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Original Research Article

MYCOVOGUE: AN EFFECTIVE FABRICATION OF BIO LEATHER BY UP- CYCLING MUSHROOM PADDY WASTE

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Abstract:

Traditional leather production causes serious environmental problems, including excessive water consumption, harmful chemical treatments, and greenhouse gas emissions, which has increased the need for safer and more sustainable alternatives. Fungal mycelium is a promising option because it is renewable, grows rapidly, and naturally decomposes in the environment. In this study, bio-leather was produced from fungal mycelium cultivated on lignocellulosic agricultural waste, allowing efficient use of biomass while reducing environmental impact. The fungus was grown under controlled temperature and moisture conditions until a thick and uniform mycelial mat was formed. After the substrate was fully colonized, the lignocellulosic agricultural residue was dried, and treated to improve flexibility. The final material had a leather-like texture and showed sufficient strength for light-use applications. Its chemical composition and structural properties were analysed using Fourier Transform Infrared Spectroscopy (FTIR) and X-Ray Diffraction (XRD). FTIR results showed absorption peaks corresponding to chitin, polysaccharides, and proteins in the mycelium structure, while XRD patterns indicated a partially crystalline arrangement related to chitin fibres that support mechanical strength. Antioxidant activity was evaluated using the phosphomolybdenum assay and demonstrated moderate total antioxidant capacity. Protein analysis confirmed the presence of structural proteins that contribute to firmness and binding within the material. Overall, the developed mycelium bio-leather was lightweight, flexible, and environmentally friendly because it avoided toxic tanning processes. Compared to animal-derived and synthetic leather, this material provides a more sustainable production method by using agricultural residues and requiring less energy. The findings suggest that mycelium-based bio-leather can serve as a practical and eco-friendly alternative for accessories, packaging, and biodegradable products, although further improvements in growth conditions and post-processing methods may enhance durability and support large-scale production.

Keywords: *Mycelium, Bio-leather, Sustainable materials, Fungal biotechnology, FTIR analysis, Biodegradable polymers.*

Introduction:

Leather is widely used all over the world for making bags, shoes, belts, jackets, car seats, and furniture [1]. The demand for leather has increased because fashion and lifestyle industries are growing very fast [2]. However, making traditional leather from animal skin causes serious environmental problems [3]. Large numbers of animals are raised for leather, which requires a lot of land, water, and food. Animals also release methane gas, which adds to global warming. During the tanning process, strong chemicals like chromium salts are used [5, 43]. These chemicals can pollute water and soil if not treated properly. Because of these reasons, traditional leather production is harmful to the environment.

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To avoid using animal skin, synthetic leather was developed. Synthetic leather is usually made from plastic materials like polyurethane (PU) and polyvinyl chloride (PVC) [10, 25]. Although this type of leather does not harm animals, it is not biodegradable. Since it is plastic-based, it takes many years to break down and can cause microplastic pollution. The production of synthetic leather also depends on petroleum, which is a non-renewable resource. So, both animal leather and synthetic leather have environmental disadvantages.

Scientists are now searching for eco-friendly and biodegradable alternatives [12, 13]. One promising option is mycelium-based bio-leather [9]. Mycelium is the root-like network of fungi that grows under the soil or inside organic matter [10]. It is made up of natural substances like chitin, polysaccharides, and proteins. These components help form a strong and flexible structure. Mycelium can grow on agricultural waste materials and bind them together naturally without the need for harmful chemicals.

In India, a large amount of paddy straw is produced after harvesting rice. Farmers often burn this waste, which causes air pollution and increases greenhouse gases [12]. Instead of burning it, paddy straw can be reused as a raw material for useful products. It contains cellulose, hemicellulose, and lignin, which are strong natural fibres. When fungal mycelium grows on this waste, it forms a thick mat that can be processed into leather-like sheets.

In this project, we developed a mycelium-based bio-leather called "**MycoVogue**" using paddy straw and natural additives. The material was prepared using eco-friendly methods without toxic tanning chemicals. We studied its chemical structure using FTIR and its internal arrangement using XRD [17, 36]. We also tested its antioxidant property and protein content to understand its strength and stability.

