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Optimizing Rearing and Breeding Conditions for *Tenebrio molitor* in Zimbabwe

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ABSTRACT

Over the past decade, Zimbabwe produced about a quarter of the national soya bean requirements, with the remainder being met by imports from neighboring countries such as South Africa, Malawi, and Zambia. This research investigates the potential of *Tenebrio molitor* larvae, or mealworms, as a sustainable protein source for animal feed. The study investigates the optimal breeding conditions for mealworms in Zimbabwe, focusing on factors such as feed composition, temperature, air circulation, relative humidity, and light preference. Particular emphasis was placed on the survival rate, development rate, and growth performance of the mealworms. To assess the effect of feed composition on growth, the mealworms were divided into 5 groups of 10 g each, each exposed to different dietary conditions. Once the optimal feed was identified, the effects of various environmental factors, including temperature, oxygen, humidity, and light, were tested. Data on mortality rates, average length, average weight, and the number of mealworms that transitioned to the pupal stage were recorded weekly for each group. The results showed that the best feed consisted of carrots and wheat bran, with mealworms achieving an average weight of 117 mg and a length of 33 mm. The development rate was 64%, and the survival rate was 98%. Overall, mealworms showed effective growth, high survival, and a good development rate when fed carrots and wheat bran, maintained at 28 °C and 80% humidity, with no light exposure but adequate air circulation.

Keywords: *Tenebrio molitor*, Development rate, Growth performance, Feed composition, Temperature, Survival rate

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Introduction

The production of soya beans in Zimbabwe has suffered a considerable decline of 46%, mainly due to difficult economic conditions, the widespread practice of farmers using saved seed (90%), failure to adopt best agronomic practices, limited technical skills, and restricted access to capital and necessary agricultural inputs [1, 2]. Soya beans are a critical protein source for both humans and livestock in the country. The reduced production has created a gap that is being filled through imports from neighboring nations like South Africa, Malawi, and Zambia. Locally, only 5 percent of the country's oil demand is met by local soya bean production, with the remainder costing the nation approximately US$119 million in soya oil imports in 2016 [3]. In light of these challenges, researchers are increasingly considering insects as viable, sustainable sources of protein to replace traditional livestock, following the guidelines set by the Food and Agriculture Organization (FAO) [4-7].

Among various insect species, mealworms (*Tenebrio molitor*), greater wax moths (*Galleria mellonella*), lesser mealworms (*Alphitobius diaperinus*), giant mealworms (*Zophobas atratus*), silkworms (*Bombyx mori*), house crickets (*Acheta domesticus*), and the African migratory locust (*Locusta migratoria migratorioides*) stand out for their potential as feed and food, especially in the European Union [8]. This research focuses on mealworms (*T. molitor*) as a sustainable protein alternative for livestock in Zimbabwe. These mealworms have been commercially raised in the United States for more than seven decades, thanks to their high protein content, potential health benefits, balanced amino acid profile, efficient feed conversion, low environmental impact, minimal water

consumption, and capacity to thrive on organic by-products. Additionally, *T. molitor* is known to degrade organic waste into valuable proteins [9, 10].

The breeding of mealworms is considered both economically feasible and rapid due to their brief life cycle [11]. However, various environmental factors like temperature, light, air circulation, humidity, feed composition, and stocking density can affect the growth, size, and development rates of mealworms [12-19]. This study aims to examine how these variables influence the growth performance of *T. molitor* mealworms in Zimbabwe.

Materials and Methods

In this study, mealworms were reared for four weeks under controlled conditions with unlimited access to feed. The feed was replaced every week to remove waste produced by the insects and any leftover food. This was done to ensure a clean environment for the mealworms and to maintain accurate results during the experiment.

