COMMERCIALISATION OF BIOMATERIALS WITHIN TEXTILES

BACKGROUND OF BIOMATERIALS

BIOMATERIAL
Term used to indicate materials that have non-specific biological association

BIOBASED
Biobased materials are 'wholly' or partly derived from biomass such as plants and trees.

BIOSYNTHETIC
Biosynthetics are synthetic polymer materials comprised, in whole or in part, of bio-derived compounds. These compounds can either be made with an input of biological origin (Biomass), and/or where the process is performed by a living microorganism.

BIOFABRICATED MATERIALS
Biofabricated materials are produced by living organisms like bacteria, yeast and mycelium

BIOFABRICATED INGREDIENTS
Biofabriated ingredients are building blocks produced by living microorganisms. They need further mechanical or chemical processing in order to make a macroscale structure

BIOASSEMBLED
A Bioassembled material is a macroscale structure that has been grown directly by living microorganisms such as mycelium

ALGAEMY
BLOOM
ALGIKNIT
ALGAE INK
BIOGARMENTRY

MYLO
REISHI
SNEATURE
MYCOTEX
FORAGER
PURA BY MOGU

BIOCOUTURE
BIOLOGIC
PILI
MALAI
FABERFUTURES

BREWED PROTIEN
BANANATEX
PINATEX
ORANGE FIBER

MICROSILK
TEXTICEL
ZI
BIOCOUTURE
BIOLOGIC

3 Billion Invested in the past 10 yerars $

CURRENT MARKET

BIOMATERIALS MARKET IS EXPECTING AN INCREASE TOWARDS
$3.84bn by **2026**
(Palmer, 2022).

SUSTAINABLE FASHION MARKET REACH
$1574.2mil by **2025**
(Ruiz, 2022).

PUSH FACTORS	PULL FACTORS
TECHNOLOGICAL ADVANCEMENTS ENVIRONMENTAL CONCERNS LEGISLATIONS GOVERNMENT FUNDING FOR R&D	CONSUMER DEMAND BRAND REPUTATION MARKET OPPORTUNITIES
BARRIES	**INHIBITORS**
HIGH CAPITIAL INVESTMENTS LIMITED AWARENESS	LIMITED SCALABILITY

Commercia
Biomaterials w

Charlotte Barras, Lena Barto
Visagan Karthikeyan, a

Fendi x Kengo Kuma

Washi paper, woven bamboo, birch bark and Tuscan olive wood more common to origami, lantern-making and kimono details Cellulose E-skin. Developed fully biodegradable nano cellulose film and clue for eco-friednly printed textiles.

Fibre composition: 85% paper, 15% cotton, inner: 45% polyester, 30% polyamide, 25% polietilene tereftalato (FENDI, 2024).

LIMITATIONS
Comprised of multiple virgin non-biomaterials. Lack of transparency relating to material source, creating concern. Further challenges are created when recycling (Wiśniewska, Reza Saeb, and Bencherif, 2023) discussed efficiency is difficult to achieve with multiple different materials.

CURRENT MATERIALS

Mycelium

Mycelium is the vegative portion of fungus, consisting of inter connected networks of branching micro filaments (Rognoli, et.al, 2022).

Lab grown, self grown.

Interconnected fibrous network of elongated cells (AntinorI, 2021)

Chemical and physical properties can be adjusted dependent on conditions of growth and the substrate they are fed upon.(Antinorl, 2021).

Bio-enginnered into shapes, by controlling its growing environment, sheets, thick, moulded (Krishani, et.al, 2023).

Algae

70% WORLDS OXYGEN CONTENT (Kramp, 2019).

BIODEGRADABLE
Under certain conditions. (Palmer & Brey, 2022).

Soft, comfortable, vegan materials, hypoallergenic, rich in minerals and trace elements (Palmer & Brey, 2022)

70% LESS WATER THAN COTTON TO GROW (Kelsun, 2024).

(Dugal, 2022) Doesnt require fresh water to grow.

