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Valorization of discarded face mask for bioactive compound synthesis and photodegradation of dye

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ARTICLE INFO

Keywords:
Face mask
Covid-19
Mask waste ash catalyst
Bisindoles
Green chemistry
Methylene blue

ABSTRACT

To keep COVID-19 at bay, most countries have mandated the use of face masks in public places and imposed heavy penalties for those who fail to do so. This has inadvertently created a huge demand for disposable face masks and worsened the problem of littering, where a large number of used masks are constantly discarded into the environment. As such, an efficient and innovative waste management strategy for the discarded face mask is urgently needed. This study presents the transformation of discarded face mask into catalyst termed ‘mask waste ash catalyst (MWAC)’ to synthesise bisindolylmethanes (BIMs), alkaloids that possess antibacterial, antioxidant and antiviral properties. Using commercially available aldehydes and indole, an excellent yield of reaction (62–94%) was achieved using the MWAC in the presence of water as the sole solvent. On the other hand, the FT-IR spectrum of MWAC showed the absorption bands at 2337 cm⁻¹, 1415 cm⁻¹ and 871 cm⁻¹, which correspond to the signals of calcium oxide. It is then proposed that the calcium oxides mainly present in MWAC can protonate oxygen atoms in the carbonyl molecule of the aldehyde group, thus facilitating the nucleophile attack by indole which consequently improved the product yield. Moreover, the MWAC is also observed to facilitate the photodegradation of methylene blue with an efficiency of up to 94.55%. Our results showed the potential applications of the MWAC derived from discarded face masks as a sustainable catalyst for bioactive compound synthesis and photodegradation of dye compounds.

1. Introduction

The COVID-19 pandemic has disrupted our daily life, forcing people to adapt to the new normal like physical distancing, working from home and wearing face masks in public places to minimise coronavirus transmission and contamination. Most countries have mandated the use of face masks in public places which resulted in their production reaching 12 million units per day to meet the high demand (Mejjad et al., 2021; Sun et al., 2020).

The face mask is made of various non-biodegradable polymers such as polypropylene, polyethylene, polyurethane, polystyrene, polycarbonate, and poly-acrylonitrile. Besides posing environmental pollution, plastic components have been detected in the sea from improper disposal of discarded face masks (Facciola et al., 2021; Selvaranjan et al., 2021). This would have caused the toxins, such as the dioxins, phthalates and other hazardous organic compounds to be adsorbed on the plastic and form a poisonous film (Williams-Wynn and Naidoo, 2020). On top of that, these plastic components also pose great harm to marine life which may subsequently put the health of humans who consumed the marine products at risk. Several studies have found negative health and environmental impacts caused by the plastic components of discarded face masks (De Sousa, 2020; Liu et al., 2021). Currently, the waste management strategy for discarded face masks includes unsupervised landfilling and incineration. These strategies are
not sustainable as the discarded face masks will be degraded into microplastic and caused ocean pollution in the long run (Fonseca et al., 2015; Pol, 2010). Therefore, the search for a sustainable approach to managing the discarded face masks is urgent to minimise their negative impact on the environment. To date, discarded face masks were repurposed for many applications such as the production of pavement base (Sabieran et al., 2021), fuel for energy (Aragaw and Mekonnen, 2021) and electronic material (Varghese and Chandran, 2021). However, these up-cycling methods incurred extra costs in segregation and logistics and most of these methods are difficult to be performed on a large scale at the industrial level (Aragaw and Mekonnen, 2021).

Bisindolylmethanes (BIMs) represent alkaloids that possess various biological properties such as antibacterial, antioxidant and antiviral (Praveen et al., 2015). Various types of catalysts have been developed for BIM syntheses such as the amberlyst-15, molecular iodine, metal nanoparticles, acid and base, NbCl₅, cellulose sulphuric acid, zeolite and ceric ammonium nitrate. However, some of these catalysts employed hazardous and expensive reagents which hampered their practical use, for instance, the utilization of imidazolium salt as catalysts in chloroform (Wang and Aldrich, 2019) and scandium (III) triflate (Tanemura, 2021) in addition with the use of non-reusable thiourea catalysts in harsh reaction condition (Rivas-Loaiza et al., 2019). As part of our continuous efforts in green and sustainable chemistry, herein, we report the transformation of discarded masks into mask waste ash catalyst (MWAC) via direct burning in a furnace for use in BIM synthesis. We hypothesised that the metals contained in the MWAC could act as catalytic sites to facilitate the synthesis of BIMs. The resulted BIM was systematically characterised using several analytical and spectroscopic techniques including nuclear magnetic resonance (NMR), gas-chromatography-mass spectrum (GC-MS), Fourier transform infrared (FT-IR), and inductive coupled plasma-optical emission spectroscopy (ICP-OES). The sample for ICP-OES was analysed in triplicates and the data were expressed in mean value ± standard deviation (SD).

