Ragul L K, 2025, 13:3
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology

An Open Access Journal

Novel Polymer Integration In Elevating Standards For Protective Coatings

Ragul L K, Associate Professor Lipsa Nayak
Department of Computer Application -PG
VISTAS, Chennai

Abstract- Bisphenol A (BPA), commonly found in plastics and tars, can leach into food and beverages, raising serious health concerns such as cardiovascular disease, diabetes, developmental issues, and metabolic disorders. This study explores the potential of bio-based lacquers made from tomato processing waste—specifically tomato pomace—as sustainable alternatives to BPA-containing metal food packaging coatings. The process involves sun-drying tomato waste (seeds, pulp, and skins), converting it to powder via microwave, and breaking down the cell walls using sodium hydroxide (NaOH) to extract lipids. These lipids undergo polymerization, which is analyzed using infrared spectroscopy to determine esterification levels. Ethanol is then added to form a waxy substance. The coatings on aluminum substrates showed superior mechanical properties and water resistance compared to TFS and ETP finishes. Additionally, Support Vector Machines (SVMs), a machine learning algorithm, were used to classify pH levels, proving effective in categorizing soil as acidic, neutral, or alkaline based on pH and environmental factors.

Keywords- Bio-based lacquer, BPA replacement, Tomato pomace, Food packaging, Sustainable materials, Protective coating, Environmental safety, System testing, White box testing, Black box testing.

I. INTRODUCTION

The rapid advancement of technology and industrialization has greatly enhanced human life, particularly in food processing and packaging. Packaging not only preserves food freshness but also extends shelf life, prevents contamination, and facilitates easy transportation and storage. Metal cans lined with protective coatings are a common choice for packaging processed foods. Traditionally, bisphenol A (BPA)-based epoxy resins have dominated this sector due to their thermal resistance, mechanical strength, and durability. However, increasing scientific evidence has highlighted the health risks associated with BPA leaching into food, leading to widespread concern and tighter regulations.

BPA, a synthetic organic compound, is widely used in polycarbonate plastics and epoxy resins, especially for lining metal cans to prevent corrosion. Although effective, BPA has been found to leach into food under high temperatures or acidic conditions, acting as an endocrine disruptor and interfering with hormonal functions. In response to these risks, regulatory bodies like the U.S. FDA and EFSA have restricted BPA's use in food-contact materials, prompting an urgent search for safer alternatives. This need has driven research towards bio-based, non-toxic, and environmentally friendly coatings that maintain the functionality of traditional packaging.

A promising solution lies in the use of agro-industrial waste, such as tomato pomace, to create bio-based materials. Tomato pomace, consisting of skins, seeds, and pulp left after juice extraction, is rich in

© 2025 Ragul L K. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly credited.

dietary fiber, essential fatty acids, antioxidants like lycopene, and other bioactive compounds. Often discarded or used as low-value animal feed, it represents an underutilized resource with significant potential.

This project proposes the development of a bio-based lacquer derived from tomato pomace to replace traditional BPA coatings in food packaging. The concept focuses on converting agricultural waste into high-value, eco-friendly materials. The extracted lipids and beneficial compounds from tomato pomace are formulated into a lacquer that provides corrosion resistance, hydrophobicity, mechanical strength, and chemical inertness—qualities essential for food packaging applications.
The benefits of a tomato-pomace-based lacquer are substantial. It reduces reliance on synthetic, petrochemical-based resources, decreases the carbon footprint, and supports sustainable agriculture by offering new value streams for food industry waste. Furthermore, it is biodegradable and non-toxic, minimizing the risks of chemical contamination in food and reducing environmental impact during disposal.

To validate its practicality, the lacquer undergoes rigorous testing, including mechanical stress analysis, corrosion resistance, and compatibility with various food types. Its performance is benchmarked against conventional BPA coatings to ensure industry competitiveness. The project also considers scalability, cost-efficiency, and compliance with international food safety standards to facilitate real-world application.

The broader significance of this project lies in its potential to revolutionize food packaging through sustainable innovation. It addresses public health concerns while promoting environmental stewardship and waste valorization. By integrating bio-based solutions into mainstream packaging technologies, this project supports a shift toward safer, more sustainable industrial practices, aligning with growing consumer demand for eco-conscious products. Continued research, development, and industry collaboration will be key to unlocking the full potential of bio-based lacquers and setting new standards for future food packaging solutions

