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EcoMask: Development of a biodegradable respirator using Sugarcane Bagasse (*Saccharum officinarum*) cellulose coated with shrimp shell chitosan and Bamboo (*Bambusoideae*) nonwoven fabric

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ABSTRACT

Disposable face mask usage has caused a significant environmental crisis, with an estimated 129 billion masks discarded globally each month. Conventional masks, mainly made from polymers like polypropylene and polyethylene, take over 50 years to decompose, rising levels of pollution in both terrestrial and marine habitats. This study presents the development of *EcoMask*, a biodegradable respirator composed of sugarcane bagasse (*Saccharum officinarum*) cellulose coated with shrimp shell-derived chitosan, and reinforced with nonwoven bamboo (*Bambusoideae*) fabric. Biodegradability tests using ISO 14855-2:2018 standards revealed that the EcoMask decomposes within 3–6 months under aerobic composting conditions, significantly faster than conventional plastic masks. Particle Filtration Efficiency (PFE) testing following ASTM-F2299 protocols indicated a moderate efficiency of 36–41%, suitable for non-medical environments. While the mask shows limited filtration performance compared to medical-grade respirators, it excels in environmental sustainability, offering a promising step toward reducing the environmental impact of plastic masks.

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INTRODUCTION

On a global scale, an estimated 129 billion disposable face masks are used and discarded monthly, which equates to approximately 4.3 billion masks per day (Prata et al., 2020). Most of these are improperly disposed of in landfills and open areas, resulting in severe terrestrial, coastal, and marine pollution (Babaahmadi et al., 2021).

Within Baguio City, Philippines, an estimated 417,834 face masks are discarded daily, generating approximately 3,585 kilograms of additional waste per day, as per Lunag et al. (2023). Surveys further show that 48.7% of Baguio residents use two face masks per day, 28.1% use one, 16.7% use three, and smaller percentages report using four (3.6%) or more than four (2.9%) masks per day. Beyond environmental concerns, prolonged mask usage has led to dermatological issues such as mask-induced acne ("maskne"), skin irritation, and pressure-related redness, highlighting the need for masks that are not only functional but also skin-friendly (Mikhail, 2023; Nguyen, 2021).

Conventional disposable masks are primarily composed of synthetic plastics, notably polyethylene terephthalate (PET), along with polystyrene, polycarbonate, polyethylene, and polyester (Selvaranjan et al., 2021). These polymers degrade through photodegradation, thermo-oxidative degradation, hydrolytic processes, or microbial activity—degradation processes that can take several decades, often exceeding 50 years (Webb et al., 2012). Given this prolonged environmental persistence, there is a critical need to redesign face masks with sustainability in mind. As Hartanto and Triastianti (2021) suggest, rather than banning plastic-based medical equipment outright, redesigning them using environmentally friendly alternatives is a more pragmatic approach.

This study thus aims to develop a biodegradable and sustainable respirator using natural, eco-friendly materials as alternatives to conventional polymers. The development is particularly urgent in light of increasing air pollution, which has been linked to elevated risks of respiratory diseases such as lung cancer and pneumonia. In 2019, air pollution in the Philippines was attributed to 32,109 deaths—approximately 29 per 100,000 population.

As stated by Jiménez-Gómez & Cecilia (2020), chitosan, a biopolymer derived from chitin, is suitable for various biomedical applications, including skin, bone, and tissue engineering, as well as wound healing, as it exhibits excellent bioactivity, biodegradability, and biocompatibility. Its polycationic nature, along with chelating and film-forming properties resulting from its active amino and hydroxyl groups, makes it especially useful for face masks with antimicrobial and comfort-enhancing features (Zou et al., 2022). Varun et al. (2017) successfully extracted chitosan from shrimp shell waste, while Parthiban et al. (2017) demonstrated that shrimp-derived chitosan outperforms those derived from crab and squilla in terms of yield, deacetylation, solubility, and viscosity. Accordingly, this study utilizes shrimp shell-derived chitosan for its superior quality and applicability.

Sugarcane, locally known as 'Tobo,' is one of the most widely cultivated crops in the Philippines, found across the country (Ardeña et al., 2022). This widespread cultivation results in significant amounts of sugarcane bagasse, a byproduct of sugar and ethanol production that contributes over 279 million tons of liquid and solid waste yearly worldwide (Ungureanu et al., 2022). Improper management of such waste poses significant environmental hazards. Sugarcane bagasse consists primarily of cellulose (40–50%) (Mahmud & Anannya, 2021), from which nanocellulose can be derived (Phanthong et al., 2018). Nanocellulose is an ideal filtration material due to its ultrafine fiber structure, excellent breathability, lightweight nature, and high filtration efficiency for particles smaller than 100 nm—qualities that offer superior comfort and performance compared to conventional mask materials (Sharma et al., 2023). Additionally, its biodegradability provides a critical advantage in mitigating waste accumulation.

Bamboo, a fast-growing and renewable resource, is another sustainable material integrated into this study. When organically sourced and untreated with harsh chemicals, bamboo is fully biodegradable (Cariki, 2021). With growth rates ranging from 100 to 250 cm per day (Prang et al., 2017), it offers a readily available and scalable resource. Mechanically extracted bamboo fibers are naturally antibacterial, moisture-absorbent, and breathable. Das

(2010) attributes these properties to bamboo kun, a unique bio-agent embedded within bamboo cellulose, which remains present in final textile products. Additionally, bamboo fibers are antistatic and non-adhesive to human skin, enhancing user comfort.