To investigate how different feed compositions affect the growth of the mealworms, they were divided into five dietary groups. Each group consisted of 10 g of mealworms, which is roughly equivalent to 100 individual insects. The five different feeding regimens were: 50 g of wheat bran alone, 50 g of wheat bran supplemented with 20 g of fresh carrots per day, 50 g of wheat bran combined with 20 g of fresh apples daily, 50 g of wheat bran supplemented with 20 g of fresh cabbage every day, and 50 g of polystyrene as a control. The dietary composition that yielded the highest growth and development rates was selected for subsequent experiments investigating the effects of various environmental factors such as temperature, light exposure, air circulation, and humidity.

To assess the impact of relative humidity, the mealworms were placed into two groups, each consisting of 10 g of mealworms. In one group, they were exposed to an environment with no added humidity, while the other group was placed in a setting with 80% humidity. The effects of temperature were explored by using three groups of mealworms, each exposed to a different temperature condition in thermostatically controlled incubators. Each group consisted of 10 g of mealworms, and the temperatures tested were 20, 28, and 35 °C.

In another experiment, the effect of air circulation on mealworm growth was evaluated by placing the insects in two different environments. One group was kept in a sealed container with no air circulation, while the other group was placed in a well-ventilated container. Finally, to investigate the effect of light, 2 groups of mealworms were used, with each group consisting of 10 g of mealworms. One group was kept in a dark environment, stored in a cupboard, while the other group was exposed to natural daylight.

For each group being studied, several key parameters, including growth performance, mortality rate, and development rate, were monitored. First, dead larvae and pupae were taken daily from each group, and the total number was recorded. Additionally, the time taken for larvae to transition into pupae was tracked for each individual in all groups. Pupae were also checked daily to note the emergence of adult beetles.

Each week, the mean weight of the mealworm larvae was measured by selecting 40 to 50 larvae randomly from each group. Similarly, the length of twenty randomly chosen mealworms was measured to calculate the average size of the larvae within each group. Lastly, the feeding behavior of mealworms in the two light conditions was assessed by measuring the amount of feed consumed weekly.

Results and Discussion

Impact of feed composition on mealworm growth, development, and survival rate

To assess how different feed compositions influence mealworm development, growth, and survival, the mean weight and size of mealworms were recorded weekly, with the findings illustrated in **Figure 1**. The data indicates that mealworms in the group fed a diet of carrots and wheat bran exhibited the most significant growth in both weight and length, while those fed with polystyrene showed the least growth. Additionally, the carrot and wheat bran group demonstrated the highest development rate, with 28 percent of the mealworms successfully transitioning into pupae, alongside the highest survival rate.