II. LITERATURE SURVEY

This article focuses on solving the consensus tracking issue in address this, the authors design a finite-time function and introduce a performance function that determines how quickly agents reach consensus with their neighbors. Two new lemmas are presented to ensure stability in the system, and a fully distributed adaptive control strategy is developed that does not require global knowledge of the network. Unlike many previous methods, which only achieve bounded consensus over time, this new approach guarantees that consensus errors fall within a specified range in a finite amount of time. Additionally, all agents are shown to track the leader’s trajectory accurately over time. This control scheme enhances precision and responsiveness in multiagent systems. Simulation results support the method’s success and demonstrate its practical potential for real-world applications where reliability and fast convergence are critical. Y. Cao and Y. Song, [1] This paper introduces an effective and straightforward method called MRACon. In this approach, each agent is assigned a reference output to follow, which is generated by a linear model using relative state information from neighboring agents. The study addresses two types of agent dynamics: For each, a tailored linear reference model is designed. In the case of general linear dynamics. For second-order systems, position consensus is reached under changing graphs that are uniformly jointly connected. The proposed method relies solely on relative state interactions between agents, avoiding the need for communication of virtual signals, making it both practical and scalable. J. Mei, W. Ren, and Y. Song. [2] This research focuses on solving the To address issues like the ripple effect caused by inaccurate compensation of time-varying inputs, the authors propose a new piecewise continuous control law and a dynamic event-triggering strategy using a time-varying triggering function. They design a clear integral that treats the sampling error as an external input, ensuring the system's stability. remains uniformly globally asymptotically stable for any threshold signal those decays exponentially. This feature also eliminates the possibility of Zeno behavior (infinitely frequent triggering). Furthermore, the method allows the prevention of excessively fast sampling by tuning the decay rate of the threshold signal. The effectiveness of this approach is demonstrated through a numerical simulation, validating its practicality and efficiency J. Fu, Y. Lv, and W. Yu. [3] This study addresses the control challenges of a specific class of nonlinear systems affected by input saturation by developing an design using the backstepping method. To manage the complications introduced by asymmetric input saturation, an auxiliary system mirroring the structure of the original system is introduced. The unknown nonlinearities within the system are effectively managed using fuzzy logic systems and their approximation capabilities. Through Lyapunov-based stability analysis. This guarantees the system's reliable performance. The proposed method is validated using both numerical examples and real-time simulations, which show that the approach is effective and practical for systems with challenging nonlinear dynamics and input constraints H. Ma, H. Li, and R. Lu [4] This paper introduces two adaptive control methods for SISO strict feedback nonlinear systems with nonlinearities, both designed to ensure prescribed performance. The first method assumes only the sign of the control gain is known, while the second relaxes this by using Lyapunov functions that don't rely on integration. Prescribed performance refers to ensuring that converges at a specific rate, and remains below a set overshoot limit. A novel output error transformation is used to convert the constrained system into an unconstrained one, simplifying control design. Stabilizing this transformed system is enough to ensure overall performance. The proposed controllers are smooth and avoid issues with controllability. Additionally, the focus on the unconstrained system makes it easier to choose control parameters and neural approximators. Mingkuan C. P. Bechlioulis and G. A. Rovithakis. [5

III. SYSTEM ANALYSIS:

Existing system: Bisphenol A (BPA)-based coatings are widely used in metal food packaging, where they serve as protective barriers applied to the interior surfaces of cans and containers. These coatings are primarily made from epoxy resins known for their excellent mechanical strength, chemical resistance, and ability to form durable, impermeable layers. This protective layer is crucial for preventing corrosion, metal leaching, and preserving the quality, taste, and safety of the food. BPA-based coatings effectively minimize direct contact between food and the metal substrate, reducing the risk of chemical reactions that could compromise food integrity. Their widespread adoption is largely due to their proven performance, reliability, and cost-effectiveness in ensuring long shelf lives and reducing food spoilage.

However, growing health and environmental concerns highlight the need for safer and more sustainable alternatives. BPA is recognized as a significant environmental pollutant due to its persistence; it does not degrade easily and can contaminate landfills and natural ecosystems for extended periods. Discarded metal cans with BPA coatings may release harmful chemicals into the soil and water, affecting wildlife and potentially entering the food chain. This contributes to broader issues like plastic pollution and ecological damage. Consequently, there is an urgent need to develop eco-friendly, non-toxic materials for food packaging that can maintain product quality while minimizing environmental impact. Addressing these concerns is critical for advancing sustainable practices in the food industry and protecting both human health and the environment.

Proposed System: The proposed framework introduces an innovative approach to food packaging by replacing traditional bisphenol A (BPA)-based coatings with a cutting-edge bio-based lacquer derived from tomato pomace. This system provides an effective alternative to BPA, addressing its significant health and environmental concerns. By utilizing tomato pomace, an underused agricultural by-product, the framework promotes eco-friendliness and non-toxicity while supporting circular economy principles and reducing reliance on harmful chemicals. The bio-based lacquer developed through this method offers several performance enhancements compared to conventional coatings. It demonstrates superior mechanical strength, ensuring durable protection of metal food containers against physical damage. Its excellent corrosion resistance also extends the shelf life of food products, maintaining packaging integrity over time. Additionally, the lacquer's hydrophobic properties effectively repel water, safeguarding the metal substrate from rust and degradation. This innovative solution not only complies with current regulatory standards for safer food packaging materials but also aligns with consumer demand for environmentally responsible and health-conscious products. Integrating this bio-based lacquer into packaging processes marks a significant advancement toward reducing environmental impact and improving public health outcomes. It provides manufacturers with a practical, sustainable alternative that enhances product safety and performance while addressing the urgent need for greener solutions.