This study addresses the urgent need for environmentally sustainable and dermatologically safe face masks by developing EcoMask, a biodegradable respirator constructed from shrimp shell chitosan, sugarcane bagasse cellulose, and bamboo nonwoven fabric. These three components offer a complementary set of properties: antibacterial activity, high filtration efficiency, breathability, biodegradability, and comfort. By integrating these materials into a single product, the study aims to contribute a meaningful solution to the environmental burden of disposable masks and promote safer, more sustainable mask usage in the face of ongoing public health challenges.

OBJECTIVES OF THE STUDY

This study aimed to develop biodegradable respirators using chitosan-coated cellulose from sugarcane bagasse (*Saccharum officinarum*) and bamboo (*Bambusoideae*) nonwoven fabric. Specifically, it sought to address the following objectives:

1. To determine the efficiency of the EcoMask in terms of biodegradability.
2. To determine the Particulate Filtration Efficiency (PFE) of the EcoMask.

MATERIALS AND METHODS

Research Design

This study used the experimental research design. According to Zubair (2023), experimental design is a scientific method used to investigate the influence of one or more independent variables on one or more dependent variables by systematically altering and applying them. Adopting a quantitative research approach, this study aimed to analyze the biodegradation rate and performance attributes of a biodegradable face mask developed from bamboo, cellulose, and sugarcane bagasse.

Research Materials

The researchers utilized the following materials in this study: sugarcane bagasse (*Saccharum officinarum*), sourced from Sugarcane & Beyond, bamboo (*Bambusoideae*), obtained from a local farm, and chitosan powder, purchased online from Chemsavers, Inc. Additional materials include biodegradable elastic cord, biodegradable plastic, organic cotton, silk screen, high-pressure water jet, heat press, and distilled water. Chemicals such as hydrochloric acid (HCl), 5% sodium hydroxide (NaOH), glacial acetic acid, and 30% hydrogen peroxide were acquired by the laboratory. Laboratory equipment such as a hot plate with magnetic stirrer, scissors, forceps, beakers, graduated cylinders, and oven were also used.

Research Methods

Production of the Filter Layer

Sugarcane stalks were washed, stripped of nodes, and cut into 4 cm sections. The rind was soaked in hot water to remove sugars, then treated with 0.1N and 1N sodium hydroxide (NaOH) solutions (100 mL per gram of rind), and heated at 121°C for 1–4 hours under atmospheric pressure with magnetic stirring (Mahmud & Anannya, 2021).

The extracted sugarcane bagasse fibers served as the filter layer of the EcoMask for their antimicrobial properties (Hernández-López et al., 2024). Using the wet-laid method, the bagasse fibers were blended with organic cotton and evenly spread on a silk screen (Aswini, 2020). High-pressure hydroentanglement at 125 bar (Sawhney et al., 2011) bonded the fibers without adhesives. After air drying, the fabric was submerged in a chitosan solution (1g chitosan per 99g deionized water) for biodegradability and antimicrobial enhancement (Lee et al., 2023). A final air-drying step preceded heat pressing at 130–135°C to improve strength and durability (Wang et al., 2013), resulting in a porous, hydrophilic, and robust nonwoven fabric.

Production of the Inner and Outer Layer

Bamboo fibers (*Bambusa vulgaris*) were extracted and reinforced through a maceration process based on the method outlined by Dos Santos et al. (2024), using a solution of 10 mL 30% hydrogen peroxide, 50 mL glacial acetic acid, and 40 mL distilled water at 60°C for 18 hours, as described by Wang et al. (2015). After drying at 65°C for 6 hours, the fibers were treated with a 5% sodium hydroxide (NaOH) solution, 10 mL per gram of fiber, for 2 hours at room temperature, following the procedure of Kudva & Pai (2024), to improve fiber strength. The treated fibers were thoroughly rinsed and oven-dried at 60°C for 3 hours.

Fabric production was carried out using the wet-laid technique, following the approach of Kore et al. (2021). The bamboo fibers were suspended in water and spread over a silk screen for even distribution. Hydroentanglement was applied using high-pressure water jets, based on the method by Sawhney et al. (2011), to interlace the fibers without the use of adhesives. Organic cotton fibers were blended into the bamboo matrix to improve softness, breathability, and moisture-wicking (Bao Lan, 2023). Furthermore, a chitosan treatment was applied to the fabric to enhance its durability, antimicrobial, and mechanical properties, making it more resistant to microbial growth and wear over time (Wu et al., 2019). Finally, the nonwoven fabric was heat-pressed at 130–135°C, as outlined by Wang et al. (2013), to enhance the material's strength and durability.

Production of the EcoMask

The face mask measured 115 mm × 140 mm, modeled after a commercially available 3D design chosen for its superior fit and comfort. Proper fit is crucial for filtration efficiency, as poor fitting can reduce effectiveness by up to 60% (Ganesapillai et al., 2022). Velasco et al. (2022) also emphasized that no mask can fully filter particles if poorly fitted. Research from the University of Cambridge found that even high-grade masks like N95 or KN95 perform similarly to cloth masks without a proper seal, but with correct fitting, filtration exceeds 95% (*Proper Fit of Face Masks Is More Important than Material*, 2021). The 3D design helps accommodate facial contours, minimizing leakage and improving performance.

