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Combined Effect of Blue Light and Ethylene Absorbers with Chitosan Elicitor Edible Coating on Quality of Feijoa (*Acca sellowiana*) Postharvest

Mahdi Asgari Gouraj[*a]

[a] *PhD Student, Department of Horticulture, Faculty of Agriculture, Islamic Azad University, Rasht, Iran*

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ABSTRACT

Feijoa (*Acca sellowiana*) fruits have a short postharvest life of approximately 4-5 weeks under cold storage. This study, conducted in December 2023, used a completely randomized design (CRD) in a factorial arrangement to evaluate the effects of blue light exposure (6, 12, or 24 h), chemical elicitors [chitosan (CS), alginate (A), or putrescine (P) at 2 mg L^{-1}], and ethylene absorbers [none (E0), zeolite (E1), or biochar (E2)] on fruit quality during storage at 4 °C and 90-95% RH. A total of 36 treatment combinations, each with three replications (three fruits per plot), were tested on 324 fruits from uniform, commercially mature trees (~6.5 °Brix). Fruits were immersed in elicitor solutions for 30 min, dried, and exposed to blue light (λ = 470 nm) for the assigned duration before storage with or without ethylene absorber sheets characterized via BET and SEM. Quality parameters assessed included durability, respiration rate, ethylene emission, decay, firmness, weight loss, chlorophyll, ion leakage, and chilling. The combination CSE2L6 (CS + biochar + 6 h blue light) extended durability to 62/25 days compared with 31 days in the control and shelf life 216/25 hours, reduced decay by 64%, and decreased respiration rate and ethylene emission by 48% and 52%, respectively. These results demonstrate that integrating edible coatings, short-duration blue light, and ethylene absorbers can substantially extend storage life and maintain physicochemical quality in feijoa, providing an eco-friendly postharvest management strategy.

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* Corresponding author: M. Asgari Gouraj
E-mail address: afshin.asgari23@gmail.com

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1. Introduction

Feijoa (Acca sellowiana (O. Berg) Burret), commonly known as Feijoa or Pineapple Guava, is an evergreen shrub or small tree belonging to the Myrtaceae family. Native to the highlands of southern Brazil, eastern Paraguay, Uruguay, northern Argentina, and Colombia, this plant thrives in temperate and tropical regions (Weston, 2010; Tunsel, 2015; Vatrano, 2022). Feijoa plants typically reach heights of 3-5 meters, although they can be maintained at smaller sizes through regular pruning (Fisher, 2020). The leaves are elliptical to ovate, measuring 3-8 cm in length and 2-4 cm in width, with a glossy dark green upper surface and a silvery-white underside (Maghri, 2020).

The flowers are large, with white petals and numerous prominent red stamens, making them attractive to pollinators (Amaral, 2019; Connell, 2020). These edible flowers contain bioactive compounds such as apigenin and cyanidin 3-O-glucoside. The fruit is typically green, walnut-sized, and oval-shaped, with a sweet, aromatic flavor reminiscent of pineapple and mint (Jackson County Master Gardener Association, 2024).

Feijoa requires between 100 and 200 chilling hours below 7 °C to produce a significant number of flowers, which is necessary to break dormancy and stimulate bud development (Woolf, Ferguson, and Plummer, 2007; University of Florida IFAS Extension, 2021). Pollination is optimal at temperatures between 13 °C and 21 °C, with high temperatures exceeding 32 °C potentially affecting pollination and fruit set (Quintero-Castillo and Garcia, 2012).

Propagation of Feijoa can be achieved through seeds, cuttings, grafting, and layering. In Iran, Feijoa is mainly grown in the northern Caspian provinces, particularly in Guilan and Mazandaran (Rasekh et al., 2021). Feijoa is adapted to temperate and tropical regions and has several known cultivars. Notable cultivars include Apollo, Opal Star, Pounamu, Anatoki, Gemini, Unique, Kakapo, Wiki Tu, Mammoth, and Triumph (Jackson County Master Gardener Association, 2024; The Plant Company, 2024).

Postharvest deterioration of fresh produce is primarily driven by accelerated respiration, ethylene-mediated senescence, oxidative stress, and microbial colonization, posing a significant challenge to extending shelf life through sustainable strategies (Xu, 2014). Blue light (400-500 nm) exposure has emerged as a non-chemical preservation approach, shown to slow chlorophyll degradation, maintain texture, reduce weight loss, and delay senescence in various fruits and vegetables (Shi, 2014). Mechanistically, blue light influences the expression of genes involved in ethylene biosynthesis, such as ACS and ACO, downregulating their activity to slow ripening (Liu et al., 2019).

Chitosan serves as both an edible coating and a chemical elicitor, forming a semi-permeable film that reduces moisture loss and gas exchange while stimulating defense mechanisms. Chitosan treatment upregulates antioxidant genes (SOD, CAT, APX, GPX), defense-related genes (PR1, PR2), and phenylpropanoid pathway genes (PAL, CHS), enhancing resistance to oxidative stress, delaying decay, and maintaining fruit quality (Salgado-Cruz et al., 2021; Gao, 2023; Pillai et al., 2024). Alginate and alginate-derived oligosaccharides similarly act as natural elicitors, upregulating antioxidant genes (SOD, CAT, APX) and phenylpropanoid biosynthetic genes (PAL, C4H, 4CL), while forming a protective barrier that limits respiration and water loss, delaying senescence and improving firmness and color retention (Shen et al., 2024; Bahmany et al., 2024).

Putrescine, a naturally occurring polyamine applied at 2 mg L^{-1}, stabilizes cell membranes, suppresses ethylene synthesis by downregulating ACS and ACO, and enhances antioxidant enzyme activity via upregulation of SOD, CAT, APX, and GPX. It also influences polyamine biosynthesis genes such as ADC and ODC, collectively contributing to delayed

ripening, reduced decay, and maintenance of firmness and soluble solids in treated fruits (Terry et al., 2004; Hanif et al., 2020; Ghosh et al., 2021). Integrating blue light exposure with natural elicitors like chitosan, alginate, or putrescine, along with ethylene absorbers such as zeolite or biochar, creates a multi-hurdle postharvest strategy (Bal et al., 2021). This approach synergistically modulates internal metabolism by enhancing antioxidant defenses, reinforces barrier defenses through edible coatings and elicitors, and regulates the storage atmosphere by removing ethylene. Collectively, this integrated strategy improves fruit firmness, sensory and nutritional quality, and microbial resilience, offering a sustainable means to extend the shelf life of perishable produce such as Feijoa (*Acca sellowiana*) under cold storage (Kutahneci et al., 2020).

