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Influence of Storage Conditions on the Physicochemical Quality of Selected Non-Climacteric Fruits

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A B S T R A C T

This study aimed to evaluate the effects of different storage conditions on the physicochemical quality of selected non-climacteric fruits, namely lemon (Citrus limon), starfruit (Averrhoa carambola), strawberry (Fragaria × ananassa), and orange (Citrus sinensis). A total of six storage treatments combining temperature (room, refrigeration, freezing) and packaging (with or without plastic wrap) were applied for a six-day period. Key quality indicators, including color parameters (L*, a*, b*) and weight loss, were monitored on days 0, 2, 4, and 6. Storage duration proved to have a more significant impact on fruit quality than temperature or packaging, particularly concerning color degradation and mass loss. The L* and b* values of most fruits peaked on day 2, indicating optimal visual appearance, before declining due to pigment degradation and senescence. Strawberry showed the highest sensitivity to storage conditions, with weight loss reaching over 77% under room temperature without packaging. In contrast, citrus fruits like lemon and orange maintained relatively stable mass and color, likely due to their thick cuticles and lower respiration rates. Plastic wrapping significantly reduced weight loss across all fruit types by maintaining a high-humidity microenvironment. These findings suggest that a combination of short-term cold storage and moisture-retentive packaging is the most effective strategy for preserving the postharvest quality of non-climacteric fruits. The study provides practical insights for small-scale distributors and consumers in tropical climates to extend shelf life and reduce postharvest losses.

Keywords: Non-climacteric, storage condition, color stability, weight loss, cold storage, packaging.

Introduction

Postharvest losses in fresh fruit commodities continue to pose significant challenges to the global food supply chain, particularly for highly perishable horticultural products. Non-climacteric fruits—such as lemon (*Citrus limon*), starfruit (*Averrhoa carambola*), strawberry (*Fragaria × ananassa*), and orange (*Citrus sinensis*)—are characterized by their inability to continue ripening after harvest due to minimal ethylene production and low respiration activity (Perotti et al., 2023). Their postharvest quality is highly dependent on storage conditions, which influence visual appearance, nutritional content, and shelf life. Without proper handling, these fruits are prone to rapid quality degradation manifested through discoloration, wilting, or microbial spoilage (Hossain et al., 2020)

Cold storage has long been recognized as an effective method to reduce postharvest metabolic activity and delay senescence in fruits. For example, Mao et al., (2022) reported that low-temperature storage could significantly preserve the anthocyanin stability in strawberries. In terms of color retention, storage temperature and relative humidity play a critical role in modulating pigment degradation, such as the oxidation of carotenoids and anthocyanins, which can be quantitatively monitored using CIELAB color parameters (L*, a*, b*) (Lombardelli et al., 2021). The protective effect of packaging has also been studied, with findings showing that polyethylene wrapping can reduce moisture loss and preserve firmness in strawberries and oranges (Begum et al., 2023). In addition to visual attributes, weight loss is a vital indicator of postharvest quality deterioration, as it reflects the extent of moisture evaporation and metabolic activity. Research by H. Abd El-Aziz, (2020) revealed that fruits like bananas and guavas stored at ambient temperatures experienced rapid weight reduction due to high transpiration rates, whereas cold storage significantly mitigated this loss.

Although several studies have addressed the individual effects of temperature or packaging on postharvest fruit quality, comparative evaluations across different non-climacteric fruits under unified storage treatments remain scarce. Furthermore, interactions between storage duration and fruit-specific responses, especially those affecting color parameters, are not yet fully understood. Previous studies often focused on a single fruit species or microbial decay, whereas few have assessed the visual quality changes over time as a function of storage temperature and packaging across multiple fruit types (Gómez et al., 2020; Muley et al., 2022). These knowledge gaps underscore the need for integrative research considering postharvest quality retention's temporal and environmental dimensions.

The present study investigates the influence of storage conditions—specifically ambient, refrigerated, and frozen environments, with and without plastic packaging—on the physicochemical characteristics of four commercially significant non-climacteric fruits. Color parameters (L*, a*, b*), fruit weight change, and weight loss are employed as objective indicators of physical quality over a six-day storage period. This research aims to provide a comparative

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analysis of storage-induced physical changes to identify optimal storage strategies for extending shelf life while preserving the aesthetic and market value of non-climacteric fruits. The findings are expected to improve postharvest handling protocols, particularly for small- to medium-scale supply chains in tropical and subtropical regions.

Materials and Methods

Sample Selection and Preparation

Four types of non-climacteric fruits—lemon (*Citrus limon*), starfruit (*Averrhoa carambola)*, strawberry (*Fragaria* × *ananassa*), and sweet orange (*Citrus sinensis*)—were selected for uniformity in size, maturity stage, and absence of mechanical or microbial damage. All fruits were sourced from a local fresh market in Semarang, Indonesia, and were processed on the same day as procurement. Prior to treatment, the fruits were rinsed with distilled water and air-dried at ambient temperature (25 ± 2°C) to eliminate surface moisture.

Experimental Design

A completely randomized design (CRD) was applied to assess the effects of storage conditions. Six storage treatments were assigned to each fruit type, namely:

A: Room temperature (25 ± 2°C) without packaging

B: Room temperature with plastic wrapping

C: Refrigeration (4 ± 1°C) without packaging

D: Refrigeration with plastic wrapping

E: Freezing (-18 ± 2°C) without packaging

F: Freezing with plastic wrapping

Fruits were stored for six days, and data collection was conducted at four time intervals: day 0 (initial), day 2, day 4, and day 6. Each treatment group included three biological replicates (n = 3).

Weight Loss Measurement

The weight loss of each fruit was determined using a digital analytical balance (accuracy ±0.01 g). Fruits were individually weighed at the start of the experiment (initial weight, Wo) and at each storage interval (final weight, Wt). Weight loss was calculated using the following formula:

Weight Loss (%) = (Wo-Wt)/Wo x100

This value represents the mass lost due to water evaporation and physiological degradation during storage. All measurements were conducted under aseptic conditions to prevent external contamination.

Color Measurement

Surface color was evaluated using a portable **colorimeter**, following the CIE Lab* **color** space. L* denotes brightness (light-dark), a* indicates the red-green axis, and b* represents the yellow-blue axis. Each fruit was measured at three equidistant points around the equator, and the average value was used for analysis.

Statistical Analysis

All data were subjected to one-way ANOVA to evaluate the effects of storage temperature, packaging condition, and storage duration on weight loss and color parameters (L*, a*, b*). Differences among means were analyzed using Tukey's HSD test at a significance level of $p < 0.05$. Statistical analysis was performed using IBM SPSS Statistics version 2.1.

