J Biochem Technol (2023) 14(1): 27-33
https://doi.org/10.51847/2rdpiKkqm7
ISSN: 0974-2328

Investigating the Optimal Conditions for Rearing and Breeding *Tenebrio molitor* in Zimbabwe

Oleen Machona, Tadiwanashe Chiweshe, Farisai Chidzwondo, Rumbidzai Mangoyi*

Received: 18 November 2022 / Received in revised form: 27 February 2023, Accepted:03 March 2023, Published online: 15 March 2023

Abstract

For the past decade, Zimbabwe has been producing approximately a quarter of soya beans per year against national demand for food, animal feed, and industrial consumption. The gap between production and demand is met by imports from Malawi, South Africa, and Zambia. This study focuses on the larvae of *Tenebrio molitor*, commonly known as mealworms, as a sustainable alternative source of protein for animal feed. Conditions for breeding the mealworms in Zimbabwe were investigated and includes the composition of feed, temperature, light preference, air circulation, and relative humidity, with a special focus on mealworms' survival rate, growth performance, and development rate. The effect of the composition of feed on the growth performance was investigated by dividing the mealworms into five groups of 10 g each (approximately 100 mealworms) and exposing them to different dietary groups. Mealworms were then fed with the best-selected feed and the effects of relative humidity, temperature, oxygen, and light were determined. Weekly, the mortality rate, average weight, average length, and the number of mealworms that developed into pupae were recorded for each group. The results showed that the best feed composition was wheat bran and carrots with average weight and length of mealworms of 117 mg and 33 mm respectively, development rate of 64 %, and survival rate of 98 %. Generally, mealworms showed effective growth, development rate, and high survival rate when fed with wheat bran and carrots, at 28 ºC and 80 % humidity, in the absence of light and the presence of air.

Keywords: Tenebrio molitor, Feed, Temperature, Growth performance, Development rate, The survival rate

Introduction

Zimbabwe's soya bean production has been reported to have declined by 46 % due to the harsh economic conditions, use of retained seed by 90 % of the farmers, lack of adherence to recommended agronomic practices, low technical skills as well as limited access to capital and inputs (Nutrition Strategy, 2021). Generally, soya bean is used as the main source of protein for humankind and livestock in Zimbabwe. Therefore, the decrease in productivity means that the gap has to be met by imports from neighboring countries like Malawi, South Africa, and Zambia. Local production is just enough to meet 5 % of the country's oil needs with the soya crude oil import bill hovering around US$119 million in 2016 (Shafique *et al*., 2021). However, researchers have decided to look for other sources of protein, particularly insects as a sustainable alternative to traditional livestock, as recommended by the Food and Agriculture Organization (FAO) of the United Nations (Megido *et al*., 2018; German Federal Institute for Risk Assessment, 2019; Mancini *et al*., 2019; Chow *et al*., 2021).

Mealworms (*Tenebrio molitor*), giant mealworms (*Zophobasatratus*), lesser mealworms (*Alphitobusdiaperinus*), greater wax moth (*Galleria mellonella*), silkworm (*Bombyxmori*), house cricket (*Achetadomesticus*) and African migratory locust (*Locustamigratoramigratorioides*) are amongst the species with the greatest potential as food and feed within the European Union (Yu *et al*., 2021). This current study focuses on rearing and breeding the larvae of *Tenebrio molitor*, commonly known as mealworms, as a sustainable alternative source of protein for livestock in Zimbabwe. *Tenebrio molitor* has been commercially produced in the US for over 70 years and is a favorable candidate for insect rearing due to its high protein content, well-balanced amino acid profile, potential health benefits, efficient feed conversion rate, low greenhouse gas emissions, low water footprint reduced land usage, ability to live on organic by-products, and available mass production technology (Shah *et al*., 2022). *Tenebrio molitor* mealworms have also been reported to biodegrade organic waste into proteins (Rumbos *et al*., 2020; Alnemer *et al*., 2022).

Mealworm breeding has been reported to be cheap and fast from an economical point of view as its life cycle is very short. However, the growth rate, size of individuals, and development rate are affected by quite several factors such as temperature, air circulation, humidity, light intensity, the composition of the feed, and density of specimens within the breeding tanks (Liu *et al*., 2020; Bordiea *et al*., 2022). Thus, this study focuses on how several factors such as the composition of feed, temperature, light intensity, humidity, and air circulation affect the growth of *Tenebrio molitor* mealworms.

