EQUILIBRIUM JOURNAL OF CHEMICAL ENGINEERING
*Homepage:*https://jurnal.uns.ac.id/equilibrium

Tenebrio molitor Larvae Feeding Strategy to Degrade Polypropylene Components from Disposable Masks

Khadijah Sayyidatun Nisa[a], Reynaldi Ivan Prasetya[a], Ibnu Maulana Hidayatullah[b*], Abdussalam Topandi[a], Fatimah Azizah Riyadi[b], Firah Gustianda Ayu[a], Frederick Soetandar[c], Dimas Rafi Narawangsa[b]

[a]*Polymeric Chemical Engineering Department, Polytechnic STMI of Jakarta, Jakarta, Indonesia 10510*
[b]*Chemical Engineering Department, Engineering Faculty, University of Indonesia, Depok, Indonesia 16424*
[c]*Department of Biotechnology and Life Science Tokyo University of Agriculture and Technology, Japan*

[*]Corresponding author: ibnu.maulana.h@che.ui.ac.id

DOI: *https://dx.doi.org/10.20961/equilibrium.v8i1.84381*

Article History
Received: 06-02-2024, Accepted: 20-05-2024, Published: 28-05-2024

Keywords:
Mask, Degrade, *Tenebrio molitor*, Microflora, Polypropylene

ABSTRACT. The surge in mask consumption during the COVID-19 pandemic led to the widespread use of disposable polypropylene masks for protection. However, the accumulation of used masks poses environmental challenges due to the slow degradation of polypropylene. Here, we investigate the potential of *Tenebrio molitor* larvae in degrading polypropylene masks, exploiting their synthetic polymer-breaking enzymes and associated microflora. In this study, we implemented various feeding strategies and established specific feed compositions to assess *T. molitor* larvae's consumption behavior towards polypropylene masks. Over a 21-day observation period, we noted a consumption rate of 0.4% of masks, with a 7.5% mortality rate among the larvae. The average daily consumption rate was 0.201 grams, resulting in a 2.3% increase in larval weight and the production of 0.4635 grams of feces. Our findings highlight the potential of *T. molitor* larvae as effective mask degraders. Optimizing cultivation conditions and feeding strategies may further enhance microbial diversity, potentially introducing more polypropylene degraders within *T. molitor*, thereby expediting mask degradation. This study emphasizes the promising role of *T. molitor* larvae in addressing the environmental challenges posed by the accumulation of polypropylene masks.

1. INTRODUCTION

The COVID-19 outbreak was declared a pandemic and global health emergency by the World Health Organization (WHO) in January 2020, spreading rapidly to multiple countries worldwide. This unprecedented pandemic has profoundly impacted waste generation and composition across various regions. Notably, the widespread use of disposable masks made of polypropylene (PP) to combat COVID-19 transmission has led to a significant surge in PP waste. Over an 18-month period from December 2019 to May 2021, approximately 1.24 trillion disposable masks were used [1]. The urgency of the COVID-19 pandemic has forced more people to use masks, dramatically increasing the rate of PP waste accumulation [2]. PP waste, characterized by its low biodegradability and associated risks if not managed properly, is typically processed using the incineration method [3]. However, during the COVID-19 pandemic, this method resulted in elevated emissions of gases and microplastic pollution, posing secondary environmental consequences for solid waste management [4].

Disposable masks typically consist of three layers, all composed of PP: an inner layer of fibrous material (non-dyed part), a middle inflatable filter part, and an outer waterproof non-woven layer [5]. PP, a type of thermoplastic polymer, is chosen for its affordability and superior thermal and mechanical properties [6,7]. Previous research has indicated that *Tenebrio molitor* microflora can reduce the subatomic load of PP by 20.4 ± 0.8%, demonstrating their ability to depolymerize PP [8]. This study aims to determine the optimal feeding strategy of *T. molitor* larvae in degrading PP, focusing on their mortality rates as a key parameter.

2. MATERIALS AND METHODS

2.1 Material

T. molitor larvae were sourced from a local market in North Jakarta, Indonesia. These larvae measured approximately 1.50 – 2.00 cm in length and weighed between 50.00 – 61.25 mg per larva. Additive-free oat bran was obtained from a North Jakarta supermarket and served as the raw material for the control group. Disposable surgical masks composed of polypropylene were obtained from authorized medical mask vendors. The outer, middle, and inner layers of these masks were utilized as experimental raw materials. Throughout the experiment, no surgical masks were replaced.

