Postharvest Quality of 'Keepsake' Apple Fruit

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Abstract. **Storage information regarding 'Keepsake' apple fruit is lacking. The objective of this research was to investigate the postharvest characteristics of 'Keepsake' apple (*Malus ×domestica* Borkh.), which is a parent of 'Honeycrisp'. Apples were obtained from three orchards in Minnesota in 2022 and 2023, assessed for quality, and stored at 0 to 1 °C or 4 to 5 °C in air. Fruit were tested for firmness, soluble solids content (SSC), and titratable acidity (TA) for up to 6 months in storage. At harvest, fruit from different orchards differed in ground color, firmness, SSC, and titratable acidity. The starch pattern index did not differ among the orchards within a year, but it was greater during the 2023 harvest than during the 2022 harvest. Fruit firmness decreased less rapidly at 0 to 1 °C than at 4 to 5 °C. Changes in SSC with storage varied by orchard, storage temperature, and year. In 2022 to 2023, SSC changes were highly variable, remained the same during storage for fruit from one orchard, increased and then decreased for fruit from another orchard, increased after 1 month of storage, and then remained unchanged thereafter for fruit from the third orchard. In 2023 to 2024, SSC was generally unchanged during storage at 0 to 1 °C, and it increased slightly over time during storage at 4 to 5 °C. Titratable acidity decreased during storage, but there was no difference between storage temperatures. These findings demonstrate the difficulty determining when to harvest 'Keepsake' fruit because neither starch pattern index nor ground color is a reliable indicator of ripeness. Growers must rely on experience and fruit redness to determine when to harvest this late-season cultivar. To prolong fruit firmness, growers should store 'Keepsake' fruit at 0 to 1 °C rather than at 4 to 5 °C.**

'Keepsake' is one of the parents of the commercially successful 'Honeycrisp' apple (Howard et al. 2017). 'Honeycrisp' fruit range in size from 7 to 10 cm and have flesh that is crisp, coarse textured, and very juicy, with a storage life is 7 months at 2.8 °C (Luby and Bedford 1992). In comparison, 'Keepsake' fruit were described (Stushnoff et al. 1980) as "small to medium sized (560 to 690 mm diameter)," with red skin, "very fine-grained, hard, very crisp, and juicy flesh," and a "very long shelf life." 'Keepsake' was released in the late 1970s "as a good late-maturing, home garden cultivar" with "excellent storage characteristics" (Stushnoff et al. 1980). The storage characteristics of 'Honeycrisp' compared with those of 'Keepsake' are unknown. Best practices for commercial storage of 'Keepsake' fruit have not been researched, despite its decades-long availability. This research aimed to identify the changes in the physiochemical characteristics of 'Keepsake' fruit during storage to determine a recommendation for storage temperature.

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Materials and methods

'Keepsake' fruit were collected from three different orchards in Minnesota in 2022 and 2023. Two of the orchards were the same in 2022 and 2023. In 2023, orchard 2 did not have any 'Keepsake' fruit; therefore, fruit were sourced from another orchard. Orchard 1 was located in Northfield, MN, USA (lat. 44°27′29.8728″N, long. −93°9′41.7744″W). Orchard 2 was in Webster, MN, USA (lat. 42°54′52.5744″N, long. 94°34′13.1268″W). Orchard 3 was in Faribault, MN, USA (lat. 44°16′7.5612″N, long. 93°13′43.0968″W). Orchard 4 was in Woodbury, MN, USA (lat. 44°53′10.536″N, long. 92°57′47.412″W). The fruit from orchard 1 were harvested on 14 Oct 2022 and 20 Oct 2023, and collected from the orchard on 22 Oct 2022 and 21 Oct 2023. Fruit from orchard 2 were harvested on 3 Oct, and collected on 8 Oct 2022. Orchard 3 fruit were harvested between 12 and 20 Oct and on 13 Oct, and they were collected from the grower on 22 Oct and 17 Oct in 2022 and 2023, respectively. Fruit from orchard 4 were harvested and collected on 12 and 17 Oct 2023, respectively.

At the orchards, fruit were stored at 0 to 4 °C between harvest and collection. All fruit were hand-harvested according to criteria used by the specific farm (date or skin color). After collection from the orchards, fruit were stored at 0 to 1 °C or 4 to 5 °C for up to 6 months.

