Rearing potential of Yellow Mealworm (Larvae of *Tenebrio molitor* L.) on Food Wastes

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ABSTRACT

The demand for protein is increasing as the global population grows. Humans mainly obtain proteins from animals through unprocessed red meat, processed meat, eggs, milk, cheese, and yogurt. However, rearing livestock and poultry, which are necessary for the production of these products, has a significant impact on the environment. Many researchers have attempted to use insects as a protein resource for food and feed. In this study, we attempted to rear yellow mealworms (larvae of *Tenebrio molitor*) using food waste (i.e., unsold lunch boxes from a university coop and vegetable waste). Our results showed that mealworms could not grow when only food waste was used as feed. By contrast, mealworms grew when we used a mixture of food waste and wheat bran, which is commonly used to feed mealworms. Therefore, we can conclude that proteins can be produced and food waste can be reduced by rearing mealworms.

Keyword: Alternative protein/ Growth performance/ Sustainable development

1. INTRODUCTION

The global population is expected to exceed 10 billion people by 2059 [1]. As the population grows, the demand for food increases naturally. In particular, global per capita protein consumption is projected to increase by 3%–20.9% by 2050, compared to the 2012 levels, according to FAO scenarios [2]. These scenarios predict that this trend will be particularly pronounced in low-income countries due to economic development. Even in the scenario with the smallest increase in protein consumption, red meat consumption is projected to increase by 50.8% in Africa and 56% in Southeast Asia [3]. Proteins are essential for human health, and protein deficiency can lead to stunted growth and anemia [4]. Therefore, increasing protein production is crucial for improving nutrition in low-income countries as well as for global food security.

Currently, proteins are primarily obtained from animal sources, such as unprocessed red meat, processed meat, eggs, milk, cheese, and yogurt. However, the environmental impact of these protein sources is greater than that of other protein sources, such as beans [5]. Beef production requires large amounts of land, water, and feed. To obtain the same amount of protein, the land area needed to produce beef is approximately 50 times the area needed for growing legumes and 20 times the area needed for nuts. This demand for land has led to the conversion of rainforests into agricultural land for beef production in Brazil, resulting in decreased biodiversity and climate change [6-9]. To address these issues, there is growing interest in the use of edible insects as alternative protein sources for food and feed.

Edible insects, such as yellow mealworms (larvae of *Tenebrio molitor*), are farmed as a protein source not only for human food but also for livestock and fish feed [10-12]. The use of edible insects as food and feed has rapidly increased worldwide. In the EU, the use of four insect species, yellow mealworm, grasshopper (*Locusta migratoria*), house cricket (*Acheta domesticus*), and lesser mealworm (*Alphitobius diaperinus*), as food was authorized in 2021. Additionally, the use of processed animal proteins (PAPs) from eight insect species [i.e., banded cricket (*Gryllodes sigillatus*), black soldier fly (*Hermetia illucens*), common housefly (*Musca domestica*), domesticated silk worm (*Bombyx mori*), field cricket (*Gryllus assimilis*), house cricket (*Acheta domesticus*), lesser mealworm (*Alphitobius diaperinus*), yellow mealworm (*T. molitor*)] has been authorized as feed for poultry, pig, and

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aquaculture fish. This expanded utilization of edible insects is driven by two main factors: they can provide nutrients comparable to other protein sources, and the environmental impact of farming edible insects is much smaller than that of producing other protein sources [13-16]. In particular, edible insect farming emits lower amounts of greenhouse gases than pig and cattle farming [13]. The relative contribution of livestock in CO_2-equivalent emissions is up to 18% of the total greenhouse gas emissions [17]. This contribution is more than 10 times that in the rearing of edible insects [13]. Similarly, the water and land area required for rearing edible insects are much smaller than that needed for pigs and cattle [18, 19]. To further promote the utilization of edible insects, it is necessary to develop breeding methods that are more efficient and have an even smaller environmental impact than the existing methods. In this study, we examined the feasibility of rearing yellow mealworms using food residue to achieve these goals.

Previous studies have explored rearing conditions by changing environmental factors, such as temperature, humidity, light conditions, and density [20]. However, only some studies have focused on waste-based feed for yellow mealworms because wheat bran is commonly used as feed for yellow mealworms (but see [21-23]). In this study, we aimed to verify how food waste commonly consumed by humans affects the growth of yellow mealworms.

