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The need for fully bio-based facemasks to counter coronavirus outbreaks: A perspective

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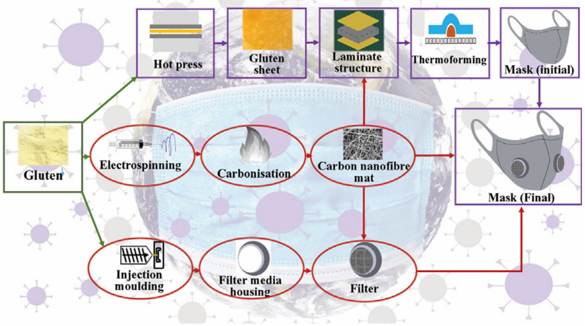
HIGHLIGHTS

- Coronavirus pandemic have made facemasks worldwide healthcare essentials
- Shortage of masks exposes medical personnel and the public to the risk of infection
- Utilisation of sustainable raw materials to develop bio-based masks is needed
- Electrospun and compression moulded gluten can be used to develop bio-based masks
- Gluten masks can be made flame retardant by adding <10 wt% of lanosol.

GRAPHICAL ABSTRACT

The possible pathway to develop fully bio-based facemasks.



The possible pathway to develop fully bio-based facemasks

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ABSTRACT

The onset of coronavirus pandemic has sparked a shortage of facemasks in almost all nations. Without this personal protective equipment, healthcare providers, essential workers, and the general public are exposed to the risk of infection. In light of the aforementioned, it is critical to balance the supply and demand for masks. COVID-19 will also ensure that masks are always considered as an essential commodity in future pandemic preparedness. Moreover, billions of facemasks are produced from petrochemicals derived raw materials, which are non-degradable upon disposal after their single use, thus causing environmental pollution and damage. The sustainable way forward is to utilise raw materials that are side-stream products of local industries to develop facemasks having equal or better efficiency than the conventional ones. In this regard, wheat gluten biopolymer, which is a by-product or co-product of cereal industries, can be electrospun into nanofibre membranes and subsequently carbonised at over 700 °C to form a network structure, which can simultaneously act as the filter media and reinforcement for gluten-based masks. In parallel, the same gluten material can be processed into cohesive thin films using plasticiser and hot press. Additionally, lanosol, a naturally-occurring substance, imparts fire (V-0 rating in vertical burn test), and microbe resistance in gluten plastics. Thus, thin films of flexible gluten with very

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low amounts of lanosol (<10 wt%) can be bonded together with the carbonised mat and shaped by thermoforming to create the facemasks. The carbon mat acting as the filter can be attached to the masks through adapters that can also be made from injection moulded gluten. The creation of these masks could simultaneously be effective in reducing the transmittance of infectious diseases and pave the way for environmentally benign sustainable products.

1. Introduction and background

The ongoing pandemic of novel coronavirus infection (COVID-19) is a global public health emergency. The rapid spread of the disease is attributed to human-to-human transmission in societal and family settings (Chan et al., 2020; Phan et al., 2020; Yao et al., 2019). As of 15 May 2020, there are 4,498,579 confirmed cases with over 300,000 deaths (Website1, 2020: https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6). The geographical expansion of the disease beyond the initial epicentre has risen the need for effective and widely available medical facilities. It also proved that the conventional production lines cannot fulfil the demand during a pandemic. The transmission of COVID-19 occurs through cough or respiratory droplets, bodily fluids, and contaminated surfaces (Chan et al., 2020). It is imperative that medical professionals are not infected, which will ensure the continued care of patients and those subclinical patients, during sickness and after recovery, do not transmit the virus. For e.g. the availability of personal protective equipment (PPEs) amongst Chinese health care workers led to very little spread of the ongoing coronavirus within hospitals. However, >25% of health care workers in Sweden were infected due to the lack of PPEs (Website2, 2020: https://time.com/5785223/medical-masks-coronavirus-covid-19/). Additionally, it is also critical that healthy individuals remain disease-free in order to curb the pandemic. Therefore, the application of aggressive protective measures like facemasks are warranted to safeguard health care personnel, patients, and healthy individuals during this pandemic and as well as for future viral outbreaks. Facemasks are also efficient in preventing infected persons from spreading the virus.

