RESEARCH PAPER

Fabrication of Herbal-Infused Polysaccharide Coatings for Enhancing Post-Harvest Shelf-Life of Fruits and Vegetables

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ABSTRACT
Post-harvest deterioration in fruits and vegetables is a major cause of loss in food quality and marketability. It even threatens global food security. Naturally derived biopolymers in the form of edible coatings provide an eco-friendly alternative to traditional storage methods. Different mixtures of guava leaf extract, aloe vera gel, neem gum, starch, vegetable oil, and citric acid were used to create herbal-infused polysaccharide-based edible coatings. Three formulations (F1, F2, and F3) were made and tested for antimicrobial activity, antioxidant potential, FTIR structural characterization, and shelf-life extension of guavas and carrots. F1 showed higher antioxidant activity with a 96.58% DPPH radical scavenging effect. It also had better antimicrobial effects against *Staphylococcus aureus* and *Pseudomonas aeruginosa*, as well as significant delays in physicochemical changes. Furthermore, shelf-life experiments revealed that the coated samples could be stored for 10 days at room temperature and 20 days in the refrigerator, while uncoated controls spoiled quickly. FTIR analysis identified functional groups such as -OH, C-H, C=O, and C-O, which contribute to film integrity and barrier properties. Overall, these findings indicate that the herbal-infused edible coating is a clean-label, biodegradable, and effective way to maintain freshness in perishable produce.

Keywords: Edible coating, polysaccharide, herbal extract, shelf-life extension, guava leaf, aloe vera, neem gum
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INTRODUCTION

Fresh fruits and vegetables are extremely perishable commodities that undergo rapid physiological and microbiological deterioration after harvest, leading to substantial economic losses and safety concerns[8,13,22]. Microbial contamination, respiration, moisture loss, and other metabolic changes accelerate browning, softening, and off-flavour development, thereby shortening storage life. The safety and marketability of fresh produce are further compromised by pathogenic microorganisms such as *Salmonella* spp., *E. coli* O157:H7, and *Pseudomonas* spp., which are frequently associated with fresh and fresh-cut fruits and vegetables [13].

The environmental impact of conventional synthetic packaging materials has intensified the need for sustainable preservation approaches[8,22,26,27]. Plant-derived edible coatings have gained considerable attention because they are non- toxic, biodegradable, and capable of forming semi-permeable films that regulate gas exchange, reduce moisture loss, and inhibit microbial growth [3,10,25]. Polysaccharide-based coatings, particularly those formulated from starches, gums, and mucilage, are well recognized for their safety, film-forming ability, and suitability for application on fresh produce [28] .The functional performance of these edible coatings can be enhanced by incorporating herbal extracts such as neem gum, which exhibits notable antimicrobial properties, *Aloe vera* gel, which is rich in bioactive polysaccharides, and guava leaves, which contain flavonoids and phenolic compounds with documented bioactivities[6,7,15,16,17,19,21,23,24]. In this context, the present study focuses on formulating and evaluating polysaccharide-based edible coatings infused with such herbal components for extending the shelf life of carrots and guavas using a clean-label and environmentally friendly strategy[2,8,9,12,22,26].

1. MATERIALS AND METHODS

1.1 Preparation of Plant Extracts and Polysaccharides

Ethanol, methanol, petroleum ether, hexane, and water were used to extract the powdered guava leaves after they had been shadedried. Fresh aloe vera gel was extracted by filtering and blending the inner parenchyma. Neem gum underwent filtering, hydration, and purification. The methods used to extract sweet potato starch were wet milling, sedimentation, and drying.

1.2 Formulation of Edible Coatings

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Three formulations were made by mixing guava leaf extract, aloe vera gel, neem gum, starch, vegetable oil, and citric acid:

- F1: Aloe gel, starch, guava extract, vegetable oil
- F2: Neem gum, starch, guava extract, vegetable oil
- F3: Aloe gel, neem gum, starch, guava extract, vegetable oil

The mixtures were heated and stirred to create a uniform slurry. Then, they were applied using the dipping technique.