2. METHODOLOGY

2.1 Experimental insects

The yellow mealworm is the larval stage of *T. molitor* L. (Coleoptera: Tenebrionidae). This species produces an average of 250–500 eggs per pair. Oviposited eggs hatch in approximately 4 days at 26–30 °C. After hatching, the larvae (i.e., yellow mealworms) grow for an average pupation duration of 112–203 days. The duration of the larval stage is influenced by temperature and photoperiod [20]. Yellow mealworms prefer temperatures between 25 and 30 °C and a dark environment [24].

2.2 Preparation for yellow mealworms

For this study, yellow mealworms were obtained from colonies maintained at the Laboratory of Evolutionary Ecology in Nagasaki University, Japan. The mealworms were reared in plastic boxes (29.8 cm length × 21 cm width × 19.5 cm height) which were filled with approximately 10 cm of feed. Mealworms were reared on wheat bran supplemented with fresh carrot slices every 2 weeks. Stock colonies were kept under constant conditions, i.e., 20 ℃, approximately 60% relative humidity (RH) and 12 h light/12 h dark cycle. For subsequent experiments, we used newly hatched larvae from colonies in the laboratory.

2.3 Rearing experiments

To examine the influence of food waste feeds on yellow mealworm growth, we selected unsold lunch boxes from a university coop and vegetable scraps (carrot and cabbage) as food waste feeds. Before the experiment, the feed was dried using a garbage dryer (MS-N53XD, Panasonic Corporation Tokyo, Japan) to reduce the water content and prevent rotting. Drying reduced the weight of lunch box residue and vegetable scraps by 50% and 90%, respectively.

We collected 4,000 yellow mealworms weighing 8–56 mg from the stocked colonies. Groups of 200 yellow mealworms were placed in 20 plastic trays (28.5 cm length × 19.4 cm width × 4.8 cm height), each filled with one of the following four feeds: 200 g wheat bran (n = 5), 100 g wheat bran + 100 g dried vegetables (n = 5), 100 g what bran + 100 g dried lunch box residue (n = 5), or 200 g dried vegetables (n = 5). Each week, we randomly selected ten yellow mealworms from each tray, weighed them, and returned them to their respective bats. Monitoring continued until half of the mealworms had pupated. No additional water was provided during the experiments.

At the start of the experiment, the weight of the mealworms, fed with different feeds, slightly differed (fed only wheat bran: mean ± s.e. = 25.72 ± 0.85 mg; fed wheat bran + dried vegetables: mean ± s.e. = 26.60 ± 1.81 mg; fed what bran + dried lunch box residue: mean ± s.e. = 29.86 ± 1.78 mg; fed

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only dried vegetables: mean ± s.e. = 22.32 ± 0.42 mg). There was a significant difference only between the weights of the mealworms that were fed a mixture of wheat bran and dried lunch box residue and dried vegetables (one-way analysis of variance [ANOVA], $F = 5.24$, $P = 0.01$, Tukey's HSD tests, $Q = 2.86$, $P = 0.006$). Furthermore, we did not test the influence of feeding only dried lunch box residue to the mealworms because the mealworms did not survive in a preliminary experiment.

2.4 Statistical analysis

To compare the weights of the mealworms fed different feeds, we performed a one-way ANOVA followed by Tukey's HSD test on the final weight measurements. These analyses were conducted using JMP Pro (version 17.0; SAS Institute, Inc., Cary, USA).

3. RESULTS AND DISCUSSION

3.1 Influence of food waste feeds on yellow mealworm weight

Over half of the yellow mealworms pupated within 10 weeks of the start of the experiment, except for those fed only dried vegetables. Conversely, mealworms fed only dried vegetables barely grew over 10 weeks (mean ± s.e. = 32.0 ± 0.92 mg) and did not pupate even after more than 15 weeks. These results show that dried vegetables alone are not suitable as feed for yellow mealworm rearing. This may be owing to the lack of water content in the dried vegetables because yellow mealworms showed the highest growth rate at over 70% RH [20], and wheat bran, which is commonly used as feed, contains approximately 10% water [25]. Therefore, water supply might enhance the growth of mealworms fed only dried vegetables.

