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Studies on nanocomposite coated parchment paper incorporated with ZnO nanoparticles and citrus limetta peel oleoresin

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Abstract
Vegetable parchment paper is a cellulose based material with excellent non-stick and grease resistant properties but lack of sealability restricts its application in food packaging. In this study, sealable Functional Nanocomposite Parchment Paper (FNPP) was developed by coating parchmentized paper with a PLA based nanocomposite containing *Citrus limetta* peel oleoresin and ZnO nanoparticles. Spectral characterisation of oleoresin showed a maximum absorption at 270nm and displayed 82.4% radical scavenging activity. FNPP exhibited a sealing strength of 202 $N \cdot m^{-1}$, antioxidant activity of 30.2% with significant antimicrobial properties. SEM-EDX revealed a smooth coating with uniformly distributed ZnO nanoparticles. FTIR and XRD analyses confirmed the successful incorporation of PLA, oleoresin, and ZnO nanoparticles within the parchment matrix. FNPP showed antimicrobial activity against *E. coli* and *S. aureus*, with inhibition zones of 14 mm and 11 mm, respectively, with improved bursting strength, smoothness, porosity, and water resistance compared to the control. Packaging trials with paneer demonstrated enhanced microbial stability, moisture retention, reduced acidity and extending shelf life which highlighting FNPP's potential as an eco-friendly active food packaging material.

Keywords: Antimicrobial property, oleoresin, parchment paper, PLA, Sealability, ZnO nanoparticles

Introduction

Vegetable parchment paper is a cellulose based composite with nonstick, grease resistant, and humidity resistant properties it gets its name from the fact that it resembles animal parchment, which is derived from animal hides, physically. Acid treated pulp is used to make vegetable parchment paper, which is then cleansed, neutralized, and dried after passing through a sulfuric acid bath. The cellulose was altered by the acid, to make it smooth and impermeable to liquids and fats which is devoid of lint, taste and odour. It is used in baking and packaging fats like butter and lard but lacks heat sealability and has poor air and moisture barrier properties. For primary packaging, vegetable parchment paper is often coated or laminated with waxes, resins, or lacquers to enhance its protective properties (Marimuthu, 2023) [18]. Foods like cheese, paneer can be wrapped in vegetable parchment that has been treated with mould inhibitors (Khatkar *et al.*, 2017) [14].

Polylactic acid (PLA), a renewable polymer derived from natural sources, has gained a lot of interest as a safer alternative to plastic due to its properties that are comparable to those of conventional plastics and its low environmental cost. Waxes and polymer film laminates composed of polyethylene, poly (ethylene co-vinyl alcohol), and polyethylene terephthalate are common alternatives. Nevertheless, these laminates cannot be recycled or composted. There is increasing interest in both research and business for lamination using biodegradable polymers, such as polyesters like polylactic acid, polyhydroxyalkanoates and polybutylene succinate (De Silva *et al.*, 2016) [7].

The Rutaceae family of plants includes a variety of plants known as citrus plants. As citrus fruit peel and pulp waste is increasing globally and posing serious waste management challenges, utilisation of these industrial and household wastes can help tackle a number of environmental and waste management issues. It was discovered that the essential oil derived from *Citrus limetta* peel had antimicrobial and antioxidant property (Shyam, 2019) [24]. At 100% concentration, *Citrus limetta* peel oleoresin showed an 87.77% DPPH radical scavenging efficacy (Javed *et al.*, 2013) [11].

Nanoparticles (NPs), typically 1–100 nm in size exhibit unique properties, and recent advancements in nanotechnology have expanded their potential applications across multiple fields (Therias *et al.*, 2012) [25]. Nanosized ZnO particles are widely used as functional inorganic materials in various coating applications, and several studies have shown that incorporating them into different polymers produces nanocomposites with enhanced functional characteristics, particularly improved antibacterial performance (Therias *et al.*, 2012) [25]. The significant antibacterial activity makes them useful not just for controlling food spoiling, but also for improving food safety by deactivating foodborne pathogens. Moreover, it has been classified as a generally recognised as safe (GRAS) product by the US Food and Drug Administration (21CFR182.8991). Comparing to other nano particles such as Ag_2O, TiO_2 and Fe_2O_3, Zinc oxide (ZnO) nanoparticles has been thoroughly investigated as an effective antibacterial agent and it is photochemically stable,

biocompatible and also exhibit Low toxicity to biological systems. It also exhibited significant bactericidal properties against a variety of bacteria, including *E. coli*, *S. pyogenes*, *S. enteritidis*, *B. subtilis*, *S. aureus*, *L. monocytogenes*, *K. pneumonia*, *P. aeruginosa*, *E. faecalis* (Akshaykranth *et al.*, 2023) [2].

Therefore, the present study aims to develop sealable vegetable parchment paper possessing antimicrobial and antioxidant properties, along with improved physical and mechanical characteristics, by coating with a PLA-oleoresin- ZnO nanocomposite.