Materials and Methods

For the determination of each factor that affects growth, mealworms were reared with an *ad libitum* supply of feed for four weeks. The feed was replaced weekly to get rid of the environment of insect waste and uneaten feed.

Determination of the Effects of Feed Composition

Oleen Machona, Tadiwanashe Chiweshe, Farisai Chidzwondo, Rumbidzai Mangoyi*
Department of Biotechnology and Biochemistry, University of Zimbabwe, Zimbabwe.

***E-mail:** rrumbie.2000@gmail.com



© 2023 The Author(s). This is an **Open Access** article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY 4.0).
https://creativecommons.org/licenses/by/4.0/deed.en

Mealworms were divided into five different dietary groups and each group consisted of 10 g (approximately 100 mealworms). The different dietary groups were as follows:
Group 1---- 50 g of wheat bran only
Group 2-----50 g of wheat bran supplemented with 20 g of fresh carrots per day,
Group 3-----50 g of wheat bran supplemented with 20 g of fresh apple per day,
Group 4----50 g of wheat bran supplemented with 20 g of fresh cabbage per day,
Group 5---- 50 g of polystyrene only.

The feed which showed the highest growth rate and development rate was selected and fed to mealworms during the investigation of the effects of humidity, light preference, air circulation, and temperature on their growth performance.

Determination of the Effects of Relative Humidity

Mealworms were divided into 2 groups and each group consisted of 10 g (approximately 100 mealworms).
Group 1---- 50 g of wheat bran and 20 g of carrots in the absence of humidity,
Group 2---- 50 g of wheat bran and carrots at 80 % humidity.

Determination of the Effects of Temperature

The effect of temperature was investigated from the three groups of mealworms exposed to different temperatures using thermostatically controlled incubators. Each group consisted of 10 g of mealworm larvae (approximately 100 mealworms).
Group 1---- 50 g of wheat bran and 20 g carrots at 28 ºC,
Group 2---- 50 g of wheat bran and 20 g carrots at 20 ºC,
Group 3---- 50 g of wheat bran and 20 g carrots at 35 ºC.

Determination of the Effects of Air Circulation (Oxygen)

The effect of air circulation was observed from two groups of mealworms. Each group consisted of 10 g of mealworm larvae (approximately 100 mealworms).
Group 1---- 50 g of wheat bran and 20 g carrots in a tightly closed container with no air circulation,
Group 2---- 50 g of wheat bran and 20 g of carrots in a well-ventilated container.

Determination of the Effects of Light

The effect of light preference was observed in two groups of mealworms. Each group consisted of 10 g of mealworm larvae (approximately 100 mealworms).
Group 1---- 50 g of wheat bran and 20 g carrots in a container in a cupboard,
Group 2---- 50 g of wheat bran and 20 g carrots in a container exposed to daylight.

Determination of Mortality Rate, Growth Performance, and Development Rate

For all the groups under investigation, mortality rate, growth performance, and development rate were determined as follows:

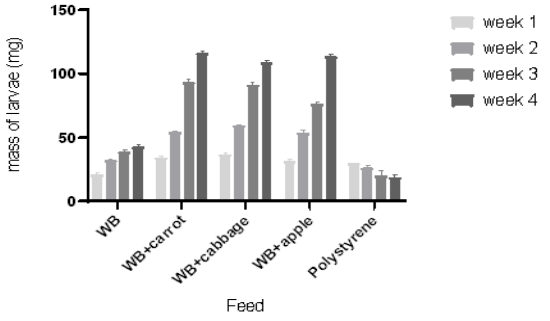
1. Mealworm pupae and dead larvae were removed daily from each group, and the numbers were recorded.
2. The time taken for larvae to develop into pupae was also recorded for each of the mealworms in all the groups
3. The separated pupae were observed daily for enclosed beetles.
4. The average weight of the mealworm larvae was recorded each week on 40 –50 randomly selected mealworms within a group.
5. The length of 20 randomly selected mealworms was measured and the average length of mealworm larvae in each group was recorded

The feeding rate of mealworms from the two groups (absence of light and presence of light) was also determined by measuring the feed consumed on weekly basis.