Formulation	Aloe gel (ml)	Neem gum (ml)	Starch (g)	Guava extract (ml)	Vegetable oil (ml)	Citric acid (g)	Water (ml)
F1	150	-	10	10	5	0.5	100
F2	-	150	10	10	5	0.5	100
F3	75	75	10	10	5	0.5	100

Table 1: Concentration of Aloe gel, Neem gum, Starch, Guava leaf extract, vegetable oil, Citric acid, and water in edible coating mixture

1.3 Antimicrobial Activity

The formulations were tested against *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Aspergillus niger*, and *A. flavus*. This was performed using the agar well diffusion method.

1.4 FTIR Characterization

ATR-FTIR spectra of F1, F2, and F3 were recorded to find functional groups that contribute to structural stability and barrier properties.

1.5 Shelf-Life Study

Carrot and guava samples were coated and stored at both room temperature and refrigerated conditions, with continuous monitoring of visual, microbial, and physicochemical parameters, including colour, pH, total soluble solids, weight loss, and titratable acidity.

1.6 Antioxidant Activity

DPPH radical-scavenging activity of F1 was tested at various concentrations.

1.7 Physicochemical Analysis of Coated and Uncoated Samples

1.7.1 Colour

The colour of coated and uncoated samples was visually assessed at regular intervals using a 5-point scale ranging from 0 (no visible change) to 4 (severe discoloration), with observations recorded and photographs captured to document progressive changes during storage.

1.7.2 pH 10% Solution

The pH levels of coated and uncoated samples were measured according to the FSSAI Manual of Methods of Analysis of Foods: Fruits & Vegetable Products (2016). A 10% (w/v) solution was prepared by dissolving 10 g of the sample in 100 ml of distilled water. A calibrated pH meter was used for measurement, and the electrode was immersed in the solution until a stable reading was obtained.

1.7.3 Weight Loss

Weight loss of coated and uncoated samples was determined by measuring their initial weight before storage and final weight after storage with an analytical balance. Weight loss (%) was calculated using the formula:

$$\text{Weight loss (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

1.7.4 Total Soluble Solids

1.7.5 Initial weight

The Total Soluble Solids (TSS) of both coated and uncoated samples were measured with a refractometer, as described in the FSSAI Manual of Methods of Analysis of Foods: Fruits & Vegetable Products. A small amount of the homogenized sample juice was placed on the refractometer prism, and the TSS reading was noted.

1.7.6 Titratable Acidity

The titratable acidity of both coated and uncoated carrot and guava samples was analysed using the AOAC Official Method 942.15. First, 5 grams of each sample were blended in 50 mL of distilled water. Then, the mixture was titrated with 0.1N sodium hydroxide (NaOH) while stirring continuously. The endpoint of the titration was reached when the pH hit 8.1. This was indicated visually by a stable light pink colour, using phenolphthalein as the indicator. The titratable acidity was calculated based on the amount of NaOH used and expressed as grams of citric acid per kilogram of the sample, using the following equation:

2. RESULTS

$$\text{Titratable Acidity (g citric acid/kg sample)} = \frac{V \times N \times 1000 \times E}{m}$$

2.1 Antimicrobial Activity

F1 showed the strongest antimicrobial effect, with large inhibition zones against *S. aureus* and *P. aeruginosa*. F2 and F3 had moderate activity. Antifungal activity was present but weaker in comparison.

Table 2: Antimicrobial activity of edible coating formulations (F1, F2, F3)

S. No	Inoculum Used	Zone of Inhibition (mm)				
		F1	F2	F3	Positive control	Negative control
1	*S. aureus*	17	15	14	15	-
2	*P. aeruginosa*	17	16	17	16	-
3	*A. niger*	14	-	8	14	-
4	*A. flavus*	13	-	-	19	-

The results showed that F1 had antimicrobial activity of 17 mm against *S. aureus*, 17 mm against *P. aeruginosa*, 14 mm against *A. niger*, and 13 mm against *A. flavus*. F2 had 15 mm against *S. aureus* and 16 mm against *P. aeruginosa*. Meanwhile, F3 demonstrated 14 mm against *S. aureus*, 17 mm against *P. aeruginosa*, and 8 mm against *A. niger*. The zones of inhibition appeared on the respective agar plates, confirming the effectiveness of the formulations

