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Original Paper

Effect of Fruit Size and Harvest Time on Storage Period and Quality of 'Kinnow' Mandarin Fruit

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***Abstract*—'Kinnow' mandarin (*Citrus reticulata* Blanco) is the premier export citrus crop of Pakistan. But there are some factors that are not being studied in relation to each other. Especially the influence of fruit size and harvest time during the prolonged storage conditions. This study evaluated the combined effect of two fruit sizes i.e., Size-1 (65–70 mm) and Size-2 (55–60 mm) and three harvest times (mid-January, mid-February, mid-March) on physical, biochemical, and phytochemical quality during 91 days cold storage (4±1°C; 90±5% RH) using a three-factor factorial CRD (3 replications, 15 fruits each). Mid-February harvest exhibited significantly superior quality ($p \leq 0.01$): Size-1 maintained higher firmness (6.69 N; LSD = 43.70), peel thickness (1.98 mm; LSD = 140.6), and TPC (442.90 µg mL^{-1} FW); Size-2 retained higher TSS (12.98 °Brix) and antioxidant activity (22.33 DPPH%). Mid-January Size-2 retained the highest ascorbic acid (110.71 mg 100 mL^{-1}). Mid-February is the optimal harvest time for premium 'Kinnow' production; mid-January is recommended for vitamin C-focused markets.**

Keywords*—*Citrus reticulata*, harvest maturity, postharvest quality, cold storage, phytochemical profile

I. Introduction

'Kinnow' mandarin, an interspecific hybrid of *Citrus nobilis* and *Citrus deliciosa*, classified as *Citrus reticulata* (Rutaceae), is Pakistan's premier export citrus with 0.361 million tonnes exported in 2023 from 156,211 ha producing 2.23 million tonnes [1–3].

The fruit is valued for its health-promoting properties, including anti-cancer, anti-inflammatory, and antimicrobial effects [4, 5]. However, declining exports due to strict quality standards and postharvest challenges remain a concern [6].

Harvest time and fruit size critically influence quality and storability. TSS, juice content, and sugar acid ratio are principal taste determinants [7]. Larger fruits are visually preferred in premium markets, while smaller fruits possess higher sugar-to-acid ratios [8, 9]. Harvest timing significantly affects peel colour, firmness, juice content, TSS, and TA [10].

Although previous studies investigated fruit size or harvest time independently, limited information exists on their combined effect on physical, biochemical, and phytochemical quality during long-term cold storage. This study examines the combined effect of fruit size and harvest maturity to identify the optimal size–harvest time combination for premium-quality 'Kinnow' export production.

II. Materials And Methods

A. Fruit collection and experimental layout

Fruits were procured from Al-Rafique Enterprises, Sargodha, at three harvest times (mid-January, mid-February, mid-March) and graded into: Size-1 (65–70 mm) and Size-2 (55–60 mm). A-grade fruits were arranged under a CRD 3-factor factorial design (3 replications × 15 fruits = 630 total). Stored at 4±1°C, 90±5% RH selected to minimise chilling injury [11] assessed at 0, 21, 35, 49, 63, 77, and 91 days of storage duration.

B. Physical parameters

Peel weight (DM-305F balance), peel thickness (digital calliper), juice content (gravimetric, % FW [12]), firmness (Lutron FR-5120, N), peel colour index: $CPCI = (1000 \times a) / (L \times b)$ [13], disease incidence/decay (1–5 scale [14, 15]), marketability (%) [16].

C. Biochemical parameters

TSS (ATAGO RX-5000 refractometer, °Brix); TA (Horwitz 1960 [17], % citric acid); $SAR = TSS / TA$; $Brim\ A = (TSS - TA \times 4) \times 16.5$ [18]; pH (HANNA HI98219); peel EC (HANNA HI98304).

D. Phytochemical analysis

TPC (Folin-Ciocalteu [19], µg mL^{-1} FW); DPPH% inhibition [19]; ascorbic acid (titrimetric [20]).

E. Statistical analysis

ANOVA under CRD 3-factor factorial arrangement; LSD test at 5% probability [21].