Materials and Methods

Raw material

Paper of 54 Grams per square meter (GSM) was purchased from local market. Waste *Citrus limetta* peels were collected from local juice shop in Redhills, Chennai. Every chemical utilised in the experiment is of analytical grade (AR quality, 99.9% pure). Methanol was procured from (Memba Chem Industries Pvt. Ltd, Mumbai) while Sulfuric acid was procured from (SimSon Pharma Limited, Mumbai). Sodium bicarbonate was procured from (Loba chemie Pvt. Ltd, Mumbai). Chloroform was procured from (Rankem Chemicals Advanced lab scientific Pvt. Ltd, Mumbai). ZnO nanoparticles used in this study was synthesized and characterized by Ilangopathy *et al.*, (2025) [10].

Extraction of oleoresin from *Citrus limetta* peel

Citrus limetta peel oleoresin was extracted using the solvent extraction technique. *Citrus limetta* peels were cut into small pieces and washed thoroughly. Washed peels were dried at 50 °C for overnight using a hot air oven then the peels of dried *Citrus limetta* peels were ground to yield a fine powder. 100 g of powder was used for extraction with methanol (1:10 Solid: Solvent ratio) at 60 ℃ for 2 h in the hot plate (Jeong *et al.*, 1998) [12]. The mixture was filtered with the help of a filter paper (Whatman no.1) and concentrated it to produce a thick orange yellow extract then the extract was stored in an air tight container at 4 ℃, away from light for further assessment.

Parchmentization of paper

Typical paper weighing 54 GSM was converted to parchment paper by parchmentization process. Two separate baths with 25% sulfuric acid and 15% sodium bicarbonate were maintained at 50 °C and lukewarm water was positioned next to the water bath. The paper was immersed in the sulfuric acid followed by sodium bicarbonate and finally in lukewarm water bath for a period of two min each. Then the paper is dried at 70 °C for 10 min using a hot air oven (Andes 1907) [4]. Parchmentized paper was stored at ambient temperature for further treatments.

Nanocomposite preparation and coating on parchmentized paper

Nanocomposite was prepared by adding 2% of PLA (w/v), 1.25% of oleoresins (v/v) and 5% of ZnO nanoparticle (w/v) to the 100 mL of chloroform and the composite was placed in a magnetic stirrer at 45 ℃ and a stirring speed of 500 rpm for 4 h (De Silva *et al.*, 2016) [7]. The prepared PLA nanocomposite was placed in a sonicator (Soltec Sonica 2200 MH Ultrasonic Cleaner, Italy) to avoid agglomeration of nanoparticles and maintained a sonication throughout coating process as ultrasonication is efficient than stirring (Sakthivel *et al.*, 2026) [21]. Dried parchment paper was immersed into PLA nanocomposite and allowed to stand for 2.5 min on each side. It is then dried for 10 min at 70 °C in a hot air oven. The same procedure was repeated twice for 1 min & 30 s. On one side of the dipped paper, spray the PLA nanocomposite and dry it at 70 °C for 10 min. The same was repeated for the other side to get the final Functional Nanocomposite Parchment Paper (FNPP).

Spectral characterization of oleoresin

Oleoresin extracted from *Citrus limetta* peel was subjected to UV-visible spectroscopy using an (Epoch microplate spectrophotometer Biotek instruments, Inc., United States) in the wavelength of 200- 800 nm (Mare *et al.*, 2023) [17].

DPPH radical scavenging activity of oleoresin

Determination of the Antiradical activity of oleoresin was done by measuring the 2, 2- diphenyl-1-picrylhydrazil (DPPH) radical scavenging activity. Equal amount of oleoresin from *Citrus limetta* peel and DPPH solution was added to a 96 well microplate followed by dark incubation for 30 min. After incubation the absorbance at 517 nm of the solution was measured using (Epoch microplate spectrophotometer Biotek instruments, Inc., United States).

The following equation gives the percentage of radical scavenging activity

$$DPPH\ scavenging\ activity = \frac{(A_0 - A_1)}{A_0} \times 100$$

Where, A_0 is the absorbance at 30 min of the control (Ascorbic acid) and A_1 is the absorbance at 30 min of the sample (Javed *et al.*, 2013) [11].

UV Light Transmittance of FNPP

The FNPP light transmittance was measured using UV-visible spectrophotometer (Epoch microplate spectrophotometer Biotek instruments, Inc., United States) within wavelength of 200- 800 nm (Pavithra *et al.*, 2015) [20].

Morphological and Elemental characterization of FNPP

FNPP surface morphology and the distribution of nanoparticles were examined with VEGA3, TESCAN (Czech Republic) Scanning Electron Microscopy (SEM). The images were captured with the SEM system (Esprit 1.9) equipped with a XFlash 5010 detector. The presence and distribution of ZnO nanoparticles were further confirmed with the Energy Dispersive X-ray Spectroscopy (EDX) coupled with SEM supplied by (Bruker Nano GmbH Berlin, Germany).

Chemical structure characterization of FNPP

PerkinElmer 1600 Infrared Spectrometer, USA was used for recording the FTIR spectra of Vegetable Parchment paper (C), PLA sheet and FNPP(T). An Attenuated Total Reflectance (ATR) mode in 4000- 400 cm^{-1} was used for the analysis.

