, M25 and M50 as in Tab. 1; source: own study

observed in R25 (2.80 g·g^{-1}). After the conversion of the diet into dry matter consumption per 1 g of growth, which is more reliable in the case of diets with different dry matter content, the lowest feed consumption occurred in the M50 group (1.17 g·g^{-1}) and the highest in the M25 group (2.18 g·g^{-1}). For diets containing the plant fraction, the lowest dry matter consumption per 1 g of larval growth was found for the R50 group (1.21 g·g^{-1}), similar to the M50 group (1.17 g·g^{-1}). The highest dietary dry matter consumption was observed in groups Ctrl (1.88 g·g^{-1}) and M25 (2.18 g·g^{-1}).

One of the key factors in enhancing the feed conversion ratio (*FCR*) for insects is their capacity to utilise water from their feed source directly. It is proposed that structured water bound in feed ingredients may benefit insects in their diet, as evidenced by the R25, R50, and R75 groups. A similar phenomenon may have occurred in the M50 group. Nevertheless, it is crucial to emphasise the importance of monitoring the high levels of protein and fat in the diet. In diets containing more than 65% dry matter (Ctrl, M25), an increase in dry matter intake of the ration was observed. Conclusions similar to those presented here were reached by Oonnx *et al.* (2015), who reported that the *FCR* of mealworm larvae was comparable to that of broiler chickens when carrots were included in the diet of the mealworms. The efficiency of by-product utilisation was evaluated in studies by Bordiean *et al.* (2022), in which chicken feed, rapeseed meal, wheat bran, and tuberous sunflower seeds were subjected to analysis. In the studies mentioned above, the dry matter *FCR* ranged from 1.53 kg·kg^{-1} to 1.59 kg·kg^{-1} for larvae fed a mixture of chicken feed and rapeseed meal. In the present study, comparable *FCR* values were observed in groups Ctrl (1.88 kg·kg^{-1}) and R75 (1.63 kg·kg^{-1}), while those in M25 were higher (2.18 kg·kg^{-1}). In the case of the R25 (1.35 kg·kg^{-1}), R50 (1.21 kg·kg^{-1}), and M50 (1.17 kg·kg^{-1}) groups, the coefficients mentioned above were found to be lower. The lowest *FCR*, indicative of optimal dietary utilisation, was observed in the M50 (1.17 kg·kg^{-1}) group, which received diets with the highest protein and fat content and average dry matter content. Among the groups receiving the plant fraction, the lowest *FCR* was observed in the R50 group (1.21 kg·kg^{-1}), which received a diet containing 50% plant fraction and a high moisture level but relatively low protein content.

It is important to note that the *FCR* for mealworm larvae obtained in our research is lower than that reported for farm animals such as poultry, pigs, and cattle. For chickens, the *FCR* is

1.60 kg·kg^{-1}; for fattened pigs, 2.52 kg·kg^{-1}; and for cattle, it is 10.60 kg·kg^{-1} (Sońta *et al.*, 2020; Tavangar *et al.*, 2021; McGettigan *et al.*, 2022).

Figure 4 presents the survival rate for the entire experimental period. The survival rate of larvae was monitored throughout the experiment. The highest rate was observed for the R50 group, with a survival rate of 86.65%. In contrast, the lowest rate was observed for the R25 group, with a survival rate of 60.00%.

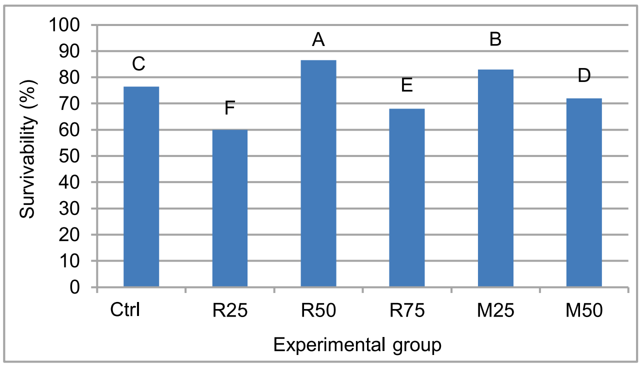

Fig. 4. Final survivability of mealworm larvae by the end of the experiment; A, B, C, D, E, F = significant values for $p \leq 0.01$; Ctrl, R25, R50, R75, M25 and M50 as in Tab. 1; source: own study

One of the key considerations in producing insects for feed is the need for high hygiene standards during rearing larvae. It is recommended that insects regularly receive a fresh feed, or that unconsumed feed be promptly removed. Furthermore, faecal matter should be removed as frequently as possible to enhance the survival rate of larvae (Deruytter, Rumbos and Athanassiou, 2021; Tavangar *et al.*, 2021). Studies on mealworms have indicated that an increased fat level in feeding rations may adversely affect survival, while a higher protein level may have a positive effect on survivability (Broekhoven van *et al.*, 2015; Oonincx *et al.*, 2015).