2. Materials and methods

2.1. Reagents and elemental analyses

The technical grade of ethyl acetate, hexane, benzaldehyde, 2-chlorobenzaldehyde, 3-chlorobenzaldehyde, 4-chlorobenzaldehyde, 2-fluorobenzaldehyde, 3-fluorobenzaldehyde, 4-fluorobenzaldehyde, 2-bromobenzaldehyde, 3-bromobenzaldehyde, 4-isopropylbenzaldehyde, 4-methoxybenzaldehyde were purchased for the preparation of bisindolylmethanes and the silica gel 60 (0.063–0.200 mm) were used as packing material in column chromatography for separation of the pure compounds. All chemicals were bought from the Sigma-Aldrich, Kuala Lumpur, Malaysia. The 1H and 13C-NMR (nuclear magnetic resonance) spectra were recorded in CDCl₃ solvent using the Bruker Avance III 400 spectrometer (Bruker Corporation, Billerica, MA, USA). The samples were then prepared by dissolving the analytes in methanol and the solutes were prepared at 20 ppm. The molecular mass of BIMs was determined over the gas chromatography-mass spectrometer (GC-MS) (Shimadzu QP2010SE), which was equipped with the Supelco silica capillary column (30 m × 0.25 mm x 0.25 μm film thickness). For the Fourier transform infrared (FT-IR), the potassium bromide pellet method was adapted to analyse the BIMs. For the FT-IR pellet preparation, about 1/8” of the bisindolylmethane was taken using a microspatula and mixed with 0.50 teaspoon of KBr in a mortar. Subsequently, the mixture was ground homogeneously using the pestle. The fine powder of bisindolylmethane was placed just enough to cover the bottom of pellet die and was pressed at 5000–10000 psi. Finally, the pellet was carefully removed from sample die and placed in FT-IR sample holder. The elemental composition of the MWAC was determined over the inductive coupled plasma-optical emission spectroscopy (ICP-OES). The sample for ICP-OES was analysed in triplicates and the data were expressed in mean value ± standard deviation (SD).

2.2. Production of mask waste ash catalyst

Fig. 2 shows the production process of MWAC. The discarded face masks were collected from the recycling sites at University Malaysia Terengganu and autoclaved at 110 °C for 10 h to eliminate all microorganisms. Then, the dried sample was cut into small pieces using a scissor after removing the nose clip. About 20 g of the sample were heated in a furnace at 700 °C for 2 h followed by cooling to room temperature. The resulted sample (i.e. MWAC) was collected as a white powder (18 g).

2.3. Synthesis and characterisation of bisindolylmethanes (BIMs)

The synthesis of BIMs was performed by adding 2 mmol of indole into a 25 mL round-bottom flask containing 1 mmol of benzaldehyde, 10 mL of water and 0.1 g of MWAC. The mixture was heated at 80 degree celsius for 3 hours while stirring at 80-120 rpm to create a homogeneous solution. Thin-layer chromatography was employed to monitor the formation of BIMs. Once the reaction was completed, the BIMs were extracted from the reaction mixture through phase separation by mixing with ethyl acetate thric (in 10 mL portions). After each separation, the aqueous layer was discarded and the organic solution was concentrated under reduced pressure over the rotary evaporator. The crude product was further purified using column chromatography with an ethyl acetate/hexane (3:7) eluent.