X-ray Diffraction (XRD) study of FNPP

Malvern Panalytical Empyrean diffractometer, UK with Cu Kα radiation (λ = 1.5406 Å) was utilised for determining the X-ray diffraction (XRD) measurements of FNPP operated in continuous scan mode at 40 kV and 15 mA and at room temperature (25 °C).

DPPH radical scavenging activity of FNPP

The antioxidant activity of FNPP was assessed by following the modified procedure of Byun *et al.,* (2010) [5]. A 0.1 g of paper sample was fragmented into tiny bits and combined with methanol (2 mL). After 3 min of intense vortexing of this mixture it was left to settle at room temperature for 3 h. Again, it was vortexed for an additional 3 min and subjected to centrifugation (Thermo Fisher Scientific, Osterode am Harz, Germany – Sorvall ST1R Plus-MD Laboratory Centrifuge) for 10 min at 830 × g. The resulting supernatant was analysed to evaluate its DPPH radical scavenging activity. A 500 µL aliquot of the methanol extract was mixed with 2 mL of methanol solution containing 0.06 mM DPPH. This combination was vortexed intensively for 1 min and then incubate in the dark for 30 min at room temperature. The mixture absorbance was measured using a UV- visible spectrometer at a wavelength of 517 nm. Methanol solution contains 0.06 mM DPPH served as the control for comparison.

The following formula gives the DPPH Radical scavenging activity of FNPP.

$$DPPH\ scavenging\ activity = \frac{(A_0 - A_1)}{A_0} \times 100$$

Where A_{sample} is the sample absorbance and $A_{control}$ is the control absorbance.

Antimicrobial activity of FNPP

The antimicrobial activity of vegetable parchment paper (C) and FNPP (T) samples was evaluated by agar disc diffusion method, following the standard procedure described by Amjadi *et al.,* (2019) [3]. *E. coli* and *S. aureus* the two foodborne pathogenic bacteria was used for evaluation. The inhibition zone diameter around the samples was measured using a caliper and reported in millimetres (mm).

Physical and mechanical properties of FNPP

The C and T was subjected for the determination of physical and mechanical properties. The physical properties such as thickness, GSM, water absorption and mechanical properties such as porosity, bursting strength, seal strength were determined by conducting various test in accordance with the corresponding standards shown in the table 1.

Table 1: Standards of test applied for Control and FNPP papers

Tests	Standards	Equipment name
Thickness(mm)	IS 1060 (Part 5/Sec 3) : 2014	Palmer digital micrometer, Spain
GSM($g \cdot m^{-2}$)	IS 1060 (Part 5/Sec 5) : 2021	Mettler Toledo AL204 Analytical Balance, USA
Cobb(absorption)($g \cdot m^{-2}$)	IS 1060 (Part 5/Sec 4) : 2014	Fabricated Cobb tester
Bursting strength(kPa)	IS 1060 (Part 6/Sec 2) : 2014	Presto Burst Genie 4.0 Computerised, Haryana
Seal strength($N \cdot m^{-1}$)	ASTM F88 - 15	Tinius Olsen 1ST UTM, USA
Porosity ($s \cdot 100\ mL^{-1}$)	IS 9894 - 1981 (RA 2018)	ABB Gurley Porosity meter, Switzerland

Antimicrobial efficacy of FNPP against Paneer

Fresh paneer samples were wrapped and sealed in (C) and (T) and stored at 4 °C. Analysed for titratable acidity by titration method (BIS, 1983) and moisture content by gravimetric method (IS:10484,1983). Total count, Yeast and mould count and Coliforms enumeration were performed following standard microbiological procedures as described by Shanaziya *et al.,* (2018) [22]. Plate Count Agar, Potato Dextrose Agar and MacConkey Agar was used for Total Plate Count, yeast and mould count and coliform count. All plates were subjected to incubation at 37 °C for 24- 48 h except yeast and mould which were incubated for a period of 72 h at 25 °C. Colony forming units per gram (CFU/g) was used to express the results.

Results and discussion

Spectral characterization of oleoresin

Oleoresin extracted from *Citrus limetta* peel was subjected to UV visible spectroscopy within the 200- 800 nm wavelength region. Result showed the highest peak of absorption at 270 nm, it indicates the phenolic compounds presence in the oleoresin and it also strongly agreed to the result obtained by Mare *et al.,* (2023) [17]. Figure 1 illustrates UV- visible spectra of *C. limetta* oleoresin.

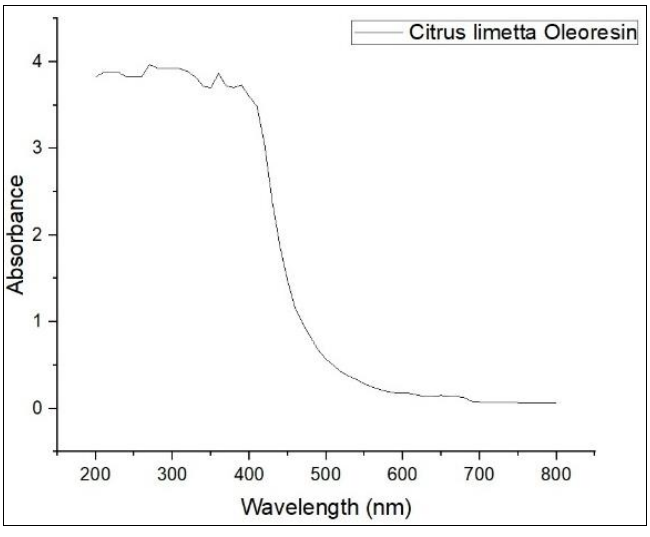


Fig 1: UV-Visible spectra of *citrus limetta* peel Oleoresin

DPPH radical scavenging activity of oleoresin

The DPPH radical scavenging technique relies on a sample's capacity to donate hydrogen in order to scavenge free DPPH radicals. The oleoresin extracted from the *Citrus limetta* peel showed 82.4% of radical scavenging activity which is comparable to the outcome of the research carried out by Javed *et al.,* (2013) [11].