The aim of this study is to evaluate the effectiveness of integrating a chitosan-based edible coating with controlled blue light exposure and ethylene absorber treatments (biochar and zeolite) in extending the postharvest shelf life of Feijoa (*Acca sellowiana*) fruit. The research focuses on how these combined eco-friendly, non-chemical strategies can synergistically reduce physiological deterioration, delay ripening, and suppress ethylene-induced senescence. Additionally, the study investigates the impact of these treatments on maintaining fruit firmness, sensory quality, and nutritional attributes during cold storage, ultimately providing insights for sustainable postharvest management of perishable fruits.

2. Materials and Methods

2. 1. Experimental Design

A factorial experiment was conducted in December 2023, combining three factors, Blue-light exposure at three durations (6, 12, and 24h), Chemical treatments at 3 levels, including elicitor chitosan, alginate and putrescine and Ethylene absorbers sheets at three levels: none (control), biochar and zeolite. This produced a total of 36 treatment combinations, arranged in a completely randomized design (CRD) with three replications. Each replication included 3 fruits per plot, totaling 324 fruits across 108 plots, with distilled water used for controls.

2. 1. 1. Plant Material and Storage

Fruits (*Acca sellowiana*) were harvested from uniform trees in *Camellia* flower and plant production (fig. 1) in Nowshahr at the commercial maturity stage (~6.5 °Brix; Jiang *et al*., 2022). Fruits were transported under sanitized conditions, sorted for uniformity, disinfected in 5% perchlorin solution for 2 minutes, rinsed, and air dried.



Figure 1. Feijoa (*Acca sellowiana*) in *Camelia* flower and plant production. (36°39′ N, 51°30′ E).

2. 1. 2. Treatment Application

Fruits were immersed in chitosan or alginate elicitor solutions (Sigma-Aldrich, based in St. Louis, Missouri, USA; a subsidiary of Merck KGaA, Darmstadt, Germany) or putrescine (Merck KGaA, Germany) for 30 minutes, then air-dried on paper towels. For blue light treatments, fruits were exposed to LED lamps emitting blue light at a peak wavelength of 470 nm. The wavelength was verified by spectrophotometer under neutral white light conditions in the growth chamber. The blue spectrum centered at 470 nm (fig. 2) falls within the visible range and is known for stimulating photoreceptor-mediated physiological responses without excessive heat buildup. The LED lamps used were manufactured by Nichia Corporation, headquartered in Tokushima (Anan), Japan - a leading global producer of high-quality blue LEDs.

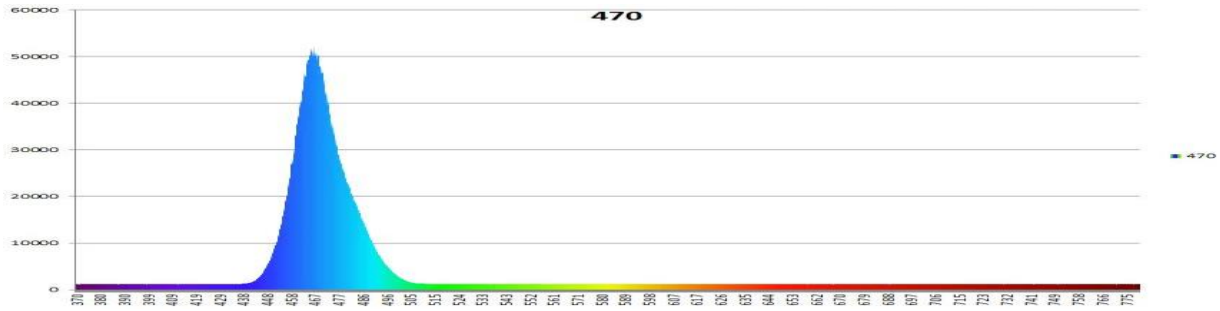


Figure 2. Emission spectrum of the blue LED lamp used in the experiment, showing a peak wavelength at 470 nm, verified by spectrophotometer. The light source was manufactured by Nichia Corporation (Tokushima, Japan).

Table 1. Treatments used in the experiment on Feijoa quality.

Treatment	Symbol
Control	C
Chitosan 2 mg/L	CS
Putrescine 2 mg/L	P
Alginate 2 mg/L	A
Light 6h	L6
Light 12h	L12
Light 24h	L24
Without an Ethylene absorber	E0
Ethylene absorber (Zeolite)	E1
Ethylene absorber (Biochar)	E2

2. 1. 3. Ethylene Absorber Preparation

Biochar and zeolite-coated paper sheets were prepared and characterized using Brunauer-Emmett-Teller (BET) surface area analysis and Scanning Electron Microscopy (SEM). BET analysis confirmed the presence of a high surface area with well-developed porosity in both materials. SEM observations showed a uniform distribution of biochar and zeolite particles on the paper fibers, with visible micro and mesopores suitable for ethylene adsorption. These structural properties indicated the potential effectiveness of the prepared sheets in reducing ethylene levels during storage.

2. 2. Storage Conditions

Treated fruits, along with 3 g of respective absorber sheets, were placed in PVDC bags, vacuum-sealed, and stored at 4 °C (RH 90-95%).

2. 3. Monitoring and Measurements

Fruits were inspected daily for quality traits including durability, weight, diameter, dry matter, chlorophyll, firmness, ion leakage, respiration rate, ethylene emission, chilling, browning, decay, texture, pH, skin: to: pulp ratio, and internal cavity diameter.

2. 4. Durability

The number of days after harvest until the initiation of brown spots on the skin was taken into consideration. Additionally, the shelf life was calculated as the time interval from removal from refrigeration to the onset of brown skin spots and loss of market acceptability.

