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RESEARCH ARTICLE

Chitosan-based biodegradable packaging: Enhancing the shelf life and quality of *Jasminum sambac* L. flowers

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Abstract

A study evaluated the effectiveness of chitosan-based biopolymer films as an alternative packaging material for enhancing the post-harvest quality and shelf life of jasmine (*Jasminum sambac* L.) flowers during export. Chitosan-tween 80 and chitosan-glycerol films were prepared using the solvent-casting method and characterized for their physical and chemical properties, including surface morphology, UV absorbance and thermal stability. The packaging effects were compared against conventional films, aluminium-foil-lined boxes with gel ice and untreated flowers in a Completely Randomized Design with 5 treatments and 4 replications. Visual and physiological parameters were evaluated over 3 days, including freshness index, flower opening index, colour retention, fragrance index, moisture content, physiological loss in weight and shelf life. The results indicated that chitosan-glycerol films exhibited superior properties, extending the shelf life to 4.16 days compared to 2.7 days in the control, offering a sustainable and cost-effective packaging solution for the floriculture industry.

Keywords

chitosan-based films; jasmine flowers; post-harvest quality; shelf-life extension; sustainable packaging

Introduction

Mogra, also known as jasmine, holds significant commercial value as a widely cultivated flower crop in India, highly prized for its captivating fragrance. The *Jasminum* genus encompasses over 200 species, with four being grown commercially in India. Of these, *Jasminum sambac*, commonly referred to as Arabian Jasmine, is the most popular species. Jasmine holds a unique and prominent position due to its elegant blooms, alluring fragrance, versatile aesthetic appeal and significant export value, providing a profitable income for flower cultivators. In India, it is esteemed as one of the most ancient and aromatic flowers, highly regarded for its cultural and commercial importance (1).

Tamil Nadu exports jasmine flowers to neighbouring countries, including Malaysia, Singapore, Sri Lanka and various Middle Eastern nations. In Tamil Nadu, key jasmine cultivation areas include Dindigul, Salem, Madurai, Tirunelveli, Virudhunagar and Trichy districts. Strung *J. sambac* flowers have strong export demand in distant markets such as the United States, with shipments taking approximately 36-48 h to reach New York by air.

However, these delicate flowers begin wilting and lose their fragrance within 24-36 h after harvest. To address this, a specialized export packaging method was developed to preserve freshness and reduce wilting. This packaging involves treating the flowers with 4 % boric acid, packing them in aluminium-foil lined boxes and enclosing them in thermocol with gel ice to maintain a cold environment. This approach has successfully extended the shelf life of the flowers to 42.88 h (2).

The present research investigated alternative packaging solutions to address the rising cargo transportation costs experienced by jasmine flower exporters. Exporters increasingly rely on ice-gel packets to maintain low temperatures within the package box and extend flowers' shelf life. Still, this approach significantly adds to the shipment's overall weight. The bulkiness and weight of the ice-gel packets reduced the number of flowers that can be transported per shipment, leading to higher freight charges. Due to the increased weight per packaged box, exporters often have to pay double the transportation cost, further decreasing their profitability. In addition, using 4 % boric acid to improve the shelf life of jasmine flowers presented risks for exporters, who must handle the chemical with protective gloves and masks to avoid exposure. There have also been reports of headaches in consumers using treated jasmine flowers, indicating potential side effects associated with the chemicals used.

Packaging films are typically produced from polymeric derived from petroleum, presenting challenges such as limited biodegradability and reliance on non-renewable resources (3). Biopolymers sourced from renewable materials have emerged as promising candidates for the next generation of packaging materials (4). Essential materials for bio-based films include polysaccharides, proteins, lipids and their derivatives (5). Among polysaccharides, chitosan has garnered significant interest from both researchers and industry professionals for its potential in food packaging, owing to its unique physicochemical characteristics, biodegradability, non-toxicity, biocompatibility, excellent film-forming ability, high reactivity and chemical stability (6). Chitosan is a distinctive natural bio-based marine polymer produced commercially through the partial deacetylation of chitin (7). Literature studies on chitosan film highlight the use of biopolymers for packaging varied food items such as fruits, vegetables and meat products, validating their effectiveness in prolonging their shelf life (8). Chitosan has also emerged as an effective encapsulating agent in the food industry, providing stability for bioactive compounds under extreme pH and temperature conditions. Its ability to protect and deliver essential oils, vitamins, antioxidants and probiotics makes it valuable for preserving sensitive ingredients. Chitosan's eco-friendly and safe nature further enhances its suitability for nutraceutical delivery systems (9). However, chitosan films in this study are used as packaging materials rather than encapsulating agents, as their role is more focused on preservation rather than delivery of active ingredients.

This study seeks to formulate a chitosan-based film for packaging jasmine flowers (*J. sambac* L.) to improve their quality and prolong shelf life during export to global markets.

Materials and Methods

The study was conducted at the Analytical Laboratory of the Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore. Uniform-sized flower buds of Arabian jasmine (*J. sambac* L.) were harvested in the morning from jasmine plants maintained by the Department of Floriculture and Landscape Architecture.