Results and Discussion

*Change of CIE L*a*b* Color Parameters*

Table 1 presents orange peels' color parameter changes (L*, a*, b*) under various storage conditions over six days. These values reflect the visual attributes of brightness, red-green hue, and yellow intensity, which are commonly used to evaluate postharvest color stability in fruits.

Table 1. Changes in CIE L*a*b* Color Parameters of Orange Peel Under Different Storage Conditions and Durations

Storage Temperature	L*	a*	b*
	Day 0		

	A (Room)	34.28 ± 8.91^{a}	-3.60 ± 0.17^{a}	17.02 ± 8.74^{a}
	B (Room and wrapped in plastic)	30.18 ± 1.33^{a}	-3.73 ± 0.18^{a}	13.35 ± 4.14^{a}
	C (Refrigerator)	34.68 ± 5.26^{a}	-4.63 ± 0.13^{a}	17.25± 3.86^{a}
	D (Refrigerator and wrapped in plastic)	32.51 ± 5.56^{a}	-4.78 ± 0.82^{a}	18.10 ± 3.03^{a}
	E (Freezer)	36.74 ± 1.92^{a}	-4.13± 0.35^{a}	19.13 ± 3.66^{a}
	F (Freezer and wrapped in plastic)	30.26 ± 6.45^{a}	-4.40 ± 2.26^{a}	13.36 ± 7.07^{a}
		Day 2		
	A (Room)	63.03 ± 4.14^{b}	-5.28 ± 0.40^{b}	24.60 ± 10.27^{b}
	B (Room and wrapped in plastic)	64.90 ± 4.33^{b}	-6.08 ± 1.61^{b}	26.06 ± 6.96^{b}
	C (Refrigerator)	63.88± 0.59^{b}	-8.10 ± 0.28^{b}	26.38 ± 1.95^{b}
	D (Refrigerator and wrapped in plastic)	61.71 ± 6.77^{b}	-6.99 ± 1.03^{b}	27.13 ± 10.48^{b}
	E (Freezer)	56.68 ± 1.98^{b}	-5.28 ± 0.28^{b}	20.36 ± 1.75^{b}
	F (Freezer and wrapped in plastic)	56.62 ± 0.62^{b}	-6.69 ± 1.65^{b}	19.12 ± 2.12^{b}
Orange		**Day 4**		
	A (Room)	29.21 ± 2.25^{c}	-1.30 ± 1.41^{c}	14.31 ± 5.81^{c}
	B (Room and wrapped in plastic)	30.91 ± 3.75^{c}	-2.76 ± 1.41^{c}	11.84 ± 3.51^{c}
	C (Refrigerator)	36.70 ± 2.12^{c}	-5.30 ± 0.48^{c}	20.83 ± 7.25^{c}
	D (Refrigerator and wrapped in plastic)	28.99 ± 11.67^{c}	-3.84± 1.44^{c}	12.29 ± 0.30^{c}
	E (Freezer)	32.33 ± 1.40^{c}	-3.59 ± 0.83^{c}	20.81 ± 10.28^{c}
	F (Freezer and wrapped in plastic)	24.13 ± 7.91^{c}	-4.13 ± 2.93^{c}	15.27 ± 13.62^{c}
		Day 6		
	A (Room)	39.61 ± 8.78^{c}	-0.16 ± 3.20^{c}	22.21 ± 10.25^{c}
	B (Room and wrapped in plastic)	36.70 ± 0.06^{c}	-3.56 ± 0.51^{c}	21.92 ± 0.23^{c}
	C (Refrigerator)	29.04 ± 0.08^{c}	-3.72 ± 0.79^{c}	13.17 ± 0.38^{c}
	D (Refrigerator and wrapped in plastic)	32.74 ± 0.08^{c}	-3.77 ± 0.07^{c}	15.97 ± 0.18^{c}
	E (Freezer)	35.97 ± 0.30^{c}	-0.80 ± 1.07^{c}	26.30 ± 0.68^{c}
	F (Freezer and wrapped in plastic)	28.56 ± 0.62^{c}	-2.87 ± 1.80^{c}	20.51 ± 15.12^{c}

*Data are presented as mean ± standard deviation (n = 3). Different superscripts in the same column and row indicate significant differences ($p < 0.05$).

The results show that neither storage temperature nor packaging type had a statistically significant impact on the color attributes of orange peel. In contrast, storage duration significantly affected the L* (lightness), a* (red-green axis), and b* (yellow-blue axis) values, with a significance threshold of $p < 0.05$. Notably, L* and b* values increased markedly up to the second day of storage, signifying the peak of visual ripeness, after which both values began to decline. Meanwhile, the a* value remained relatively consistent throughout the storage period, suggesting that the red-orange pigmentation of the peel experienced minimal variation. Further examination revealed that the most pronounced changes in color parameters occurred between day 0 and day 2, and again between day 2 and day 4. These findings highlight the predominance of storage duration over temperature in influencing the visual appearance of orange peel. Accordingly, short-term storage of up to two days may preserve or even improve the fruit's external coloration, whereas extended storage leads to quality deterioration.

From a physiological standpoint, the lack of significant influence from temperature and packaging can be attributed to the stable metabolic activity of oranges stored under moderate thermal conditions, such as ambient or slightly chilled environments (Owoyemi et al., 2022). This metabolic stability limits the enzymatic degradation of color pigments (Y. Chen et al., 2023). Moreover, the orange peel's naturally thick and waxy cuticle provides a physical barrier that minimizes pigment alterations caused by environmental exposure over short storage periods (Lewandowska et al., 2020).

The early increase in L* and b* values up to day two is likely associated with the biosynthesis and accumulation of carotenoid pigments, including beta-cryptoxanthin, lutein, and β-carotene, which contribute to the peel's bright yellow-orange coloration. β-carotene is responsible for the bright yellow-orange color of the orange peel (Otani et al., 2020). Peak accumulation of these pigments reflects the optimal visual maturity of the fruit. However, the decrease in the L* and b* values after day 2 suggests the onset of pigment degradation due to aging and oxidative stress. This mechanism may involve enzymatic activities, particularly polyphenol oxidase (PPO) and peroxidase, which initiate the browning process in the skin (Derardja et al., 2022). The stability of a* values during storage is attributed to the lack of dominance of red pigments such as lycopene or anthocyanins in the sweet orange species used. Therefore, the red-green discoloration spectrum (a*) did not exhibit significant fluctuations within the observed storage period (Yan et al., 2023).