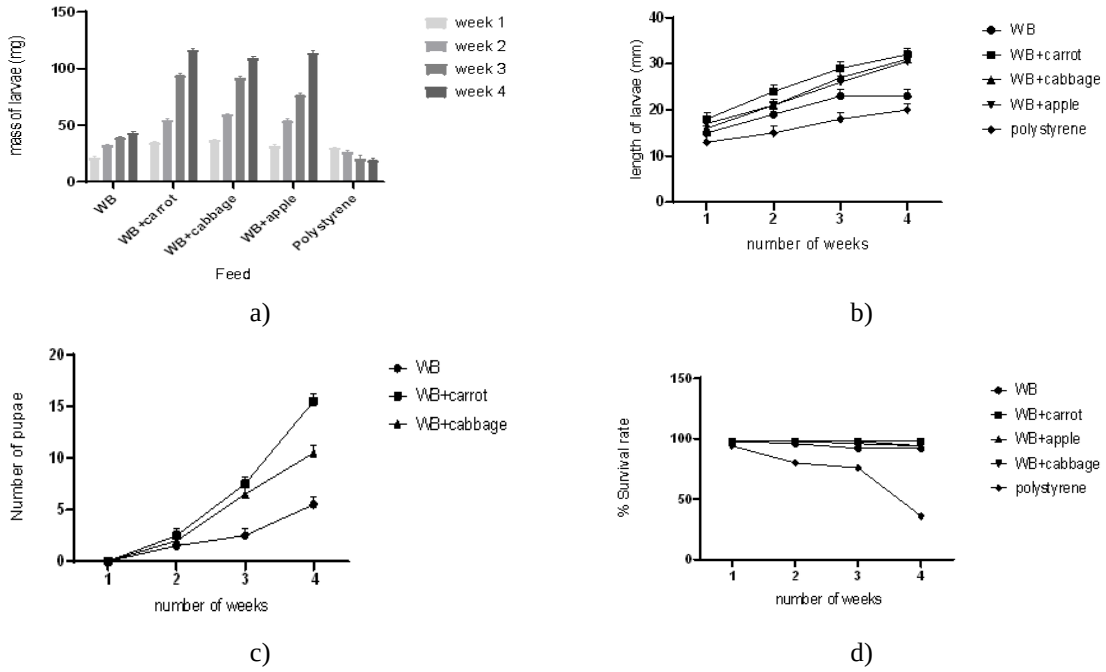


Figure 1. Effects of different feed compositions on weight, size, development rate, and survival rate of mealworms; a) changes in the average weight of mealworms, b) changes in the average length of mealworms, c) number of pupae that developed from the larvae stage, and d) the % survival rate of mealworms; all values are mean ± SD for n = 2.

The effect of feed composition on mealworm development, growth, and survival

Mealworms (*T. molitor*), a widely recognized edible insect, have been utilized for consumption across the globe and are routinely farmed. The success of mealworm farming depends on several factors, including temperature, humidity, feed, light preferences, air circulation, and the environment in which they are bred. Among these, the type of feed plays a critical role in their development; choosing inappropriate feed can impede growth or even lead to the death of the larvae. In this study, to enhance feed quality and improve rearing efficiency, wheat bran was supplemented with various fruits and vegetables. Additionally, polystyrene foam was included in the experiment to evaluate its potential as an environmentally sustainable feed source and its impact on waste management.

As shown in **Figure 1**, the mealworms fed polystyrene exhibited the lowest survival rate, which can be attributed to its insufficient nutritional content. In contrast, mealworms that were fed a mixture of wheat bran with either fruits or vegetables had the highest survival rates and experienced the least mortality. These groups also demonstrated a notable improvement in both weight and length, alongside the quickest transition from larvae to pupae and eventually to adults. This underscores the importance of selecting the right feed to optimize growth. A shorter life cycle in insects is a key indicator of effective farming. Moreover, feed composition also affects the nutritional quality of the insects, as previously noted in the literature.

Temperature's impact on mealworm development, growth, and survival

The effect of temperature on mealworm growth was tested by rearing them at three different temperatures: 20, 28, and 35 °C. The results, presented in **Figure 2**, indicate that mealworms reared at 35 °C showed the fastest progression from larvae to pupae, and eventually to adult beetles. However, mealworms maintained at 28 °C exhibited the highest mean weight, length, and survival rate. The group reared at 20 °C had the lowest survival rate, as well as smaller average weight and length.

