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Growth Potential of Yellow Mealworm Reared on Industrial Residues

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Abstract: Since the world's population will continue to grow in the next decades, the problem of providing people with food will deepen. One-third of the food production volume is wasted while nearly one in ten people in the world suffer from hunger. To reduce the negative impact of human activity on the environment and meet the needs of the population, alternative sources of protein are proposed. Yellow mealworm larvae can be used as a source of food and animal feed. Therefore, this study aimed to compare the growth performance, feed conversion ratio (FCR) and efficiency of ingested feed (ECI) by yellow mealworm larvae fed 13 different diets containing chicken feed (CF), rapeseed meal (RM), wheat bran (WB) and willowleaf sunflower (WS) residues after the process of supercritical CO_2 extraction. The mean dry individual bodyweight for all diets used in the experiment was 31.44 mg dry matter (d.m.) Mealworms fed diet mixes that contained WB demonstrated the highest dry individual larval weight (from 40.9 to 47.9 mg d.m.). A significantly lower dry individual larval weight was found for mealworms fed solely WS residues (3.9 mg d.m.). The FCR ranged from 1.57 to 2.08, for pure CF and pure WS diet, respectively. The ECI of yellow mealworm larvae varied significantly (mean value 20.1%) and depended on the diet. Moreover, the ECI of mealworm was significantly the lowest and amounted to 5.9% for the pure WS diet. The industrial residues investigated in this study can be successfully used for mealworm farming, excluding pure willowleaf sunflower residues.

Keywords: *Tenebrio molitor*; edible insects; larval development; feed conversion ratio; agricultural and industrial residues; lignocellulosic biomass; bioconversion

1. Introduction

Since the world's population is predicted to reach 10 billion in the next three decades [1], it poses a problem for humanity and a challenge [2] for researchers and scientists. Nowadays, one-third of food is wasted [3,4] and nearly one in ten people suffer from hunger and food insecurity [5]. Another problem related to food quality, i.e., obesity, results from the overconsumption of some products, especially animal products [6]. Thus, there is enormous pressure on the environment to meet the demand for food [7]. About 26% of all arable land are pastures designated for animal farming, while 33% of arable land is used for feed crops. Thus, out of the total arable land, about 70% is used for animal husbandry [4]. The consumption of meat and other proteins from livestock, especially cattle, is inefficient and involves excessive expenses and activities to the detriment of the environment [8]. It was estimated that if cattle farming was reduced at least 50%, it would offer abundant environmental benefits and reduce the area of land used for the cultivation of maize used for feed [9]. An increase in the demand for poultry, eggs [10], fish and seafood [11] is expected. Consequently, new feed sources will be sought to improve growth rates and energy efficiency by replacing soymeal and fishmeal [12].

Food loss occurs throughout the whole supply chain, causing various economic, environmental, and social issues [13]. Frequently, such losses are caused by the end consumer, especially living in developed countries [14,15]. Annually, 1.3 billion tonnes of food are wasted [16]. In Europe (EU27) the food lost is estimated at approximately 89 million tonnes, or 179 kg per capita, excluding the losses from agricultural production [17].

To reduce the negative impact of food production operations on the environment while meeting the demand of the population, new alternative sources of protein and foods are proposed [9]. Insects are known to feature high bioconversion ratios of residues from agriculture and food waste [18]. In this context, insects can be a source of protein that can contribute to more efficient protein conversion. The consumption of insects, also called entomophagy, has been known since ancient times [19]. There are currently over 2000 known insects in different development stages that are consumed around the world [20]. The relatively recent use of insects as animal feed, components for food and feed as well as protein on a larger scale has begun in Europe, especially following the recommendation of the European Food Safety Authority (EFSA) in 2015 [21]. In some western countries, stores/markets and restaurants already offer insects for human consumption [22], while the use of insects as feed for small pets, poultry and fishery and other livestock is becoming more popular [23–27]. According to recent studies, the yellow mealworm (*Tenebrio molitor* L.) is one of the most reared insects in Europe [28–30]. This species can convert many substrates originating from the agricultural, baking and brewing industries [31,32]. This insect has been studied broadly to confirm its nutritional values and resistance to harmful compounds (mycotoxins, pesticides, heavy metals, etc.) [28]. It is highly likely that in the near future yellow mealworm will be used on a large scale as food (e.g., animal protein), either whole or only certain compounds (chitin, fatty acids, amino acids, proteins) or other beneficial components. Recent Regulation 2283/2015 and Regulation 2017/893 of the European Commission authorise the production of animal protein from insects (including yellow mealworm) for food and feed purposed in the European Union [33,34].