2.2 Method

T. molitor larvae were subjected to a feeding strategy involving oat brans after a 24-hour fasting period to initiate the experimental diet. One hundred larvae were randomly chosen and placed in a container (20×15×10 cm) to maintain an optimal larval density for growth [9]. Throughout the larval rearing phase, all containers were maintained at room temperature (25°C), which is the ideal condition for cultivating *T. molitor* larvae.

The feeding strategy employed utilized varying ratios of oat bran and cut masks, with experimental groups consisting of 0% oat bran, 25% oat bran, 75% oat bran, and 100% oat bran. Initially, *T. molitor* larvae were fed a mixture of oat bran and mask equivalent to 30% of the total larvae's weight in each group. Additionally, once weekly, a slice of potato was provided, comprising 50% of the total larvae weight in each group. Subsequently, *T. molitor* larvae were fed the mixed food for approximately 7 days and adjusted to any remaining food in the container. Pupae were then separated from the larvae container to prevent cannibalism, and any deceased larvae were promptly separated from the colony [8]. Oat brans were added to the control group at the beginning of the experiment, with additional oat brans added every three days.

3. RESULTS AND DISCUSSION

T. molitor larvae can be proven to degrade masks by biting directly on the mask, and physical evidence is in the form of changes in shape/holes in the mask (Figure 1). All variations of *T. molitor* larvae provided with cut masks demonstrated an increase in weight during the 21-day observation period, with the highest percentage weight increase of 18.35% in the 50% oat variation. The percentage increase in weight of *T. molitor* larvae in each variation was 2.26% for 0% oats, 14.13% for 25% wheat, and 17.56% for 75% oats. It can be revealed that *T. molitor* larvae can thrive by eating unusual foods. *T. molitor* larvae have been proven to survive in a feed ratio of 50% oat bran and 50% mask, so *T. molitor* larvae have the opportunity to be used in processing mask waste that is safe for the environment.

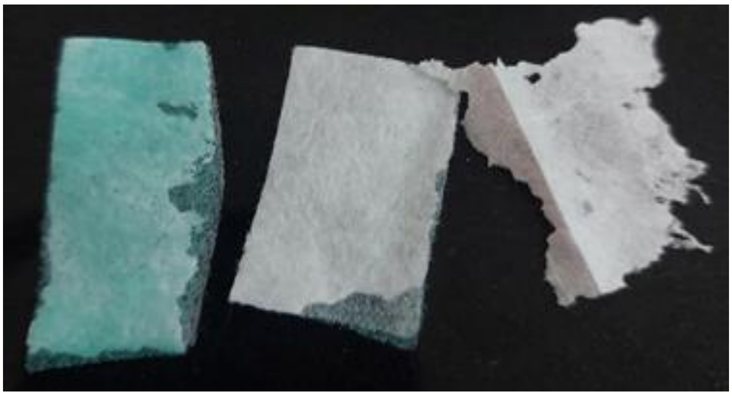

Figure 1. Mask Samples Degraded by *T. molitor*

Figure 2 shows an increasing trend in a graph, further proving the mask's influence on the larvae's feed content and the impact of cultivation time on the larvae's mass. Still, it can also be seen that within 21 days, the increase in larval mass was not constant since the larval mass still decreased within several days. *This phenomenon* could be caused by the nutritional needs of the larvae not being met. The masks given as larval feed only contain oxygen, carbon, hydrogen, alcohol and phenol [10]. *T. molitor* larvae require several nutrients such as amino acids, sodium, nitrogen, phosphorus, potassium, trace elements, and others for long-term survival and development [8].

T. molitor larvae have demonstrated their capacity to degrade masks, leading to observable physical changes such as shape alterations or the presence of holes in the mask (Figure 1). Throughout the 21-day observation period, all groups of *T. molitor* larvae provided with cut masks exhibited an increase in weight. The group with a 50% oat content showed the highest percentage weight increase, reaching 18.35%. The percentage weight increase varied across different oat content ratios, with 2.26% for 0% oats, 14.13% for 25% oats, and 17.56% for 75% oats. This indicates the adaptive feeding behavior of *T. molitor* larvae to mask. The ability of *T. molitor* larvae to survive on a diet comprising 50% oat bran and 50% mask material highlights their potential in processing mask waste in an environmentally friendly manner.

