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Article

Comparative Analysis of Shelf-Life, Antioxidant Activity, and Phytochemical Contents of Australian-Grown and Imported Dragon Fruit under Ambient Conditions

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Abstract: Dragon fruit (*Hylocereus* spp.), renowned for its aesthetic appeal and rich antioxidant content, has gained global popularity due to its numerous health benefits. In Australia, despite growing commercial interest in cultivating dragon fruit, there is uncertainty for local growers stemming from competition with imported varieties. Notably, there is a lack of comparative research on the shelf-life, antioxidant activity, and phytochemical contents of Australian-grown versus imported dragon fruit, which is crucial for enhancing market competitiveness and consumer perception. This study compares the shelf-life, antioxidant activity, and phytochemical content of Australian-grown and imported dragon fruits under ambient conditions, addressing the competitive challenges faced by local growers. Freshly harvested white-flesh (*Hylocereus undatus*) and red-flesh (*H. polyrhizus*) dragon fruit were sourced from Queensland and the Northern Territory and imported fruit were sourced from an importer in Queensland. All fruit were assessed for key quality parameters including peel color, firmness, weight loss, total soluble solids (TSS), pH, titratable acidity (TA), total phenolic content (TPC), total flavonoid content (TFC), ferric reducing antioxidant power (FRAP), cupric reducing antioxidant capacity (CUPRAC), total betalain content (TBC), and total anthocyanin content (TAC). The results indicate that Australian-grown white dragon fruits exhibited average one day longer shelf-life with less color degradation, better firmness retention, and less decline in weight loss, TSS, and acidity compared to imported fruits. Australian-grown red dragon fruits showed similar shelf-life compared to fruits from overseas. Antioxidant activities and phytochemicals were consistently higher in Australian-grown fruits throughout their shelf-life. These findings indicate that Australian-grown dragon fruits offer better physical quality and retain more nutritional value, which could enhance their marketability.

Keywords: dragon fruit; white-flesh; red-flesh; Australian-grown; imported; shelf-life; ambient; antioxidant activity; phytochemicals

1. Introduction

Pitaya, commonly known as dragon fruit, originates from several cactus species within the *Cactaceae* family [1]. Although native to regions in Mexico and northern South



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America [2], its cultivation has extended significantly to tropical and subtropical areas, including Vietnam, China, and Australia [3]. The optimal growth conditions for dragon fruit include annual rainfall between 25 to 51 inches and the ability to withstand temperatures up to 40 °C [4]. Dragon fruit, with its cactus-like adaptations, thrives in environments with high light intensity and warm climates, as long as it receives sufficient water and is grown in fertile soils [4].

Dragon fruit is a valuable source of antioxidant phytochemicals, which contribute to various health benefits. Recent research on its bioactive properties has substantiated these health-promoting effects, including its antioxidant capacity, antidiabetic, anticancer, anti-inflammatory, antihyperlipidemic, and anti-obesity properties, as well as its hepatoprotective and prebiotic potential. The presence of polyphenols, betalains, carotenoids, flavonoids, alkaloids, terpenoids, steroids, tannins, and saponins in dragon fruit plays a significant role in mediating these beneficial effects [4].

Dragon fruit was introduced to Australia in the 1970s, and its cultivation has since expanded to Queensland (QLD), the Northern Territory (NT), Western Australia (WA), and New South Wales (NSW) [5]. By 2010, NT had become the principal cultivation region, with approximately 35,000 planting sites (one planting site consists of around three individual plants) and accounting for over 60% of the national production, which is over 50,000 planting site in total [6]. Southeast Queensland has also experienced rapid cultivation growth due to rising market demand.

Three primary species of dragon fruit can be identified by their skin and pulp colors: *Hylocereus undatus* (white-flesh), *H. polyrhizus* (red-flesh), and *H. megalanthus* (yellow) [7]. Studies indicate that white- and red-flesh varieties are predominantly grown in Australia, with *H. undatus* being the major cultivar in the NT and *H. polyrhizus* yielding significant production in QLD [6] (Figure 1).

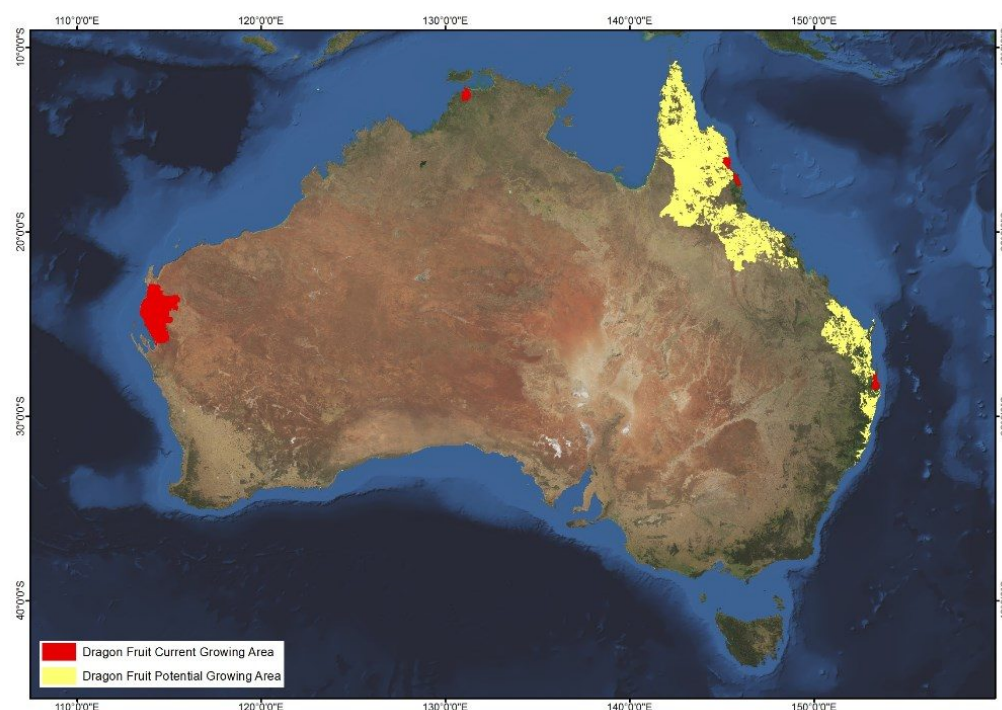


Figure 1. Current dragon fruit cultivation regions in Australia [8].

Recent research, such as the study by Chen [9], has explored the phytochemical profile of Australian-grown dragon fruit, identifying key compounds like polyphenols, flavonoids, and betalains that contribute to its antioxidant capacity. There is a notable lack of research on the quality of Australian-grown dragon fruits, particularly regarding their shelf-life and antioxidant capacity. Despite the increasing commercial interest in dragon fruit cultivation

in Australia, owing to its low maintenance and high nutritional value, the future remains uncertain for Australian growers [10]. The market's opening to imports (mainly Asian countries such as Vietnam, Philippines, and Malaysia) in 2017 has introduced substantial price competition, posing challenges for domestic growers who face higher cultivation, transportation, and operational costs, especially in remote areas [11]. This competition has adversely impacted business confidence and constrained the expansion of the local dragon fruit industry. Furthermore, there is a notable lack of research on the quality of Australian-grown dragon fruits, particularly regarding their shelf-life and antioxidant capacity. Addressing these research gaps would not only elevate the value and appeal of local produced dragon fruits but also contribute to the global understanding of their nutritional benefits.

This study assessed the current offerings of the Australian dragon fruit market and aimed to highlight the possible competitive advantages of Australian-grown over the imported dragon fruits regarding on their quality and antioxidant characteristics during shelf-life. Results of this research are expected to enhance consumer perceptions, strengthen the market position of the Australian-grown dragon fruit, potentially assist with establishing industry standards tailored to the local-grown dragon fruit, and, most importantly, support the domestic growers for future growth of the Australian grown fruit.

2. Materials and Methods

2.1. Samples

The Australian-grown white-and red-flesh dragon fruits were freshly received from two farms in Humpty Doo, NT and four farms in Sunshine Coast, QLD, based on growers' harvesting experience and fruit availability. Imported samples (originally from Vietnam) were collected from JE Tipper, a wholesaler based in Brisbane, QLD. After washing with tap water and air drying, the samples were stored in air ventilated baskets under ambient conditions (see Section 2.3 for details) for further analysis.

2.2. Chemicals and Reagents

All the chemicals, reagents and standards were analytical grade purchased from ChemSupply Australia Pty Ltd. (Gillman, Australia). All dilutions and preparation of aqueous solutions are made using deionized water, unless otherwise specified. Solutions were stored at 4 °C in the refrigerator until they were used.

2.3. Shelf-Life

The shelf-life evaluation was conducted through a controlled storage experiment, where uniformed size dragon fruit samples without physical damage were selected and stored in corrugated fiberboard boxes (6 fruits in each) under ambient temperature and humidity conditions monitored by Tapo T310 (Table 1). Regular assessments were performed at predetermined intervals (every second day) to track changes in selected parameters throughout the storage period. In detail, the shelf-life of Australian-grown and overseas dragon fruits were determined by counting the number of days from the date of receipt until samples were failed to meet the criteria of Class II fruit based on the Codex Alimentarius Standard for dragon fruit CXS 237-2003 [12]. According to this standard, defects on the appearance of the Class II fruits are less than 2 cm² of the total surface of the fruit [12]. The collected data from two seasons were combined and statistically analyzed to identify trends and significant differences in quality attributes. The overall shelf-life of Australian-grown dragon fruit was calculated by averaging the results from QLD and NT in this study.

Factors such as peel color, firmness, weight loss, Brix, pH, and titratable acidity were recorded, as they are crucial for assessing overall quality and marketability of dragon fruit.

Individual analyses were conducted the day after samples receipt, except for fruits from the NT, which were tested on the fourth day due to extended transportation time. For peel color and firmness, three samples were randomly chosen for each designated shelf-life point to ensure a representative assessment of the entire batch of fruit. Triplicate

measurements were taken for each sample to ensure comprehensive coverage of each fruit. After measuring color and firmness, the three samples were blended to create a homogeneous juice mixture. This blended juice was then utilized to test the remaining analytical parameters, with all tests conducted in triplicate to ensure reliability and consistency of the results.

Table 1. Temperature and humidity conditions during shelf-life evaluation.

Origin	Temperature Range (°C)	Humidity Range (%)
First season		
QLD	20.4–24.7	54–82
NT	22.3–25.6	63–89
Overseas	20.2–23.8	55–80
Second season		
QLD	20.5–24.6	50–82
Overseas	20.0–24.0	54–78

QLD: Queensland; NT: Northern Territory.

2.3.1. Peel Color

For determining the color of the dragon fruit peel, hyperspectral images were captured using a Hyperspectral Camera Specim IQ manufactured by Specim, Spectral Imaging LTD., Oulu, Finland. Subsequently, a determination program was developed using PyCharm CE codes (version 2023.3.1) to calculate the color value of a randomly selected circular area on the dragon fruit peel (Figure 2). Following the partial least squares regression (PLSR) color index model well-developed by Wanitchang et al. [13], the color value in this experiment was computed as the logarithm of the reflectance ratio at 681 nm and 551 nm, specifically represented as $\log(R_{681}/R_{551})$. To eliminate potential background effects, a white reference pad was utilized during the color measurement process. Triplicate measurements were taken for each sample to ensure a representative assessment of the whole fruit.

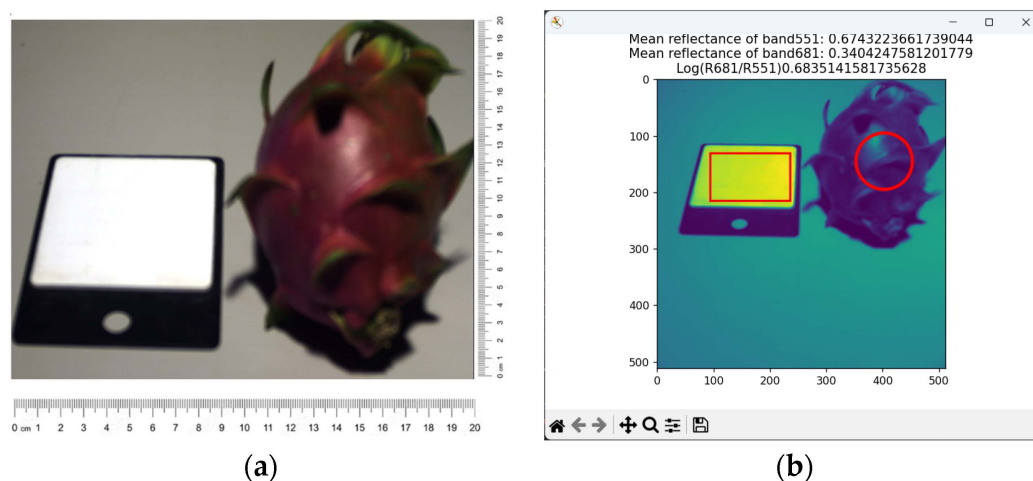


Figure 2. Color measurement process. (a) Hyperspectral image captured by hyperspectral camera; (b) Result window of PyCharm CE color determination program. The rectangular area helps in calibration using the white reference, while the circle indicates the region of interest on the dragon fruit as described in Section 2.3.1.

2.3.2. Firmness

Firmness measurements of the dragon fruit were performed using an EZ SX Texture Analyzer (Shimadzu, Australia) coupled with a 5 mm diameter indentation elasticity jig. The firmness was presented as the maximum force for breaking the peel. The penetration point was selected at the center of the peel. Triplicate measurements were taken for each sample to ensure a representative assessment of the whole fruit.

2.3.3. Weight Loss (%)

Weight loss was measured by subtracting the current weight from the initial weight of the sample and expressed as a percentage. This is calculated using the formula:

$$\text{Weight Loss (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

where:

W_1 = Initial weight of the sample (g)

W_2 = Current weight of the sample (g)

2.3.4. Total Soluble Solids (TSS), pH and Titratable Acidity

Total soluble solids were measured using a refractometer (PAL-1, ATAGO), and pH was measured with a pH meter (Orion Star™ A211 Benchtop pH Meter, Thermo Fisher Scientific, Australia).