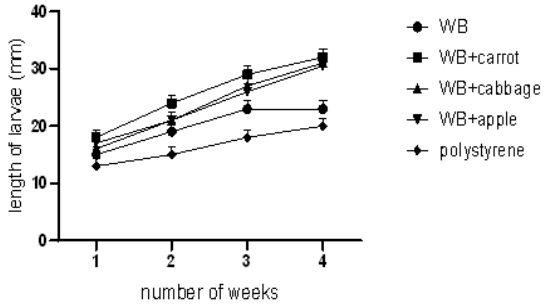
Results and Discussion

The Effects of Feed Composition on the Growth, Development, and Survival Rate of Mealworms

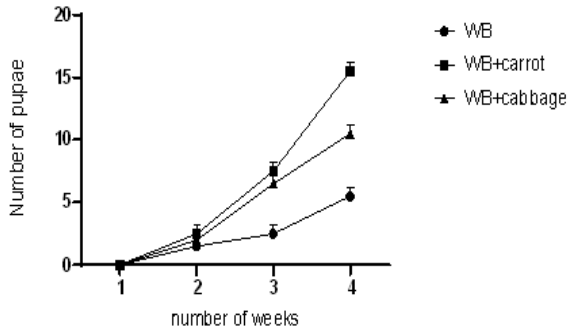
The average weight and the size of the mealworms from each dietary group were measured on weekly basis to determine the effects of different feed compositions, and results are reported in **(Figure 1)**. The results show the highest increase in both the average weight and the length of mealworms from the group that was fed with wheat bran and carrots and the lowest increase from the group that was fed with polystyrene. The wheat bran and carrots group also showed the highest development rate as well as the survival rate as 28 % of the mealworms developed into pupae (Kumar *et al.*, 2022).



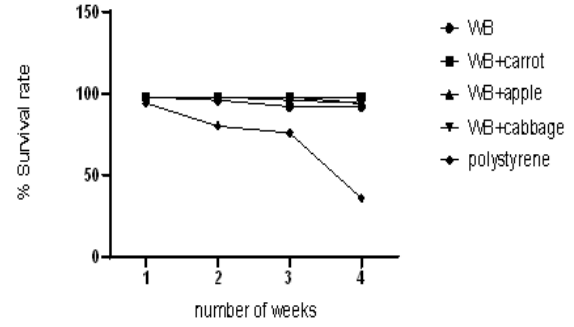
a)



b)



c)



d)

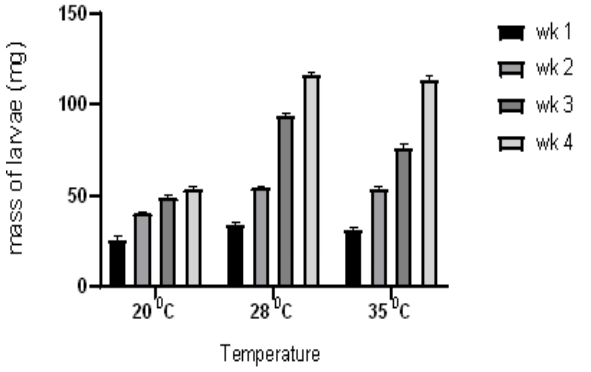
Figure 1. Effects of different feed compositions on weight, size, development rate, and survival rate of mealworms. a) changes in the average weight of mealworms, b) changes in the average length of mealworms, c) number of pupae that developed from the larvae stage, d) the % survival rate of mealworms.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

The larvae of *Tenebrio molitor*, also known as mealworms, which belong to the species of edible insects have long been used as food worldwide and are commonly bred (Józefiak *et al*., 2018; Sogari *et al*., 2019). The efficiency of rearing is influenced by many factors and these include temperature, relative humidity, feed, light preference, oxygen, and the region of rearing. The composition of the feed is one of the key factors in the whole rearing such that improper choice of feed results in slowing down the larvae development or death of the mealworms (Yang *et al*., 2018; Valdés *et al*., 2022). In this particular study, to guarantee the quality of feed as well as to increase the efficiency of rearing and production of insects, the wheat bran was further enriched and supplemented with fruits and vegetables. Polystyrene foam was added to the experiment as feed to investigate the sustainability of the state of nature and waste disposal.