Table 2. Changes in CIE L*a*b* Color Parameters of Strawberry Under Different Storage Conditions and Durations

	Storage Temperature	L*	a*	b*
		Day 0		
	A (Room)	25.73 ± 4.71	16.47 ± 5.19^{a}	7.67 ± 3.72
	B (Room and wrapped in plastic)	21.77 ± 3.21	15.54 ± 3.22^{ab}	8.96 ± 1.78
	C (Refrigerator)	20.12 ± 3.85	13.31 ± 1.32^{ab}	5.87 ± 0.16
	D (Refrigerator and wrapped in plastic)	19.98 ± 1.67	12.29 ± 4.40^{ab}	5.33 ± 2.96
	E (Freezer)	16.94 ± 2.74	6.71 ± 2.62^{ab}	3.40 ± 2.43
	F (Freezer and wrapped in plastic)	20.63 ± 2.50	14.31 ± 1.06^{b}	6.52 ± 0.62
		Day 2		
	A (Room)	15.88 ± 0.71	5.23 ± 1.85^{a}	2.66 ± 0.65
	B (Room and wrapped in plastic)	19.06 ± 2.18	9.79 ± 1.09^{ab}	3.95 ± 0.61
	C (Refrigerator)	22.72 ± 6.14	13.87 ± 4.71^{ab}	7.12 ± 2.63
	D (Refrigerator and wrapped in plastic)	20.77 ± 9.72	14.47 ± 8.47^{ab}	6.14 ± 5.54
	E (Freezer)	18.63 ± 5.05	14.85 ± 3.63^{ab}	5.99 ± 3.27
	F (Freezer and wrapped in plastic)	21.62 ± 3.03	16.38 ± 3.51^{b}	7.68 ± 0.48
Strawberry		Day 4		
	A (Room)	19.92 ± 2.06	7.80 ± 0.25^{a}	2.22 ± 0.25
	B (Room and wrapped in plastic)	20.86 ± 0.91	9.46 ± 0.71^{ab}	4.32 ± 1.53
	C (Refrigerator)	21.68 ± 0.68	14.84 ± 1.41^{ab}	6.23 ± 0.33
	D (Refrigerator and wrapped in plastic)	22.68 ± 5.40	13.46 ± 2.09^{ab}	4.97 ± 2.22
	E (Freezer)	19.29 ± 0.27	14.18 ± 3.14^{ab}	4.68 ± 1.19
	F (Freezer and wrapped in plastic)	26.29 ± 8.22	17.94 ± 3.79^{b}	6.93 ± 2.25
		Day 6		
	A (Room)	15.33 ± 2.14	3.23 ± 3.52^{a}	0.20 ± 1.10
	B (Room and wrapped in plastic)	19.15 ± 6.49	2.93 ± 0.75^{ab}	1.41 ± 2.39
	C (Refrigerator)	30.67 ± 11.41	15.76 ± 2.15^{ab}	6.47 ± 0.18
	D (Refrigerator and wrapped in plastic)	27.39 ± 3.78	14.30 ± 3.42^{ab}	5.89 ± 1.99
	E (Freezer)	19.84 ± 0.17	7.84 ± 2.86^{ab}	2.01 ± 1.46
	F (Freezer and wrapped in plastic)	30.37 ± 18.48	18.26 ± 12.73^{b}	6.04 ± 4.89

*Data are presented as mean ± standard deviation (n = 3). Different superscripts in the same column and row indicate significant differences ($p < 0.05$).

The color alteration of strawberries during storage (Table 2) is predominantly influenced by the duration of storage rather than by the temperature or packaging method. Observations indicated that the second day of storage represents the apex of the fruit's visual quality, as evidenced by the highest L* (brightness), a* (red intensity), and b* (yellow component) values. The vibrant red hue and fresh appearance at this juncture suggest the stability of anthocyanins, the primary pigments responsible for the red coloration of strawberries. However, subsequent to this peak, the fruits begin to exhibit signs of withering and a reduction in color intensity, primarily due to pigment degradation, which is largely attributed to enzymatic activities, such as polyphenol oxidase (PPO) and oxidative stress during storage (Serra et al., 2021).

Statistical analysis revealed that L* and b* values were not significantly different between temperature treatments or storage durations ($p > 0.05$). This suggests that the brightness and yellow component of strawberries remain relatively stable during storage, possibly because supporting pigments, such as flavonols or minor carotenoids, are not readily degraded over a short storage period. Conversely, the a* value, indicative of red color intensity, showed significant differences between storage temperatures ($p < 0.05$), although it was unaffected by storage duration. Strawberries stored at room temperature (A) exhibited the highest a* values, indicating that warm temperatures could stimulate anthocyanin biosynthesis to a certain extent (Teo et al., 2022). In contrast, storage at freezing temperatures, particularly with plastic wrapping (F), resulted in a significant decrease in a* value. This is likely due to damage to the cell structure caused by freezing as well as denaturation of anthocyanins, which are known to be highly sensitive to extremely low temperatures (Y. Chen et al., 2023).

Table 3. Changes in CIE L*a*b* Color Parameters of Starfruit Under Different Storage Conditions and Durations

	Storage Temperature	**L***	**a***	**b***
		Day 0		
	A (Room)	22.51 ± 7.14	-1.05 ± 1.00	12.71 ± 3.44
	B (Room and wrapped in plastic)	20.09 ± 5.61	-0.15 ± 0.49	10.52 ± 1.90
	C (Refrigerator)	23.69 ± 5.28	-0.11 ± 1.54	15.75 ± 5.13
	D (Refrigerator and wrapped in plastic)	29.49 ± 1.97	-1.86 ± 0.06	13.85 ± 2.02
	E (Freezer)	22.59 ± 1.23	0.50 ± 2.26	11.78 ± 5.03
	F (Freezer and wrapped in plastic)	34.16 ± 13.35	1.22 ± 2.83	14.84 ± 6.45
		Day 2		
	A (Room)	44.36 ± 30.77	7.34 ± 2.88	27.16 ± 18.53
	B (Room and wrapped in plastic)	38.56 ± 25.29	3.10 ± 3.14	19.72 ± 12.47
	C (Refrigerator)	47.57 ± 25.64	2.96 ± 1.78	27.90 ± 15.44
	D (Refrigerator and wrapped in plastic)	39.71 ± 24.93	1.58 ± 3.73	21.80 ± 13.63
	E (Freezer)	40.14 ± 35.33	4.99 ± 0.78	18.80 ± 18.07
	F (Freezer and wrapped in plastic)	36.78 ± 21.98	3.09 ± 0.49	17.25 ± 9.83
Starfruit		**Day 4**		
	A (Room)	25.58 ± 0.99	5.62 ± 1.90	12.44 ± 1.73
	B (Room and wrapped in plastic)	25.75 ± 4.03	2.32 ± 0.62	11.99 ± 2.84
	C (Refrigerator)	22.86 ± 7.30	0.73 ± 0.83	9.36 ± 8.03
	D (Refrigerator and wrapped in plastic)	32.05 ± 11.47	-0.08 ± 1.36	10.55 ± 0.92
	E (Freezer)	14.85 ± 5.30	1.31 ± 1.00	1.49 ± 2.19
	F (Freezer and wrapped in plastic)	24.57 ± 18.88	1.26 ± 0.54	2.80 ± 3.87
		Day 6		
	A (Room)	19.21 ± 1.65	7.14 ± 0.96	12.42 ± 1.10
	B (Room and wrapped in plastic)	18.16 ± 4.81	3.83 ± 0.35	10.41 ± 5.53
	C (Refrigerator)	19.91 ± 0.30	2.33 ± 1.51	10.63 ± 1.74
	D (Refrigerator and wrapped in plastic)	22.03 ± 5.11	0.48 ± 1.39	13.82 ± 3.54
	E (Freezer)	16.23 ± 8.92	1.84 ± 0.74	4.84 ± 5.80