Titrateable acidity was determined using a modified AOAC method [14]. A total of 10 g of homogenized juice mixture was mixed thoroughly with 50 mL deionized water. The resulting mixture was then titrated against 0.1 N sodium hydroxide until the pH reached 8.2, as monitored by the pH meter. The result was calculated as malic acid equivalent (MAE) using the formula:

$$\text{Titrateable Acidity (\%)} = \frac{N \times V \times M}{m} \times 100$$

where:

N = Normality of NaOH

V = Volume of NaOH is used (mL)

M = Molecular weight of malic acid (134.0874 g/mol)

m = Weight of the sample (g)

2.4. Antioxidant and Phytochemical Assays

2.4.1. Extraction

A modified version of the aqueous-methanolic extraction technique developed by Johnson et al. [15] was employed. In this approach, one gram of pre-homogenized dragon fruit pulp juice (obtained as described in Section 2.3) was carefully weighed and placed into a 50 mL centrifuge tube. For the extraction of total betalain and anthocyanin content, 10 mL of a 90% methanol solution (acidified with 0.1% hydrochloric, v/v) was added. For total phenolic content (TPC), total flavonoids, ferric reducing antioxidant power (FRAP) and cupric reducing antioxidant capacity (CUPRAC) analyses, 10 mL of a 90% aqueous methanol solution was used. The tube was then vigorously mixed using a vortex mixer and placed on a platform shaker at 200 rpm for 15 min in darkness at room temperature. Following this, the mixture was centrifuged at 3000 rpm for 6 min (Thermo Scientific Heraeus Megafuge 16). The supernatant was filtered through Whatman qualitative filter paper (Grade 1, 90 mm diameter with 11 μ m pore size), and the resulting filtrate was collected and stored (in fridge at -4 °C) for further analysis.

2.4.2. Measurement of Phytochemical Contents and Antioxidant Activity

Total phenolic content was determined by a Folin–Ciocalteu (FC) assay developed by Johnson et al. [16]. An aliquot of methanolic extract (400 μ L) was combined with 2 mL of a 10-fold diluted FC reagent and then subjected to a 10 min incubation period in darkness at room temperature. Subsequently, 2 mL of sodium carbonate (7.5%, w/v) was added to the mixture, followed by an additional 30 min incubation at 40 °C. After the incubation, a portion of the resulting solution was transferred to a cuvette for absorbance measurement at 760 nm using a UV-Vis spectrophotometer (Genesys 10S UV-Vis, Thermo Scientific, Adelaide, Australia). Milli-Q water was used to blank the instrument and gallic

acid (0–100 ppm) was utilized as the calibration standard, and the results were presented as milligrams of gallic acid equivalents (GAE) per 100 g of fresh weight of the sample (mg GAE/100 g FW).

Total flavonoid content was measured by modifying an aluminum chloride colorimetric assay developed by Chen et al. [9]. An aliquot of the methanolic extract (400 µL) was combined with 400 µL of methanolic aluminum chloride solution (10%) and 600 µL of aqueous sodium acetate solution (1 M), followed by a 30 min incubation at room temperature. The resulting mixture was then transferred to a cuvette for absorbance measurement at 415 nm using a UV-Vis spectrophotometer (Genesys 10S UV-Vis, Thermo Scientific, Australia). Milli-Q water was used to blank the instrument and quercetin (0–20 ppm) was used as the standard, and the results were reported as milligrams of quercetin equivalents (QE) per 100 g of fresh weight of the sample (mg QE/100 g FW).

The FRAP assay was conducted in accordance with a modified protocol as originally devised by Johnson et al. [17]. An aliquot of the dragon fruit methanolic extract (100 µL) was first combined with 3 mL of FRAP solution consisting of 300 mM aqueous sodium acetate at pH 3.56, 20 mM ferric chloride, and 10 mM TPTZ (2,4,6-tri(2-pyridyl)-s-triazine), combined in a 10:1:1 ratio. The resulting mixture was then incubated at 37 °C for 4 min. After incubation, a portion of the mixture was transferred to a cuvette for absorbance measurement at 593 nm using a UV-Vis spectrophotometer (Genesys 10S UV-Vis, Thermo Scientific, Australia). Milli-Q water was used to blank the instrument and trolox (0–100 ppm) was used as calibration standard, and the results were expressed as milligrams Trolox equivalents (TE) per 100 g of fresh weight of the sample (mg TE/100 g FW).

The CUPRAC assay was conducted following a modified methodology developed by Johnson et al. [17]. An aliquot of the dragon fruit methanolic extract (100 µL) was combined with 1 mL of a 10 mM aqueous copper (II) chloride, 1 mL of 1 M ammonium acetate, 1 mL of a 7.5 mM neocuproine solution, and 1 mL of distilled water. This mixture was then incubated at 50 °C in darkness for 30 min. Subsequently, the absorbance of the mixture was measured utilizing a UV-Vis spectrophotometer (Genesys 10S UV-Vis, Thermo Scientific, Australia) at 450 nm. Milli-Q water was used to blank the instrument and trolox (0–400 ppm) was used as calibration standard and the results were expressed as milligrams of Trolox equivalents (TE) per 100 g of fresh weight of the sample (mg TE/100 g FW).

The method for the determination of TBC was modified from Zitha et al. [18]. Total betalain content (TBC) was the sum up of betacyanin and betaxanthin contents in the dragon fruit pulp. Milli-Q water was used to blank the instrument and an aliquot of the methanolic extract (2 mL) was transferred to a cuvette for absorbance reading using a UV-Vis spectrophotometer (Genesys 10S UV-Vis, Thermo Scientific, Australia) at 538 nm for betacyanin and 483 nm for betaxanthin. The results were computed using the following formulas and reported as milligrams per 100 g of fresh weight of the sample (mg/100 g FW)

$$\text{Betacyanin (mg}\cdot\text{100g}^{-1}\text{)} = \frac{A_1 \times \text{DF} \times M_1 \times V \times 1000}{\eta_1 \times W \times L} \times 100$$

$$\text{Betaxanthin (mg}\cdot\text{100g}^{-1}\text{)} = \frac{A_2 \times \text{DF} \times M_2 \times V \times 1000}{\eta_2 \times W \times L \times 10} \times 100$$

where:

A_1 = Absorbance at 538 nm

A_2 = Absorbance at 483 nm

DF = Dilution Factor (if necessary)

M_1 = Molecular Weight of Betanin (550 g/mol)

M_2 = Molecular Weight of Indicaxanthin (308 g/mol)

V = Volume of the Extract (L)

η_1 = Molar Extinction Coefficient of Betanin (60,000 L/mol·cm)

η_2 = Molar Extinction Coefficient of Indicaxanthin (48,000 L/mol·cm)

W = Sample Mass (g)

L = Path Length (1 cm)

The TAC was determined utilizing a modified protocol derived from the work of Zitha et al. [18]. In this method, milli-Q water was used to blank the instrument and 2 mL of acidified methanolic extract was transferred to a cuvette for absorbance reading using a UV-Vis spectrophotometer (Genesys 10S UV-Vis, Thermo Scientific, Australia) at 535 nm. The results were computed using the following formula and reported as milligrams of cyanidin-3-glucoside equivalents (CGE) per 100 g of fresh weight of the sample (mg CGE/100 g FW).

$$\text{Total Anthocyanin Content (mg}\cdot\text{100g}^{-1}\text{)} = \frac{A \times \text{DF} \times M \times V \times 1000}{W \times \epsilon \times L} \times 100$$

where:

A = Absorbance at 535 nm

DF = Dilution Factor

M = Molecular weight of cyanidin-3-glucoside (449.2 g/mol)

V = Volume of sample extraction (L)

W = Weight of the sample (g)

ϵ = Molar Absorptivity (26,900 L/mol)

L = Path Length (1 cm)

2.5. Statistical Analysis

All analysis and tests were conducted in triplicates for each sample, with results expressed as mean $\pm$ standard deviation (SD, $n = 3$) on a fresh weight (FW) basis. Statistical analysis was performed using SPSS (version 29.0.1). One-way analysis of variance (ANOVA) was used to evaluate the effects of storage days and sample regions or varieties on shelf-life quality parameters (color, firmness, weight loss, TSS, pH, and TA), antioxidant activities (FRAP and CUPRAC) and phytochemical measurements (TPC, TFC, TBC, and TAC). Tukey's Honestly Significant Difference (HSD) test was applied to analyze variations among varieties/regions concerning shelf-life parameters, antioxidant activities, and phytochemical contents. Pearson's correlation coefficients were calculated to assess significant correlations ($p < 0.05$; two-tailed) among shelf-life quality parameters antioxidant activities and phytochemical contents.

3. Results and Discussion

3.1. Fruit Quality during Shelf-Life

The quality changes during the shelf-life of dragon fruit in this study encompass the analysis of color, firmness, weight loss, total soluble solids (TSS), pH, and titratable acidity (TA) throughout the storage period. The Results and Discussion Section focuses specifically on the differences between different regions. This approach was taken because several previous studies have already compared the fruit quality during shelf-life of white- and red-flesh varieties, revealing that the red-flesh variety has typically shorter shelf-life and exhibits higher a^* values and lower L^* values for color, lower firmness, greater weight loss, higher TSS, and lower TA compared to the white-flesh variety [19–21]. Similar trends in these shelf-life parameters were also observed in this study. The detailed results for these parameters are shown in Table A1 in Appendix A.

3.1.1. Color

Color originates from the natural pigments present in fruits and vegetables, many of which undergo transformation as the plant progresses through stages of maturation and ripening [22]. It is also a critical quality attribute in fruits, significantly influencing consumer choices and preferences. Measuring the color of fruits serves as an indirect indicator of other quality attributes due to its simplicity, operation speed, and strong correlation with other physicochemical properties [23]. In this study, the color index $\log (R_{681}/R_{551})$ value serves as a quantitative measure that correlates with the color of the dragon fruit peel. A higher value corresponds to a less red peel, while a lower value suggests more intense red coloration. The color development of dragon fruit during shelf-life is shown in Figure 3.

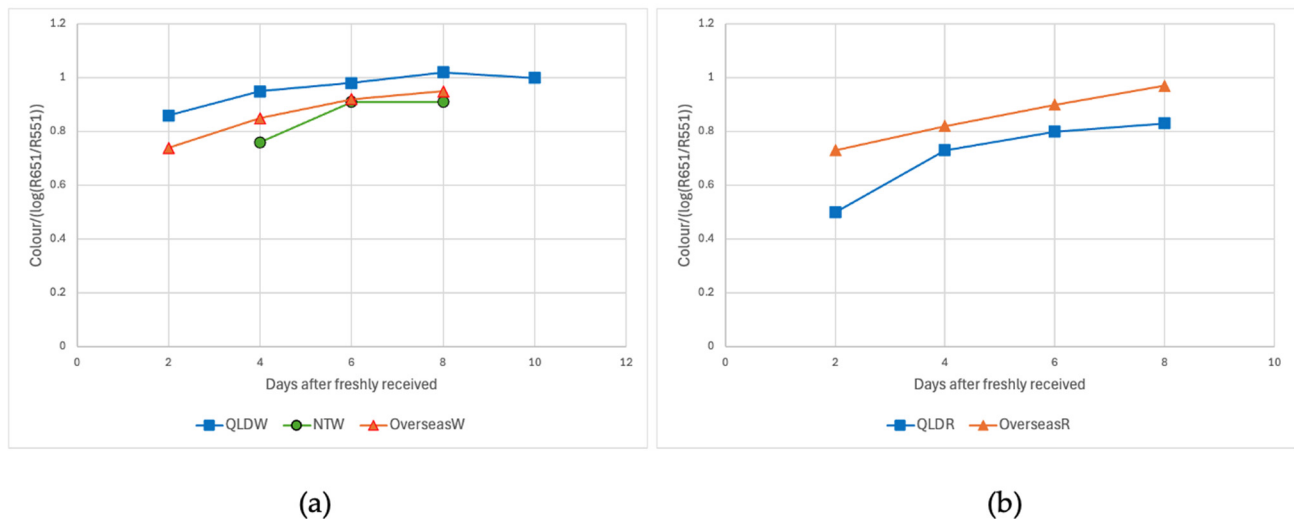


Figure 3. Development of peel color in dragon fruit during shelf-life under ambient conditions. (a) White-flesh dragon fruit peel color development during shelf-life; (b) red-flesh dragon fruit peel color development during shelf-life. QLDW, Queensland-grown white-flesh dragon fruit; NTW: Northern Territory-grown white-flesh dragon fruit; OverseasW, overseas-grown white-flesh dragon fruit; QLDR, Queensland-grown red-flesh dragon fruit; OverseasR, overseas-grown red-flesh dragon fruit.

It is reported that the intensity of the red color of the peel progressively diminished as senescence begins in dragon fruit [24]. In this study, the overall trend of peel color development in dragon fruit observed using a hyperspectral camera showed similar results to those reported by Lata et al. [21] using a colorimeter with decreases in L^* and a^* value (indicating decreases in the red pigment and lightness of the dragon fruit peel). For white-flesh dragon fruit, NTW exhibited the most stable red coloration during its shelf-life (ranging from 0.76 ± 0.06 to 0.91 ± 0.03), followed by OverseasW (from 0.74 ± 0.14 to 0.95 ± 0.17). QLDW had the least red coloration intensity throughout its shelf-life, starting at 0.86 ± 0.10 on day 2 and reaching 1.00 ± 0.05 on day 10. For red-flesh dragon fruit, QLDR showed more intensive red coloration than OverseasR during its shelf-life, with values increasing from 0.50 ± 0.13 on day 2 to 0.83 ± 0.09 on day 8, whereas OverseasR started at 0.73 ± 0.05 and ended at 0.97 ± 0.10 on day 8. According to this study, for the white-flesh variety, fruits from NT may appear more appealing to consumers four days after harvest when stored under ambient conditions, followed by the overseas-grown and QLD-grown fruits. Conversely, QLD-grown red-flesh dragon fruit may appear more appealing to consumers than the overseas variety throughout the entire shelf-life when stored under ambient conditions.

Betalain is the primary pigment responsible for the red coloration of the dragon fruit peel [25]. The storage of dragon fruit under ambient conditions leads to the degradation of this pigment, resulting in discoloration and browning, primarily due to its sensitivity to light and temperature variations [26]. This phenomenon of color degradation under ambient storage has also been observed in other fruits, such as banana [27], mandarin [28], and pomegranate [29].

3.1.2. Firmness

Firmness is a critical quality parameter in shelf-life evaluation. In fruits and vegetables, it is not only related to textural and freshness of the fresh produce, but structural integrity affected by enzymatic activity, moisture loss, cell wall degradation, etc. [30] These processes will soften the product, leading to poor consumer perception and reduced marketability [31]. The evaluation of changes in firmness of both Australian-grown and the imported dragon fruit during shelf-life stored under ambient conditions were conducted (Figure 4).