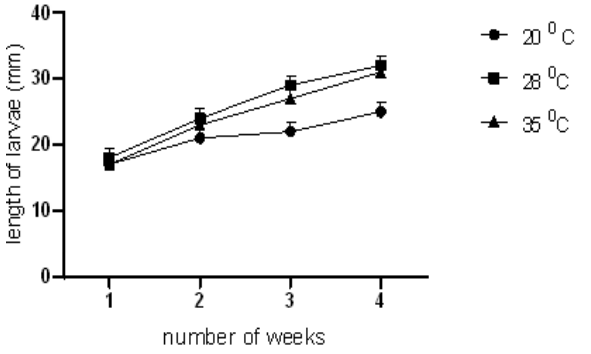
(Figure 1) shows that mealworms fed with polystyrene had the least % survival rate and this was caused by the fact that there is low nutritional value in polystyrene. The groups fed with wheat bran and apple, wheat bran and cabbage, wheat bran and carrots, and wheat bran only had the lowest mortality rates. It was observed that wheat bran supplemented with either a fruit or vegetable had a positive effect on life development as mealworms in these groups increased in weight and length and also had the most accelerated rate of development into pupae and then adults. The choice of feed is crucial as it results in rearing gain; a short life cycle of insects is considered in determining if one is a good farmer or not (Yang *et al*., 2015). It has also been reviewed that feed also affects the nutritional value of edible insects (Costa *et al*., 2020).

The Effects of Temperature on the Growth, Development, and Survival Rate of Mealworms

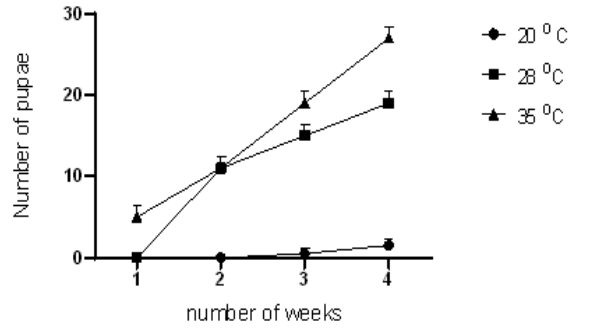
Mealworms were reared at different temperatures of 20 ºC, 28 ºC, and 35 ºC and **(Figure 2)** shows the results that were obtained. There was an increase in the development rate of the mealworms from larvae stage to pupae and finally beetles at 35 ºC **(Figure 2C)**. However, at 28 ºC mealworms had the highest average weight and length as well as the survival rate. The lowest survival rate, average weight, and length were observed from the group of mealworms reared at 20 ºC.



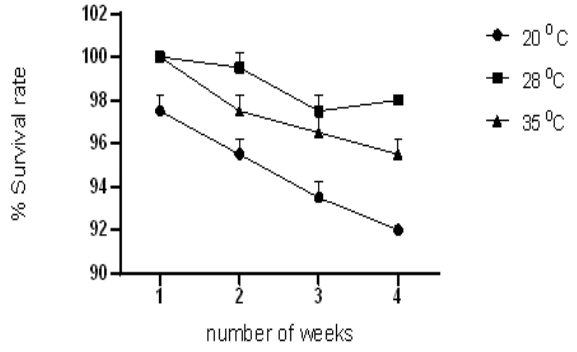
a)



b)



c)



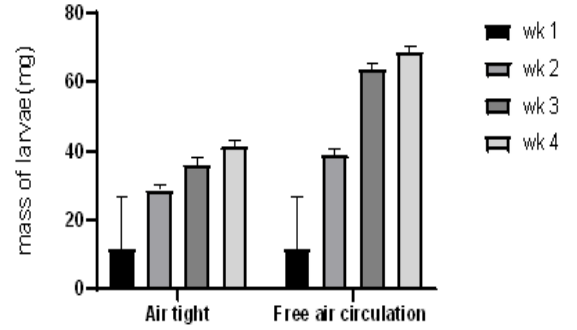
d)

Figure 2. Effects of temperature on weight, length, 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, d) the % survival rate of mealworms. All values are mean±SD for N=2

