



Ingestion and biodegradation of disposable surgical masks by yellow mealworms *Tenebrio molitor* larvae: Differences in mask layers and effects on the larval gut microbiome

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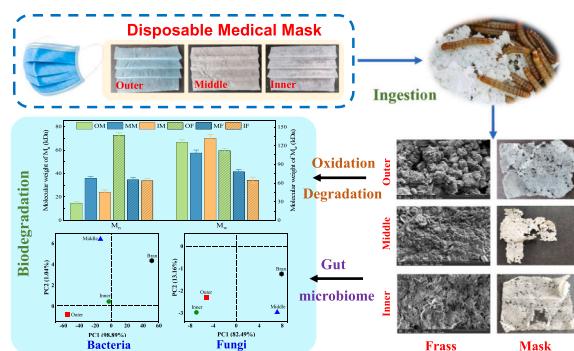
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HIGHLIGHTS

- Surgical masks of PP material could be ingested and degraded by yellow mealworms.
- The depolymerization of mask middle layers is different from that of other layers.
- Both larval gut bacteria and fungi are differently influenced by mask layer diets.
- Gut microbiomes are different for crystalline thermoplastic structures of mask layers.

GRAPHICAL ABSTRACT



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ABSTRACT

During the COVID-19 pandemic, the usage and production of face masks considerably increased, resulting in large quantities of mask waste accumulating in the natural environment. To investigate whether masks of polypropylene (PP) material could be ingested and degraded by insect worms like PP foam plastic, yellow mealworms were provided with different layers of disposable surgical masks as sole diets for 30 d. Although mask layers, especially the middle layer of melt-blown filter, could be ingested by yellow mealworms, sole mask layer diets had adverse effects on the larval survival and growth. Analyses of Fourier transform infrared spectroscopy, differential scanning calorimeter and thermogravimetric, and gel permeation chromatography demonstrated the changes of functional groups, thermostability and molecular weights in frass compared to original masks, indicating the partial oxidation and degradation of masks. And the depolymerization of the middle layer of masks by yellow mealworms was different from that of other layers. The larval gut bacterial and fungal microbiomes were assessed by Illumina MiSeq, indicating that both of them shifted upon sole layer mask diets. Changes in

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relative abundances of dominant bacterial and fungal genera demonstrated the strong association between gut microbiome and mask degradation. For instance, unclassified Enterobacteriaceae was closely associated with outer layers degradation. *Lactococcus* and unclassified Ascomycota were responsible for middle layers degradation, while *Lactococcus* and *Morganella* for inner layers degradation. In conclusion, disposable surgical masks of PP material could be ingested and biodegraded by yellow mealworms. The diversities of gut bacterial and fungal microbiomes were associated with the differences in rigid crystalline structures of the layer masks.

1. Introduction

During the global epidemic of Coronavirus disease 2019 (COVID-19), wearing a face mask was strongly recommended to prevent infection and fight the spread of COVID-19 (Cheng et al., 2021; Morawska et al., 2020). The disposable surgical mask, as one of the simplest and most cost-effective public health measures to prevent person-to-person disease transmission, especially in situations where it was difficult to maintain effective social distance (Centers for Disease Control and Prevention (CDC), 2021), was promoted to wear in public worldwide (Li et al., 2020) and demanded in large quantities (Tesfalidet et al., 2022). The production and usage of disposable surgical masks in the three years of the epidemic have increased to an unprecedented level. In 2022, the World Health Organization (WHO) estimated that roughly 89 million medical masks were required globally per month (Li et al., 2022). Although medical masks have made indispensable contributions in epidemic prevention and control, their production and usage would significantly decline as WHO declared end of global health emergency (Wise, 2023). However, as one of the important plastic wastes, the adverse effects of masks discarded without proper disposal on the ecological environment and human health need widespread attention (Fadare and Okoffo, 2020).

Commonly, a surgical mask or disposable mask consists of three layers: an outer layer (non-woven fabric and colored), a middle layer (melt-blown filter), and an inner layer (fiber material or non-woven fabric) (Aragaw, 2020), all of which are composed of polypropylene (PP) materials with different rigid crystalline thermoplastic structures (Shen et al., 2021). Although previous studies on PP foam plastics have confirmed that the partial oxidation, mineralization, and degradation of PP foam plastics after passing through the gut of worms (Terence, 1997; Riudavets et al., 2007; Yang et al., 2020a), it remains to be revealed whether the PP material surgical masks could be ingested and degraded by insects, and whether the core gut functional microorganisms would be different in the degradation process due to the significant structural difference between surgical masks and ordinary foam plastics.

We hypothesize that insect worms are also able to feed on and degrade surgical masks, and the degradation and functional microbiota effects of different layers of masks are different. To test this hypothesis, the most commonly used insect larvae of yellow mealworms *T. molitor* were fed with the outer, middle or inner layers of disposable surgical masks as the sole diet with bran as the control under the same condition for 30 days. The analyses of frass samples using scanning electron microscopy (SEM), attenuated total reflection-Fourier transform infrared spectroscopy (ATR-FTIR), thermogravimetric analysis (TGA) and gel permeation chromatography (GPC) confirmed the degradation of different layers of masks in larval guts. Illumina MiSeq results of 16S rRNA and ITS genes demonstrated the changes in gut bacterial and fungal diversities with a sole mask diet, providing a reference for the isolation of functional microorganisms involved in PP plastic degradation.