LOWER CO_2 FOOTPRINT (Chen et al., 2022)

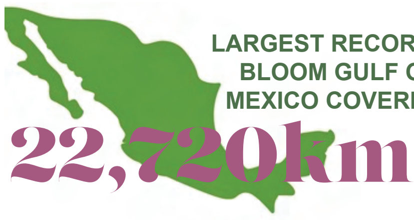
ALGAE BASED

The first step in manufacturing involves extracting the fibers from the algae which can be grown domestically or found in the wild. They undergo a process called kraft cooking which involves cooking the algae with chemicals to separate the cellulose. This is then bleached multiple times using NaOH and H2O2. They then undergo finishes to enhance their properties to get the desired results.

MYCELIUM

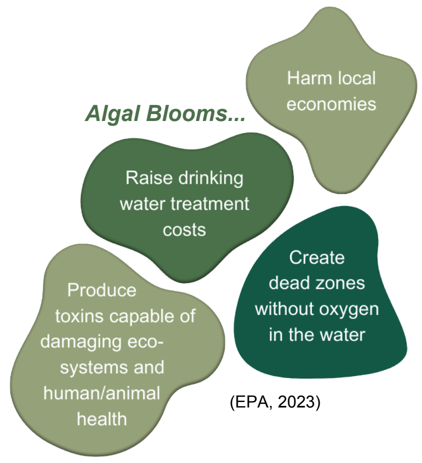
Mycelium leather is produced by letting the threadlike roots of the mycelium grow and self-assemble into thin sheets which are then processed and tanned. Mycelium is also used to manufacture the foams used in footwear in a similar way by using a foam shaped mold to grow the sheets. Brands like Adidas have already started to explore this approach (Adidas, 2021).

ENVIRONMENTAL IMPACTS



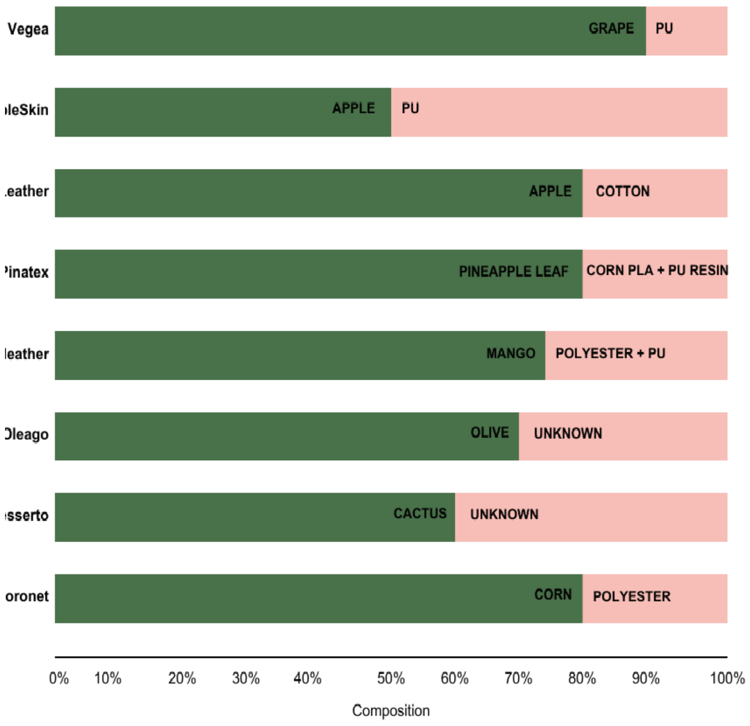
1 polyester shirt can take
200 YEARS to DECOMPOSE
(Stanes & Gibson, 2017)

Of global waste water is from the fashion industry
(Cho, 2021)



1 laundry load deposits

Microfibres into water waste
(European Parliment, 2020)