Figure 3:Aspergillus niger

Figure 2: Pseudomonas aeruginosa

Figure 4: *Aspergillus flavus*

2.2 FTIR Analysis

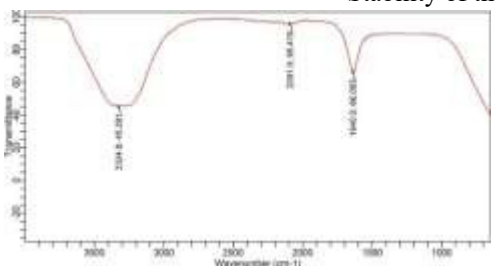
The ATR-FTIR spectra of the films were analysed in the mid-infrared region (4000-650 cm^{-1}), revealing key absorbance bands for each formulation. Formulation 1 (F1) showed peaks at 3324.78 cm^{-1}, 2091.03 cm^{-1}, and 1640.02 cm^{-1}. Formulation 2 (F2) exhibited a broader range of peaks, including 3339.69 cm^{-1}, 2925.96 cm^{-1}, 2855.14 cm^{-1},1744.39 cm^{-1} ,1640.03 cm^{-1}, 1461.12 cm^{-1}, 1237.47 cm^{-1}, 1144.29 cm^{-1}, 2124.58 cm^{-1}, and 2087.31 cm^{-1}. Formulation 3 (F3) displayed peaks at 3339.69 cm^{-1}, 2091.04 cm^{-1}, 1636.30 cm^{-1}, and 1248.65 cm^{-1}. The ATR-FTIR spectrum of the edible coating formulations is represented in Fig. 5,6, & 7.

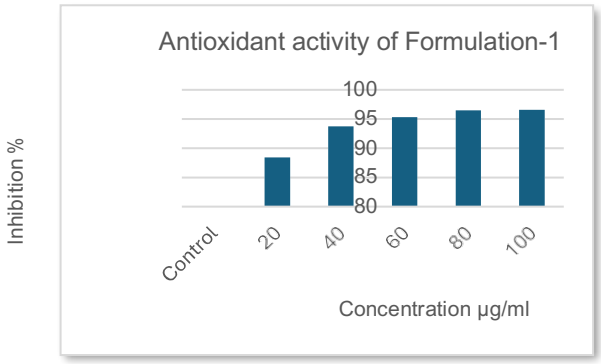
The FTIR spectra of the formulations indicate the presence of key functional groups, reflecting differences in their chemical composition. Formulation-1 (F1) exhibits peaks corresponding to carbonyl (C=O) stretching and hydroxyl (O-H) stretching, suggesting the presence of carboxylic acids or hydroxyl-containing compounds. Formulation-2 (F2) shows additional peaks for C-O stretching and C-H vibrations, indicating the presence of polysaccharides or other oxygenated functional groups. Formulation-3 (F3) shares similar functional groups with slight variations in intensity, suggesting potential molecular interactions or modifications. These spectral differences highlight structural variations between the formulations, which may influence their functional properties.

FTIR spectra revealed peaks corresponding to hydroxyl (-OH), carbonyl (C=O), C-H stretching, and ester (C-O) groups. These functional groups contribute to:

- Hydrogen bonding
- Matrix strength

- Improved barrier properties
- Stability of the coating film





2.3 Antioxidant Activity

F1 showed a high DPPH inhibition of 96.58%, indicating strong radical-scavenging potential, which contributes to delayed oxidation and extended freshness.

Figure 5: ATR-FTIR analysis of Formulation-1(F1)

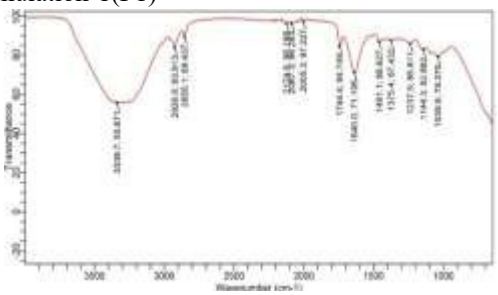


Figure 6: ATR-FTIR analysis of

Formulation-2(F2)

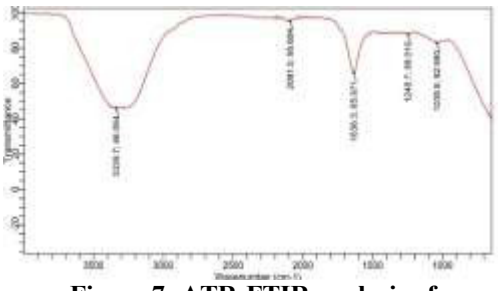


Figure 7: ATR-FTIR analysis of

Formulation-3(F3)

