Supplementary Information (SI) for Sustainable Food Technology.

Supplementary File

Antimicrobial silver nanoparticles doped poly(vinyl alcohol)/guar gum/gum ghatti nanocomposites: A multifaceted step towards sustainable packaging

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S.1 Packaging Studies of Coriander Leaves

Fresh coriander leaves (*Coriandrum sativum*, locally cultivated in Dharwad, Karnataka, India) were procured directly from nearby farmers and transported to the laboratory within 2 h of harvest. The leaves were carefully inspected and sorted manually to maintain uniformity in colour, size, and structural integrity. Leaves showing signs of insect infestation, microbial spoilage, discolouration, or mechanical damage were discarded to minimize variability in the experimental samples. The selected leaves were grouped into bunches of approximately 50 g and used for packaging studies. Storage experiments were conducted under ambient laboratory conditions of 22-24 °C and relative humidity of approximately 85% for a period of 5 days.

Based on preliminary mechanical evaluation, PGGA-0 and PGGA-1 films were selected for the packaging study owing to their suitable tensile properties. Equal quantities of coriander leaves were packed in the respective films and monitored throughout the storage period for physicochemical and sensory changes.

S.1.1 Percentage Weight Loss

Weight loss of coriander leaves during storage was used as an indicator of moisture loss and quality deterioration. For each treatment (PGGA-0 and PGGA-1), three replicates were analyzed[1]. The initial weight of the packaged leaves was recorded using a calibrated analytical balance. At predetermined intervals during storage, the samples were removed and weighed again. The percentage weight loss was calculated on a fresh weight basis using the following relationship:

$$Weight\ Loss\ (\%) = \frac{Initial\ weight - \ Final\ weight}{Initial\ weight} X\ 100$$

where the weights are expressed in grams.

S.1.2 Determination of Total Soluble Solids and pH

The total soluble solids (TSS) content of coriander leaves was determined from the extracted filtrate. Approximately 2 g of fresh leaves were homogenized and filtered through cheesecloth to obtain a clear extract. The filtrate was analyzed using a digital refractometer (Cole-Palmer), and the results were recorded in °Brix [1].

For pH measurement, 1 g of coriander leaf tissue was homogenized with 10 mL of distilled water. The pH of the resulting solution was measured using a temperature-compensated bench pH meter (Digital pH Meter, India). Each treatment was analyzed in triplicate to ensure reproducibility.

S.1.3 Determination of Total Chlorophyll Content

Chlorophyll content was analyzed as an indicator of the retention of green colour and freshness of the coriander leaves during storage[1]. A sample of 0.5 g of leaf tissue was ground using a mortar and pestle with 3 mL of acetone, followed by the addition of 5 mL of 80% acetone. The mixture was centrifuged at 4000 rpm for 10 min to separate the extract. The final volume of the supernatant was adjusted to 10 mL with 80% acetone. The absorbance of the extract was measured at 663 nm and 645 nm using a UV-Vis spectrophotometer (JASCO V-670, Japan). The total chlorophyll content was calculated using the following expression:

$$Total\ chlorophyll\ (mg/g) = \frac{(20.29\ A_{663} + 8.05\ A_{645})X\ V}{1000\ X\ W}$$

where A_{663} and A_{645} represent absorbance values at the respective wavelengths, (V) is the total volume of extract (mL), and (W) is the weight of the sample (g).

S.1.4 Sensory Evaluation

The sensory quality of packaged coriander leaves was assessed throughout the storage period by a panel of evaluators (3 members). The parameters considered included visual appearance, colour retention, texture, and overall acceptability. The samples packaged with PGGA-0 and PGGA-1 films were compared at different storage intervals to determine the effectiveness of the films in maintaining the freshness and marketable quality of coriander leaves. Each attribute was scored using a standard hedonic scale, and the average values were reported