2.4. Photocatalytic degradation analysis

Photocatalytic degradation analysis was assessed by exposing aqueous MB, green 19, red 120 and orange 16 solutions to sunlight with and without the addition of MWAC. A total of 15 mg of MWAC was added into a 50 mL beaker containing 15 mL of MB (10 ppm), green 19 (10 ppm), red 120 (10 ppm) and orange 16 (10 ppm). The mixture was agitated for 30 min in the absence of sunlight to achieve the adsorption/desorption equilibrium of MB molecules with the MWAC. The degradation percentage of MB was done in triplicate and was determined by measuring its absorbance at 0, 2, and 3 h of sunlight exposure using a Shimadzu UV–vis spectrometer (Shimadzu Corporation, Tokyo, Japan) at a wavelength of 663 nm. The percentage of dye degradation was
calculated using Equation (1).

\[
\% \text{ Degradation} = \left( \frac{C_0 - Ct}{C_0} \right) \times 100
\]  

(1)

where \(C_0\) is the initial concentration and \(C_t\) is the concentration after time \(t\).

2.5. Photodegradation products analysis using liquid chromatography-mass spectrometry (LC-MS)

Analysis of MB metabolites was conducted after 3 h of incubation. The samples were filtered using a 0.45 \(\mu\)m nylon membrane filter followed by analysis using liquid chromatography (LCMS, Shimadzu) with Shim-pack GISS column (length: 75 mm; internal diameter: 3 mm, 3 \(\mu\)m) equipped. The mobile phase consisted of two solutions, namely 0.1% formic acid and acetonitrile. Then, 2 \(\mu\)L of samples were filled into autosampler vials. The LC-MS was set with a column temperature of 40 \(^\circ\)C. MS interface used is Electro Spray Ionization (ESI) while the NIST spectral library stored in the computer software was used to identify the metabolites by comparing the retention time and fragmentation pattern.

3. Results and discussion

3.1. Fourier transform infrared analysis to determine the functional groups on MWAC

The Fourier transform infrared (FT-IR) analysis was performed on MWAC and its relative intensity, shape and stretching frequencies of all signals are shown in Fig. 3. The absorption bands at 1415 cm\(^{-1}\) and 1000 cm\(^{-1}\) on the FT-IR spectrum corresponded to the signals of calcium oxide containing material (Ismail et al., 2016). This result was in agreement to a previous study, which found that the calcium phosphate was used as the filtering material in mask (Zhao et al., 2018). In addition, there was also a sharp band at 780.0 cm\(^{-1}\) that represents an out-of-plane bending of the C-O bond. Overall, all signals in the FT-IR agreed with previous literature (Ismail et al., 2016). Overall, the current FT-IR result add to the validity to previous result (Zhao et al., 2018) that calcium phosphate was used as the filtering material in mask and one of the major metals in MWAC.

3.2. Scanning electron microscopy (SEM) analysis on surgical face masks and mask waste ash catalyst (MWAC)

The MWAC and surgical masks were characterized under SEM analysis as shown in Fig. 4. The SEM image of the surgical face mask (Fig. 4a) shows the long fibers which are interconnected to form a network with empty spaces of 50–100 of microns, the result was concurred with a previous literature (Stewart et al., 2022). In contrast, the SEM image of MWAC (Fig. 4b) shows fibre-like and porous morphology, with plenty of grain boundaries. These pores sites available at the MWAC could act as catalytic sites for catalysis of bisindolylmethanes synthesis and photodegradation of dyes. The result of the SEM image was also found to be in agreement to previous literature, which suggested the pores after calcined at higher temperature may serves as catalytic sites for adsorption and photodegradation to take place (Loo et al., 2018).

3.3. Experiment on the optimization of reaction condition of BIMs synthesis

The optimized reaction condition of BIMs synthesis was investigated by adopting various amounts of MWAC catalyst, the volume of water, reaction time and temperatures (Table 1, entries 1–9). About 1 mmol of benzaldehyde and 2 mmol of indole were employed as starting materials in the optimization experiment. In the beginning, these materials were added into a 100 mL round bottom flask containing 0.05 g MWAC and 10 mL of water. The reaction mixture was left for stirring at 50 \(^\circ\)C. Then, the product yield obtained was 40% after 1 h (Table 1, entry 2). It was found that different volumes of water used and reaction times have an insignificant effect on the product yield (Table 1, entry 3–4). The reaction yield was enhanced to 70% with the increasing amount of MWAC (Table 1, entry 5), by lowering the activation energy of reaction. When 0.1 g of MWAC was added to the reaction mixture at 80 \(^\circ\)C for 5 h, the highest reaction yield was recorded at 94% (Table 1, entry 9). Overall, the optimized reaction condition was determined to be the volume of water (10.0 mL), amount of MWAC (0.1 g), temperature (80 \(^\circ\)C), and reaction time (1 h) (Table 1, entry 9).
3.4. Synthesis of various BIMs employing the optimized reaction conditions