Chitosan-tween 80 and chitosan-glycerol films were prepared using solvent-casting, with chitosan (Sigma Aldrich Chemicals Pvt. Ltd., Bangalore, India) as the main biopolymer. Polyethylene glycol (MW: 6000; HiMedia Laboratories Pvt. Ltd., Karnataka, India) and D-sorbitol (MW: 181.17; CDH Fine Chemicals, New Delhi, India) were used as primary plasticizers, while glycerol (MW: 92.09; CDH Fine Chemicals) and tween 80 (Polysorbate 80; MW: 1310; Astron Chemicals, Gujarat, India) were incorporated as separate components. A conventional film (NK Enterprises, Haryana, India) and the standard export packaging method using aluminium-lined boxes with ice gel were included for comparison.

The experiment adopted a Completely Randomized Design (CRD) with 5 treatments and 4 replications to evaluate the packaging effects on jasmine flowers. The treatments included: T_1 (packing with chitosan-tween 80 film), T_2 (packing with chitosan-glycerol film), T_3 (packing with conventional film), T_4 (packing under gel-ice condition) and T_5 (no packaging).

Preparation of chitosan-based films

Chitosan-tween 80 and chitosan-glycerol films were prepared using the solvent-casting method. A 5 % chitosan solution (w/v) was prepared using 5 % acetic acid and a separate mixture of 15 g PEG and 15 g sorbitol was dissolved in 100 mL of distilled water. The PEG-sorbitol solution was gradually added to the chitosan solution in a 1:3 ratio under continuous stirring. For the chitosan-tween 80 films, tween 80 was incorporated dropwise, whereas, for the chitosan-glycerol film, 3 % glycerol solution was used as an alternative. Both film-forming solutions were stirred for 6 h, rested for 10 min and then 200 mL was poured onto a 25 cm × 25 cm glass plate and then dried in a hot air oven at 50–60 °C. The dried films were carefully peeled, dried at room temperature and stored for further analysis (Fig. 1).

Packaging methodology of jasmine flowers using chitosan biofilm

Jasmine flowers were strung into garlands and packed in different films inside thermocol boxes (53 × 38 × 37 cm). The packaged flowers were refrigerated at 5 °C and observations were recorded at 24, 48 and 72 h (Fig. 2). Visual assessments, such as freshness, flower opening, fragrance, colour retention and shelf life, were evaluated using he-

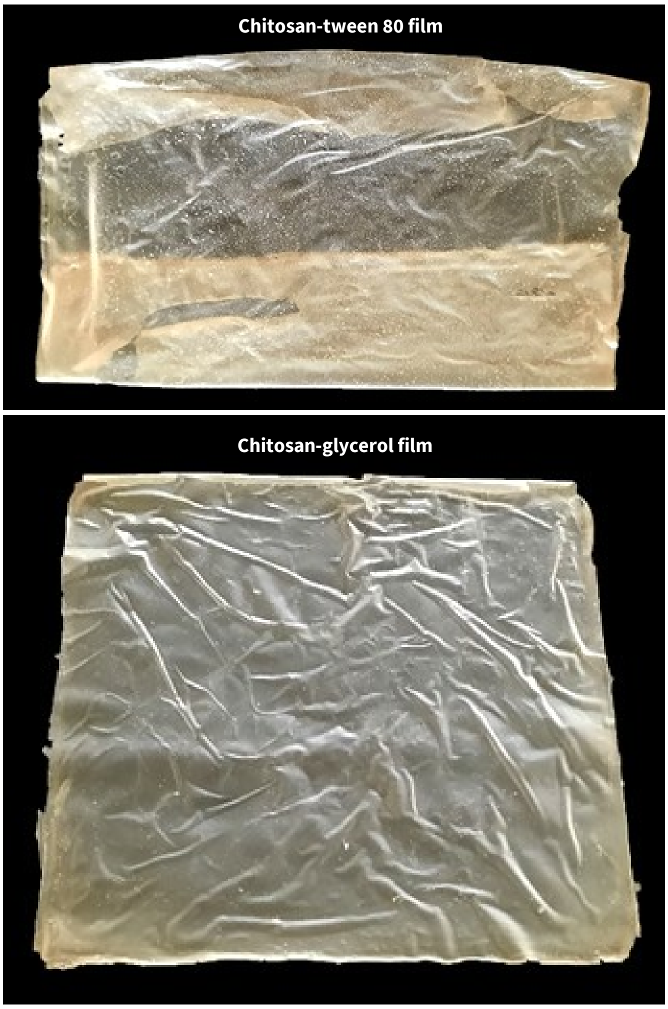

Fig. 1. Images of chitosan-based films prepared by solvent casting method.

donic scale scoring (10). Physiological parameters such as physiological loss in weight, moisture content, membrane integrity (11) and relative water content were also measured. The methodology was employed to conduct a comprehensive statistical data analysis (12).