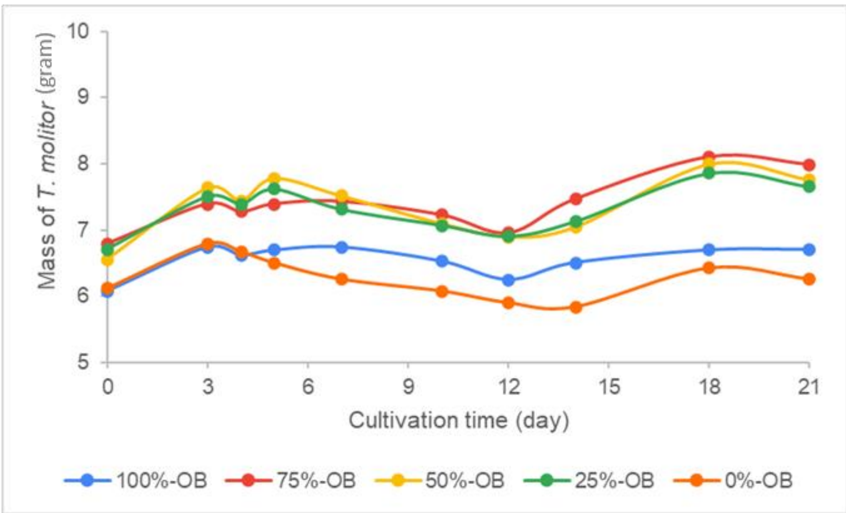

Figure 2. *T. molitor* Larval Mass during Cultivation Period

Figure 2 depicts an increasing trend, providing additional evidence of the masks' influence on larval feed composition and the impact of cultivation time on larval mass. However, it is noteworthy that the increase in larval mass was not consistent throughout the 21 days, as there were periods of decrease, possibly due to insufficient nutritional content in the masks. Masks used as larval feed primarily consist of oxygen, carbon, hydrogen, alcohol, and phenol [10], while *T. molitor* larvae require a broader range of nutrients such as amino acids, sodium, nitrogen, phosphorus, potassium, trace elements, among others, for sustained survival and development [8].

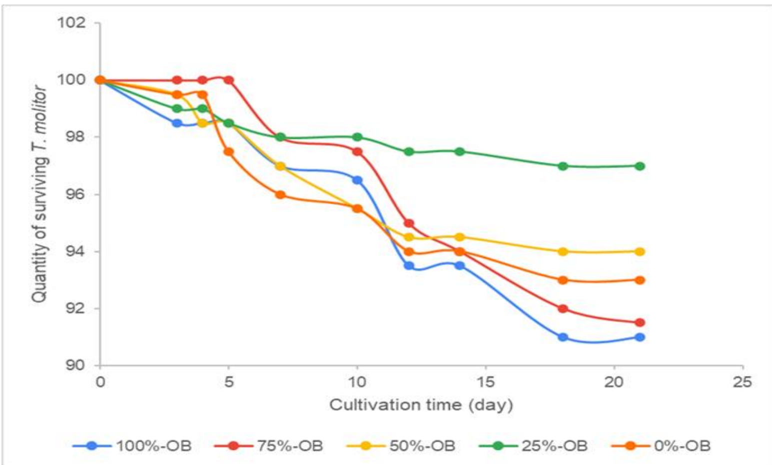

Figure 3. *T. molitor* Mortality Rate

The mortality graph depicted in Figure 3 illustrates that the highest survival rate, with 97 larvae, was observed in the 25%-OB variant, while the lowest survival rate, with 91 larvae, was noted in the 100%-OB group. The findings suggest that the mortality rate of *T. molitor* larvae fed with 100% oats was higher compared to other variants where masks were included in the diet. This difference could be attributed to the rapid growth of certain larvae, leading them to undergo pupation and transformation into beetles quicker than those in other feed groups. Consequently, larvae that progressed to the pupal or beetle stage were removed from the population, influencing the overall survival rate. This approach was implemented because the primary objective of this study was to utilize larvae for degradation purposes and prevent cannibalism [8].