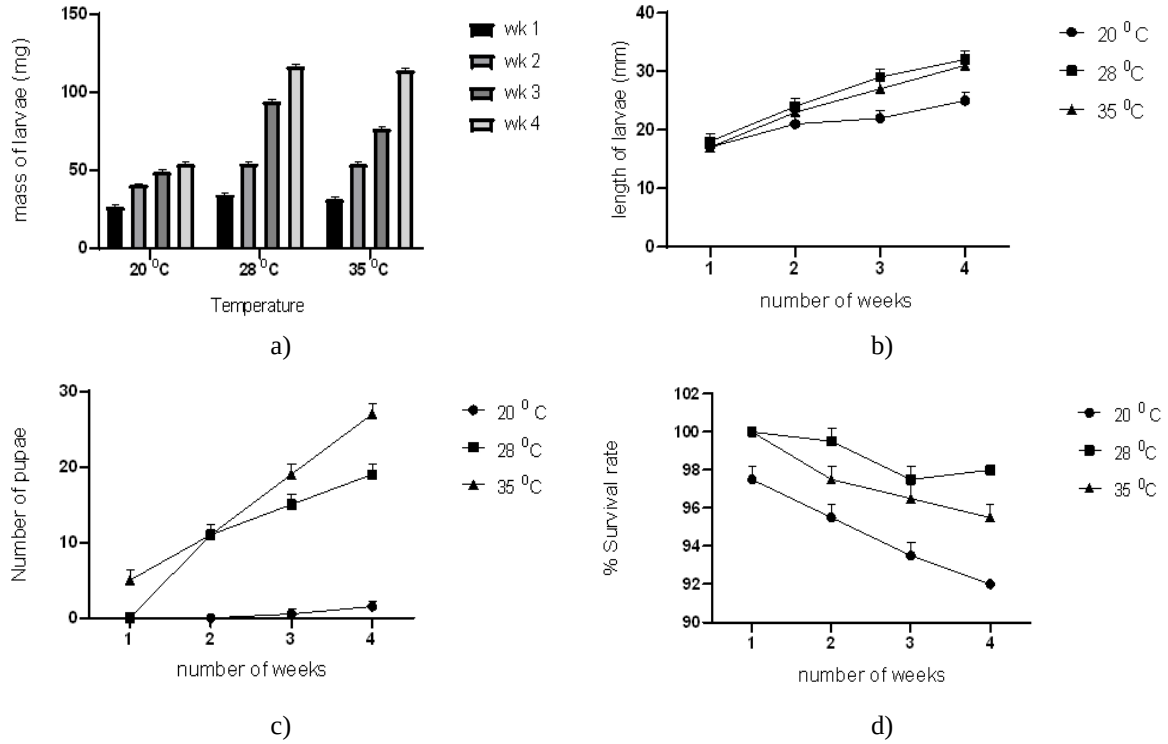
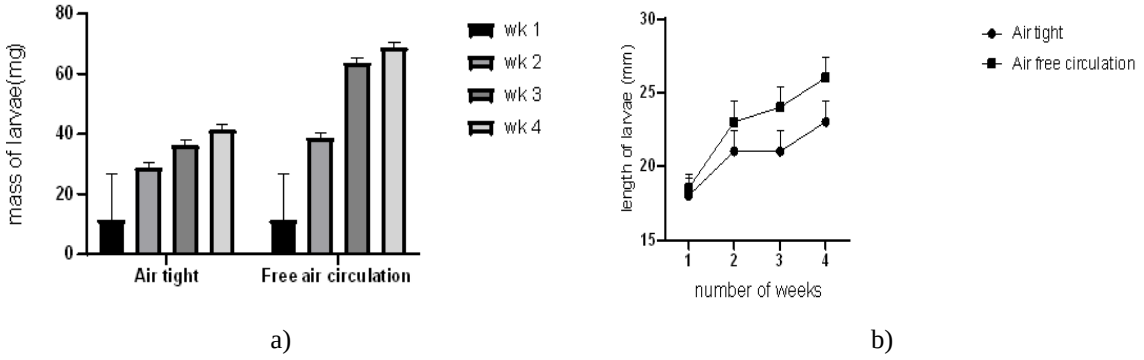