Various commercially available aldehydes were selected for the synthesis of BIMs as the control experiment. As shown in Table 2, various substituted BIMs were yielded in a range of 60–94% (Table 2, entries 1–11). After substituting benzaldehydes with electron-withdrawing groups, BIMs were produced in high yields adopting the optimized reaction conditions (Table 2, entries 2–9). It was found that the electron-donating substituted benzaldehydes produced a lower yield than the electron-withdrawing benzaldehydes at a longer reaction time. This could be explained by the electron-donating effect of the substituted benzaldehydes that caused the carbons on the carbonyl groups to become less electropositive (Table 2, entries 10–11).

3.5. Recyclability study on MWAC

The remarkable enhancement of BIMs synthesis catalysed by the MWAC catalytic system had not been well understood. In this study, we found that calcium was one of the primary metals in MWAC as characterised by inductive coupled plasma-mass spectrometry (ICP-MS), which produced the following output: Ca (79,600 ± 0.32 ppm), K (4260 ± 1.11 ppm), Na (3880 ± 2.12 ppm), Mg (185 ± 2.65 ppm), Fe (490 ± 0.47 ppm), Al (1256 ± 1.32 ppm), Sr (83 ± 0.45 ppm), Mn (17 ± 0.22 ppm), B (12 ± 0.34 ppm), Zn (2360 ± 4.54 ppm), Cu (288 ± 3.11 ppm), Ni (36 ± 0.32 ppm), Zn (2360 ± 4.32 ppm), Ba (8 ± 0.15 ppm) and Pb (3 ± 0.12 ppm). In the recyclability experiment, after the recovery of MWAC by filtration and drying in a desiccator from the reaction mixture, the elements remained detectable in the recovered MWAC (Fig. 5) even after five consecutive usages of MWAC. The result of this finding indicates that MWAC could be a potential recyclable catalyst. Moreover, the yield of product 3a in the recyclability test was found to be 90–94%. In addition, our results showed that when the MWAC was substituted with the CaO (1 mol%) under identical reaction conditions, a good yield of 3a (90%) was synthesized. Therefore, it could be postulated that the metal oxide present in MWAC, especially calcium oxide, could protonate the oxygen atom in the carbonyl molecules of the aldehyde group, thus facilitating the nucleophile attack of indole (Fiorito et al., 2016).

According to recent literature (Table 3), most of the methods used to produce BIMs employed the condensation of indole and benzaldehyde with different catalysts. Although a high yield of BIMs was obtained, the methods and catalysts used were found to be expensive, non-recyclable and toxic to the environment. The strategy presented in this study could eliminate the use of dangerous chemicals while sustaining the environment by proposing an alternative usage for discarded face masks during the pandemic.

| Table 1 | Optimization of reaction condition for BIM production. |
|---------|-------------------------------------------------------|
| Entry   | Volume of water (mL) | MWAC  |
| (g)     | Time (h) | Temperature (°C) | Yield (%) |
| 1       | –       | 0.05             | 1 50 33   |
| 2       | 10      | 0.05             | 1 50 40   |
| 3       | 5       | 0.05             | 1 50 37   |
| 4       | 20      | 0.05             | 1 50 38   |
| 5       | 10      | 0.10             | 1 50 70   |
| 6       | 10      | 0.15             | 1 50 67   |
| 7       | 10      | 0.10             | 1 60 79   |
| 8       | 10      | 0.10             | 1 70 89   |
| 9       | 10      | 0.10             | 1 80 94   |
| 10      | 10      | 0.10             | 1 90 92   |
| 11      | 10      | 0.10             | 2 80 90   |

* Isolated yield of product 3a.