Figure 8: Graphical representation of Antioxidant activity of Formulation-1

2.4 Physicochemical Properties of Coated and Uncoated Samples

2.4.1 Colour

Colour scores indicated that coated samples maintained fresh appearance longer than uncoated ones. At room temperature, uncoated samples showed slight discoloration by Day 5 and moderate discoloration by Day 10, whereas coated samples scored 0 (no discoloration) up to Day 10. Under refrigeration, both coated and uncoated samples remained fresh until Day 10; by Day 20, uncoated samples reached high discoloration, while coated samples showed only slight discoloration.

Table 3: 5-point scale for colour analysis

Score	Description
0	No visible colour change (fresh appearance retained)
1	Slight discoloration (minor dullness, barely noticeable)
2	Moderate discoloration (visible fading, but still acceptable)
3	High discoloration (noticeable browning or loss of fresh appearance)
4	Severe discoloration (significant browning, not suitable for consumption)

Formulation-1 (F1) using 5-point scale

Table 4: Colour analysis of coated and uncoated

Storage Duration (Days)	Uncoated (Room temperature)	Coated (Room temperature)	Uncoated (Refrigeration temperature)	Coated (Refrigeration temperature)
1	0	0	0	0
5	1	0	0	0
10	2	1	1	0
15	-	-	2	0
20	-	-	3	1

2.4.2 pH

The coating helped maintain pH stability. For carrots stored at room temperature, pH decreased from 6.20 (uncoated) to 5.05 (coated), which is favourable for inhibiting microbial growth. In refrigerated carrots, coated samples showed slightly higher pH (6.22) than uncoated (5.47). For guavas, pH values remained relatively stable, with minor differences between coated and uncoated samples, indicating preserved acidity and quality.

Table 5: pH analysis of coated and uncoated samples

Sample	Storage condition	Uncoated pH	Coated pH
Carrot	Room temperature	6.20	5.05
	Refrigeration temperature	5.47	6.22
Guava	Room temperature	4.22	4.55
	Refrigeration temperature	3.93	3.92

3.4.3 Weight Loss

Weight loss was consistently lower in coated samples. For carrots, weight loss at room temperature decreased from 3.94% (uncoated) to 2.96% (coated), and under refrigeration from 6.41% to 1.07%. For guavas, weight loss dropped from 1.31% to 1.04% at room temperature and from 3.22% to 1.04% under refrigeration.

$$\text{Weight loss (\%)} = \frac{Initial\ weight - Final\ weight}{Initial\ weight} \times 100$$

Table 6: Weight loss percentage of coated and uncoated samples

Sample	Storage condition	Weight loss %	
		Uncoated sample	Coated sample
Carrot	Room temperature	3.94	2.96
	Refrigeration temperature	6.41	1.07
Guava	Room temperature	1.31	1.04
	Refrigeration temperature	3.22	1.04

3.4.4 Total Soluble Solids

Sample	Storage condition	Titratable acidity (g)	
		Uncoated sample	Coated sample
Carrot	Room temperature	0.07	0.09
	Refrigeration temperature	0.14	0.12
Guava	Room temperature	0.30	0.29
	Refrigeration temperature	0.42	0.52

Coated samples had lower TSS values, indicating slower conversion of starches to sugars and delayed ripening. For carrots at room temperature, TSS decreased from 14.4 g in uncoated samples to 6.4 g in coated samples. Similar trends were observed for guavas, where TSS dropped from 12.7 g (uncoated) to 6.0 g (coated) at room temperature.

Table 7: Total Soluble Solids in coated and uncoated samples

Sample	Storage condition	Total Soluble Solids (g)	
		Uncoated sample	Coated sample
Carrot	Room temperature	14.4	6.4
	Refrigeration temperature	6.3	5.80
Guava	Room temperature	12.7	6.0
	Refrigeration temperature	9.7	9.2

3.4.5 Titratable Acidity

The coating helped regulate titratable acidity. In carrots, room temperature acidity increased slightly in coated samples (0.09 g) compared with uncoated (0.07 g), and refrigerated carrots showed slightly lower acidity in coated samples (0.12
g) than in uncoated (0.14 g). In guavas, coated samples retained organic acids more effectively under refrigeration.