2. Materials and methods

2.1. Larvae and feedstocks

Yellow mealworms larvae were purchased from Wuxi Insects Breeding Plant, Jiangsu, China. The larvae were approximately $1.50 \pm$

0.15 cm in length and 54.43 ± 3.21 mg/larva in weight. Natural wheat bran without any additives was purchased from the specialty stores and used as the feedstock for control groups. Disposable surgical masks of polypropylene material were purchased from the designated drug mask sales office, and the outer, middle and inner layers of masks were used as experimental feedstocks. No surgical mask was replaced during the experiment. To initiate the experimental diets, the larvae were firstly fed with bran and then starved for 72 h.

2.2. Larval growth and plastics consumption

Four test groups were included in the experiment, including a bran-fed control, three mask-fed groups (outer, middle, and inner) with three replicates in each group. For each group, 150 yellow mealworms were randomly selected incubated in a container ($15 \times 10 \times 7$ cm) to maintain the convenient density for good larval growth (Przemieniecki et al., 2019). All groups were kept under the controlled condition of 25 ± 1 °C, 60 ± 5 % humidity, and a dark environment (Zaelor and Kitthawee, 2018; Luo et al., 2021) for 30 days. Before the experiment, the edge adhesive and tensioning tape of the surgical masks were cut off, cleaned with distilled water, and dried at 30 °C for 2 days. At the beginning of the experiment, 5 g bran was added in the control groups, and additional 5 g bran was supplemented every 5 days. Two pieces of outer, middle or inner layers surgical masks were added in each mask diet group as sole feedstock for 30 days. Dead larvae and molting exoskeleton were removed immediately via daily checking. Weights of mask layers and larvae were measured every 5 days. Larval survival rates, accumulative net weight changes, and cumulative mask consumptions were calculated at 5-day intervals by comparing to the initial amounts or weights of the experiment.

2.3. Depolymerization of different mask layers

Collection and analysis of residual polymers of masks in the larval frass were performed as our previous description in the Supplementary (Luo et al., 2021). To observe the frass of different layer masks-fed larvae, the scanning electron microscope (SEM, Apreo 2 C, Thermo Scientific, Inc., USA) characterization was conducted. Before observation, the frass samples were dipped on the conductive adhesive of the sample table, sprayed with gold to increase electrical conductivity, and then placed under the SEM for morphology observation and micro area composition analysis (Wang et al., 2022c; Peng et al., 2019). Attenuated total reflection-Fourier transform infrared spectroscopy (ATR-FTIR, Vertex70, Brock Instruments, Germany), differential scanning calorimeter and thermogravimetric analysis (DSC-TGA, SDT Q600, TA Instruments, USA) and gel permeation chromatography (GPC, PL-GPC50, Agilent Technologies, Inc., USA) analyses were employed to characterize the depolymerization and degradation of residual polymers in the different layer masks-fed larval frass and compared to the original different layer masks. The procedures of ATR-FTIR, DSC-TGA and GPC were performed as described in the literatures (Wang et al., 2022a; Yang et al., 2020a, 2020b; Wang et al., 2022b) and provided in the Supporting Information (Method S1).

2.4. Gut microbiome analysis

At the end of the 30-day experiment, 30 yellow mealworms were

randomly selected from each group for the gut microbiome analysis. The larval guts from each group were pooled into 1 mL of sterile normal saline placed in a 2 mL sterile centrifuge tube (Yang et al., 2014). The procedures of sample preparation and primer selection were performed as described in our previous study (Wang et al., 2022c) and provided in Supporting Information (Method S2).

2.5. Statistical analysis

Statistical analyses of plastic consumption rates, survival rates and weight changes were performed in Prism (version 8) (Brandon et al., 2018). The pairwise comparisons were performed with the Student's *t*-test (Yang et al., 2020a; Yang et al., 2020b). All *p*-values were adjusted *p*-values and all error values were average \pm standard deviation.

3. Results and discussions

3.1. Larval growth and plastics consumption

The ingestion of different layers of surgical masks by yellow mealworms was shown in Fig. 1a. All layers of the surgical mask were ingested by yellow mealworms, but with different preferences. The ingestion of the middle layer (filter layer) was more significant than the outer and inner layers (nonwoven fabric), which was suggested due to the more compact physical structure of the melt blown filtration. Although the mask consumption of all groups decreased significantly as the cycle extended, the middle layer consumption was higher than that of the other layers. Over the 30-days incubation period, the cumulative