Facemasks have become a worldwide healthcare necessity in the wake of the COVID-19 pandemic and are especially important in the initial stages when information regarding infection potency and transmission is lacking. Filtering facemasks are non-pharmacologically used for decreasing the inhalation exposure to airborne particles associated with health hazards, like influenza viruses, thereby preventing rapid transmission of infectious diseases. The central function of a facemask is to ensure that the wearer does not expel aerosols thereby potentially infecting others (Yao et al., 2019). Although health care workers usually use these respiratory protection devices, they are extended to non-occupational use and become actively sought after commodity during an epidemic or pandemic (Cohen and Enserink, 2009). At present, masks have become a universal requirement since there is a dearth of other personal protective measures like vaccines and antiviral drugs. Moreover, N95 respirators are generally in short supply and are not available in numerous countries during an ongoing pandemic (Loeb et al., 2009). The retailers of many countries report a shortage of masks whereas online retailers like Amazon are rising the prices exorbitantly (Website2, 2020). In addition, most masks are made of non-renewable petroleum-based polymers like polypropylene, polystyrene, polycarbonate, polyethylene, and polyester (Website3, 2020: https://www.thomasnet.com/articles/other/how-surgical-masks-are-made/) that are non-biodegradable and contribute towards environmental pollution and subsequent secondary health challenges. In light of the aforementioned discussion, there is an urgent need to rapidly develop facemasks that are fully bio-based and effective along with being low cost, lightweight, comfortable, and disposable (Belkin, 1997).

For facemasks, filter media is one of the most important components. In general, fibrous materials are used to create particulate matter (PM) filters, which can be designed according to a particular size of a PM. PM can be classified as ultrafine (< 0.1 μm), fine (0.1–2.5 μm) and course (2.5–10 μm), denoted as PM 0.1, PM 2.5 and PM 10, respectively (Kadam et al., 2018). The filtration occurs through interception, inertial impaction, diffusion, inter-molecular/electrostatic/gravitational interactions of the target particles on the surface of the filter medium. For virion particles, whose diameter is very small (ca. 20–400 nm), Brownian diffusion is the central filtration mechanism (Mao, 2017). An infected individual through breathing, speech, sneezing, and coughing, releases pathogenic aerosols. Facemasks, therefore, provide respiratory protection from the infected subject by the filtration capability of the media against the aerosol particles. Since the size of a coronavirus is in the range of 160–200 nm (Pellett et al., 2014), non-woven filter media would be much more effective than the woven counterparts (Chellamani et al., 2013). In fact, non-woven filters exhibit higher barrier properties compared to cotton, petroleum-based polymers (e.g. polyester) and some woven filters of advanced nature. Non-woven filter performs its action through interactions between the target PM and individual fibres of the filter medium (Chellamani et al., 2013). These non-woven filter media can be manufactured by the process of electrospinning that is one of the most cost-effective and facile methods to create fibrous membranes having a variety of fibre diameter and porosity (Purwar et al., 2016).

Electrospun filter membranes have shown great potential for filtration applications through controlled manufacturing that allows tailored material structure for targeted applications (Lv et al., 2018; Neisiany et al., 2020). Versatile fibres can be produced from an array of raw materials by the electrospinning process with the diameters in the range of tens of nanometres to micrometres (Zhu et al., 2017). Electrospun membranes offer high filtration efficiency owing to large porosity (ca. 80%) contributed by concurrently open and interconnected pore structures and a high specific surface area (Zhu et al., 2019). Despite electrospun fibrous membranes possessing highly porous non-woven structure that aids in filtration application, their mechanical strength remains inferior owing to weak fibre-fibre interactions through physical entanglements. This issue can be somewhat alleviated by a partial alignment of the electrospun fibres (Andersson et al., 2014; Strain et al., 2015). In a previous study, aligned electrospun nanofibers exhibited 250 and 450% improvement in tensile strength and modulus, respectively, in comparison with the randomly oriented nanofibers (Andersson et al., 2012). An electrospinning setup is shown in Fig. 1a, constituting of a high-voltage power source, a syringe pump for producing the polymer solution jet, a grounded collector, a spinneret that is electrically conductive, and a polymer solution that is to be electrospun. The spinnability and the final fibre properties are factors of three aspects, namely, processing, polymer solution, and environmental parameters. The processing parameters include applied voltage, feed rate and air gap whereas polymer solution parameters include concentration, solution viscosity, polymer's molecular weight, and solvent's evaporation. The environmental parameters are related to temperature and humidity (Lee et al., 2018). For the filtration of virion particles, the pore size of the filter membrane is the deterministic factor for its performance. Studies have shown that the pore size of randomly oriented electrospun nanofibre mats is affected by the diameter of individual fibres. For