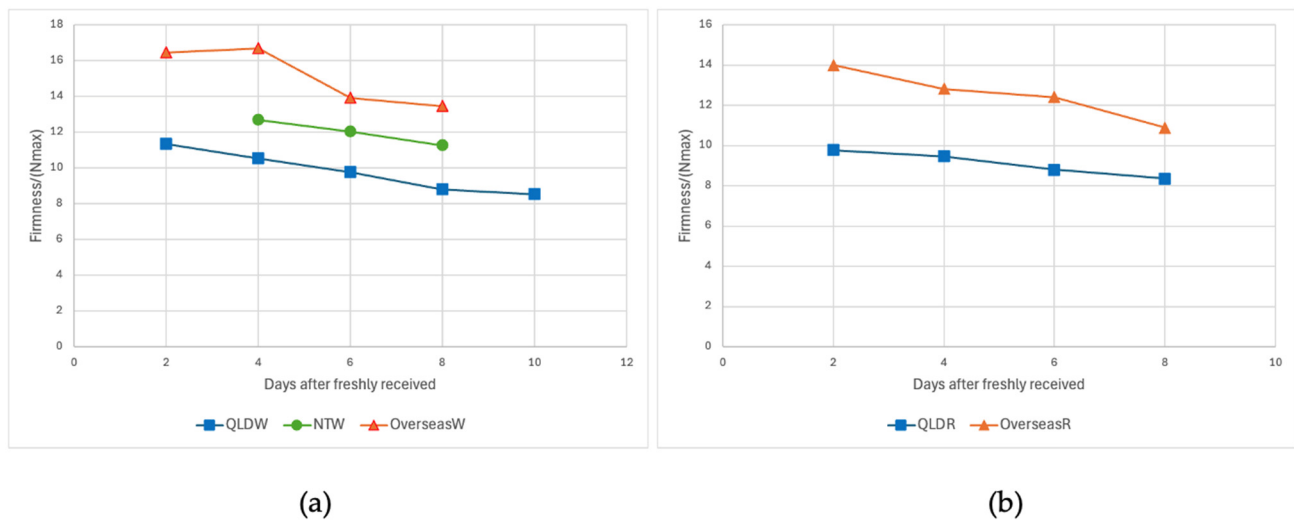


Figure 4. Changes in the firmness of dragon fruit stored under ambient conditions during its shelf-life. (a) Changes in the firmness of white-flesh dragon fruit during shelf-life; (b) changes in the firmness of red-flesh dragon fruit during shelf-life. QLDW, Queensland-grown white-flesh dragon fruit; NTW: Northern Territory-grown white-flesh dragon fruit; OverseasW, overseas-grown white-flesh dragon fruit; QLDR, Queensland-grown red-flesh dragon fruit; OverseasR, overseas-grown red-flesh dragon fruit.

An overall descending trend in firmness was observed across all groups. For the white-flesh dragon fruits, OverseasW exhibited the highest firmness throughout its shelf-life, starting at 16.45 ± 3.44 N_{Max} on day 2 and decreasing to 13.46 ± 1.09 N_{Max} on day 8. This was followed by NTW, which ranged from 12.69 ± 1.95 N_{Max} on day 4 to 11.26 ± 0.51 N_{Max} on day 8, and QLDW, which started at 11.34 ± 2.26 N_{Max} on day 2 and dropped to 8.54 ± 1.76 N_{Max} on day 10. Similarly, imported red-flesh dragon fruit maintained higher firmness than QLD-grown throughout its shelf-life, with values ranging from 13.99 ± 1.09 N_{Max} to 10.89 ± 0.89 N_{Max} and from 9.78 ± 1.27 N_{Max} to 8.35 ± 1.06 N_{Max}, respectively. These results surpass those reported by Lata et al. [21] for fruit stored under similar conditions in India, where white-flesh fruit firmness ranged from 10.20 N on day 2 to 8.73 N on day 7, and red-flesh fruit firmness ranged from 7.55 N on day 2 and 5.10 N on day 7. Similar decreases for fruits stored under ambient conditions have also been observed in mango [32] and lemon [33].

The values of firmness serve as critical insights into the freshness, quality, and marketability of fruits. A higher value often indicates that the structural integrity of the fruit is maintained, which correlates with lower enzymatic activity and less cell wall degradation, thereby reduced the potential of spoilage [31]. High value is also associated with a reduced risk of mechanical damage during handling and transportation [34]. For both white- and red-flesh dragon fruits, the imported fruits may retain better structural integrity than the Australian-grown fruits, resulting in less enzymatic activity and a reduced potential for spoilage and mechanical damage during handling.

The firmness of both imported white- and red-flesh dragon fruits experienced a more rapid decrease throughout shelf-life compared to the Australian-grown fruit. This may be because the overseas fruits were transported under refrigerated conditions to prevent quality loss during long-distance transportation. The suppressed enzymatic activities in fruits under refrigerated conditions can be accelerated when the fruits are removed to ambient conditions, resulting in a rapid decrease in firmness [35].

The higher firmness values of imported dragon fruit compared to Australian-grown dragon fruit are likely because the overseas growers often harvest fruits earlier. Firmness of dragon fruit tends to be higher at earlier maturity stage [36] and the structural integrity of dragon fruit is preserved during long periods of transportation and storage [37]. Unlike

dragon fruits from the overseas, Australian-grown dragon fruits are often harvested at a later maturity stage to maximize the marketability for local consumers, focusing on appearance, taste, and overall quality.

3.1.3. Weight Loss

Weight loss is a critical parameter in evaluating the shelf-life of fresh produce, significantly affecting overall quality. Since fruits are typically sold by weight, substantial weight loss during shelf-life can lead to reduced marketability [38]. The weight loss in Australian-grown and imported dragon fruits during shelf-life is shown in Figure 5, indicating a general increasing trend across all groups. Imported fruits exhibited the highest weight loss throughout shelf-life for both white- and red-flesh varieties, starting at $2.36 \pm 0.84\%$ on day 4 and increasing to $6.27 \pm 1.52\%$ on day 8 for white-flesh fruits, and from $2.71 \pm 1.03\%$ on day 4 to $7.31 \pm 1.32\%$ on day 8 for red-flesh fruits. Queensland-grown (QLD) white-flesh fruits demonstrated higher weight loss than Northern Territory-grown (NT) white-flesh fruits throughout the shelf-life, ranging from $1.33 \pm 0.42\%$ (day 4) to $4.01 \pm 0.84\%$ (day 10) and from $1.19 \pm 0.17\%$ (day 6) to $2.41 \pm 0.28\%$ (day 8), respectively. The QLD-grown red-flesh variety showed weight loss from $2.71 \pm 1.03\%$ on day 4 to $5.70 \pm 1.88\%$ on day 8. These findings are consistent with similar research on Indian-grown dragon fruit conducted by Lata et al. [21].

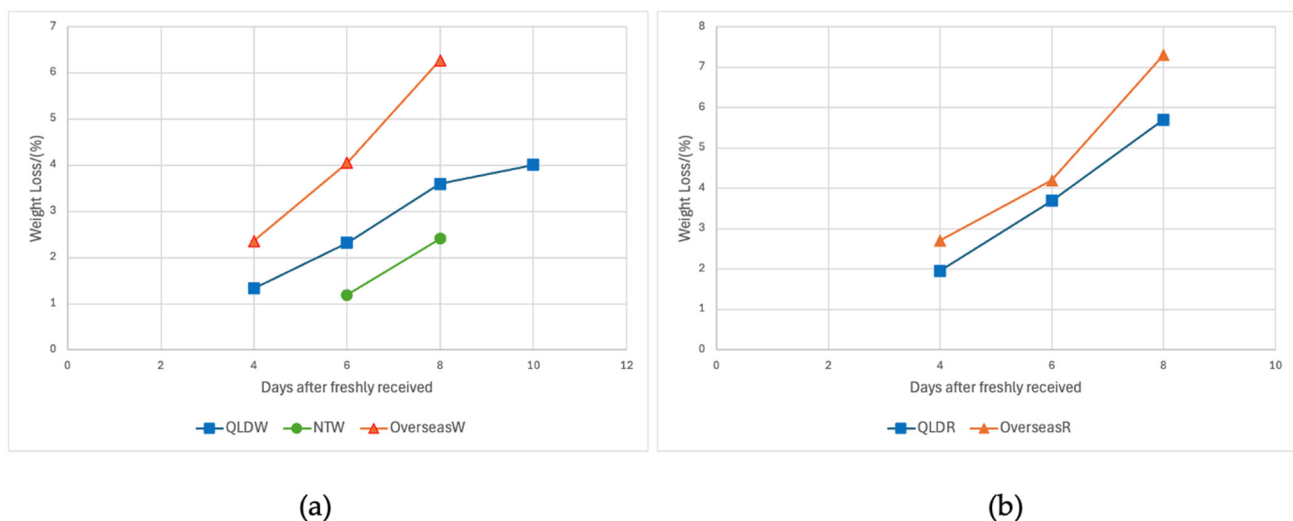


Figure 5. Weight loss of dragon fruit during shelf-life stored under ambient conditions. (a) Weight loss of white-flesh dragon fruit during shelf-life; (b) weight loss of red-flesh dragon fruit during shelf-life. QLDW, Queensland-grown white-flesh dragon fruit; NTW: Northern Territory-grown white-flesh dragon fruit; OverseasW, overseas-grown white-flesh dragon fruit; QLDR, Queensland-grown red-flesh dragon fruit; OverseasR, overseas-grown red-flesh dragon fruit.

Weight loss primarily reflects the moisture loss of fresh produce during respiration and transpiration [38]. This water loss causes significant reductions in cell turgor pressure, leading to decreased firmness and a shriveled appearance [37]. Dehydration not only concentrates nutrients such as sugars but also increases oxidative stress, which can result in the decline of essential nutrients, including vitamins and volatile compounds responsible for odor and flavor [39]. Additionally, moisture loss can impact the activity of enzymes like polyphenol oxidase (PPO), which may oxidize phenolic compounds, thereby reducing their antioxidant capacities [39]. Other enzymes, such as pectinase [40] and beta-glucosidase [41], play a pivotal role in the hydrolysis and degradation of polysaccharides and other cellular components during dehydration. Consequently, higher weight loss throughout the shelf-life suggests that imported white- and red-flesh dragon fruits may experience accelerated deterioration and shortened shelf-life under ambient conditions compared to Australian-

grown fruits. Higher weight loss also implies that imported fruits are exposed to greater oxidative stress, potentially reducing their visual quality and nutritional value.

3.1.4. TSS (°Brix)

The total soluble solids (TSS) content is an indicator of the concentration of the soluble solids (mainly sugar contents) in fruit juice, serving as indicator of sugar content, in other words, sweetness [39]. Changes of TSS in Australian-grown and imported dragon fruit during shelf-life under ambient conditions are shown in Figure 6.

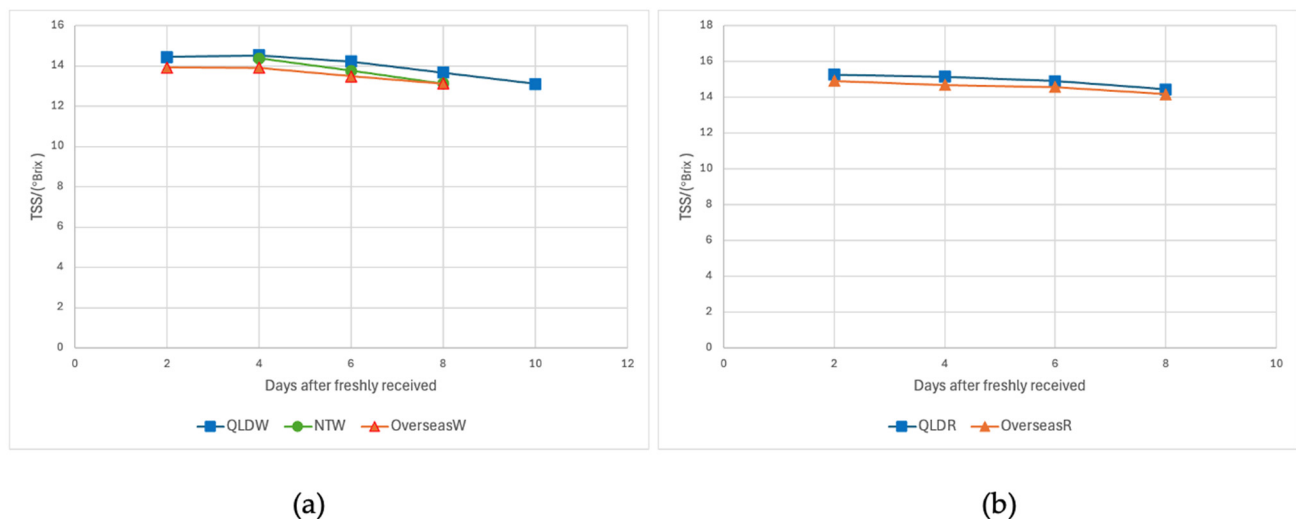


Figure 6. Changes in the total soluble solids (TSS) of dragon fruit stored under ambient conditions during its shelf-life. (a) Changes in the TSS of white-flesh dragon fruit during shelf-life; (b) changes in the TSS of red-flesh dragon fruit during shelf-life. QLDW, Queensland-grown white-flesh dragon fruit; NTW: Northern Territory-grown white-flesh dragon fruit; OverseasW, overseas-grown white-flesh dragon fruit; QLDR, Queensland-grown red-flesh dragon fruit; OverseasR, overseas-grown red-flesh dragon fruit.

Figure 6 shows the changes in total soluble solids (TSS) of Australian-grown and imported dragon fruit over the course of their shelf-life when stored at ambient temperature. A slow decreasing trend was observed across all groups. This reduction in TSS under ambient storage conditions has been observed in other fruits, such as strawberries [42], papayas [43], and peaches [44]. Throughout the shelf-life, both imported white- and red-flesh dragon fruits exhibited lower TSS values compared to Australian-grown fruits. For white-flesh fruits, the TSS started at $13.92 \pm 0.57\%$ on day 2 and decreased to $13.13 \pm 0.59\%$ on day 8, while red-flesh fruits began at $14.92 \pm 1.22\%$ on day 2 and dropped to $14.17 \pm 1.50\%$ on day 8. Among the Australian-grown white-flesh dragon fruits, those grown in Queensland (QLD) showed higher TSS throughout the shelf-life, ranging from $14.43 \pm 0.83\%$ on day 2 to $13.11 \pm 1.22\%$ on day 10. Northern Territory (NT)-grown white-flesh dragon fruits ranged from $14.37 \pm 0.29\%$ on day 4 to $13.13 \pm 0.35\%$ on day 8. For QLD-grown red-flesh varieties, the TSS started at $14.92 \pm 1.22\%$ on day 2 and dropped to $14.17 \pm 1.50\%$ on day 8. These findings are consistent with similar research on Indian-grown dragon fruit conducted by Lata et al. [21]. The results from this study indicate that Australian-grown dragon fruits maintain a higher sweetness level compared to imported dragon fruits throughout their shelf-life under ambient conditions.