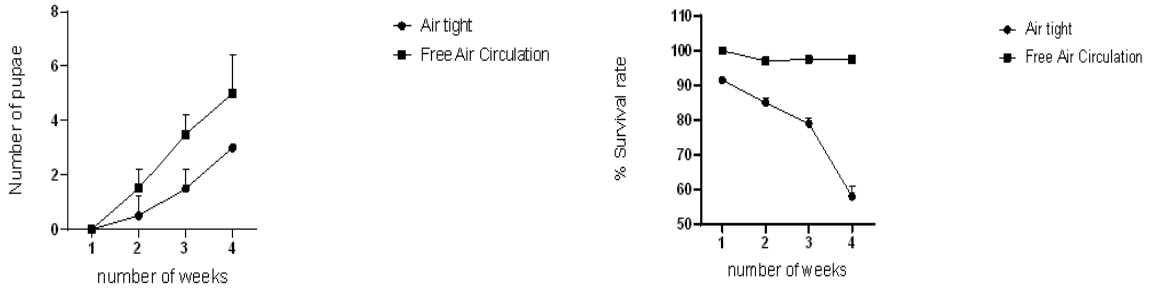
Figure 2. Impact of temperature on mealworm weight, length, development rate, and survival rate; a) variation in the average weight of mealworms, b) changes in the average length of mealworms, c) number of pupae that developed from larvae, and d) percentage survival rate of mealworms; all values are expressed as mean ± SD for n = 2.

Figure 2 reveals that the best temperature range for *T. molitor* breeding and rearing in Zimbabwe is 28 °C. These results align with the findings of Xu *et al*. [20], who examined the ideal conditions for mealworm cultivation. At 28 °C, the mealworms exhibited the highest survival rate of 98%, along with a mean weight of 117.5 mg and a mean length of 33 mm. Insects typically have various adaptations to endure colder temperatures, with water loss being one of the key mechanisms [21]. In this study, the mealworm group reared at 20 °C experienced a delay in pupation, potentially due to dehydration or water loss.

Influence of air circulation on mealworm development, growth, and survival

Mealworms were raised in environments with and without air circulation, and the findings are displayed in **Figure 3**. The findings indicate that mealworms demonstrate better development, growth, and survival rates when oxygen is present compared to environments without air circulation.



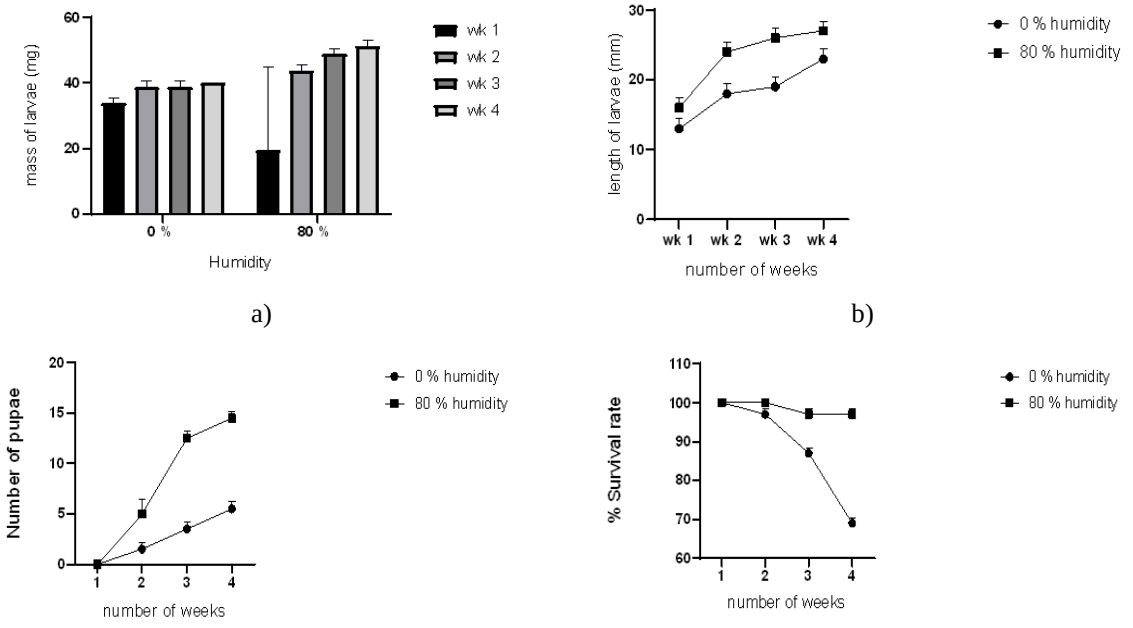


c) d)