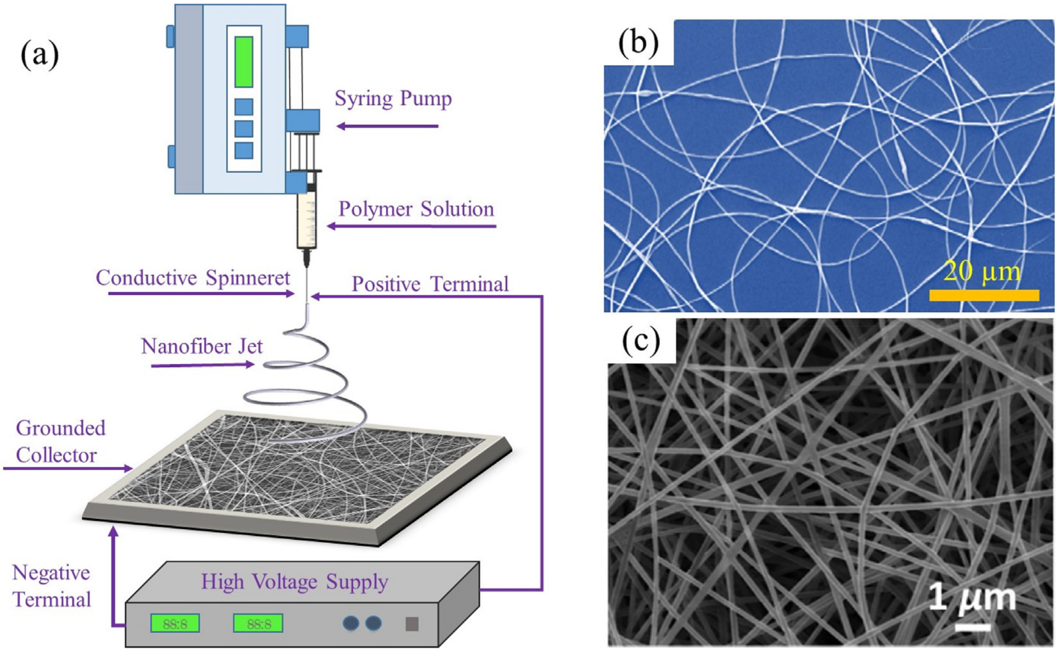

Fig. 1. (a) Schematic illustration of the electrospinning process to produce gluten nanofibre mats. (b) SEM micrograph of gluten nanofibers, modified from (Johansson et al., 2010). (c) SEM images of PVA/gluten nanofiber, reproduced with permission from (Dhandayuthapani et al., 2014). Copyright 2014 American Chemical Society.

example, in a study by Ma et al. (Ma et al., 2011) it was reported that the average and maximum pore size of a nanofibre membrane were, respectively, ca. 3 and 10 times the average diameter of the individual nanofibers. Hence, a 'designer' nanofibre membrane having preferred pore size and fibre diameter can be produced by modification of the electrospinning parameters. A wide range of biopolymers, including poly(vinyl alcohol), poly(ethylene oxide), poly(lactic acid), poly(lactic-co-glycolic acid), alginate, chitin, chitosan, cellulose acetate, polycaprolactone or blends of these biopolymers, have been utilised to develop electrospun nanofibre membranes for filtration (Kadam et al., 2018; Lv et al., 2018). It should be noted that some of them are biodegradable while others are not. In addition, carbonisation of some of these biopolymers is possible and have been studied previously.