middle layer consumption of 122.67 ± 2.50 mg was approximately three folds of the outer layers of 43.33 ± 0.65 mg and two folds of the inner layers of 68.00 ± 2.50 mg, respectively (Fig. 1b). Compared with previous studies (Yang et al., 2020a), the middle layer consumption of yellow mealworms was much higher than that of PP foam, while the outer or inner layer consumption was lower than that of PP foam. The reason presumably due to the outer and inner layers of masks are made of plastic fiber nonwovens, which are relatively difficult to ingest. The survival rates of each group during the 30-days experiment were calculated as shown in Fig. 1c. The survival rate of bran-fed group was 73.85 ± 9.48 %, which was similar to the previous studies (Lou et al., 2021), indicating that the culture condition could meet the larval normal growth. The survival rate of the bran-fed group was significantly higher than that of the mask-fed groups. The overall larval survival rates showed a significant downward trend, with the inner layer-fed group showing a significant decrease from the beginning until reaching the lowest at the end. Similar downward trends of survival rates in the middle layer-fed group and outer layer-fed group were also observed, but after 20-days, the outer layer-fed group had a more obvious decrease, ultimately lower than that of the middle layer-fed group. Although the survival rate was in the order of middle-fed > outer-fed > inner-fed groups, the overall difference was not significant (*p* > 0.05) at about <60 %, which was significantly lower than that in the previous study of yellow mealworms fed with PP foam plastics (Yang et al., 2020a). In addition, Yang et al. (2020a) also confirmed that the co-feeding of bran with PP foam by yellow mealworms could significantly increase the consumption of PP foam. The total PP mass consumption in the bran + PP diet group was 1.68 times higher than that of

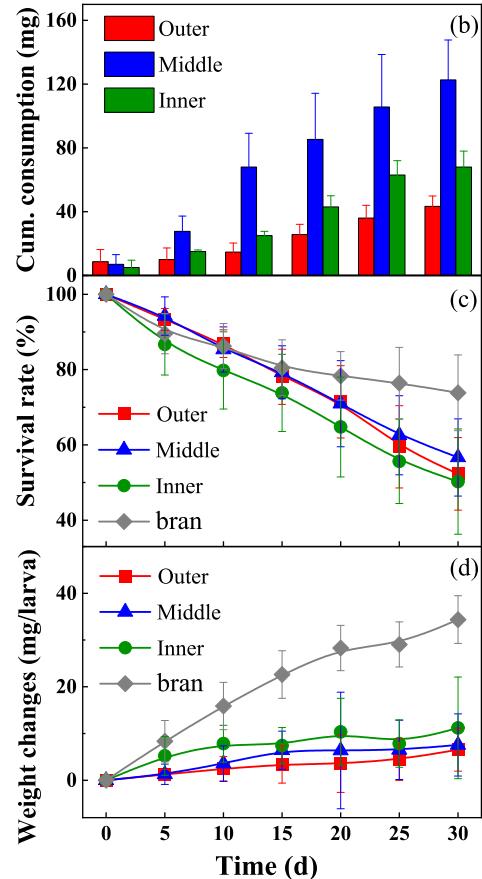
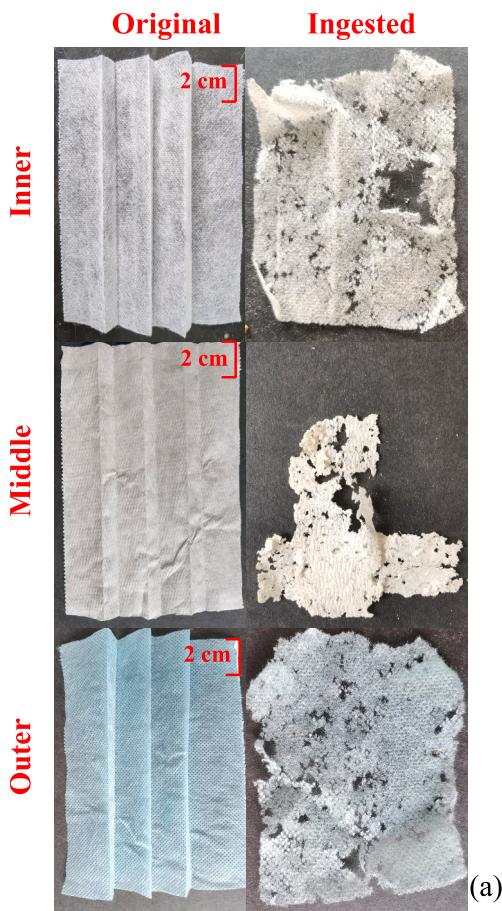


Fig. 1. Surgical mask consumption of different layers and effects on yellow mealworms. Original and ingested by yellow mealworms of different layer surgical masks (a); Different layer surgical mask cumulative consumption (b), larvae survival rates (c) and net weight changes (d) of yellow mealworms.

PP only, and the survival rate also increased. Therefore, the consumption of masks could also be increased by supplementing some nutrients to ensure the survival of yellow mealworm and a higher ingestion efficiency. The average cumulative net weight changes of yellow mealworms continuously increased during the experiment (Fig. 1d). In the bran-fed group, the average net weight changes continuously increased by 34.37 ± 2.86 mg/larva during the 30-day experiment. Although the final result was that the inner-fed group had the highest weight gain, the difference between them was actually not significant ($p < 0.05$). Compared to previous studies on feeding foam plastics and wheat bran (Wang et al., 2022a; Yang et al., 2020a), the weight of larvae fed with masks only slightly increased, indicating that the nutritional deficiency of masks as the sole diet was more obvious. The results indicated that sole mask layer diets had significant adverse effects on the survival and growth of yellow mealworms.