III. Results And Discussion

A. Physical quality parameters

1) Peel weight (g): FPW showed significant variation for fruit size, harvest time, storage period, and harvest time ×

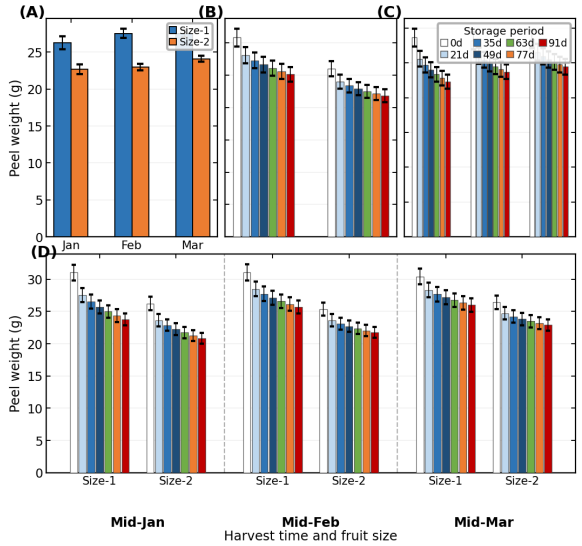


Fig. 1. Peel weight (g) of 'Kinnow' mandarin: (A) harvest time × fruit size (mean of all storage periods); (B) fruit size × storage duration (mean of all harvest times); (C) harvest time × storage duration (mean of both sizes); (D) all three factors combined. Bars ±SE (n = 3).

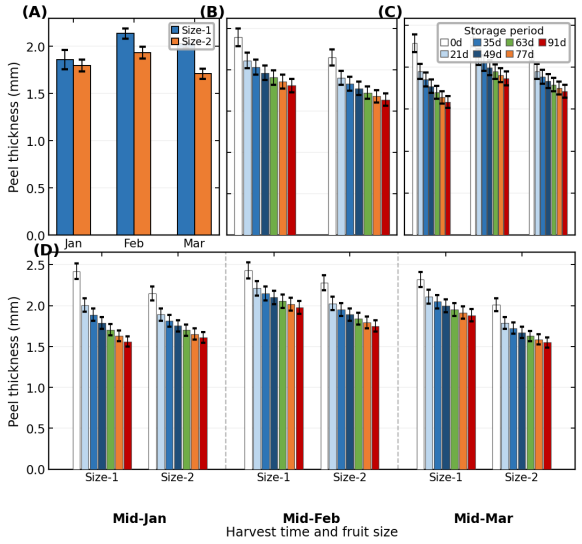


Fig. 2. Peel thickness (mm): (A) harvest time × fruit size; (B) fruit size × storage duration; (C) harvest time × storage duration; (D) all three factors combined. Bars ±SE (n = 3).

storage period and harvest time × fruit size interactions. FPW increased with delayed harvest; Size-1 exhibited higher peel weight than Size-2 across all harvest times (Fig. 1). The size × harvest time interaction (LSD = 4.22, $p \leq 0.05$) revealed Size-1 from mid-March retained the highest FPW (26.00 g) while Size-2 from mid-January showed the greatest decline (20.6% reduction).

The initial FPW increase with maturity is attributed to higher lignin concentration and cuticle waxes [22]. Greater peel weight loss during storage results from higher metabolic activity and transpiration rate [23].

2) Peel thickness (mm): Peel thickness showed significant differences for fruit size, harvest time, storage period, and the fruit size × harvest time interaction. Mid-February fruit showed highest peel thickness; Size-1 maintained higher values (2.18 mm) than Size-2 (Fig. 2). The significant size × harvest time interaction (LSD = 22.18, $p \leq 0.01$) showed Size-1 from mid-February retained 1.98 mm after 91 days (18.5% reduction), while Size-2 from mid-March showed the greatest decline (22.9%).

This pattern reflects lignin deposition and cuticle wax accumulation during maturation, with decline attributed to senescence and moisture loss [10, 24].

3) Firmness (N): Firmness showed significant variation for harvest time, storage period, and interactions of harvest time × fruit size, fruit size × storage period, and harvest time × storage period. Firmness peaked at mid-February harvest then declined in mid-March (Fig. 3). The size × harvest time interaction (LSD = 5.87, $p \leq 0.05$) showed Size-2 from mid-February retained the highest firmness (7.42 N) after 91 days, suggesting smaller fruit confer structural advantage through higher surface-area-to-volume ratio.