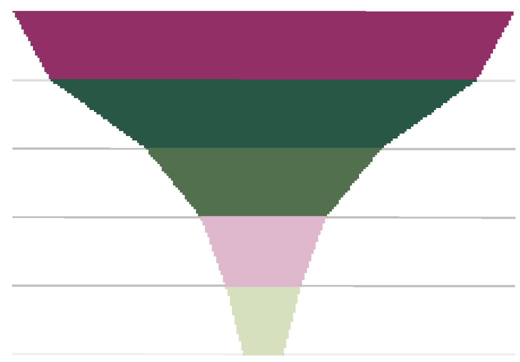


alisation of within Textiles

oszewicz, Olivia Heywood,
and Madeleine Turner

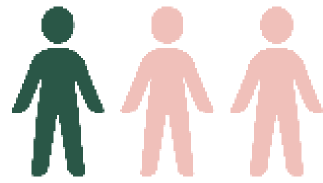
SOCIAL ACCEPTANCE OF BIOMATERIALS

CONSUMER MOTIVATIONS TO BUY BIOMATERIALS



Consumer behaviour will play a major role in supporting the successful transition to a bio-based economy (Gaffey et al., 2021), hence why it's crucial to gain a wide perspective on the current buying habits and consumer perceptions towards biomaterials to assess the climate of acceptance and integration in the future.

1 in every 3 participants have a Positive Perception of Sustainability and Eco-friendliness



CONSUMER RESPONSES

"Biomaterial products will become more popular and the demand will increase as they become more readily available"

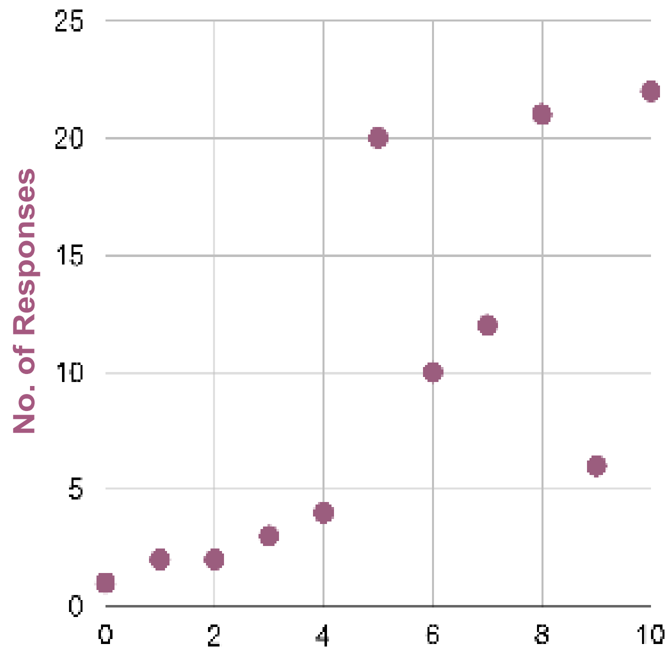
"Who wouldn't want it if it's the same price and better for the environment?"

"I will purchase biomaterial products if produced in a conscious manner"

Purchased biomaterial products before:
Bamboo socks
Sea grass bags
Piñatex leather bag

Happy to pay premium for biomaterials products.
£105 & £115

HOW LIKELY CONSUMERS WOULD PURCHASE BIOMATERIALS IF THEY ARE COMMERCIALLY AVAILABLE



KEY:
0- EXTREMELY UNLIKELY
5- NOT SURE
10- EXTREMELY LIKELY

(United Nations, 2024)

UN SUSTAINABLE DEVELOPMENT GOALS

MYCELIUM

ALGAE

Strategies to push the commercialisation of biomaterials will include...

a Commercialising bio-based dyes
b Representation and development in CAD
c Biomaterial use in performance footwear
d Testing and performance
e Mass manufacturing

Commercialising Bio-Based Dyes in Textiles and Apparel

Madeleine Turner · 10887674
BSc Fashion Technology
Department of Materials

Introduction

Chemical use in textile wet processing is culpable for 20% of global water pollution [1] making an industry-wide transition to more sustainable materials and processes essential.

After over a century of synthetic dyeing, recent innovations including microbial dyes from labs like PILI and Colorofix have re-ignited the industry's appreciation for bio-based dyes.

This research investigates the use of bio-based dyes and their potential for commercialisation within textiles and apparel, utilising primary and secondary research to inform a critical evaluation.

Research Aims

To what extent are bio-based dyes a suitable replacement or large-scale alternative for synthetic dyes in the textile and apparel industry?

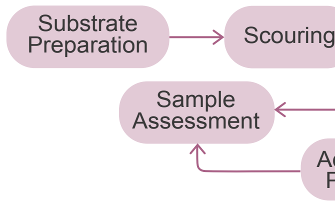
- Provide an overview of bio-based dyes and their classification, extraction, and application.
- Investigate the performance of bio-based dyes in comparison to synthetic dyes from a perspective of both durability and aesthetics.
- Investigate the application of bio-based dyes on both established and next-gen materials.
- Outline challenges and barriers to change.
- Discuss opportunities for further work and future innovations.