2. 5. Respiration Rate

Respiration rate was measured using gas chromatography. Twenty-four hours after treatment, fruits were placed in a sealed container for one hour, and the concentration of carbon dioxide in the headspace was recorded. Based on that data, the respiration rate was calculated and expressed in mg CO_2 / kg / h (Guo, 2019).

2. 6. Ethylene emission

Twenty-four hours after treatment, a single fruit was placed in a sealed container for 24 hours. A portion of the internal air from the container was then sent to the Tehran-based Arman Shimi Co. laboratory for analysis. Ethylene concentration was measured using a GC-ALT gas chromatography system, and the emission rate was expressed as $\mu L\ C_2H_4\ kg^{1}\ h^{1}$ (Bohinc *et al*., 2024).

2. 7. Browning

Browning index (BI): Brown discoloration was visually assigned to five classes (Fawole *et al*., 2020).

0 (none), 1 (1-25%), 2 (25-50%), 3 (50-75%), and 4 (>75%, Mohamed *et al*., 2021).
BI was computed using:

BI = Browning level × number of fruits at that level ÷ total fruit count × 5

Higher index values reflect more extensive and severe browning.

2. 8. Texture

Texture analysis was performed using a penetration test based on the protocol of (Riberino *et al*., 2013). Fruit samples were tested on a TA-XT Plus Texture Analyser (Stable Micro Systems, UK), using a 3 mm diameter stainless steel rod probe. The Exponent 6.1.4.0 software recorded and integrated force-displacement curves (Basile *et al*., 2022). The probe

penetrated the fruit to a 3 mm depth at a test speed of 3 mm/s (pre-test at 1 mm/s, Zhang *et al*., 2025). Each treatment was replicated three times.

2. 9. Weight Loss

Each fruit was weighed daily for 8 consecutive days on a high-accuracy digital scale (±0.001 g). Daily weight loss was expressed as:

Weight loss (%) = Initial weight - Subsequent weight ÷ Initial weight × 100

2. 10. Dry Matter

Feijoa fruits were first weighed to determine their initial wet weight. Samples were then dehydrated (e.g., in an oven until constant weight) to measure dry weight. The percentage of dry matter was calculated using the formula described by Teixeira *et al*. (2023).

Dry matter (%) = Wet weight - Dry weight ÷ Wet weight × 100

2. 11. Decay

Each week, figs from each experimental replicate were removed from storage and visually inspected to evaluate decay on both surface and internal tissues. Decay percentage was calculated using the formula described by (Yang *et al*., 2019).

Decay (%) = Number of decayed fruits ÷ Total number of fruits × 100

2. 12. Firmness

Firmness measurements were performed on days 2, 5, and 6 of storage. Fruits were peeled on opposing equatorial sides. A 3 mm stainless-steel probe was applied using a texture analyzer to penetrate 1 cm below the skin at 25.4 cm/min. Three punctures were made per fruit at equal spacing. Pulp firmness was quantified using an OSK-10576 firmness tester (USA) and expressed in kg/cm², representing the peak pressure recorded during penetration (Hertog, 2022).

2. 13. pH

The pH of Feijoa fruits was determined using a Milwaukee MW101 PRO pH meter manufactured in South Korea. Measurements were conducted in the laboratory, with three replicates per sample.

2. 14. Ion Leakage

The ion leakage assessment method described by Chan (1985) was adapted for Feijoa fruit by excising a 10-mm diameter disc from the distal end of the skin using a cork borer. The tissue was immersed in 25 mL of 0.4% mannitol solution at ambient temperature (Voichek *et al*., 2023). After 4 h of gentle agitation at 100 rpm, the initial electrical conductivity (EC_1) of the solution was measured using a Metrohm 644 conductivity meter.

Subsequently, the solution containing the tissue was autoclaved at 121 °C for 20 minutes to release all electrolytes. After cooling to room temperature for 24 hours, the final electrical conductivity (EC_2) was measured. The percentage of ion leakage was calculated using the formula:

Ion Leakage (%) = EC_2 - EC_1 ÷ EC_2 × 100

This method is adapted from McCollum and McDonald (1991), who utilized electrolyte leakage as an indicator of chilling injury in grapefruit (Megias, 2022).

2. 15. Chilling

For each sampling event, five Feijoa fruits per treatment were selected at random and transferred to ambient laboratory conditions (25 °C) for 24 hours. Chilling injury symptoms were defined as: sunken brown spots on the fruit surface and browning of seeds, classified into four severity levels:

Level 0: no chilling injury

Level 1: 1-25% browning/pitting

Level 2: 25-50% browning/pitting

Level 3: more than 50% browning/pitting

Let ni be the number of fruits at severity level i, and N be the total number of fruits

The Chilling Injury Index (CII) was calculated using:

CII (%) = number of fruits at that level - total fruit number ÷ maximum × 100

A higher CII value indicates more severe chilling damage.

2. 16. Chlorophyll

Chlorophyll pigments were extracted from 0.5 g of fresh Feijoa peel using 80 % (v/v) acetone. The samples were homogenized and incubated in the dark at 4 °C for 4 hours to prevent pigment degradation. The extracts were then centrifuged at 5,000 rpm for 10 minutes, and the supernatant was collected for spectrophotometric analysis. Absorbance readings were recorded at 645 nm and 663 nm using a UV-Vis spectrophotometer Jenway 6405 (Jenway Limited, United Kingdom)**.** The concentration chlorophyll was calculated according to Lichtenthaler (1987), with minor modifications based on recent studies (e.g., Zhang *et al*., 2022). Results were expressed as milligrams per gram of fresh weight (mg g^{-1} FW).

2. 17. Diameter

Fruit diameter was measured using a digital micrometer, and values were converted to and recorded in millimeters (mm).

2. 18. Internal Cavity Diameter

Similarly, the internal cavity diameter was measured with a digital micrometer and converted to millimeters (mm).

