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Using the concept of circular economy to reduce the environmental impact of COVID-19 face mask waste

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ABSTRACT

COVID-19 pandemic has posed severe threats to the society globally. World Health Organization (WHO) guidelines suggest that people wear face masks as a precautionary measure daily. This has resulted in the generation of massive amounts of mask-associated waste in the environment. Owing to the criticality of the epidemic, there has not been a large-scale investigation on where to discard masks, making this situation daunting. As the pandemic continues, the use of masks continues to increase; repeated use and disposal of masks has become an imperative issue. Most disposable masks comprise chemical fibers in the filter layer. Without proper treatment and disposal, these large amounts of chemical waste will eventually flow into rivers or oceans, leading to serious pollution. Therefore, to reduce the negative effects on the marine environment, it is crucial that we produce reusable masks and reduce disposable wearing habits. This study aimed to resolve this challenge using textile materials created by recycling fish-scale waste. Functional and comfortable masks manufactured without chemical additives to achieve multiple functions can increase the willingness to wear and be reused. Hence, product use can be prolonged, and the use of disposable masks can be curtailed. The product manufactured herein is biodegradable in nature, thus conforming to the green sustainable initiative.

1. Introduction

The ongoing COVID-19 pandemic not only has a severe impact on human health but also affects national economy and daily human life. Avoiding and minimizing infections are major approaches to control the spread of the virus. Face masks are typically used as primary Personal Protective Equipment (PPE) [1–6]. According to a Centers for Disease Control and Prevention (CDC) report, wearing medical or nonmedical masks in indoor public places can effectively decrease SARS-CoV-2 transmission [7]. The report stated that wearing a medical mask could reduce the infection rate by 66%. The N95 mask, often used by medical staff, has the greatest effect, with a capability to reduce infection rate by 83%, followed by the cloth mask at only 56%. These real-world data underscore the significance of wearing masks. Most masks are worn indoors and in public places to diminish the risk of contracting the novel coronavirus. To date, there is still no remedy to completely solve the problem of the novel coronavirus [8–10]. Therefore, masks will become an indispensable necessity of life for people in upcoming years.

Face masks function as a physical barrier for the mouth and nose to prevent exposure to airborne droplets, which may carry the virus directly into or out of the respiratory tract. Both N95 and normal medical masks have the following three-layered structure: the outermost layer is mainly used for waterproofing, which can prevent the attachment of potential virus droplets, the middle layer filters fine particles, and the inner layer is skin-friendly and used to absorb the wearer's sweat and mouth foam [11]. Some medical masks have additional middle layers for structural support or extra filtration functionality. Face masks with various structural designs are discarded after only a brief use. Disposal of mask waste has become a grave environmental challenge during the COVID-19 pandemic [12–17]. According to a survey, >25% of people use >5 face masks every day [18]. Most face masks contain plastics or their derivatives. Thus, the widespread use of masks has

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generated millions of tons of plastic waste within a short period of time [14,18,19]. For example, traditional medical masks use meltblown nonwoven fabric as the filter layer and chemical fiber polypropylene (PP). Like plastic bottles or other chemical fiber products, they do not decompose easily. When people from all over the world use one or more disposable masks daily, many discarded masks inevitably accumulate in the environment. If these discarded masks are not properly processed, they end up polluting rivers and oceans. Pollutants circulate upward through the food supply chain and eventually harm human beings [20–22].

Therefore, reducing the use of disposable medical masks has become an emergent global concern. The design of reusable masks is imperative to meet sustainable environmental needs in the post-epidemic era [23–25]. Our study considers this problem from the perspective of the fabric material used to create masks. Table 1 lists the common fabric materials found in medical and non-medical masks. Outer layer of the mask comprises non-absorbent materials, such as cotton, polyester, or a blend of polyesters. The middle layer serves a key filtering function and is usually composed of nonwoven polypropylene fibers. Activated carbon nanofibers are also used in the middle layer of masks to enhance the filtration performance of toxic dust molecules [26]. The inner layer of the mask must absorb droplets from the exhaled breath. Cotton and bicomponent fibers are typically used as hydrophilic materials. A bicomponent fiber is composed of two polymers extruded from the same spinneret, with both polymers within the same filament, for example, a PP/PE composite, also called an ES fiber. It is also vital to choose a light-colored fabric to determine whether it is soiled or wet.