Following Mańkowski et al. (2023), the mask layers were assembled with bamboo nonwoven fabric as both outer and inner layers, and sugarcane fibers coated in chitosan as the filter layer. A biodegradable polymer film served as the adhesive, and layers were bonded using heating plates at 190–230°C to enhance mechanical stability. Lastly, two 6-inch elastic cords were heat-pressed onto the fabric to ensure a secure and lasting attachment.

Data Collection

Biodegradability Test

The study adopted the International Organization for Standardization (ISO) 14855-2:2018 standard to evaluate the biodegradability of the EcoMask. The EcoMask was prepared for testing by cutting it into uniform 2 cm × 2 cm fragments to optimize microbial exposure. The test material's total organic carbon (TOC) was analyzed to calculate the theoretical carbon dioxide (CO_2) output during biodegradation. The EcoMask fragments were then mixed with the compost inoculum made of matured compost at a dry mass ratio of 1:6 and placed into composting vessels, alongside control vessels containing only inoculum and a reference material such as TLC-grade cellulose.

The composting vessels were incubated at 58°C ± 2°C to simulate aerobic composting conditions. Carbon dioxide-free air was continuously supplied to maintain aerobic conditions, with regular monitoring of CO2 evolution using gas chromatography or absorption in sodium hydroxide.

The test continued until CO2 evolution stabilized, indicating the plateau phase of biodegradation. The percentage biodegradation of the EcoMask was calculated by comparing the cumulative CO2 evolved to its theoretical maximum (International Organization for Standardization, 2018).

Particulate Filtration Efficiency

To assess Particulate Filtration Efficiency, the ASTM-F2299 method was used. Prior to testing the three EcoMask samples across three trials, the system's aerosol generation and measurement stability were confirmed through calibration and checks for complete aerosol drying and stable particle counts without a specimen. For each trial, an EcoMask sample was placed in the test system, and the required airflows were re-established, with the Optical Particle Counter (OPC) airflow monitored and adjusted for the sample's pressure drop. The temperature, relative humidity, and pressure drop across the mask were recorded. Upstream (before the filter) and downstream (after the filter) aerosol particle counts were measured and recorded over five 1-minute intervals. Extended sampling (up to 5 minutes) occurred if downstream counts were below 100 to ensure sufficient data without overloading the filter. Upstream count stability was continuously monitored. Ultimately, the decimal efficiency for each trial was calculated. This decimal value was then multiplied by 100 to express the Particulate Filtration Efficiency as a percentage (*SIST - Slovenian Institute for Standardization*, 2016).

RESULTS AND DISCUSSION

Biodegradability Test

The EcoMask was tested for biodegradability under aerobic conditions to determine its environmental impact over time. The mask is made from sugarcane bagasse (*Saccharum officinarum*) (SCB) cellulose, coated with shrimp shell chitosan, and layered with bamboo (*Bambusoideae*) nonwoven fabric as the inner and outer layers. Three trials were conducted to observe how long the mask takes to degrade under consistent conditions.

Degradation analysis was conducted using GC-MS (Gas Chromatography-Mass Spectrometry), a method frequently employed in biodegradation studies of bioplastics and bacteria-based polyethylene products (Shahnawaz et al., 2016; Cho et al., 2022). To ensure consistency in biodegradability results, all trials were conducted under controlled aerobic conditions with a consistent storage temperature of 24–26°C and identical EcoMask composition.

Table 1. Biodegradability of EcoMask

Parameter	Trial 1	Trial 2	Trial 3
Storage Conditions	24–26°C, aerobic	24–26°C, aerobic	24–26°C, aerobic
Composition	SCB cellulose, chitosan coating, bamboo non-woven fabric	SCB cellulose, chitosan coating, bamboo non-woven fabric	SCB cellulose, chitosan coating, bamboo non-woven fabric
Thickness	0.3 inches	0.3 inches	0.3 inches
Time to Complete Biodegradation	4 months	3 months	6 months

Based on Table 1, Trial 1 recorded a degradation time of 4 months, while Trial 2 exhibited the fastest biodegradation at 3 months. Trial 3 took 6 months, the longest among the trials. The variation in degradation time observed may be attributed to factors such as material characteristics and experimental procedures. The mask's thickness of 0.3 inches could also be a contributing variable, as noted by Folino et al. (2020), where material thickness affects biodegradation rates.

The EcoMask's biodegradation performance aligns with the European Union's standards for compostable materials (EN 13432:20006; EN 14995:20067), which require that >90% of the material be converted into CO_2, water, and minerals within 6 months. By comparison, most traditional face masks are composed of polypropylene (PP), a non-biodegradable plastic that remains in the environment for decades. Studies indicate that PP plastics typically take 20–30 years to degrade in landfills (Tesfaldet & Ndeh, 2022) and over 10 years under aerobic or anaerobic conditions, with some estimates suggesting degradation periods of hundreds of years (Oliveira et al., 2023).

These results highlight the EcoMask as a viable, eco-friendly alternative to conventional face masks, supporting global initiatives to reduce plastic pollution and addressing the environmental issues associated with single-use protective equipment.

Particulate Filtration Efficiency

The EcoMask's particulate filtration efficiency (PFE) was evaluated at the Virgen Milagrosa University Foundation laboratory using the Automated Filter Tester 8130. Three trials were conducted to assess its performance in filtering airborne particles sized 2 to 4 micrometers.