UV Light Transmittance of FNPP

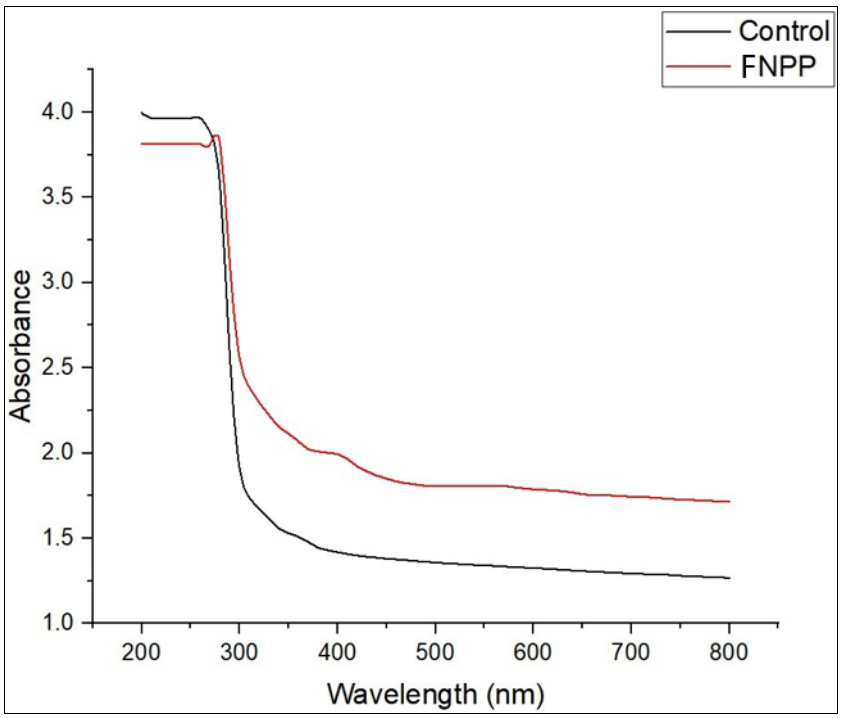


Fig 2: UV-Visible spectra of control and FNPP

Figure 2 displays the UV-visible spectra of FNPP (T) and vegetable parchment paper (C). Maximum absorption peaks for the (C) and (T) were observed at 200 nm and 280 nm, respectively. This confirms the presence of coating agents such as PLA, oleoresin and particularly ZnO nanoparticles in the FNPP by their absorption under UV-visible radiation, thereby restricting transmittance. The Figure 2 illustrates the differences between vegetable parchment paper and FNPP, indicating that PLA, oleoresin and ZnO nanoparticles are well adsorbed on the surface of the FNPP. These results comply with findings from previous studies by Pavithra *et al.*, (2015) [20].

Morphological and Elemental characterization of FNPP

The developed FNPP (T) were observed under Scanning Electron Microscopy (SEM). The SEM image figure 3(1)A and 3(1)C showed the smooth surface morphology of the FNPP which indicates that PLA has good film forming ability (Dai *et al.*, 2022) [6]. The figure 3(1)D visualised few porous air vacuoles which may be developed due to the spraying technology adopted for surface coating. In figure 3(1)B The ZnO nanoparticles were agglomerated, which can be seen as cluster of white dots immersed in the PLA coating. Agglomeration of ZnO nanoparticles and the slight deformations on the surface might be due to the charge interaction between the phenolic groups present on the surface of ZnO nanoparticles and the PLA molecules (Therias *et al.*, 2012) [25]. The presence of ZnO nanoparticles in the developed FNPP (T) was additionally confirmed by performing EDX. The EDX data showed the presence of Oxygen (99.22%) and Zinc (0.78%). The utilisation of base paper and *C. limetta* peel oleoresin in the Treated (T) paper may contribute to the higher concentration of oxygen (Yadav and Ahmaruzzaman 2022) [26].