Film Characterization and Analysis

UV -VIS transmittance studies

The UV-VIS absorbance spectra of chitosan-tween 80 and chitosan-glycerol films were analyzed using a UV-VIS spectrophotometer (SPECORD 210 plus) at the Nano-hub laboratory, Tamil Nadu Agricultural University, Coimbatore. Film samples (45 mm × 10 mm) were prepared by dissolving them in distilled water with 2-3 drops of 0.1 M HCl (13). Absorbance was measured between 200 and 800 nm, using distilled water as a blank, to assess transparency and UV-blocking efficiency. The results were compared to evaluate the impact of plasticizers and surfactants on film transparency and UV protection.

SEM analysis

The chitosan-tween 80 and chitosan-glycerol films were analyzed using a Scanning Electron Microscope (QUANTA 200; FEI; ICON ANALYTICAL Company, Navi Mumbai, Maharashtra, India) at DRDO BU CLS, Bharathiar University Campus, Coimbatore, India with an accelerating voltage of 5 kV. The film samples were mounted on specimen stubs and coated with a gold layer via sputter coating before imaging (14). Surface micrographs of the films were acquired at various magnifications, such as 800x, 3000x, 6000x and 12000x.

Fig. 2. Packaging of jasmine flowers in chitosan-based films, conventional film and placed in thermocol box for storage under refrigeration.

TGA analysis

The thermal stability and decomposition properties of chitosan-tween 80 and chitosan-glycerol films were evaluated using a thermogravimetric analyzer (TG/DTA-EXSTAR /6300) at Prof. CNR Rao Research Centre, Avinashilingam University, Coimbatore, India. Film samples (~10 mg each) were subjected to temperatures ranging from 30 to 800 °C at a heating rate of 20 °C/min. Nitrogen was used as a purge gas to maintain a controlled, inert atmosphere (15).

Thickness

The thickness of the chitosan-Tween 80 and chitosan-glycerol films was assessed using a Digimatic Vernier Caliper (0-150 mm; Aerospace, Sudershan Measuring and Engineering Pvt. Ltd, New Delhi, India) with an accuracy of ± 0.02 mm. Measurements were taken on all 4 sides of each film sample and recorded in mm.

Flower Parameters

Freshness index (FI)

The freshness index indicated as a percentage of intact jasmine flowers is a visual evaluation metric to assess the rate of blooms that maintained their freshness without signs of petal drooping or browning. The scoring method for calculating the freshness index is detailed in Table 1. The freshness index (FI) was computed using the following formula as given in Eqn. 1 (16).

$$FI = \frac{(7 \times X_1) + (6 \times X_2) + (5 \times X_3) + (4 \times\times X_4) + (3 \times X_5) + (2 \times X_6) + (1 \times X_7)}{(X_1+X_2+X_3+X_4+X_5+X_6+X_7) \times 7} \times 100 \quad \text{.........(Eqn. 1)}$$

Table 1. Scoring criteria for assessing the freshness index in jasmine flowers.

Condition of flowers	Score	Number of flower buds
Almost all buds turgid	7	X_1
Partial to half-open flowers, turgid	6	X_2
Half to fully open flowers, turgid	5	X_3
Partial to half-open flowers, slightly wilted	4	X_4
Half to full open flowers, slightly wilted	3	X_5
Partial to half-open flowers, fully wilted	2	X_6
Half to full open flowers, fully wilted	1	X_7

Flower opening index (FOI)

The flower-opening index was visually assessed, indicating the number of fully bloomed jasmine flowers. Rapid petal opening adversely affects both shelf life and market value. The score utilized for the flower opening index is presented in Table 2. The flower opening index (FOI) was computed using the following formula as given in Eqn. 2 (16),

$$FOI = \frac{(0 \times X_1) + (1 \times X_2) + (2 \times X_3) + (3 \times X_4)}{(X_1 + X_2 + X_3 + X_4) \times 4} \times 100 \quad \text{.........(Eqn. 2)}$$

Table 2. Scoring criteria for flower opening index in jasmine flowers.

Stage of Flowers	Score	Number of flower buds
Unopened buds	0	X_1
Slightly opened	1	X_2
Half opened	2	X_3
Fully opened	3	X_4

Colour retention index (CRI)

The preservation of the white colour in jasmine flower buds was assessed using a specific scoring method represented in Table 3. The formula for calculating the colour retention index was computed in Eqn. 3 (2).

$$CRI = \frac{(9 \times X_1) + (8 \times X_2) + (7 \times X_3) + (6 \times X_4) + (5 \times X_5) + (4 \times X_6) + (3 \times X_7)(2 \times X_8) + (1 \times X_9)}{(X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9) \times 9} \times 100 \quad \text{........(Eqn.3)}$$

Table 3. Scoring criteria for colour retention index in jasmine flowers.

Flower bud colouration	Score	Number of flower buds
Bright white	9	X_1
Dull white	8	X_2
Cream or yellowish	7	X_3
1 to 10% brown	6	X_4
11 to 15 % brown	5	X_5
16 to 50 % brown	4	X_6
51 to 75% brown	3	X_7
76 to 90% brown	2	X_8
All brown	1	X_9

Table 4. Scoring criteria for fragrance index in jasmine flowers.