Table 2. Particulate Filtration Efficiency of EcoMask

Composition of Ecomask	Trial 1	Trial 2	Trial 3
SCB cellulose coated with shrimp shell chitosan and Bamboo nonwoven fabric	36%	38%	41%

As shown in Table 2, the results indicated a PFE of 36% in Trial 1, 38% in Trial 2, and 41% in Trial 3. These percentages represent the proportion of airborne particles that were successfully filtered by the mask. Although there was a slight improvement across the trials, the filtration efficiency remains well below the 95% minimum required for approval by the National Institute for Occupational Safety and Health (NIOSH) for particulate filtering facepiece respirators.

Several factors may explain this lower performance. The structure and chemical composition of mask materials significantly influences filtration efficiency (Ardon-Dryer et al., 2021). The EcoMask's filtration layer is composed of sugarcane bagasse cellulose coated with chitosan, which, while environmentally friendly, does not possess the same structural characteristics or electrostatic properties as synthetic materials such as polypropylene. These synthetic fibers are engineered for high filtration efficiency through tight fiber packing, electrostatic charge, and optimized structure. The thickness, fiber diameter, and fiber packing density of the EcoMask's biodegradable materials may also play a role in limiting its performance (Wang et al., 2023).

Table 3. Particulate Filtration Efficiency of Different Mask Types

Mask Type	PFE Range (%)
EcoMask	36 – 41 (mean 38.33)
Single/multi-layer natural materials	< 30
Cloth masks	16 – 23
Surgical masks	42 – 88
N95 / KN95 respirators	83 – 99

As shown in Table 3, comparing the particulate filtration efficiencies of different masks, studies indicate that most single and multi-layer combinations of natural materials, like those used in the EcoMask, typically exhibit filtration efficiencies of less than 30% (Kwong et al., 2021). In comparison, synthetic materials used in N95 and KN95 respirators achieve filtration efficiencies of 83–99% for particles sized around 0.3 µm, while surgical masks offer a PFE range of 42–88%, and cloth masks show a lower range of 16–23% (Sankhyan et al., 2021). The EcoMask's PFE of 36–41% (mean: 38.33%) falls within the lower end of filtration efficiency ranges observed in existing studies, highlighting a noticeable performance gap compared to conventional masks.

CONCLUSION AND RECOMMENDATION

Conclusion

In conclusion, this study aimed to develop a biodegradable respirator face mask utilizing chitosan-coated cellulose fiber obtained from sugarcane bagasse and bamboo non-woven fabric to help mitigate environmental pollution by providing an effective and biodegradable alternative, potentially transforming future mask production and usage. The study revealed that the EcoMask is highly biodegradable, capable of decomposing within an average of 4.3 months under aerobic conditions. The biodegradability trials showed varying results: Trial 1 decomposed in 4 months, Trial 2 in 3 months, and Trial 3 in 6 months. These variations suggest that environmental conditions affect the decomposition rate, but overall, the EcoMask demonstrates consistent and promising biodegradability. In comparison, regular respirators made from synthetic materials can take years to break down, significantly contributing to long-term environmental pollution, making the EcoMask a more sustainable alternative.

While the biodegradability of the EcoMask is promising, the Particulate Filtration Efficiency (PFE) results, with levels ranging from 36% to 41% (mean: 38.33%), indicate that the mask's filtration performance does not meet the international standards required for medical-grade face masks, which typically require a minimum of 95% filtration efficiency, particularly in filtering smaller particulate matter and airborne pathogens. This limitation highlights the need for further refinement of the filtration layer to enhance its protective capacity, ensuring it can achieve higher filtration efficiency while maintaining adequate breathability.

Recommendation

Based on these findings, it is recommended that future researchers refine certain experimental parameters to optimize the effectiveness of the EcoMask. Firstly, conducting prolonged degradation experiments beyond six months would provide a complete picture of the mask's decomposition rate in various environments. Secondly, testing pre-use and post-use samples would offer insights into material structure changes over time. Thirdly, investigating a wider range of environmental conditions, such as varying temperatures and humidity levels, would enhance understanding of the mask's real-world performance. Fourthly, thoroughly combing the extracted bamboo fibers before blending with biodegradable cotton would ensure a smoother, more uniform texture. Lastly, to enhance user experience, treating the mask with a light "bamboo-charcoal" scent is recommended to neutralize any natural odors from the raw materials.

To enhance the EcoMask's filtration efficiency while maintaining biodegradability, future research should explore advanced strategies. One promising approach could be the incorporation of degradable nanofiber filters developed via electrospinning, which have demonstrated superior filtration performance (Shen et al., 2023). Additionally, bacterial cellulose has been identified as a biodegradable material with high purity, mechanical strength, and a nanoscale fiber network capable of effectively trapping particulate matter (Sharma et al., 2023). Chitosan coatings, particularly in the form of nanowhiskers, have also shown significant improvements in particulate matter (PM) removal efficiency when applied to various fabrics (Lee et al., 2023). For example, Lee et al. (2023) reported that a five-layer cotton fabric coated with chitosan nanowhiskers achieved a PM2.5 removal efficiency of 96%. These findings suggest that integrating bacterial cellulose-based layers with chitosan nanowhisker coatings, and potentially incorporating degradable electrospun nanofiber filters, could substantially improve the EcoMask's protective capabilities without compromising its environmental sustainability.