This paper presents preliminary results of a study which aimed to compare the growth performance, feed conversion ratio, efficiency of ingested feed by mealworm larvae fed with different types of agricultural and industrial residues.

2. Materials and Methods

2.1. Experimental Insects

The mealworm *Tenebrio molitor* (Linnaeus, Coleoptera: Tenebrionidae) larvae were obtained from a commercial supplier (CRICKETSFARM, Motycz-Józefin, Poland) specializing in growing insects in Poland. The insects were maintained under laboratory conditions (relative humidity: 55–60%, air temperature: 28 °C, photoperiod: 12 h). The purchased mealworm larvae were reared to obtain a colony of matured individuals. The mealworms were fed ad libitum with chicken feed milled at 3 mm and supplied with fresh carrots three times a week. The insects were kept in plastic containers (35 × 23 × 13 cm) with 3 mm aeration holes in the sides, closed with a lid. Hygrometers were installed to enable the verification of the parameters in the boxes. Three weeks later, the first pupas appeared. A total of 6–7 days later after first pupation a new adult generation was obtained. The adults were placed in the "adult box" that was built with the mosquito mesh on the bottom that allowed the eggs to fall into a collection box. The pupas/beetles were collected until it was sufficient to obtain a high number of eggs in a short collecting period (3–4 days). Hatching was estimated to last 7–10 days after egg collection. Newly hatched larvae were fed ad libitum on the chicken feed, supplied with fresh carrot slices for four weeks. The chicken feed was composed of corn, wheat gluten feed, wheat, soybean meal (with GMO), calcium carbonate, vegetable oil, sodium chloride and rapeseed meal. This procedure allowed the larvae to grow to a size enabling their easy and safe collection for the main experiment (feed conversion).

2.2. Diet Preparation, Larval Growth and Measurements during the Experiment

Before the beginning of the experiment, some of the cheapest types of agricultural/industrial residues were selected. Diets were obtained from commercial companies from Poland (except for willowleaf sunflower pellets, which were obtained from another experiment conducted in the Department of Plant Breeding and Seed Production of the University Warmia and Mazury in Olsztyn, Poland). The experimental diet mixes were composed of (1) chicken feed used as a control feed (CF), (2) rapeseed meal (RM), (3) wheat bran (WB) and (4) pelleted willowleaf sunflower (WS) biomass originating from residues after supercritical CO_2 extraction of active compounds.

All feeds were comminuted to obtain 3 mm particles. The obtained meal was sieved through a 300 µm sieve to remove the smallest particles with sizes similar to the larva faeces. Subsequently, the nutritional value of all the feeds was determined, including dry matter, ash, nitrogen/protein content and crude fat (Table 1). Experimental feeds were mixed in different weight proportions with chicken feed: only residual feed (0%), 25%, 50%, and 75% CF (Table 2). In this way, 13 types of feed mixes were obtained. The diets were stored at −20 °C until the start of the experiment.

Table 1. Main components of chicken feed (control) and industrial residues used for different diets.

Substrate	Ash (% d.m.)	Fibre Content (% d.m.)	Crude Fat (% d.m.)	Protein (% d.m.)
Chicken feed (CF)	12.89	3.23	2.38	20.11
Rapeseed meal (RM)	7.39	11.12	1.78	35.52
Wheat bran (WB)	5.82	8.68	2.9	18.63
Willowleaf sunflower (WS)	9.49	22.64	0.76	10.56

Table 2. Composition of experimental diets for the feed conversion experiment.

No.	Diet	Residual Feed Proportion (%)	Chicken Feed Proportion (%)
1.	CF (control)	-	100
2.	RM 100	100	-
3.	RM 75/CF 25	75	25
4.	RM 50/CF 50	50	50
5.	RM 25/CF 75	25	75
6.	WB 100	100	-
7.	WB 75/CF 25	75	25
8.	WB 50/CF 50	50	50
9.	WB 25/CF 75	25	75
10.	WS 100	100	-
11.	WS 75/CF 25	75	25
12.	WS 50/CF 50	50	50
13.	WS 25/CF 75	25	75

CF (chicken feed), RM (rapeseed meal), WB (wheat bran), WS (willowleaf sunflower).