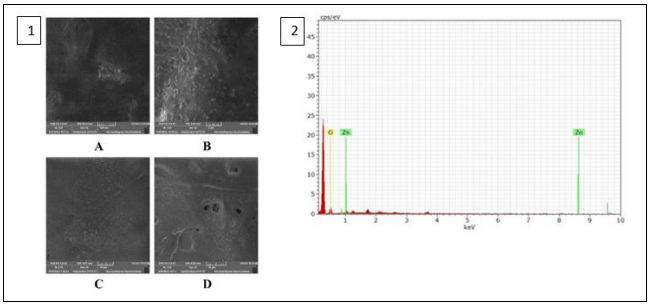


Fig 3: 1) SEM images of FNPP at A) 500 nm, B)2 µm, C) 20 µm, D) 50 µm 2) EDX spectrum of FNPP

Chemical structure characterization of FNPP

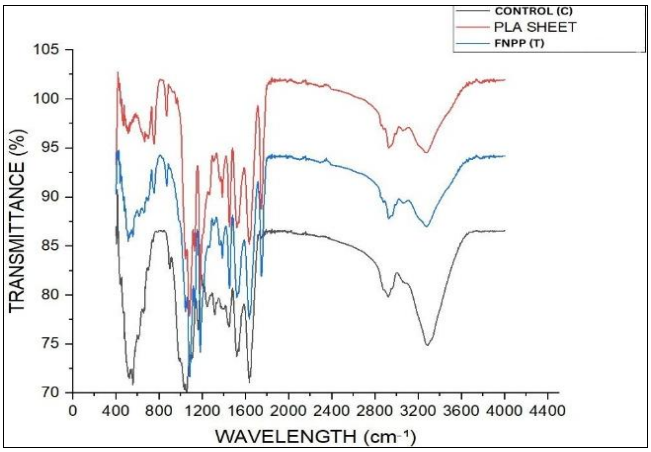


Fig 4: FTIR spectra of Parchment paper(C), PLA sheet and PLA coated paper (T)

The intermolecular interactions between PLA biopolymer, ZnO nanoparticles and *Citrus limetta* peel oleoresin were analysed using FTIR. The Figure 4 shows the FTIR spectra of three samples such as plain PLA sheet, vegetable parchment paper (C) and FNPP (T). The pure PLA sheet exhibited several characteristics peak at 2900, 1750, 1450, 1180, 1080, 870 cm^{-1}. The bands at 2900 cm^{-1}, 1750 cm^{-1}, 1450 cm^{-1}, was corresponded to -C-H- stretching, C=O stretching of ester group, -C-H- symmetric and asymmetric deformations correspondingly. The spectra of 1180 cm^{-1} and 1080 cm^{-1} ensures the presence of C-O stretching and bending vibrations. These results are highly consistent with the PLA film's FTIR spectrum reported by Kim *et al.,* (2019) [15]. The presence of strong C=O ester, -C-H- stretching vibrations and above results confirm the PLA polymeric structure. The FTIR spectrum of parchment paper shows absorbance peaks at wavenumber 3330 cm^{-1} (stretching vibration of the O–H functional group) and intramolecular hydrogen bond vibration in cellulose, at wavenumber 2900 cm^{-1} (stretching vibration of C–H functional group), at wavenumber 1600 cm^{-1} (C=O stretching vibration), at Wavenumber 1250 cm^{-1} (C–C stretching, C–O–H, C–C–H deformation) and at wavenumber 1050 cm^{-1} corresponds to the stretching vibration of the C–O bond in cellulose. The above results agreed with the results obtained by Manandhar *et al.,* (2022) [16]. The above functional groups identified are consistent with the basic structure of cellulose and confirms it as a paper (Manandhar *et al.,* 2022) [16]. The FTIR spectrum of FNPP poses both characteristics of the above with slight modifications such as the intensification of the peaks at 1750 cm^{-1}, 1450 cm^{-1}, 1180 cm^{-1}, 1080 cm^{-1} was greatly reduced when compared to that of PLA sheet ensures the thinner PLA coating on the paper. The peak at 430 cm^{-1} is due to Zn–O stretching vibrations and some new peaks existed at 2920 cm^{-1} and 2850 cm^{-1} attributed to C–H stretching vibrations (alkane), 1740 cm^{-1} is related with the C=O stretching vibrations of ester linkages and 1600–1650 cm^{-1} peaks were attributed to the (conjugated alkene) C═C stretching vibrations (Deo and Sakhale 2024; Yadav and Ahmaruzzaman 2022) [8,26]. These changes in intensities and the introduction of new peaks due to essential oil addition is also observed by Heydari-Majd *et al.,* (2022) [9].