3.2. Degradation and oxidation of masks

The frass pellets of larvae feeding on different layers of masks were observed having obvious differences, as shown in Fig. 2. The frass pellets of the outer layer-fed group were larger than those of middle and inner layer-fed groups. This was suggested to be due to the differences in PP material of different layers, and the fiber structure of the inner and outer layers of masks, as well as the mixed un-degraded and partial-degraded mask textiles in the frass (Fig. 2a). The frass of masks-fed larvae was observed and analyzed by SEM to further compare the morphological differences among the frass of larvae fed with different layers of masks (Fig. 2b). Due to the different rigid crystalline, the frass of yellow mealworms feeding on different layers of masks also differed. Although both inner and outer layers were lumpy and tightly structured, their appearances in larval frass were in great of difference. In contrast, the frass of middle layer masks group had a more pronounced structural fragmentation with thread-like structures.

The depolymerization and biodegradation of ingested outer, middle and inner mask layers were characterized by using ATR-FTIR, DSC-TGA and GPC analyses (Fig. 3). The ATR-FTIR spectra of the original mask and frass samples of mask-fed larvae were shown in Fig. 3a-c. The

spectra of original different layer mask were similar, indicating that the materials of the outer, middle and inner masks were produced with the same basic material of polypropylene. For frass samples of outer-, middle- and inner-fed larvae, the peak at 2913 cm^{-1} , 2908 cm^{-1} and 2912 cm^{-1} as C—H stretch bonds were much weaker than original mask with higher peak intensities. The appearance of new peaks at around 1650 – 1660 cm^{-1} was attributed to the C=O stretch in the frass samples, confirming the incorporation of oxygen into the polymer chains due to the oxidation. The ATR-FTIR results indicated the occurrence of oxidation and degradation of different layer mask after passing through larval guts.

The DSC-TGA analysis provided evidence that new compounds were produced in the frass of yellow mealworms fed with the masks (Fig. 3d-f). The weight losses of outer, middle and inner mask layers occurred in a narrower temperature range of 363 – $477\text{ }^{\circ}\text{C}$ compared with those of mask-fed larval frass. For the outer-, middle- and inner-fed groups, the weight loss occurred in two stages and accelerated in the stage of 215 – $460\text{ }^{\circ}\text{C}$ with the mass loss of 59.64 %, 59.37 % and 59.91 %, respectively, which was significantly lower than those of the original mask groups. The results indicated that the frass contained not only residual mask samples but also new organic substances (Wang et al., 2022a; Yang et al., 2020a). The outer- and inner-fed groups had similar endothermic temperatures at $411.23\text{ }^{\circ}\text{C}$ and $412.83\text{ }^{\circ}\text{C}$, respectively, while the maximum decomposition rates appeared at $312.17\text{ }^{\circ}\text{C}$ in the middle-fed group. The difference in the maximum decomposition rate indicated that the mask derived frass contained new organic substances with different thermal properties (Peng et al., 2020). The DSC-TGA results confirmed that the disposable medical mask had undergone different degrees of degradation in yellow mealworm guts.

The GPC analysis was conducted to examine the biodegradation performance of the three layers of masks with different molecular weights (Fig. 3g). After passing through the larval gut, the changes in number average weights (M_n) and weight average weights (M_w) of outer, middle and inner layers showed different patterns. The M_w of the residue polymer of outer and inner layers were reduced by 10.42 % (original 124.90 ± 4.77 vs. frass 111.89 ± 3.57 kDa) and 51.11 % (original 131.99 ± 6.03 vs. frass 64.52 ± 4.94 kDa), respectively. The