Figure 3. The impact of air circulation on the mealworms' growth, development, and survival; mealworms that had access to proper air circulation showed greater growth and development, with a higher survival rate, compared to those kept in an environment without airflow; the presence of oxygen seemed to positively influence the mealworms' weight, length, development rate, and overall survival; the results underline the importance of maintaining adequate ventilation during the rearing process to ensure the optimal health and development of *T. molitor*.

The results from this finding highlight the significance of oxygen in the efficient rearing and breeding of *T. molitor* mealworms, as shown in **Figure 3**. Mealworms that were kept in an air-tight container experienced higher mortality rates compared to those housed in a well-ventilated environment. The presence of air circulation was crucial in promoting better survival and overall growth of the mealworms, emphasizing the importance of adequate ventilation for mealworm farming.

The mealworms were reared under two different humidity conditions: no humidity and 80% humidity. The results, presented in **Figure 4**, indicate that mealworms reared at 80% humidity exhibited better growth and development compared to those in an environment without humidity. The increased humidity likely played a key role in enhancing the mealworms' overall health, suggesting that maintaining optimal moisture levels is critical for promoting their development and survival.



a) b)

c) d)

Figure 4. The effects of varying humidity levels on the weight, length, development rate, and survival of mealworms; mealworms reared at 80% humidity exhibited better growth and development compared to those kept in conditions without any humidity; specifically, those in a humid environment showed higher survival rates, greater weight gains, and faster development into pupae; these findings suggest that maintaining appropriate humidity levels is vital for optimizing the health and productivity of *T. molitor* mealworms.

Relative humidity plays a crucial role in the development, growth, and overall survival of *T. molitor* mealworms. As shown in **Figure 4**, mealworms raised under 80% humidity displayed higher average body weight and length, a greater number of pupae, and a better survival rate compared to those kept in environments with 0% humidity. This emphasizes the importance of maintaining humid conditions for effective breeding and rearing.

Another critical factor in mealworm cultivation is their light preference. When mealworms were reared in different light conditions, the results revealed a clear preference for darkness. As shown in **Figure 5**, mealworms raised in the absence of light exhibited increased weight, length, and development, along with improved survival rates. Additionally, these mealworms consumed food at a higher rate when kept in the dark, as indicated by the faster depletion of feed mass **(Figure 5e)**. These findings suggest that mealworms thrive and grow more efficiently in darker conditions, highlighting the importance of controlling light exposure for optimal rearing conditions.