X-ray Diffraction (XRD) study of FNPP

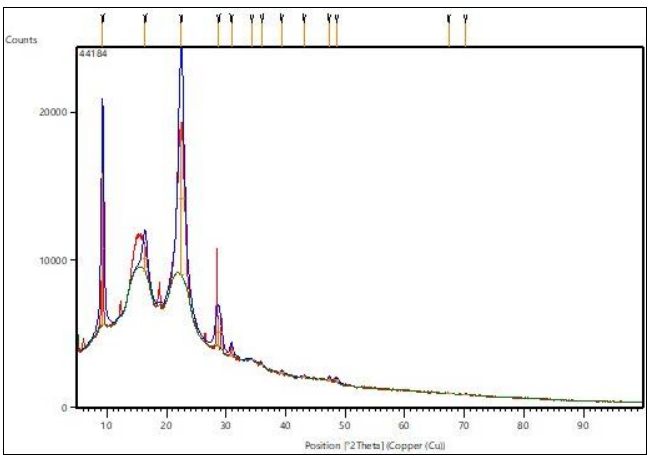


Fig 5: XRD patterns of FNPP

The Figure 5 displays the X–ray diffraction patterns of the FNPP. The specific diffraction peaks observed at 2θ = 16.3875º and 22.4644º are attributed to the characteristic diffraction planes of the orthorhombic crystalline structure of PLA. In addition, the peaks at 2θ = 34.3395º, 36.0154º, 47.3249º and 67.3283º correspond to (002), (101), (102), (112) planes respectively, confirming the presence of ZnO nanoparticles with a hexagonal wurtzite structure. The relatively low intensity of ZnO diffraction peaks may be attributed to the homogenous dispersion of nanoparticles within the polymer matrix, which is made possible by ultrasonic treatment and these results align well with the previously reported studies (Akshaykranth *et al.,* 2023) [2].

DPPH radical scavenging activity of FNPP

C and T paper radical scavenging activity was assessed to be 14.6% and 30.2%. This showed that the FNPP had higher antioxidant activity when compared to that of vegetable parchment paper. The obtained RSA of FNPP was higher than the RSA of PLA film containing only ZnO nanoparticles developed by Dai *et al.,* (2022) [6]. This ensures that the antioxidant activity of FNPP paper is majorly contributed by the oleoresin from *C. limetta* peel in addition to that of ZnO nanoparticles.

Antimicrobial activity of FNPP

Disc diffusion method was used for assessing the antibacterial activity of C, T and PLA/oleoresin coated paper (T1) against *E. coli* and *S. aureus*. The zone of inhibition for C and T samples against bacteria are shown in figure 6. The C and PLA/oleoresin coated paper (T1) exhibited no antibacterial activity. However, T showed inhibition zones of 14 mm and 11 mm towards *E. coli* and *S. aureus*, respectively, due to the presence of ZnO nanoparticles. These results comply with the antimicrobial activity of the PLA/ZnO nanoparticles film developed by Amjadi *et al.,* (2019) [3].

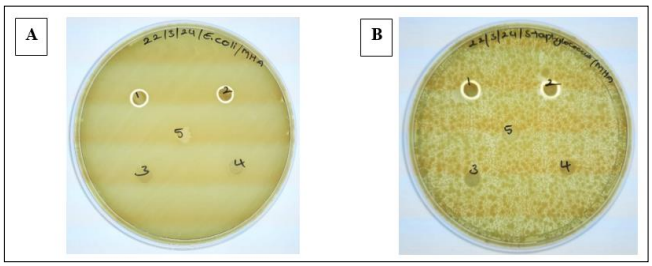


Fig 6: A) Antimicrobial activity against *E. coli* B) Antimicrobial activity against *S. aureus*

Physical and mechanical properties of FNPP

The result obtained from the conducted test is shown in the table 2. It shows that the FNPP (T) having more thickness and GSM when compared to that of C. This Characteristics is in accordance to the result obtained by Shankar *et al.,* (2019) [23], in which the coated paper having higher thickness and GSM when compared to that of Silicone coated parchment paper. Higher GSM and thickness in T paper is attributed due to the usage of higher GSM paper for the development of T paper and the PLA coating. Measuring the water absorption by cobb method shows that the T paper having higher water resistance (reduced WA) than that of C paper this property complies with the result that the coated paper having increased water resistance than

uncoated is obtained by Shankar *et al.,* (2019) [23] and Nilsuwan *et al.,* (2018) [19]. The increased water resistance of the T paper was due to covering the hydrophilic surface of the paper with the hydrophobic PLA composite. Increased burst strength and porosity (reduced permeability) value in T paper compared to that of C shows that the paper is well coated by covering the pores with the PLA nanocomposite. Improved burst strength and porosity value in coated paper is also observed by Shankar *et al.,* (2019) [23]. The seal strength is an important parameter used to determine the quality of packaging materials. T paper shows a seal strength of 202 N/m. This sealing property is due to that of PLA coatings and the seal strength of T is almost equivalent to the seal strength of PLA film (Nilsuwan *et al.,* 2018) [19]. C doesn't show any sealing property due to the absence of sealable PLA coatings.

Table 2: Results of physical and mechanical test conducted on Control and FNPP

Test	Control (C)	FNPP(T)
Thickness (mm)	0.0348	0.0844
GSM ($g \cdot m^{-2}$)	35.44	72.44
Cobb ($g \cdot m^{-2}$)	45.196	15.4
Bursting strength (kPa)	108.4	293.8
Seal strength ($N \cdot m^{-1}$)	Not sealable	202
Smoothness and porosity ($s \cdot 100\ mL^{-1}$)	277	815