Quality testing. Fruit were analyzed on the day of collection from the orchards, and after 1, 3, and 6 months of cold storage. For each analysis time, 10 fruit per orchard were assessed for firmness and soluble solids content; then, they were peeled and cored, and the remaining flesh was cubed and stored at −80 °C. The starch pattern index was determined only at harvest. For starch staining, a half cross-section of each fruit was swabbed with a potassium–iodine solution and visually rated as the percentage of the surface that was stained (Blanpied and Silsby 1992). Flesh firmness was measured by a puncture test using a drill press-mounted FT30 penetrometer (Wagner Instruments, Greenwich, CT, USA) fitted with an 11-mm tip. Measurements of two opposing equatorial sides of each fruit on peeled areas were performed. The soluble solids content of juice was measured using penetrometer measurements of each fruit using an ATC-1E refractometer (Atago, Co. Ltd., Tokyo, Japan). Titratable acidity (TA) was measured using 5-mL juice samples manually titrated with 0.1 M NaOH using a buret.

Statistical analysis. Data were analyzed using an analysis of variance (ANOVA) with R statistical software (version 4.1.2; The R Foundation for Statistical Computing, Vienna, Austria). Normality of residuals was verified for all data and transformed if needed before the ANOVA was performed. Harvest indices were analyzed as a function of the orchard. Storage quality measurements were analyzed as functions of the storage temperature, storage duration, and orchard. Separation of