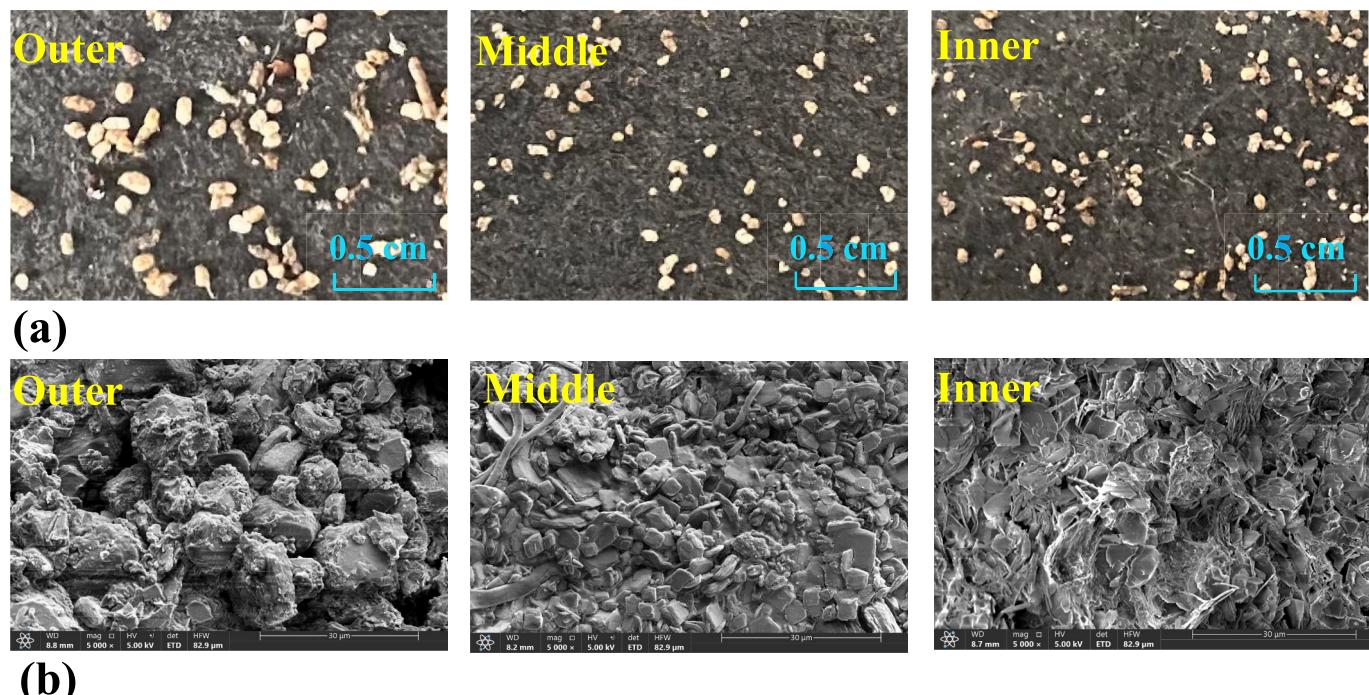


Fig. 2. Morphology of frass samples fed with different layer surgical masks. (a) Frass images of different layer masks-fed yellow mealworms; (b) SEM images of frass from different layer surgical mask fed yellow mealworms.