CDC recommends washing of reusable face masks after each use. Therefore, wash durability is a principal factor for determining the material for reusable face mask. Deodorizability is also a critical factor prolonging the use of face masks. In addition, decomposition of the mask material is also a key factor in reducing the impact on environmental sustainability. Considering these factors for sustainable mask usage, general synthetic fibers such as PP are washable but are not easy to decompose and deodorize. Conversely, natural fibers such as cotton, although decomposable and washable, are prone to odors. Therefore, we have considered a material that can be used as a substitute for cotton and can be biodegraded and deodorized. In this study, collagen-modified viscose, which adheres to the concept of circular economy, was used to design the inner layer of the mask [27].

2. Material and methods

2.1. Biodegradable collagen-modified viscose fabrics as alternative material for face masks

Fig. 1 depicts the production of proposed material for an environment friendly mask design. Collagen is a waste by-product extracted from fish scales recovered from aquaculture fisheries [28]. The regular viscose fiber manufactured is composed of 100% regenerated cellulose. Cellulose pulp, the raw material of viscose fiber, comes from nature and has biodegradable properties that other manufactured fibers lack. The cellulose pulp used in this study was supplied by the FORMOSA CHEMICALS & FIBER CORPORATION (FCFC) and passed the Oeko-Tex Standard 100 (safety certification standard for environment friendly textiles without derived toxic substances [29]) and the Forest Management and Production and Marketing Chain of Custody (FSC CoC) certification verification [30]. Collagen-modified viscose preparation involves two steps: extraction of collagen peptides from fish scales and production of collagen-modified viscose.

Table 1
Properties of common fabric materials used in face mask layers.

Layer	Material	Less odor	Wash-durable	Biodegradable
Outside layer	Polypropylene Fiber	Y	Y	N
	Cotton Fiber	Y	Y	Y
Middle layer	MB Polypropylene Fiber	Y	Y	N
	Activated carbon nanofibers	Y	Y	Y
Inside layer	ES Bicomponent Fiber	N	Y	N
	Cotton Fiber	N	Y	Y

2.2. Collagen peptide extraction

The recycled aquaculture fish scales were washed, dried, freeze-dried, smashed, and then broken down into short amino acids with enzymes. Collagen peptides were obtained after filtration. This enzyme was isolated from the bacterial strain. The method of extracting collagen from fish scales has been well developed over the past decade.

2.3. Collagen-modified viscose production

The materials used for producing collagen-modified viscose include collagen peptides obtained from fish scales and cellulose pulp. The collagen peptides were added in the “Ripening” step of manufacturing along with the dispersant and aldehyde. Molar ratio of the collagen peptides to that of cellulose solution was 3:7. Supramolecular polymerization technology was used for polymerization via the wetting spinning method to create collagen-modified viscose (Fig. 1).

Collagen-modified viscose can be blended with different textile materials and spun into different staple yarns. Then, the fabric mills select the yarn for knitting or weaving collagen-modified viscose fabrics.

2.4. Comparative test design of inner layer materials of masks

To compare whether the materials used in this study have better degradability as compared to cotton-derived inner layer of the mask. There are two types of face masks, as shown in Fig. 2, whose outer layers are composed of the same pure cotton-knitted fabric, but their inner layers vary. One is general cotton fabric, while the other one is the proposed collagen-modified viscose fabric.