This study shows that agricultural waste and fungal biotechnology can be combined to create a biodegradable and environmentally safe alternative to traditional leather [20, 27, 42].

MycoVogue may help reduce pollution while providing a sustainable material for fashion and other useful products.

Materials and Methods:

1. **Materials:**

   The main material used in this study was fungal mycelium from *Pleurotus ostreatus* mushrooms [21, 24]. The lignocellulosic agricultural waste used as a substrate was collected from IIT Bombay, Maharashtra, India, and mainly consisted of paddy straw rich in cellulose, hemicellulose, and lignin [30]. These natural components provide structural support and help create strong bio-leather.

   Other materials used in the preparation of **MycoVogue** bio-leather included agar-agar to make the mixture viscous, *Multani mitt*i (China clay) for texture, psyllium husk powder as a natural thickening agent, glycerol as a plasticizer to improve flexibility, clove oil for antimicrobial protection, and sodium alginate gel as an eco-friendly tanning and retanning agent [23, 44]. All the chemicals used were of reagent grade. All equipment and glassware were sterilized before use to avoid contamination.

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2. **Methods:**

Preparation of MycoVogue (Mycelium-Based Bio-Leather):

The production of **MycoVogue** bio-leather began with collecting lignocellulosic agricultural residue, which was dried in a hot air oven. Once dry, the material was ground into a fine powder and sieved to ensure smoothness [29, 31]. This powder was mixed with a universal solvent using a magnetic stirrer, and agar-agar was added to make the mixture viscous [23, 25].

Multani mitti (China clay), psyllium husk powder, glycerol, and clove oil were then added, followed by sodium alginate gel, which was prepared by sieving and dissolving it gradually in the solvent [7]. The mixture was thoroughly blended to form a uniform bio-leather paste. The final mixture was spread evenly on a tray and left to dry completely. After drying, the bio-leather was carefully removed from the tray. A final layer of clove oil was applied to the surface[17,38,40].

Fig 1. Mycelium based MycoVogue Bio-leather

Comprehensive characterization was performed to evaluate the structural, chemical, and functional properties of the developed mycelium bio-leather.

Fourier Transform Infrared Spectroscopy (FTIR):

We used FTIR analysis to find out what kinds of chemical groups are in the mycelium bio-leather. Small pieces of the dried bio-leather were prepared and scanned with infrared light [32,38]. The results showed signals that match chitin, polysaccharides, and proteins, which are allfound in fungal cell walls [33]. Some peaks showed hydroxyl and amide groups, confirmingthe presence of natural biopolymers. The detection of amide I and amide II bands showed thatproteins are present, which help hold the material together and give it strength [34]. Overall, the analysis proved that the bio-leather is made mostly of natural components and does notcontain any synthetic tanning chemicals, making it safe for the environment [17].

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X-Ray Diffraction (XRD):

We used X-ray diffraction (XRD) to see how the bio-leather is structured at the microscopic level. The samples were scanned to find out how the molecules are arranged inside the material.

The results showed that the bio-leather has a semi-crystalline structure. This comes mostly from chitin fibres in the fungal cell walls [29, 36]. Some sharp peaks in the pattern showed that parts of the material are neatly ordered, while the blurry areas came from proteins and polysaccharides that are more random. Having this mix of ordered and messy parts helps the bio-leather stay strong but still flexible [31]. It makes the material sturdy without being too stiff, which is important for things like MycoVogue products.

Antioxidant Activity Test:

Antioxidant activity has been evaluated from mycelium bio-leather extract to study its potential to fight against oxidation using the phosphomolybdenum assay [40, 41]. This method involves how much the molybdenum compounds get reduced, which we can measure as a colour change. Initially the extracts from the bio-leather was made and mixed them with the test solution under careful conditions. If the extract has antioxidants, it changes the colour, and that shows it can fight reactive molecules. Our results showed that the extract could moderately stop oxidation, which means it has helpful compounds like phenolics and polysaccharides. These antioxidants might make the bio-leather last longer and resist damage from oxygen [18,40].