2. 19. Skin-to-Pulp Ratio (%)

Whole Feijoa fruits were weighed immediately after harvest (fresh weight). Peels were carefully separated, weighed, and the ratio expressed as the percentage of peel weight relative to whole fruit weight (Nguema *et al*., 2025).

3. Results

3. 1. Durability

The effects of various treatments on the durability of Feijoa fruits were significant at $P \leq 0.01$ (Table 2). The longest durability was observed in treatment CSE2L6 (62/25 days), whereas the control lasted only 11.33 days. The shortest among treatments was ~28 days (AE1L12, Table 3). Chitosan coatings and blue light exposure improved fruit storage longevity by reducing moisture loss and delaying ripening.

3.1.1. Respiration Rate

Respiration rate differed significantly among treatments ($P \leq 0.01$, Table 2). The lowest rates were recorded in PE1L6 and AE1L6 (10.04 mg/kg/h), while the control showed 49.42 mg/kg/h (Table 3). Coatings and light treatments effectively reduced respiration, slowing senescence. The marked reduction in respiratory activity suggests improved metabolic stability and delayed ripening processes. Such effects are crucial for extending postharvest storage life and maintaining quality attributes during marketing.

Table 2 Analysis of variance of Postharvest Quality Parameters of Feijoa Fruits

Source of Variation	df	Durability (FD)	Respiration (Res)	Ethylene (Eth)	Browning (Bro)	Texture (Tex)	Weight (Wei)	Dry Matter (Dm)	Decay (Dec)
Ethylene	2	358.77**	22.13**	369.77**	217.89^{ns}	31.75**	25.75*	30561**	7.58^{ns}
Treatment	3	4993.29**	3.65**	70.65^{ns}	301.2**	69.77**	14.89^{ns}	5301**	294.83**
Blue Light	2	614.33**	3.45**	1839.61**	124.68^{ns}	539.6**	25.28*	59478**	391.59**
E × T	6	299.5**	9.29**	471.89**	614.89**	125.61**	133.43**	30185**	208.84**
E × BL	4	678.73**	66.31**	1674.66**	557.64**	316.61**	226.77**	89225**	929.13**
T × BL	6	159.58**	13.98**	426.06**	374.36**	173.16**	359.6**	63161**	361.61**
E × T × BL	12	277.5**	16.36**	343.07**	852.82**	130.03**	213.05**	54800**	222.53**
Error	72	29.13	0.33	25.58	74.66	4.49	10.58	2456.82	6.36
C.V. (%)	–	5.62	5.35	6.62	7.28	5.33	5.22	5.63	5.34

Table 2 (continued)

Source of Variation	df	Firmness (Fir)	PH	Ion Leakage (EL)	Chilling (Chi)	Chlorophyll (Chl)	Diameter (Dia)	Internal Cavity Diameter (Idc)	Skin-to-Pulp Ratio (Rsm)
Ethylene	2	4.4**	1.26**	983.28**	1025**	1.008**	2.52**	1.96**	103.99**
Treatment	3	1.24**	27.43**	592.94**	598.44**	0.39^{ns}	27.41**	58.86**	499.66**
Blue Light	2	17**	1.53**	315.18**	8500**	2.97**	0.64**	11.02**	4253**
E × T	6	3.88*	2.33**	557.57**	730.95**	1.19**	0.31*	0.81**	143**
E × BL	4	15.06**	0.34^{ns}	836.51**	2275**	7.53**	1.32**	5.16**	141.47**
T × BL	6	5.45**	1.07**	634.41**	707.32**	1.37**	0.78**	0.68*	591.7**
E × T × BL	12	1.97**	0.95**	277.53**	741.21**	2.34**	0.83**	1.25**	156**
Error	72	0.43	0.23	68.03	102.19	0.16	0.12	0.26	4.48
C.V. (%)	—	5.82	4.93	5.46	6.26	5.43	3.69	5.31	9.27

** = significant at $P \leq 0.01$; * = $P \leq 0.05$; ns = not significant.

3.1.2. Ethylene Emission

Ethylene production was significantly affected by treatments ($P \leq 0.01$, Table 2). The highest emission occurred in the control (57.37%), while the lowest was observed in CSE1L12 (28.55%, Table 3). Treatments modulated ethylene biosynthesis, contributing to delayed ripening.

3.2. Browning

Browning index was significantly different among treatments ($P \leq 0.01$, Table 2). The control showed the highest index (60.91%), whereas CSE0L24 exhibited the lowest (52.97%, Table 3). Browning primarily occurred on the skin, and coatings reduced oxidation-related discoloration.

Table 3. Mean comparison of Postharvest Quality Parameters of Feijoa Fruits.