F (Freezer and wrapped in plastic)	16.82 ± 5.57	2.51 ± 1.82	7.00 ± 6.36

*Data are presented as mean ± standard deviation (n = 3). Different superscripts in the same column and row indicate significant differences ($p < 0.05$).

The color of starfruit (Table 3) exhibits significant changes throughout the storage period, with the second day marking the highest intensity and brightness of its yellow-reddish tones. This point reflects the fruit's peak visual ripeness, vital for consumer acceptance due to its influence on external appearance. Following this stage, the fruit's coloration begins to fade due to aging processes and the breakdown of pigments, leading to a decline in visual quality (Kapoor et al., 2022). This degradation is closely linked to elevated activity of oxidative enzymes, particularly peroxidase and polyphenol oxidase (PPO), which catalyze the deterioration of color-related compounds (Serra et al., 2021).

Statistical analysis revealed that the storage temperature did not significantly affect the color parameters L*, a*, and b* ($p > 0.05$). However, storage duration significantly affected all three parameters ($p < 0.05$), confirming that time exerted a more decisive influence on visual quality changes than temperature. The L* value increased significantly on day 2 compared to days 0, 4, and 6, indicating a temporary increase in brightness due to pigment accumulation during early storage (Somogyi et al., 2021). Thereafter, it declined as senescence and skin browning occurred. The a* value exhibited significant variation across days 0, 2, and 6, indicating increased red pigmentation, likely resulting from ripening-related color transition. The b* value also increased on day 2, demonstrating an enhanced yellow color intensity, typically associated with carotenoid accumulation (e.g., lutein and beta-carotene).

Table 4. Changes in CIE L*a*b* Color Parameters of Lemon Under Different Storage Conditions and Durations

	Storage Temperature	**L***	**a***	**b***
		Day 0		
	A (Room)	68.79 ± 18.99[a]	5.86 ± 7.67[a]	19.68 ± 39.34[a]
	B (Room and wrapped in plastic)	71.16 ± 30.68[a]	3.35 ± 9.47[a]	18.63 ± 34.47[a]
	C (Refrigerator)	81.70 ± 35.02[a]	7.05 ± 8.33[a]	29.80 ± 28.09[a]
	D (Refrigerator and wrapped in plastic)	98.03 ± 62.35[a]	5.44 ± 10.58[a]	30.32 ± 27.21[a]
	E (Freezer)	96.88 ± 56.37[a]	8.36 ± 2.63[a]	38.02 ± 16.12[a]
	F (Freezer and wrapped in plastic)	55.10 ± 2.38[a]	10.81 ± 3.19[a]	49.21 ± 7.09[a]
		Day 2		
	A (Room)	42.76 ± 15.78[c]	9.67 ± 2.76[ab]	39.27 ± 10.39[ab]
	B (Room and wrapped in plastic)	47.28 ± 16.94[c]	8.34 ± 1.27[ab]	41.13 ± 12.74[ab]
	C (Refrigerator)	41.44 ± 27.18[c]	8.43 ± 2.59[ab]	37.13 ± 22.13[ab]
	D (Refrigerator and wrapped in plastic)	28.04 ± 14.96[c]	5.19 ± 0.61[ab]	24.30 ± 12.05[ab]
	E (Freezer)	37.56 ± 23.19[c]	7.82 ± 4.50[ab]	34.79 ± 21.00[ab]
	F (Freezer and wrapped in plastic)	32.71 ± 19.73[c]	6.04 ± 3.34[ab]	28.45 ± 16.84[ab]
Lemon		**Day 4**		
	A (Room)	61.41 ± 12.57[b]	13.39 ± 1.03[b]	56.26 ± 8.06[b]
	B (Room and wrapped in plastic)	65.41 ± 2.96[b]	12.74 ± 2.49[b]	57.17 ± 2.76[b]
	C (Refrigerator)	59.62 ± 2.40[b]	12.31 ± 4.03[b]	53.42 ± 3.03[b]
	D (Refrigerator and wrapped in plastic)	59.21 ± 0.44[b]	10.76 ± 4.55[b]	50.96 ± 0.23[b]
	E (Freezer)	53.04 ± 1.73[b]	9.11 ± 0.27[b]	47.48 ± 1.10[b]
	F (Freezer and wrapped in plastic)	53.90 ± 8.94[b]	7.90 ± 0.57[b]	44.42 ± 6.90[b]
		Day 6		
	A (Room)	43.70 ± 12.25[c]	10.60 ± 2.06[ab]	39.51 ± 10.65[ab]
	B (Room and wrapped in plastic)	44.36 ± 3.62[c]	14.49 ± 9.07[ab]	37.60 ± 3.56[ab]

C (Refrigerator)	53.74 ± 7.01^{c}	12.58 ± 5.71^{ab}	47.17 ± 6.52^{ab}
D (Refrigerator and wrapped in plastic)	48.68 ± 6.14^{c}	8.53 ± 2.22^{ab}	40.13 ± 4.91^{ab}
E (Freezer)	46.44 ± 9.08^{c}	7.50 ± 1.36^{ab}	41.45 ± 5.98^{ab}
F (Freezer and wrapped in plastic)	46.63 ± 9.72^{c}	6.48 ± 0.54^{ab}	38.42 ± 6.56^{ab}

*Data are presented as mean ± standard deviation (n = 3). Different superscripts in the same column and row indicate significant differences ($p < 0.05$).