3.1.5. pH

Monitoring pH is essential in evaluating the shelf-life of fresh produce, as it is closely related to the growth of bacteria, yeast, and mold [39]. Additionally, pH serves as an indicator of the stability of health-promoting nutrients and pigments, such as betacyanin [45]. Figure 7 illustrates the pH changes in Australian-grown and imported dragon fruits during

shelf-life under ambient conditions. An overall increasing trend was observed across all groups. Throughout the shelf-life, both imported white- and red-flesh dragon fruits exhibited lower pH values compared to Australian-grown fruits. For white-flesh fruits, the pH began at 4.42 ± 0.03 on day 2 and rose to 5.09 ± 0.06 by day 8, while red-flesh fruits started at 4.86 ± 0.02 on day 2 and increased to 5.53 ± 0.02 by day 8. Among the Australian-grown white-flesh dragon fruits, those cultivated in Queensland (QLD) maintained higher pH levels throughout the shelf-life, ranging from 4.56 ± 0.22 on day 2 to 5.45 ± 0.19 by day 10, whereas Northern Territory (NT)-grown fruits ranged from 4.61 ± 0.12 on day 4 to 5.19 ± 0.06 by day 8. For QLD-grown red-flesh varieties, the pH started at 4.86 ± 0.02 on day 2 and increased to 5.53 ± 0.02 by day 8. The results from this study suggest that imported dragon fruits have a reduced capacity to maintain their nutritional levels and are more susceptible to spoilage when stored under ambient conditions. These results are consistent with similar research on Indian-grown dragon fruit conducted by Lata et al. [21]. A similar increasing trend of pH has also been reported in other fruits such as litchi [46] and mango [47].

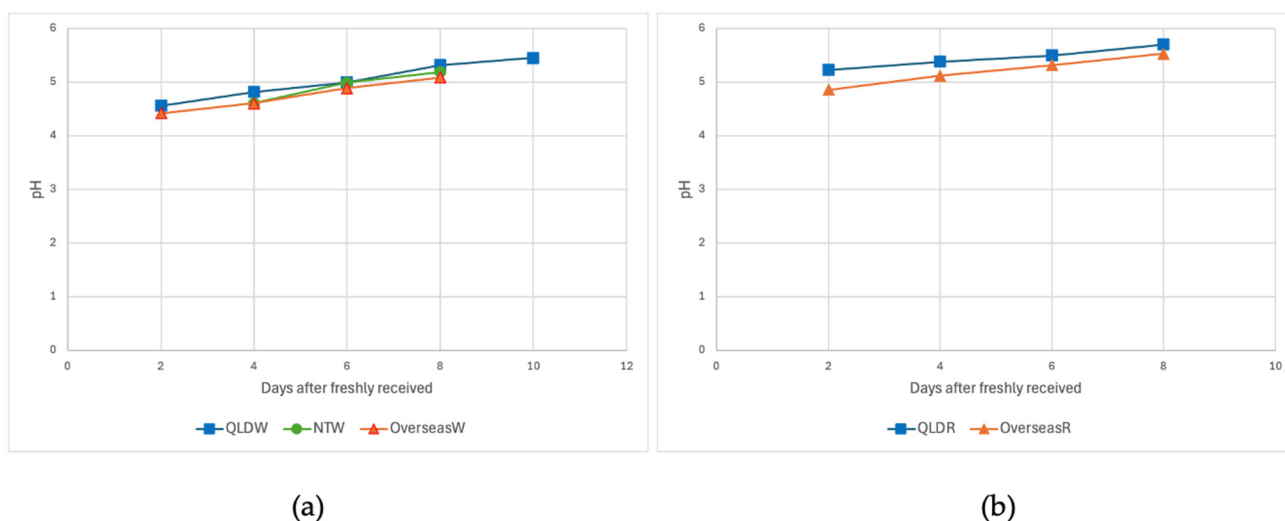


Figure 7. Changes in the pH of dragon fruit stored under ambient conditions during its shelf-life. (a) Changes in the pH of white-flesh dragon fruit during shelf-life; (b) changes in the pH of red-flesh dragon fruit during shelf-life. QLDW, Queensland-grown white-flesh dragon fruit; NTW: Northern Territory-grown white-flesh dragon fruit; OverseasW, overseas-grown white-flesh dragon fruit; QLDR, Queensland-grown red-flesh dragon fruit; OverseasR, overseas-grown red-flesh dragon fruit.

Several processes occur within fruits during storage that contribute to a rise in pH. Under ambient storage conditions, enzymatic activity increases, and enzymes including citrate synthase (CS) and malic enzyme (ME) [48] convert organic acid such as citric and malic acid into sugars and other neutral compounds [49]. Additionally, the fruit respiration process can also break acids into carbon dioxide and water, leading to a decrease in acidity, and thus an increase in the pH [50].

3.1.6. TA

Titrateable acidity (TA) is crucial in evaluating the shelf-life of fruits, as higher acidity levels can inhibit microbial growth, thereby reducing the risk of spoilage [51]. Changes in TA in Australian-grown and imported dragon fruit during shelf-life under ambient conditions are presented in Figure 8. An overall declining trend can be observed across all groups, consistent with findings from similar studies on Indian-grown dragon fruit by Lata et al. and other fruits such as plums [52], apples [53], and pears [54]. For white-flesh dragon fruits, Queensland-grown (QLDW) started with a TA value of $0.62 \pm 0.23\%$ on day 2, declining to $0.24 \pm 0.01\%$ by day 10. In comparison, the imported white-flesh fruits (OverseasW) began at $0.61 \pm 0.02\%$ on day 2 and decreased to $0.29 \pm 0.01\%$ by day

8. The Northern Territory-grown white-flesh dragon fruits (NTW) showed TA values of $0.39 \pm 0.02\%$ on day 4, reducing to $0.30 \pm 0.04\%$ by day 8. For red-flesh dragon fruits, Queensland-grown (QLDR) exhibited a decrease from $0.38 \pm 0.13\%$ on day 2 to $0.23 \pm 0.07\%$ by day 8, whereas the imported red-flesh dragon fruits (OverseasR) started at $0.46 \pm 0.01\%$ on day 2 and declined to $0.19 \pm 0.03\%$ by day 8. Notably, Australian-grown dragon fruits maintained higher TA levels after day 4 compared to imported fruits, suggesting better acidity retention and potentially fresher taste.

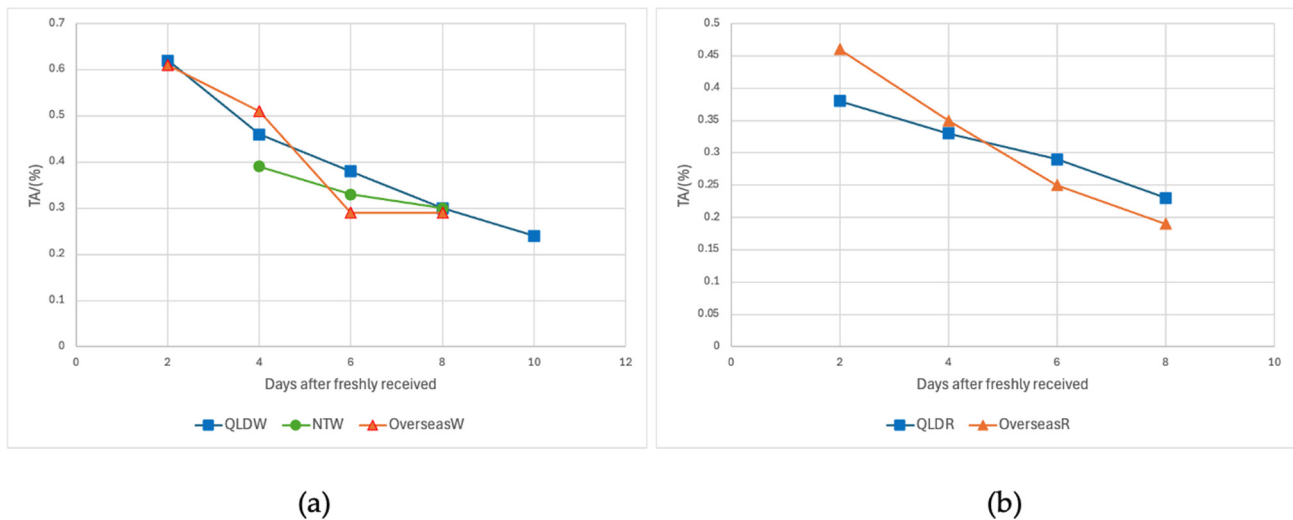


Figure 8. Changes in the titratable acidity (TA) of dragon fruit stored under ambient conditions during its shelf-life. (a) Changes in the TA of white-flesh dragon fruit during shelf-life; (b) changes in the TA of red-flesh dragon fruit during shelf-life. QLDW, Queensland-grown white-flesh dragon fruit; NTW, Northern Territory-grown white-flesh dragon fruit; OverseasW, overseas-grown white-flesh dragon fruit; QLDR, Queensland-grown red-flesh dragon fruit; OverseasR, overseas-grown red-flesh dragon fruit.

The initial higher TA in imported dragon fruits followed by a rapid decrease from day 4 to day 6 is likely due to refrigerated transportation, which slows down metabolism and enzymatic activities, resulting in lower organic acid consumption [55]. In contrast, Australian-grown dragon fruits experienced relatively consistent ambient conditions post-harvest, leading to a gradual decrease in TA. This temperature effect has also been observed in other fruits such as aronia berry [56] and strawberry [57]. Similar to pH, the mature stage of the dragon fruit also significantly impacts TA [58]. Zitha et al. reported significant TA changes occurred in red-flesh dragon fruit, ranging from 1.28% to 0.20% of malic acid from 28 to 42 days after anthesis [18].

3.1.7. Overall Shelf-Life

The shelf-life of dragon fruits was assessed by counting the number of days from the receipt date until the samples no longer met the criteria for Class II fruit (see Section 2.3) according to the Codex Alimentarius Standard for dragon fruit (CXS 237-2003). For white-flesh dragon fruits, freshly received Australian-grown fruit has an average of 9 days of shelf-life under ambient conditions, whereas freshly received imported fruit has an average of 8 days of shelf-life. For the red-flesh variety, the shelf-life is identical for both Australian-grown and imported dragon fruit, at 8 days after being freshly harvested or received. The slightly longer shelf-life observed in Australian-grown white-flesh dragon fruit is likely caused by higher TSS and TA at the beginning and lower weight loss (see Table A1) during storage (Table 2).

Table 2. Overall shelf-life of Australian-grown and imported dragon fruit stored under ambient conditions.

	Days after Being Freshly Received
White-flesh dragon fruit	
Australian-grown	9
Imported	8
Red-flesh dragon fruit	
Australian-grown	8
Imported	8

Recent studies have explored various postharvest techniques to extend the shelf-life of dragon fruit, encompassing physical, chemical, and biological preservation methods. Lau et al. reported that white-flesh dragon fruit treated with hot water at 55 °C for 15 min and subsequently bagged in sealed, hole-free polyethylene plastic bags maintained their physical appearance significantly better and exhibited a much lower incidence of disease infestation for up to 21 days in chilled storage, compared to those stored under similar conditions without heat treatment [59]. Wu et al. applied blue light to red-flesh dragon fruit and found that this treatment slowed down the decrease in total soluble solids (TSS), titratable acidity (TA), and antioxidant activities during storage [60]. Calcium chloride treatment has been reported by Awang et al. [61] and Ghani et al. [62] as an efficient chemical approach to prolong the shelf-life of red-flesh dragon fruit. This treatment significantly increased the firmness and slow down the decline in pH, TSS, and TA of the fruit during storage. Chitosan coating has been utilized for decay prevention in postharvest fruits and vegetables. Prashanth et al. [63] indicated that in dragon fruit treated with 4% chitosan coating, the trends of weight loss, firmness, TSS and TA were significantly slowed down, demonstrating decay inhibition capacity. Biological approaches, such as plant essential oil treatment, have also been investigated. Chaemsanit et al. [64] reported that applying 700 µL/L of peppermint oil on coconut shell granular activated carbon inhibited 100% of decay mold and fungi during storage at 25 °C. These techniques can be recommended for postharvest handling of dragon fruit in Australia to enhance competitiveness with imported dragon fruits.