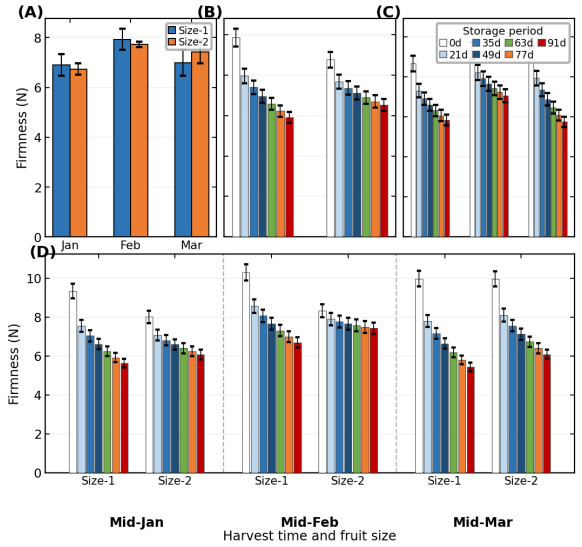


Fig. 3. Firmness (N): (A) harvest time × fruit size; (B) fruit size × storage duration; (C) harvest time × storage duration; (D) all three factors combined. Bars ±SE (n = 3).

Firmness decline is attributed to dissolution of cell wall components and pectin reduction [25], correlated with weight loss and catabolic activity [24].

4) Juice content (%): Juice content showed significant variation for harvest time, storage period, and all two-way and three-way interactions. Size-1 retained maximum juice content (30.8%) after 91 days; mid-March fruit showed the highest values (31.16%) after 91 days (Fig. 4). The three-way interaction ($p \leq 0.01$) revealed that Size-1 from mid-February represented the best overall compromise between juice retention and superior biochemical quality for extended export storage.

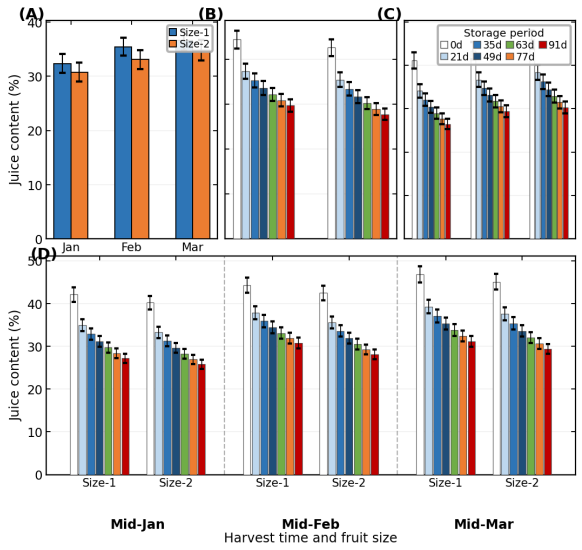


Fig. 4. Juice content (%): (A) harvest time × fruit size; (B) fruit size × storage duration; (C) harvest time × storage duration; (D) all three factors combined. Bars ±SE (n = 3).

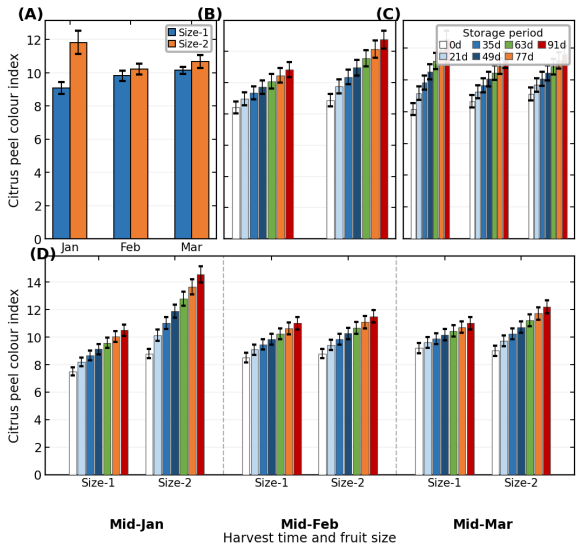


Fig. 5. Citrus peel colour index: (A) harvest time × fruit size; (B) fruit size × storage duration; (C) harvest time × storage duration; (D) all three factors combined. Bars ±SE (n = 3).

Juice content increases with maturity and is well-documented [22]. Linear decrease during storage is attributed to water loss, metabolic activities, and enzymatic hydrolysis [25, 26].