Protein Estimation:

Protein content has been evaluated using Folin- Lawry method [42]. Proteins are important because they help hold the material together and make it stronger. The bio-leather powder were mixed with chemicals that react with protein, and the colour change was measured using a colorimeter. The results showed that the lignocellulosic agricultural residue in the material contains protein. These proteins help keep the sheets intact by connecting the chitin fibres and other parts like polysaccharides, making the bio-leather more stable and stronger [15, 42].

Product Formulation:

The final version of MycoVogue was made by adjusting the growth conditions and treatments to make it strong, flexible, and look good. The thickness and feel of the bio-leather were controlled by carefully drying and treating it. Adding a softening treatment made it bend easily without breaking. The surface was also finished to make it smooth and slightly resistant to moisture [23].

The finished bio-leather had:

- A lightweight feel
- Soft and foldable texture
- A natural, earthy look
- Biodegradable material [11]
- No harmful tanning chemicals

This makes it suitable for things like eco-friendly accessories, packaging, decorative items, and other biodegradable products. The process is also sustainable because it uses leftover agricultural waste and avoids

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energy-heavy methods. By adjusting how dense the fungus grows, how long it incubates, and how the material is treated afterward, it may be possible to make it even stronger and easier to produce on a large scale.

Fig 2. Lignocellulosic agricultural residue

Results:

MycoVogue Fabrication:

The production of MycoVogue bio-leather started with collecting lignocellulosic agricultural waste, such as paddy straw, which was dried in a hot air oven at 60°C. The dried material was then ground into a fine powder and sieved to ensure uniform particle size [29]. This powder was mixed with a solvent using a magnetic stirrer, and agar-agar was added to make a viscous mixture. To improve the texture, Multani mitti (China clay) was incorporated, followed by psyllium husk powder as a natural agent. Glycerol was added to act as a plasticizer, providing flexibility to the bio-leather, and clove oil was included to give antimicrobial properties. Finally, sodium alginate gel was gradually mixed in, serving as an eco-friendly tanning and retanning agent that reduces the need for harmful chemicals like chromium salts and formaldehyde [8]. The resulting mixture was spread evenly on a tray and left to dry completely. Once dried, the bio-leather was carefully removed from the tray, and a final layer of clove oil was applied to enhance shine and prevent microbial growth [6].

This process produced flexible, smooth, and uniform bio-leather entirely from renewable and biodegradable materials, suitable for crafting items like handbags, wallets, and other eco- friendly products [28,44].

Characterization:

The MycoVogue bio-leather was analysed using a combination of spectroscopic, crystallographic, biochemical, and functional assays to evaluate its chemical composition, structural properties, and potential bioactivity.

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FTIR Analysis:

We used FTIR (Fourier Transform Infrared Spectroscopy) to find out what kinds of chemical groups were in the mycelium bio-leather [38]. The results showed peaks that matched chitin, including the amide I and amide II bands, which indicate the presence of N-acetylglucosamine units [39]. Other peaks showed signals from polysaccharides and proteins, confirming the natural composition of the lignocellulosic agricultural residue. These molecules are important because they help the bio-leather stay strong while still being flexible. Overall, the FTIR results showed that the fungal mycelium successfully turned the natural polymers from the paddy waste into a solid and cohesive biomaterial [24].