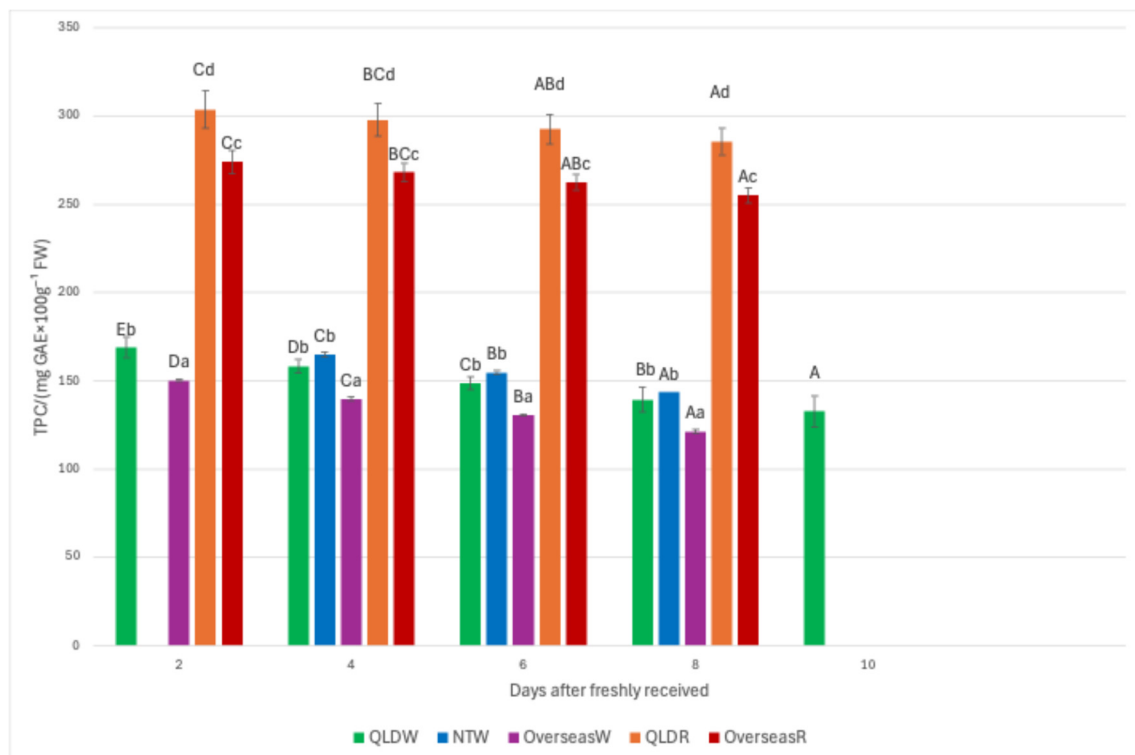
3.2. Antioxidant Activities

Dragon fruit is known for its rich antioxidant contents, which plays a critical role in protecting cells from oxidative stress and free radical-induced damage [65]. These antioxidants are associated with numerous health benefits such as anti-inflammatory, anti-cancer, and anti-obesity properties [25]. In this study, the analysis of antioxidant activities during shelf-life of dragon fruits includes measurements of total phenolic content (TPC), total flavonoid content (TFC), ferric reducing antioxidant power (FRAP), cupric reducing antioxidant capacity (CUPRAC), total betalain content (TBC, applicable to red-flesh fruits only), and total anthocyanin content (TAC, applicable to red-flesh fruits only). Detailed data for these analyses are provided in Tables A2 and A3 in Appendix A. It is worth noting that different concentration level of antioxidative compounds presented in dragon fruits depends on the cultivar and factors affecting cultivation and harvest, such as soil, climate conditions, irrigation, fertilization, etc. [66–70].

3.2.1. Results

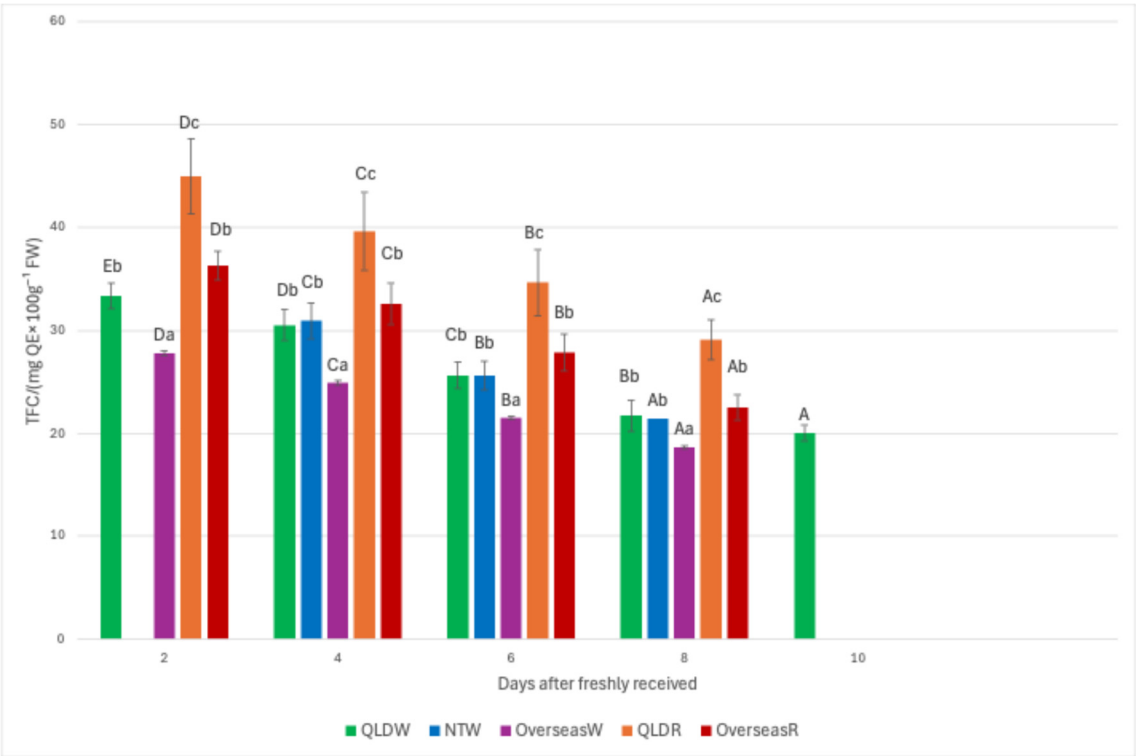
The bar graph in Figure 9 illustrates the total phenolic content (TPC), total flavonoid content (TFC), ferric reducing antioxidant power (FRAP), cupric reducing antioxidant capacity (CUPRAC), total betalain content (TBC), and total anthocyanin content (TAC) in Australian-grown and imported dragon fruits throughout their shelf-life under ambient conditions. An overall decline trend can be observed across all groups. This decreasing trend matches with previous similar study on Indian-grown dragon fruit reported by Lata et al. [21].

The total phenolic content (TPC) in Australian-grown and imported dragon fruits throughout their shelf-life under ambient conditions is exhibited in Figure 9a. Queensland-grown white-flesh dragon fruits (QLDW) started with a TPC of 168.94 ± 5.86 mg GAE/100 g FW on day 2, decreasing to 132.84 ± 8.74 mg GAE/100 g FW by day 10. Northern Territory-grown white-flesh (NTW) fruits had a TPC of 164.95 ± 1.66 mg GAE/100 g FW on day 4, reducing to 143.71 ± 1.23 mg GAE/100 g FW by day 8. There is no significant difference ($p > 0.05$) in TPC between QLDW and NTW across shelf-life. In contrast, the imported white-flesh dragon fruits (OverseasW) began at 150.25 ± 0.72 mg GAE/100 g FW on day 2 and dropped to 121.31 ± 1.03 mg GAE/100 g FW by day 8. For the red-flesh varieties, Queensland-grown (QLDR) fruits exhibited the highest TPC values, starting at 303.70 ± 10.44 mg GAE/100 g FW on day 2 and slightly decreasing to 285.44 ± 7.48 mg GAE/100 g FW by day 8. The imported red-flesh fruits (OverseasR) started at 273.98 ± 6.41 mg GAE/100 g FW on day 2 and decreased to 255.04 ± 4.38 mg GAE/100 g FW by day 8. Observation of this study indicates that red-flesh dragon fruit has higher TPC than white-flesh fruit, which is identical to the similar study on Indian-grown dragon fruit study conducted by Lata et al. [21]. Overall, the data suggests that Australian-grown dragon fruits maintain higher TPC levels throughout their shelf-life compared to imported fruits. This indicates better retention of antioxidant properties and potentially higher nutritional quality. In addition, Zakaria et al. [71] reported a TPC value of 11.47 ± 0.01 mg GAE/100 g FW in white-flesh and 20.50 ± 0.02 mg GAE/100 g FW in red-flesh dragon fruit from Malaysia, indicating Australian-grown dragon fruits have higher concentration level of total phenolics. According to study conducted by Arivalagan et al. [72], dragon fruits from India also exhibited lower TPC results, with 24.8 ± 0.9 mg GAE/100 g FW in white-flesh and 48.3 ± 3.9 mg GAE/100 g FW in the red-flesh dragon fruit.

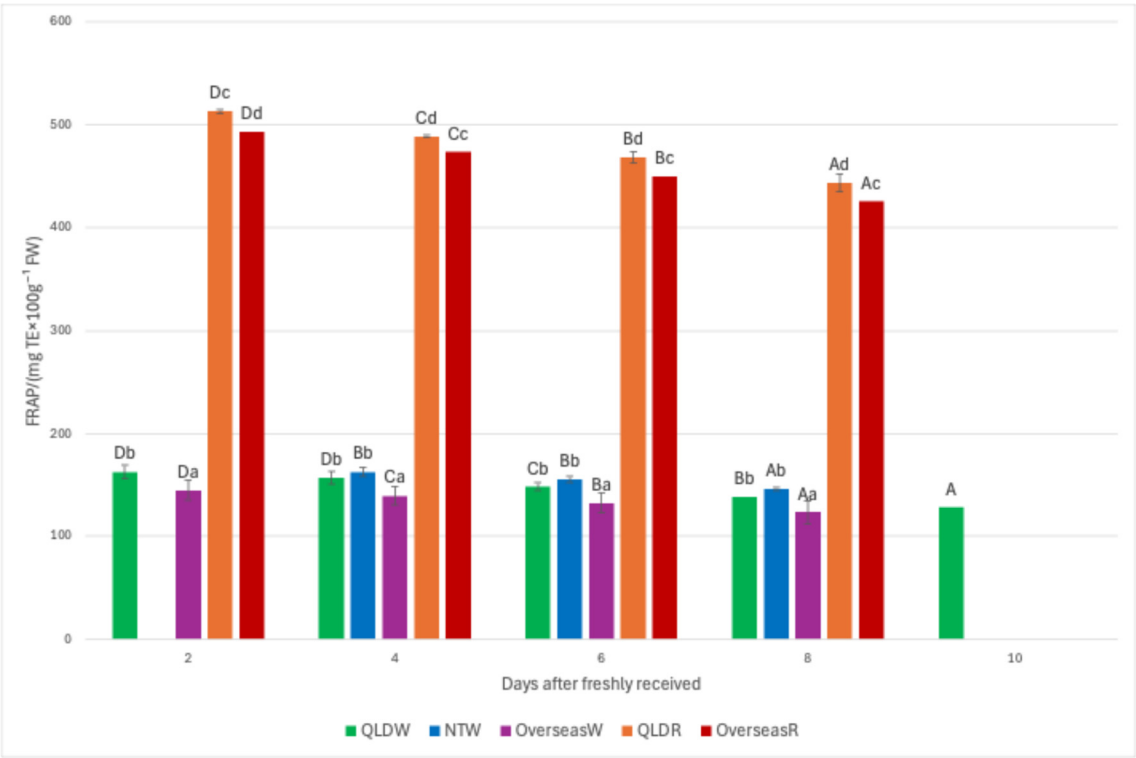


(a)

Figure 9. Cont.

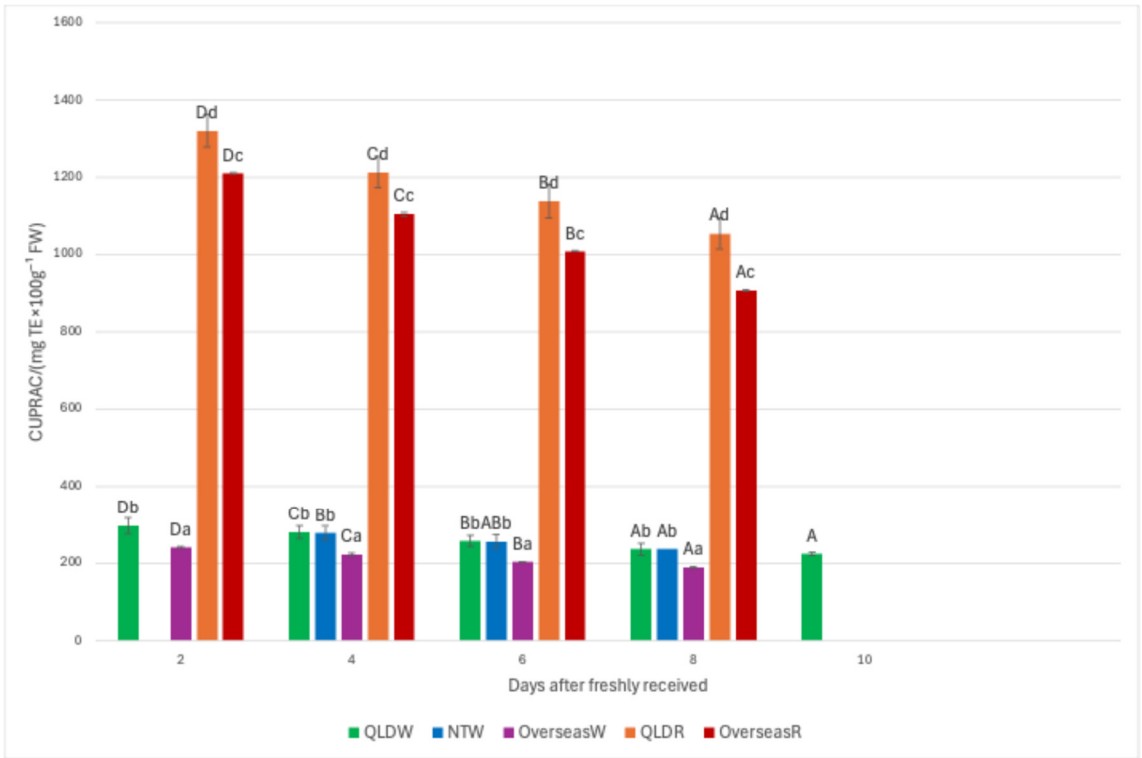


(b)

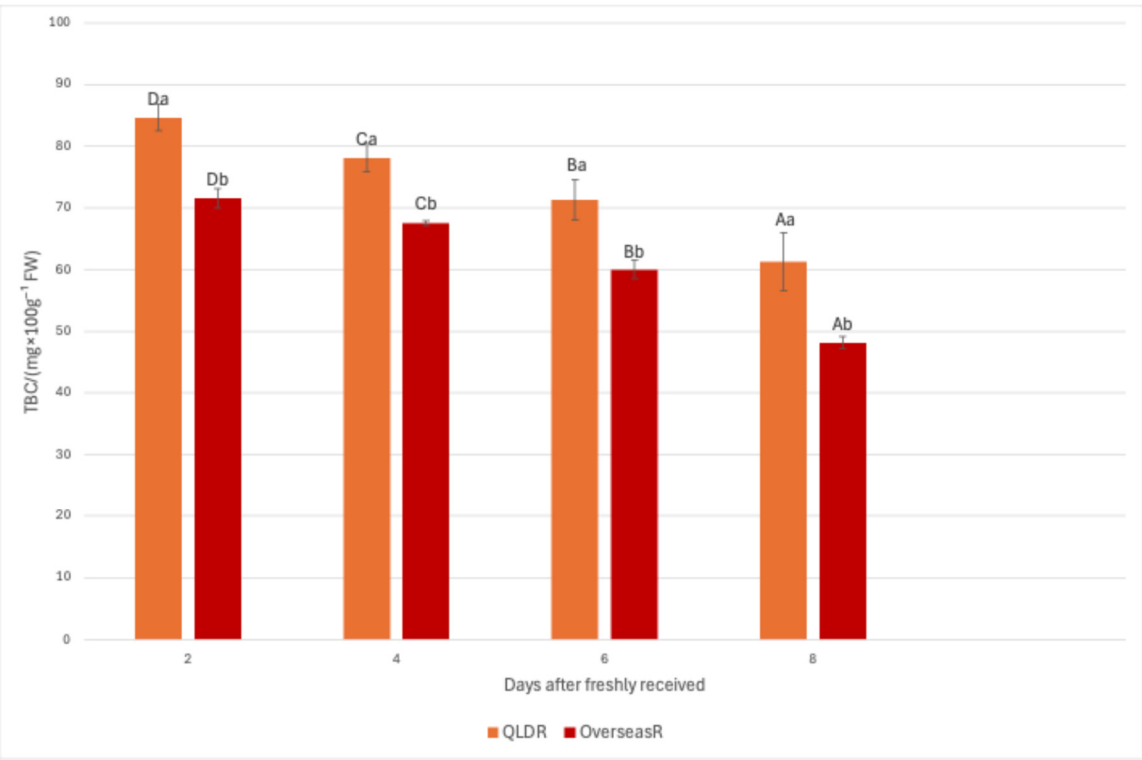


(c)

Figure 9. Cont.