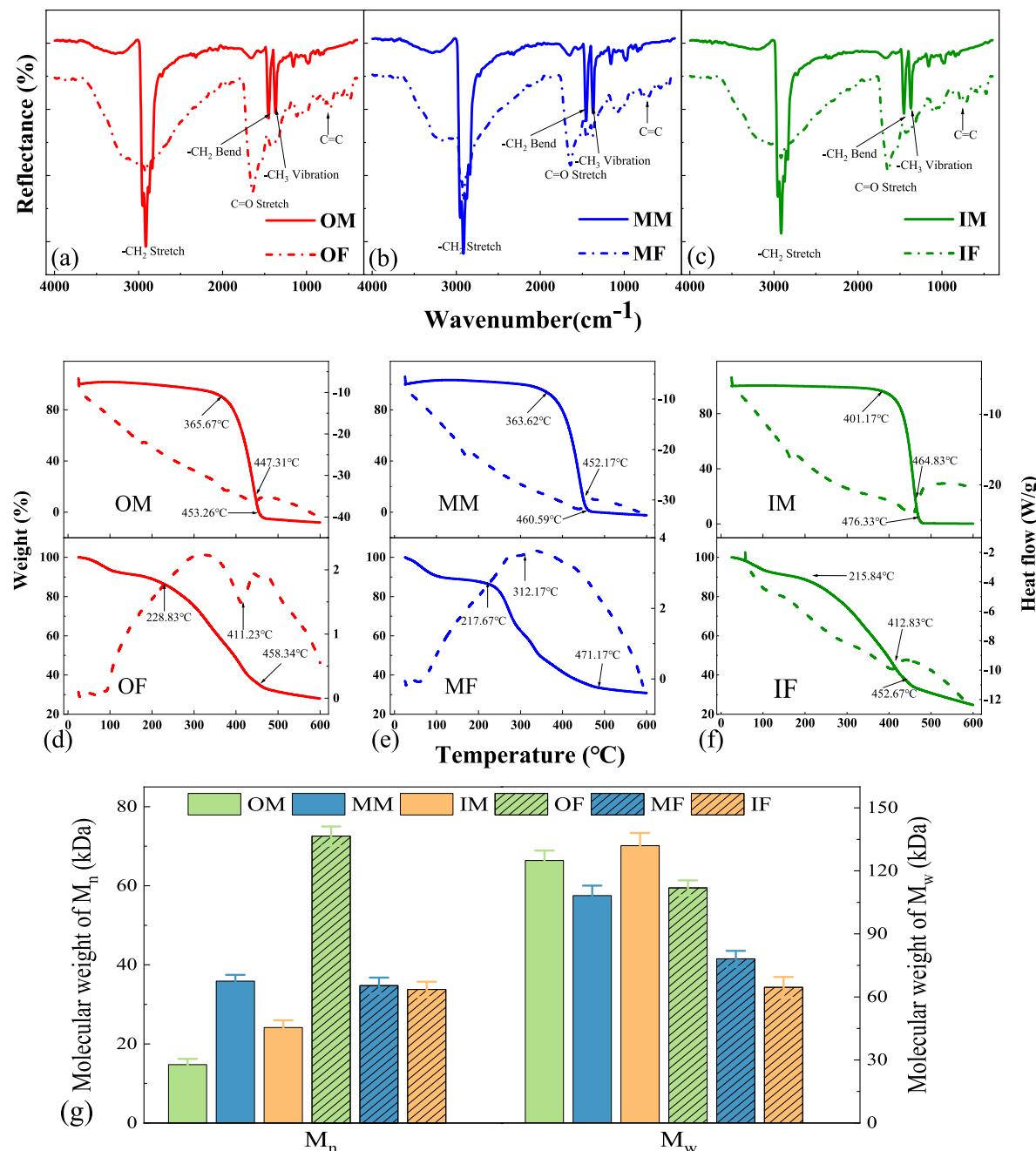


Fig. 3. Characterization of biodegradation of surgical mask by yellow mealworms *T. molitor* larvae. Analyses of mask outer layer and frass of outer layer-fed larvae by ATR-FTIR (a) and TGA (d); Analyses of mask middle layer and frass of middle layer-fed larvae by ATR-FTIR (b) and TGA (e); Analyses of mask inner layer and frass of inner layer-fed larvae by ATR-FTIR (c) and TGA (f). GPC analysis of number average weights (M_n) and weight average weights (M_w) for different layer original surgical mask and masks-fed larval frass (g). OM = outer layer of mask; OF = frass of outer layer-fed larvae; MM = middle layer of mask; MF = frass of middle layer-fed larvae; IM = inner layer of mask; IF = frass of inner layer-fed larvae.

M_n of the outer and inner layers residue significantly increased from 14.77 and 24.15 to 72.56 kDa and 33.79 kDa, respectively. The outer and inner layers of masks showed a same depolymerization pattern, with M_w decreasing and M_n increasing, which is a typical limited depolymerization. The depolymerization of the middle layer of masks by yellow mealworms was similar to the previous study on depolymerization of PP plastic by superworms (Yang et al., 2020a) that the M_n of middle layer reduced by 3.20 % (original 35.89 ± 1.58 vs. frass 34.74 ± 2.01 kDa), and the M_w reduced by 27.86 % (original 108.23 ± 4.74 vs. frass 78.08 ± 3.84 kDa). The M_n and M_w significant decreased, indicating a broad depolymerization of middle layer of masks occurred in yellow mealworms. In summary, the GPC analysis results also confirmed that all

three layers of disposable surgical masks were biodegraded in yellow mealworms.

3.3. Response of gut-bacterial microbiome to masks ingestion

Illumina Miseq of the 16S rRNA gene was used to investigate the impact of mask diets on the gut bacterial community. The average of 62,937 sequences were obtained and the sampling coverages were above 99 %, suggesting that the sequencing result was capable of detecting most of the reads. The OTU number of bran-fed control groups (78) were lower than that of outer-, middle- and inner-fed groups (92, 91, 90), indicating that feeding masks slightly increased the gut bacterial

community diversity. Shannon, Chao and Simpson Indices estimating the gut bacterial species richness and diversity were summarized in Table S4. The increased Shannon index and decreased Simpson index also indicated that the bacterial richness was increased in yellow mealworms with sole middle layer mask diet, while bacterial richness was slightly decreased in groups of both inner and outer layer masks (Table S4).

Principal component analysis (PCA) based on Unweighted Unifrac revealed clusters associated with the different diets (Fig. 4a). The gut-bacterial communities of middle- and inner-layer fed groups were similar, and significantly different from that of the bran-fed group, indicating that the composition of the gut-bacterial community was distinct from larvae feeding on normal diets. The results suggested that changes in larval gut bacterial community were shaped by the type of