S.2 Results and Discussion

S.2.1 Visual Shelf-Life Analysis

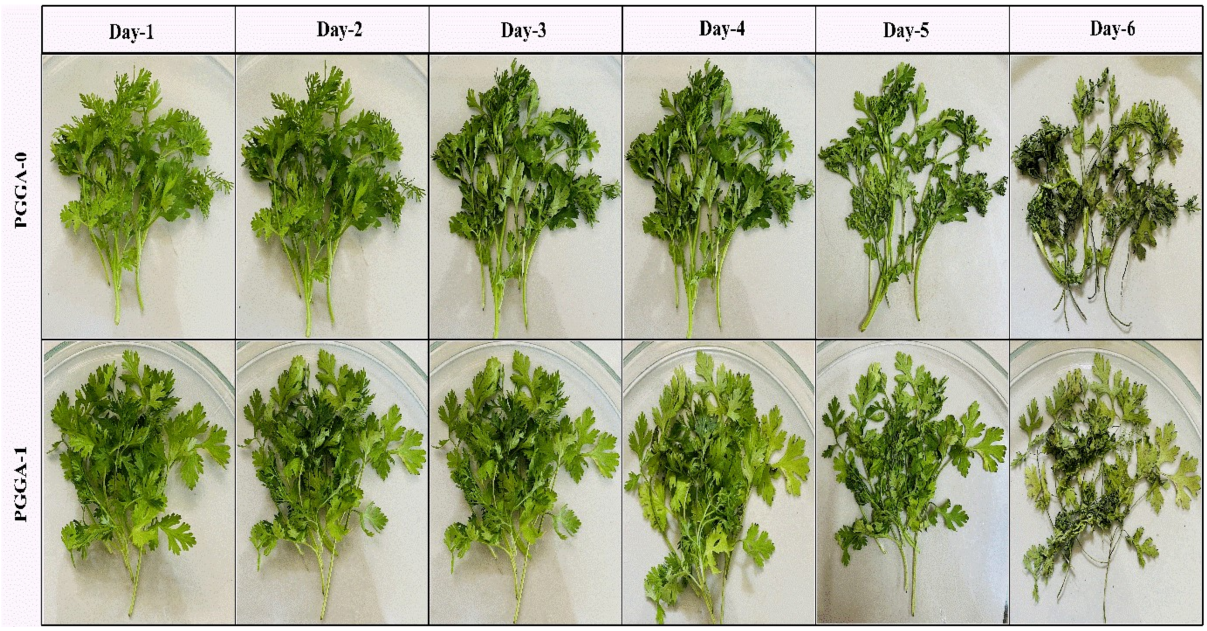

Fig.S1 Visual representation of PGGA-0 and PGGA-1 packaged coriander leaves

The visual progression of coriander leaves packaged using PGGA-0 (control) and PGGA-1 films over 6 days is shown in Figure S1. Fresh samples (Day 1) exhibited bright green colouration and structural integrity in both treatments. However, progressive deterioration was evident during storage. In PGGA-0 (control), noticeable wilting, loss of turgidity, and discolouration began from Day 3 and became severe by Day 5-6, indicating rapid moisture loss and senescence. In contrast, PGGA-1 packaged samples retained comparatively better freshness, with delayed wilting and higher green colour retention up to Day 4-5. Even on Day 6, although degradation was visible, structural integrity and colour retention were superior compared to PGGA-0. This behaviour aligns with previously reported active packaging systems, where incorporation of bioactive or barrier-enhancing components delays physiological degradation and moisture loss.

S.2.2 Percentage Weight Loss

Weight loss is a critical indicator of transpiration and metabolic activity. The percentage weight loss of coriander leaves increased progressively during storage for both films, indicating continuous moisture loss and physiological degradation. However, a significantly lower ($p < 0.05$) weight loss was observed in samples packaged with PGGA-1 compared to PGGA-0. By Day 6, PGGA-0 exhibited a maximum weight loss of 25.36 ± 0.78%, whereas PGGA-1 limited the loss to 17.15 ± 0.69%, demonstrating improved moisture retention. This reduction in weight loss for PGGA-1 can be attributed to the incorporation of silver nanoparticles, which likely enhanced the barrier properties of the polymeric matrix by reducing free volume and water vapour permeability. Additionally, the antimicrobial activity of silver nanoparticles may have contributed to reduced metabolic activity and transpiration rates, thereby slowing down senescence. In contrast, the PGGA-0 film, lacking active nanofillers, exhibited higher moisture diffusion and faster dehydration.

Table S1. Physicochemical (weight loss, TSS, pH, chlorophyll) and sensory changes of samples packaged with PGGA-0 and PGGA-1 films during 6 days of storage

