Physicochemical quality of hardy kiwifruit (Actinidia arguta L. cv. Cheongsan) during ripening is influenced by harvest maturity

Narae Han, Hyowon Park, Chul-Woo Kim, Mun-Seop Kim and Uk Lee

Division of Forest Special Products, Korea Forest Research Institute, Suwon, Korea

1. Introduction

Actinidia arguta hardy kiwifruit or baby kiwifruit, is a widely cultivated fruit species in East Asia, and consumer preference for the fruit has increased due to well-balanced sweet and sour taste and intense flavor (Fisk et al. 2006; Oh et al. 2017). Hardy kiwifruit have a smooth and edible skin, and the fruit size is smaller than green flesh kiwifruit (A. deliciosa) (Fisk et al. 2008). The fruit are considered healthy as they contain high amounts of vitamin C, approximately 150–200 mg per 100 g of fresh fruit (Krupa et al. 2011; Oh et al. 2017). The fruit is also rich in phenolic compounds, lutein, and minerals (such as, P, Ca, Fe, and Zn) (Latocha et al. 2011). New cultivars of hardy kiwifruit have been developed in South Korea, such as ‘Cheongsan’, ‘Saehan’, ‘Daesung’, ‘Chilbo’, and ‘Autumn Sense’, and are mainly cultivated in Gangwon-do (Kim et al. 2014; Oh et al. 2014; Lim et al. 2016).

One of the main disadvantages of hardy kiwifruit is their short shelf-life due to rapid softening and dehydration (Latocha et al. 2014). Therefore, the fruit is commonly harvested before being ripened on the vine because they are too soft to package when fully ripe (Fisk et al. 2006; Krupa et al. 2011). The fruit is ripened during cold storage, which is a common practice in green flesh kiwifruit (Strik and Hummer 2006). Furthermore, the optimal harvest time for green flesh kiwifruit has been reported as when the soluble solids content (SSC) of the fruit is reached to 6.5% (Fisk et al. 2006). However, there is limited information on the ideal harvest time for hardy kiwifruit. The ideal harvest date and postharvest storability of the hardy kiwifruit are important to produce fruit of intense flavor, taste, and texture for commercial markets.

The main objective of the study was to determine the effects of harvest maturity (based on the SSC) on the quality of stored ‘Cheongsan’ hardy kiwifruit by monitoring physicochemical parameters. The study will provide basic information on the postharvest quality of ‘Cheongsan’ hardy kiwifruit, which will be helpful for further studies on extending the shelf-life of the fruit.

2. Materials and methods

2.1. Plant materials

Hardy kiwifruit cultivar ‘Cheongsan’ was grown in Wonju-si, Gangwon-do, Korea (127° 89’ E; 37° 45’ N). The fruit were harvested at two different maturity stages, based on the SSC, on August 29, 2018 (average SSC 6%, ‘harvest 1’) and September 10, 2018 (average SSC 8%, ‘harvest 2’). The fruit selected were of uniform size, appearance, and free from defects, and they were packed in low-vent polypropylene containers (179 mm × 132 mm × 78 mm, Easepack, Seoul, Korea) with 20–22 fruit (approximately 200 g of fruit) per
container. The fruit was stored at 22 ± 1 °C with relative humidity of around 85% for one week. The fruit was collected from three plastic containers on days 0, 1, 3, 5, and 7 of ripening for physiochemical analysis; 20 fruit were collected per plastic container. To analyze the content of total phenolic compounds (TPC), the fruit was directly frozen in liquid nitrogen and stored at −80 °C prior to analysis.