Research Met

Primary research

- Seven bio-based dyes were using seaweed and cotton s
- L*a*b* values were recorded assess visual similarities.
- Colour fastness to washing gauge performance for use

Sample preparation:

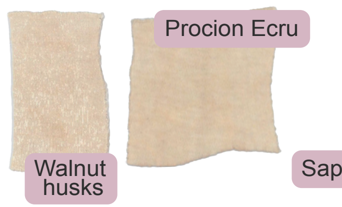


Secondary research

An in-depth review of industry and supported conclusions made from example, whilst bio-based dyes o colours with mordanting and post- with shade reproducibility limit the

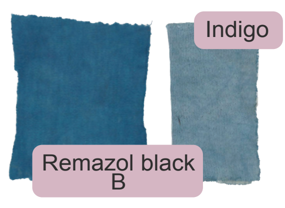
Results

The following samples offer a rep of bio-based and synthetic dyes



ΔE variance 18.57

Issues arose with the evenness of natural dyes in comparison to synthetic dyes, however the method used likely influenced t



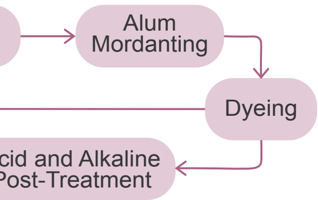
ΔE

Th va pa the Lo im

hods

tested against synthetic dyes
substrates.
d with a spectrophotometer to

tests were also undertaken to
in textiles and apparel.

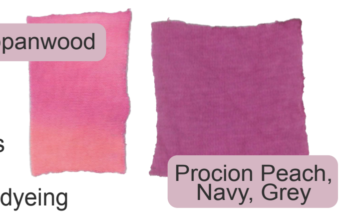


d academic literature also
n experimental research. For
ffer a potentially wide range of
-treatments [2], current issues
eir scalability [3].

presentation of the full selection
tested.

ΔE variance 0.95

Natural dyes have shown the
ability to closely match
synthetic colours.



s

dyeing
his.

E variance 11.58

e main differences in L*a*b*
lues related to the lightness
rameter, suggesting issues with
e saturation of natural dyes.
nger dyeing times could
prove this.

Conclusions

Synthetic dyes

Benefits

- Excellent reproducibility of colours.
- Good colour fastness properties.
- Can benefit from economies of scale; affordable manufacturing.

Drawbacks

- Negative environmental impacts.
- Employee and consumer safety concerns.

Bio-based dyes

Benefits

- Innovations in microbial dyes offer improved colour fastness in comparison to traditional animal and plant bio-based dyes [4].
- Research into mordants has also offered improved fastness properties [2].
- Microbial dyes also offer savings in water use and land use, preventing further issues with natural resource depletion [4].

Drawbacks

- Poor reproducibility of colours due to several factors such as agroclimatic variations [3].
- Further research into the production of standardised dye powders is needed to improve this.

Whilst the primary and secondary research conducted offers a promising overview of the utilisation of bio-based dyes as a large-scale alternative for synthetics, more in-depth research is needed to provide a conclusive picture on the suitability of bio-based dyes as a commercial replacement.

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[1] European Parliament. (2024). *The impact of textile production and waste on the environment (infographics).* Available at: https://www.europarl.europa.eu/topics/en/article/20201208STO93327 (Accessed: April 29, 2024).
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Representation and Development of Biomaterials in Fashion CAD

Lena Bartoszewicz · 10881816
BSc Fashion Technology
Department of Materials

Introduction

Derived from organisms, biomaterials offer an eco-friendly alternative, opening up an innovative approach to tackle the sustainability demands the fashion industry is facing. Commercialising biomaterials presents challenges around scalability, cost, and working with new material properties. Computer-Aided Design (CAD) emerges as a promising solution that enables virtual experimentation to understand biomaterial capabilities, allowing precise design and product visualisation, reducing the need for physical sampling. Leveraging CAD can help bridge the gap between biomaterial's potential and their commercial use in fashion.