During storage, the color of lemons (Table 4) undergoes significant changes that are more influenced by storage duration than by storage temperature. Color parameters such as L* (brightness), a* (green-red component), and b* (blue-yellow component) showed fluctuations reflecting postharvest physiological and biochemical processes such as pigment degradation, color transition, and changes in fruit skin texture.

The b* value, which represents the intensity of the yellow color, peaked on day 4, indicating the best visual phase of the lemon fruit before it started to degrade. The a* value increased over time, indicating a color transition from green to reddish, a standard indicator of the ripening process in lemons. Statistical analysis showed that storage duration had a significant effect on all three color parameters (L*, a*, and b*) ($p < 0.05$), whereas storage temperature showed no significant effect ($p > 0.05$). This means that the time factor is an essential determinant of the deterioration of the visual quality of lemons during storage, most likely due to pigment degradation (mainly chlorophyll and carotenoids) caused by senescence processes and enzymatic activity, metabolic changes such as increased reactive oxygen species (ROS), which trigger pigment oxidation, and changes in skin surface texture, which can affect light reflectance and color perception (A. Chen et al., 2021; Pott et al., 2020).

The four non-climacteric fruits—oranges, strawberries, starfruit, and lemons—exhibit different trends in color change. This is also influenced by their fruit classification, namely tropical and subtropical fruits. For oranges and starfruit, the highest L-value was observed on the second day, while for lemons, it was on the fourth day. Meanwhile, strawberries showed a declining trend in their L-value from day 2 to day 4, except when stored in refrigerator temperatures. Regarding the a and b values: for oranges, the a-value generally decreased from the first to the last day of observation, while the b-value tended to fluctuate. For strawberries, both a and b values fluctuated. Starfruit showed a general increase in its a-value and a fluctuating b-value. Meanwhile, lemons had optimal a and b values on the fourth day.

Change of Fruit Weight

The variation in fruit mass (Fig.1-4) observed across different storage conditions and durations reflects the physiological responses of each fruit type to environmental factors such as temperature and packaging. Weight loss in fresh produce is primarily driven by transpiration and respiration processes, which result in moisture evaporation and carbon substrate utilisation. These losses are strongly affected by the fruit's surface morphology, skin permeability, metabolic rate, and ambient humidity (Khanal et al., 2021; Strano et al., 2022)

Oranges exhibited relatively stable fruit mass throughout the storage period, particularly under plastic-wrapped treatments (B and D), where weight loss was negligible. This is consistent with previous studies showing that citrus fruits have a natural advantage in water retention due to their thick, waxy cuticle and relatively low surface permeability (Jiang et al., 2022; Khanal et al., 2021)In contrast, treatment A (room temperature without packaging) led to a more pronounced decrease in mass by day 6, indicating higher transpiration rates in the absence of humidity control. Plastic wrapping's effectiveness in reducing weight loss is attributed to its ability to create a high-humidity microenvironment that lowers the vapor pressure deficit between the fruit surface and surrounding air (Mulyawanti et al., 2022).

Due to their soft epidermis, high respiration rate, and lack of a protective wax layer, strawberries experienced the most significant mass reduction, up to nearly 60% in treatment A. These observations align with Hurtado et al., (2021) who reported that strawberries are highly sensitive to water loss when stored under ambient conditions. Refrigerated storage combined with plastic wrapping (treatment D) was the most effective in minimizing moisture loss, reducing weight loss to under 10% by day 6. This is in agreement with Hou et al., (2021), which emphasized that maintaining high relative humidity and low temperature significantly curtails transpiration in soft-skinned fruits. Conversely, while treatments E and F (freezing) preserved mass during storage, they pose a risk of structural damage from ice crystal formation, which may lead to drip loss upon thawing (Fadiji et al., 2021).

Starfruit showed moderate weight loss across treatments, with a particularly noticeable decrease under treatment A, highlighting its vulnerability to dehydration in ambient air. The shape and surface area of starfruit, combined with relatively thin skin, likely facilitate higher transpiration rates. Treatment C (refrigeration without plastic) displayed large variation in mass, which may be due to differences in individual fruit surface area or cuticle integrity. The benefit of plastic packaging in reducing mass loss was evident in treatments D and F, in line with previous reports that enclosed packaging mitigates moisture loss by maintaining a saturated atmosphere around the fruit (Lufu et al., 2021). Nonetheless, the risk of condensation and microbial spoilage within sealed packaging must be managed through optimized ventilation.

Similar to oranges, Lemons maintained fruit mass relatively well across all treatments, particularly under refrigerated and plastic-wrapped conditions. The thick and oil-rich rind of lemons provides an effective barrier against moisture diffusion (Jiang et al., 2022). Treatments B and D showed minimal weight loss, underscoring the efficacy of combined low temperature and plastic wrapping. Weight stability was preserved under freezing conditions (E and F), although the long-term sensory quality and texture may still be compromised. These results confirm that citrus fruits, due to their physiological structure, are less prone to rapid water loss compared to other non-climacteric fruits (Strano et al., 2022).