By addressing these recommendations, future developments could ensure the EcoMask becomes a viable, eco-friendly alternative for both medical and everyday use.

REFERENCES

Ardeña, R.A., Pardillo, N.A., Gemida, J.V. (2022). Sugarcane growth through fermented bamboo shoot application. *International Research Journal of Science, Technology, Education, and Management*, 2(1), 178-184. https://doi.org/10.5281/zenodo.6496857

Ardon-Dryer, K., Warzywoda, J., Tekin, R., Biros, J., Almodovar, S., Weeks, B. L., Hope-Weeks, L. J., & Sacco, A. Jr. (2021). Mask material filtration efficiency and mask fitting at the crossroads: Implications during pandemic times. *Aerosol and Air Quality Research, 21*, 200571. https://doi.org/10.4209/aaqr.200571

Aswini, M. (2020). Design and fabrication of lab-scale wet-laid equipment to develop wet-laid nonwoven for the application of absorbent core of disposable nursing pad. *Journal of Industrial Textiles*. Advance online publication. https://doi.org/10.1177/1528083719893715

Babaahmadi, V., Amid, H., Naeimirad, M., & Ramakrishna, S. (2021). Biodegradable and multifunctional surgical face masks: A brief review on demands during COVID-19 pandemic, recent developments, and future perspectives. *Science of the Total Environment, 798,* 149233. https://doi.org/10.1016/j.scitotenv.2021.149233

Bamboo into fabric: Unveiling the transformation process. (2022). *WELL FABRIC*. https://wellfabric.com/?fbclid=IwAR1HdrkjklTLzCHqLfbWoUURRRQImUiWZ5FfvPhxshO31mIMWZCENitR0yk

Bao Lan. (2023). 5 advantages of bamboo cotton fabric in sustainable attire. *WELL FABRIC - Eco Fabric Supplier*. https://wellfabric.com/what-is-bamboo-cotton-fabric/

Cariki. (2021). Are bamboo clothes eco friendly? *Cariki*. https://cariki.co.uk/blogs/the-green-road/are-bamboo-clothes-eco-friendly#:~:text=Bamboo%20is%20biodegradable%3A%20Organic%20bamboo

Cho, J. Y., Kim, S. H., Cho, D. H., Jung, H. J., Kim, B. C., Bhatia, S. K., Gurav, R., Lee, J., Park, S.-H., Park, K., Joo, H.-S., & Yang, Y.-H. (2022). Simultaneous monitoring of each component on degradation of blended bioplastic using gas chromatography-mass spectrometry. *Analytical Biochemistry*, *655*, 114832. https://doi.org/10.1016/j.ab.2022.114832

Ciuffreda, S., Picotti, C., & Pescio, P. (2020). Medical face masks on the market: Review of materials, characteristics and performed tests. https://cdnmedia.eurofins.com/european-west/media/12146819/medical_face_mask_report_v13.pdf

Das, S. (2010). Fibres and fabrics used in home textiles. In *Woodhead Publishing India*. https://doi.org/10.1533/9780857094032.22

Dos Santos, A., Ribeiro, M., Corrêa, A., Rodrigues, J., Silva, D., Junio, R., & Monteiro, S. (2024). Morphological, chemical and mechanical properties of hybrid polyester composites reinforced with bamboo fibers and kaolin waste. *Journal of Materials Research and Technology*, *30*, 1–15. https://doi.org/10.1016/j.jmrt.2024.03.003

European Committee for Standardization. (2019). *NBN EN 14683:2019+AC:2019: Medical face masks - Requirements and test methods*. https://www.edana.org/docs/default-source/international-standards/nbn-en-14683_2019-ac-2019_e.pdf?sfvrsn=3797c92b_4

Farooq, S., Mir, S. A., Shah, M. A., & Manickavasagan, A. (2022). Chapter 2 - Extraction techniques (S. A. Mir, A. Manickavasagan, & M. A. Shah, Eds.). In *Advances in Bioprocess Technology* (pp. xx–xx). Academic Press. https://doi.org/10.1016/B978-0-12-822475-5.00005-3

Fisher, S. (2020). How to sew a basic face mask. *The Spruce*. https://www.thespruce.com/how-to-sew-face-mask-4802114

Folino, A., Karageorgiou, A., Calabrò, P., & Komilis, D. (2020). Biodegradation of wasted bioplastics in natural and industrial environments: A review. *Sustainability, 12*(15), 6030. https://doi.org/10.3390/su12156030

Forster, M. (2022). Reducing car pollution - Washington state department of ecology. *Ecology.wa.gov*. https://ecology.wa.gov/Issues-and-local-projects/Education-training/What-you-can-do/Reducing-car-pollution

Ganesapillai, M., Mondal, B., Sarkar, I., Sinha, A., Ray, S. S., Kwon, Y.-N., Nakamura, K., & Govardhan, K. (2022). The face behind the Covid-19 mask — A comprehensive review. *Environmental Technology & Innovation, 28*, 102837. https://doi.org/10.1016/j.eti.2022.102837

Hartanto, B. W., & Triastianti, R. D. (2021). Eco-friendly masks preferences during COVID-19 pandemic in Indonesia. *Cleaner and Responsible Consumption, 4*, 100044. https://doi.org/10.1016/j.clrc.2021.100044