Research Aims

- This research aims to explore the integration of emerging biomaterials - mycelium, agar bioplastic, and algae yarn, in industry-standard 3D CAD programs.
- It seeks to identify their capabilities and limitations while also examining the broader opportunities, challenges, and potential impacts on the future of sustainable product development.
- Serve as an introductory exploration into this innovative venture, advocating for the commercialisation of biomaterials in an environmentally, socially, and economically responsible manner.

Methods

Used for digitising scanned biomaterial samples, creating texture mapping, inputting physics properties, and utilizing its AI enhancement tools.

sh
in
onto

Results

Each bi
advanta

Digitalising Difficulty Scale

Least → *Most*

Image to Texture Map
AI Enhancement
Physical Properties

Image to Texture Map
AI Enhancement
Physical Properties

Image to Texture Map
AI Enhancement
Physical Properties

The primary limitation lies in the **lack**
disables maximum simulation accura

All final replicas of the biomateria
CLO3D, receiving the same data, an
modelled in SEDDI Textura.

However, due to these CAD program
conventional textiles, it becomes c
materials of variable tensile and
restriction delays the progress of sus

SEDDI

Textura

g

Utilized for prototyping a sports
oe, showcasing a commercially
viable fashion product, and
tegrating modeled biomaterials
it to assess virtual appearance
and mechanical performance.

omaterial presented individual
ges and challenges during the
digitalization process.

of physics tools, which
cy and realism.

ls were well translated into
d capturing all texture details

ns being designed to work with
hallenging to experiment with
drape characteristics. This
stainable product development.

Conclusions

How can fashion professionals use biomaterials in CAD?

Designers can endlessly experiment with biomaterials through virtual sampling, eliminating the need for physical prototypes.

Manufacturers can use 3D product previews to better comprehend the expected output smoothing the production process and strengthening marketing operations.

Material Scientists can provide virtual samples for buyers and conduct pre-production testing, helping understand biomaterial interactions for improved performance and marketing to brands.

Using CAD for product development in a business causes:

15–30% **Cost Reductions** (Jhanji, 2018)

40–50% **Quicker Release to the Market** (Jhanji, 2018).

15–20% **Lowered Carbon Footprint** (Papahristu & Bilalis, 2016)

and...
Supports 3 UN Sustainability Development Goals

What strategies can promote this endeavour into the fashion industry?

1. *FURTHER RESEARCH*
2. *INDUSTRY COLLABORATION*
3. *EDUCATION*
4. *POLICY AND FUNDING*

References

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Jhanji, Y. (2018). Computer-aided Design—garment Designing and Patternmaking. Automation in Garment Manufacturing, pp.253–290.

Viability of Biomaterials in Performance Footwear

Charlotte Barras · 10680206
BSc Fashion Technology
Department of Materials

Introduction

The sports apparel/ footwear market is saturated with synthetic chemically derived environmentally detrimental materials (Newman, 2020). There is limited academic research on biomaterials in performance sports footwear (Das, 2020;Souza, et.al, 2016). The current commercially available biomaterials are faux leather alternatives and are not suited to these technical textile applications, a result of restricting mechanical properties (Liu & Chen, et.al, 2022).

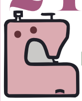
WORLDS SUPPLY OF SYNTHETIC FABRICS

64%

2021

(Engelhardt, 2022)

24 Billion



PAIRS SHOES MANUFACTURED EACH YEAR

94%

PAIRS SHOES END UP IN LANDFILL

(Bruckbauer, 2024)

Key Impacts Synthetic Textiles:
- Depleting resources
- Microfibre shedding
- Quality of land, water & air
- Endangers human health
- Destroys ecosystems

(Palacios-Mateo, et.al, 2021).

Research Aims

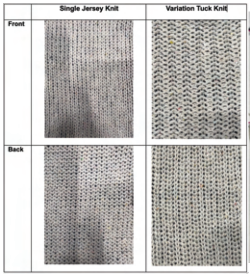
- Contribute to R & D of sustainable bio-material alternatives within the performance sports footwear applications.
- Specifically, exploring potential suitability, durability and ease of integration into sports shoe product development of seaweed and algae-based materials.