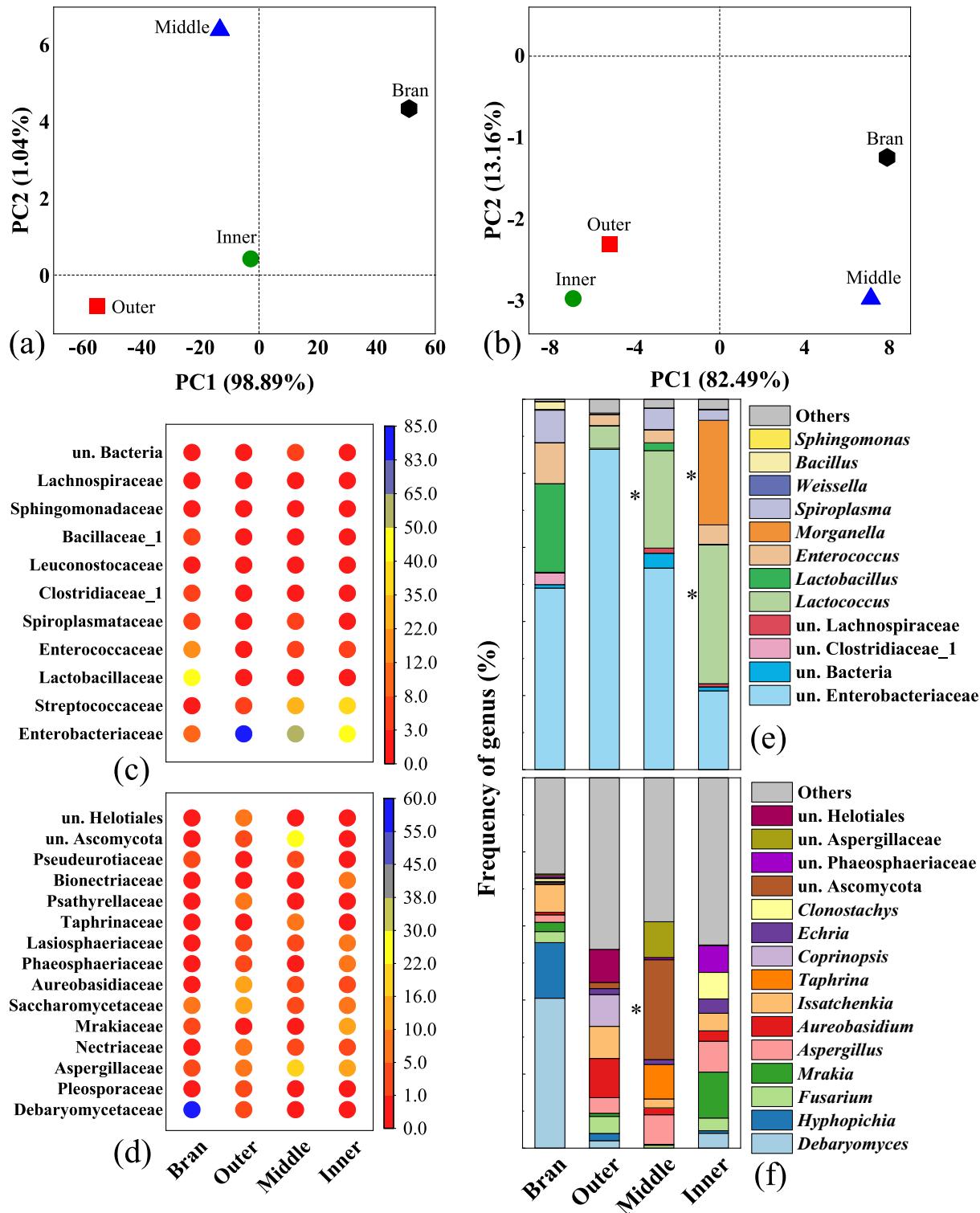


Fig. 4. Analysis of gut microbial community in yellow mealworms with different layer of surgical mask diets. Principal coordinate analysis based on Unweighted Unifrac of gut bacteria (a) and fungi (b) at phylum level; Relative bacterial (c) and fungal (d) abundances at family level; Relative bacterial (e) and fungal (f) abundances at genus level (Relative abundance cutoff is 3.0 %).

feedstocks.

At the family level, an analysis of bacterial community compositions revealed that Lactobacillaceae and Enterococcaceae were the dominant families in bran-fed group, with relative abundances of 47.87 % and 20.79 %, respectively (Fig. 4c). An obvious difference in predominant family was detected between the gut bacterial community in the outer-fed group and bran fed group, abundances of Enterobacteriaceae were significantly higher in the outer-fed groups, accounting for 86.71 %, comparing to bran-fed group, accounting for 9.51 %. Abundances of Enterobacteriaceae and Streptococcaceae were significantly higher in middle-fed and inner-fed group, compared to the bran-fed control. The result indicated that changes in the gut bacterial community of yellow mealworms with different mask layer diets were significantly different.

Further analysis at genus level indicated changes in relative abundances after feeding different layer masks (Fig. 4e). In the outer-fed group, community shift was mainly associated with the increased relative abundances of unclassified Enterobacteriaceae and *Lactococcus*, accounting for 86.52 % and 6.04 %, all increased comparing to the relative abundances of 49.00 % and 0.17 % in bran-fed group. Unclassified Enterobacteriaceae was also found to be strongly associated with degradation of LDPE, PS and PU in superworms *Z. atratus* larvae (Luo et al., 2021; Wang et al., 2022a). The increase of Enterobacteriaceae was consistent with the results of PP foam ingestion by insect worms (Yang et al., 2020a). *Lactococcus* was common insect gut-associated bacteria that contribute to regulating and maintaining the health of the gut microbiome environment (Brandon et al., 2018; Lou et al., 2021). *Lactococcus* was strongly associated with PP degradation by *T. molitor* larvae (Yang et al., 2020a). In the middle-fed group, *Lactococcus* was significantly higher, accounting for 26.29 %, compared to bran- and outer-fed groups. In the inner-fed group, the dominant genera were *Lactococcus*, *Morganella* and unclassified Enterobacteriaceae, with relative abundances of 37.49 %, 28.24 % and 21.27 %, respectively. A significant increase in *Morganella* suggested a strong correlation with the diet of the inner layer of the surgical mask. Previous studies also reported the presence of *Morganella* in the gut of yellow mealworms and superworms on PP diet (Yang et al., 2020a). Unclassified Enterobacteriaceae, accounted for a large proportion in all diets, including bran-, outer layer-, middle layer- and inner layer-fed groups, and was a member of Enterobacteriaceae, which strongly associated with plastics degradation. Previous studies have confirmed that strains belonging to Enterobacteriaceae, isolated from insect's gut, have the ability to degrade plastics (Arunrattiyakorn et al., 2022; Yang et al., 2014). Therefore, full-length 16S rRNA gene sequencing is suggested for follow-up studies to uncover the genera within unclassified Enterobacteriaceae that play important roles in plastic polymer degradation.