5) Citrus peel colour index: CPCI exhibited significant differences for all main effects and interactions. CPCI increased with harvest time and storage period. Size-2 showed a higher CPCI (11.5 score) than Size-1 (10.5 score) after 91 days; Size-2 from mid-January exhibited the highest CPCI (14.55 score) (Fig. 5). The three-way interaction indicated that Size-2 from mid-January develops colour most intensely during cold storage due to greater temperature-induced chlorophyll breakdown and carotenoid expression [27].

Peel colour increases with maturity and storage is consistent with earlier reports for mandarin cultivars [13, 27].

B. Biochemical quality parameters

1) Total soluble solids (°Brix): TSS showed significant differences for harvest time, storage period, and all two-way and three-way interactions. TSS increased with advancing harvest time and during storage; mid-March recorded highest TSS (15.9–16.1 °Brix) after 91 days (Fig. 6). The three-way interaction ($p \leq 0.01$) highlighted that while mid-March achieves highest absolute TSS, mid-February provides the most commercially desirable balance of sweetness with maintained acidity for export acceptability.

TSS is widely used as a maturity and sweetness index for citrus [28], with increasing TSS through February harvest consistent with Manzoor *et al.* [10] and Kashyap *et al.* [29].

2) pH: Juice pH showed highly significant differences for all main effects and interactions. pH increased linearly with harvest time and during storage; mid-March showed highest pH (4.92) for Size-2 after 91 days (Fig. 7). The significant

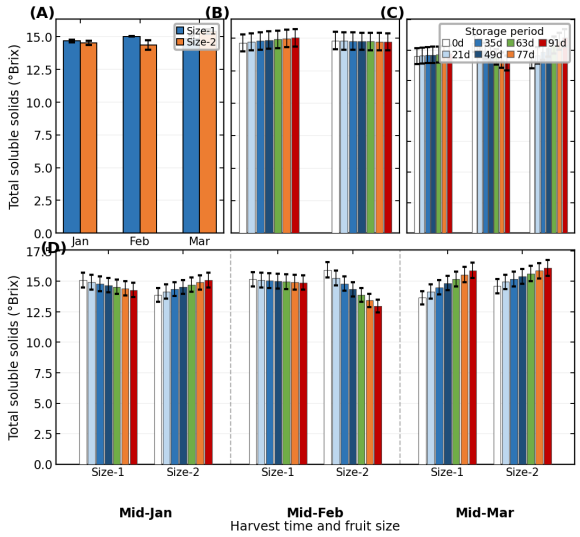


Fig. 6. Total soluble solids (°Brix): (A) harvest time × fruit size; (B) fruit size × storage duration; (C) harvest time × storage duration; (D) all three factors combined. Bars ±SE (n = 3).

fruit size × harvest time interaction ($p \leq 0.01$) showed pH differentiation is most pronounced in mid-March fruit — Size-1 reaching 4.92 vs. 4.71 for Size-2 — suggesting larger late-harvest fruit lose organic acids more rapidly.

The rise in pH with maturity reflects decreasing organic acid content [10], further increasing during storage as citric acid is consumed in respiration [23].

3) Electrical conductivity (EC, %): Peel EC showed significant differences for harvest time, storage period, and all two-way and three-way interactions. EC increased with delayed harvest time; mid-February fruit showed the lowest EC (87.70%) vs. mid-January (91.99%) and mid-March (91.91%) after 91 days (Fig. 8). Lower EC in

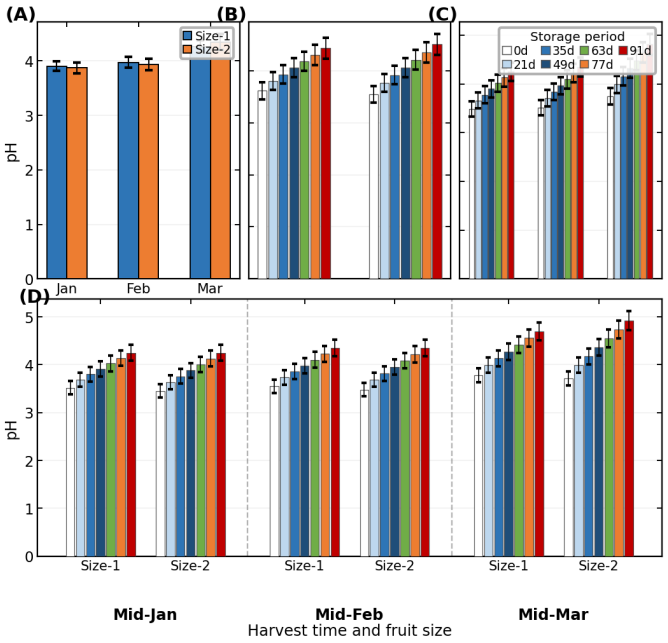


Fig. 7. pH of juice: (A) harvest time × fruit size; (B) fruit size × storage duration; (C) harvest time × storage duration; (D) all three factors combined. Bars ±SE (n = 3).