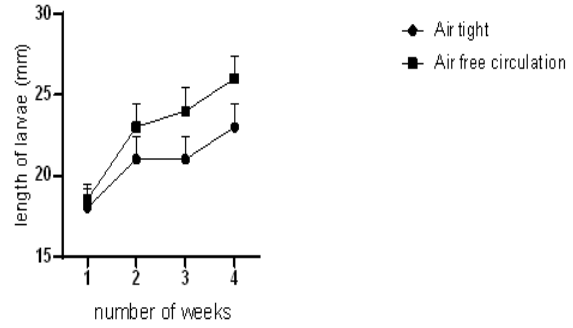
(Figure 2) shows that the optimum temperature for rearing and breeding of *Tenebrio molitor* in Zimbabwe in the range tested is 28 °C. The results obtained were in line with Xu *et al.* (2012), who also investigated the optimum temperature for breeding mealworms (*Tenebrio molitor*) (Xu *et al*., 2012). At 28 °C, mealworms had the highest survival rate of 98 %, the highest average weight of 117.5 mg, and the highest average length of 33 mm. Generally, insects have different adaptations to survive when exposed to low temperatures. One of the ways is water loss (Orkusz, 2021) and in this present study, the group of mealworms bred at 20 °C delayed developing into pupae, which could be a result of water loss.

The Effects of Air Circulation on the Growth, Development, and Survival Rate of Mealworms

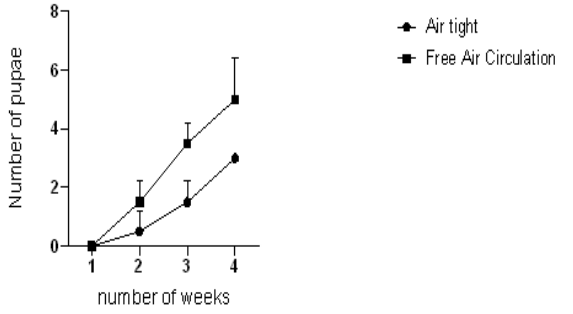
Mealworms were reared in the presence and absence of oxygen and the results are shown in **(Figure 3)**. The results show that mealworms grow, develop, and survive better in the presence of light than in the absence of light.



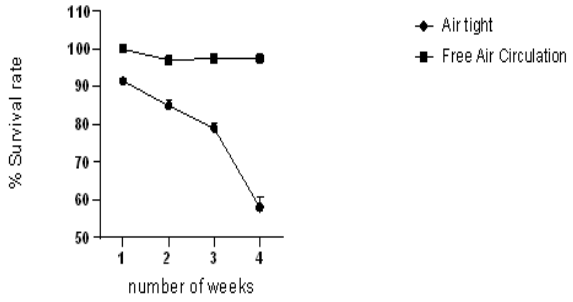
a)



b)



c)



d)

Figure 3. Effects of air circulation on weight, length, 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, d) the % survival rate of mealworms. All values are mean±SD for N=2

Results from this study showed that oxygen is an important factor in the efficient breeding and rearing of *Tenebrio molitor* mealworms **(Figure 3)**. There was a high mortality rate in the group of mealworms reared in an air-tight container compared to the group of mealworms that were reared in a well-ventilated space.

The Effects of Humidity on the Growth, Development, and Survival Rate of Mealworms

Mealworms were reared in the absence of humidity and at 80 % humidity, and results are shown in **(Figure 4)**. At 80 % humidity mealworms grew and developed better than in the absence of humidity.