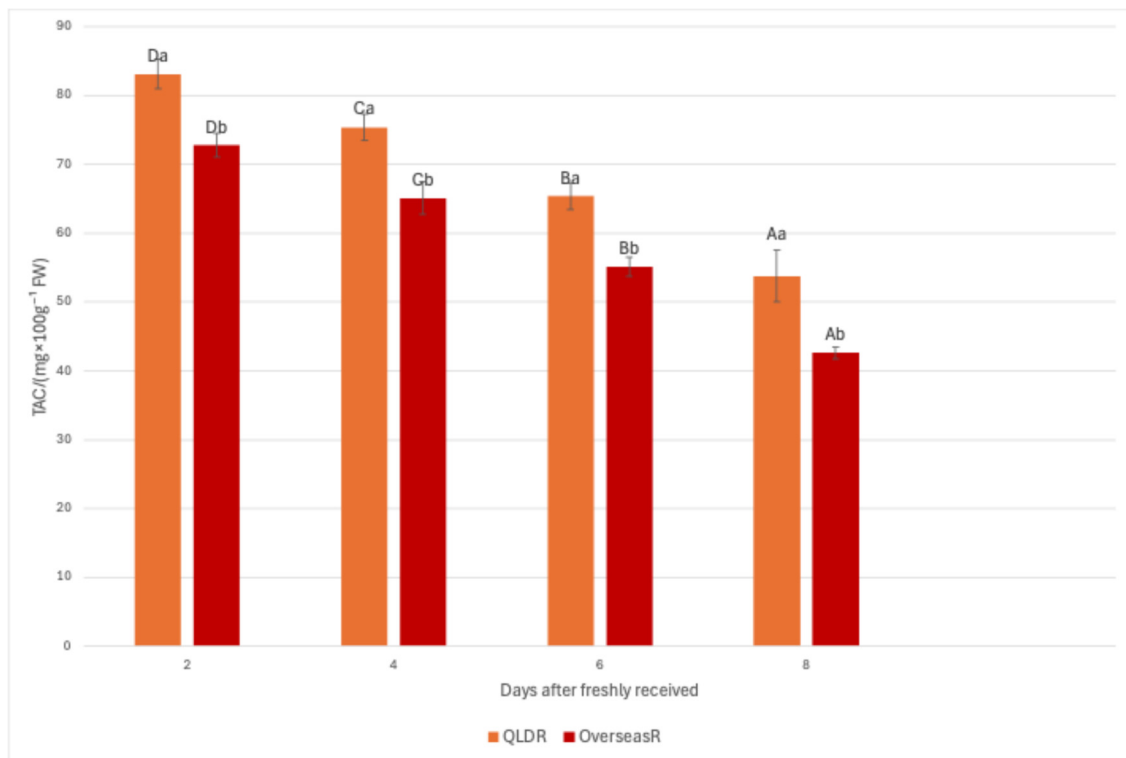


(d)



(e)

Figure 9. Cont.



(f)

Figure 9. Phytochemical contents and antioxidant activity of Australian-grown and imported dragon fruit during shelf-life under ambient conditions. (a) Changes in TPC during shelf-life; (b) changes in TFC during shelf-life; (c) changes in FRAP during shelf-life; (d) changes in CUPRAC during shelf-life; (e) changes in TBC during shelf-life; (f) changes in TAC during shelf-life. QLDW, Queensland-grown white-flesh dragon fruit; NTW: Northern Territory-grown white-flesh dragon fruit; OverseasW, overseas-grown white-flesh dragon fruit; QLDR, Queensland-grown red-flesh dragon fruit; OverseasR, overseas-grown red-flesh dragon fruit. ^{A,B,C,D,E} Different capital letters indicate statistically significant differences across shelf-life days for the same region or variety ($p < 0.05$). ^{a,b,c,d} Different lowercase letters indicate statistically significant differences across regions or varieties ($p < 0.05$).

The total flavonoid content (TFC) in Australian-grown and imported dragon fruits throughout their shelf-life under ambient conditions is shown in Figure 9b. An overall decreasing trend can be observed across all groups, identical to the previous shelf-life study on Indian-grown dragon fruits under ambient conditions conducted by Lata et al. [21]. Queensland-grown white-flesh dragon fruits (QLDW) began with a TFC of 33.37 ± 1.22 mg QE/100 g FW on day 2, showing a gradual decrease to 20.07 ± 0.76 mg QE/100 g FW by day 10. In comparison, the imported white-flesh dragon fruits (OverseasW) started at 27.78 ± 0.23 mg QE/100 g FW on day 2 and dropped to 18.69 ± 0.15 mg QE/100 g FW by day 8, consistently showing lower TFC values than QLDW. Northern Territory-grown white-flesh dragon fruits (NTW) showed TFC values of 30.95 ± 1.81 mg QE/100 g FW on day 4, decreasing to 21.47 ± 1.36 mg QE/100 g FW by day 8. While the TFC levels of NTW and QLDW were similar and showed no significant difference ($p > 0.05$), both consistently showed higher TFC values compared to OverseasW. For the red-flesh dragon fruits, Queensland-grown dragon fruits (QLDR) exhibited the highest TFC values among the five groups, starting at 45.00 ± 3.64 mg QE/100 g FW on day 2 and gradually decreasing to 29.13 ± 1.93 mg QE/100 g FW by day 8. These values were notably higher than those of the imported red-flesh dragon fruits (OverseasR), which began at 36.32 ± 1.37 mg QE/100 g FW and fell to 22.54 ± 1.25 mg QE/100 g FW by day 8. The significant differences ($p < 0.05$) in TFC values between QLDW/NTW and OverseasW,

as well as between QLDR and OverseasR, highlight the better retention of flavonoids in Australian-grown dragon fruits compared to imported fruits, thus exhibiting the advantage of Australian-grown fruits in retaining their health benefits during storage. Total flavonoid content in Australian-grown dragon fruits in this study also demonstrated slightly higher values than Indian-grown fruits reported by Arivalagan et al. [72], with 19.7 ± 4.1 mg CE/100 g FW in white-flesh and 31.2 ± 1.3 mg CE/100 g FW in red-flesh dragon fruits. In addition, compared to a recent study on Malaysian dragon fruits conducted by Zakaria et al. [71] who reported 2.96 ± 0.01 mg QE/100 g FW in white-flesh and 4.18 ± 0.01 mg QE/100 g FW in red-flesh dragon fruit, Australian-grown dragon fruits showed significantly higher TFC.

Ferric reducing antioxidant power (FRAP) assay is a widely used for the determination of antioxidant activities. This assay evaluates the total antioxidant power by quantifying the reduction of ferric ions (Fe^{3+}) to ferrous ions (Fe^{2+}) by the antioxidants present in the fruits [73]. The changes of ferric reducing antioxidant power in Australian-grown and imported dragon fruits throughout their shelf-life under ambient conditions is shown in Figure 9c. An overall decreasing trend can be observed across all groups. This trend throughout shelf-life is identical to a similar shelf-life research on Indian-grown dragon fruits under ambient conditions conducted by Lata et al. [21] and Malaysian-grown fruits conducted by Ismail et al. [74]. Queensland-grown white-flesh dragon fruits (QLDW) started with a FRAP value of 163.19 ± 6.61 mg TE/100 g FW on day 2, which decreased to 128.81 ± 4.80 mg TE/100 g FW by day 10. Comparatively, the imported white-flesh dragon fruits (OverseasW) began at 145.37 ± 1.23 mg TE/100 g FW on day 2 and dropped to 123.32 ± 1.35 mg TE/100 g FW by day 8, consistently showing lower FRAP values than QLDW. Northern Territory-grown white-flesh dragon fruits (NTW) exhibited FRAP values of 163.17 ± 6.34 mg TE/100 g FW on day 4, decreasing to 146.59 ± 3.83 mg TE/100 g FW by day 8. Although there is no significant difference ($p > 0.05$) between QLDW and NTW, both maintained higher values than OverseasW. For the red-flesh variety, Queensland-grown red-flesh dragon fruit (QLDR) showed the highest FRAP values among all groups, starting at 513.15 ± 9.85 mg TE/100 g FW on day 2 and decreasing to 443.54 ± 11.55 mg TE/100 g FW by day 8. These values were significantly higher ($p < 0.05$) than those of the imported red-flesh dragon fruits (OverseasR), which started at 493.11 ± 1.99 mg TE/100 g FW on day 2 and fell to 425.70 ± 8.35 mg TE/100 g FW by day 8. The consistently higher FRAP values in Australian-grown dragon fruits highlight their better retention of antioxidant properties throughout their shelf-life under ambient conditions compared to imported fruits. The statistically significant differences suggest the influence of regional and varietal differences on the antioxidant capacity of dragon fruits. The ferric reducing antioxidant power in Australian-grown dragon fruit in this study exhibited higher values than Indonesian dragon fruit reported by Pangesty et al. [75] with a value of 0.04 mg AAE/g in red-flesh and 0.03 mg AAE/g in white-flesh dragon fruit.

The cupric reducing antioxidant capacity (CUPRAC) assay measures the reducing capacity of copper(II)-neocuproine (Cu(II)-Nc) complex to the copper(I)-neocuproine (Cu(I)-Nc) complex in antioxidants in fruits [76]. The changes of cupric reducing antioxidant capacity in Australian-grown and imported dragon fruits throughout their shelf-life under ambient conditions is shown in Figure 9d. An overall decreasing trend can be observed across all groups. Queensland-grown white-flesh dragon fruits (QLDW) began with a CUPRAC value of 296.39 ± 20.58 mg TE/100 g FW on day 2, decreasing to 223.82 ± 4.86 mg TE/100 g FW by day 10. In contrast, the imported white-flesh dragon fruits (OverseasW) started at 240.32 ± 2.20 mg TE/100 g FW on day 2 and dropped to 188.00 ± 2.12 mg TE/100 g FW by day 8, consistently showing lower CUPRAC values than QLDW. Northern Territory-grown white-flesh dragon fruits (NTW) exhibited CUPRAC values of 277.43 ± 22.87 mg TE/100 g FW on day 4, decreasing to 235.33 ± 17.34 mg TE/100 g FW by day 8. Although there was no significant difference ($p > 0.05$) between QLDW and NTW, both exhibited higher values compared to OverseasW. For the red-flesh fruits, Queensland-grown red-flesh dragon fruits (QLDR) exhibited the highest CUPRAC values among

all groups, starting at 1319.71 ± 42.34 mg TE/100 g FW on day 2 and gradually decreasing to 1053.93 ± 39.97 mg TE/100 g FW by day 8. These values were significantly higher ($p < 0.05$) than those of the imported red-flesh variety (OverseasR), which began at 1210.38 ± 1.43 mg TE/100 g FW on day 2 and fell to 906.43 ± 1.79 mg TE/100 g FW by day 8. Australian-grown dragon fruits demonstrated consistently higher CUPRAC values, which suggests they retain their antioxidant properties more effectively during storage than imported dragon fruits. The presence of statistically significant differences emphasizes the role of regional and varietal factors in influencing the antioxidant capacity of dragon fruits. Al-Mekhlafi et al. reported a CUPRAC value of 23.05 ± 2.14 mg μ MTE/g FW in red-flesh dragon fruit and 15.76 ± 1.38 mg μ MTE/g FW in white-flesh dragon fruit from Thailand [66]. Sharma et al. reported a CUPRAC value of 525.60 ± 13.8 μ mol TE/100 g FW in white-flesh dragon fruit and 917.00 ± 18.99 μ mol TE/100 g FW in red-flesh dragon fruit from India [77]. Comparing to those two regions, Australian-grown dragon fruits showed comparable CUPRAC value.