IV MODULES

A.Admin: In this work, the input videos are recorded from 7 live people. Figure 2 provides the original-colored frames. Because of the outdoor conditions, there a varied lighting conditions. This is why the frames inside the video have to be pre-processed for image enhancement purposes. Histogram stretching is used to enhance the images by improving their contrast which otherwise is low in these images.

B.Waste Process: Employees in the waste process module sign up by providing their name, email, mobile number, and employee ID. After admin approval, they receive login credentials. They upload datasets based on admin requirements, dry the tomato pomace through sunlight and oven heating, powder it, and submit the report. Finally, the employee logs out after completing the process.

C.Lipid Extraction: The lipid extraction employee registers with basic details and, after admin approval, logs in using credentials sent via email. They view admin requirements and accepted waste reports, upload a dataset for sodium hydroxide calculation, and perform lipid extraction from the treated pomace. After completing the process, they send the calculation and extraction reports to the admin before logging out.

D.Lacqure Formation: The lacquer formation employee registers with basic details and, after admin approval, logs in using credentials sent via email. They view the accepted lipid extraction report, upload a dataset containing client ID, tomato type, extraction efficiency, and pH level, and calculate the ethyl alcohol estimation. The results are sent to the admin, and the employee logs out after successful processing.

E.Protective Testing: The defensive testing employee registers with basic details and, after admin approval, logs in using the provided credentials. They view the approved lacquer formation report, upload a dataset containing client ID, tomato type, initial pH, buffer capacity, and concentration to calculate pH levels, extraction amount, and safety rate. After completing all calculations, the results are sent to the admin, and the employee logs out.