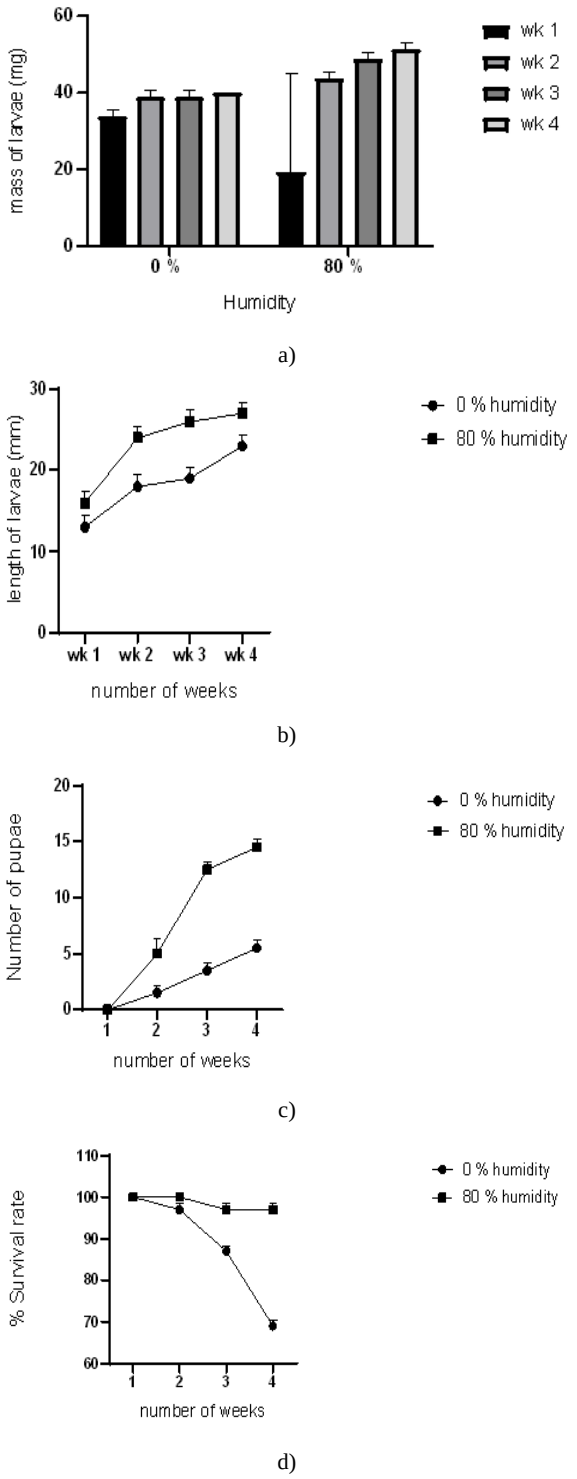
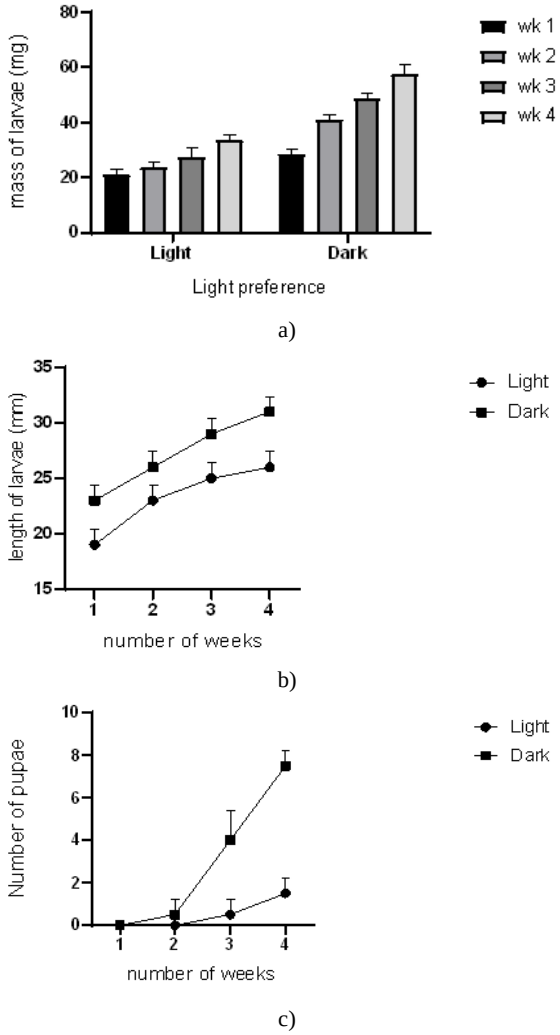


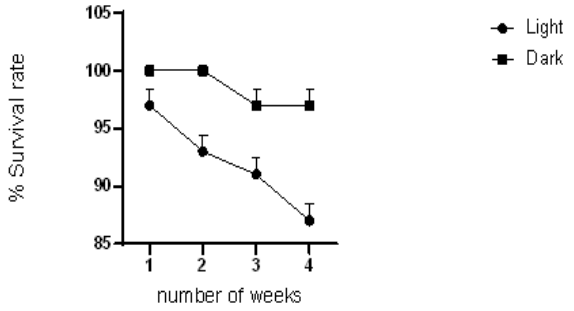
Figure 4. Effects of humidity on weight, length, development rate, and survival rate of mealworms. a) changes in the average weight of mealworms, b) changes in the average length of mealworms, c) number of pupae that developed from the larvae stage, d) the % survival rate of mealworms. All values are mean±SD for N=2

Relative humidity has also been shown to have an impact on the lifecycle, growth, and development rate of *Tenebrio molitor* mealworms as the group of mealworms with 80 % humidity had the higher average mass and average length, number of pupae collected as well as the survival rate compared to the group of mealworms with 0 % humidity as shown in **(Figure 4)**. This indicated that mealworms require the presence of humid conditions for efficient rearing and breeding. Another important factor in rearing mealworms is to know their growth rate in the presence or absence of light.