Antimicrobial efficacy of FNPP against Paneer

Titratable acidity of paneer packed in both C and T was initially 0.72% lactic acid on 0^{th} day. The acidity of paneer in both C and T increased during storage at refrigeration temperature. The acidity levels of paneer in C and T increased, reaching 0.90% and 0.81% lactic acid on the 5^{th} day, and 0.94% and 0.85% lactic acid on the 8^{th} day respectively. Increase in titratable acidity of paneer was the indication of spoilage by the activity of lactose fermenting bacteria. The rate of acidity development in paneer packed in T was slower than the paneer in C. Increase in titratable acidity of paneer samples during storage was also noted by Khatkar *et al.,* (2017) [14]. Initial moisture content of paneer in both C and T was 50.79%. A decrease in moisture content of paneer in both C and T was observed during storage, reaching 36.4% in C and 42% in T by the 5^{th} day. Decreasing moisture content of paneer during storage is also noted by Abdullah *et al.,* (2022) [1]. However, T exhibited better moisture barrier properties than C. Moisture content of paneer increased to 43.15% in C and 45.83% in T on the 8^{th} day, possibly due to the moisture transmission after five days. As per IS:10484 (1983), the recommended limits for paneer are $<5 \times 10^5$ CFU/g for total plate count, <250 CFU/g for yeast and mould count, and <90 CFU/g for coliform count. The total plate count (TPC) of paneer in C and T significantly decreased from 5200- 1700 CFU/g and 5200- 700 CFU/g in 8 days. The greater reduction in total plate count of paneer in T was attributed due to the antimicrobial activity of FNPP, while the reduction in C may be due to unavailability of oxygen. Similar results of decreasing TPC during storage of paneer was observed by Khatkar *et al.,* (2017) [14]. The coliform count of paneer in C and T decreased from 100- 10 CFU/g and 100- NIL CFU/g respectively, demonstrating the antimicrobial efficacy of ZnO nanoparticle in FNPP against coliforms. The Yeast and Mould count varies from NIL- 510 CFU/g in C and NIL- 230 CFU/g in T. The antifungal property of oleoresin and ZnO nanoparticles contributed to the lower growth of yeast and mould compared to C and also T shows less efficacy against yeast and mould growth. The obtained result of yeast and mould count was in agreement with Karunamay *et al.,* (2020) [13]. Microbiological count of control (C) and FNPP (T) paneer during storage period was mentioned in table 3.

Table 3: Microbiological count of control (C) and FNPP (T) paneer during storage period

	Total plate count ($CFU \cdot g^{-1}$)			Yeast and mould count ($CFU \cdot g^{-1}$)			Coliforms count ($CFU \cdot g^{-1}$)		
day	0^{th}	5^{th}	8^{th}	0^{th}	5^{th}	8^{th}	0^{th}	5^{th}	8^{th}
C	5200	2600	1700	NIL	360	510	100	60	10
T	5200	1100	700	NIL	110	230	100	20	NIL

Conclusion

In this study, normal paper of 54 GSM was transformed into parchment paper through the process of parchmentization. The conventional silicone coating of parchment paper was replaced with PLA nanocomposite containing *Citrus limetta* peel oleoresin and ZnO nanoparticles. Extracted oleoresin had good antioxidant activity. SEM images of FNPP showed the smooth surface morphology of PLA coatings on the parchmentized paper, with some pores and agglomeration of nanoparticles. EDX confirmed the presence of ZnO nanoparticles, while FTIR spectra indicated that the ZnO nanoparticles/Oleoresin nanocomposite blended well with PLA biopolymeric chain and the presence of ZnO nanoparticles is further confirmed by XRD. Antibacterial test demonstrated that the developed FNPP effectively restricts the growth of *E. coli* and *S. aureus.* The coating of PLA nanocomposite on parchmentized paper surface significantly enhanced the mechanical and physical properties of the paper compared to the control. Control and FNPP were subjected to packaging test showed that % T.A, Moisture content and Microbiological analysis indicated a significantly prolonged shelf life for paneer packed in T compared to C. In conclusion, coating Parchmentized paper with a PLA nanocomposite containing ZnO nanoparticles and oleoresin successfully endowed the FNPP with antioxidant, antibacterial activities, as well as enhanced physical and mechanical properties and good sealability. This makes FNPP highly promising for food packaging applications. Up to day five of the shelflife test, the FNPP demonstrated an excellent moisture barrier; however, after that, moisture transmission was permitted. Future research should focus on improving the moisture barrier property by adopting advanced techniques.

Declarations

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Conflicts of Interest/Competing Interests

The authors declare no conflicts of interest or competing interests.