Treatment	FD (days)	Res (mg/kg/h)	Eth (%)	Bro (%)	Tex (g)	Wei (g)	Dm (%)	Dec (%)
Control	8^{l}	48.66^{a}	51.01^{a}	59.84^{a}	11.99^{hi}	72.52^{bc}	122.12^{f}	82.64^{e}
CSE0L6	47.67^{c-f}	14.18^{ef}	26.88^{bc}	19.09^{d}	15.73$^{f–i}$	31.76^{gh}	384.22^{de}	37.14^{f}
CSE0L12	60.33^{ab}	14.54^{ef}	28.05^{bc}	16.39^{d}	26.22^{b}	36.33^{ef}	532.16^{a-c}	38.62^{f}
CSE0L24	41.67^{e-g}	9.68^{j-l}	27.33^{bc}	21.54^{cd}	17.4^{fg}	22.05^{j}	619.38^{a}	37.31^{f}
Control	10^{j}	44.48^{c}	56.46^{a}	60.91^{a}	11.37^{i}	75.07^{ab}	124.14^{f}	82.30^{e}
CSE1L6	45.33^{d-g}	14.28^{ef}	26.11^{b-d}	33.37^{bc}	13.8^{g-i}	26.29^{i}	461.60^{b-e}	37.25^{f}
CSE1L12	43.33^{d-g}	14.61^{ef}	28.55^{b}	23.24^{bd}	11.33^{i}	36.03^{ef}	337.14^{f}	39.17^{f}
CSE1L24	36^{g-i}	13.34^{gh}	21.29^{b-g}	22.97^{bd}	11.67^{i}	42.26^{d}	450.32^{b-e}	44.93^{e}
Control	9^{j}	40.4^{e}	57.37^{a}	53.33^{a}	11.46^{i}	74.46^{a-c}	125.61^{f}	87.74^{a}
CSE2L6	62.33^{a}	10.6^{i-k}	24.69^{b-f}	16.41^{d}	26.4^{b}	16.32^{k}	627.08^{a}	13.31^{k}
CSE2L12	40.33^{e-h}	11.5^{h-j}	22.29^{b-g}	14.77^{d}	19.97$^{d–f}$	36.68^{ef}	334.45^{f}	28.44^{g}
CSE2L24	39.67^{e-h}	9.42^{kl}	16.99^{fg}	22.55^{bd}	21.56^{c-e}	36.97^{ef}	218.42^{f}	27.52^{gh}
Control	10.67^{j}	41.12^{e}	53.1^{a}	53.55^{a}	11.48^{i}	71.5^{c}	122.72^{ı}	85.75^{ab}
PE0L6	46^{d-g}	11.95^{hi}	18.42^{d-g}	17.79^{d}	17.65^{e-g}	37.96^{e}	219.00^{f}	25.57$^{g–ı}$
PE0L12	37^{g-i}	11.61^{hi}	23.7^{b-g}	55.14^{a}	11.56^{i}	31.94^{gh}	498.40^{a-e}	45.40^{e}
PE0L24	39^{f-h}	12.04^{hi}	17.37^{e-g}	23.10^{bd}	37.59^{a}	31.5^{h}	578.94^{ab}	22.72^{ı}
Control	8^{j}	41.44^{e}	55.31^{a}	56.24^{a}	11.33^{i}	76.5^{a}	116.99^{f}	84.11^{bc}
PE1L6	44.67^{d-g}	10.4^{i-k}	16.57^{g}	16.46^{d}	29.02^{b}	32.28^{gh}	542.93^{ab}	26.47^{gh}
PE1L12	43.33^{d-g}	8.7^{l}	20.55^{c-g}	18.07^{d}	34.75^{a}	33.74$^{f–h}$	227.34^{gh}	27.34^{gh}
PE1L24	40^{e-h}	10.87^{i-k}	16.02^{g}	33.84^{b}	36.72^{a}	34.82^{e-h}	246.56^{f}	26.33^{gh}
Control	9^{j}	41.84^{de}	52.76^{a}	53.74^{a}	11.77^{i}	74.08^{a-c}	146.56^{f}	86.31^{ab}
PE2L6	52.33^{b-d}	14.32^{ef}	21.01^{b-g}	53.17^{a}	21.99^{cd}	42.52^{d}	365.07^{e}	43.64^{e}
PE2L12	49.33^{c-f}	15.18^{ef}	21.62^{b-g}	25.76^{bd}	15.73$^{f–i}$	21.76^{j}	208.72^{f}	37.14^{f}
PE2L24	57^{ac}	15.87^{f}	22.05^{b-g}	16.39^{d}	26.22^{b}	19.66^{j}	222.12^{f}	38.62^{f}
Control	10.67^{j}	46.63^{b}	51^{a}	54.87^{a}	11.7^{c-e}	72.29^{i}	124.22^{b-e}	81.64^{d}
AE0L6	48^{c-f}	11.81^{hi}	23.46^{b-g}	17.58^{d}	21.4^{i}	26.05^{bc}	465.49^{b-e}	12.30^{k}
AE0L12	48.67^{c-f}	15.28^{e}	24.78^{b-e}	33.37^{bc}	21.8^{c-e}	35.07^{e-g}	312.30^{k}	12.25^{k}
AE0L24	50^{c-e}	15.61^{e}	21.55^{b-g}	23.24^{bd}	21.67^{c-e}	36.03^{ef}	542.10^{ab}	39.17^{f}
Control	11.33^{j}	43.34^{cd}	51.29^{a}	52.97^{a}	12.01^{hi}	72.26^{bc}	224.32^{hı}	84.93^{a-c}
AE1L6	40^{b}	10.4^{i-l}	17.37^{e-g}	16.66^{d}	25.13^{bc}	34.46^{e-h}	550.66^{ab}	17.74^{j}
AE1L12	28^{i}	10.6^{i-k}	24.69^{b-f}	16.41^{d}	26.4^{b}	16.32^{k}	227.74^{j}	24.32^{hı}
AE1L24	30.33^{hi}	11.5^{h-j}	22.29^{b-g}	14.77^{d}	19.97$^{d–f}$	36.68^{ef}	619.38^{a}	27.51^{gh}
Control	8.67^{j}	49.42^{a}	53.66^{a}	55.88^{a}	11.56^{g-i}	73.96^{c}	129.22^{b-e}	86.52^{ab}
AE2L6	35.67^{g-i}	11.12^{h-j}	16.43^{g}	33.55^{bc}	16.14$^{f–h}$	37.97^{a}	322.25^{k}	28.39^{g}
AE2L12	37.33^{g-i}	11.95^{hi}	18.42^{d-g}	17.79^{d}	11.98^{i}	43.35^{d}	231.60^{f}	27.34^{gh}
AE2L24	49.67^{c-e}	11.61^{hi}	23.7^{b-g}	25.14^{bd}	11.84^{i}	43.35^{d}	501.93^{a-d}	45.40^{e}

The same letters in each column indicate no significant difference at the 5% probability level based on Duncan's test. FD: Fruit durability, Res: Respiration, Eth: Ethylene, Bro: Browning, Tex: Textural, Wei: Weight, Dm: Dry matter, Dec: Decay.

Table 3. (continued).

