Development of a Fatliquoring System from an Industrial Waste-Derived Inclusion Compound for a Sustainable Waste-to-Wealth Approach

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Development of a Fatliquoring System from an Industrial

Waste-Derived Inclusion Compound for a Sustainable

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Waste-to-Wealth Approach

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Abstract

The softness of leather is strongly influenced by the fatliquor, which is typically produced through the chemical modification of oils and applied as a surfactant-based emulsion. This study presents a novel fatliquoring formulation that incorporates a discarded industrial by-product in the form of a cyclodextrinbased inclusion compound. This compound is integrated into a fatliquoring system to deliver not only effective fiber lubrication but also enhanced electrical conductivity in crust leather. Anacardic acid, containing both phenolic and long-chain fatty acid groups, forms a hydrophilic and stable inclusion complex upon association with cyclodextrin. This complex functions as an efficient fatliquor with improved emulsion stability, superior penetration into the collagen matrix, and uniform fiber lubrication, as demonstrated through physicochemical analyses. Leathers treated with the new formulation exhibited marked improvements in softness, tensile strength, tear resistance, and—most notably—consistent conductive behaviour, all achieved without compromising mechanical performance. Additionally, the posttanning effluent displayed a positive regulatory effect on plant growth. This innovation offers dual benefits: the valorization of low-value industrial waste and the development of functional conductive crust leathers suitable for emerging smart-material and technical

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applications. The findings highlight the promise of inclusion chemistry as a sustainable approach for converting industrial residues into high-performance materials for the leather sector.

Keywords: Inclusion Compound, Cyclodextrin, Anacardic Acid, Fatliquor, Post tanning, Sustainability, Leather Technology

1. Introduction

The leather industry is shifting toward sustainable, functional materials amid rising environmental concerns and material science advances. Traditional processes generate toxic chromium residues, prompting exploration of green alternatives like cyclodextrin (CD)-based tanning agents, which offer biodegradability, non-toxicity, and renewability. Derived from starch, CDs feature a toroidal structure with a hydrophobic cavity and hydrophilic exterior, ideal for forming inclusion complexes that boost chemical reactivity and surface functionalization in polymers and biomaterials.[1]

Integrating CD derivatives into leather yields impressive results: enhanced mechanical strength, thermal stability, and compatibility with eco-friendly tanning. Recent studies on -cyclodextrin chrome-free agents like -TCD and -GCD show treated leathers achieving shrinkage temperatures over 80°C, denser fiber packing, and less yellowing—paving the way for high-performance, sustainable leather production.[2]

β β β

Anacardic acid comprises a group of phenolic lipids primarily found in cashew nut shells (Anacardium occidentale), generated as waste during cashew oil processing. These compounds feature a salicylic acid core attached to a saturated or unsaturated alkyl side chain, typically with 15 or 17 carbon atoms. Renowned for their antibacterial, antioxidant, and anti-inflammatory properties, anacardic acids show potent antimicrobial activity—especially against Gram-positive bacteria like Streptococcus mutans and tuberculosis pathogens. They are partially soluble in ethanol and ether but poorly soluble in water, limiting some applications. [3,4]

In the leather industry, anacardic oil—extracted from cashew nut shells—serves as a natural tanning agent thanks to its phenolic compounds, which bind effectively with hide collagen. Cashew husks contain 19-21% tannins, and studies have explored anacardic oil for vegetable tanning, though its oily nature demands process adjustments like reduced fatliquor. Beyond tanning, anacardic acid offers pharmaceutical and cosmetic potential through its antioxidant properties (protecting cells from oxidative stress) and antibacterial activity. Overall, anacardic oil emerges as a versatile natural resource, enabling greener, value-added leather processing with added bioactivity.[5]

Cyclodextrin (CD) inclusion compounds are molecular complexes where a hydrophobic guest molecule is encapsulated within the hydrophobic cavity of a cyclodextrin—a cone-shaped cyclic oligosaccharide made of glucose subunits, featuring a hydrophilic outer surface. This host-guest interaction modifies the guest's physicochemical properties, enhancing solubility, stability, bioavailability, and sometimes biological activity. Common types include -CD (6 glucose units), -CD (7 units, the

Alcoholic solution of Anacardic acid dissolved in aqueous solution of Cyclodextrin and heated for approximately 5-10 hours, at a temperature range of 100-150 oC with 400 rpm to form the inclusion compound. The product (ANAC -CD) thus formed has been used as fatliquor in leather processing.