Seaweed Y

PRIMARY RESEAR

Sample Developement →

Seaweed Yarn Samples



RESULTS

Yarn Tensile Test

	Mean Tensile Strain Strength at Tensile Break (%)	Mean Force a Break (mN)
100% Seaweed Yarn	14.37	13,315.2852
100% Cotton Yarn	8.36	10781.3864

Moisture Absorbance

	Percentage Moisture absorbance (Initial after 1hour soaking)	Percentage Moisture absorbance (Initial after 1 soaking)
Cotton	181.6%	-1.6%
Seaweed	170.4%	-0.69%

CONCLUSIONS

Air Permeability- Open work s characteristic in sporting activit Bhardwaj, 2023). **Tuck stitch c suited** for sports shoe applicat **breathability** and reduces disc sweat.

Moisture Absorbance- Seawe was **11% lower** than cotton. Co causes discomfort during exerc **Seaweed yarn** is more **suitabl** not be ideal for sports footwear properties are **crucial**.

Burst Strength- Plain knit prov **tuck stitch manufacturing co** stress points throughout structu and **points of weakness.**

Yarn Tensile- Seaweed has h than cotton, thus the potential f cotton. Seaweeds **washability** strength with wet yarn is much **hydrogen bonds** with water m

arn

RCH: Seaweed Yarn

Textile Testing

& Prototypes

at

1hour

Air Permeability

	Air Permeability ($l/m^2/s$)
Plain/ Jersey Knit	1330
Knit Tuck	1560

Burst Test

	Burst time	Pressure
Plain/Jersey knit	10:03:05	0215.5
Knit tuck	10:05:18	0212.0

structures ->air circulation -> key
ties (Roy, Udhayakumar &
derivative of seaweed **more**
ions, as it **enhances**
comfort caused by heat and

eed yarn moisture absorbance
otton retains moisture which
cise (Souza, et. al, 2016).
le than cotton, though may
r where **moisture wicking**

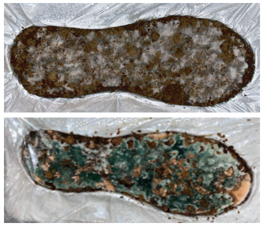
ved stronger in the bust test. The
omplexity adds **tension** to
ure. This means less flexibility

higher mechanical strength
for it to be an alternative to
is outstanding, the tensile
stronger, due to **intramolecular**
nolecules (Das, 2020).

Bio- Foams

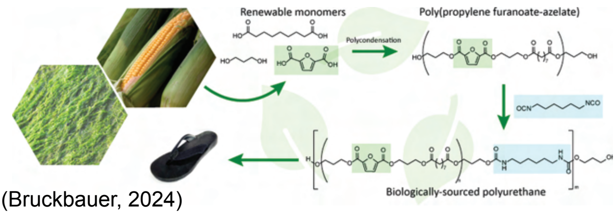
PRIMARY RESEARCH: Bio-foams

Mycelium Foam Developement → Cultivation Analysis



SECONDARY RESEARCH: Bio-foams

Renewable and biodegradable polyurethane foams derived from algae.



(Bruckbauer, 2024)

CONCLUSIONS

Fits commercial mechanical tolerances for footwear, thermally stable and is biodegradable (Bruckbauer, 2024).

COMMERCIAL
Easily integrated into traditional manufacturing

DURABLE
Mechanical properties in commercial tollerance

Algae based Aliphatic diiocyanates PU foams

Bio-degradable in compostable condtions
SUSTAINABLE

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Testing Biomaterial Performance for Textiles and Apparel

Olivia Heywood · 10693292
BSc Fashion Technology
Department of Materials

Introduction

The dependence on synthetic and natural materials are creating a global environmental crisis. The development of biomaterials offers a step forward in offsetting these issues.

However, for the successful commercialisation of biomaterials within textiles, consumer trust needs to be gained through performance testing (Hu, 2008). Current testing research focuses on aesthetic tests (He, Wang & Zheng, 2021; Kooroshina, Dumitrescu & Rijkers, 2021), highlighting the gap within performance-based research.

This research experiments with various formulations of agar and gelatine, assessing their performance using ISO textile testing methods for commercialisation in textiles and apparel.