Treatment	Fir (kg/cm^2)	PH	EL (%)	Chi (%)	Chl (mg/ml)	Dia (mm)	Idc (mm)	Rsm (g)
Control	1.09^{k}	9.23^{ab}	75.1^{a}	75.28^{a}	1.09^{k}	4.98^{a}	4.45^{a}	11.09^{j}
CSE0L6	2.36^{h}	5.33^{j}	37.34^{fh}	36.39$^{b–f}$	4.60^{e}	3.64$^{d–f}$	1.87^{bc}	22.35^{gh}
CSE0L12	2.15^{h-j}	7.43^{d}	44.55^{c-g}	46.4^{b}	4.42^{f}	3.26^{f}	1.84^{bc}	28.80^{ef}
CSE0L24	2.57^{gh}	8.26^{c}	41.98^{d-g}	24.15^{fg}	4.49^{f}	2.77^{g}	1.88^{bc}	32.56$^{e–f}$
Control	1.14^{k}	9.16^{ab}	75.11^{a}	71.8^{a}	1.23^{k}	4.73^{ab}	4.79^{a}	11.07^{j}
CSE1L6	3.54^{ef}	6.36^{f-i}	22.89^{i}	33.96^{c-e}	4.23^{g}	3.68$^{d–f}$	1.84^{bc}	41.71^{ab}
CSE1L12	3.17^{fg}	7.30^{d-f}	50.13^{c-f}	23.2^{g}	4.32^{g}	4.75^{ab}	1.86^{bc}	31.48^{c-f}
CSE1L24	3.44^{ef}	7.26^{d-g}	47.82^{c-g}	72.47^{a}	2.90^{i}	4.37^{bc}	1.68^{bc}	34.96^{c-e}
Control	1.34^{k}	9.30^{ab}	76.01^{a}	45.38^{b}	1.33^{k}	3.70$^{d–f}$	4.75^{a}	13.17^{ij}
CSE2L6	3.33^{f}	6.26^{hi}	47.21^{c-g}	24.8$^{e–g}$	6.23^{a}	4.70^{ab}	1.76^{bc}	36.43^{b-d}
CSE2L12	5.27^{bc}	7.00$^{d–h}$	44.95^{c-g}	28.74$^{d–g}$	5.56^{ab}	3.69$^{d–f}$	1.84^{bc}	29.55$^{d–f}$
CSE2L24	4.16^{de}	8.40^{bc}	40.54^{e-g}	25.28$^{e–g}$	5.95^{a}	3.48$^{d–f}$	1.76^{bc}	43.7^{a}
Control	1.47$^{i–k}$	9.30^{ab}	74.57^{a}	76.39^{a}	1.35^{k}	3.77$^{d–f}$	4.65^{a}	12.64^{j}
PE0L6	6.51^{a}	6.40$^{e–ı}$	44^{c-g}	25.38$^{e–g}$	5.54^{ab}	4.66^{ab}	1.77^{bc}	31.84^{c-f}
PE0L12	2.18^{h-j}	7.30$^{d–f}$	37.95^{fg}	25.41$^{e–g}$	3.07^{i}	3.45$^{d–f}$	1.66^{c}	21.88^{gh}
PE0L24	4.65^{cd}	7.26$^{d–g}$	42.82^{d-g}	33.2^{b-e}	4.99^{b}	3.35^{ef}	1.70^{bc}	21.89^{gh}
Control	1.22^{k}	9.23^{ab}	75.4^{a}	77.21^{a}	1.52^{k}	3.35^{ef}	4.72^{a}	12.2^{j}
PE1L6	5.33^{bc}	6.30$^{g–ı}$	36^{gh}	44.53^{b}	4.24^{g}	4.77^{ab}	1.73^{bc}	31.67^{c-f}
PE1L12	5.44^{b}	7.36^{de}	54.13^{b-e}	35.29^{b}	4.93^{b}	3.98^{cd}	1.65^{c}	38.2$^{a–c}$
PE1L24	6.32^{a}	6.26^{hi}	57.26^{bc}	44.79^{b}	5.13^{b}	4.74^{ab}	1.71^{bc}	21.81^{gh}
Control	1.51$^{i–k}$	9.26^{ab}	76.85^{a}	75.96^{a}	1.35^{k}	3.93$^{c–e}$	4.75^{a}	12.38^{j}
PE2L6	2.22^{hi}	7.14$^{d–h}$	25.1^{hi}	41.92^{bc}	3.06^{i}	4.77^{ab}	2.45^{bc}	21.09^{gh}
PE2L12	3.36^{f}	6.66$^{d–ı}$	37.34^{fh}	25.13^{e-g}	4.60^{e}	4.68^{ab}	2.53^{bc}	22.35^{gh}
PE2L24	4.15^{de}	7.10$^{d–h}$	41.22^{e-g}	26.4^{e-g}	4.08^{h}	3.75$^{d–f}$	2.84^{b}	19.80^{gh}
Control	1.57$^{i–k}$	9.26^{ab}	71.98^{a}	70.54^{a}	1.49^{k}	3.71$^{d–f}$	4.55^{a}	18.9^{hı}
AE0L6	3.14^{fg}	5.83^{ij}	55.11^{b-d}	45.96^{c}	3.86^{h}	4.70^{ab}	2.79^{bc}	26.07^{fg}
AE0L12	3.54^{ef}	7.36^{de}	22.89^{i}	23.96^{fg}	4.23^{g}	3.70$^{d–f}$	2.84^{b}	31.71^{c-f}
AE0L24	3.17^{fg}	6.30$^{g–ı}$	50.13^{c-f}	32.92^{a}	4.32^{g}	3.69$^{d–f}$	2.52^{bc}	31.48^{c-f}
Control	1.44^{j}	9.16^{ab}	77.82^{a}	74.61^{a}	1.23^{k}	3.48$^{d–f}$	4.75^{a}	11.22^{j}
AE1L6	2.34^{h}	6.63$^{d–ı}$	46.01^{c-g}	24.61$^{e–g}$	4.33^{g}	4.88^{a}	4.63^{a}	22.17^{gh}
AE1L12	6.33^{a}	6.60$^{d–ı}$	47.21^{c-g}	42.92^{bc}	5.23^{b}	3.64$^{d–f}$	4.43^{a}	21.77^{gh}
AE1L24	5.27^{bc}	6.66$^{d–ı}$	64.95^{ab}	45.89^{b}	4.22^{g}	3.26^{f}	4.17^{a}	21.55^{gh}
Control	1.49$^{i–k}$	9.40^{a}	73.88^{a}	75.89^{a}	1.28^{k}	2.77^{g}	4.65^{a}	11.7^{j}
AE2L6	3.47^{ef}	7.30$^{d–f}$	41.24^{e-g}	25.1^{e-g}	5.35^{b}	4.73^{ab}	4.43^{a}	31.64^{c-f}
AE2L12	4.51^{d}	6.73^{d-i}	44^{e-i}	76.11^{a}	3.21^{i}	3.68^{d-f}	2.44^{bc}	31.41^{c-f}
AE2L24	2.18^{h-j}	6.20^{hi}	37.95^{g-i}	44.15^{a}	3.10^{i}	4.75^{ab}	1.66^{c}	31.21^{d-f}