2.2. Physicochemical analysis

For respiration measurements, five fruit was placed into a 250-mL sealed jar with a septum in the lid for one replicate. After one hour, the headspace gas sample was collected through the septum and immediately injected into a headspace gas analyzer (CheckMate 3; Mocon dansensor Inc., Ringsted, Denmark). The respiration rate was calculated for five replicates and expressed in mg kg\(^{-1}\) h\(^{-1}\). Fruit weight loss is presented as the percentage of weight at each sampling time relative to the initial weight immediately after packaging. Ten selected fruit was used for weight loss evaluation at each time point. Fruit firmness was determined using a texture analyzer (CR-3000EX-S; Sun Scientific Co., Ltd., Tokyo, Japan) with a 5-mm-diameter probe punch. Each fruit was subjected to a compression speed of 250 mm min\(^{-1}\) after contact and penetration to 10 mm, approximately at the center of the flat surface of the fruit. The results are presented as the mean maximum peak force from 36 replicates and expressed in Newton (N). Marketability was visually assessed by the number of fruit showing decay symptoms from fungal and mold developmental in 10 individual fruit. Marketability is presented as the percentage of the number of fruit with decay symptoms at each sampling time relative to the number of total fruit in the packaging. The SSC and titratable acidity (TA) were measured in nine replicates, each with a combined extract from four fruit. A refractometer (PR-101α; ATAGO Co., Ltd., Tokyo, Japan) was used to assess the SSC in the juice obtained from whole fruit squeezed, and results are expressed in percent. The TA was determined using a TA meter (GMK-835N; G-Won Hitech Co., Ltd., Seoul, Korea) and is expressed as percent anhydrous citric acid as anhydrous citric acid is the dominant organic acid in the genus Actinidia (Marsh et al. 2004).

2.3. Measurement of the content of total phenolic compounds

Ten fruit were collected from each container and macerated for 1 min, and then the tissues were homogenized using a mixer. A slurry sample (5 g) from the homogenate was mixed with 30 mL of 100% methanol and homogenized. The mixture was stirred for one hour in dark at 24 ± 1 °C. The mixture was then centrifuged at 3,000 g for 15 min and the supernatant was collected. The TPC was determined using Folin–Ciocalteu reagent, with gallic acid as the standard (Slinkard and Singleton 1977); the experiment was performed in triplicate. The absorption of the solution was measured using a UV spectrophotometer (NanoPhotometer NP80; Implen Inc., Munich, Germany) at 735 nm, and the results are expressed as mg gallic acid equivalence (GAE) per kg of fresh weight (fw). The TPC was quantified using a standard curve, with gallic acid concentration between 50 and 200 mg L\(^{-1}\).

2.4. Statistical analysis

All data are presented as the mean of replicates followed by standard error. The figures were produced using Sigma Plot 12.0 software (Systat Software Inc., San Jose, CA, USA). An independent t-test at p < .05 was conducted to analyze differences between the maturity stages (harvest 1 vs. harvest 2) using SPSS statistical software version 18 (SPSS, Inc., Chicago, IL, USA). Statistical significance based on Tukey’s multiple range test at p < .05, and analysis of variance (ANOVA) were performed during storage period using SPSS statistical software.

3. Results

3.1. Quality of ‘Cheongsan’ hardy kiwifruit at harvest was affected by fruit maturity

The physicochemical and nutritional characteristics of ‘Cheongsan’ hardy kiwifruit at harvest are presented in Table 1. The fresh and dry weights of fruit were 1.4 and 1.7 times higher in ‘harvest 2’ fruit than in ‘harvest 1’ fruit, respectively, as the fruit were still growing before harvest. The fruit SSC was significantly higher in ‘harvest 2’ than in ‘harvest 1’. However, there was no significant difference in the TA between the two groups. ‘harvest 2’ fruit also showed significantly higher firmness than ‘harvest 1’ fruit. ‘harvest 2’ fruit had significantly higher TPC than ‘harvest 1’.

3.2. Respiration rate of ‘Cheongsan’ hardy kiwifruit during ripening

Fruit stored at 22 °C for seven days are shown in Figure 1. A high respiration rate, which is a critical factor associated with the ripening of climacteric fruit, was observed in both ‘harvest 1’ and ‘harvest 2’ fruit during ripening (Figure 2(A)). The respiration rate of ‘harvest 1’ fruit sharply increased after ripening for one day from 0.8 to 1.7 mg kg\(^{-1}\) h\(^{-1}\), and then gradually decreased to its initial level during the seven-day ripening periods. ‘harvest 2’ fruit showed a similar respiration pattern to that of ‘harvest 1’ fruit; however, the initial level of respiration was 1.5 times higher in ‘harvest 2’ fruit than in ‘harvest 1’ fruit. The highest respiration rate was observed one and two days after ripening in ‘harvest 1’ and ‘harvest 2’ fruit, respectively, and was approximately 1.6–1.7 mg kg\(^{-1}\) h\(^{-1}\).
Table 1. Effects of harvest maturity on the physicochemical properties of hardy kiwifruit.