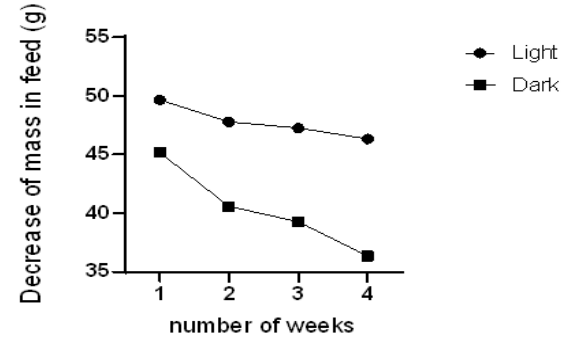
The Effects of Light Preference on Growth, Development, and Survival Rate of Mealworms

The mealworms were reared in the presence and absence of light and the results are shown in **(Figure 5)**. Results show that mealworms favor darkness over light as an increase in the average weight and length of the mealworms from the absence of light group was observed. The increase in development and survival rate was also observed in this group. The feeding rate of these mealworms was also investigated and results show that mealworms feed at a greater rate in the dark than in the presence of light as explained by a gradual decrease of mass in the feed **(Figure 5E)**.





d)



e)

Figure 5. Effects of light on weight, length, 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. d) the % survival rate of mealworms, e) decrease in mass of the feed. All values are mean±SD for N=2

(Figure 5) confirms that mealworms develop more efficiently in the absence of light as the figure shows a higher survival rate, average mass, and length of mealworms reared in darkness as compared to those reared in the presence of light. The feeding rate of mealworms in the dark was also found to be more than that of mealworms in the presence of light. This feeding behavior of mealworms is similar to the adults which are also called the darkling beetles as they are fond of darkness. They are often found underneath rocks and logs because of the leaf litter's abundant covering and high resource for nutrients (Riekkinen *et al*., 2022).

Conclusion

Mealworms showed effective growth, development rate, and high survival rate when fed with wheat bran and carrots, at 28 ºC, in the absence of light, in the presence of air (oxygen), and in 80 % humidity.

Acknowledgments: The University of Zimbabwe Research Board (Harare, Zimbabwe) is acknowledged.

Conflict of interest: None

Financial support: Reagents used in this study were provided by the Biotechnology and Biochemistry Department at the University of Zimbabwe, Zimbabwe.

Ethics statement: None

References

Alnemer, S., Alajlan, A. M., Alqarni, A. N., Alshanbari, S. H., Alhejazi, M. A., Matrood, M. A., Alkathiri, M. S., Almutairi, M. S., Aldayhani, A. B., Daabash, M. D. A., et al. (2022). Knowledge and practices of Riyadh-based dentists in managing traumatic dental injuries. *Annals Journal of Dental and Medical Assisting*, *2*(1), 22-25. doi:10.51847/ZGZXIiiSUR

Bordiean, A., Krzyżaniak, M., Aljewicz, M., & Stolarski, M. J. (2022). Influence of Different Diets on Growth and Nutritional Composition of Yellow Mealworm. *Foods*, *11*(19), 3075.

Chow, C. Y., Riantiningtyas, R. R., Sørensen, H., & Frøst, M. B. (2021). School children cooking and eating insects as part of a teaching program–Effects of cooking, insect type, tasting order and food neophobia on hedonic response. *Food Quality and Preference*, *87*, 104027.

Costa, S., Pedro, S., Lourenço, H., Batista, I., Teixeira, B., Bandarra, N. M., Murta, D., Nunes, R., & Pires, C. (2020). Evaluation of Tenebrio molitor larvae as an alternative food source. *NFS Journal*, *21*, 57-64.

German Federal Institute for Risk Assessment (BfR), National Reference Laboratory for Animal protein in Feed, NRL-AP, Garino, C., Zagon, J., & Braeuning, A. (2019). Insects in food and feed–allergenicity risk assessment and analytical detection. *EFSA Journal*, *17*, e170907.