3.4. Response of gut-fungal microbiome to masks ingestion

Illumina MiSeq sequencing of the ITS gene was used to investigate the effects of different diets with layers of masks on gut fungal communities of yellow mealworms. The diversity of gut fungal communities in larvae significantly shifted with different layer mask diets compared to the control group. The species richness and diversity estimators of OTUs, Shannon and Simpson, for larval gut-fungi were summarized in Table S1. The number of OTUs in the control group was 23, which significantly increased to 57, 82, and 117 in the outer-, middle-, and inner-fed groups, respectively. These results indicated that feeding with masks significantly increased the diversity of the gut fungal community, especially in the inner-fed group.

Principal component analysis (PCA) based on Unweighted Unifrac exhibited distinction in the core gut fungi with different diets (Fig. 4b). The gut fungal microbiomes in mask-fed groups were similar, especially between middle- and inner-fed groups. Similar to the gut-bacterial results, PCA analysis results suggested that the gut-fungal microbiome shifts were associated with sole mask layer diets.

As shown in the bubble plot (Fig. 4d), *Debaryomycetaceae* was the

predominant family in bran-fed group accounting for 55.50 %. In the outer-fed group, there were three predominant fungal families including Aspergillaceae, Saccharomycetaceae and Aureobasidiaceae. Aspergillaceae and unclassified Ascomycota were the predominant family in the middle-fed group accounting for 20.11 % and 26.95 %, respectively. While Aspergillaceae and Mrakiaceae were the predominant families in inner-fed group. The relative abundance of Aspergillaceae was higher in all mask-fed yellow mealworms compared to the bran-fed control, indicating a strong association with the surgical mask diet in yellow mealworms.

Differential abundance analysis was used to assess whether particular fungal genera (relative abundances >1 %) were associated with different diets (Fig. 4f). In contrast to gut bacteria, the mask-fed group had a higher fungal diversity compared to bran-fed groups. Yeasts of *Hyphopichia* and *Debaryomyces* were the predominant fungi in guts of bran-fed yellow mealworms. In outer-fed group, the relative abundance of fungal genera was relatively lower than that of in bran-fed group. Four OTUs, including *Aureobasidium*, *Issatchenkia*, *Coprinopsis* and unclassified Helotiales were the dominants, accounting for 10.57 %, 8.66 %, 8.59 % and 8.93 %, respectively. In middle-fed group, the dominant genera were unclassified Ascomycota, *Taphrina* and *Aspergillus*, accounting for 26.95 %, 9.29 % and 8 %, respectively. Ascomycota and *Taphrina*, which were not mentioned in previous studies, showed a significant increase of 99 % in the bran-fed group. Previous studies have confirmed the plastic biodegradation capacity of *Aspergillus*, such as *A. flavus* PEDX3 from the gut of *Galleria mellonella* larvae for PE degradation (Zhang et al., 2020), and *A. tubingensis* from soil for PU degradation (Khan et al., 2017). Similar to the outer layer-fed group, the relative abundances of each fungal genus were relatively low in the inner layer-fed group, and no prominent dominant genus was observed. The dominant genera were *Mrakia* and *Aspergillus*, accounting for 12.41 % and 8.32 %, respectively. *Mrakia*, a cold-adapted yeasts, had not been mentioned in previous studies related to plastic degradation. *Aspergillus* appeared in all the mask diets with a high relative abundance, indicating a close relationship to the mask degradation.

Overall, the gut fungal diversity of yellow mealworms increased significantly after feeding on different layers of masks, which is consistent with our previous study on the increase of gut fungal diversity after larvae feeding on plastic (Wang et al., 2022c). This study confirmed that insect gut fungi played important roles in the depolymerization and degradation of plastics and masks polymers.

4. Implications

This study focused on the pollution and treatment of disposable surgical mask wastes in the post epidemic era. On the basis of previous studies on the biodegradation of foam plastic wastes by insect worms, the ingestion and degradation of disposable surgical masks by larvae of yellow mealworms *T. molitor* were investigated. Our work showed that ingestion and degradation of different layers of masks were significantly different by yellow mealworms. The middle layer of masks was found to be more extensively depolymerized and biodegraded than outer and inner layers in gut of yellow mealworms, as determined by GPC analysis. The larval gut microbial community underwent significant changes, with decreased bacterial diversity and increased relative abundance of *Lactococcus* and *Morganella*. Gut fungal diversity increased significantly, and unclassified Ascomycota was strongly associated with middle layer degradation. Although yellow mealworms can ingest and degrade masks of PP material, doing so was more difficult than degrading PP foam plastics due to the different layer structure of masks (lamellae and fibers). For plastic waste, such as disposable surgical masks, future work should focus on isolating functional microorganisms, identifying and purifying functional enzymes for plastic biodegradation. Additionally, efforts should also be made to explore the microbial relationship between insect worms and mask degradation processes to uncover degradation mechanisms and improve efficiency.

CRediT authorship contribution statement

Jiaming Wang: Investigation, Writing - Original Draft.
Chi Zhang: Investigation.
Xin Zhao: Supervision, Writing- Reviewing and Editing, Funding acquisition.
Yue Weng: Investigation.
Xinrui Nan: Investigation.
Xiaoyu Han: Writing- Reviewing and Editing.
Chen Li: Writing- Reviewing and Editing.
Baoqin Liu: Project administration, Writing- Reviewing and Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.scitotenv.2023.166808>.

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