Hernández-López, R., López-Malo, A., Navarro-Amador, R., & Ramírez-Corona, N. (2024). Sustainable filters with antimicrobial action from sugarcane bagasse: A novel waste utilization approach. *Waste, 2*(1), 122–135. https://doi.org/10.3390/waste2010007

International Organization for Standardization. (2018). *ISO 14855-2:2018*. https://www.iso.org/standard/72046.html

Jiménez-Gómez, C. P., & Cecilia, J. A. (2020). Chitosan: A natural biopolymer with a wide and varied range of applications. *Molecules, 25*(17), 3981. https://doi.org/10.3390/molecules25173981

Kore, S., Spencer, R., Ghossein, H., Slaven, L., Knight, D., Unser, J., & Vaidya, U. (2021). Performance of hybridized bamboo-carbon fiber reinforced polypropylene composites processed using wet laid technique. *Composites Part C: Open Access*, *6*, 100185. https://doi.org/10.1016/j.jcomc.2021.100185

Kudva, A., T, M. G., & Pai, D. (2024). Influence of chemical treatment on the physical and mechanical properties of bamboo fibers as potential reinforcement for polymer composites. *Journal of Natural Fibers, 21*(1). https://doi.org/10.1080/15440478.2024.2332698

Kwong, L. H., Wilson, R., Kumar, S., Crider, Y. S., Reyes Sanchez, Y., Rempel, D., & Pillarisetti, A. (2021). Review of the breathability and filtration efficiency of common household materials for face masks. *ACS Nano, 15*(4), 5904–5924. https://doi.org/10.1021/acsnano.0c10146

Lan, B. (2023, July 31). 5 advantages of bamboo cotton fabric in sustainable attire. *WELL FABRIC - Eco Fabric Supplier*. https://wellfabric.com/what-is-bamboo-cotton-fabric/

Lee, M., Sung Yeon Hwang, Jun Mo Koo, Jeon, H., Hyo Jeong Kim, Oh, D. X., & Park, J. (2023). Chitosan coating in the form of polymer and nanowhiskers on clothing fabrics for improved particulate matter removal efficiency in face mask filters. *Journal of Natural Fibers, 20*(1). https://doi.org/10.1080/15440478.2023.2187507

Lunag, M. N., Abana, A. S., Agcaoili, J. P., Arellano, J. K. T., Caluza, C. A. G., Decena, N. B. V., Paz, E. R. D., Delgado, L. A. B., Obero, A. F., Ocampo, D. M. E., & Sacdalan, C. A. D. (2023). Face mask and medical waste generation in the City of Baguio, Philippines: Its current management and GHG footprint. *Journal of Material Cycles and Waste Management*. https://doi.org/10.1007/s10163-023-01601-2

Mahmud, Md. A., & Anannya, F. R. (2021). Sugarcane bagasse - A source of cellulosic fiber for diverse applications. *Heliyon*, *7*(8), e07771. https://doi.org/10.1016/j.heliyon.2021.e07771

Mańkowski, J., Zimniewska, M., Gieparda, W., Romanowska, B., Kicińska-Jakubowska, A., Kołodziej, J., Foksowicz-Flaczyk, J., Rojewski, S., Bujnowicz, K., Przybylska, P., Kwiatkowska, E., Alam, Md. A., Różańska, W., Wawro, A., & Hołderna-Kędzia, E. (2023). Development of a layer made of natural fibers to improve the ecological performance of the face mask type II. *Materials, 16*(16), 5668. https://doi.org/10.3390/ma16165668

Mikhail, M. (2020, June). 8 tips to prevent acne caused by face masks ("Maskne"). *GoodRx*. https://www.goodrx.com/conditions/acne/masks-maskne?fbclid=IwAR3nNsQHFAfWiqUPKwzeQpeVOe6RzP3Y4Euni64ZlK6wEvUENQPkNSzZQ1M

Nguyen, J. (2021). Skin reactions to face masks. *DermNet NZ*. https://dermnetnz.org/topics/skin-reactions-to-face-masks?fbclid=IwAR3H9P1P6Qputjcr48686rHNMhH4WdaizwG-tlhahg84CCDz3Xx2PKIoQ94

Oliveira, A. M., Patrício-Silva, A. L., Soares Amvm, D., Barceló, D., Armando, D., & Rocha-Santos, T. (2023). Current knowledge on the presence, biodegradation, and toxicity of discarded face masks in the environment. *Journal of Environmental Chemical Engineering*, *11*(2), 109308. https://doi.org/10.1016/j.jece.2023.109308

Parthiban, F., Balasundari, S., Gopalakannan, A., Rathnakumar, K., & Felix, S. (2017). Comparison of the Quality of Chitin and Chitosan from Shrimp, Crab and Squilla Waste. *Current World Environment*, *12*(3), 670–677. https://doi.org/10.12944/cwe.12.3.18

Phanthong, P., Reubroycharoen, P., Hao, X., Xu, G., Abudula, A., & Guan, G. (2018). Nanocellulose: Extraction and application. *Carbon Resources Conversion, 1*(1), 32–43. https://doi.org/10.1016/j.crcon.2018.05.004

Prang, A., Thompson, A., Shaughnessy, K., Wimberley, V., & Koontz, M. (2017). An experimental study toward eco-friendly bamboo fiber extraction for textiles. https://ir-api.ua.edu/api/core/bitstreams/50da5552-b4d5-47a8-ac7d-87851bf5bbc1/content