The experimental trial began after hatching and after 4 weeks of undisturbed growth of mealworm, which was fed ad libitum with chicken feed. Fifty small larvae were placed in a plastic container ("diet box") (22 × 13 × 5 cm) with aeration holes on the sides, covered by a lid. Each diet box was provided with 3.1 g of experimental feed (weekly) and 2 g of carrots (twice a week). Each diet was tested in three replications. To maintain the same humidity in boxes, carrots were changed twice a week, except in the first week when it was replaced only once. Weekly larval development parameters were monitored by counting the larval survival rate and mealworm weight. The feed and carrot amounts were measured and the non-consumed feed and carrot remains were dried to calculate the amount of consumed feed and carrots. When the first pupae were observed, all larvae were counted per container and left for fasting for 24 h before harvesting. The next day, the larvae were weighed and sacrificed by freezing at −20 °C.

2.3. Feed Conversion Efficiency Experiment

Determinations of live larvae weight gain (LWG) as well as individual weights (IW) (mg fresh matter (f.m.)) were carried out weekly. For this purpose, 20 randomly chosen larvae from each box were weighed and placed back in the container for further experiments.

To determine the feed consumption, the feed and carrots not consumed during each week were weighed and dried at 105 °C until a constant mass was achieved. Feed consumption in the dry and wet form (FC) was calculated by subtracting the remaining feed mass from the feed provided at the start of each experimental week. A similar procedure was used for carrots twice a week. From week 7, when the feed and carrot consumption increased in some diet boxes, the decision was made to increase the feed and carrot amount from 3.1 to 4.5 g for feed and from 2 to 3 g and week later to 4 g of carrot. Frass was removed by sieving through 300 µm openings (from week 4), while 400 and 500 µm openings were used for larvae fed with wheat bran diets due to larger faeces particles.

Feed conversion efficiency was calculated weekly based on fresh feed conversion ratio (FCR) and the FCR and efficiency of conversion of ingested feed (ECI) were recorded at the end of the experiment. The ECI was [35] calculated as:

$$\text{ECI} = (\text{final weight}/\text{weight of ingested food}) \times 100\ [\%] \quad (1)$$

and expressed for the dry form. The feed conversion ratio (FCR) was calculated by dividing the total mean individual consumption by the total mean individual weight gain [36] and expressed for the fresh form:

$$\text{FCR} = \text{weight of ingested food}/\text{weight gained} \quad (2)$$

2.4. Statistical Analysis

Individual fresh larval weight and larval weight gain were analysed with a one-way ANOVA for multiple comparisons and Wilk's multidimensional test for multiple comparisons at $\alpha = 0.05$. Data on final survival rate, final larval dry weight, FCR and ECI were analysed with a one-way ANOVA. Homogeneous groups for all features were determined using Tukey's (HSD) multiple test at $\alpha = 0.05$. All statistical analyses were performed with the Statistica 13 software package (TIBCO Software Inc., Palo Alto, CA, USA).

3. Results and Discussion

The multidimensional test for multiple comparisons (Table 3) presents *p*-values of the individual weights and weight gains depending on the week and the interaction of week and feed. It was found that both traits (dependent variables) significantly differed and these differences were determined by the factor and the interactions between factors. Moreover, the results of one-way ANOVA (Table 4) for final larval dry weight, FCR and ECI differed significantly. However, the type of feed had no significant effect on the survival rate of yellow mealworm larvae.

Table 3. Results of the multidimensional test (Wilk's) for multiple comparisons.

Source of Variation	Individual Weight			Weight Gain		
	df	F	*p*	df	F	*p*
Week	8	640.6	<0.001	7	721.3	<0.001
Week×Feed	98	3.3	<0.001	84	3.7	<0.001

Table 4. Results of a one-way ANOVA.

Source of Variation	Survival	Dry Weight	FCR	ECI
df			12	
F	0.80	41.9	39.7	53.0
p	0.65	<0.001	<0.001	<0.001