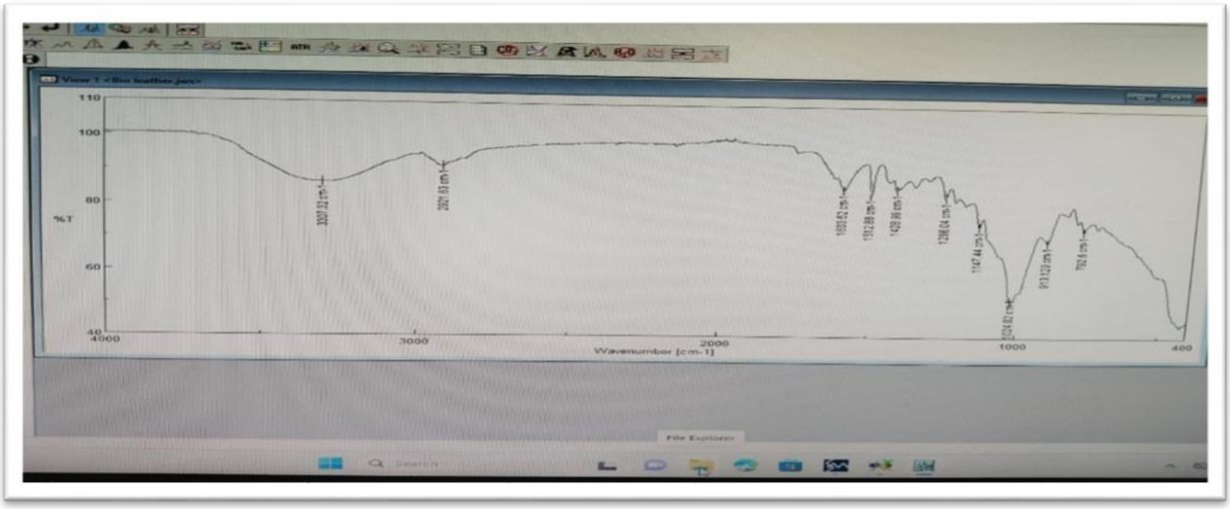

Fig 3. FTIR pattern of MycoVogue bio-leather

We recorded the FTIR spectrum of the bio-leather from 4000 to 400 cm^{-1} to see what functional groups were present. The spectrum showed several peaks, which tell us that the material is made of different natural polymers. A broad peak around 3307 cm^{-1} comes from O–H and N– H stretching. This broad shape suggests hydrogen bonding, which is common in the hydroxyl groups of polysaccharides and the amide groups in proteins. The peak at 2921 cm^{-1} is due to C–H stretching in $-CH_2$ and $-CH_3$ groups, showing that the material has an organic polymer backbone. The peak at 1630 cm^{-1} is the Amide I band, caused by C=O stretching in proteins or chitin, while the 1512 cm^{-1} peak is the Amide II band, coming from N–H bending and C–N stretching. These peaks confirm that proteins and nitrogen-containing polymers are present. The band at 1428 cm^{-1} is from CH_2 bending in polysaccharides, and the 1266 cm^{-1} peak (Amide III) comes from C–N stretching in proteins or chitin. Peaks at 1144 cm^{-1} and 1024 cm^{-1} are from C–O–C and C–O stretching, showing the presence of sugar units with glycosidic bonds.The peak at 913 cm^{-1} indicates β-glycosidic linkages in carbohydrates, and the small band near 792 cm^{-1} may come from vibrations in ring structures. Overall, these FTIR results confirm that the bio-leather is made of proteins, chitin, and polysaccharides, giving it a strong and flexible structure.

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XRD Analysis:

We used X-ray diffraction (XRD) to study how the mycelium bio-leather is structured. The patterns we saw showed both broad, fuzzy peaks and some small sharp peaks, which means the material is partly crystalline and partly amorphous [36]. The crystalline parts come from chitin fibres, which make the material stronger, while the amorphous parts help it stay flexible. This mix of rigid and soft areas is important for using the bio-leather in things like wearable products or packaging [35].

The XRD scan was done from 10° to 80° (2θ) using Cu Kα radiation. The results showed a wide peak around 20°–22°, and there were no sharp, clear peaks across the range [37]. This broad peak shows that most of the bio-leather is amorphous, which is normal for biological materials where the molecules aren't perfectly lined up in a crystal structure. In the bio-leather, the broad peak comes from semi-crystalline areas of chitin and β-glucans in the fungal cell walls. The peak is wide because these crystalline regions are small and spread out within the amorphous matrix. The intensity also slowly decreases beyond 30°, which shows there are no significant mineral or inorganic parts in the material [36].

Having mostly amorphous structure is good for bio-leather because it makes it soft, bendable, and easier to work with. Materials with low crystallinity usually bend better, which is exactly what we want for sustainable leather alternatives.