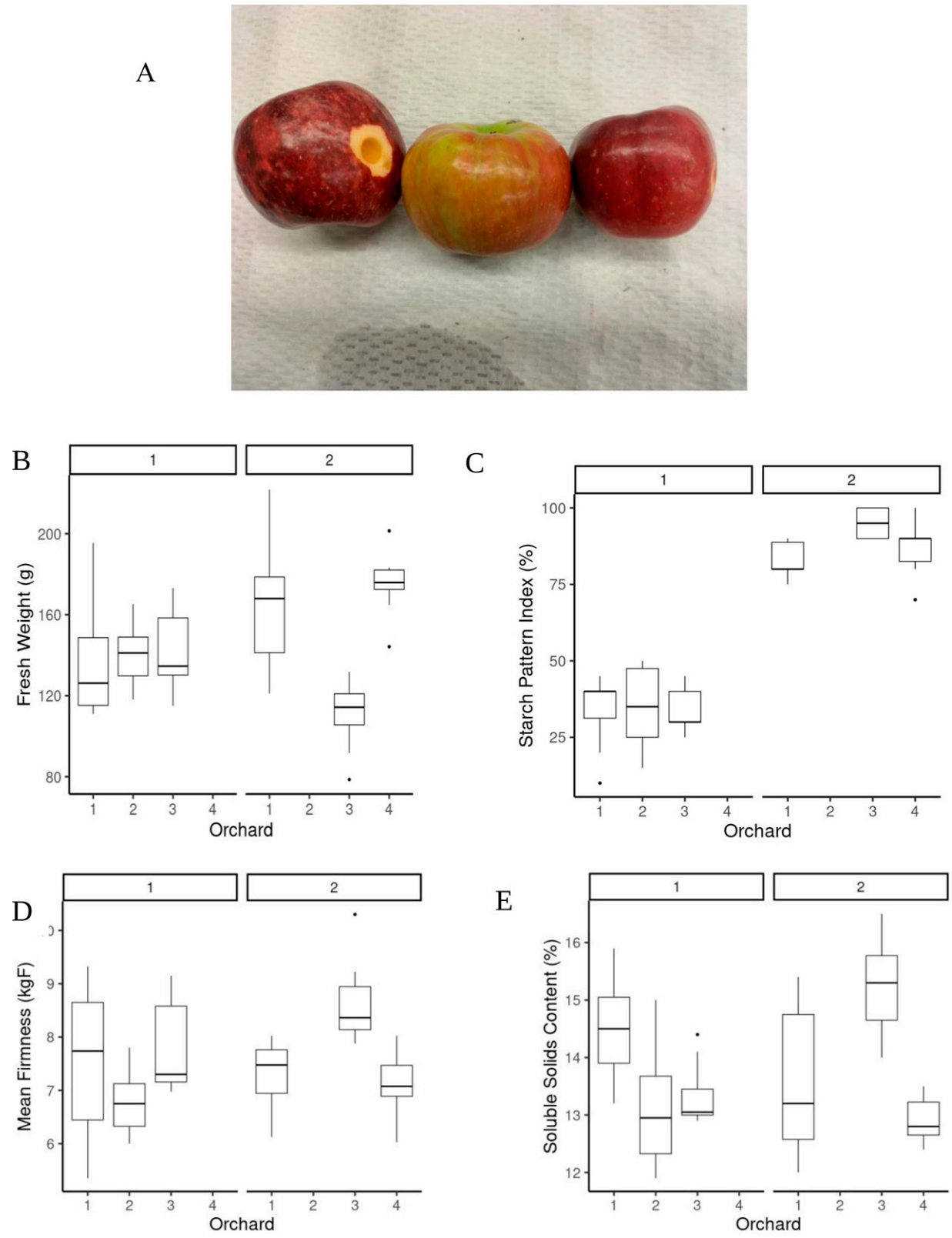

Fig. 1. Appearance of 'Keepsake' fruit at harvest collected from three orchards in 2022 (A). Quality parameters of 'Keepsake' fruit obtained from three different orchards in 2022 (1 in rectangle at top of each graph) and 2023 (2 in rectangle at top of each graph) and assessed on the day of collection: fresh weight (B); starch pattern index (C); firmness (D); and soluble solids content (SSC) (E). Orchard 2 did not have fruit in 2023; therefore, fruit were instead collected from orchard 4. The flesh starch pattern index was determined using iodine staining. Firmness was determined by a puncture test. The SSC of expressed juice was determined based on firmness testing and using a hand-held refractometer. Ten fruit per orchard were used for each assay. 1 kgF = 2.2 lbF; 1°Brix = 1% Brix; 1 g·L^{-1} = 0.1% titratable acidity.

means was performed using Tukey's honestly significant difference test.

Results and discussion

In 2022, 'Keepsake' fruit from orchard 1 had a yellow background color (Fig. 1A). The background color of the fruit from orchard 2 was not detectable because of the uniformly dark red overcolor. Fruit from orchard 3 had a green background color. Redness of fruit was not measured in 2022. The mean redness of fruit values collected in 2023 were 89% ± 11.4% (*SD*) for orchard 1, 54% ± 8.5% for orchard 3, and 66% ± 8.4% for orchard 4.

The fresh weight of fruit among the different orchards was similar in 2022 and generally between the two years (Fig. 1B), with the exception of fruit from orchard 3 in 2023 compared with those in 2022 and in the other orchards in 2023. Minnesota suffered drought in Summer 2023, and many orchards had a difficult time providing enough irrigation for successful apple fruit production.

Starch measurements at harvest in 2022 (Fig. 1C) showed that the fruit from all three orchards had similar levels. An optimal starch pattern index for the 'Keepsake' fruit harvest has not been previously established; therefore, there is no standard. The mean starch ratings were 40%, 35%, and 30% for fruit from orchards 1, 2, and 3, respectively. These ratings were not statistically different according to the ANOVA ($P = 0.99$), despite the green background color of fruit from orchard 3. Therefore, the background color was not a good indicator of the starch pattern index for 'Keepsake' fruit. Fruit harvested in 2023 were starchier than fruit harvested in 2022 (Fig. 1C), but there was no difference among fruit from the different orchards.

In both years, fruit firmness at harvest did not differ among orchards at harvest (Fig. 1D), except for the firmness of fruit from orchard 3 in 2023 compared with that of fruit from the other orchards in 2023 ($P = 0.02$ and 0.004 compared with orchards 1 and 4, respectively). Fruit from all orchards stored at 0 to 1 °C lost firmness slowly in both years (Fig. 2A). The pattern of firmness loss was similar in both years, and it was