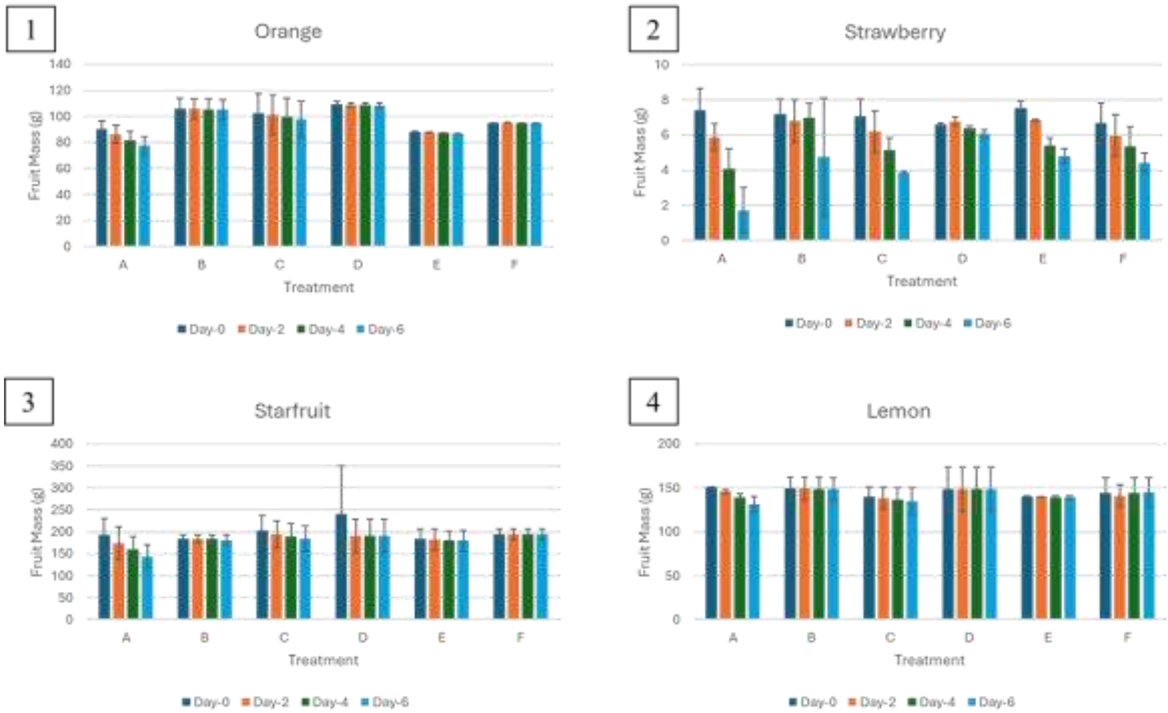

Fig. 1-4. Mass Change of Selected Non-Climacteric Fruit Under Different Storage Conditions and Durations

In summary, the data demonstrate that cold storage combined with plastic packaging consistently offers the most effective strategy for minimizing postharvest weight loss across all fruit types. This combination reduces the rate of transpiration and respiration by lowering temperature and maintaining high relative humidity, thereby preserving cellular water and delaying senescence. These findings align with prior studies that advocate for integrated storage management to extend shelf life and maintain postharvest quality (Anusha et al., 2024)

Weight Loss

Table 5 summarizes the percentage of weight loss for four non-climacteric fruits—orange, strawberry, starfruit, and lemon—under six different storage treatments. The data are presented as mean ± standard deviation (n = 3), with different superscript letters indicating statistically significant differences ($p < 0.05$) within and across fruit types.

Table 5. Weight Loss of Selected Non-Climacteric Fruit Under Different Storage Conditions and Durations

Storage Treatment	Non-Climacteric Fruit			
	Orange	Strawberry	Starfruit	Lemon
A	14.346±1.63^{aB}	77.741±13.56^{aA}	24.947±1.03^{aB}	13.250±5.79^{aB}
B	0.712±0.04^{bA}	36.404±39.14^{bA}	1.309±1.41^{bB}	0.635±0.21^{bB}
C	4.017±0.93^{bB}	44.855±8.55^{bA}	9.129±1.03^{bB}	3.642±2.87^{bB}
D	0.716±0.63^{bB}	7.774±2.47^{bA}	15.972±21.94^{bB}	0.209±0.08^{bB}
E	1.509±0.38^{bB}	35.747±8.81^{bA}	1.575±0.24^{bB}	0.543±0.36^{bB}
F	0.358±0.03^{bB}	32.135±19.71^{bA}	-0.072±0.35^{bB}	-0.442±0.31^{bB}

*Data are presented as mean ± standard deviation (n = 3). Different superscripts in the same column and row indicate significant differences ($p < 0.05$).

The weight loss of oranges varied significantly across storage treatments, with the highest value observed in treatment A (14.35 ± 1.63%), which was statistically different from most other treatments (superscript A). This result confirms that room temperature without packaging accelerates water loss due to high transpiration rates, even in fruits with protective thick rinds. Treatments B, D, and F—representing storage with plastic packaging under ambient, refrigerated, and frozen conditions, respectively—showed minimal weight losses (0.71%, 0.72%, and 0.36%), all bearing superscript B, indicating no significant differences among them. This supports the role of plastic wrapping in maintaining a high-humidity microenvironment that reduces vapor pressure deficit and slows down moisture loss. The intermediate loss in treatment C (refrigeration without packaging, 4.02%) and E (freezer without packaging, 1.51%) indicates that while temperature reduction slows respiration, the absence of packaging still permits considerable water evaporation. These findings are consistent with previous reports suggesting that low temperatures combined with packaging significantly reduce postharvest water loss in citrus fruits (Strano et al., 2022)

Among all fruits analyzed, strawberries experienced the most severe weight loss, particularly in treatment A (77.74 ± 13.56%), which was significantly higher than all other treatments (superscript A). This extreme sensitivity to dehydration can be attributed to the fruit's soft, unprotected epidermis, high surface-area-to-volume ratio, and active stomata that facilitate rapid moisture loss. Treatment D (refrigerated with plastic) resulted in the lowest weight loss (7.77 ± 4.63%), statistically grouped under superscript B, and proven to be the most effective condition for minimizing desiccation. Intermediate weight loss values were observed in treatments B, C, E, and F (ranging from 32.13% to 44.86%), many of which were statistically similar (superscripts BA and B). These results confirm that strawberries benefit significantly from cold and humid environments, especially when combined with moisture-retentive packaging (Ikegaya et al., 2020). However, while freezing treatments showed some reduction in weight loss, tissue damage due to ice crystal formation may still compromise fruit quality after thawing (Sun et al., 2023)

Starfruit displayed moderate but variable weight loss depending on storage conditions. The highest loss occurred under treatment A (24.95 ± 1.03%), statistically different from all other treatments (superscript A), illustrating the fruit's susceptibility to ambient dehydration. In contrast, the lowest weight change was recorded under treatment F (−0.07 ± 0.35%), statistically grouped under superscript B, suggesting either moisture gain from condensation or negligible water loss. Treatments B, C, D, and E showed minor to moderate weight losses (1.3% to 15.97%), with overlapping superscripts indicating no statistically significant differences. The large standard deviation in treatment D (15.97 ± 21.94%) implies variability in fruit surface structure or packaging-induced condensation. Starfruit's semi-thin skin and rigid structure may facilitate uneven transpiration, but results confirm that storage with plastic wrapping and reduced temperature (especially freezing) effectively minimizes mass loss (Lameira et al., 2020). These outcomes support earlier findings that suggest moisture retention in tropical fruits can be improved through modified-atmosphere storage (Olveira-Bouzas et al., 2023).

Lemons showed weight loss trends similar to oranges, with the highest reduction in treatment A (13.25 ± 5.79%) and the lowest in treatment F (−0.44 ± 0.31%). Although the negative value in treatment F suggests a slight gain in weight, possibly due to moisture condensation within the plastic packaging during freezing, it was not significantly different from other low-loss treatments (superscript B). Treatments B, D, and E (ranging from 0.20% to 0.63%) also resulted in low weight loss, statistically grouped, confirming the effectiveness of both refrigeration and packaging in preserving fruit mass. Treatment C (refrigeration without packaging) exhibited moderate loss (3.64%), indicating that packaging provides additional protection against water vapor exchange (Ji et al., 2022). The lemon's thick, oil-rich cuticle contributes to its natural resistance to transpiration; however, the findings suggest that even such resilient fruits benefit from plastic wrapping under controlled temperatures. These observations reinforce that packaging and temperature control are crucial even for fruits with inherently protective anatomical features (Yildiz et al., 2024).