A nutritive control feed (CF) was chosen for the first weeks after the hatching of mealworms, which provided them with enough elements to grow until week 4. This feed was also safely used and verified before the experiment. In other experiments, however, wheat bran was used as the control feed [37,38]. In the present study, at the beginning of the experiment, the mean weight of mealworms was 0.88 mg f.m. (Figure 1). At the end of week 1 of the experiment, mealworm weight almost doubled for mealworms reared on wheat bran (2.05 mg f.m.). The lowest weight was found for larvae grown on willowleaf sunflower (WS 100) (1.27 mg f.m.). During the experimental period, mealworms doubled their mass weekly, except for those fed with WS 100. Overall, the mealworms fed diets mixes with wheat brans had the highest body weight during the rearing experiment compared with the mealworms fed other diets. Thus, at the last measurement (week 9) mealworms weight was 134.4., 125.9, 124.6 and 114.2 mg f.m. for WB 100, WB 75, WB 50, WB 25, respectively. A slightly lower fresh weight (114.7 mg per larvae) was found in another study for mealworms fed with wheat bran and cabbage leaves as a water source [39]. The second-highest final weight (75 mg f.m.) in the penultimate week of measurements was found for mealworms fed the RM 25/CF 75 diet, followed by the control feed (67.7 mg f.m.). However, during the last week of the experiment, the weight of mealworms fed control feed (111 mg f.m.) outperformed the weight of mealworms (99.2 mg f.m.) fed RM 25/CF 75 diet. This indicates that the growing mealworms rely on significant amounts of CF rather than on RM in the diet. An almost similar weight of mealworms was noted for the insects grown on diets with a high amount of CF in WS diets. The mean mealworm weight for all diets in the final week was 95.6 mg f.m. The lowest mealworm weight (14.8 mg f.m.) was found for the individuals grown on WS 100. The composition of feed (Table 1) is an important factor for the growth and development of insects. The WS diet had probably inadequate nutritional composition for mealworms, having only 10.56% d.m. protein, and the highest fibre content (22.64% d.m.) compared to other diets. Harsányi et al. [40] found that the mass of yellow mealworm, giant mealworm and house cricket was significantly higher when insects were reared on chicken feed than on low quality organic wastes. As reported by Li et al. [39] mealworms fed wheat bran for the initial 10 days, followed by fermented straw and old cabbage leaves, demonstrate higher fresh weights (64.4 mg per larvae) than for mealworms fed the WS diet in the present study.

Individual larval weight gain (LWG) (Figure 2) was another parameter determined in the present experiment. The highest LWG was noted for mealworms fed diets containing WB until week 8 of the experiment, especially for larvae fed WB 100. However, the LWG of mealworms fed CF diets increased from week 7 and from week 8 they demonstrated higher LWG than the insects fed WB diets. It can be observed that mealworms fed CF diets displayed higher LWG with a surprisingly rapid increase, i.e., from 14.93 mg f.m. in week 7 to 34.47 mg f.m. in week 8, while the insects fed WB diets demonstrated a more uniform increase in weight (18.20 mg f.m. in week 6, 28.55 and 35.73 mg f.m. in week 7 and 8, respectively). In the final week of the experiment, some irregularities in LWG were observed for mealworms fed some diets. This can be confirmed in the final week when LWG decreased to 32.63 and 28.37 mg f.m. for mealworms fed diets WB 100 and WB 75/CF 25, respectively. A similar decrease and difference between week 8 and 9 were observed for mealworms fed diets RM 25/CF 75 and WS 100 (from 36.07 mg f.m. to 24.27 mg f.m. and from 4.32 to 2.85 mg f.m., respectively). The other diets did not cause significant LWG decreases during the experimental period and the growth values were uniform. It may be assumed that mealworms fed diets RM 25/CF 75, WB 100, and WB 75/CF 25 grew sufficiently and their metabolism slowed down as they prepared for pupation [41]. In the penultimate week, the mealworms' weight gain was no longer significant since their metabolism slowed down and they prepared for the pupation stage. Urrejola et al. [41] presented the bodyweight of *Tenebrio molitor* insects during different developmental stages fed various diets. It was shown that during the final larval stages there was no significant weight gain. This also could be explained based on the observation of Weaver [42] that further developmental stages are coprophagous. As previously mentioned, the experiment was stopped when the first pupae were obtained (diet WB 100 week 9). Consequently, it was assumed that further pupations would occur for the rest of the mealworms fed other diets. High LWGs for the WS 25/CF 75 diet were observed from week 7. This may be explained by an excess of chicken feed in the diet which was more willingly consumed by larvae instead of WS.