It is worthwhile to utilise bio-based materials for the development of the masks. In this direction, new production approaches are required, and an ideal solution would combine the use of low-cost precursors (Srinivasan et al., 2015). A previous study (Strain et al., 2015) also provides inspiration to utilise more environment-friendly materials rather than conventional fossil-based counterparts. The authors of the investigation electrospun recycled polyethylene terephthalate (rPET) to develop fibrous membranes for cigarette smoke filtration. Gluten, a by- or co-product from cereal processing industries is an attractive biopolymer due to its good barrier and cohesive properties (possibility to form e.g. films and plates) and reasonably good mechanical characteristics (Das et al., 2020a; Das et al., 2019b; Wang et al., 2019). Additionally, gluten can be rendered fire resistant with the incorporation of naturally occurring lanosol (Das et al., 2020b). Gluten, like most commodity polymers (e.g. polyethylene and polypropylene), can be processed using established methods of compression moulding, injection moulding, extrusion and thermoforming to create a variety of shapes that include thin films and complex geometries (Capezza et al., 2020b; Rasel et al., 2016; Redl et al., 1999). Furthermore, gluten can also be electrospun into nanofibre membranes. In a study, 5 wt% gluten was blended with polyvinyl alcohol (PVA) and electrospun into nanofibre mats that exhibited a filtration efficiency of 99% towards gold and silver nanoparticles (Dhandayuthapani et al., 2014). Another study successfully electrospun gluten (with PVA) into nanofibre membranes using various solvents such as ethanol, acetic acid, and 2-propanol (Aziz et al., 2019). The electrospun gluten nanofibre membrane can subsequently be thermo-chemically carbonised (i.e. pyrolysis) at high temperature and under an inert atmosphere to render them mechanically strong and to enhance the surface area of the individual fibres. It is, therefore, possible to make carbon nanofibre mats from gluten, which would serve as a great candidate for the development of the masks. The performance of masks should be demonstrated in mainly four areas, namely, filter efficiency, flammability, fluid resistance, and differential pressure (Oberg and Brosseau, 2008). Hence, there is a possibility for the development of green carbon nanofibre mats from gluten and its integration with gluten biopolymer treated with lanosol to create novel fully bio-based masks that possess greater filter efficiency under cyclic or pulsatile breathing conditions. It is envisaged that the developed masks will simultaneously be fire resistant and biodegradable.

For the development of the masks, interdisciplinary research covering gluten electrospinning, thermo-chemical conversion, gluten biopolymer processing, and mask testing needs to be addressed. Gluten electrospinning will allow the production of self-standing mats having continuous fibres and controllable diameters (hence desired pore size). In addition, since electrospinning relies on electrostatic charges, a recent study has shown that gluten can be chemically modified for providing more charges, which could be useful in the tailor-making of electrospun gluten fibres (Capezza et al., 2020a). Thermo-chemical conversion would carbonise the gluten mats into carbon fibre membranes having high specific surface area. Biopolymer processing would bestow beneficial fire retardancy through the addition of lanosol to gluten and application of compression moulding to initially create the carbonised gluten nanofibre mats laminated between plasticised gluten films. This should be followed by the shaping of the masks using a vacuum forming technique. Finally, the efficiency of the filter media, i.e. the exposed carbonised nanofibre mats, in the developed masks should be evaluated for particle penetration under constant airflow. This article portrays the need for the development of masks, with alternative raw materials and processes to counter viral outbreaks. Additionally, the article provides a possible pathway for the manufacturing of the masks, which could inspire researchers to concurrently realise the exigency of their requirement during the ongoing and for future viral outbreaks and initiate studies in this regard. This is one of the first articles to highlight the need for fully bio-based facemasks for pandemic preparedness, which also indicates a route for their manufacturing, especially when referring to disposable products.

2. Possible method for the facemask development

The two main components of the masks are carbonised gluten nanofibre mat and gluten with fire retardant lanosol. Two challenges need to be addressed for the successful development of the masks. The first is to create a pore size in the electrospun carbon membranes that will be able to filter coronavirus virions in the size range of 120–160 nm (Pellett et al., 2014). The second challenge is to enhance the moisture and fire resistance and increase the mechanical properties of gluten by reinforcement with the same electrospun carbon mat. The required research should thus be subdivided into four multidisciplinary areas leading to the development of the mask. The areas are 1) production of carbon nanofiber mat from gluten via electrospinning, 2) production of carbon nanofibre reinforced gluten laminates, 3) production of masks using vacuum forming, and 4) evaluation of mask's performance. Initially, gluten could be blended with PVA and pre-formed into nanofibre mats through electrospinning. The gluten requires solvents to enhance the spinnability of the nanofibre membranes. Fig. 1b shows a scanning electron microscopy (SEM) image of electrospun neat gluten, whose morphology is analogous to another previously reported study of PVA/gluten nanofibers prepared by Dhandayuthapani et al., 2014 for water filtration. The developed nanofibre mat could then be subjected to carbonisation in any pyrolysis reactor under N_2 atmosphere at a treatment temperature of over 700 °C. The prepared material's nano/micro-structure should be evaluated by electron and atomic force microscopy. Infrared and Raman spectroscopy along with X-ray diffraction should be employed to perform chemical/structural analysis of the mat before and after carbonisation. BET analysis should be done to elucidate the carbonised mat's specific surface area and porosity. Fig. 2 shows a schematic representation of the carbonisation processes.