Fragrance level	Score
Least and Undesirable	1
Mild	2
Strong	3
Very strong	4

Fragrance index

The fragrance emitted by the flowers was assessed and measured according to a specific scoring method, as shown in Table 4 (16).

Shelf life

The shelf life of jasmine flowers was measured by the days at which at least 50 % of the blooms remained fresh without exhibiting pink or brown deterioration (16). The results were subjected to statistical analysis according to the methodology described (17).

Physiological loss in weight (PLW)

The percentage of physiological loss in weight (PLW) for all flower packages was determined by averaging the measurements from the replicated samples and employing the following formula as given in Eqn. 4 (16),

$$\text{PLW (\%)} = \frac{\text{Fresh weight (day I) - Weight (day II)}}{\text{Fresh weight (day I)}} \times 100 \quad \text{..........(Eqn. 4)}$$

Moisture content

The moisture content of the flower buds was evaluated by measuring both fresh weight and dry weight of the buds, which were dried in a hot air oven at 70 °C (16). This moisture content was represented as a % based on the fresh weight and calculated using the following formula, as given Eqn 5.

$$\text{Moisture content \%} = \frac{\text{Fresh weight - dry weight}}{\text{Fresh weight}} \times 100 \quad \text{..........(Eqn. 5)}$$

Results and Discussion

Chitosan film analysis

UV -Vis

The UV-VIS transmittance studies of chitosan-tween 80 film and chitosan-glycerol film are shown in Fig. 3. The chitosan-tween 80 film revealed a maximum absorbance of 2.5033 A at 198 nm, indicating strong UV absorption, likely due to UV-active functional groups. Absorbance decreased beyond 198 nm, suggesting selective UV absorption in the 190–198 nm range, likely due to specific chemical bonds or structures within the sample, such as amines or carboxyl groups, characteristic of the composite structure. Similarly, the chitosan-glycerol film exhibited a peak absorbance of 2.2274 A at 196 nm, likely due to interactions between chitosan's amine and glycerols' hydroxyl groups, making it suitable for UV-blocking. These results align with previous studies (18), which found that chitosan -treated cellulose demonstrated strong UV-Vis absorption below 220 nm. The weaker absorption at wavelengths greater than 230 nm further supports chitosan-based films' UV- UV-blocking potential.

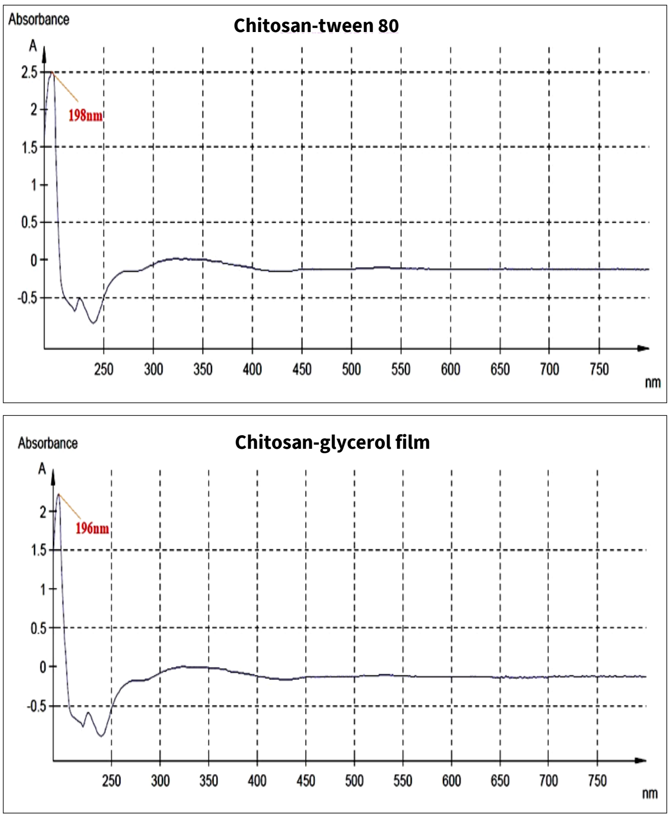

Fig. 3. UV absorbance spectra of chitosan-based films.

SEM analysis

The SEM analysis of chitosan-tween 80 and chitosan-glycerol films (Fig. 4), both plasticized with PEG and sorbitol, revealed notable differences in surface morphology. The chitosan-tween 80 films displayed a heterogenous