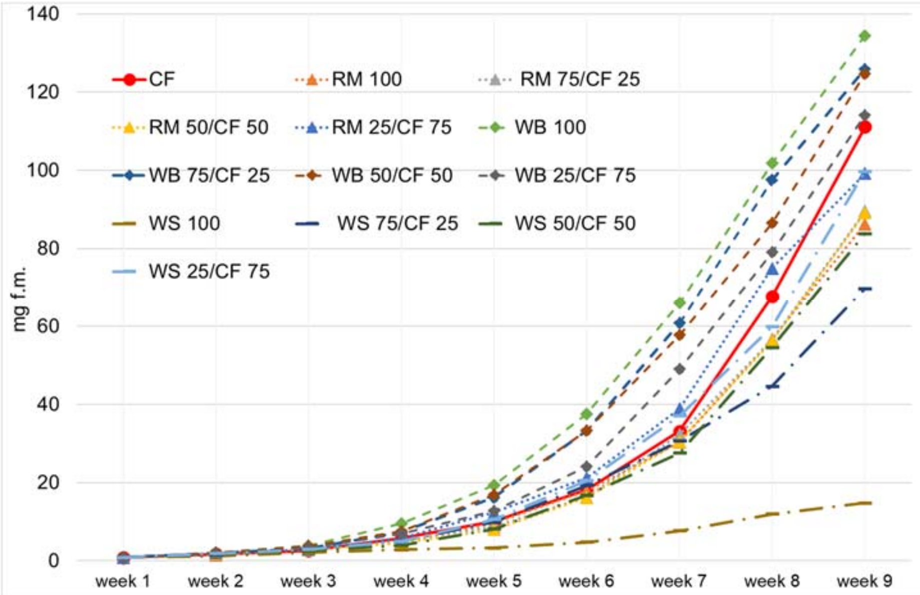

Figure 1. Individual larvae weight depending on the type of diet and week of rearing; CF (chicken feed), RM (rapeseed meal), WB (wheat bran) and WS (willowleaf sunflower).

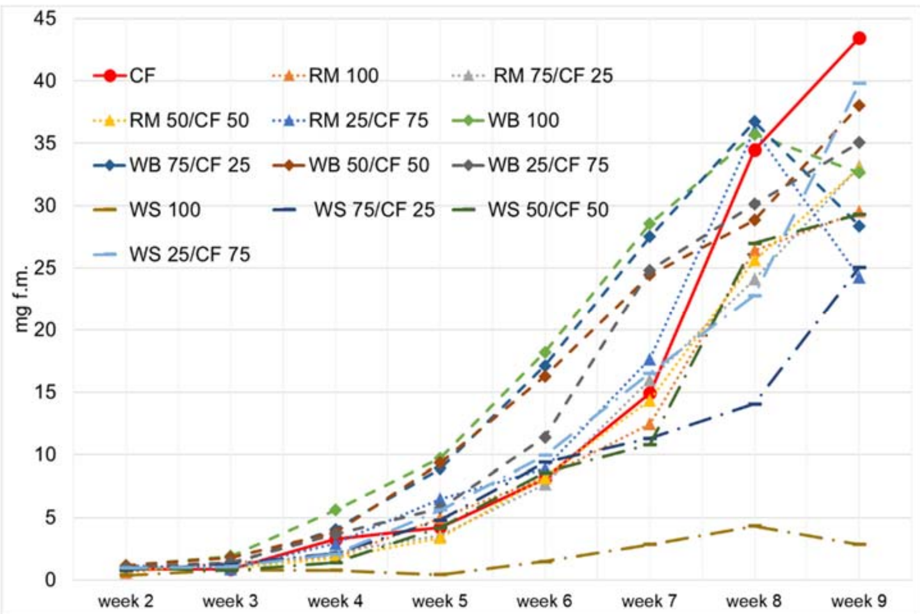

Figure 2. Individual larval weight gain depending on the type of diet and week of rearing; CF (chicken feed), RM (rapeseed meal), WB (wheat bran) and WS (willowleaf sunflower).