2.5. Trials for evaluating the properties of moisture regain and deodorization

The proposed face mask design with collagen-modified viscose products was tested for moisture regain, deodorization, comfort, and launderability. The results were compared to a common mask with a cotton inner layer. The moisture test was performed according to the JIS L1030–2 [31] and ASTM D2495–07 standards [32]. The sample was placed in a 20 °C and 65% relative humidity (RH) environment for 24 h, and the wet weight was measured. The sample was then dried in an oven at 105 °C for 1.5 h, reweighed, and again subjected to drying in an oven until there was no further change in weight (dry weight). The ratio of moisture regain is defined as:

$$\text{Moisture regain }(\%) = \frac{\mathrm{W}-\mathrm{D}}{D} \times 100, \tag{1}$$

where D is the dry weight (g) and W is the wet weight of the sample (g).

A deodorization test was conducted to measure the effectiveness of test materials i.e., regular cotton knitting fabric and collagen-modified viscose fabric, for their ability to reduce unpleasant smell produced by breathing. Detector tube tests were performed according to the standard deodorant testing method, ISO 17299-2 [33]. The test method measures odor-component chemicals such as ammonia and acetic acid. The test conditions included (a) amount of specimen: 10 × 10 cm; (b) test vessel: Tedlar bag (5 L); (c) gas volume: 3 L in vessel; (d) temperature and humidity: 20 °C, 65% RH; and (e) machine wash at 80 ± 5 °F under AATCC 135–2012 [34].