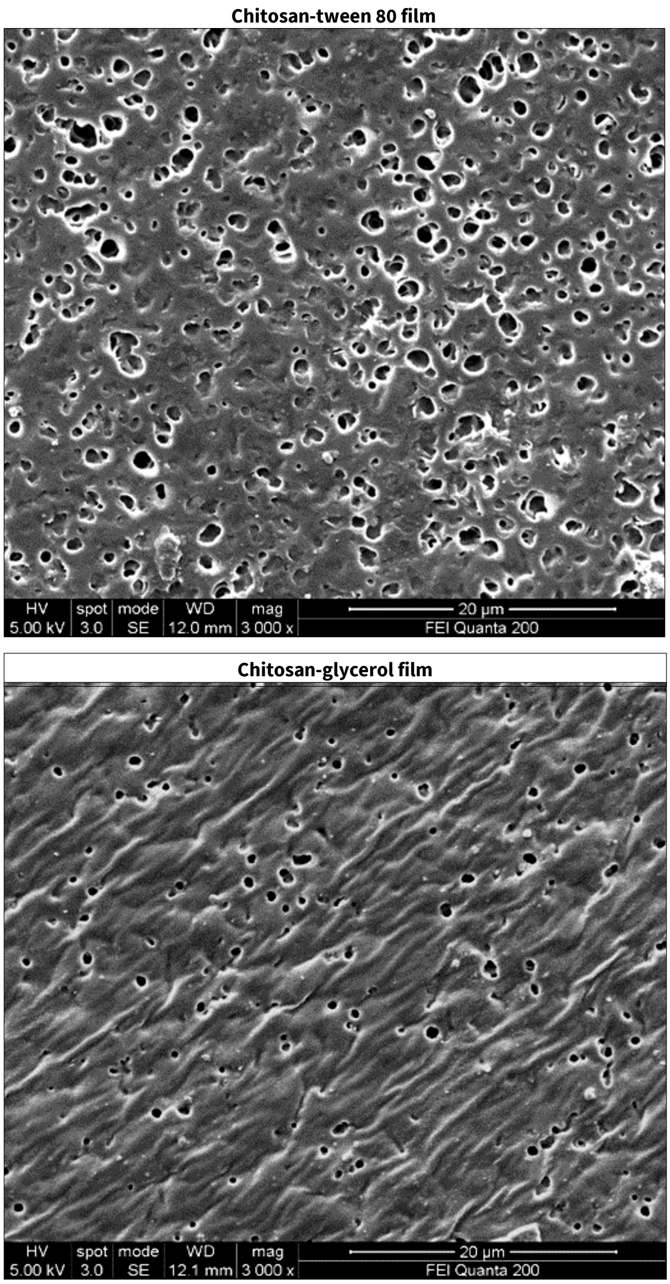

Fig. 4. Scanning electron micrographs of chitosan-based films at a magnification of 3000x and scale bar of 20 µm.

structure, indicative of effective plasticizer incorporation and enhanced permeability. Conversely, the chitosan-glycerol film demonstrated a smoother, more homogenous surface with less air bubble formation compared to the chitosan-tween 80 films, indicating that the film components in the chitosan-glycerol film were wholly mixed and can provide enhanced mechanical properties for packaging. This aligns with findings (19), who reported smooth and uniform surfaces for pure chitosan films. In a study, the effect of blending chitosan with PEG on surface morphology revealed that PEG incorporation led to irregular holes due to phase separation, a phenomenon consistent with the current study's findings (20). Similarly, chitosan films prepared with sorbitol revealed that the addition of sorbitol produced homogeneous, smooth films with no discontinuities, reflecting good miscibility and compatibility (21). These studies illustrate that plasticizer choice significantly affects the films' surface characteristics, mechanical strength and potential applications.

TGA analysis

The thermogravimetric analysis (TGA) of the chitosan-tween 80 and chitosan-glycerol films (Fig. 5), both plasticized with PEG and sorbitol, revealed distinct thermal degradation profiles. The chitosan-tween 80 film exhibits a three-stage degradation process, with an initial weight loss of around 5-8.2 % below 150 °C due to moisture evaporation. Its primary decomposition occurs between 200 °C and 400 °C, where 60-78.9 % of its mass is lost, corresponding to the breakdown of the chitosan matrix and plasticizers. The film's weight loss slows beyond 400 °C, leaving a residual mass of 8.2-15 % at 800 °C, indicating partial carbonization.