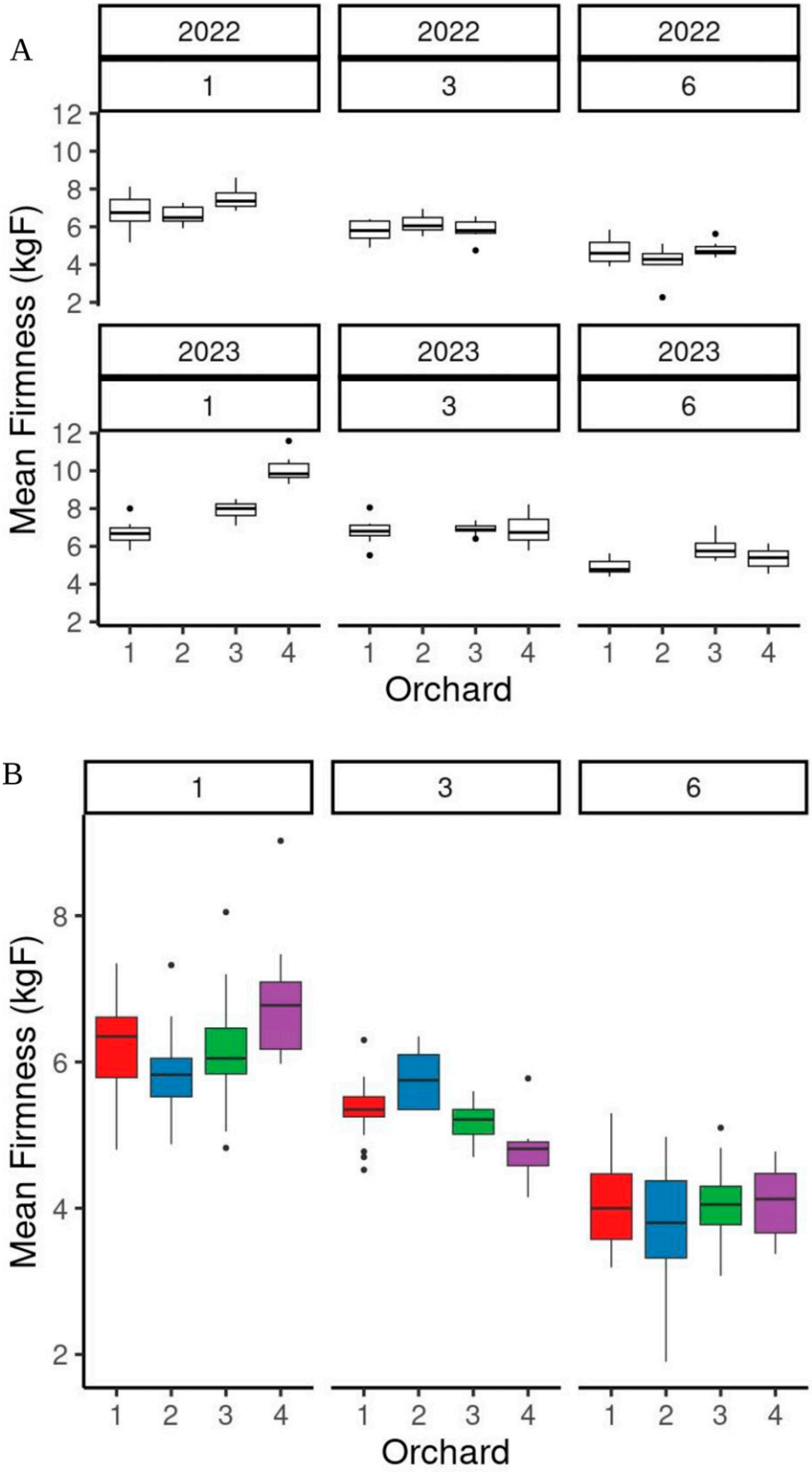

Fig. 2. Firmness of 'Keepsake' fruit stored at 0 to 1 °C (A) or 4 to 5 °C (B) for 1, 3, and 6 months. There was no difference in fruit firmness measured in 2022 and 2023 for fruit stored at 4 to 5 °C; therefore, data were aggregated (B). Firmness was measured on two sides of each fruit using a puncture test with a drill press-mounted penetrometer. 0 °C = 32 °F; 4 °C = 39 °F; 1 kgF = 2.2 lbF.

more precipitous for fruit stored at 4 to 5 °C (Fig. 2B). To maintain fruit firmness up to 1 month in storage, growers should store 'Keepsake' fruit at 0 to 1 °C.

In 2022, the soluble solids content (SSC) at harvest was greater for fruit from orchard 1 (14.5 ± 0.9%) than that for fruit from the other two orchards (13.2 ± 1.1% and 13.3 ± 0.5%) (Fig. 1E). In 2023, the SSC of fruit from orchard was different from that of fruit from orchards 1 and 4 ($P = 0.003$ and $P < 0.001$ for orchards 1 and 4, respectively), as well as in 2022 ($P < 0.001$). The 2023 orchard 3 fruit were small (Fig. 1B), which may have led to a higher concentration of sugars.