The groups exhibiting the lowest protein and fat intake were also characterised by the lowest survival rate, with 60.0% (R25) and 68.0% (R75) at the end of the study period. In the R50 group, survival was the highest (86.5%). An illustrative example is the M50 group, where the larvae exhibited the most rapid growth, the highest of all the experimental groups. Furthermore, the M50 group exhibited a relatively low feed conversion ratio, which did not correspond with the low survival rate of approximately 72.0% and was comparable to the survival rate of the Ctrl group of 76.5%. In this group, the larvae received the greatest quantity of protein and fat in their diet, a nutritional profile that, according to research, could potentially reduce survival. That is supported by the high survival rates observed in the M25 group (83.0%), in which the larvae consumed diets with a lower protein content than in the M50 group but with half the fat content.

THE CHEMICAL COMPOSITION OF THE LARVAE

The chemical composition of the diet and its nutritional value had a significant impact on the chemical composition of the larvae, as evidenced by the results presented in Table 4. The highest dry matter content was observed in the larvae receiving meat groups (M25 – 38.32%, M50 – 38.40%), while the lowest was observed in the Ctrl group (35.68%). In the Ctrl group and the groups with the plant fraction, the protein content in the larvae was equal and significantly lower than that observed in the groups receiving the meat fraction (M25 – 51.54% and M50 – 52.68%). The highest fat content was observed in the groups receiving meat in the diets (M25 – 37.02% and M50 – 42.08%), followed by the control diet (36.92%), and the lowest in the groups receiving 25% and 75% of the plant fraction in the diet (R25 – 30.58% and R75 – 28.58%) ($p \leq 0.01$). The highest crude ash content was observed in larvae from groups Ctrl (4.03%) and R25 (4.25%), while the lowest was found in groups R50 (3.53%) and M50 (3.42%).

Concerning the chemical composition of the larvae and the nutritional value of the diets, it can be observed that an increased intake of protein or fat in the diet results in an elevated protein and fat content in the larvae. A comparable correlation is evident in the context of ash content in larvae. Similar relationships, indicating a connection between diet composition and larvae composition, were identified in a previous study (Harsányi *et al.*, 2020). The authors observed that a diet comprising a mixture of chickens and a higher protein intake increased larvae' protein content. In animal husbandry, the energy content of feed plays a pivotal role as it influences growth parameters and profit margins (Herrero *et al.*, 2013). However, in the case of food insects, the key parameter is the protein content and its quality (House, 1961; Lundy and Parrella, 2015).

The differences in the fatty acid profiles between the groups are presented in Table 5. The highest content of saturated fatty acids (SFA) was observed in the fat of larvae from the R25 group (25.01 g·kg^{-1}), while the lowest content was observed in the fat of the M25 group (21.99 g·kg^{-1}). A comparable proportion of PUFA (polyunsaturated fatty acids) was observed across all groups.

Table 4. Mean (± *SD*) chemical composition of mealworm larvae in experimental groups

Component	Content (% DM) in group					
	Ctrl	R25	R50	R75	M25	M50
Dry matter	35.68 ±0.36^{E}	37.63 ±0.77^{C}	37.05 ±0.32^{D}	36.54 ±0.42^{F}	38.32 ±0.30^{B}	38.40 ±0.38^{A}
Crude protein	45.22 ±0.60^{C}	44.48 ±0.47^{Cc}	44.86 ±0.73^{Cd}	45.74 ±0.33^{CD}	51.54 ±0.38^{B}	52.68 ±0.23^{A}
Crude fat	36.92 ±1.02^{B}	30.58 ±0.74^{D}	34.64 ±0.72^{C}	28.58 ±1.21^{E}	37.02 ±0.29^{B}	42.08 ±0.59^{A}
Crude ash	4.03 ±0.31^{a}	4.25 ±0.15^{Aa}	3.53 ±0.12^{Bb}	3.57 ±0.44^{b}	3.86 ±0.29^{NS}	3.42 ±0.42^{Bbc}

Explanations: Ctrl, R25, R50, R75, M25 and M50 as in Tab. 1, A, B, C, D, E, F = significant values for $p \leq 0.01$, a, b, c, d = significant values for $p \leq 0.05$, NS = not significant.
Source: own study.

Table 5. The mean values (±*SD*) of fatty acids profiles in the fat of larvae of experimental groups (g·kg^{-1})