From the table, it can also be observed that: Treatment A (room temperature, without packaging) caused the highest weight loss (e.g., 14.35 ± 1.63% for oranges), this confirms that room temperature with high transpiration rates and thin-skinned fruits leads to rapid water loss. Treatments B, D, and F (Refrigerated/Frozen Storage, and Refrigerated with Plastic Packaging) showed minimal weight loss (0.71%, 0.72%, and 0.36%), this indicates that low-temperature storage (refrigerated/frozen) and/or with plastic packaging are very effective in reducing water loss and maintaining humidity. Treatment C (Refrigerated, without packaging) resulted in intermediate weight loss (4.02% for oranges), this suggests that refrigeration alone (without packaging) is better than room temperature without packaging, but less effective compared to frozen storage or storage with plastic packaging. Treatment E (Frozen, without packaging) showed lower weight loss (1.04% for oranges) compared to room temperature, but slightly higher than treatments B, D, and F, this indicates that freezing is effective, but packaging still helps.

Conclusion

The results of this study demonstrate that storage duration plays a more decisive role than storage temperature or packaging in determining the physicochemical quality of non-climacteric fruits. Among the four fruits tested, strawberries were the most susceptible to weight loss and color degradation, especially under ambient conditions without packaging. Oranges and lemons, due to their protective peels and slower metabolism, exhibited better resilience and retained their mass and appearance across most treatments. Starfruit showed moderate variability depending on storage conditions, but responded positively to refrigerated or frozen storage with plastic wrap. Across all fruit types, plastic wrapping significantly reduced weight loss, indicating the importance of maintaining a humid microenvironment during storage. Although cold and frozen conditions effectively slowed degradation, the peak visual and color quality was generally observed on day two, suggesting that short-term storage is optimal for appearance-based marketability. The study underscores the need to integrate storage time, temperature, and packaging to maintain postharvest fruit quality. These findings are particularly relevant for small-scale producers and retailers in tropical and subtropical regions seeking affordable, effective postharvest handling strategies to reduce losses and improve product presentation. Future studies should consider including sensory analysis and nutritional profiling to comprehensively evaluate storage impacts on fruit quality.

References

Begum, T., Follett, P. A., Shankar, S., Moskovchenko, L., Salmieri, S., & Lacroix, M. (2023). Evaluation of bioactive low‐density polyethylene (LDPE) nanocomposite films in combined treatment with irradiation on strawberry shelf‐life extension. Journal of Food Science, 88(5), 2141–2161. doi: 10.1111/1750-3841.16551

Chen, A., Liu, L., Liu, X., Fu, Y., Li, J., Zhao, J., & Hou, X. (2021). Exploring the differential stages of the pigment metabolism by pre-harvest bagging and post-harvest ethylene de-greening of Eureka lemon peel. PeerJ, 9, e11504. doi: 10.7717/peerj.11504

Chen, Y., Belwal, T., Xu, Y., Ma, Q., Li, D., Li, L., Xiao, H., & Luo, Z. (2023). Updated insights into anthocyanin stability behavior from bases to cases: Why and why not anthocyanins lose during food processing. Critical Reviews in Food Science and Nutrition, 63(27), 8639–8671. doi: 10.1080/10408398.2022.2063250

Derardja, A. eddine, Pretzler, M., Kampatsikas, I., Radovic, M., Fabisikova, A., Zehl, M., Barkat, M., & Rompel, A. (2022). Polyphenol oxidase and enzymatic browning in apricot (Prunus armeniaca L.): Effect on phenolic composition and deduction of main substrates. Current Research in Food Science, 5, 196–206. doi: 10.1016/j.crfs.2021.12.015

Fadiji, T., Ashtiani, S.-H. M., Onwude, D. I., Li, Z., & Opara, U. L. (2021). Finite Element Method for Freezing and Thawing Industrial Food Processes. Foods, 10(4), 869. doi: 10.3390/foods10040869

Gómez, J. M., Mendoza, S. M., Herrera, A. O., & Castellanos, D. A. (2020). Evaluation and modeling of changes in color, firmness, and physicochemical shelf life of cut pineapple (Ananas comosus) slices in equilibrium‐modified atmosphere packaging. Journal of Food Science, 85(11), 3899–3908. doi: 10.1111/1750-3841.15469

H. Abd El-Aziz, M. (2020). Effect of Hydro-cooling and Immersion in Salicylic Acid and Citric Acid on Quality and Storability of Guava Fruits (Psidium guajava L.). Annals of Agricultural Science, Moshtohor, 58(3), 615–632. doi: 10.21608/assjm.2020.127287

Hossain, M., Karim, M., & Juthee, S. (2020). Postharvest physiological and biochemical alterations in fruits: a review. Fundamental and Applied Agriculture, 0, 1. doi: 10.5455/faa.22077

Hou, X., Li, H., Zhang, W., Yao, Z., Wang, Y., & Du, T. (2021). Water transport in fleshy fruits: Research advances, methodologies, and future directions. Physiologia Plantarum, 172(4), 2203–2216. doi: 10.1111/ppl.13468

Hurtado, G., & Knoche, M. (2021). Water Soaking Disorder in Strawberries: Triggers, Factors, and Mechanisms. Frontiers in Plant Science, 12. doi: 10.3389/fpls.2021.694123

Ikegaya, A., Ohba, S., Nakajima, T., Toyoizumi, T., Ito, S., & Arai, E. (2020). Practical long‐term storage of strawberries in refrigerated containers at ice temperature. Food Science & Nutrition, 8(9), 5138–5148. doi: 10.1002/fsn3.1817

Ji, X., Huang, X., Shi, F., Geng, Z., Li, D., Yin, B. C., & Zhang, J. (2022). Enhancing the water vapor barrier of eco-friendly, emulsion-coated paper via a bilayer-like structure design. Materials Express, 12(5), 726–734. doi: 10.1166/mex.2022.2180

Jiang, H., Zhang, W., Xu, Y., Chen, L., Cao, J., & Jiang, W. (2022). An advance on nutritional profile, phytochemical profile, nutraceutical properties, and potential industrial applications of lemon peels: A comprehensive review. Trends in Food Science & Technology, 124, 219–236. doi: 10.1016/j.tifs.2022.04.019