The mean dry individual larval weight for all diets used in the present experiment was 31.44 mg d.m. (Figure 3). The significantly highest dry weight was noted for mealworms reared on WB 100 and WB 75 diets and was 47.9 and 44.0 mg d.m., respectively. Other mixes of WB and CF produced very similar results. Mealworm reared on CF (control diet) were classified in the homogeneous group b together with diets RM 25/CF 75 and WS 25/CF 75 and the dry weights ranged from 32.3 to 34.5 mg d.m. It was noted that a high CF share in WS diets increased the dry larval weight. Mealworms fed RM diets (except RM 25/RM 75) and the WS 50/CF 50 diet demonstrated the same dry individual larval weight (25.9–28.1 mg d.m.). In the present study, mealworms grown on WB diets displayed the highest dry weight. This is contrary to the observations made by Li et al. [39], who found that the dry weight of larvae fed wheat bran was approximately 35.5 and 16.6 mg for larvae grown on plant waste diet (fermented straw and old cabbage leaves). For mealworms fed only a wheat bran diet, without any moisture supplementation, larvae dry weight was 35.9 mg [37]. In the current study, the mealworms were supplemented with carrot, which contributed to the higher individual larvae weight. In the present study, the significantly lowest dry individual larval weight was reported for diets based solely on WS, which was only 3.9 mg d.m. after week 9 of the experiment. It is possible that for other WS/CF mixes, mealworms fed more on CF and only accidentally on WS, based on self-selection of feed. The self-selection of feed was described by Morales-Ramos et al. [38], who noted that larvae selected the best components of mixed diets [41] to optimise their nutrition and growth. This habit was observed in other tenebrionids as well [43]. Willowleaf sunflower residues may be difficult to digest, possibly because of the high fibre content and low amount of non-fibrous carbohydrates (Table 1). Presumably, the residues could also be toxic for mealworms. The toxicity of some feed components for mealworm larvae has been mentioned in other research [31]. Another explanation is that when insects experience a lack of nutrients they tend to consume less and, as a result, they gain less weight [44]. The observations made during the present study revealed that the survival rate of mealworm fed WS diets was the same as for other diets (mean value for all feeds 96.5%), although the nutritional composition of the WS diet was probably insufficiently optimised for insect development and growth.

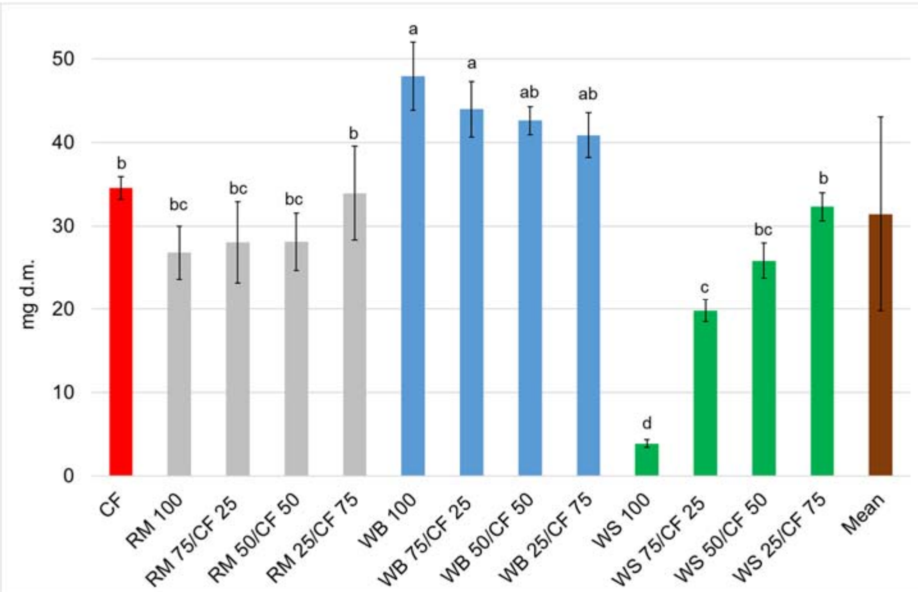

Figure 3. Final dry individual larva weight depending on the type of diet; CF (chicken feed), RM (rapeseed meal), WB (wheat bran) and WS (willowleaf sunflower); a, b, c . . . - letters mean that values are statistically different (Tukey's test at $p < 0.05$).

In the present study, the FCR for all diets except WS 100 (Figure 4) was statistically the same and ranged from 1.57 to 2.08 for CF and WB 100, respectively. It was observed that mealworm fed diets containing WB showed a slightly higher FCR than other diets. The significantly highest FCR