Table 8: Titratable acidity in coated and uncoated samples

3.5 Shelf-Life Enhancement

To assess shelf-life performance, treated carrots and guavas were stored under various conditions following coating and drying. Both the coated samples (F1, F2, and F3) and the uncoated controls were kept refrigerated and at room temperature. Coated samples initially maintained acceptable quality at room temperature, but by day eight, mold growth and spoiling had appeared in F2 and F3; F1 showed little deterioration and better colour and texture retention. Samples without coating showed the quickest deterioration. All coated formulations had longer shelf lives when stored in a refrigerator as opposed to at room temperature; F1 showed the most stability by retaining colour, texture, and structural integrity for a longer period of time. Despite progressive shrinkage and discoloration, F2 and F3 performed better than uncoated samples. F1 demonstrated the best overall preservation capability by considerably postponing spoilage and preserving quality. This antioxidant activity and subsequent physicochemical analyses dueility an
to its enhanced stab

Figure 9: Shelf- life analysis of carrot and guava stores in room temperature

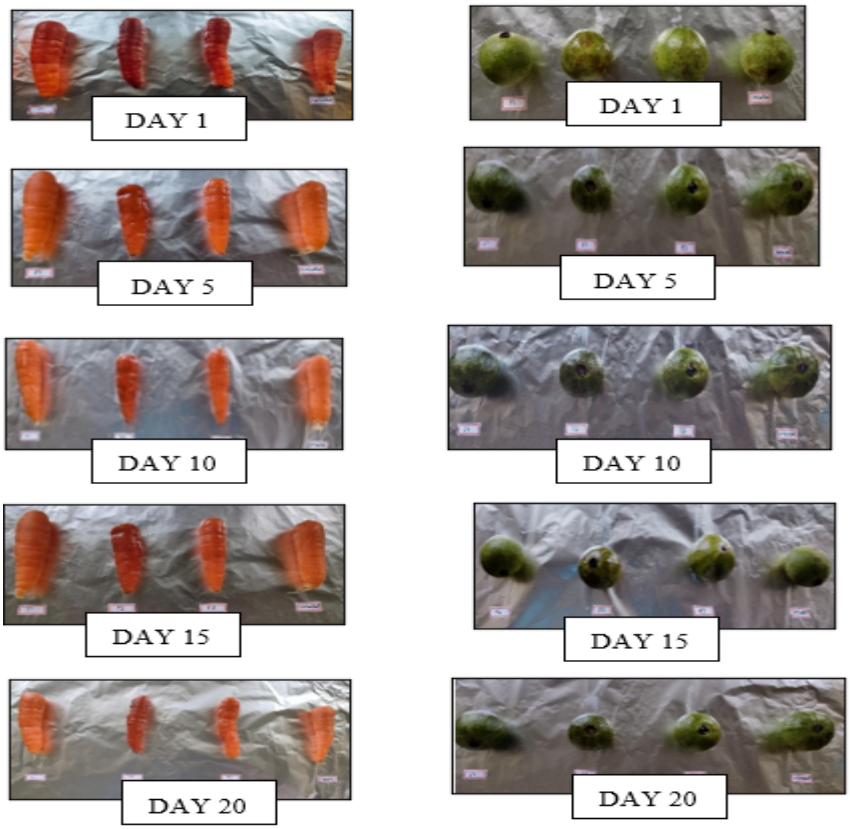


Figure 10: Shelf-life analysis of carrot and guava stores in refrigeration temperature

4. DISCUSSION

The integration of herbal bio actives into

polysaccharide matrices significantly enhances the stability and functionality of edible coatings[3,8,10,22,25,26].

Antimicrobial Activity

The antimicrobial activity of the edible coatings (F1, F2, and F3) depended on their composition. F1, which contains *Aloe vera*, was the most effective against *S. aureus* and *P. aeruginosa*, and this can be attributed to the phenolic and flavonoid compounds present in *Aloe vera* and guava leaf extracts that are known for their antimicrobial potential[2,6,9,12,17,21,24] .F2, made from neem gum, showed weaker antifungal activity but moderate antibacterial effects, likely because its high viscosity limited the release and diffusion of bioactive constituents[7,12,15,16,22] . F3, a blend of neem gum and *Aloe vera*, displayed weaker antifungal effects but balanced antibacterial properties, as the interactions between hydrocolloids and plant bio actives influenced its overall performance [3,7,10,22,25].