The SSC did not vary by storage temperature ($P = 0.2$) in 2022; however, it changed with storage time ($P = 0.003$) and by orchard ($P = 0.03$). In 2022, the SSC of stored fruit from orchard 1 was the same as that at harvest (Fig. 3A and B), and after 1 and 3 months of storage, regardless of storage temperature. In contrast, the SSC of fruit from orchard 2 varied with storage temperature and time, with increases between 1 and 3 months and decreases between 3 and 6 months at 0 to 1 °C; however, it remained the same at 4 to 5 °C. The mean SSC of orchard 3 fruit increased between harvest and 1 month of storage at both 0 to 1 °C and 4 to 5 °C, and it did not change through 6 months of storage. In 2023, changes in SSC did not vary by storage temperature for fruit from orchards 1 and 3; however it was high after 1 month for orchard 4 fruit stored at 0 to 1 °C. Thereafter, the SSC decreased to similar levels after 3 and 6 months in storage for both years and storage temperatures. The high mean SSC of 1-month old orchard 4 fruit stored at 0 to 1 °C was unexpected. Because the starch pattern index of the fruit from orchard 4 was similar to that of fruit from other orchards at harvest (Fig. 1C), perhaps much of the starch in the orchard 4 fruit was rapidly converted to sugar during the first month of storage at 0 to 1 °C. In general, the SSC of stored 'Keepsake' fruit varied more by year and after storage at 4 to 5 °C than by orchard source.