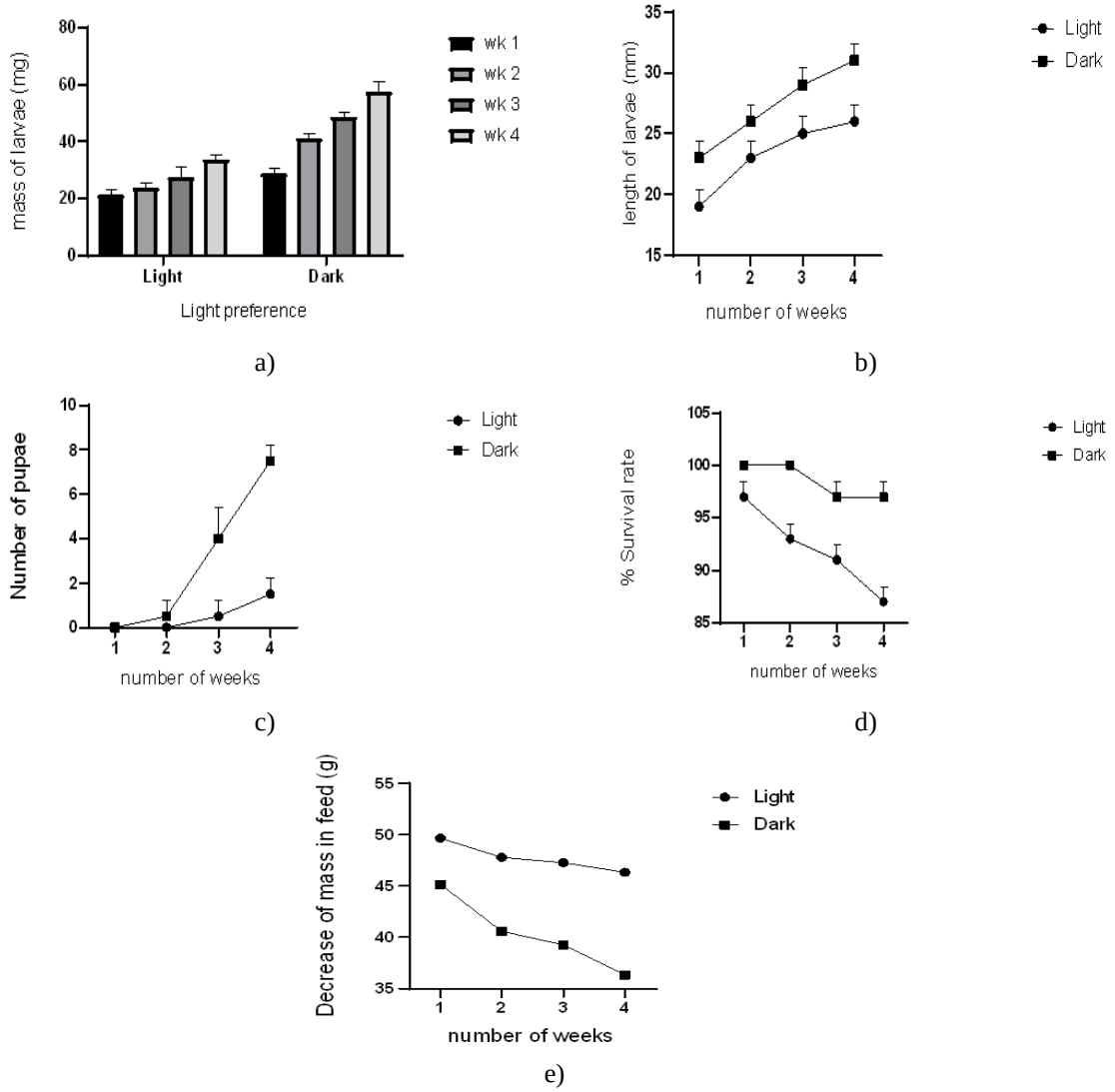


Figure 5. Impact of light conditions on the weight, size, development, and survival of mealworms; a) variation in the average weight of mealworms, b) variation in the average length of mealworms, c) number of pupae that developed from larvae, d) percentage of mealworm survival, and e) reduction in feed mass; all values are expressed as mean ± SD for n = 2.

Figure 5 demonstrates that mealworms show improved development in the absence of light. The data reveal that mealworms kept in darkness had a higher survival rate, greater average mass, and length compared to those exposed to light. Additionally, the mealworms in the dark consumed more feed than those in the light. This feeding preference is consistent with the behavior of adult mealworms, also known as darkling beetles, which tend to thrive in dark environments. These beetles are commonly found under rocks and logs, where leaf litter provides both adequate cover and a rich nutrient source [22].

Conclusion

Mealworms demonstrated optimal growth, development, and survival when provided with wheat bran and carrots as feed, maintained at 28 °C, in dark conditions, with adequate air circulation (oxygen), and 80% humidity.

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Conflict of Interest: None

Financial Support: None

Ethics Statement: None

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