Although, rigid gluten can have a tensile strength similar to that of commercial polypropylene, the addition of plasticiser will reduce that property. Moreover, gluten is susceptible to degradation by fire and is vulnerable to moisture uptake (Das et al., 2019b). Thus, gluten should be treated with ca. 4 wt% lanosol that will achieve self-extinguishment and yield the V-0 rate indicating the highest classification for flame resistance (Das et al., 2020b). Table 1 also indicates that lanosol significantly improves the fire-retarding properties of gluten as investigated through a cone calorimeter. For the purpose of facemask production, and safe storage, it is important to also perform UL94 and cone calorimetry tests for the filter medium in its end-use configuration; that is, performing tests on the combined carbon nanofiber mat/reinforced lanosol-treated gluten laminates, as well as on the adapter material. The aim with such tests would be to vary various parameters, such as the lanosol concentration for example, in order to obtain an optimized overall fire safety for production, transport and storage of the facemasks.

A previous study has shown that the addition of carbon to gluten improves both mechanical properties and water resistance (Fig. 3) (Das et al., 2019a). The moisture resistance of gluten could be further increased by the addition of a renewably sourced wet strength additive of polyaminoamide epichlorohydrin (PAE). Hence, electrospun carbon nanofibre mat could be laminated by glycerol plasticised gluten films (containing lanosol) using a hot press that will render the entire structure strong, fire, and moisture resistant. The aforementioned properties should be assessed by mechanical analysis in a universal testing machine (ASTM D638), flammability characterisation in the cone calorimeter (ASTM E1354), vertical burn test (ASTM D6413 Flame resistance of textiles) and water vapour transmission rate by 25 cm^2 VF2201 permeability cups (ASTM D1653). It is envisaged that the laminate structure will have a tensile strength of ca. 15 MPa and the moisture resistance will improve by ca. 38% (Das et al., 2019a; Gällstedt et al., 2004). Vacuum forming could be employed to shape the laminate structure into masks. In parallel, filter media adapter should be prepared by injection moulding lanosol added gluten without (or with only a small amount) plasticiser. The electrospun carbon mat should then be affixed onto the adapter, which should be assembled together with the vacuum formed structure to develop the final product of the facemask (Fig. 4). Table 2 summarises the regulations and/or tests that are utilised to certify masks. The development of masks from bio-based resources having similar properties to the synthetic polymers at a lower cost would result in a decreased environmental footprint, with the potential to reduce their price, thus enabling their widespread use to bolster pandemic preparedness.

3. Discussion and concluding remarks

Every member of the society should contribute towards the effort to curb the current (and future) pandemic and the research to develop fully bio-based facemasks will be a step towards the betterment of the quality of life during global health crises. Successful research will facilitate the development of facemasks that could be used by both medical professionals and the public to restrict the transmittance of infectious diseases. The availability of facemasks in societies is particularly important during the surge of novel diseases, like the current COVID-19 when vaccines and anti-viral drugs are things of the future. The provision for the obtainability of the proposed masks will prevent panic, discourage price intensification, and provide potential employment during a pandemic or epidemic. On the other hand, society will be benefited, as the materials used to manufacture the masks will replace petroleum-

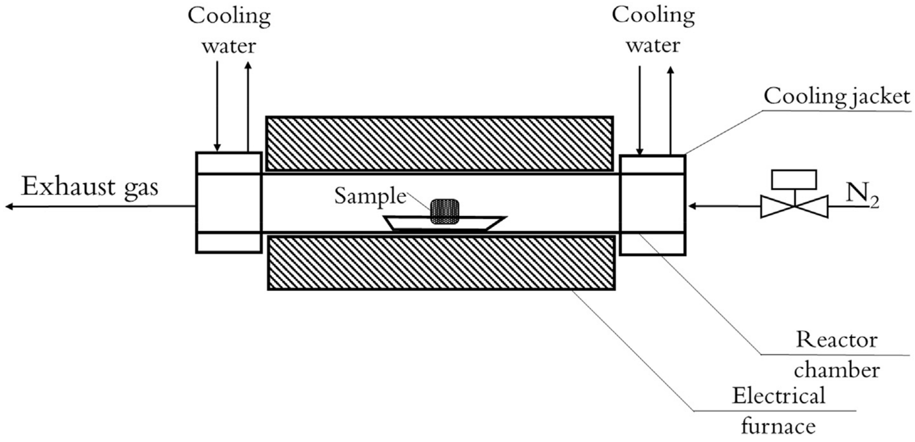

Fig. 2. Schematic illustration of the carbonisation process that can produce carbon nanofibre mats (cooling jacket aids in rapid temperature reduction after the completion of reaction).