The concentration of total betalain content in red-flesh dragon fruit pulp is associated with fruit nutritional value and shelf-life [72]. Betalains include two main subclasses, betacyanins (red to violet pigments) and betaxanthins (yellow to orange pigments), which are strong antioxidative compounds with potential of scavenging of free radicals and minimizing oxidative stress [78]. These antioxidant properties assist with maintaining nutritional quality of the fruit during storage. Changes of total betalain content in Australian-grown and imported red-flesh dragon fruits during shelf-life under ambient conditions are shown in Figure 9e. Initially, QLDR exhibited a TBC of 84.63 ± 2.15 mg/100 g FW on day 2, which gradually decreased to 61.29 ± 4.71 mg/100 g FW by day 8. In contrast, OverseasR started with a TBC of 71.65 ± 1.57 mg/100 g FW on day 2 and declined to 48.16 ± 0.99 mg/100 g FW by day 8. Notably, QLDR consistently showed higher TBC values than OverseasR at every shelf-life testing point, as indicated by different lowercase letters indicating significant differences ($p < 0.05$). For instance, on day 2, QLDR fruits had a significantly higher TBC than OverseasR (84.63 vs. 71.65 mg/100 g FW). This trend persisted with QLDR maintaining higher TBC levels on day 4 (78.15 ± 2.29 mg/100 g FW) and day 6 (71.31 ± 3.22 mg/100 g FW) compared to OverseasR (67.59 ± 0.42 mg/100 g FW and 60.01 ± 1.49 mg/100 g FW, respectively). By day 8, QLDR retained a TBC of 61.29 ± 4.71 mg/100 g FW, significantly higher than 48.16 ± 0.99 mg/100 g FW of OverseasR. These results exhibit the capacity of Australian-grown red-flesh dragon fruit in maintaining its TBC, leading to less decline in antioxidant properties and visual appeal of the pulp, and thus emphasize higher nutritional and quality attributes during storage. In addition, an overall decreasing trend can be observed for both groups, which is identical to the study on Indian-grown dragon fruit conducted by Lata et al. [21] reporting a TBC of 129.96 mg BCE/100 g FW at the start and gradually decreased to 104.56 mg BCE/100 g FW on day 7. These results are slightly higher than Australian-grown and imported red-flesh dragon fruits in this study. Rodriguez et al. reported a betalains concentration of 42.71 ± 2.48 mg/100 g FW in Philippine-grown red-flesh dragon fruit after being freshly harvested from the farm [79], which only showed half of amount of betalains presented in Australian-grown red-flesh dragon fruit. Due to the higher betalains exhibited in the Australian-grown red-flesh dragon fruits, consuming them potentially provides higher capabilities on facilitating weight management [80], enhancing digestive health [81], lowering LDL (low-density lipoprotein) cholesterol [82], and boosting the immune system of human body [83].

Similar to betalains, anthocyanins are antioxidative pigments show health benefits potentials such as anti-cardiovascular diseases, anti-diabetes and anti-cancer [84]. In dragon fruit, it not only contributes to the vibrant color, but also oxidative stability of the fruit, which assists with preserving the quality during storage [85]. Figure 9f shows the changes of total anthocyanin content of Australian-grown and imported red-flesh dragon fruits during shelf-life under ambient conditions. Initially, QLDR exhibited a TAC of 83.12 ± 2.11 mg/100 g FW on day 2, which dropped to 53.78 ± 3.77 mg/100 g FW by day 8.

In contrast, OverseasR started with a TAC of 72.78 ± 1.75 mg/100 g FW on day 2, decreasing to 42.65 ± 0.87 mg/100 g FW by day 8. Notable significant differences ($p < 0.05$) between QLDR and OverseasR fruits at each shelf-life testing point, as indicated by different lower-case letters, highlight that Queensland-grown red-flesh dragon fruits consistently maintained higher TAC levels throughout the storage period. On day 2, QLDR fruits had a significantly higher TAC compared to OverseasR (83.12 ± 2.11 vs. 72.78 ± 1.75 mg/100 g FW). This trend maintained over the subsequent days, with QLDR exhibiting higher TAC on day 4 (75.38 ± 1.92 mg/100 g FW) and day 6 (65.35 ± 1.87 mg/100 g FW), in contrast to OverseasR (65.09 ± 2.36 mg/100 g FW and 55.14 ± 1.36 mg/100 g FW, respectively). By day 8, QLDR fruits retained a TAC of 53.78 ± 3.77 mg/100 g FW, significantly higher than the results of 42.65 ± 0.87 mg/100 g FW observed in OverseasR. An overall decreasing trend of TAC can also be observed across both groups. Similar trends have been reported in strawberries [86] and blackberries [87]. Khoo et al. reported a TAC level of 15.16 ± 0.02 mg/g FW in red-flesh dragon fruit grown in China [88], while Zitha et al. found a TAC level of 18.07 mg cy-3-glu/100 g FW in red-flesh dragon fruit from Brazil [18]. It is important to note that the methodology used in this study differs from those applied in the aforementioned research. Additionally, variations in climate, soil, and cultivation conditions also contribute to the differences in TAC results.

3.2.2. Discussion

The decline in TPC during shelf-life under ambient conditions is likely due to oxidation and active enzymes in fruit. Phenolic compounds can experience rapid oxidation when exposed to higher oxygen level, stronger light conditions, and higher temperatures [89]. Enzymes such as polyphenol oxidase (PPO) and peroxidase (POD) are more active in relative high temperature (ambient temperature), leading to rapid catalyzation of degradation of the phenolic compounds [90]. The significant differences in TPC between Australian-grown and imported dragon fruit is likely due to the maturity stage when being harvested and transportation. Both Trong et al. [91] and Zitha et al. [18] reported an increase of TPC on red-flesh dragon fruit during fruit development. Imported fruits are often harvested at earlier maturity stage, and thus contribute to lower TPC. In addition, imported fruits may experience more environmental stress such as temperature fluctuations during transportation, which can lead to degradation of phenolic compounds [92].

As one of the subclass of the phenolic compounds, flavonoids are known for their strong antioxidant properties including anti-inflammatory due to their ability of reducing the risk of cardiovascular diseases and cancer, and antimicrobial properties which protect fruits from spoilage, and thus extend their shelf-life [93]. As flavonoids are groups of phenolic compounds, the decreasing shelf-life under ambient conditions is likely due to accelerated oxidation [89] and enzymatic activities [90]. Australian-grown dragon fruits exhibited higher TFC across their shelf-life compared to imported fruits is likely due to the maturity stage after being harvested and long-distance transportation. Studies conducted by Elmastaş et al., Vvedenskaya, et al., and Dong et al. reported an increasing flavonoid contents during ripening of *Rosa* species [94], cranberries [95], and bananas [96], respectively. Because imported fruits are often harvested at earlier maturity stage than Australian-grown fruits, higher TFC can be found in Australian-grown dragon fruits.

Significant higher values in CUPRAC than FRAP for each group are observed. Unlike FRAP assay, which works only on hydrophilic antioxidants [97] that can reduce Fe^{3+} to Fe^{2+} , CUPRAC assay measures a broader range of hydrophilic and lipophilic antioxidants including phenolic compounds, carotenoids, and vitamins [98]. In addition, the Cu(II)/Cu(I) redox couple employed in the CUPRAC assay has a higher redox potential compared to the Fe(III)/Fe(II) couple used in the FRAP assay [99]. This characteristic allows the CUPRAC assay to detect a wider variety of antioxidant compounds, including those with higher redox potentials that might not effectively reduce Fe^{3+} in the FRAP assay. In addition, the CUPRAC assay is capable of detecting antioxidant activity through both radical scavenging and reducing mechanisms [100]. This broad sensitivity allows it to measure higher

antioxidant capacities than the FRAP assay, which primarily assesses reducing power only. It is also worth noting that the significant difference between FRAP and CUPRAC results also indicates the complexity of dragon fruit's matrix, which contains diverse antioxidative compounds and exhibits various interactions.

Several factors can significantly impact the stability of betalains. These pigments are particularly sensitive to high temperatures, which can accelerate their degradation, thereby affecting both the coloration and antioxidant activities of the fruit. Research by Woo et al. [101] and Chew et al. [26] reported that exposure to higher temperatures accelerates the breakdown of betalains in dragon fruit into betalamic acid, cyclo-Dopa, and amines. In addition, betalains are most stable at a pH range of 4–7 [102]. Any deviations from this range can lead to the breakdown of the chromophore structure, thus resulting in color loss of the fruit and reduced antioxidant properties [102]. High levels of UV light [103] and oxygen [78] can also cause degradation of betalains. Imported dragon fruits may have higher chances of being exposed to those destabilizing factors due to long-distance transportation, resulting in lower total betalain contents compared to Australian-grown dragon fruits.

It has been reported that high anthocyanin content in fruits and plants is associated with pathogen resistance. The presence of anthocyanins significantly decreases the abundance of toxin-producing pathogenic bacteria in the host, such as *Desulfovibrio* sp. and *Enterococcus* [104]. It can also induce the production of pathogenesis-related proteins and phytoalexins which are defensive compounds that enhance resistance to diseases and pathogen attacks [105]. As a subclass of flavonoids, anthocyanins help reduce oxidative stress, which aids in maintaining cell membrane integrity and consequently delays the quality degradation of the fruits [106]. Due to these antimicrobial properties, Australian-grown red-flesh dragon fruit, with its higher TAC compared to imported varieties, is at a lower risk of spoilage during storage.

Australian-grown dragon fruits showed overall higher antioxidant capacity than the imported dragon fruits, exhibiting higher TPC, TFC, FRAP, CUPRAC, TBC (red-flesh dragon fruit), and TAC (red-flesh dragon fruit) values. This suggests that Australian-grown fruits have richer content in phenolic compounds, flavonoids, betalains (red-flesh dragon fruit), and anthocyanins (red-flesh dragon fruit). The higher FRAP and CUPRAC results indicate higher overall antioxidant activities in dragon fruits from Australia than the imported ones. For consumers, it translates to greater health benefits, boosting overall wellness. Fresh fruit containing higher antioxidant levels is also more resistant to pathogens, leading to greater durability during transportation and storage, thereby maintaining its quality throughout its shelf-life.

The differences in antioxidant parameters between Australian-grown and imported dragon fruits are likely due to differences in agricultural practices. The imported fruits are often harvested at an earlier maturity stage than fruits from Australia to overcome the quality loss during the long-distance of transportation and to remain fresh when they reach their destination [107]. It has been reported that the level of antioxidative compounds in dragon fruit increases during fruit development [18,92]. As a result, imported dragon fruits are often harvested when their levels of antioxidative compounds are still low. Additionally, imported dragon fruits have higher risk of experiencing temperature fluctuations, light exposure, and high oxygen level, resulting in the degradation of antioxidants [108]. Finally, soil quality, climate conditions, and farming techniques can also impact the quality of the fruit, resulting in different concentration of antioxidative compounds [109,110].

The Codex Alimentarius is a compilation of internationally accepted food standards to ensure fair practices in food trade [111]. For dragon fruit, the Codex Alimentarius standard CXS 237-2003 primarily focuses on physical parameters including size and weight to classify the fruit. These standards help maintain consistency and quality in the global market by specifying acceptable ranges for these physical characteristics. However, the current standard does not account for the nutritional or antioxidant properties of dragon fruit, which attracts consumers attention due to their health benefits. Given the rising interest

in the health-promoting aspects of foods, it would be beneficial for future revisions of the standard to consider incorporating antioxidant-related parameters. Including such criteria could provide a more comprehensive quality assessment, reflecting both the physical attributes and the nutritional value of dragon fruit.

3.3. Correlation between Shelf-Life Parameters and Antioxidant Activities

Pearson correlation coefficient analysis was conducted between shelf-life and antioxidant activity related parameters (Figure 10). Strong correlations were observed between the TPC, TFC, FRAP, and CUPRAC in dragon fruit, indicating antioxidant activities (CUPRAC and FRAP) are highly dependent on the phenolic and flavonoid content. Furthermore, total betalain content is strongly correlated ($r = 0.965$) with total anthocyanin content, which both of the pigments contribute to the coloration in red-flesh dragon fruit. There is also a strong correlation between pH and titratable acidity ($r = -0.814$) in dragon fruit during shelf-life.

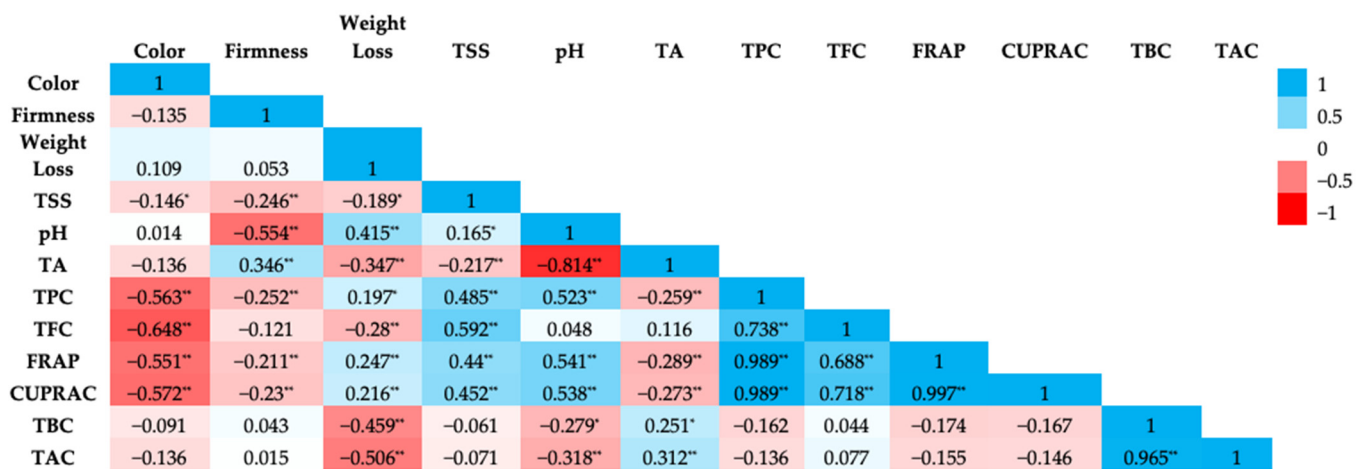


Figure 10. Pearson's correlation coefficients between shelf-life parameters and antioxidant activities. *. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed).

The color index $\log(R_{681}/R_{551})$ of dragon fruit used in this study increases during shelf-life. Moderate negative correlations can be observed between color and antioxidant activity related parameters including TPC, TFC, FRAP, and CUPRAC, with $r = -0.563$, -0.648 , -0.551 , and -0.572 , respectively. This indicates that dragon fruit color loss has moderate correlations with the degradation of total phenolic compounds, total flavonoids, ferric reducing antioxidant power, and cupric reducing antioxidant capacity in dragon fruit. Similar relationships between color and antioxidant activity have been reported in other fruit, such as apple [112], banana [113], grape, strawberry, and plum [114]. Firmness shows a moderate negative correlation with pH ($r = -0.554$), suggesting dragon fruit losses firmness as pH increases during shelf-life. Total soluble solids show slightly less moderate correlations with TPC ($r = 0.485$), FRAP ($r = 0.44$), and CUPRAC ($r = 0.452$), and moderate correlation with TFC ($r = 0.592$), indicating that a decrease in TSS can be associated with those antioxidant activity related parameters in dragon fruit. Counterintuitive moderate correlations ($r > 0.5$) between pH and TPC, FRAP, and CUPRAC are also exhibited. These correlations are likely due to the findings from the dragon fruit shelf-life quality study, where the fruits did not exhibit a significant drop in antioxidant levels in the early stages, despite a sharp increase in pH. In contrast, antioxidant levels showed a steep decline while pH values remained stable in the later stages of shelf-life.