| Table 2 | Isolated yield of BIM synthesis using various aldehydes (R<sub>1</sub>). |
|---------|----------------------------------------------------------------------------|
| Entry   | R<sub>1</sub> | Product | Reaction time (h) | Isolated yield (%) |
| 1       | H           | 3a      | 5                 | 94               |
| 2       | 2-Cl        | 3b      | 5                 | 86               |
| 3       | 3-Cl        | 3c      | 5                 | 84               |
| 4       | 4-Cl        | 3d      | 5                 | 83               |
| 5       | 2-F         | 3e      | 5                 | 87               |
| 6       | 3-F         | 3f      | 5                 | 75               |
| 7       | 4-F         | 3g      | 5                 | 74               |
| 8       | 2-Br        | 3h      | 5                 | 71               |
| 9       | 3-Br        | 3i      | 5                 | 70               |
| 10      | 4-OCH<sub>3</sub> | 3j | 12                | 60               |
| 11      | 4-(CH<sub>3</sub>)<sub>2</sub>CH | 3k | 12                | 63               |

Fig. 4. The SEM images of surgical masks and MWAC.

Fig. 5. Recyclability test of MWAC for the synthesis of product 3a.
3.6. Photodegradation of dyes catalysed by the MWAC

To explore the versatility of the MWAC, it was then utilized as a potential photocatalyst for dye degradation. Four types of dye were involved in this experiment which are methylene blue (MB), green 19, red 120 and orange 16. The photodegradation of the dye experiment was performed at the initial dye concentration of 10 ppm. Fig. 6 shows the colour changes in MB from 0 to 3 h. At 0 h, the dye degradation with and without MWAC-photocatalyst showed a similar observation in terms of spectrum trending. After 3 h, the dyes solution recorded a significant reduction in absorbance in the presence of MWAC-photocatalyst as shown in Fig. 7. It was found that the MWAC showed the highest degradation efficiency of 94.55% for the MB followed by 37.63% for green 19 and 30.21% for red 120, while the lowest degradation efficiency was recorded at 5.59% for orange 16. This can be explained by the fact that the MWAC has provided a high adsorption capacity and more active sites for reacting with MB during chemical reaction (Vanthana Sree et al., 2020). In contrast, the control dye (without MWAC-photocatalyst) remained at a higher absorbance reading. In this study, MB resulted in a higher degrading capacity than the three other dyes. Therefore, MB was chosen to further study their degradation mechanisms capacity.

There are several factors influencing the degradation process such as contact time, initial concentration of dye, photocatalyst loading amount, solution pH and nature of the light source (Alkaykh et al., 2020). According to Tichapondwa et al. (2020), the optimum MB concentration for the best photocatalytic degradation efficiency was in the range of 2.5–10 ppm. This concurs with our finding that the use of 10 ppm of MB concentration achieved up to 94.55% of the degradation efficiency after 180 min. The presence of MWAC has improved the MB degradation efficiency as well. Therefore, the MWAC could be employed as a potential photocatalyst for dye degradation in the future, thus allowing for the sustainable reuse of discarded face masks (Vanthana Sree et al., 2020).

3.7. Photodegradation of MB products and mechanism

The photodegradation products generated during the degradation process catalysed by MWAC were analysed using LCMS-IT-TOF. The mass spectroscopy results revealed the presence of one metabolite from the MB degradation process. This metabolite was identified as C_{15}H_{12}O_3 (Benzoic acid, 4-benzoyl-, methyl ester) based on the comparison with the standards and their fragment ions in the mass spectra. The possible degradation of MB is presented in Fig. 8, where the reduction trend of the molecular weight is within expectation. This finding is supported by Houas et al. (2001), the degradation pathway has been determined by the identification of intermediate products of MB based on decreasing the molecular weight. The proposed reaction mechanism could be inferred from the fragmentation of the MB dye compound with a molecular weight of 284.12, which is the loss of two methyl groups (CH_3–CH_3) and one nitrogen ion, forming an ion of [M + H]^+ and released the new compound as C_{15}H_{12}O_3. The cleavage of two methyl groups from the MB dye has also been found in previous studies (Chen et al., 2008; Wahab et al., 2011). Overall, the MS/MS data suggested the
great photocatalytic performance of MWAC in the photodegradation of methylene blue.