Table 1
Improvement of the fire retarding properties of gluten with lanosol addition (Note the significant reduction in PHRR value). Table modified from (Das et al., 2020b).

Samples	Cone calorimeter results						
	TTI (s)	PHRR (kW/m^2)	TPHRR (s)	THR (MJ/m^2)	FPI (m^2s/kW)	CO (kg/kg)	CO_2 (kg/kg)
Gluten	28.5 ± 0.7	703.4 ± 48.7	207.5 ± 60.1	103.7 ± 2.3	0.041	0.031 ± 0.002	1.28 ± 0.04
Gluten + 4 wt% Lanosol	31.0 ± 2.8	353.3 ± 3.4	115.0 ± 70.7	89.6 ± 7.4	0.088	0.048 ± 0.010	1.13 ± 0.04

TTI = Time to ignition; PHRR = Peak heat release rate (lower is better); TPHRR = Time to PHRR; THR = Total heat release; FPI = Fire performance index (higher is better).

based plastics, thereby reducing greenhouse gas emissions. Moreover, since the raw materials for the development of the proposed masks are by- or co-products of industries, it will promote the sustainable use of resources. It will also be beneficial for companies as they will be able to sell their gluten products with higher added value. All the aforementioned aspects will not only aid in stabilising society during an outbreak but also enrich it by enhancing the resiliency to bounce back and thrive after the disaster.

In the wake of coronavirus pandemic, facemasks have become a worldwide healthcare essential. During disease outbreaks, it is a daunting task to match the supply and demand for masks. The current masks, that are made of non-renewable resources and are non-biodegradable, are pernicious towards the environment. The disposal of single-use masks made from petroleum-based polymers creates harmful microplastics in the environment. In a recent study, microplastics have been found in Antarctic sea ice for the first time despite being geographically distant from sizeable plastic pollution sources (Kelly et al., 2020). Thus, there is an urgent need to increase the disposal efficacy of masks by incorporating raw materials that are inherently innocuous towards the environment and provide superior performance properties, as well. One of the biggest advantages of using gluten plastic is its rapid degradation in outdoor habitats into harmless products. On 27 March 2020, H&M, a major Swedish fashion retailer announced the production of FFP2 category facemasks in China that are to be distributed in hospitals. Since the masks can be made from raw materials readily available in all countries having cereal processing industries with gluten as by- or co-product, the production can be shifted to domestic facilities.

The constituent that can be used to develop the masks is a value-added product, whose utilisation minimises pollution and promotes a greener environment. Pyrolysis or thermo-chemical conversion is the carbon-neutral (or negative) technique to valorise bio-based resources into carbons. These carbons are extremely resistant to decomposition by chemicals and combustion while being hypo-allergic, as well. Thus, the application of these carbons in developing products (here masks) will concurrently ensure public safety and bestow superior performance properties. On the other hand, although gluten is susceptible to degradation in outdoor environments, they remain intact in less harsh indoor applications. In fact, gluten is very robust in applications that are hydrophobic in nature, e.g. fats and oils. Additionally, the increasing precedence of gluten intolerance and consequently lowered production of wheat-based consumables create motivation for producing plastic products from this industrial side-stream. Furthermore, lanosol, a naturally-occurring compound, that imparts beneficial fire retardancy in gluten also renders it microbe-resistant, which is an important consideration when using gluten for making masks. Fig. 5 shows lanosol added gluten creating an inhibition zone against *E.coli* (Das et al., 2019a).

The entire process of production to distribution of the masks can be made domestic involving minimal transportation that will simultaneously save energy and reduce pollution. The process that can be used to carbonise electrospun gluten nanofibre is often slow pyrolysis, which can potentially offset 2.2 million tons of CO_2 equivalent (Kung et al., 2014). The resulting carbon from pyrolysis has a considerably lower carbon footprint compared to carbons from petroleum-based sources (Bartocci et al., 2016). Similarly, gluten has a lower carbon footprint than oil-based polymers and some bio-based polymers (e.g. poly (lactic acid), PLA), as well. Alternative bio-based polymers such as PLA could be also be considered as raw material for the replacement of petroleum-based plastics and applications thereof. However, life cycle analysis has shown that the utilisation of wheat gluten protein by-product (from the wheat starch industry) results in better environmental characteristics than PLA (i.e. lower environmental impact). In addition, the worldwide wheat production was >700 million tons in 2018, thus producing an estimated amount of >1 million tonnes/year of wheat gluten readily available as raw material for future applications. The production is higher than the demand by the food market, creating an extra motivation for their use as a bio-based resource (Deng et al., 2013).