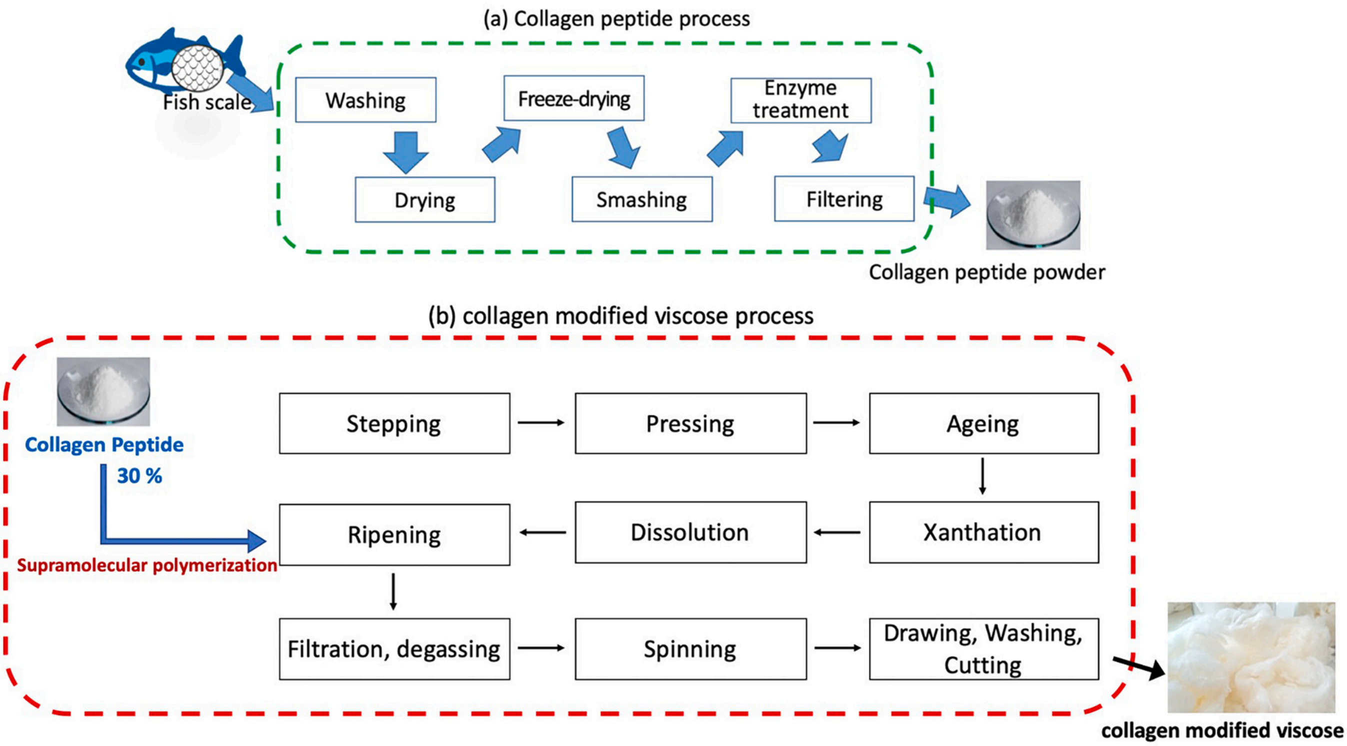

Fig. 1. Illustration of the production of collagen-modified viscose with fish scales. (a) The first part is to obtain collagen peptide from recycle fish scales. (b) The second part is the polymerization process of collagen peptide and cellulose solution.

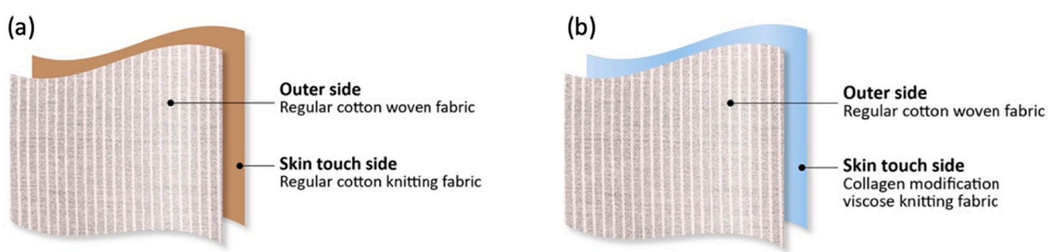

Fig. 2. Comparison of different mask designs. (a) The inner layer (side exposed to the skin) of mask made with cotton knitted fabric, (b) The inner layer of mask made with the proposed collagen-modified viscose fabric.

2.6. Tests for comfort and launderability

For comparing comfort levels of masks, we performed a blinded test on 20 people (men and women aged between 25 and 65 years). They wore two types of masks and rated them on a scale of 1 to 5, where 1 = very uncomfortable, 2 = uncomfortable, 3 = normal, 4 = comfortable, and 5 = very comfortable, respectively. Launderability studies consisted of two tests involving 20 or more people (males and females aged between 25 and 65 years). The first test was evaluation of the duration of bad odor while wearing an unwashed mask. The users recorded the day they first sensed an unpleasant smell while wearing the same mask for 2 h a day. The second test was a similar test to determine the duration for development of unpleasant smell while wearing a washed mask. Users recorded the day when they sensed an unpleasant smell from wearing the same mask, which was washed daily. After many washes, the odor in the mask could not be removed and the number of days was recorded. If the number of days was >30, it was marked as >30, and the value was calculated as 30.

2.7. Tests for filtration efficiency

The filtration efficiency of masks can be measured in different ways [35]. Bacterial Filtration Efficiency (BFE) testing evaluates the protection of filter materials and equipment, such as face shields against bioaerosols. Filtration efficiency was evaluated according to the ASTM F2100–19 protocol by using salt aerosols with a size of 100-nm. The ASTM F2100 and EN 14683 specifications stipulate the testing requirements for medical masks [35]. In the filtration efficiency test of medical masks, a differential pressure (Delta P) test was also performed. Virus Filtration Efficiency (VFE) testing followed the same procedure as BFE, except that the challenge organism used was bacteriophage phiX174.