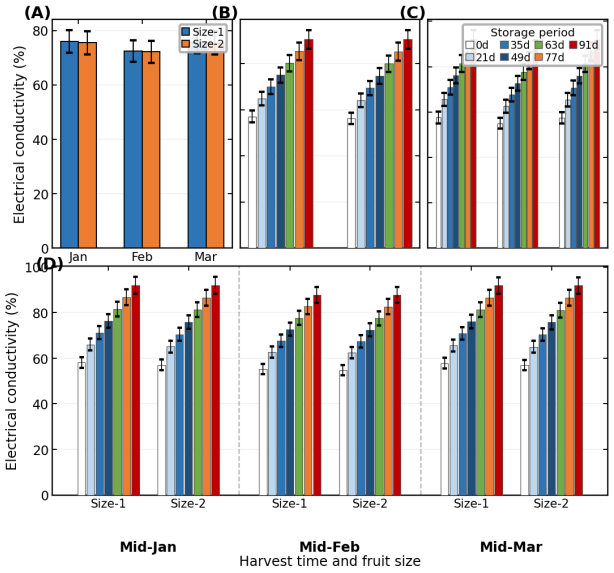


Fig. 8. Peel electrical conductivity (%): (A) harvest time × fruit size; (B) fruit size × storage duration; (C) harvest time × storage duration; (D) all three factors combined. Bars ±SE (n = 3).

mid-February fruit indicates superior membrane integrity throughout cold storage, with direct implications for chilling injury susceptibility management.

Peel EC reflects membrane integrity and cellular stress during cold storage [30]. Zhang *et al.* [31] and Khalid *et al.* [32] reported similar increases during storage.

4) Titratable acidity (TA, %): TA showed significant differences for fruit size, harvest time, storage period, and interactions of fruit size × harvest time and harvest time ×

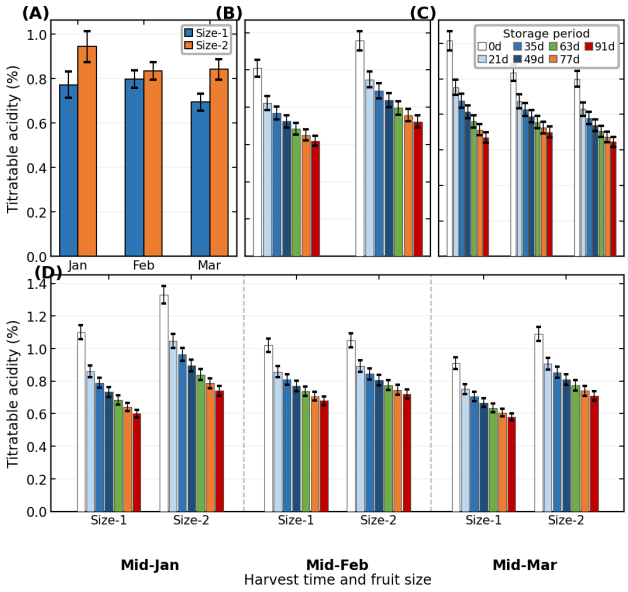


Fig. 9. Titratable acidity (%): (A) harvest time × fruit size; (B) fruit size × storage duration; (C) harvest time × storage duration; (D) all three factors combined. Bars ±SE (n = 3).

storage period. TA decreased with maturity; mid-February fruit maintained highest TA (0.71–0.72%) after 91 days (Fig. 9). Preservation of higher TA in mid-February fruit is commercially significant for maintaining favourable SAR and Brim A scores key export quality indicators for 'Kinnow' mandarin.

Decline in TA is attributed to citric and malic acid utilisation in respiration [23, 33], consistent with Khalid *et al.* [32] and Baswal *et al.* [34].