4. CONCLUSION

In conclusion, the study's findings confirm that *T. molitor* larvae possess the capability to degrade masks, as supported by visible alterations in shape. Over the 21-day observation period, masks provided as larval food showed increased weight, particularly in the 50% oat variant, highlighting the larvae's adaptability to this diet. Survival rates varied, with the 25%-OB variation exhibiting the highest rate of 97 individuals, while the 100%-OB variant had the lowest rate at 91 individuals. This variation in survival rates likely results from the larvae's efficient utilization of oat nutrition, promoting rapid growth and transition to pupae or beetles, thus reducing the larval population. These results emphasize *T. molitor* larvae's potential as effective agents for mask degradation. Future studies could focus on optimizing feeding strategies to improve degradation rates.

ACKNOWLEDGEMENTS

This research was supported by the Universitas Indonesia with Publikasi Terindeks Internasional (grant number NKB-514/UN2.RST/HKP.05.00/2023). We are grateful for the labor facility from Polytechnic STMI of Jakarta.

REFERENCES

[1] G. A. Idowu, A. O. Olalemi, and A. F. Aiyesanmi, "Environmental impacts of covid-19 pandemic: Release of microplastics, organic contaminants and trace metals from face masks under ambient environmental conditions," *Environ Res*, vol. 217, p. 114956, Jan. 2023, doi: 10.1016/j.envres.2022.114956.

[2] N. B. Douti, E. E. Y. Amuah, E. Acheampong, P. Dankwa, R. W. Kazapoe, and E. P. Agyemang, "Management of face masks driven by the COVID-19 pandemic, possible implications and proposed policies: A household perspective," *World Development Sustainability*, vol. 3, p. 100093, Dec. 2023, doi: 10.1016/j.wds.2023.100093.

[3] P. Rajeev, A. Ramesh, S. Navaratnam, and J. Sanjayan, "Using Fibre recovered from face mask waste to improve printability in 3D concrete printing," *Cem Concr Compos*, vol. 139, p. 105047, May 2023, doi: 10.1016/j.cemconcomp.2023.105047.

[4] A. Hosseinzadeh, R. Hayati, N. Alinejad, and A. Badeenezhad, "Main challenges caused by the epidemic on hospital waste management and their control methods: A case study based on the experience of the Covid-19 pandemic," *Case Studies in Chemical and Environmental Engineering*, vol. 8, p. 100441, Dec. 2023, doi: 10.1016/j.cscee.2023.100441.

[5] T. A. Aragaw, "Surgical face masks as a potential source for microplastic pollution in the COVID-19 scenario," *Mar Pollut Bull*, vol. 159, p. 111517, Oct. 2020, doi: 10.1016/j.marpolbul.2020.111517.

[6] Y. Li *et al.*, "Life-cycle assessment reveals disposable surgical masks in 2020–2022 led to more than 18 million tons of carbon emissions," *One Earth*, vol. 6, no. 9, pp. 1258–1268, Sep. 2023, doi: 10.1016/j.oneear.2023.08.008., vol. 197, pp. 1–33, Nov. 2014, doi: 10.1016/j.anifeedsci.2014.07.008.

[7] A. Alsabri, F. Tahir, and S. G. Al-Ghamdi, "Environmental impacts of polypropylene (PP) production and prospects of its recycling in the GCC region," *Mater Today Proc*, vol. 56, pp. 2245–2251, 2022, doi: 10.1016/j.matpr.2021.11.574.

[8] S.-S. Yang *et al.*, "Biodegradation of polypropylene by yellow mealworms (Tenebrio molitor) and superworms (Zophobas atratus) via gut-microbe-dependent depolymerization," *Science of The Total Environment*, vol. 756, p. 144087, Feb. 2021, doi: 10.1016/j.scitotenv.2020.144087.

[9] S. W. Przemieniecki, A. Kosewska, S. Ciesielski, and O. Kosewska, "Changes in the gut microbiome and enzymatic profile of Tenebrio molitor larvae biodegrading cellulose, polyethylene and polystyrene waste," *Environmental Pollution*, vol. 256, p. 113265, Jan. 2020, doi: 10.1016/j.envpol.2019.113265.

[10] P. Karthikeyan, M. Subagunasekar, N. Lenin, and K. Prabhu, "Abundance, spatial distribution, and chemical characterization of face masks on the beaches of SE Kanyakumari, India," *Mar Pollut Bull*, vol. 192, p. 115031, Jul. 2023, doi: 10.1016/j.marpolbul.2023.115031.