Kapoor, L., Simkin, A. J., George Priya Doss, C., & Siva, R. (2022). Fruit ripening: dynamics and integrated analysis of carotenoids and anthocyanins. BMC Plant Biology, 22(1), 27. doi: 10.1186/s12870-021-03411-w

Khanal, B. P., Imoro, Y., Chen, Y. H., Straube, J., & Knoche, M. (2021). Surface moisture increases microcracking and water vapour permeance of apple fruit skin. Plant Biology, 23(1), 74–82. doi: 10.1111/plb.13178

Lameira, R. das C., Silva, B. M. P. da, Valentini, S. R. de T., Cia, P., & Bron, I. U. (2020). Refrigeration and modified atmosphere to the conservation of 'Malasia' Star fruit. Ciência Rural, 50(5). doi: 10.1590/0103-8478cr20190646

Lewandowska, M., Keyl, A., & Feussner, I. (2020). Wax biosynthesis in response to danger: its regulation upon abiotic and biotic stress. New Phytologist, 227(3), 698–713. doi: 10.1111/nph.16571

Lombardelli, C., Benucci, I., & Esti, M. (2021). Novel food colorants from tomatoes: Stability of carotenoid-containing chromoplasts under different storage conditions. LWT, 140, 110725. doi: 10.1016/j.lwt.2020.110725

Lufu, R., Ambaw, A., & Opara, U. L. (2021). The Influence of Internal Packaging (Liners) on Moisture Dynamics and Physical and Physiological Quality of Pomegranate Fruit during Cold Storage. Foods, 10(6), 1388. doi: 10.3390/foods10061388

M.Anusha, Sri, K. R., Lokesh, M., Deepthi, N. M., & Malleswari, M. D. (2024). Postharvest Management Techniques for Improved Shelf Life of Horticultural Crops: A Review. Journal of Experimental Agriculture International, 46(11), 362–380. doi: 10.9734/jeai/2024/v46i113059

Mao, W., Han, Y., Chen, Y., Sun, M., Feng, Q., Li, L., Liu, L., Zhang, K., Wei, L., Han, Z., & Li, B. (2022). Low temperature inhibits anthocyanin accumulation in strawberry fruit by activating FvMAPK3-induced phosphorylation of FvMYB10 and degradation of Chalcone Synthase 1. The Plant Cell, 34(4), 1226–1249. doi: 10.1093/plcell/koac006

Muley, A. B., Kedia, P., Pegu, K., Kausley, S. B., & Rai, B. (2022). Analyzing the physical and biochemical changes in strawberries during storage at different temperatures and the development of kinetic models. Journal of Food Measurement and Characterization, 16(1), 222–247. doi: 10.1007/s11694-021-01146-8

Mulyawanti, I., Widayanti, S. M., Dewandari, K. T., & Iriani, E. S. (2022). The Effect of Packaging Methods on Characteristics of Zalacca During Storage. IOP Conference Series: Earth and Environmental Science, 1024(1), 012030. doi: 10.1088/1755-1315/1024/1/012030

Olveira-Bouzas, V., Pita-Calvo, C., Romero-Rodríguez, M. Á., & Vázquez-Odériz, M. L. (2023). Evaluation of a Packaging System in Pallets Under Modified Atmosphere to Extend the Shelf-life of 'Padrón' Peppers Stored at Refrigeration Temperature. Food and Bioprocess Technology, 16(4), 785–803. doi: 10.1007/s11947-022-02966-2

Otani, S., Miki, S., Nakamura, Y., Ishimoto, K., Ago, Y., & Nakagawa, S. (2020). Improved Bioavailability of β-Carotene by Amorphous Solid Dispersion Technology in Rats. Journal of Nutritional Science and Vitaminology, 66(2), 207–210. doi: 10.3177/jnsv.66.207

Owoyemi, A., Porat, R., Lichter, A., Doron-Faigenboim, A., Jovani, O., Koenigstein, N., & Salzer, Y. (2022). Large-Scale, High-Throughput Phenotyping of the Postharvest Storage Performance of 'Rustenburg' Navel Oranges and the Development of Shelf-Life Prediction Models. Foods, 11(13), 1840. doi: 10.3390/foods11131840

Perotti, M. F., Posé, D., & Martín-Pizarro, C. (2023). Non-climacteric fruit development and ripening regulation: 'the phytohormones show.' Journal of Experimental Botany, 74(20), 6237–6253. doi: 10.1093/jxb/erad271

Pott, D. M., Vallarino, J. G., & Osorio, S. (2020). Metabolite Changes during Postharvest Storage: Effects on Fruit Quality Traits. Metabolites, 10(5), 187. doi: 10.3390/metabo10050187

Serra, S., Anthony, B., Boscolo Sesillo, F., Masia, A., & Musacchi, S. (2021). Determination of Post-Harvest Biochemical Composition, Enzymatic Activities, and Oxidative Browning in 14 Apple Cultivars. Foods, 10(1), 186. doi: 10.3390/foods10010186

Somogyi, E., Lázár, J., Bodor, P., & Kaszab, T. (2021). Colour of grapevine (Vitis vinifera L.) accessions influenced by the length of cold storage •. Progress in Agricultural Engineering Sciences, 16(S2), 109–116. doi: 10.1556/446.2020.20013

Strano, M. C., Altieri, G., Allegra, M., Di Renzo, G. C., Paterna, G., Matera, A., & Genovese, F. (2022). Postharvest Technologies of Fresh Citrus Fruit: Advances and Recent Developments for the Loss Reduction during Handling and Storage. Horticulturae, 8(7), 612. doi: 10.3390/horticulturae8070612

Sun, L., Zhu, Z., & Sun, D.-W. (2023). Regulating ice formation for enhancing frozen food quality: Materials, mechanisms and challenges. Trends in Food Science & Technology, 139, 104116. doi: 10.1016/j.tifs.2023.07.013

Teo, J., Mohan, R., Zhang, S., Gui, Y., Sng, B. J. R., Jang, I.-C., & Yin, Z. (2022). Optimization of light and temperature in indoor farming to boost anthocyanin biosynthesis and accumulation in Indigo Rose tomato. Vegetable Research, 2(1), 1–11. doi: 10.48130/VR-2022-0018

Yan, S., Li, Y., Liu, J., Si, D., & Zhang, X. (2023). Guideline for extraction, qualitative, quantitative, and stability analysis of anthocyanins. EFood, 4(1). doi: 10.1002/efd2.59

Yildiz, A. Y., & Karaca, H. (2024). The protective role of shell, packaging technique and storage temperature in lipid oxidation in walnuts of different varieties. Postharvest Biology and Technology, 210, 112747. doi: 10.1016/j.postharvbio.2023.112747