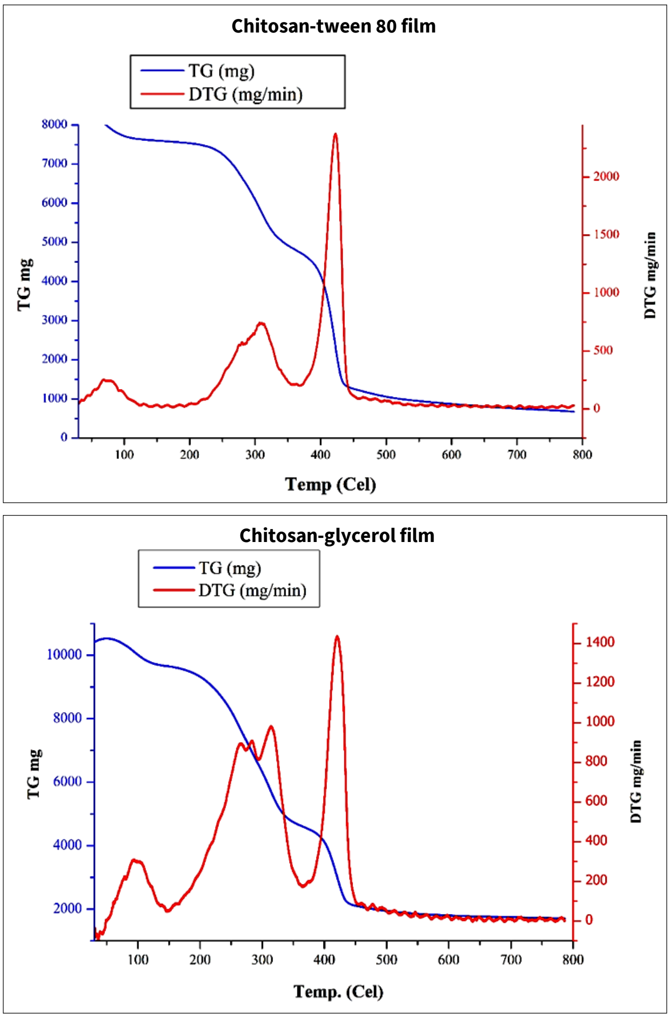

Fig. 5. Thermogravimetric analysis of chitosan-based films.

Similarly, the chitosan-glycerol film exhibited an initial weight loss of 5-7 % below 150 °C, and like the chitosan-tween 80 film, it experienced 60-65 % mass loss between 200 °C and 400 °C. However, this film undergoes additional decomposition between 400 °C and 600 °C, leading to a higher residual mass of 25-30 % at 700 °C. The more significant residue indicates that the chitosan-glycerol film retains more carbonaceous material, which enhances its thermal stability but may compromise its biodegradability. Similar studies have been done (22) investigating the thermal stability of chitosan-based films with various additives over time using thermogravimetric analysis (TGA). Their findings showed that additives like glycerol, tween 20 and tween 80 degraded over time, reducing to 70 % of their original amount after 100 days, leading to lower thermal stability.

In contrast, polyethene glycol (PEG) and citric acid (CA) remained stable, retaining nearly 100 % of their initial concentration. Citric acid effectively binds within the chitosan matrix, creating a durable and resilient structure that experienced little to no degradation over time. This cross-linked material showed no significant changes in colour, structural integrity or evaporation while maintaining thermal stability. These attributes make it highly suitable for applications where long-lasting stability and strength are essential. According to the findings, PEG and CA demonstrated superior long-term performance in chitosan-based films.

Based on the present study, it can inferred that both chitosan-tween 80 and chitosan-glycerol films provide flexibility due to the addition of plasticizers (PEG and sorbitol), but they serve different packaging needs. The chitosan-glycerol film is more suitable for applications that require higher thermal resilience, as it can endure temperature fluctuations without losing stability. In contrast, the chitosan-tween 80 film is ideal for environmentally friendly packaging, as it decomposes more readily and leaves less residual mass, making it a better option for biodegradable uses.

Thickness

Chitosan-tween 80 film and chitosan-glycerol film were evaluated for thickness using a Digimatic vernier calliper with a 0-150 mm measuring scale. The thinness of chitosan -based films enhances flexibility, allowing it to conform to irregular shapes, but may reduce mechanical strength, making it prone to damage. Thicker films offer greater strength and durability but at the cost of reduced flexibility. Achieving the right balance between these factors is critical for optimal performance in packaging applications. The thickness of chitosan-tween 80 film was 0.16 mm ± 0.02 mm, which is 63.04 gauge and chitosan-glycerol film had a thickness of 0.13 mm ± 0.02 mm, which is 51.22 gauge. The conventional film recorded a thickness of 0.015

mm, equivalent to 60 gauge (15). These findings indicate that the thickness of chitosan-tween 80 films was higher than that of conventional film and chitosan-glycerol film. Despite being thinner, the chitosan-glycerol film performed better for packaging delicate items, like jasmine flowers, due to its flexibility and reduced brittleness.

Fig. 6. Results show the quality of jasmine flowers packaged in chitosan-based films, conventional film**,** gel-ice condition and with no packaging after 3 days (72 h) of storage under refrigeration at 5°C.

Effect of Chitosan-Based Film Packaging in Jasmine Flowers

The visual and physiological parameters of jasmine flowers treated with chitosan-based films and conventional packaging methods were observed and recorded after 3 days of storage (Fig. 6). The findings are given as follows:

Freshness index

From Day 1 to Day 3, the freshness index of jasmine flowers (Table 5) declined across all treatments. T_2 (chitosan-glycerol film) consistently maintained the highest freshness index, ranging from 93.54 % on Day 1 to 86.78 % on Day 3, indicating its effectiveness in preserving flower quality. T_3 (conventional film) followed closely, decreasing values from 92.08 % to 84.66 %. Moderate reductions were observed in T_1 (chitosan-tween 80 films) and T_4 (ice-gel condition), while T_5 (without packaging) showed the steepest decline, dropping from 88.67 % on Day 1 to 80.56 % on Day 3. The data demonstrate that packaging significantly impacts freshness retention, with chitosan-based films being the most effective. The chitosan-glycerol film minimized moisture loss, slowed senescence and inhibited microbial growth, proving the most effective treatment. Similarly, a study on different packaging methods in jasmines revealed that flowers packed in a 200-gauge PE bag without ventilation maintained higher freshness and flower opening. In contrast, unpacked flowers lost freshness and bud stage within 24 h (16).