Parameter	**Film**	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**
Weight Loss (%)	PGGA-0	0.00 ± 00	3.11 ± 0.22	7.74 ± 0.45	12.55 ± 0.42	18.82 ± 0.54	25.26 ± 0.88
	PGGA-1	0.00 ± 00	2.15 ± 0.08	5.36 ± 0.17	8.24 ± 0.61	12.58 ± 0.65	17.25 ± 0.89
TSS (°Brix)	PGGA-0	10.22 ± 0.24	10.38 ± 0.28	10.86 ± 0.11	11.44 ± 0.36	12.31 ± 0.40	12.85 ± 0.24
	PGGA-1	10.22 ± 0.34	10.31 ± 0.17	10.55 ± 0.15	10.93 ± 0.21	11.37 ± 0.24	11.8 ± 0.27
pH	PGGA-0	5.56 ± 0.05	5.62 ± 0.08	5.71 ± 0.06	5.82 ± 0.06	5.97 ± 0.07	6.17 ± 0.07
	PGGA-1	5.56 ± 0.02	5.67 ± 0.04	5.75 ± 0.05	5.95 ± 0.05	6.04 ± 0.04	6.27 ± 0.08
Chlorophyll (mg/g)	PGGA-0	2.85 ± 0.11	2.61 ± 0.11	2.20 ± 0.08	1.83 ± 0.07	1.43 ± 0.06	0.99 ± 0.04
	PGGA-1	2.85 ± 0.13	2.72 ± 0.21	2.45 ± 0.12	2.22 ± 0.08	1.95 ± 0.02	1.64 ± 0.05
Sensory Score (9-point)	PGGA-0	9.0 ± 0.0	7.7 ± 0.3	6.7 ± 0.4	5.3 ± 0.5	3.8 ± 0.4	2.9 ± 0.3
	PGGA-1	9.0 ± 0.0	8.5 ± 0.2	7.7 ± 0.3	6.5 ± 0.4	5.6 ± 0.5	4.2 ± 0.4

S.2.3 Total Soluble Solids (TSS) and pH Changes

The total soluble solids (TSS) of coriander leaves showed a gradual increase during the storage period for both packaging systems, reflecting moisture loss and concentration of soluble constituents. The higher TSS in PGGA-0 can be attributed to accelerated moisture loss, leading to the concentration of sugars and other soluble metabolites. Conversely, the reduced TSS variation in PGGA-1 suggests improved moisture retention and a more stable internal environment within the package. The incorporation of silver nanoparticles likely contributed to enhanced barrier properties and reduced respiration-driven biochemical changes, thereby slowing the accumulation of soluble solids.

The increase in pH can be associated with the degradation of organic acids and the accumulation of basic metabolites during respiration and microbial activity. The relatively moderated pH shift in PGGA-1 suggests a slower rate of biochemical deterioration, which may be attributed to the antimicrobial action of silver nanoparticles and improved barrier properties of the film. These factors likely reduce microbial proliferation and metabolic turnover, thereby stabilizing the internal biochemical environment. In contrast, PGGA-0, lacking active nanofillers, permits faster degradation processes, resulting in more pronounced changes.

S.2.4 Total Chlorophyll Content and Sensory Evaluation

The total chlorophyll content of coriander leaves decreased progressively during storage for both packaging systems, indicating degradation of green pigments associated with senescence and loss of freshness. By Day 6, chlorophyll content in PGGA-0 decreased to 0.98 ± 0.05 mg/g, whereas PGGA-1 maintained a higher value of 1.65 ± 0.07 mg/g, demonstrating improved preservation of green colour. The rapid decline in chlorophyll in PGGA-0 can be attributed to enhanced enzymatic degradation (chlorophyllase activity) and oxidative reactions under higher moisture loss and oxygen exposure. In contrast, the improved retention in PGGA-1 may be due to the combined effect of better barrier properties and the presence of silver nanoparticles, which can reduce oxidative stress and microbial activity.

Sensory evaluation revealed a continuous decline in overall acceptability of coriander leaves with increasing storage time for both films. However, PGGA-1 packaged samples consistently received higher sensory scores compared to PGGA-0 throughout the storage period. By Day 6, PGGA-0 samples exhibited a sharp decline in acceptability (2.5 ± 0.3), characterized by severe wilting, discolouration, and loss of freshness, whereas PGGA-1 retained a comparatively higher score (4.6 ± 0.4), indicating moderate acceptability. The better sensory performance of PGGA-1 can be correlated with its ability to preserve key quality attributes such as colour, texture, and freshness, as supported by chlorophyll retention and reduced weight loss. The incorporation of silver nanoparticles likely contributed to reduced microbial spoilage and delayed deterioration, thereby maintaining overall quality perception. In contrast, PGGA-0 showed rapid quality degradation due to higher moisture loss and faster biochemical changes. These findings confirm that PGGA-1 is more effective in extending the sensory shelf life of coriander leaves under ambient storage conditions.

Reference

[1] S. Pawde, S. R. Chaudhari, and R. S. Matche, ‘Active Packaging for Strawberry and Coriander: A Natural Extract Impregnated Paper’, *ACS Food Science & Technology*, vol. 4, no. 5, pp. 1166–1178, May 2024, doi: 10.1021/acsfoodscitech.4c00001.