5) Sugar acid ratio (SAR) and Brix minus acids (Brim A): SAR and Brim A showed highly significant differences for all main effects and interactions. SAR increased with harvest time; Size-2 from mid-March recorded the highest SAR (26.11) at 91 days. Size-2 from mid-February exhibited the highest Brim A (166.29 score) after 91 days (Fig. 10). The three-way interaction ($p \leq 0.01$) revealed that despite Size-2 from mid-March recording higher SAR (26.11), its lower TA indicates this is driven by acid loss rather than genuine sugar accumulation adversely affecting the tangy-sweet flavour balance that commands premium export value.

Brim A is preferred over SAR as a sensory index for citrus, better reflecting consumer taste preferences at varying maturity levels [35–37].

C. *Phytochemical quality parameters*

1) Ascorbic acid (mg 100 mL⁻¹): Ascorbic acid showed highly significant differences for harvest time, storage period, and all two-way and three-way interactions. Ascorbic acid declined with harvest time and storage. Size-2 from mid-January retained the highest ascorbic acid (110.71 mg 100 mL⁻¹) after 91 days (Fig. 11). The three-way interaction ($p \leq 0.01$) confirms smaller fruit combined with early harvest is the

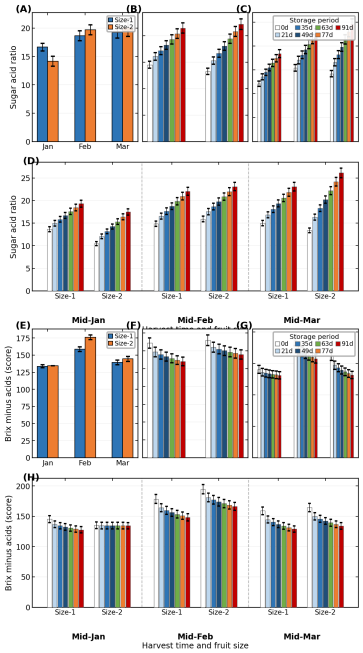


Fig. 10. Sugar acid ratio (panels A–D) and Brix minus acids score (panels E–H): (A,E) harvest time × fruit size; (B,F) fruit size × storage duration; (C,G) harvest time × storage duration; (D,H) all three factors combined. Bars ±SE (n = 3).

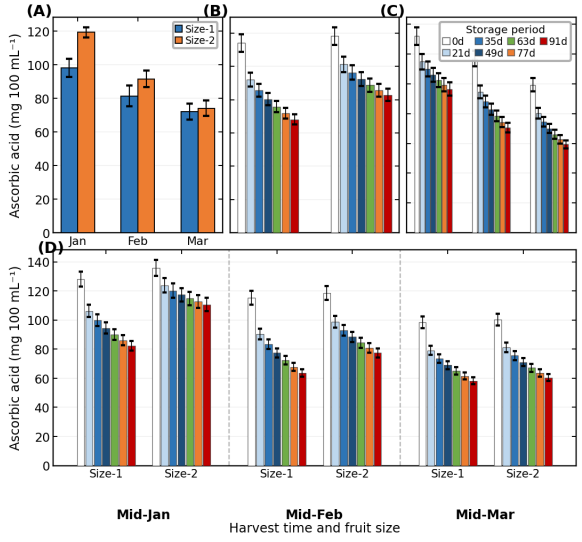


Fig. 11. Ascorbic acid (mg 100 mL⁻¹): (A) harvest time × fruit size; (B) fruit size × storage duration; (C) harvest time × storage duration; (D) all three factors combined. Bars ±SE (n = 3).

best strategy for preserving vitamin C during extended cold storage directly valuable for nutritionally focused markets.

Ascorbic acid decline with maturity is consistent with Manzoor *et al.* [10]. Cold storage slows oxidative degradation [34, 38]; Lo'ay and Dawood [39] reported similar linear decline in mandarin during prolonged storage.