The same letters in each column indicate no significant difference at the 5% probability level based on Duncan's test. Fir: Firmness, PH: PH, EL: Ion leakage, Chi: Chilling, Chl: Chlorophyll, Dia: Diameter, Idc: Internal diameter cavity, Rsm: Ratio skin to meet.

3.3. Texture

Fruit texture varied significantly ($P \leq 0.01$, Table 2). The highest texture was observed in PE0L24 (37.59 g), and the control had the lowest (11.7 g, Table 3). Coatings and light treatments slowed softening and maintained structural integrity.

3.4. Weight Loss

Weight loss differed among treatments ($P \leq 0.01$, Table 2). The control showed the highest loss (76.5 g), while the lowest was 71.5 g (Table 3). Treatments minimized water loss during storage.

3.5. Dry Matter

Dry matter content increased with storage and varied among treatments ($P \leq 0.01$, Table 2). The highest was in CSE2L6 (627.08%), and the lowest in the control (116.99%, Table 3), reflecting water loss and fruit respiration dynamics.

3.6. Decay

Decay percentage differed significantly ($P \leq 0.01$, Table 2). Control fruits showed 87.74%, whereas AE0L24 had the lowest at 12.05% (Table 3). Coatings and light exposure reduced decay incidence.

3.7. Firmness

Firmness was significantly affected ($P \leq 0.01$, Table 2). AE1L12 had the highest firmness (6.33 kg/cm²), while the control had 1.09 kg/cm² (Table 3). Treatments delayed softening by preserving cell wall structure.

3.8. pH

pH values were significantly different among treatments ($P \leq 0.01$, Table 2). The lowest pH was CSE0L6 (5.33) and the highest control pH was 9.40 (Table 3). Coatings and blue light increased acidity by preserving organic acids.

3.9. Ion Leakage

Ion leakage varied significantly ($P \leq 0.01$, Table 2). The control had the highest leakage (77.82%), while AE0L12 had the lowest (22.89%, Table 3). Treatments maintained membrane integrity.

3.10. Chilling

Chilling injury was significantly affected ($P \leq 0.01$, Table 2). The lowest injury occurred in CSE1L12 (23.2%), and the control showed the highest (77.21%, Table 3). Treatments reduced physiological disorders associated with low temperatures.

3.11. Chlorophyll

Chlorophyll content differed significantly ($P \leq 0.01$, Table 2). CSE2L6 showed the highest content (6.23 mg/mL), whereas the control had 1.52 mg/mL (Table 3). Treatments preserved chlorophyll and photosynthetic pigments.

3.12. Fruit Diameter

Diameter changes were significant ($P \leq 0.01$, Table 2). AE1L6 showed the greatest increase (4.88 mm), CSE0L24 the smallest (2.77 mm), and control was 4.98 mm (Table 3). Treatments helped maintain fruit size by reducing water loss and tissue collapse.

3.13. Internal Cavity Diameter

Internal cavity diameter change differed significantly ($P \leq 0.01$, Table 2). PE1L12 had the smallest change (1.65 mm), and control the largest (4.79 mm, Table 3). Coatings stabilized internal tissue structure.

3.14. Skin-to-Pulp Ratio

Skin-to-pulp ratio was significantly affected ($P \leq 0.01$, Table 2). The highest ratio was in CSE2L24 (43.07 g), the lowest in PE2PL24 (19.8 g), and control showed 11.07 g (Table 3). Treatments preserved fruit tissues and reduced structural degradation.