Józefiak, A., Kierończyk, B., Rawski, M., Mazurkiewicz, J., Benzertiha, A., Gobbi, P., Nogales-Merida, S., Świątkiewicz, S., & Józefiak, D. (2018). Full-fat insect meals as feed additive–the effect on broiler chicken growth performance and gastrointestinal tract microbiota. *Journal of Animal and Feed Sciences*, *27*(2), 131-139.

Kumar, D., Gurunathan, D., Jabin, Z., & Talal, S. (2022). Comparative efficacy of aromatherapy and conscious sedation in pediatric dental anxiety management. *Annals Journal of Dental and Medical Assisting*, *2*(1), 14-21. doi:10.51847/TVRFhVaiIQ

Liu, C., Masri, J., Perez, V., Maya, C., & Zhao, J. (2020). Growth performance and nutrient composition of mealworms (Tenebrio molitor) fed on fresh plant materials-supplemented diets. *Foods*, *9*(2), 151.

Mancini, S., Moruzzo, R., Riccioli, F., & Paci, G. (2019). European consumers' readiness to adopt insects as food. A review. *Food Research International*, *122*, 661-678.

Megido, R. C., Poelaert, C., Ernens, M., Liotta, M., Blecker, C., Danthine, S., Tyteca, E., Haubruge, É., Alabi, T., Bindelle, J., et al. (2018). Effect of household cooking techniques on the microbiological load and the nutritional quality of mealworms (Tenebrio molitor L. 1758). *Food Research International*, *106*, 503-508.

Nutrition Strategy. (2021). Ministry of Health and Child Care. Harare. 2021.

Orkusz, A. (2021). Edible insects versus meat—Nutritional comparison: Knowledge of their composition is the key to good health. *Nutrients*, *13*(4), 1207.

Riekkinen, K., Väkeväinen, K., & Korhonen, J. (2022). The Effect of Substrate on the Nutrient Content and Fatty Acid Composition of Edible Insects. *Insects*, *13*(7), 590.

Rumbos, C. I., Karapanagiotidis, I. T., Mente, E., Psofakis, P., & Athanassiou, C. G. (2020). Evaluation of various commodities for the development of the yellow mealworm, Tenebrio molitor. *Scientific Reports*, *10*(1), 11224.

Shafique, L., Abdel-Latif, H. M., Hassan, F. U., Alagawany, M., Naiel, M. A., Dawood, M. A., Yilmaz, S., & Liu, Q. (2021). The feasibility of using yellow mealworms (Tenebrio molitor): Towards a sustainable aquafeed industry. *Animals*, *11*(3), 811.

Shah, A. A., Totakul, P., Matra, M., Cherdthong, A., Hanboonsong, Y., & Wanapat, M. (2022). Nutritional composition of various insects and potential uses as alternative protein sources in animal diets. *Animal Bioscience*, *35*(2), 317-331.

Sogari, G., Amato, M., Biasato, I., Chiesa, S., & Gasco, L. (2019). The potential role of insects as feed: A multi-perspective review. *Animals*, *9*(4), 119.

Valdés, F., Villanueva, V., Durán, E., Campos, F., Avendaño, C., Sánchez, M., Domingoz-Araujo, C., & Valenzuela, C. (2022). Insects as feed for companion and exotic pets: a current trend. *Animals*, *12*(11), 1450.

Xu, S., Gu, M., Liu, X., & Yang, L. (2012). Experimental population life table of Tenebrio molitor at different temperatures. *Journal of Henan Agricultural Sciences*, *41*(3), 85-89.

Yang, S. S., Wu, W. M., Brandon, A. M., Fan, H. Q., Receveur, J. P., Li, Y., Wang, Z. Y., Fan, R., McClellan, R. L., Gao, S. H., et al. (2018). Ubiquity of polystyrene digestion and biodegradation within yellow mealworms, larvae of Tenebrio molitor Linnaeus (Coleoptera: Tenebrionidae). *Chemosphere*, *212*, 262-271.

Yang, Y., Yang, J., Wu, W. M., Zhao, J., Song, Y., Gao, L., Yang, R., & Jiang, L. (2015). Biodegradation and mineralization of polystyrene by plastic-eating mealworms: part 2. Role of gut microorganisms. *Environmental Science & Technology*, *49*(20), 12087-12093.

Yu, X., He, Q., & Wang, D. (2021). Dynamic analysis of major components in the different developmental stages of Tenebrio molitor. *Frontiers in Nutrition*, *8*, 689746.