2.8. Comparison of disposable and reusable face masks using life cycle assessments

Although reusable masks can reduce the overall wastage, microfibers released after cleansing the mask diffuse into the aquatic environment [36]. There have been more discussions on the sustainability of reusable masks [37–48]. To compare single-use and reusable face masks, we performed a meta-analysis of life cycle assessment. As depicted in Fig. 3, the scope of our analysis considered simplified factors, including raw materials used, number of reuses, washing practices, and end-of-life disposals. Common parts of a mask include an inner layer, a middle layer, an outer layer, a nose bridge strip (to keep it in place for reducing air leakage), side strips (to prevent the ear straps from falling off), and mask bands. The materials used were mainly non-woven fabrics and cotton fabrics. Table 2 lists the raw materials of a common medical mask and the proposed reusable mask. For reusability, the weight of this mask (15.4 g) is approximately six times that of an ordinary medical mask (2.6 g).

3. Results and discussion

3.1. Filtration efficiency test results

This study aimed to promote reusable face masks for daily use to curtail the amount of mask waste generated due to the spread of COVID-19. Table 3 demonstrates the results of the filtration effectiveness tests performed by Nelson Lab according to the ASTM F2100 and EN 14683 (2019) methods for a facial mask product with an inner layer of collagen-modified viscose fabric. All test results reached 99% for VFE and BFE tests, and the Delta P ranged from 5.4 to 6.1 mm H_20/cm^2.

3.2. Moisture regain and deodorization test results

Table 4 presents the results of the moisture regain test (%) for both the samples i.e., regular and collagen-modified viscose fabric. It was observed that the average moisture regain of face masks derived from collagen modified viscose was 17.02%, whereas that of the regular cotton fabric was 8.96%. The superior moisture regain of the collagen-modified viscose augments its prospects for better skin sensation when wearing the mask.

The deodorization results for collagen-modified viscose fabrics are presented in Table 5. After 2 h, experimental samples demonstrated much better deodorization potential than the blank test. The blank test followed the same test procedure without exposing the sample to the vessel. The results indicated that face mask with the proposed collagen-modified viscose fabric had better deodorizing ability than regular cotton.

3.3. Comfort and launderability tests results

To reduce the amount of mask wastage, reusability testing is necessary. In all three test comparisons in Tables 6-8, face masks with collagen-modified viscose presented a significant improvement in comfort and launderability as compared to regular cotton fabric as the inner mask layer. Table 6 depicts that the proposed material has a better skin-touch feeling in a 20-person blind test ($p < 0.01$).

In the blind test of the unwashed mask (Table 7), cotton masks were worn for an average of 1.8 days before the testers sensed an unpleasant smell. The new material mask could be worn for an average of 3.95 days before the testers sensed an unpleasant smell. The duration of wearing the proposed mask was found to be twice that of the cotton mask. In the blind test for washed mask (Table 8), washed cotton masks were worn for an average of 12.55 days before there was an unpleasant smell, whereas the new material mask was worn for an average of 26.65 days. All results demonstrate that the face mask with the proposed collagen-

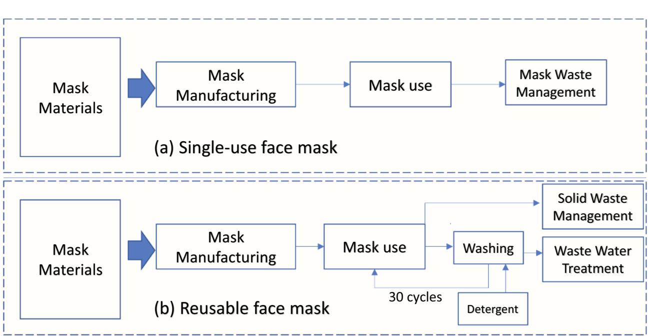

Fig. 3. Scope of the life cycle assessment for single-use and reusable masks.

Table 2
Raw materials for single-use and reusable masks.