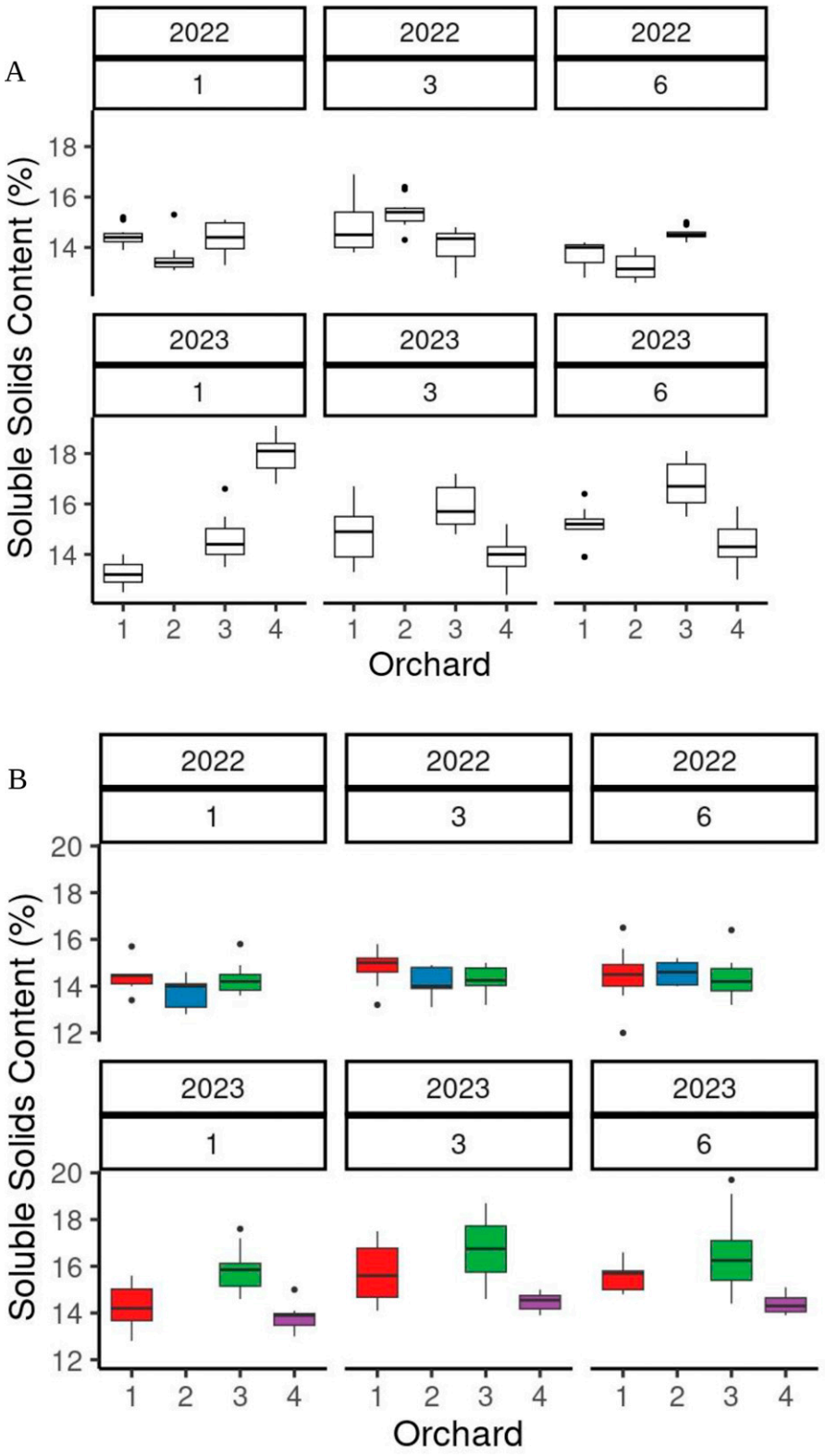

Fig. 3. Soluble solids content of 'Keepsake' fruit stored at 0 to 1 °C (A) or 4 to 5 °C (B) after 1, 3, and 6 months in 2022 and 2023. The SSC was measured using juice expressed during the firmness testing and pipetted onto a hand-held refractometer. 0 °C = 32 °F; 4 °C = 39 °F.

The TA was measured only at harvest in 2022 and at harvest and throughout storage in 2023. There was no difference in the mean TA at harvest between years or orchards; however, TA of orchard 1 fruit was highly variable in 2023 (Fig. 4A). The mean ± *SD* values of TA for 2022 fruit at harvest ranged from 8 ± 1.1 g·L^{-1} for orchard 1 to 5.9 ± 1.2 and 6.4 ± 2.3 g·L^{-1} for orchards 2 and 3, respectively. In 2023, the mean TA of fruit from orchards 1, 3, and 4 were 7.9 ± 3.87 g·L^{-1}, 6.8 ± 2.2 g·L^{-1}, and 9.6 ± 0.9 g·L^{-1}, respectively. In 2023, the fruit TA decreased from harvest throughout storage (Fig. 4B), and with little difference between storage temperatures ($P = 0.047$), with the exception of that of orchard 3, for which the 1-month mean TA at 0 to 1 °C was 6.7 ± 1.0 g·L^{-1}; however, at 4 to 5 °C, it was 3.9 ± 1.0 g·L^{-1} ($P = 0.02$).

Bitter pit was observed in one fruit from orchard 3 after 1 month of storage in fruit harvested in 2022, and in three fruit from orchard 1 after 3 months of storage at 0 to 1 °C. No other storage disorders, such as soft scald or soggy breakdown, detected in stored 'Honeycrisp' fruit (Al Shoffe et al. 2020), were observed in the stored 2022 'Keepsake' fruit. In 2023, only one fruit each from orchards 1 and 4 developed bitter pit after 6 months of storage at 4 to 5 °C. Because of a temperature regulation problem in the 0 to 1 °C cooler in 2023, fruit in that cooler were exposed to temperatures lower than 0 °C for 1 to 2 weeks and developed internal browning (Fig. 5).

This study aimed to investigate the effects of storage temperature and time on the firmness, SSC, and TA of 'Keepsake' apple fruit by using fruit from three different orchards to determine general storage recommendations. Fruit firmness was maintained better up to 3 months with 0 to 1 °C storage; however, after 6 months of storage, fruit firmness was similar regardless of storage temperature. 'Keepsake' fruit did not retain firmness through 6 months of storage, unlike the fruit of its progeny, 'Honeycrisp' (Tong et al. 1999), and did not develop many storage disorders. The SSC changes varied by orchard and storage temperature and time. The fruit TA decreased regardless of