4. Conclusions

This study concludes that the Australian-grown dragon fruits outperform imported dragon fruits in quality and antioxidant activity related parameters throughout shelf-life

under ambient conditions. These Australian-grown fruits experienced less weight loss, and maintained better peel color, firmness, total soluble solids, and acidity during storage. The higher values of TPC, TFC, FRAP, CUPRAC, TBC, and TAC in Australian-grown dragon fruits maintained throughout their shelf-life further highlight their nutritional quality and potential health benefits. It is worth noting that these differences are likely due to variations in agricultural practices, maturity at harvest, and environmental conditions during transportation of the imported dragon fruits. Furthermore, strong correlations between antioxidant parameters provide insights into the physiological changes that occur during dragon fruit storage. The findings of this study reveal the potential of Australian-grown dragon fruits to secure a stronger market position due to their slightly longer shelf-life and better quality, which offer a distinct competitive advantage over imported dragon fruits. Future research could further explore the optimization of postharvest handling techniques to amplify these potentials, and thus further enhance the marketability of Australian-grown dragon fruits.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Changes of shelf-life related parameters of Australian-grown and imported dragon fruits under ambient conditions.

Day	Origin/ Variety	Color/ log(R ₆₈₁ /R ₅₅₁)	Firmness/ N _{Max}	Weight Loss/%	TSS/° Brix	pH	TA/%, as MAE
2	QLDW	0.86 ± 0.10 ^{Ab}	11.34 ± 2.26 ^{Ca}	-	14.43 ± 0.83 ^{Bab}	4.56 ± 0.22 ^{Aa}	0.62 ± 0.23 ^{Cb}
	NTW	-	-	-	-	-	-
	OverseasW	0.74 ± 0.14 ^{Ab}	16.45 ± 3.44 ^{Ab}	-	13.92 ± 0.57 ^{Aa}	4.42 ± 0.03 ^{Aa}	0.61 ± 0.02 ^{Db}
	QLDR	0.50 ± 0.13 ^{Aa}	9.78 ± 1.27 ^{Ba}	-	15.27 ± 1.16 ^{Ab}	5.23 ± 0.17 ^{Ac}	0.38 ± 0.13 ^{Ba}
	OverseasR	0.73 ± 0.05 ^{Ab}	13.99 ± 1.09 ^{Bb}	-	14.92 ± 1.22 ^{Aab}	4.86 ± 0.02 ^{Ab}	0.46 ± 0.01 ^{Dab}
	QLDW	0.95 ± 0.08 ^{Bb}	10.53 ± 1.81 ^{BCab}	1.33 ± 0.42 ^{Aab}	14.53 ± 0.84 ^{Ba}	4.82 ± 0.17 ^{Bb}	0.46 ± 0.14 ^{Bab}
4	NTW	0.76 ± 0.06 ^{Aa}	12.69 ± 1.95 ^{Ab}	-	14.37 ± 0.29 ^{Ca}	4.61 ± 0.12 ^{Aa}	0.39 ± 0.02 ^{Bab}
	OverseasW	0.85 ± 0.16 ^{Aab}	16.68 ± 2.76 ^{Ac}	2.36 ± 0.84 ^{Ab}	13.90 ± 0.77 ^{Aa}	4.61 ± 0.04 ^{Ba}	0.51 ± 0.02 ^{Cb}
	QLDR	0.73 ± 0.12 ^{Ba}	9.47 ± 1.10 ^{ABa}	1.96 ± 0.51 ^{Aab}	15.14 ± 1.34 ^{Aa}	5.38 ± 0.15 ^{ABd}	0.33 ± 0.10 ^{Ba}
	OverseasR	0.82 ± 0.07 ^{ABab}	12.81 ± 1.19 ^{ABb}	2.71 ± 1.03 ^{Ab}	14.68 ± 1.19 ^{Aa}	5.12 ± 0.11 ^{Bc}	0.35 ± 0.01 ^{Ca}

Table A1. Cont.

Day	Origin/ Variety	Color/ log(R ₆₈₁ /R ₅₅₁)	Firmness/ N _{Max}	Weight Loss/%	TSS/° Brix	pH	TA/%, as MAE
6	QLDW	0.98 ± 0.07 ^{Bb}	9.76 ± 1.70 ^{ABCa}	2.32 ± 0.53 ^{Ba}	14.22 ± 0.78 ^{Bab}	5.00 ± 0.09 ^{Ca}	0.38 ± 0.09 ^{ABbc}
	NTW	0.91 ± 0.06 ^{Bab}	12.03 ± 1.03 ^{Ab}	1.19 ± 0.17 ^a	13.75 ± 0.43 ^{Bab}	4.99 ± 0.13 ^{Ba}	0.33 ± 0.03 ^{Aabc}
	OverseasW	0.92 ± 0.18 ^{Aab}	13.91 ± 1.53 ^{Ab}	4.05 ± 1.06 ^{Ab}	13.48 ± 0.53 ^{Aa}	4.89 ± 0.01 ^{Ca}	0.29 ± 0.01 ^{Bc}
	QLDR	0.80 ± 0.11 ^{Ba}	8.81 ± 1.48 ^{ABa}	3.69 ± 1.19 ^{Bb}	14.90 ± 1.31 ^{Ab}	5.50 ± 0.14 ^{Bc}	0.29 ± 0.08 ^{ABab}
	OverseasR	0.90 ± 0.13 ^{Bab}	12.41 ± 1.87 ^{ABb}	4.20 ± 0.46 ^{Ab}	14.57 ± 1.28 ^{Aab}	5.32 ± 0.08 ^{Cb}	0.25 ± 0.01 ^{Ba}
8	QLDW	1.02 ± 0.06 ^{Bb}	8.80 ± 1.40 ^{ABa}	3.60 ± 0.99 ^{Ca}	13.67 ± 0.80 ^{Aa}	5.32 ± 0.15 ^{Db}	0.30 ± 0.09 ^{Ab}
	NTW	0.91 ± 0.03 ^{Bab}	11.26 ± 0.51 ^{Ab}	2.41 ± 0.28 ^a	13.13 ± 0.35 ^{Aa}	5.19 ± 0.06 ^{Cab}	0.30 ± 0.04 ^{Ab}
	OverseasW	0.95 ± 0.17 ^{Ab}	13.46 ± 1.09 ^{Ac}	6.27 ± 1.52 ^{Bb}	13.13 ± 0.59 ^{Aa}	5.09 ± 0.06 ^{Da}	0.29 ± 0.01 ^{Ab}
	QLDR	0.83 ± 0.09 ^{Ba}	8.35 ± 1.06 ^{Aa}	5.70 ± 1.88 ^{Cb}	14.44 ± 1.16 ^{Aa}	5.70 ± 0.17 ^{Cc}	0.23 ± 0.07 ^{Aab}
	OverseasR	0.97 ± 0.10 ^{Bb}	10.89 ± 0.89 ^{Ab}	7.31 ± 1.32 ^{Bb}	14.17 ± 1.50 ^{Aa}	5.53 ± 0.02 ^{Dc}	0.19 ± 0.03 ^{Aa}
10	QLDW	1.00 ± 0.05 ^B	8.54 ± 1.76 ^A	4.01 ± 0.84 ^C	13.11 ± 1.22 ^A	5.45 ± 0.19 ^D	0.24 ± 0.01 ^A

Results are presented as mean ± SD (standard deviation, $n = 3$). ^{A,B,C,D} Different capital letters indicate statistically significant differences across shelf-life days for the same region ($p < 0.05$). ^{a,b,c,d} Different lowercase letters indicate statistically significant differences across regions ($p < 0.05$). QLDW, Queensland-grown white-flesh dragon fruit; NTW: Northern Territory-grown white-flesh dragon fruit; OverseasW, overseas-grown white-flesh dragon fruit; QLDR, Queensland-grown red-flesh dragon fruit; OverseasR, overseas-grown red-flesh dragon fruit.

Table A2. Changes of TPC, TFC, FRAP, and CUPRAC during shelf-life of Australian-grown and imported dragon fruits.

Day	Origin/Variety	TPC/ (mg GAE/100 g FW)	TFC/ (mg QE/100 g FW)	FRAP/ (mg TE/100 g FW)	CUPRAC/ (mg TE/100 g FW)
2	QLDW	168.94 ± 5.86 ^{Eb}	33.37 ± 1.22 ^{Eb}	163.19 ± 6.61 ^{Db}	296.39 ± 20.58 ^{Db}
	NTW	-	-	-	-
	OverseasW	150.25 ± 0.72 ^{Da}	27.78 ± 0.23 ^{Da}	145.37 ± 1.23 ^{Da}	240.32 ± 2.20 ^{Da}
	QLDR	303.70 ± 10.44 ^{Cd}	45.00 ± 3.64 ^{Dc}	513.15 ± 9.85 ^{Dc}	1319.71 ± 42.34 ^{Dd}
	OverseasR	273.98 ± 6.41 ^{Cc}	36.32 ± 1.37 ^{Db}	493.11 ± 1.99 ^{Dd}	1210.38 ± 1.43 ^{Dc}
4	QLDW	158.36 ± 3.75 ^{Db}	30.54 ± 1.49 ^{Db}	157.45 ± 7.03 ^{Db}	279.02 ± 16.51 ^{Cb}
	NTW	164.95 ± 1.66 ^{Cb}	30.95 ± 1.81 ^{Cb}	163.17 ± 6.34 ^{Bb}	277.43 ± 22.87 ^{Bb}
	OverseasW	139.84 ± 1.02 ^{Ca}	24.92 ± 0.23 ^{Ca}	139.93 ± 3.93 ^{Ca}	221.71 ± 5.12 ^{Ca}
	QLDR	297.74 ± 9.31 ^{BCd}	39.65 ± 3.78 ^{Cc}	488.78 ± 8.69 ^{Cd}	1212.78 ± 40.79 ^{Cd}
	OverseasR	268.23 ± 5.18 ^{BCc}	32.59 ± 2.02 ^{Cb}	473.95 ± 1.01 ^{Cc}	1103.78 ± 4.47 ^{Cc}
6	QLDW	148.73 ± 3.79 ^{Cb}	25.67 ± 1.27 ^{Cb}	148.95 ± 6.16 ^{Cb}	256.63 ± 14.79 ^{Bb}
	NTW	154.74 ± 1.52 ^{Bb}	25.65 ± 1.72 ^{Bb}	155.74 ± 6.26 ^{Bb}	255.69 ± 18.33 ^{ABb}
	OverseasW	130.71 ± 0.60 ^{Ba}	21.53 ± 0.15 ^{Ba}	132.69 ± 2.90 ^{Ba}	203.43 ± 0.68 ^{Ba}
	QLDR	292.50 ± 8.29 ^{ABd}	34.68 ± 3.22 ^{Bc}	468.19 ± 9.84 ^{Bd}	1137.74 ± 43.02 ^{Bd}
	OverseasR	262.50 ± 4.57 ^{ABc}	27.88 ± 1.78 ^{Bb}	449.85 ± 5.33 ^{Bc}	1008.24 ± 1.38 ^{Bc}
8	QLDW	139.38 ± 6.91 ^{Bb}	21.74 ± 1.54 ^{Bb}	139.10 ± 4.70 ^{Bb}	235.25 ± 15.73 ^{Ab}
	NTW	143.71 ± 1.23 ^{Ab}	21.47 ± 1.36 ^{Ab}	146.59 ± 3.83 ^{Ab}	235.33 ± 17.34 ^{Ab}
	OverseasW	121.31 ± 1.03 ^{Aa}	18.69 ± 0.15 ^{Aa}	123.32 ± 1.35 ^{Aa}	188.00 ± 2.12 ^{Aa}
	QLDR	285.44 ± 7.48 ^{Ad}	29.13 ± 1.93 ^{Ac}	443.54 ± 11.55 ^{Ad}	1053.93 ± 39.97 ^{Ad}
	OverseasR	255.04 ± 4.38 ^{Ac}	22.54 ± 1.25 ^{Ab}	425.70 ± 8.35 ^{Ac}	906.43 ± 1.79 ^{Ac}
10	QLDW	132.84 ± 8.74 ^A	20.07 ± 0.76 ^A	128.81 ± 4.80 ^A	223.82 ± 4.86 ^A

Results are presented as mean ± SD (standard deviation, $n = 3$). ^{A,B,C,D,E} Different capital letters indicate statistically significant differences across shelf-life days for the same region ($p < 0.05$). ^{a,b,c,d} Different lowercase letters indicate statistically significant differences across regions ($p < 0.05$). QLDW, Queensland-grown white-flesh dragon fruit; NTW: Northern Territory-grown white-flesh dragon fruit; OverseasW, overseas-grown white-flesh dragon fruit; QLDR, Queensland-grown red-flesh dragon fruit; OverseasR, overseas-grown red-flesh dragon fruit.

Table A3. Changes of TBC and TAC during shelf-life of Australian-grown and imported red-flesh dragon fruits.

Day	Origin/Variety	TBC/(mg/100 g FW)	TAC/(mg/100 g FW)
2	QLDR	84.63 ± 2.15 ^{Da}	83.12 ± 2.11 ^{Da}
	OverseasR	71.65 ± 1.57 ^{Db}	72.78 ± 1.75 ^{Db}
4	QLDR	78.15 ± 2.29 ^{Ca}	75.38 ± 1.92 ^{Ca}
	OverseasR	67.59 ± 0.42 ^{Cb}	65.09 ± 2.36 ^{Cb}
6	QLDR	71.31 ± 3.22 ^{Ba}	65.35 ± 1.87 ^{Ba}
	OverseasR	60.01 ± 1.49 ^{Bb}	55.14 ± 1.36 ^{Bb}
8	QLDR	61.29 ± 4.71 ^{Aa}	53.78 ± 3.77 ^{Aa}
	OverseasR	48.16 ± 0.99 ^{Ab}	42.65 ± 0.87 ^{Ab}

Results are presented as mean ± SD (standard deviation, n = 3). ^{A,B,C,D} Different capital letters indicate statistically significant differences across shelf-life days for the same region ($p < 0.05$). ^{a,b} Different lowercase letters indicate statistically significant differences across regions ($p < 0.05$). QLDR, Queensland-grown red-flesh dragon fruit; OverseasR, overseas-grown red-flesh dragon fruit.

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