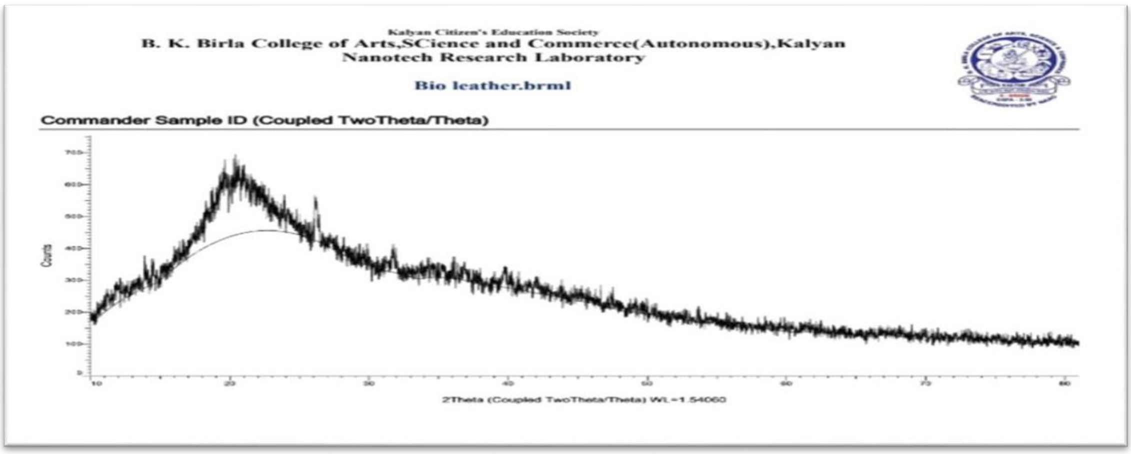

Fig.4: XRD pattern of MycoVogue bio-leather.

The XRD pattern of the prepared bio-leather was recorded using Cu Kα radiation (λ = 1.5406 Å) over a 2θ range of 10°–80°.The pattern shows a broad peak around 2θ ≈ 20–22°, with no sharp peaks. This means that the bio-leather is mostly amorphous, with only small semi- crystalline regions. Such broad peaks are common in materials made from collagen, cellulose, proteins, or other hydrogen-bonded polymers. The lack of sharp reflections also shows that there are no mineral or highly crystalline inorganic parts in the material. Using Bragg's Law, For the broad peak at 2θ ≈ 20° (θ ≈ 10°), the d-spacing is about 4.4 Å. This

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distance represents the spacing between polymer chains that are held together by hydrogen bonds, similar to the arrangement in collagen or cellulose fibres. Since the XRD pattern mainly shows a broad halo, the bio-leather has low crystallinity. This semi-crystalline structure with mostly amorphous domains is actually good for bio-leather because it: Makes the material flexible and bendable, improves toughness and foldability, prevents brittleness, which would happen if it were highly crystalline. The mostly amorphous structure suggests that the polymer chains are randomly arranged but still have strong hydrogen bonding. This gives the bio-leather good flexibility and ensures it is free from inorganic contaminants. Overall, the XRD results show that the bio-leather has the right structure to be a strong, flexible, and eco-friendly material.

Determination of antioxidant property of MycoVogue bio-leather:

The antioxidant property of MycoVogue bio-leather was measured using the phosphomolybdenum assay [40, 41]. This test helps determine the material's ability to neutralize free radicals, which is important because antioxidant compounds can prevent oxidative damage and support the safety of the material when it encounters human skin [45].

The results showed moderate antioxidant activity, likely due to phenolic compounds and polysaccharides present in the fungal mycelium. The inclusion of paddy fibre may have added extra natural antioxidants from the plant material. The graph shows the relationship between absorbance (y-axis) and concentration (x-axis). The points formed a straight line, and the regression equation had a high correlation coefficient (R^2 close to 1), meaning absorbance increased proportionally with concentration. The slope (0.0056) shows the sensitivity of the method, and the near-zero intercept (–0.0014) indicates minimal background interference. The strong linear response confirms that the method is reliable and can be used to calculate the antioxidant content of unknown bio-leather samples. Overall, the moderate antioxidant activity supports the claim that MycoVogue is safe for human skin, as it can reduce oxidative stress [19] and potential irritation caused by reactive compounds.