Flower opening index

The flower opening index of jasmine flowers (Table 5) increased progressively from Day 0 to Day 3 across all treatments. On Day 1, T_5 (without packaging) recorded the highest flower opening index at 26.503 %, which rose sharply, reaching 60.0 % on Day 3. This indicates a rapid opening rate and reduced flower longevity without packaging. T_3 (conventional film) also showed a substantial increase from 25.0 % on Day 1 to 47.0 % on Day 3. Moderate flower opening was observed in T_4 (ice-gel condition) and T_1 (chitosan-tween 80 films).

In contrast, T_2 (chitosan-glycerol film) had the lowest flower opening index across all days, suggesting better preservation of bud stage and delayed flower opening. The chitosan-glycerol film efficiently delayed flower blooming by forming a protective barrier that minimized moisture loss and slowed physiological changes, extending the jasmine flowers' shelf life, while the absence of packaging led to the fastest opening and deterioration of flowers. Similarly, a study on different packaging methods in *J. sambac* stated that a 200-gauge PE bag without ventilation maintained a higher flower opening index (16).

Colour retention index

The study demonstrated that different post-harvest treatments and packaging methods significantly influenced the colour retention and flower opening index of jasmine flowers during storage (Table 5). Among the treatments, T_2 (chitosan-glycerol film) showed the highest effectiveness in maintaining colour retention, dropping only from 98.78 % on Day 0 to 90.84 % on Day 3, while T_5 (without packaging) exhibited the steepest decline. In terms of colour retention, jasmine flower buds treated with Boric acid + EFF showed the highest colour retention index. This may be due to boric acid's antimicrobial properties and Enhanced freshness formulation (EFF) based on hexanol's role in maintaining cellular integrity together with slow senescence, preserving the flowers' colour and appearance during storage (23). Overall, chitosan-glycerol film packaging material preserved flower quality by creating a moisture-retentive environment that slowed degradation processes.

Fragrance index

The fragrance index of jasmine flowers showed stability across all treatments on Day 0 and Day 1, but differences became apparent from Day 2 onwards. T_1 (chitosan-tween

Table 5. Results on visual parameters of jasmine flowers under different packaging treatments over 3 days.

Treatment	Visual parameter observed from day 0 to 3 (%)											
	Freshness index				Flower opening index				Colour retention index			
	0	1	2	3	0	1	2	3	0	1	2	3
T_1 chitosan-tween 80 film	94.82	91.48	87.45	84.02	18	25.5	32.5	40	96.65	95.54	94.32	89.33
T_2 chitosan-glycerol film	95.85	93.54	90.27	86.78	18.5	22	29.5	35.5	98.78	97.86	95.89	90.85
T_3 conventional film	94.32	92.08	88.23	84.66	20.5	25	38.5	47	97.86	96.33	94.76	89.78
T_4 gel-ice condition	93.86	90.43	86.69	83.01	19	26	37	44	95.67	94.85	92.78	88.65
T_5 no package	92.17	88.67	85.02	80.56	18	26.5	45.5	60	93.56	91.87	88.67	83.82
CD @ 5%	2.85	2.22	1.82	2.63	0.518	1.003	1.043	0.862	2.094	2.777	3.144	2.954
SE (d)	1.340	1.044	0.855	1.237	0.241	0.467	0.485	0.401	0.974	1.291	1.462	1.373

Table 6. Fragrance score of jasmine flowers under different packaging treatments over 3 days.

Treatment details	DAY 0	DAY1	DAY2	DAY3
T_1 chitosan-tween 80 film	2	2	3	4
T_2 chitosan-glycerol film	2	2	3	3
T_3 conventional film	2	3	3	2
T_4 gel-ice condition	2	2	3	3
T_5 no package	2	3	4	1

80 films), T_2 (chitosan-glycerol film) and T_4 (ice-gel condition) maintained a moderate fragrance index of 3 by Day 3, while T_5 (without packaging) exhibited the fastest decline to an index of 1 (Table 6). In comparison, post-harvest treatments such as Boric acid 4 % + 600 ppm EFF, Boric acid 4 % + ice gel packing and 800 ppm EFF also retained a high fragrance index of 3 (23). This indicates that chitosan-glycerol film performed well under packaging without additional chemical treatments.

Moisture content

The moisture content of jasmine flowers showed a gradual decline over three days across all treatments (Table 7). T_2 (chitosan-glycerol film) exhibited the highest moisture retention from 95.83 % to 81.77 % (Day 3). T_1 (chitosan-tween 80 films) followed closely, with moisture content reducing from 95.49 % to 80.3 % by Day 3. In contrast, T_5 (without packaging) showed the steepest decline in moisture content, dropping from 95.32 % to 58.28 % over the same period, reflecting poor moisture retention. Similarly, the export packaging technology of jasmine flowers revealed that when flowers were treated with 4 % boric and packed in ice-gel condition, they had a high moisture content (51.91 %) after 36 h of packaging (2). These findings suggest that chitosan-based film packaging, such as chitosan-glycerol film, can help in moisture control due to their hydrophilic nature, which allows the films impermeability, thus playing a role in enhancing the shelf life of jasmine flowers.