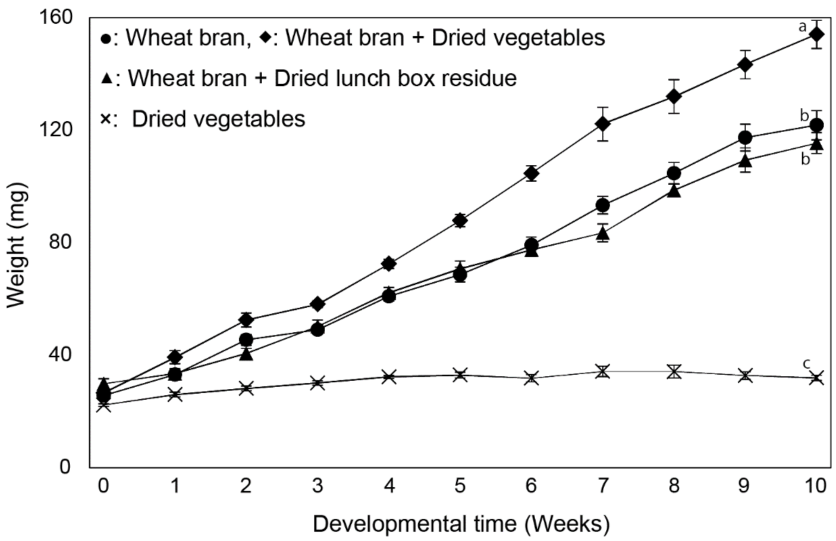

Figure 1. Change in weight of mealworms that were fed different feeds (mean ± s.e.). Lowercase letters refer to means that were significantly different in Tukey's HSD tests.

At 10 weeks, the mealworms, except for those fed only dried vegetables, increased in weight by five to seven times compared to their initial weight at the start of the experiment. The weight of the mealworms that were fed a mixture of wheat bran and dried vegetables (mean ± s.e. = 154.0 ± 5.02 mg) was significantly more than that of mealworms fed only wheat bran (mean ± s.e. = 121.8 ± 5.21 mg) and those fed a mixture of wheat bran and dried lunch box residue (mean ± s.e. = 115.42 ± 3.69 mg) (One-way ANOVA, $F = 161.89$, $P < 0.001$; Fig. 1). These results suggest that dried vegetables mixed with wheat bran can be used as feed for mealworm rearing (Fig. 1). Although none of the mealworms fed only dried lunch box residue survived in a preliminary experiment, these results also showed that a mixture of wheat bran and dried lunch box residue can be used as feed for mealworm rearing (Fig. 1). The results suggest that even feeds that are unsuitable on their own can be used for mealworm rearing

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when mixed with wheat bran. Mealworm rearing, thus, has the potential to reduce food and agricultural waste (e.g., chicken dropping and sugarcane bagasse).

The growth of mealworms fed a mixture of wheat bran and dried vegetables (carrots and cabbages) was better than that of mealworms fed wheat bran alone (Fig. 1). This result suggests that dried vegetables can compensate for the nutrients lacking in wheat bran, supporting the growth of mealworms. Generally, some nutrients (vitamin C, lycopene, etc.) are reduced by heating and drying in vegetables and fruits [26]. Similarly in carrots, vitamin C content is significantly reduced by heat processing [27]. On the other hand, the content of carotenoids (alpha/beta carotenes) is stable [27, 28]. Therefore, our results may be attributed to these carotenoids. Another study suggested that carrots positively affect the survival and growth of mealworms [29]. It was hypothesized that this effect was caused by the reduction of oxidative stress and stimulation of the immune system of mealworms owing to the carotenoids present in carrots. Oxidative stress negatively affects insect growth [30, 31]. Carotenoids can reduce oxidative stress through their role as antioxidants [32].

Our results indicate that food waste can be used as a feed for mealworm rearing. Wheat bran is the primary feed used in conventional mealworm-rearing methods. Although wheat bran is a by-product of flour production, its production has an environmental impact. Therefore, to decrease the environmental impact of mealworm rearing, the feed used should be changed from wheat bran to a mixture of wheat bran and food waste.

3.2 Future studies

In the present study, we focused on the effects of different feeds on mealworm growth. However, we did not assess the effect of different feeds on the nutritional composition of mealworms. Further studies are needed to compare the nutritive composition of mealworms fed only wheat bran with those fed a mixture of wheat bran and food wastes.

Furthermore, the selected food wastes could not be used as feed for mealworm rearing in this study. To decrease the environmental impact of mealworm rearing, it is necessary to identify food waste that can be used alone.

4. CONCLUSIONS

Based on the rearing experiments and data analyses conducted in this study. The following conclusions were drawn:

1. To reduce food waste by yellow mealworm rearing, we can use a mixture of wheat bran and food waste as feed because using food waste alone is insufficient.

2. To reduce environmental impacts, including CO_2 emissions, of protein production through edible insect rearing, we should promote the mass rearing of edible insects and develop efficient rearing methods.

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