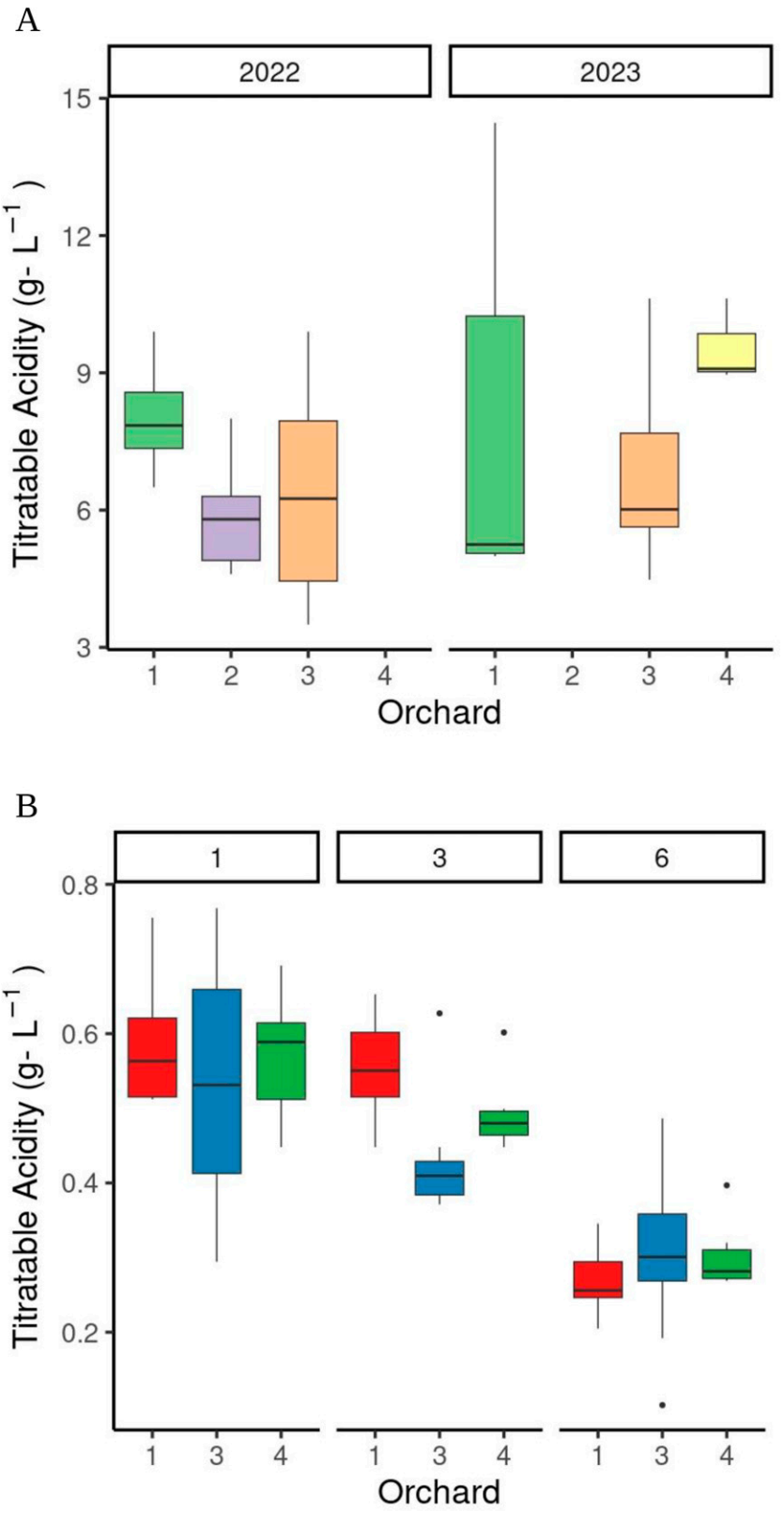

Fig. 4. Titratable acidity (TA) of 'Keepsake' fruit at harvest aggregated for 2022 and 2023 (A) or after storage for 1 to 6 months in 2023 (B). There was no effect on TA by storage temperature, with the exception of that of the fruit from orchard 3 stored for 1 month; therefore, data collected for fruit stored at 0 to 1 °C and 4 to 5 °C were aggregated. The TA was measured by manually titrating 5 mL of juice with 0.1 M NaOH using a buret. 0 °C = 32 °F; 4 °C = 39 °F.

Fig. 5. Interior of 'Keepsake' fruit inadvertently chilled below 0 °C (32 °F) because of technical problems with the cooler in 2023.

storage temperature. Growers should store 'Keepsake' fruit at 0 to 1 °C rather than at 4 to 5 °C for up to 3 months if they want to maintain fruit firmness and lower fruit TA.

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