Fatty acid	Content (g·kg^{-1}) in group					
	Ctrl	R25	R50	R75	M25	M50
SFA	22.71 ±1.52	25.01 ±1.68	23.07 ±1.55	23.98 ±1.61	21.55 ±1.44	21.99 ±1.47
MUFA	49.23 ±3.30	48.31 ±3.24	49.22 ±3.30	50.28 ±3.37	53.98 ±3.62	53.65 ±3.59
PUFA	21.29 ±1.43	20.05 ±1.34	20.94 ±1.40	19.16 ±1.28	19.37 ±1.30	19.26 ±1.29
TFA	0.22 ±0.01	0.20 ±0.01	0.20 ±0.01	0.20 ±0.01	0.22 ±0.01	0.22 ±0.01
n-3	0.40 ±0.03	0.56 ±0.04	0.59 ±0.04	0.54 ±0.04	0.68 ±0.05	0.78 ±0.05
n-6	20.89 ±1.40	19.49 ±1.31	20.34 ±1.36	18.61 ±1.25	18.70 ±1.25	18.48 ±1.24
PUFA/SFA	0.94:1	0.80:1	0.91:1	0.80:1	0.90:1	0.88:1
n-6:n-3	52.25:1	34.80:1	37.47:1	34.46:1	27.5:1	23.69:1

Explanations: Ctrl, R25, R50, R75, M25 and M50 as in Tab. 1, SFA = saturated fatty acids, MUFA = monounsaturated fatty acids, PUFA = polyunsaturated fatty acids, TFA = trans fatty acids, n-3 = omega 3 fatty acids, n-6 = omega 6 fatty acids.
Source: own study.

Among the PUFA, n-6 (omega 6 fatty acids) were the most prevalent, with a higher percentage observed in the Ctrl group (20.89 g·kg^{-1}) and those receiving plant material in their diets (R25 – 19.49 g·kg^{-1}, R50 – 20.34 g·kg^{-1}). The proportion of n-3 (omega 3 fatty acids) in all groups was notably lower than that of n-6. However, a higher percentage of n-3 was observed when the animals were fed diets with the animal fraction (M25 – 0.68 g·kg^{-1} and M50 – 0.78 g·kg^{-1}) compared to the groups receiving the plant fraction (R25 – 0.56 g·kg^{-1}, R50 – 0.59 g·kg^{-1}, R75 – 0.54 g·kg^{-1}), especially the Ctrl group (0.40 g·kg^{-1}). A high proportion of n-6 and a low n-3 resulted in a wide n-6:n-3 ratio, with the highest ratio observed in the Ctrl group and the lowest ratio observed in the M25 (27.5:1) and M50 (23.69:1) groups. The ratio of PUFA to SFA was identical in all experimental groups.

Due to their high-fat content, mealworms introduced into animal diets would constitute an essential source of fat and energy. Consequently, the composition of fatty acids is paramount, as it may influence the quality of the feed, animal health, and, ultimately, the nutritional value of animal products. Furthermore, the palatability of animal feed is also influenced by the fat content and its composition (Wiseman and Gamsworthy, 1997).

Table 6 illustrates the potential for feed production for mealworms and the estimated number of mealworm larvae that could be produced annually in Poland and the EU. As the proportion of by-products in the diet increases, the quantity of mealworm feed produced declines. Replacing 25% of oatmeal with the plant fraction in the insect diet can yield up to 0.631 teragrams of insects in Poland and up to 7.625 teragrams in the EU. At the national and EU levels, implementing a system for producing mealworms for feed would provide an additional source of protein and energy, consistent with the assumption of producing protein components in Europe. It is important to note that the calculations presented here are based on the exclusive use of by-products from the catering industry, representing 9% of the total waste generated (EC, 2023).

As the quantity of grain incorporated into the diet increases, the proportion of imported post-extraction soybean meal replaced by the grain also increases. Incorporating 25% of plant by-products into the diet of mealworms allows for the replacement of approximately 23.5% of post-extraction soybean meal.

Table 6. The potential annual production of plant by-products as feed for yellow mealworms and the potential annual production of insects

Parameter	Production (Tg) in group		
	R25	R50	R75
Number of gastronomic plant by-products by year in Poland	0.442		
IFP in Poland	1.767	0.883	0.589
MLP in Poland	0.631	0.269	0.148
IFP in EU	21.350	10.675	7.117
MLP in EU	7.625	3.245	1.784

Explanations: Ctrl, R25, R50, R75, M25 and M50 as in Tab. 1, *IFP* = potential insects feed production, *MLP* = potential mealworm larvae production.
Source: own study.

That is of particular importance in the context of limiting crops and deficiencies of protein components. The local protein feed production will reduce the carbon footprint due to the shortened supply chains. Furthermore, the management of gastronomy by-products addresses the issue of composting these products, which can contaminate soil and groundwater.

CONCLUSIONS

The research findings indicate that utilising gastronomic by-products in the diet of mealworm larvae is a viable option, provided that EU legislation permits it. Using these products on a larger scale in larval feeding would result in a notable increase in feed protein and fat production at the national and EU levels while simultaneously reducing the number of by-products destined for disposal. The highest feed intake was observed in the experimental groups. It can be reasonably concluded that the experimental feed was more desirable for mealworms than the conventional feed. The experimental groups demonstrated superior feed utilisation and higher larvae mass gains than the Ctrl group. This type of diet had a significant impact on the survivability of larvae. The highest survival rate was observed in the R50 group, while the lowest was in the M25 group. Considering the parameters tested, the optimal vegetable-to-meat fraction ratio is 50%.

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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