Type	Material ([41,44,45]	Weight (g)
Single-use surgical mask (2.6 g)	Polypropylene (PP)	1.9
	Polyurethane (PU)	0.2
	Polyethylene (PE)	0.3
	Iron wire	0.2
Reusable modified viscose mask (15.4 g)	Cotton	7.0
	Polypropylene (PP)	3.2
	Polyurethane (PU)	2.4
	Collagen-modified viscose	2.0
	Iron wire	0.8

Table 3
Result of filtration efficiency tests by Nelson Labs.

Test no.	Percent VFE (%)[a]	Percent BFE (%)[b]	Delta P (mm H_2O/cm^2)[b]
1	>99.9	>99.9	5.4
2	>99.9	>99.9	6.1
3	>99.9	>99.9	5.9
4	>99.9	99.9	5.9
5	>99.9	>99.9	5.8

[a] The study number of Virus Filtration Efficiency (VFE) test is 1,272,273-S01.
[b] The study number of Bacterial filtration efficiency (BFE) test is 1,272,274-S01.

Table 4
Result of moisture regain test.

Sample	Wet Weight (g)	Dry Weight (g)	Moisture Regain (%)
Regular cotton knitting fabric	0.99	0.907	9.15
	1.042	0.956	9.00
	1.059	0.974	8.73
Mean	1.030	0.946	**8.96**
Collagen modified viscose knitting fabric	1.097	0.933	17.58
	1.079	0.929	16.15
	1.11	0.946	17.34
Average	1.095	0.936	**17.02**

Note: The significant difference between two treatments is at $\alpha = 0.05$.

Table 5
Result of deodorization test.

Gas	Sample	Time	Blank Test (ppm)	Testing sample (ppm)	Reduction (%)
Ammonia (ISO 17299-2)	Regular cotton knitting fabric	0 h	100	100	0
		After 2 h	100	100	
	Collagen-modified viscose knitting fabric	0 h	100	100	80
		After 2 h	100	20	
Acetic acid (ISO 17299-2)	Regular cotton knitting fabric	0 h	30	30	90
		After 2 h	30	3	
	Collagen-modified viscose knitting fabric	0 h	30	30	100
		After 2 h	30	0	

Table 6
Comparison of the comfort level of masks using the Five-Point Scale.

No. of tester	A (Regular cotton knitting fabric)	B (Collagen-modified viscose knitting fabric)
No.1	3	4
No.2	3	5
No.3	4	5
No.4	3	4
No.5	3	5
No.6	4	4
No.7	4	4
No.8	3	4
No.9	3	4
No.10	4	5
No.11	4	4
No.12	3	5
No.13	3	5
No.14	3	4
No.15	4	5
No.16	4	4
No.17	3	5
No.18	3	5
No.19	3	4
No.20	4	5
Average	3.40 ± 0.50	4.50 ± 0.51

*$p < 0.01$ (five-point scale; with 5 points being the most comfortable).

Table 7
Comparison of the duration for wearing unwashed mask.

No. of tester	A* (Regular cotton knitting fabric)	B (Collagen modified viscose knitting fabric)
No.1	2	5
No.2	2	4
No.3	1	3
No.4	1	2
No.5	2	3
No.6	2	3
No.7	2	5
No.8	3	7
No.9	2	4
No.10	1	2
No.11	1	3
No.12	2	4
No.13	2	3
No.14	2	6
No.15	1	2
No.16	3	6
No.17	2	5
No.18	2	4
No.19	1	3
No.20	2	5
Average	1.80 ± 0.62	3.95 ± 1.43

* The day when the tester senses a bad smell while wearing the same mask for 2 h per day. $p < 0.01$.

modified viscose fabric has an extended usage and can thereby reduce the amount of mask wastage.