Research Aims

To what extent can biomaterial performance be assessed using ISO textile testing methods, using investigations of agar and gelatine as examples.

- Investigate different formulations of agar and gelatine.
- Conduct ISO textile tests to evaluate biomaterial performance and suitability for commercialisation.
- Identify and discuss challenges faced in sample preparation and testing.
- Outline potential future applications and considerations, including a Product Lifecycle Assessment and certifications.

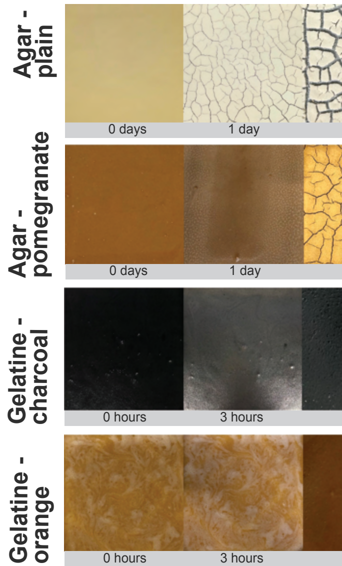
Research Met

Using an agar-based bioplastic f
different additives (pomegranate
charcoal) were assessed for perf

- ★ Tensile (BS EN ISO 13934-1
- ★ Martindale Abrasion (BS EN

Issues with strength and thicknes
namely air permeability, burst, ar
out. This highlighted challenges v
textile testing machines for use i

Results



Conclusions

- Biomaterials should not be h
standards as traditional mate
standards would be develop
- Additives can improve bioma
- Activated charcoal biomateri
integrated within smart mate
- Strict environmental are requ
agar.
- Increasing the ratio of plastic
highly drapeable biomaterial
- Plasticisers remove the need
with natural fibres for strengt

hods

ormulation (Materiom, 2024),
peel, orange peel, activated
formance during textile tests.

:2013)

ISO 12947)

ss prohibited further tests,
nd drape, from being carried
with the suitability of
n biomaterial testing.

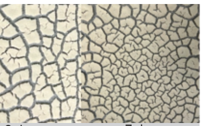
Original formulation:

Agar 30g + Water 175ml + Vegetable Glycerol 12.5g + Additive 6g

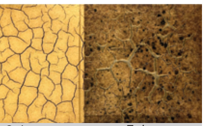
Improved formulation:

Gelatine* 36g + Water 150ml + Vegetable Glycerol 12g + Additive 6g + Olbas Oil 2 drops

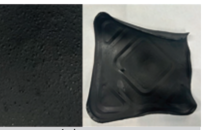
*Gelatine was used due to issues with external conditions interacting with the composition of agar.



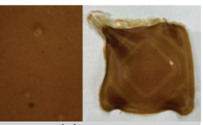
2 days 7 days



2 days 7 days



4 days +



4 days +

Agar

- After 1-2 days, the agar biomaterial became extremely brittle and therefore unfit for purpose.
- Possible reasons for cracks include arid air conditions, not enough water in the formulation, unsuitable agar species, and the presence of corn starch as a thickener.
- After 7 days, the cracks became more defined and mold was present. This is unacceptable due to the nature of textile apparel being in contact with the skin.
- Olbas Oil has been recommended as antimicrobial additive (Hamoud et al., 2012).

Gelatine

- Due to the presence of Olbas Oil, all samples remained intact, without mold, and suitable for testing.
- The orange peel additive displayed the largest tensile displacement at break (stretch) at 20.17mm.
- The activated charcoal additive required the most force to break, at 744.15N.
- Abrasion testing suggests that gelatine-based biomaterials perform to a higher standard in comparison to traditional textiles.

Addative	Force (N)	Tensile Strain Displacement (mm)
Plain	171.5	18.96
Pomegranate Peel	250.26	11.68
Orange Peel	94.91	20.17
Activated Charcoal	744.15	5.07

held to the same ISO testing
erials, ideally biomaterial
ed.
aterial performance.
ials have the potential to be
erials due to their conductivity.
uired for successful setting of

ciser has the potential to create
ls.
d for biomaterials to be blended
th and durability improvements.