2) Total antioxidants (DPPH% inhibition): TAO showed highly significant differences for all main effects and interactions. TAO increased from mid-January to mid-

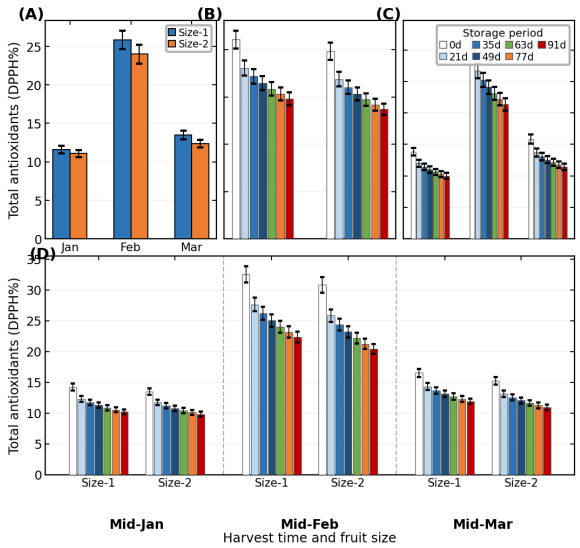


Fig. 12. Total antioxidants (DPPH% inhibition): (A) harvest time × fruit size; (B) fruit size × storage duration; (C) harvest time × storage duration; (D) all three factors combined. Bars ±SE (n = 3).

February then declined in mid-March. Size-1 from mid-February recorded the highest TAO (22.33 DPPH%) after 91 days (Fig. 12). The three-way interaction ($p \leq 0.01$) confirms a clear advantage for Size-1 from mid-February in preserving antioxidant activity, likely due to greater peel thickness providing a larger phenolic reservoir and barrier against oxidative degradation.

Flavonoids and phenolic acids are the primary contributors to antioxidant capacity [40]. Khalid *et al.* [32] reported declining antioxidant activity during storage.

3) Total phenolic content (TPC, µg mL⁻¹ FW): TPC showed significant differences for all main effects and interactions. TPC peaked at mid-February harvest then declined in mid-March. Size-1 from mid-February maintained the highest TPC (442.90 µg mL⁻¹ FW) after 91 days (Fig. 13). The three-way interaction ($p \leq 0.01$) confirms Size-1 from mid-February retains 74.0% of initial TPC (598.3 µg mL⁻¹ FW) vs. only 65.4% retention in Size-2 from mid-March demonstrating the size–harvest time combination as the key determinant of phenolic retention.

Phenolic biosynthesis peaks as fruit ripens [34]. Larger fruits generally exhibit higher TPC during cold storage [38], consistent with present findings.

IV. Conclusions

Harvest time is the dominant factor influencing 'Kinnow' mandarin quality during cold storage, with fruit size providing a significant modifying role through interaction effects. Mid-February harvest is recommended for export and long-term cold storage, particularly for Size-1 (65–70 mm), which produced the best balance of physical firmness, peel integrity, biochemical quality, and phytochemical retention. For markets prioritising vitamin C content, Size-2 (55–60 mm) harvested in mid-January is recommended. These findings provide a

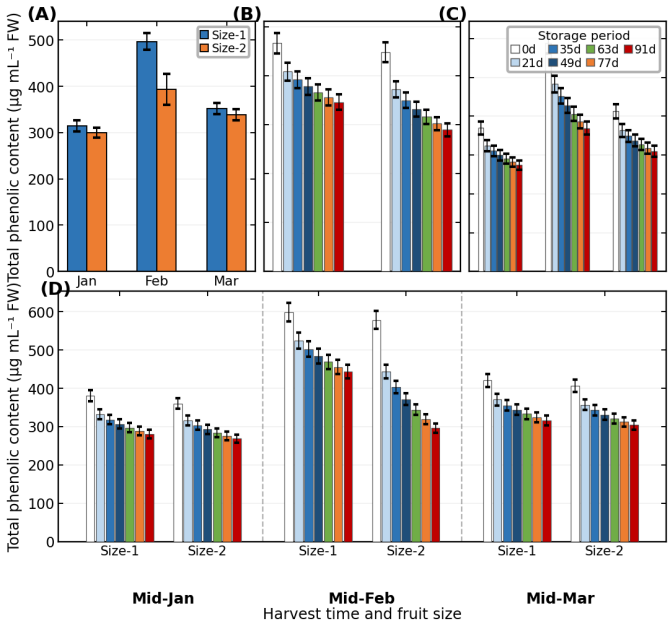


Fig. 13. Total phenolic content (µg mL⁻¹ FW): (A) harvest time × fruit size; (B) fruit size × storage duration; (C) harvest time × storage duration; (D) all three factors combined. Bars ±SE (n = 3).

scientifically validated basis for growers and exporters to optimise harvest scheduling and fruit grading decisions.

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