3.8. Limitations and future research on MWAC

The current work has demonstrated an efficient and recyclable catalyst (i.e., MWAC) that can be applied in BIMs syntheses and photodegradation of dye. However, more research is needed in the future to confirm the applicability and practicality of the MWAC, such as the synthesis of other bioactive heterocyclic compounds and photodegradation of neurotoxic artificial dyes. In addition, the efficiency of photodegradation on methylene blue contained in a real wastewater sample catalysed by the MWAC should be evaluated to add validity to the current work. The MWAC could also be tested for its ability to degrade organic solvents and chemical spills that create pollution to the environment.

4. Conclusion

In summary, an efficient synthesis of the BIMs catalysed by MWAC is revealed. Overall, a considerably good yield of BIMs was obtained at 62–94%. The MWAC also showed remarkable effectiveness of 94.55% in the photodegradation of MB. This study explores a sustainable management strategy for discarded face masks by producing a versatile catalyst for the photodegradation of problematic dye and organic compound syntheses without the use of conventional hazardous solvents. Most importantly, in this time of the pandemic, which had brought on a host of adverse environmental impacts, the concept of this study is in line with “waste to wealth” by providing a sustainable method of waste management for discarded face masks.

Credit author statement

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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.

Acknowledgement

The author would like to thank the Ministry of Education Malaysia for the Fundamental Research Grant Scheme (FRGS) (Vot. No. 59499), UMT/RMC/FRGS/1/2018/59499(1).

References

Alkaykh, S., Mbarak, A., Ali-Shattle, E.E., 2020. Photocatalytic degradation of methylene blue dye in aqueous solution by MnTiO3 nanoparticles under solar irradiation. Heliyen 6 (4), e00663.
Aragaw, T.A., Mekonnen, B.A., 2021. Current plastics pollution threats due to COVID-19 and its possible mitigation techniques: a waste-to-energy conversion via Pyrolysis. Environ. Syst. Res. 10, 1–11. https://doi.org/10.1186/s40068-020-00217-x.
Aziri, N., Ghoshbeglio, E., Manocheri, Z., 2012. Green procedure for the synthesis of bis(indolyl)methanes in water. Sci. Iran. 19, 574–578. https://doi.org/10.1016/j.sci.2011.11.043.
Chen, T., Zheng, Y., Lin, J.M., Chen, G., 2008. Study on the photocatalytic degradation of methyl orange in water using Ag/ZnO as catalyst by liquid chromatography, electrospray ionization ion-trap mass spectrometry. J. Am. Soc. Mass Spectrom. 19 (7), 997–1003.
De Sousa, F.D.B., 2020. Pros and cons of plastic during the COVID-19 pandemic. Recycling 5, 27. https://doi.org/10.3390/recy5040027.
degradation of organic pollutants. J. Clean. Prod. 270 https://doi.org/10.1016/j.
clepro.2020.122294.
Varghese, H., Chandran, A., 2021. Triboelectric nanogenerator from used surgical face
mask and waste mylar materials aiding the circular economy. ACS Appl. Mater.
Interfaces 13, 51132–51140.
Wahab, R., Hwang, I.H., Kim, Y.S., Shin, H.S., 2011. Photocatalytic activity of zinc oxide
micro-flowers synthesized via solution method. Chem. Eng. J. 168, 359–366.
Wang, X., Aldrich, C.C., 2019. Development of an imidazole salt catalytic system for the
preparation of bis (indolyl) methanes and bis (naphthyl) methane. PLoS One 14,
e0216008. https://doi.org/10.1371/journal.pone.0216008.
Williams-Wynn, M.D., Naidoo, P., 2020. A review of the treatment options for marine
plastic waste in South Africa. Mar. Pollut. Bull. 161, 111785 https://doi.org/
10.1016/j.marpolbul.2020.111785.
Zhao, L., Jiang, L., Li, H., Hu, C., Sun, J., Li, L., Meng, F., Dong, Z., Zhou, C., 2018.
Synthesis and characterization of silver-incorporated calcium phosphate
antibacterial nanocomposites for mask filtration material. Compos. B Eng. 153,
387–392. https://doi.org/10.1016/j.compositesb.2018.09.004.