Prata, J. C., Silva, A. L. P., Walker, T. R., Duarte, A. C., & Rocha-Santos, T. (2020). COVID-19 pandemic repercussions on the use and management of plastics. *Environmental Science & Technology*, *54*(13), 7760–7765. https://doi.org/10.1021/acs.est.0c02178

Proper fit of face masks is more important than material, study suggests. (2021, February 11). University of Cambridge. https://www.cam.ac.uk/research/news/proper-fit-of-face-masks-is-more-important-than-material-study-suggests

Saleh, Y., Nasr, A., Zaki, H., Mohamed, M., & Kandile, N. (2016). Extraction and characterization of chitosan from shrimp shells. *Journal of Scientific Research in Science, 33*(part 1), 396–407. https://doi.org/10.21608/jsrs.2016.17145

Sankhyan, S., Heinselman, K. N., Ciesielski, P. N., Barnes, T., Himmel, M. E., Teed, H., Patel, S., & Vance, M. E. (2021). Filtration performance of layering masks and face coverings and the reusability of cotton masks after repeated washing and drying. *Aerosol and Air Quality Research*, *21*, 210117. https://doi.org/10.4209/aaqr.210117

Sawhney, P., Allen, C., Reynolds, M., Condon, B., & Slopek, R. (2011). Effect of water pressure on absorbency of hydroentangled greige cotton non-woven fabrics. *Textile Research Journal*, *82*(1), 21–26. https://doi.org/10.1177/0040517511416276

Selvaranjan, K., Navaratnam, S., Rajeev, P., & Ravintherakumaran, N. (2021). Environmental challenges induced by extensive use of face masks during COVID-19: A review and potential solutions. *Environmental Challenges*, *3*(100039), 100039. https://doi.org/10.1016/j.envc.2021.100039

Sharma, P., Mittal, M., Yadav, A., & Aggarwal, N. K. (2023). Bacterial cellulose: Nano-biomaterial for biodegradable face masks – A greener approach towards environment. *Environmental Nanotechnology, Monitoring & Management*, *19*, 100759. https://doi.org/10.1016/j.enmm.2022.100759

Shen, R., Guo, Y., Wang, S., Tuerxun, A., He, J., & Bian, Y. (2023). Biodegradable electrospun nanofiber membranes as promising candidates for the development of face masks. *International Journal of Environmental Research and Public Health*, *20*(2), 1306. https://doi.org/10.3390/ijerph20021306

SIST - Slovenian Institute for Standardization. (2016). Standard test method for determining the initial efficiency of materials used in medical face masks to penetration by particulates using latex spheres. https://doi.org/10.1520/F2299_F2299M-03R17.10.1520/F2299_F2299M-24

Soo, X. Y. D., Wang, S., Yeo, C. C. J., Li, J., Ni, X. P., Jiang, L., Xue, K., Li, Z., Fei, X., Zhu, Q., & Loh, X. J. (2021). Polylactic acid face masks: Are these the sustainable solutions in times of COVID-19 pandemic? *Science of the Total Environment*, 151084. https://doi.org/10.1016/j.scitotenv.2021.151084

Tesfaldet, Y. T., & Ndeh, N. T. (2022). Assessing face masks in the environment by means of the DPSIR framework. *The Science of the Total Environment*, *814*, 152859. https://doi.org/10.1016/j.scitotenv.2021.152859

Teli, M. D., & Sheikh, J. (2012). Extraction of chitosan from shrimp shells waste and application in antibacterial finishing of bamboo rayon. *International Journal of Biological Macromolecules, 50*(5), 1195–1200. https://doi.org/10.1016/j.ijbiomac.2012.04.003

Ungureanu, N., Vlăduț, V., & Biriș, S.-Ș. (2022). Sustainable valorization of waste and by-products from sugarcane processing. *Sustainability*, *14*(17), 11089. https://doi.org/10.3390/su141711089

Varun, T. K., Senani, S., Jayapal, N., Chikkerur, J., Roy, S., Tekulapally, V. B., Gautam, M., & Kumar, N. (2017). Extraction of chitosan and its oligomers from shrimp shell waste, their characterization and antimicrobial effect. *Veterinary World, 10*(2), 170–175. https://doi.org/10.14202/vetworld.2017.170-175

Velasco, E., Hieu Ha, H., Duc Pham, A., & Rastan, S. (2022). Effectiveness of wearing face masks against traffic particles on the streets of Ho Chi Minh City, Vietnam. *Environmental Science: Atmospheres, 2*(6), 1450–1468. https://doi.org/10.1039/D2EA00071G

Wang, H., Tian, G., Li, W., Ren, D., Zhang, X., & Yu, Y. (2015). Sensitivity of bamboo fiber longitudinal tensile properties to moisture content variation under the fiber saturation point. *Journal of Wood Science*, *61*(3), 262–269. https://doi.org/10.1007/s10086-015-1466-y

Webb, H., Arnott, J., Crawford, R., & Ivanova, E. (2012). Plastic degradation and its environmental implications with special reference to poly(ethylene terephthalate). *Polymers*, *5*(1), 1–18. https://doi.org/10.3390/polym5010001

Wu, J. (2022). What is EN14683? The European standard for face masks! Medtecs Group. https://business.medtecs.com/en14683/

Wu, Y., Bian, Y., Yang, F., Ding, Y., & Chen, K. (2019). Preparation and properties of chitosan/graphene modified bamboo fiber fabrics. *Polymers, 11*(10), 1540. https://doi.org/10.3390/polym11101540