(4.42) was found for mealworm reared on the WS 100 diet. The experimental insects are cold-blooded mini-livestock and they do not need to maintain constant body temperature. In a study by Smil [45], the FCR for chicken was 2.5, for swine was 5.0 and it doubled for cattle (when FCR is expressed in kg of feed per kg of live weight). These values for livestock are much higher if expressed in kg of feed per kg of edible weight and double or even higher for cattle (4.5, 9,4 and 25, for chicken, swine, cattle, respectively) [45], while the mealworm larvae can be consumed entirely without any subsequent waste. Thus, insects have a better feed conversion ratio compared with other livestock [46]. The FCR can also differ between different insect species. Thus, the insects used for human consumption have a higher FCR than those used for fodder purposes, such as BSF (black soldier fly), which can be reared on wet substrates like fruits and vegetables and their derived products [32,47]. As mealworms are often used for food and feed purposes, their FCR can differ, depending on the quality of used feed for their growth. The FCR values for mealworms in the present experiment are similar to those obtained in a study by van Broekhoven et al. [31], in which the FCR of mealworms ranged from 2.62 to 6.05, depending on the feed mix quality. Thus, mealworms fed an HPLS (high protein low starch) diet produced the lowest FCR values. The highest FCR values were obtained for insects grown on an LPHS (low protein high starch) diet. It was concluded that an LPHS diet lacks nutrients and might contain some compounds that are toxic or hard to digest by mealworms. Oonincx et al. [32] found that mealworms had high FCRs (ranging from 3.8 to 19.1) when fed various quality feeds. The highest FCR values calculated for fresh weight (19.1 and 10.0) were reported for mealworms fed diets with low protein content (LPHF—low protein and high fat, and LPLF—low protein and low fat) supplemented with carrots. However, these results in the replication without carrot supplementation demonstrated almost half of these values, i.e., 5.3 and 6.1, respectively. The diets were prepared from food by-products, such as cookies and breadcrumbs, potato peels and beet molasses. For comparison, the same diets were fed to BSF (insects widely used for fodder purposes) and the FCR values obtained were considerably lower and varied from 2.3 to 2.6 [32].

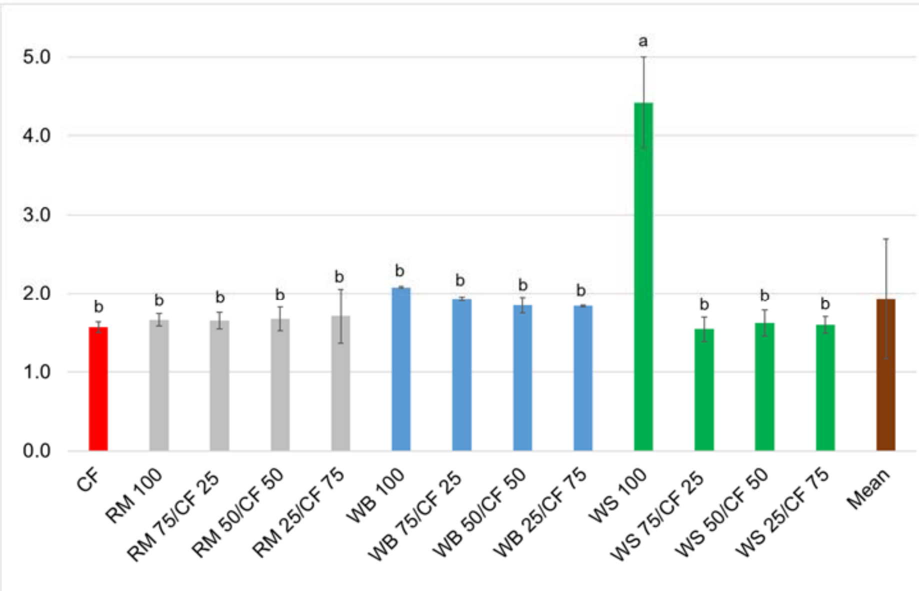

Figure 4. Feed-conversion ratio (FCR) depending on the type of feed, results on a fresh basis; CF (chicken feed), RM (rapeseed meal), WB (wheat bran) and WS (willowleaf sunflower); a, b, c ... letters mean that the values are statistically different (Tukey's test at $p < 0.05$).

The results of the present study on ECI of yellow mealworm larvae are significantly different for various feed types (Figure 5). The mean value for mealworms fed in this experiment was 20.1%. The highest ECI (23.9%) was noted for mealworms fed the RM 25/CF 75 diet. A very similar value (23.3%) was reported for mealworms fed the WS 25/CF 75 diet. A slightly (but statistically significant) lower ECI value was calculated for mealworms fed the RM 25/CF 50 diet. As for FCR, the ECI value for mealworms fed the WS 100 diet was significantly lower and was only 5.9%.