α β

Post Tanning Process

Steps Experimental Control Percentage taken Time pH

Washing Water Water 100% 60'

Neutralization NaHCO3 NaHCO3 0.5-1.5% 2 x 15 + 30' pH = 5.5-6

most widely used due to its ideal cavity size, safety, and availability), and -CD (8 units); modified variants like methylated or hydroxypropyl- -CD offer superior solubility and complexation. Applications span drug delivery (boosting water solubility and therapeutic efficacy), pharmaceuticals, cosmetics, food, agriculture, and environmental protection. Techniques such as NMR, FTIR, and XRD confirm complex formation and elucidate interactions. Overall, CD inclusion compounds harness host-guest chemistry to optimize hydrophobic molecules for broader use. This pronounced difference in the fatliquoring indicates that the effluent exerts a stimulatory effect on seed growth, potentially because nutrient enrichment dominates over toxic components at the tested concentration, as supported by findings from comparative phytotoxicity studies.[6]

γ

β

This study develops and characterizes a novel class of conductive crust leather by incorporating anacardic acid into -cyclodextrin inclusion complexes, which serve as fatliquors to yield soft, electrically conductive leather. The approach bridges traditional craftsmanship with modern smart materials, producing eco-friendly leather suitable for wearable electronics, interactive fashion, and intelligent upholstery—advancing sustainable, multifunctional leather technologies. [7,8]

β

2. Methodology

Retanning Phenol -Melamine Phenol -Melamine 14% 60'

Fatliquoring ANAC -CD Turkey Red Oil 7% 60'

Fixing Formic Acid Formic Acid 1% 3 x10'+ 30' pH=4, pile it

Post Tanning Process

3. Results and Discussion

The formation of inclusion compound with Cyclodextrin and Anacardic acid can be easily assessed using FT-IR spectroscopy. This technique helps in determining the bands of vibrations of the individual moiety in the process of complex formation. Inclusion complex formation is generally identified by a change in intensity,

disappearance, and widening as well as shifting of peaks. Moreover, the peaks of ANAC-CD were observed to be smoothed, suggesting the prevalence of high intermolecular interaction between ANAC and -CD. The IR band of the -CD is absent in the inclusion complex (ANACCD) spectra. This shows that a strong interaction of ANAC molecule inside the CD cavity and thereby validating the inclusion complex formation.

β β

The scanning electron micrograph of -cyclodextrin and the inclusion compound ANAC-CD at different magnification give crystalline arrangement of ANAC-CD with respect to cyclodextrin. The anacardic acid includes cyclodextrin contributes sharp edges show the product with its finest and purest form. The product is giving conductivity at the rate of 0.02 - 0.1 mS/cm.

β

4. Physical Properties

The Post tanned crust leather samples of Control and Anacardic Cyclodextrin (ANAC-CD) indicates that the tensile strength, elongation and extension at break have far better value than the control leather. The Scanning electron micrographs of post-tanned leathers show the fullness and increased the smoothing of the surface. The fibres are more open in ANAC-CD as compared to Commercial. This indicates the impact of the inclusion compound ANAC-CD on post-tanning is much better than the leather fibre of experimental leather.

In the seed germination experiment using post tanned leather processed effluent, the experimental group exposed to the effluent solution exhibited drastic growth, with rapid radical emergence and significant elongation observed within 48 hours, achieving over 90% germination rates and average radical lengths exceeding 2 cm. In contrast, the control group treated with distilled water showed no improvement whatsoever, displaying 0% germination and no visible signs of radical or hypocotyl development over the same period. This marked disparity highlights the effluent's stimulatory effect on seed growth, potentially due to nutrient enrichment outweighing toxicity at the tested concentration, as evidenced by comparative phytotoxicity studies.

5. Conclusion

In this study the Anacardic Acid, the byproduct that released from cashew nut industry has been utilised in leather industry as fatliquor. The inclusion compound has been made successfully from Anacardic Acid and Cyclodextrin. The prepared product further act as fatliquor to give crust leather having conductive property with wide application. Moreover, the effluent that released to the nature is showing plant growth stating that the product is not even polluting the environment and supporting the green chemistry compared to the commercial fatliquoring system.

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