3.4. *Environmental impacts of reusable face masks from life cycle assessments*

To investigate the potential environmental impacts associated with the proposed reusable fabric mask, we conducted a meta-analysis of life cycle assessment (LCA) from previous studies [37–40,42,44,49]. According to International Standards ISO 14040 [50], life cycle assessment is carried out in four distinct phases: goal and scope, life-cycle inventory (LCI) analysis, life-cycle impact assessment (LCIA), and life-cycle interpretation. LCI phase requires reference flows of all raw materials for each production step [44]. We followed the report of LCI and LCIA from reference [44,45,49]. Our inventory data are referenced to local EPA and industry sector data [51] and data from literature [42], examining the carbon footprint of the production and disposal of surgical masks using LCA, carbon dioxide produced according to ISO 14067:2018 The equivalent weight was 32.7 g per mask [51]. For the fabric masks in this study, the carbon footprint according to ISO 14067:2018 may be estimated to be 900 g of carbon dioxide equivalent. An additional 4.7 g CO_2eq carbon footprint per wash is required per mask [42]. The fabric mask can be washed 200 times and still works. When people wear 200 surgical masks for 200 days, a total of 6540 g of CO_2eq will be produced. If people replace the surgical mask with a fabric mask and wash it 200 times, a total of only 1840 g of CO_2eq will be produced, which can reduce carbon emissions by 72%.

Table 8
Comparison of the duration for wearing daily washed mask.

No. of tester	A (Regular cotton knitting fabric)	B (Collagen modified viscose knitting fabric)
No.1	12	28
No.2	10	30
No.3	13	>30
No.4	9	18
No.5	14	>30
No.6	7	20
No.7	12	>30
No.8	7	>30
No.9	10	21
No.10	10	>30
No.11	12	>30
No.12	12	19
No.13	18	30
No.14	14	28
No.15	8	21
No.16	20	>30
No.17	18	>30
No.18	25	30
No.19	14	>30
No.20	6	18
Average	12.55 ± 4.78	26.65 ± 4.89

*Daily washing continued for several days, and the odor of the mask could not be removed. If the number of days was >30, it was marked as >30, and the value was calculated as 30. $p < 0.01$.

3.5. *Using circular economy for sustainable design of face mask*

Collagen-modified viscose is obtained predominantly from discarded fish scale from the aquaculture industry. According to 2018 data from the United Nations Food and Agriculture Organization (FAO), global fish production reached 170 million metric tons, of which aquaculture fisheries accounted for 82 million metric tons. Approximately 35% of total fish production includes waste, such as internal organs and bones, which can be reused as feed or for other purposes. Single fish scales, a rarely reused byproduct, account for approximately 1–5% of the total waste. Large fish catches generate huge amounts of discarded fish scales. Food factories either bury or incinerate the scales, which can cause serious damage, such as soil acidification or air pollution. Therefore, fishery waste has become a pressing environmental problem. Collagen-modified viscose successfully fulfills the concept of circular economy by recycling waste fish scales into collagen peptides. Viscose fibers are polymerized and modified to include additional attributes such as biomimetic properties, including higher moisture absorption and deodorization as compared to ordinary viscose fibers [15]. Our tests showed that these natural characteristics helped retain the efficacy of deodorant after washing. The material is biodegradable, making it more environment friendly, while also offering the benefits of sustainability, functionality, and comfort.

To solve the challenge of marine debris caused by the escalating amount of mask wastage, this study demonstrated feasibility of designing and producing face masks that are comfortable and durable in nature. Collagen-modified viscose is recommended as the inner layer of the mask. The waste fish scales are recycled and refined to produce a collagen peptide formula, which is polymerized and modified with viscose fiber to create a new type of viscose fiber, thereby upgrading the value of the previously futile fishery waste and championing circular economy. Collagen-modified viscose has soft, skin-friendly attributes that can ameliorate the comfort of users and has natural deodorizing properties that can prolong its freshness. These properties were not significantly affected even after washing with water. Decreasing the dependence on single-use masks by effectively extending the lifetime of masks can limit the environmental problems triggered by discarded masks. Collagen-modified viscose is an environment friendly, efficient, and biodegradable textile.