Considering that the major medical protective products are non-disposable, the need to find a safe biodegradable alternative is a key factor. If the product ends up in the environment via land-fields in countries with less stringent waste-assortment policies, it must be ensured that the degradation products are safer than traditional polymers. Here, gluten represents an advantage, as it would not degrade into

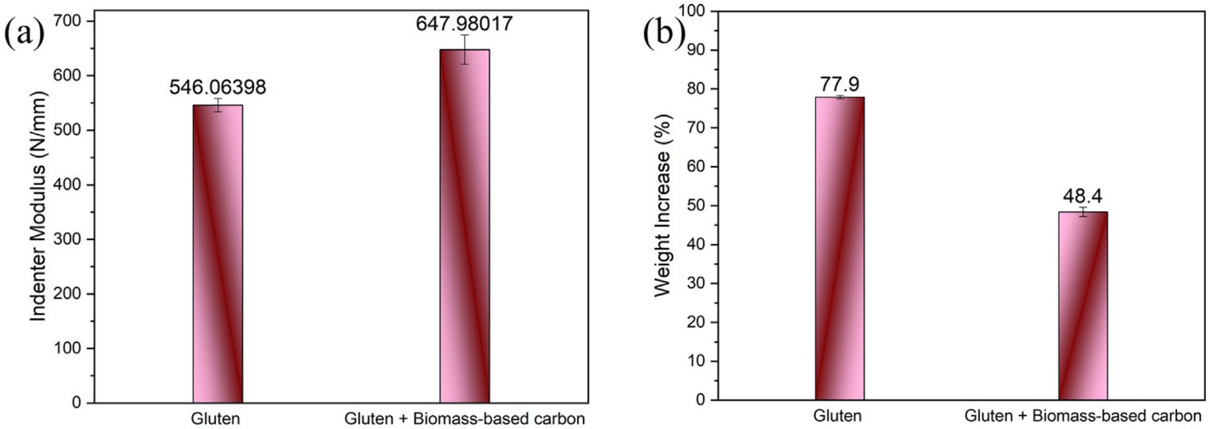

Fig. 3. (a) The enhancement of mechanical property of gluten with addition of carbon, (b) reduction in water sorption in gluten as a result of carbon addition. Figure modified from (Das et al., 2019a).

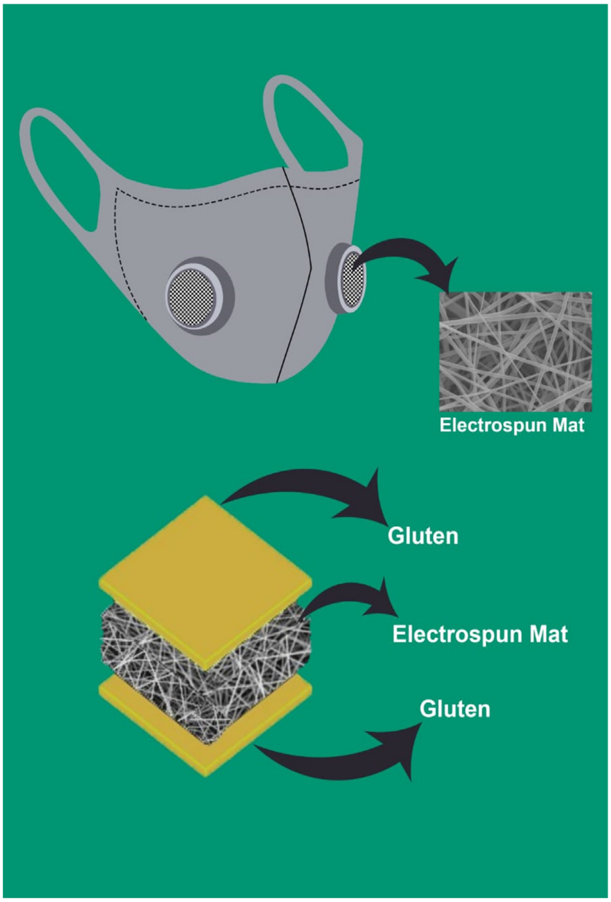

Fig. 4. Schematic showing the final shape and internal structure of the potential facemasks.