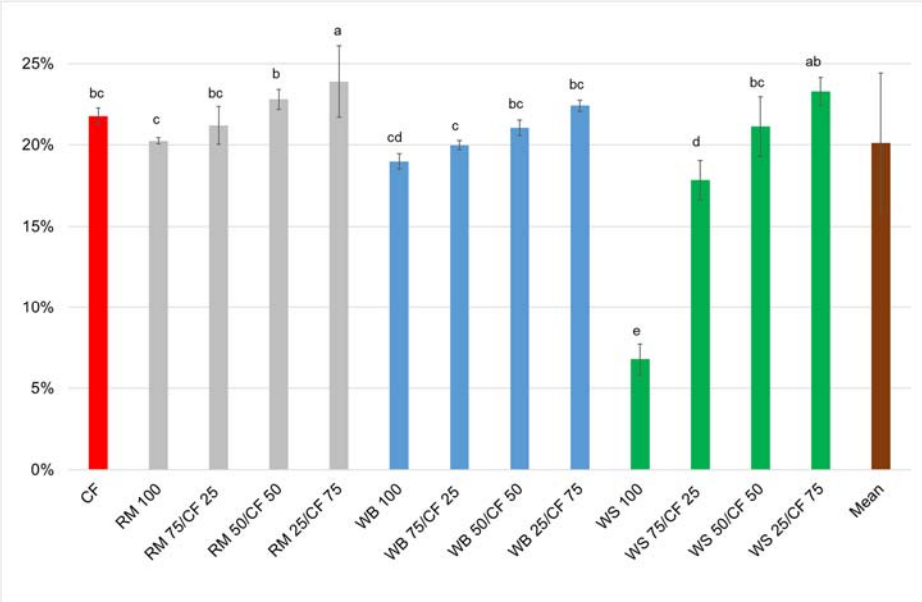

Figure 5. Efficiency of Conversion of Ingested feed (ECI) depending on the type of feed, results on a dry basis; CF (chicken feed), RM (rapeseed meal), WB (wheat bran) and WS (willowleaf sunflower); a, b, c . . . - letters mean that the values are statistically different (Tukey's test at $p < 0.05$).

The ECI values reported for insects vary considerably from species to species, depending on the quality of feed. The ECI of the most commonly used insect reared on by-products (spent grains, beer yeasts, cookie crumbs, potato peels, beet molasses and bread) solely for animal feed purposes ranged from 3% to 9% (12% control) for house cricket, 16% to 30% (14% control) for Argentinean cockroach and from 17% to 24% for black soldier fly [32]. Collavo et al. [48] reported much higher ECI values for house crickets (59%) fed a human refuse diet. Van Broekhoven et al. [31] reported that ECI values for yellow mealworm fed bakery by-products ranged from 16.8% to 28.9%. In the same study, the authors investigated two other mealworm species fed the same types of diets and reared under the same conditions. Giant mealworm (*Zophobas morio*) demonstrated slightly higher ECI values (15.8–33.3%) than the yellow mealworm. The ECI of the lesser mealworm (*Alphitobius diaperinus*) was higher for high protein diets (23.0–34.4%) and much lower (6.4%) when the species was fed low protein diets [31].

4. Conclusions

Yellow mealworm is a species easily adaptable to different feed types. The present study tested the growth, development, FCR and ECI of yellow mealworm larvae fed 13 different diets. Generally, mealworms developed well during the experiment for all diets, except those containing a large share of willowleaf sunflower residues. The individual dry larvae weight was the highest for mealworms fed WB diets, followed by those fed CF and RM diets, which confirm that the best "common food" for mealworms should be cereal residues. The WS diet containing 75% of chicken feed also demonstrated high dry weight and it can probably be attributed to the self-selection of the chicken feed component rather than the WS residues. Larvae grown on a WS 100 diet displayed very low final dry weights (only 3.9 mg d.m.). The FCR for all diets, except for WS 100, was at a similar level and ranged from 1.55 to 2.08. This is a satisfactory result and can be compared with the FCR of poultry. The highest FCR was found for mealworms fed the WS 100 diet (4.42). Therefore, it can be concluded that willowleaf sunflower residues are not recommended as mealworm feed. It can be stated that the industrial residues investigated in this study can be successfully used for mealworm farming, excluding the willowleaf sunflower. These results will be used in subsequent research to estimate the best diets and time of insect harvesting using various industrial residues as feed. Moreover, to obtain more reliable results, especially for FCR and ECI, the above research should be continued.

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Conflicts of Interest: The authors declare no conflict of interest.

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