Table 7. Results on physiological parameters of jasmine flowers under different packaging treatments over 3 days.

Treatment	Physiological parameters observed from day 0 to 3 (%)							
	Moisture content				Physiological loss in weight			
	0	1	2	3	0	1	2	3
T_1 chitosan-tween 80 film	95.49	92.65	86.36	80.30	0	26.33	48.63	71.25
T_2 chitosan-glycerol film	95.83	93.86	87.77	81.77	0	25.96	44.95	70.99
T_3 conventional film	95.22	91.07	83.93	77.00	0	26.72	52.63	73.11
T_4 gel-ice condition	95.74	92.87	86.96	66.47	0	26.27	47.63	72.21
T_5 no package	95.32	90.66	79.65	58.28	0	27.9	54.03	74.68
CD @5%	2.72	1.64	1.65	1.03	0	0.46	1.24	2.47
SE (d)	1.295	0.769	0.774	0.484	0	0.214	0.581	1.158

Physiological Loss in weight

The physiological Loss in weight (PLW) of jasmine flowers increased progressively across all treatments over 3 days, indicating moisture and mass reduction (Table 7). T_1 (chitosan-tween 80 films) and T_2 (chitosan-glycerol film) showed lower PLW, recording 71.25 % and 70.99 % on Day 3 respectively, demonstrating effective weight retention. T_3 (conventional film) exhibited a higher PLW of 73.11 %, while T_4 (ice-gel condition) reached 72.21 %, indicating moderate effectiveness in controlling weight loss. The highest PLW was observed in T_5 (without packaging), which substantially increased to 74.68 % by Day 3, reflecting the least efficiency in minimizing weight loss. In export packaging, jasmine flowers showed low PLW (2.59 %) when treated with 4 % boric acid and packed in a thermocol box under gel-ice condition after 36 h of packaging (2). Based on these findings, chitosan-based films can be suggested as an effective method of reducing physiological weight, thereby preserving the quality and marketability of jasmine flowers during storage.

Shelf life

After packaging, the shelf-life data of jasmine flowers revealed significant differences among various treatments (Table 8). T_2 (chitosan-glycerol film) exhibited the most extended shelf life of 4.16 days, followed by T_1 (chitosan-tween 80 films) and T_3 (conventional film) with 3.8 and 3.7 days, respectively. T_4 (ice-gel condition) showed a shelf life of 3 days, while T_5 (without packaging) recorded the shortest shelf life of 2.7 days. In current trends, the export packaging technology adopted for jasmine flowers involved treating flowers with 4 % boric acid, placing them in aluminium-foil lined boxes and further packing in thermocol with gel ice under cold conditions and it effectively extended the shelf life to 42.88 h (2). These findings suggest that chitosan-based film packaging can effectively maintain flower quality and shelf life even without additional post-harvest treatments.

Table 8: Shelf life of jasmine flowers under different packaging treatments.

Treatment details	Days
T_1 chitosan-tween 80 film	3.80
T_2 chitosan-glycerol film	4.16
T_3 conventional film	3.70
T_4 gel-ice condition	3.00
T_5 no package	2.70
CD @5%	0.097
SE(d)	0.046

Conclusion

The study demonstrated the potential of chitosan-based biopolymer films as an effective alternative to conventional packaging methods for enhancing the post-harvest quality and shelf life of jasmine flowers (*Jasminum sambac* L.) during export. Chitosan-tween 80 and chitosan-glycerol films were developed using the solvent-casting method and evaluated in comparison with traditional packaging (aluminium-foil lined boxes with ice-gel) and untreated flowers. With its smooth surface morphology and superior flexibility, the chitosan-glycerol film exhibited enhanced impermeability and higher moisture retention, making it the most effective packaging material. It outperformed other methods regarding freshness index, flower opening control and reduction in physiological weight loss, extending the shelf life up to 4.16 days. This superior performance can be attributed to the interaction between chitosan's amine and glycerol hydroxyl groups, improving film strength and moisture resistance. The findings suggest that incorporating chitosan-based films, with their high biodegradability and UV-blocking capabilities, can significantly minimize the need for gel-ice and chemical treatments, reducing transportation costs and environmental impact. This study also underscores the need to improve the mechanical properties of chitosan-glycerol films for packaging, along with scaling up the production of chitosan biopolymers to address current challenges related to cost and resource availability. Overcoming these barriers would position chitosan-based films as a promising, sustainable and cost-effective packaging material, enhancing the global marketability of jasmine flowers while mitigating environmental concerns associated with conventional packaging.

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Authors' contributions

FA carried out the experiment, took observations and analyzed the data. CR guided the research by formulating the research concept, helped secure funds for research and approved the final manuscript. GM reviewed the manuscript and helped in procuring research grants. PM helped edit, summarize and revise the manuscript. DM contributed by imposing the experiment and helped in summarizing and revising the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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AI Declaration

During the preparation of this work, the author(s) not used AI tools and the author(s) reviewed and edited the content as needed and take (s) full responsibility for the content of the publication.

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