During COVID-19 pandemic, the massive waste of disposable face masks has posed a heavy burden on the environment. In addition to environmental concerns, wearing single-use masks also impacts consumers' affordability. Therefore, there has been much research on the development of alternatives to single-use masks. To be able to be washed repeatedly, the choice of fabric material of reusable face masks is imperative. The proposed collagen-modified viscose has three characteristics: deodorization, degradability, and washing resistance. It can be used as a skin-friendly and comfortable inner layer of a reusable mask.

4. Conclusions

Owing to the COVID-19 pandemic, wearing masks in public places or during transportation is mandatory in most countries to reduce the risk of airborne virus transmission and infection. WHO recommends that people use non-medical grade masks in their daily lives, leaving medical masks primarily for use in medical institutions [4]. As the pandemic is still ongoing, collagen-modified viscose is suitable as a reusable mask inner-layer material because of its patented process. The material itself has natural properties and weaving it into a fabric can offer diverse functional applications.

To address the environmental problems caused by single-use masks, some manufacturers have begun to design masks using pure cotton, which can be reused. However, like reusable cloth masks, cotton masks have some challenges, including the accumulation of various odors even after repeated washing, which affects the user's willingness to reuse the mask. To overcome this problem, most manufacturers add chemicals, such as zinc oxide or deodorant additives, to the inner layer of the fabric and spray the coating to make these masks less prone to odors when worn and used. Masks created using chemical additive coatings will not initially produce an odor, but after washing, the efficacy of these chemicals gradually decreases, thereby limiting its shelf life. In addition, use of chemical additives is not advisable as they have an impact on the long-term respiratory health of the human body; masks processed with such additives can have health and safety issues. Collagen-modified viscose is produced from natural raw materials and has biodegradable properties that synthetic fibers lack. The production of collagen-modified viscose confers environmental protection by considering various waste reduction aspects, allowing recycling of wastewater and waste gas with a hope to achieve a truly environment friendly product that is also environmentally sustainable.

Abbreviations

ACNF	Activated carbon nanofibers
BFE	Bacterial Filtration Efficiency
COVID-19	Coronavirus disease of 2019
DTY	Draw textured yarns
ES	PP/PE composite
GWP	Global warming potential
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
MB	melt-blown
NF	nanofiber
MR	Moisture regain
NWPP	Non-Woven Polypropylene
PE	Polyethylene
PET	Polyethylene terephthalate
PFE	Particle Filtration Efficiency
PP	Polypropylene
PPSB	Spunbonded polypropylene
PU	Polyurethane
RH	Relative humidity
VFE	Viral Filtration Efficiency

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CRediT authorship contribution statement

Erh-Jen Hou: Conceptualization, Methodology, Resources, Project administration, Writing – original draft, Writing – review & editing. **Yun-Yu Hsieh:** Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Ting-Wei Hsu:** Investigation, Data curation, Visualization. **Chi-Shih Huang:** Methodology, Validation. **Ying-Chou Lee:** Supervision, Formal analysis. **Yu-San Han:** Supervision, Validation. **Hsueh-Ting Chu:** Conceptualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

This research was sponsored by Camangi Corporation (Taiwan) and may lead to the development of products that may be licensed to Camangi Corporation (Taiwan), in which we have a business and/or financial interest. The trade name of the proposed bionic silk viscose fiber is "UMORFIL Beauty Fiber".

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This research was sponsored by Camangi Corporation (Taiwan) and may lead to the development of products that may be licensed to Camangi Corporation (Taiwan), in which we have a business and/or financial interest. We have disclosed those interests fully to SAGE Publishing, and have in place an approved plan for managing any potential conflicts arising from this arrangement. The trade name of the proposed collagen-modified viscose fiber is "UMORFIL N6U".

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.susmat.2022.e00475.

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