V. SYSTEM DESIGN

- Architecture Diagram
- E-R Diagram
- Use Case Diagram

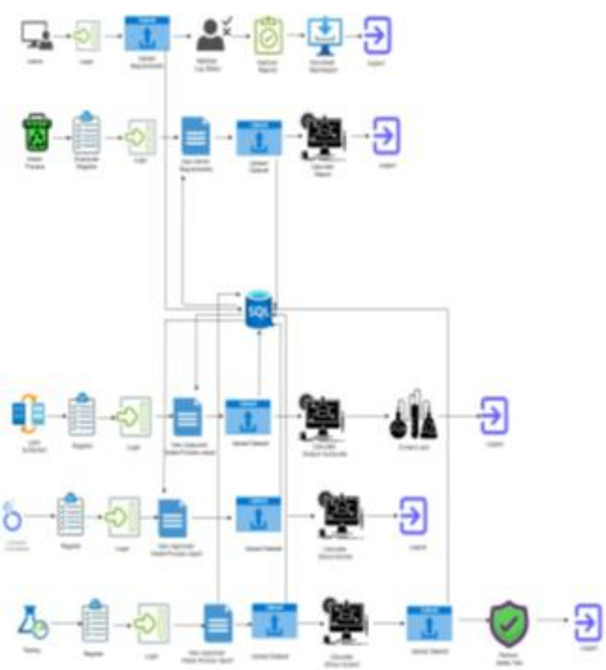

Fig 1: Architecture Diagram

Fig 2: E-R Diagram

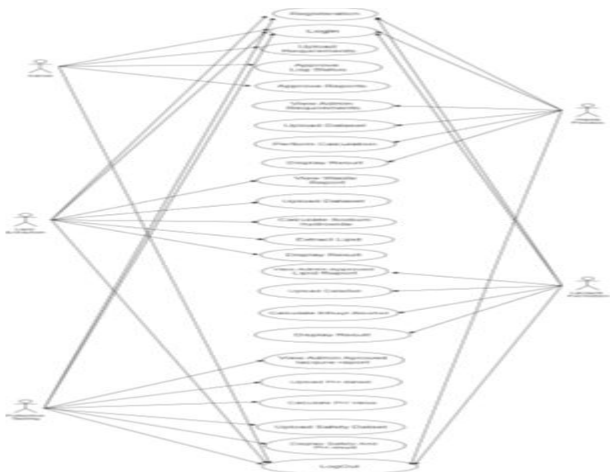

Fig 3: Use Case Diagram

VI. EXPERIMENTAL ANALYSIS

To The project aims to develop a sustainable bio-based lacquer derived from tomato pomace as a safer alternative to conventional BPA-based coatings in food packaging. Experimental analysis assessed the lacquer's chemical composition, mechanical strength, hydrophobicity, thermal and corrosion resistance. Lipids extracted from dried tomato pomace were blended with ethyl alcohol and natural binders to formulate the lacquer, applied to metal and plastic substrates, and dried under controlled conditions. Adhesion tests, tensile strength measurements, and water contact angle analyses confirmed excellent substrate bonding, moderate mechanical resilience, and strong hydrophobicity. Further corrosion tests under acidic and alkaline environments validated its durability. Safety evaluations showed the lacquer to be non-toxic and compliant with food safety regulations. System testing was conducted through unit, integration, and validation stages to ensure cohesive module interaction, data flow, and performance under real-world conditions. Results confirmed the lacquer maintained its properties after exposure to moisture, heat, and acidic environments. Using Young's Equation, the lacquer's hydrophobicity was quantified, showing high contact angles (>90°), indicating superior water resistance. Overall, the bio-based lacquer proves to be a health-conscious, eco-friendly, and industry-viable solution, promoting waste valorization and circular economy practices while enhancing food packaging safety and durability.

CONCLUSION

The development of a bio-based lacquer system using tomato pomace as an alternative to Bisphenol A (BPA)-based coatings offers a significant advancement in sustainable food packaging. This solution addresses health concerns associated with BPA, an endocrine disruptor, while utilizing agricultural waste, promoting environmental sustainability, and supporting circular economy principles. The lacquer, derived from lipids and natural polymers in tomato pomace, exhibits excellent hydrophobicity, corrosion resistance, mechanical strength, and food safety compliance, making it a viable replacement for BPA-based coatings. The modular system for lacquer production—from waste processing to protective testing—provides a scalable, cost-effective approach for commercialization. Experimental analyses and system testing confirmed its efficiency and practicality. Future improvements could include optimizing formulation, environmental testing, and incorporating smart quality-monitoring technologies. This bio-based lacquer system presents a health-conscious, eco-friendly alternative to harmful chemicals, promoting responsible waste use and offering a sustainable solution for the future of food packaging.

REFERENCE:

1. Y. Cao and Y. Song, "Performance guaranteed consensus tracking control of nonlinear multiagent systems: A finite-time function-based approach," IEEE Trans. Neural Netw. Learn. Syst., vol. 32, no. 4, pp. 1536–1546, Apr. 2021.
2. L. Cao, H. Li, G. Dong, and R. Lu, "Event-triggered control for multiagent systems with sensor faults and input saturation," IEEE Trans. Syst., Man, Cybern., Syst., vol. 51, no. 6, pp. 3855–3866, Jun. 2021.
3. C. Huang, Z. Liu, C. L. P. Chen, and Y. Zhang, "Adaptive fixedtime neural control for uncertain nonlinear multiagent systems," IEEE Trans. Neural Netw. Learn. Syst., early access, Apr. 28, 2022, doi: 10.1109/TNNLS.2022.3165836.
4. G. Chen, Y. Song, and Y. Guan, "Terminal sliding mode-based consensus tracking control for networked uncertain mechanical systems on digraphs," IEEE Trans. Neural Netw. Learn. Syst., vol. 29, no. 3, pp. 749–756, Mar. 2018.
5. J. Mei, W. Ren, and Y. Song, "A unified framework for adaptive leaderless consensus of uncertain multiagent systems under directed graphs," IEEE Trans. Autom. Control, vol. 66, no. 12, pp. 6179–6186, Dec. 2021.
6. Y. Li, Y.-X. Li, and S. Tong, "Event-based finite-time control for nonlinear multiagent systems with asymptotic tracking," IEEE Trans. Autom. Control, vol. 68, no. 6, pp. 3790–3797, Jun. 2023.
7. J. Fu, Y. Lv, and W. Yu, "Robust adaptive time-varying region tracking control of multi-robot systems," Sci. China Inf. Sci., vol. 66, no. 5, May 2023, Art. no. 159202.
8. H. Li, J. Luo, H. Ma, and Q. Zhou, "Observer-based event-triggered iterative learning consensus for locally Lipschitz nonlinear MASs," IEEE Trans. Cognit. Develop. Syst., early access, May 10, 2023, doi: 10.1109/TCDS.2023.3274794.
9. H. Ren, Z. Cheng, J. Qin, and R. Lu, "Deception attacks on eventtriggered distributed consensus estimation for nonlinear systems," Automatica, vol. 154, Aug. 2023, Art. no. 111100.
10. Y. Zhang, J. Sun, H. Liang, and H. Li, "Event-triggered adaptive tracking control for multiagent systems with unknown disturbances," IEEE Trans. Cybern., vol. 50, no. 3, pp. 890–901, Mar. 2020.