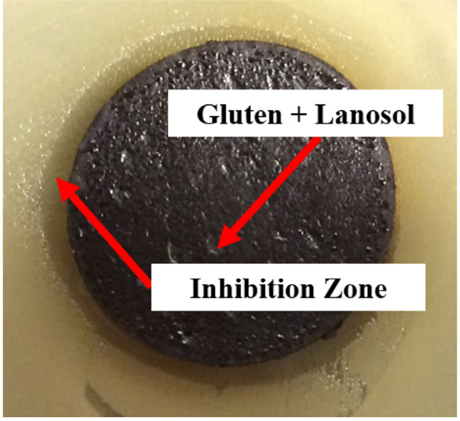

Fig. 5. Lanosol added gluten creating inhibition zone towards E.coli (Image modified from (Das et al., 2019a).

microplastics but rather into nitrogen-based components that could even work as a soil conditioner. In conclusion, successful research in mask development will provide societal support in pandemic preparedness by enabling the reduction of infectious disease transmission. Simultaneously, the process of mask development will promote the use of bio-based resources, curtail greenhouse gas emissions and abate the production of harmful microplastics. Thus, this research can contribute to the overcoming of multiple technological and societal challenges on natural resources exploitation in a high-value novel application.

This idea for facemask development has three main advantages. On the societal front, the successful creation of the masks will alleviate the dire shortage of facemasks during pandemics/epidemics, which consequently will aid in the control of disease spread. Regarding economic benefits, the developmental activity will provide opportunities for companies to manufacture the proposed masks domestically thereby creating jobs locally and boosting the economy nationally. Finally, concerning the environment, successful research will promote utilisation of renewable raw materials, curb pollution, and encourage a holistic sustainable production. Therefore, the development of fully bio-based masks having superior performance properties aptly fits into the paradigm for new socio-economic development where it can be used to both valorise wastes and create novel and necessary facemasks for pandemic preparedness.

Declaration of competing interests

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.

Table 2
Regulations/test used to certify facemasks.

Regulation / Test	Scope	Limitation	Note
Swedish Standard SS-EN 149 + A1:2009	Respiratory protective devices – Filtering half masks to protect against particles	At least 92% of the tested elements cannot leak >5% particles	Value taken for FFP3 device class.
NIOSH 42 CFR 84 US (NIOSH 1995)	Filtering capacity	At least 95% of the influent particles should be filtered	NaCl particles are used as surrogate particles. Typical values for N95 respirator masks.
T4D bacteriophage virus filtration, by Tiliket et al., 2011	Test the filtration property of different filter layers	1 h filtration time resulted on “infinite” T4D virus capture, while 2 h gave 1.1×10^8	Based on a FFP2 mask
Relative survivability (RS) of MS2 viruses on filters, by Junter and Lebrun, 2017	Test the ratio of virus survival on treated filters relative to untreated filters	1. PF PP filter (DuPont™ 01361 N): RS = 1 ± 0.1. 2. CCF coarse pore cellulose filter paper (Whatman™ Grade 54): RS = 1 ± 0.2. 3.FCF fine pore cellulose filter paper (Whatman™ Grade 50): RS = 1 ± 0.15	
ASTM F2100 – 19e1	Standard specification for performance of materials used in medical facemasks	Medical facemask materials are required to: 1. Bacterial filtration >95% 2. Sub-micron particle filtration efficiency (0.1 μm) > 95. 3. Resistance to penetration of blood >80%. 4. Flame spread Class 1	Values based on a Level 1 barrier. 1. Bacterial filtration efficiency based on Test Method F2101. 2. Sub-micron Particle Filtration based on Test Method F2299 3. Resistance to Penetration by Synthetic Blood based on Test Method F1862. 4. Flammability based on 16 CFR Part 1610

CRediT authorship contribution statement

Oisik Das: Conceptualization, Writing - original draft, Writing - review & editing, Visualization, Formal analysis, Methodology.**Rasoul Esmaeely Neisiany:**Writing - review & editing, Visualization, Formal analysis, Methodology.**Antonio Jose Capezza:**Writing - review & editing, Visualization, Formal analysis.**Mikael S. Hedenqvist:**Writing - review & editing, Visualization.**Michael Försth:**Writing - review & editing, Formal analysis.**Qiang Xu:**Writing - review & editing.**Lin Jiang:**Writing - review & editing.**Dongxiao Ji:**Writing - review & editing.**Seeram Ramakrishna:**Conceptualization, Writing - review & editing, Funding acquisition.

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