Zou, Q., Gai, Y., Cai, Y., Gai, X., Xiong, S., Wei, N., Jiang, M., Chen, L., Liu, Y., & Gai, J. (2022). Eco-friendly chitosan@silver/plant fiber membranes for masks with thermal comfortability and self-sterilization. *Cellulose*, *29*(10), 5711–5724. https://doi.org/10.1007/s10570-022-04582-x

Zubair, A. (2023). Experimental research design-types & process. ResearchGate. https://www.researchgate.net/publication/367044021_Experimental_Research_Design-types_process

APPENDICES

APPENDIX A
Documentation

I. Preparation of Materials

		
Fig. 1 Cutting of bamboo and sugarcane bagasse	*Fig. 2 Weighing of sugarcane bagasse*	*Fig. 3 Weighing of bamboo*

II. Extraction of Fibers

A. Bamboo (*Bambusoideae*)

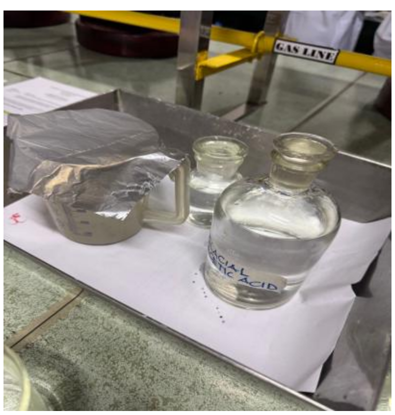		
Fig. 4 30% Hydrogen Peroxide, Glacial Acetic Acid, and Distilled Water	*Fig. 5 Preparation of maceration solution*	*Fig. 6 Five parts of glacial acetic acid, and four parts distilled water in a 250ml beaker*

		
Fig. 7 Maceration solution with labels for 3 trials	*Fig. 8 Soaking the bamboo in maceration process for 18 hours at room temperature*	*Fig. 9 Washing of macerated bamboo fibers with distilled water*

		
	Fig. 10 Drying of bamboo in an oven for 18 hours at 65°C	

B. Sugarcane Bagasse (*Saccharum officinarum*)

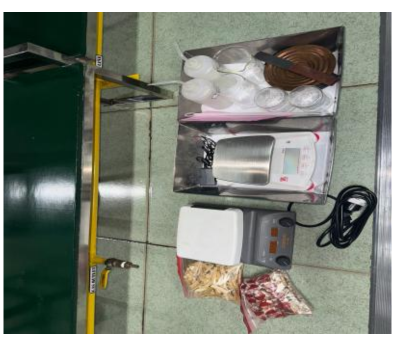	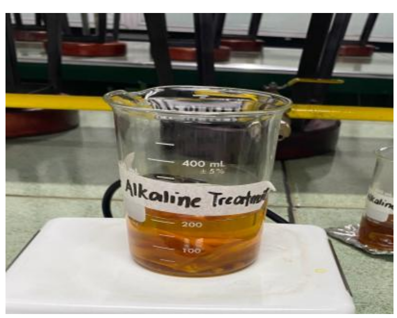	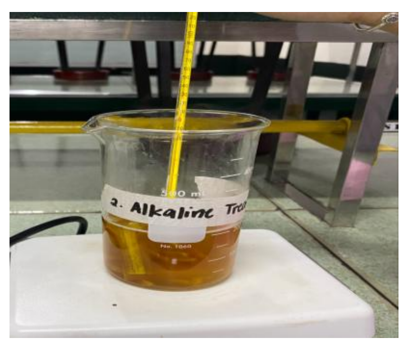
Fig. 11 Preparation of materials	*Fig. 12 SCB in sodium hydroxide (NaOH) solution*	*Fig. 13 SCB treatment for 4 hours with continuous use of magnetic stirring while being heated*

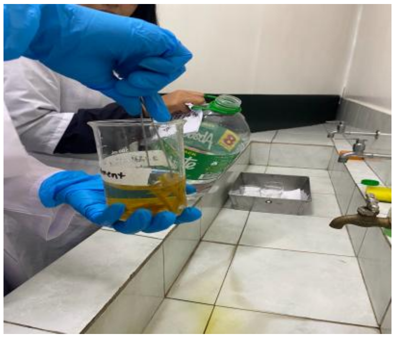

Fig. 14 Washing off the alkaline treatment

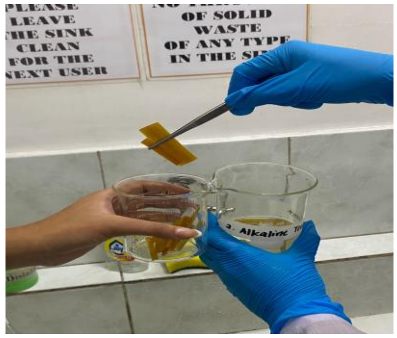

Fig. 15 Transferring the washed SCB from the treatment

Fig. 16 Drying of SCB in an oven for 1 hour at 80°C

III. Production of the bamboo and sugarcane bagasse nonwoven fabric

Fig. 17 Preparation of materials

Fig. 18 Layering of organic cotton and extracted fibers

Fig. 19 High-pressure jet compaction of organic cotton and SCB

Fig. 20 Deionized water with shrimp shell chitosan powder

Fig. 21 Coating the filter layer with chitosan solution

Fig. 22 Air drying of the fabric