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Mass Manufacturing of Biomaterials for Commercialisation

Visagan Karthikeyan · 10906247
BSc Fashion Technology
Department of Materials

Introduction

According to D'Itria and Colombi (2022), new textile innovations in the past 5 years strongly focus on biobased textile solutions by developing new materials. This will also bring new innovations in designs and trends. For these materials to penetrate the mass market, they need to be commercially viable and socially acceptable. A key factor involved in making them commercially viable is the need for mass manufacturing supply chains.

This project aims to explore the current market landscape, conduct a case study on exisiting mass manufacturing companies and develop a sample supply chain to produce a mycelium sole.

Current Market Landscape

Luxury brands are begining to incorporate bio-based materials in their products improving consumer perception and accpetance. Trends usually trickle down to other market segments, making them ideal to introduce new innovations.

The industry has already begun to transform with biomaterial innovators like Bolt Threads and MycoWorks setting up mass manufacturing plants. Lee et al. (2020) states that the demand for these next gen materials is much higher than the supply and most next-gen materials are still in development.

Case Study

Mylo:
Bolt Thread's alternative myce
manufacturing plant that uses
to produce one million square
located in California (Bolt Thre
manufacturing of Mylo was hal
of funding that was meant to ta
commercial scale.

Reishi:
Reishi is manufactured in Myc
plant which began operations i
plant is capable of producing m
Reishi per year and recently a
product has exceeded the qua
their small scale labs. MycoWo
constantly introducing new pa
(MycoWorks, 2023a).

Model Supply

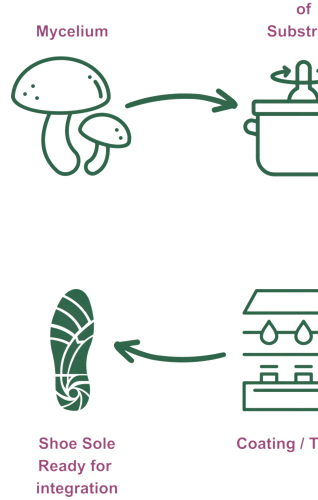


Figure 1: Mycelium growin

47.5
Billion USD
Projected
net revenue
by 2025

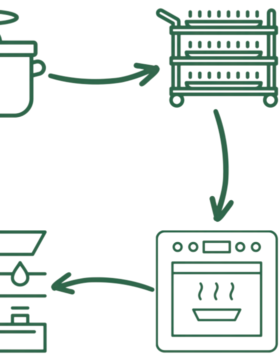
Agricu
Waste
Subst

lium-based leather Mylo
100% renewable electricity
feet of Mylo per year is
ads, 2019). The
lted in July 2023 due to lack
ake Mylo manufacturing to a

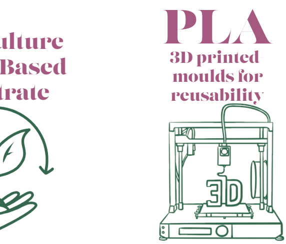
owork's South Carolina
in September 2023. This
millions of square feet of
nnounced that the harvested
lity of the ones produced in
ork continues to grow and is
rtnerships with brands

Chain

tion



g processes (Perfecti, 2020)



Conclusions

Key Takeaways from Case Studies:

Reishi:

- The demand for the product and and performance was insufficient
- Constant flexibility and product development is needed

Mycoworks:

- Identify and target consumers
- Offer transparency and flexibility
- Strong product
- Sustainable development

The model supply chain developed adresses all the key points for their success or failure.

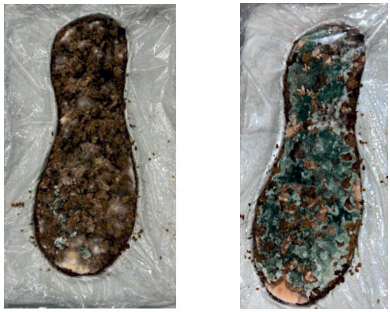


Figure 2: Mycelium Growth Progress (Author's own, 2024)

To better understand the process of producing myceluim soles, an attempt was made at growing a sample. This experiment was met with failure as the samples were contaminated (See Figure 2). The inferences made from the experiment were taken into consideration when designing the supply chain. The lack of access to a room which could maintain the ideal conditions needed to grow mycelium was the main limitation faced.

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