Protein Estimation:

The protein content of MycoVogue bio-leather was measured to see how structural proteins contribute to the strength and stability of the material. The results confirmed that fungal proteins are present and act as natural binders in the mycelium. These proteins connect with chitin and polysaccharides to form a strong network, which improves both the flexibility and durability of the bio-leather [15, 42]. This natural arrangement is like how proteins work in animal leather, showing that fungal biomaterials can be a sustainable alternative.

The graph shows how absorbance changes with protein concentration. From 0.2 to 0.8 units, absorbance gradually increased from 0.11 to 0.19, showing a positive relationship as expected in colour-based assays. At concentration 1, absorbance jumped to 0.46, which is higher than the gradual trend. This could be due to experimental error, pipetting mistakes, or the assay nearing saturation. The blank had very low absorbance, showing that background interference is minimal. The unknown sample gave an absorbance of 0.375, which is within the range of the standard curve, so its concentration can be calculated using the linear part of the curve. Overall, the data mostly follow a steady increase, which agrees with Beer–Lambert's law, but the higher concentration shows that only the linear range should be used for accurate calculations.

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Product:

The final MycoVogue bio-leather had a look and feel like regular leather, with good flexibility and a natural earthy colour, but it was made entirely from renewable and biodegradable materials. After drying, the bio-leather was smooth, uniform, and had moderate strength, making it suitable for light-use items. The material is lightweight, eco-friendly, and does not require the harmful chemical tanning used in animal leather, which makes it safe for both people and the environment. The XRD results showed a semi-crystalline structure, and FTIR analysis confirmed the presence of natural polymers. The moderate antioxidant activity and protein content suggest that the bio-leather is both durable and flexible while maintaining useful bioactive properties. We were able to make a small women's handbag from MycoVogue bio-leather, and it could be shaped, stitched, and handled just like a regular leather product.

This shows that the material is practical for real-life applications. By using lignocellulosic agricultural waste as the main raw material, MycoVogue helps reduce leftover plant residues that are often burned or thrown away. At the same time, it produces a biodegradable leather alternative, which can help reduce plastic and animal leather pollution. These features make MycoVogue a promising material for eco-friendly items like handbags, wallets, and belts, as well as for sustainable packaging and other products.

Fig.5. Prototype handbag developed from the synthesized MycoVogue bio-leather

Conclusion:

This study successfully showed that MycoVogue bio-leather can be made using fungal mycelium grown on lignocellulosic agricultural waste, resulting in flexible, leather-like bio- leather with a smooth and uniform texture. FTIR and XRD tests confirmed the presence of chitin, polysaccharides, and structural proteins, which help give the material strength and hold it together. Tests for antioxidant activity and protein content showed that the bio-leather also has useful bioactive properties.

The final MycoVogue bio-leather is fully biodegradable, environmentally friendly, and does not need harmful chemical tanning, making it a sustainable alternative to both animal and synthetic leather. This work demonstrates a practical way to use agricultural waste while creating durable, safe, and eco-conscious leather-like materials that can be used for fashion items, accessories, and other applications.

Future Scope:

In the future, MycoVogue bio-leather can be improved in many ways to make it stronger, more durable, and suitable for different uses. The formulation can be adjusted to increase strength, water resistance, and abrasion resistance so that it lasts longer in real-life applications. Large- scale production methods can be developed to make the material cost-effective and suitable for commercial manufacturing. It can also be improved for upholstery purposes such as sofa covers, chair linings, and interior decoration materials. With better surface finishing and thickness control, it may even be used in automotive interiors. By slightly changing the composition, especially by increasing fibre content, the same material could also be developed into a biodegradable paper alternative for eco-friendly packaging, notebooks, and craft materials. Future studies can also focus on testing biodegradability, footprint, and skin safety [45] to prove that it is environmentally friendly and safe for human use. With continuous research and innovation, MycoVogue has the potential to become a sustainable substitute for animal leather, synthetic leather, and even some paper-based materials.

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