References

1. Ahmed Abdullah JA, Jimenez-Rosado M, Guerrero A, Romero A. Biopolymer based films reinforced with

green synthesized zinc oxide nanoparticles. Polymers, 2022, 14(23).
2. Akshaykranth A, Jayarambabu N, Venkatappa Rao T, Rakesh Kumar R, Srinivasa Rao L. Antibacterial activity study of ZnO incorporated biodegradable poly(lactic acid) films for food packaging applications. Polymer Bulletin,2023:80(2):1369-1384.
3. Amjadi S, Emaminia S, Davudian SH, Pourmohammad S, Hamishehkar H, Roufegarinejad L. Preparation and characterization of gelatin based nanocomposite containing chitosan nanofiber and ZnO nanoparticles. Carbohydrate Polymers,2019:216:376-384.
4. Andés LE. The treatment of paper for special purposes: A practical introduction to the preparation of paper products for a great variety of purposes. Scott, Greenwood & Son, 1907.
5. Byun Y, Kim YT, Whiteside S. Characterization of an antioxidant polylactic acid (PLA) film prepared with α-tocopherol, BHT and polyethylene glycol using film cast extruder. Journal of Food Engineering,2010:100(2):239-244.
6. Dai L, Li R, Liang Y, Liu Y, Zhang W, Shi S. Development of pomegranate peel extract and nano ZnO coreinforced polylactic acid film for active food packaging. Membranes,2022:12(11):1108.
7. De Silva RT, Soheilmoghaddam M, Goh KL, Wahit MU, Bee SAH, Chai SP, et al. Influence of the processing methods on the properties of poly(lactic acid)/halloysite nanocomposites. Polymer Composites,2016:37(3):861-869.
8. Deo SK, Sakhale BK. Phytochemical analysis of *Citrus limetta* using high resolution liquid chromatography mass spectrometry (HR-LCMS) and FTIR. Sustainable Agriculture, Food and Environmental Research, 2024, 12(2).
9. Heydari-Majd M, Ghanbarzadeh B, Shahidi-Noghabi M, Abdolshahi A, Dahmardeh S, Malek Mohammadi M. Poly(lactic acid) based bionanocomposites: Effects of ZnO nanoparticles and essential oils on physicochemical properties. Polymer Bulletin,2022:79(1):97-119.
10. Ilangopathy M, Kumanan V, Balaraman M, Sundaram M, Soundian E. Phytomediated fabrication of zinc oxide and zinc oxide silver nanocomposite using *Mangifera indica* leaf extract: Characterization, antibacterial, antibiofilm and antioxidant activity. ChemistrySelect,2025:10(46):e03851.
11. Javed S, Ahmad R, Shahzad K, Nawaz S, Saeed S, Saleem Y. Chemical constituents, antimicrobial and antioxidant activity of essential oil of *Citrus limetta* var. Mitha (sweet lime) peel in Pakistan. African Journal of Microbiology Research,2013:7(24):3071-3077.
12. Jeong JW, Lee YC, Lee KM, Kim IH, Lee MS. Manufacture condition of oleoresin using citron peel. Korean Journal of Food Science and Technology,1998:30(1):139-145.
13. Karunamay S, Badhe SR, Shulka V, Jaiswal S. Effect of essential oil of clove and oregano treated edible packaging film in extending the shelf life of paneer. The Pharma Innovation Journal,2020:9(7):317-322.
14. Khatkar AB, Ray A, Kaur A. Studies on shelf life extension of paneer with the addition of plant essential oil and different packaging materials. International Journal of Current Microbiology and Applied Sciences,2017:6:376-389.
15. Kim I, Viswanathan K, Kasi G, Sadeghi K, Thanakkasaranee S, Seo J. Poly(lactic acid)/ZnO bionanocomposite films with positively charged ZnO as potential antimicrobial food packaging materials. Polymers,2019:11(9):1427.
16. Manandhar S, Shrestha B, Sciortino F, Ariga K, Shrestha LK. Recycling waste paper for further implementation: XRD, FTIR, SEM, and EDS studies. Journal of Oleo Science,2022:71(4):619-626.
17. Mare R, Pujia R, Maurotti S, Greco S, Cardamone A, Coppoletta AR, et al. Assessment of Mediterranean citrus peel flavonoids and their antioxidant capacity using an innovative UV-Vis spectrophotometric approach. Plants,2023:12(23):4046.
18. Marimuthu P. Replacement of single use plastic by paper products in food packaging—an overview. IPPTA Journal,2023:35(2):119-124.
19. Nilsuwan K, Benjakul S, Prodpran T. Physical/thermal properties and heat seal ability of bilayer films based on fish gelatin and poly(lactic acid). Food Hydrocolloids,2018:77:248-256.
20. Pavithra R, Gunasekaran S, Sailatha E, Kamatchi S. Investigations on paper making raw materials and determination of paper quality by FTIR-UATR and UV-Vis DRS spectroscopy. International Journal of Current Research and Academic Review,2015:3:42-59.
21. Sakthivel M, Pitchaimuthu S, Ramkumar R, Arjunan S. Optimization of gluten-free muffin formulations: Enhancing functional and physicochemical properties of kodo millet flour through extrusion. Journal of Food Science and Technology, 2026, 1-10. DOI: https://doi.org/10.1007/s13197-026-06681-0
22. Shanaziya ASF, Mangalika ULP, Nayananjalie WAD. Effect of different coagulants on the quality of paneer made from cow milk. International Journal of Scientific and Research Publications,2018:8(4):189-194.
23. Shankar S, Bang YJ, Rhim JW. Antibacterial LDPE/GSE/Mel/ZnONP composite film coated wrapping paper for convenience food packaging application. Food Packaging and Shelf Life,2019:22:100421.
24. Shyam J. The phytochemical and pharmacological activity of *Citrus limetta* peel extracts. Journal of Global Biosciences,2019:8(8):6382-6396.
25. Therias S, Larché JF, Bussière PO, Gardette JL, Murariu M, Dubois P. Photochemical behavior of polylactide/ZnO nanocomposite films. Biomacromolecules,2012:13(10):3283-3291.
26. Yadav G, Ahmaruzzaman M. *Citrus limetta* peel derived catalyst for sustainable production of biodiesel. ACS Omega,2022:7(32):28534-28544.