Discussion

The postharvest quality and storability of feijoa fruits are significantly influenced by environmental factors, chemical treatments, and light conditions. In this study, the combined application of short-term blue light (6 h), chitosan edible coatings, and ethylene absorbers (CSE2L6) had the most pronounced effects across fifteen measured quality attributes. This integrated approach enhanced fruit durability, reduced decay, and maintained physicochemical and biochemical traits. The observed effects are consistent with prior studies showing that combined light and coating treatments synergistically improve postharvest performance in perishable fruits (Wei et al., 2022; Zhang et al., 2023). CSE2L6 significantly extended the storage life of feijoa, maintaining fruit integrity longer than any single or dual treatment. Short-term blue light suppressed ethylene biosynthesis, slowing senescence and tissue degradation (Li et al., 2021; Zhang et al., 2022). Chitosan coatings reduced water loss by acting as semi-permeable barriers, preserving firmness and preventing tissue collapse (Jahani et al., 2023; Zhang et al., 2023). Ethylene absorbers like biochar further delayed ripening by lowering environmental ethylene levels (Kutahneci et al., 2020; Asrey et al., 2023). Similar improvements in durability were reported in strawberries and kiwifruit when using blue light and chitosan coatings (Wei et al., 2022; Zhang et al., 2023). The respiration rate of feijoa fruits was significantly reduced under CSE2L6 treatment. Blue light inhibited respiratory enzymes, while chitosan coating restricted gas exchange, collectively lowering metabolic activity (Zhang et al., 2022). This reduction in respiration slows energy consumption and senescence, consistent with findings in strawberries and kiwifruit (Li et al., 2021; Sun et al., 2024). By moderating the metabolic rate, fruits maintained higher structural integrity and delayed spoilage. CSE2L6 decreased ethylene emission by approximately 52% relative to the control. Blue light suppressed ACC synthase and ACC oxidase activities, key enzymes in ethylene biosynthesis (Li et al., 2021). Concurrently, ethylene absorbers such as biochar trapped atmospheric ethylene, further slowing ripening (Kutahneci et al., 2020; Asrey et al., 2023). Comparable reductions in ethylene were observed in kiwifruit and strawberries under similar treatments, contributing to extended shelf life (Wei et al., 2022; Zhang et al., 2023). Decay in CSE2L6-treated fruits was significantly lower than in control fruits. The combined effect of reduced ethylene, lower respiration, and chitosan-induced antimicrobial activity mitigated microbial growth (Xu et al., 2021; Jahani et al., 2023). Similar reductions in decay were documented in guava, tomatoes, and strawberries using chitosan coatings (Wei et al., 2022; Zhang et al., 2023). These findings demonstrate the potential of integrative treatments to preserve both safety and quality during extended storage. Firmness was maintained at higher levels in CSE2L6-treated fruits, reflecting reduced cell wall degradation. Chitosan acted as a physical barrier preventing water loss, while blue light enhanced phenolic and flavonoid accumulation, protecting the cell wall (Wei et al., 2022; Zhang et al., 2023). Similar effects on firmness were reported in strawberries and kiwifruit, where combined light and coating treatments slowed softening (Jahani et al., 2023; Sun et al., 2024). Maintaining firmness is critical for consumer acceptability and mechanical handling. The browning index was lower under CSE2L6 treatment. Blue light and chitosan synergistically increased antioxidant enzyme activities, reducing oxidative damage to phenolic compounds and membranes (Xu et al., 2021; Zhang et al., 2023). Comparable decreases in enzymatic browning were observed in kiwifruit and apples under light and chitosan treatments, indicating preservation of visual quality (Wei et al., 2022). CSE2L6 minimized weight loss by reducing transpiration and water evaporation. Chitosan coating functioned as a semi-permeable barrier, while lower respiration reduced metabolic water loss (Jahani et al., 2023). Similar effects have been reported in strawberries and kiwifruit, where coatings and light exposure preserved fresh weight and marketable yield (Wei et al., 2022; Zhang et al., 2023). Dry matter content remained stable under CSE2L6 treatment due to reduced respiration and water loss. Light and coating treatments slowed the utilization of soluble sugars for

metabolism, preserving nutritional quality (Li et al., 2021; Sun et al., 2024). Comparable findings were reported in kiwifruit and guava under postharvest blue light and chitosan treatments. CSE2L6 maintained stable pH levels, likely due to slowed organic acid catabolism under reduced respiration and ethylene suppression (Asrey et al., 2023; Zhang et al., 2023). Similar pH stabilization was observed in strawberries and apples treated with chitosan coatings and light interventions, contributing to extended freshness and sensory quality (Wei et al., 2022). CSE2L6 decreased ion leakage, indicating preserved membrane integrity. Blue light and chitosan enhanced antioxidant defenses and secondary metabolite accumulation, protecting cell membranes from oxidative stress (Xu et al., 2021; Wei et al., 2022). Similar reductions in EL were reported in strawberries and kiwifruit, supporting the role of integrative treatments in maintaining cellular homeostasis. Chilling injury was mitigated under CSE2L6 treatment. Reduced respiration and enhanced antioxidant activity prevented lipid peroxidation and membrane disruption (Jahani et al., 2023; Zhang et al., 2023). Kiwifruit and mango studies similarly reported that chitosan coatings combined with light exposure alleviated cold-induced tissue damage. Chlorophyll retention was higher in CSE2L6-treated fruits, reflecting delayed senescence and reduced oxidative degradation (Wei et al., 2022; Zhang et al., 2023). Comparable effects were documented in apples and kiwifruit treated with blue light and chitosan coatings, preserving green color and photosynthetic pigments. The maintenance of fruit diameter under CSE2L6 indicates limited tissue shrinkage and water loss. Coating and reduced respiration slowed cellular contraction, similar to observations in strawberries and kiwifruit (Li et al., 2021; Sun et al., 2024). Maintaining size is important for market quality and consumer appeal. CSE2L6 preserved the internal cavity size, reflecting protection of tissue integrity. The combination of blue light, chitosan, and ethylene absorbers prevented collapse and maintained hydration (Asrey et al., 2023; Zhang et al., 2023). Similar effects were reported in kiwifruit and pomegranate under comparable postharvest treatments. The skin-to-pulp ratio was maintained in CSE2L6-treated fruits, demonstrating protection of peel and pulp tissues. Reduced weight loss and cell wall degradation under this treatment preserved structural balance (Wei et al., 2022; Jahani et al., 2023). Similar observations were made in strawberries and kiwifruit, highlighting the role of integrative strategies in sustaining fruit morphology. Collectively, these studies indicate that a combination of blue light exposure, chitosan-based coatings, and ethylene management can significantly enhance the postharvest quality of fruits and edible flowers. The present study corroborates these findings by showing that treatments such as blue light irradiation and edible coatings maintained higher chlorophyll content, reduced ion leakage, and preserved tissue firmness in feijoa fruits. The observed improvements in Rsm (ratio of skin to mesocarp) and pH further suggest a retardation of senescence and better maintenance of structural integrity, aligning with previous observations in citrus and strawberries (Ballester and Lafuente, 2016; Liu et al., 2019). These integrated approaches not only delay biochemical and physiological deterioration but also maintain nutritional and sensory attributes, which are critical for both marketability and consumer acceptance. In conclusion, combining light quality manipulation with biopolymer-based coatings and ethylene regulation offers a comprehensive strategy to optimize postharvest longevity and quality. Future research should focus on optimizing treatment intensity and duration, as well as exploring synergistic effects of multiple interventions to further improve the shelf life of perishable horticultural commodities.

Conclusion

In summary, the integration of light quality manipulation, biopolymer-based coatings, and ethylene regulation provides an effective strategy to enhance postharvest longevity and maintain quality. Future studies should aim to optimize treatment intensity and duration and investigate potential synergistic effects of combined interventions to further extend the shelf life of perishable horticultural products.

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Conflicts of Interest

The authors declare no conflict of interest.

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