FTIR Interpretation

FTIR analysis of the edible coating formulations (F1, F2, F3) confirmed the presence of functional groups like hydroxyl (-OH), carbonyl (C=O), ester (C-O), and alkane (C-H). This shows that polysaccharides and bioactive compounds are present [3,10,18,22,25]. F1 (aloe vera-based) displayed strong O-H stretching at 3324.78 cm^{-1} and C=O stretching at 1640.02 cm^{-1}. These results relate to hydrogen bonding and water retention in aloe vera polysaccharides[4,9,21,23,24]. F2 (neem gum- based) had peaks at 2925.96 cm^{-1} (C-H) and 1744.39 cm^{-1} (ester). This indicates a denser polysaccharide network typical of plant gums [3,7,15,18,22]. F3 (aloe vera + neem gum) showed overlapping O-H (3339.69 cm^{-1}) and C=O (1636.30 cm^{-1}) peaks. This demonstrates interactions between hydrocolloids, creating a stable yet flexible coating [3,10,18,22,25]. These findings highlight F1's flexibility, F2's rigid structure, and F3's balanced properties, combining the strengths of both hydrocolloids [3,8,10,22,25].

Shelf-Life Improvement

Shelf-life analysis was conducted at room temperature and in refrigeration [4,8,9,20,22,26]. At room temperature, F1 (aloe vera- based) lasted the longest, up to 10 days, while F2 and F3 began to show shrinkage, discoloration, and ripening by day 6 [4,9,20,22]. *Aloe vera* gel coatings can extend shelf life by more than 1.34 times compared to uncoated produce because they reduce respiration rate, ethylene production, and microbial spoilage[4,8,9,20,23,24]. In refrigeration, all three formulations stayed stable for 15 days; however, by day 20, F1 still had better texture and appearance than F2 and F3 [4,9,20,22,26].

Antioxidant Activity

The high DPPH radical-scavenging activity of F1, reaching 96.58% at 100 µg/mL, shows that it has strong antioxidant compounds[6,9,17,19,21,24,25]. These likely come from guava leaf polyphenols and aloe vera bioactives[1,6,9,17,19,21,23,24]. These antioxidants could help reduce oxidative browning and maintain quality during storage [8,19,22,25]. Similar findings were observed for antioxidant-enriched edible films and coatings, which slowed the loss of quality in fresh produce [8,19,22,25,27] .

Physicochemical Analyses

Physicochemical analyses confirmed the coating's protective function. Better moisture retention is demonstrated by the coated samples' reduced weight loss. This result is in line with research that applied mucilage-based or protein- polysaccharide coatings to fruits and vegetables[3,8,20,22,27,28]. Slower carbohydrate breakdown and delayed ripening are indicated by the coated samples' lower total soluble solids (TSS). This is particularly true at room temperature, when dehydration and metabolic changes caused uncoated fruits to exhibit higher sugar concentrations [8,9,20,22]. The stabilized pH and controlled titratable acidity in coated carrots and guavas suggest that the coating reduces microbial growth and metabolic changes, helping to maintain overall quality [3,8,20,22,26].

F1 is a promising environmentally friendly coating for postharvest use in fruits and vegetables, according to these findings [4,8,9,20,22,26]. But there are still some restrictions. The coating's mechanical characteristics and scalability were not thoroughly investigated, and consumer acceptability was not evaluated. Future work should concentrate on enhancing the rheology of the formulation, carefully evaluating its mechanical and barrier qualities, and investigating large-scale manufacturing, legal compliance, and consumer feedback [10,18,22,25,26,27].

5. CONCLUSION

This study developed a biodegradable polysaccharide coating that is infused with herbs to extend the shelf life of fresh produce[3,8,22,25,26]. The F1 formulation showed improved structural, antioxidant, and antimicrobial properties [4,6,9,17,19,21,24].This means that fresh food could be preserved using this product[4,8,9,20,22,26]. The coating is affordable, safe, and environmentally friendly. It fits well with the global trend towards sustainable postharvest technologies [2,8,22,25,26,27].

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