|               | Fresh weight (g) | Dry weight (g) | SSC (%) | TA (%) | Firmness (N) | TPC (mg GAE kg⁻¹fw) |
|---------------|-----------------|----------------|---------|--------|--------------|---------------------|
| harvest 1     | 9.8 ± 0.1*      | 1.2 ± 0.1      | 6.1 ± 0.3* | 1.1 ± 0.0 | 10.7 ± 0.4*   | 6.66 ± 15.2         |
| harvest 2     | 10.9 ± 0.2      | 2.9 ± 0.1      | 8.3 ± 0.4 | 1.0 ± 0.0 | 29.7 ± 1.0    | 1400.0 ± 36.4       |

Physicochemical analyses of ‘Cheongsan’ hardy kiwifruit harvested at two different maturities, at a soluble solids content (SSC) of 6% in ‘harvest 1’ and 8% SSC in ‘harvest 2’.

Data are presented as mean ± standard error.
SSC: soluble solids content; TA: titratable acidity; TPC: total phenolic compounds; GAE: gallic acid equivalent; fw: fresh weight.

Indicates a significant difference at $p < .05$ between ‘harvest 1’ and ‘harvest 2’ determined by independent t-test.

Figure 1. Later harvest improved hardy kiwifruit appearance after ripening. The appearances of ‘Cheongsan’ hardy kiwifruit harvested at two different maturities, at a soluble solids content of 6% in ‘harvest 1’ and 8% in ‘harvest 2’.

3.3. Fruit firmness, weight loss and marketability of ‘cheongsan’ hardy kiwifruit during ripening

The primary factor responsible for reduced quality of stored hardy kiwifruit is rapid softening due to water loss and decay. Therefore, weight loss and firmness are basic indexes for determining fruit senescence (Ghiani et al. 2011; Atkinson et al. 2012; Wang et al. 2015). The rate of weight loss gradually increased during ripening to over 10% in ‘harvest 1’ fruit and 6% in ‘harvest 2’ fruit by the end of ripening (Figure 2(B)). ‘Harvest 1’ fruit exhibited a rapid decline in fruit firmness, down to 4.0 N three days after ripening; however, ‘harvest 2’ fruit showed relatively high firmness until five days of ripening (Figure 2(C)). Fruit firmness decreased after ripening for seven days, and it reached 3.0 N and 6.6 N in ‘harvest 1’ and ‘harvest 2’ fruit, respectively. After ripening for seven days, the marketability of ‘harvest 1’ fruit decreased by 67% because the fruit was decayed by fungal and mold development (Figure 2(D)).

3.4. Soluble solids content and titratable acidity of ‘cheongsan’ hardy kiwifruit during ripening

The SSC and TA are important parameters determining the taste and consumer acceptability of vine-ripened fruit including hardy kiwifruit. There was a 190.2% and 195.2% increase in the SSC of ‘harvest 1’ and ‘harvest 2’ fruit, respectively, compared with their initial SSC (Figure 2(E)). Only a negligible change was observed in the SSC of ‘harvest 1’ fruit three days after ripening, and the SSC was approximately 11.2–12.2%; whereas, the SSC of ‘harvest 2’ fruit consistently increased throughout the ripening period, and reached up to 16.2% seven days after ripening. The TA detected in the fruit of ‘harvest 1’ and ‘harvest 2’ was unstable during ripening (Figure 2(F)). In ‘harvest 1’ fruit, the TA decreased one day after ripening from 1.12% to 0.86%, and then slightly increased until 5 days in ripening. On the other hand, the TA in ‘harvest 2’ fruit increased from 1.04 at harvest to 1.55 at three days in ripening, but it was 45.8% decreased at the end of ripening compared to three days in ripening.

4. Discussion

We found that the respiration rate of ‘Cheongsan’ hardy kiwifruit peaked shortly after harvest. In a previous study, the A. aruguta cultivars showed a typical climacteric characteristic with a high respiration rates during storage (Lim et al. 2016). Wang et al. (2015) demonstrated that the respiration rate is highly correlated with the ethylene production rate during the ripening of climacteric fruit, including hardy kiwifruit, and thus postharvest treatments (such as, application of 1-methylcyclopromene [1-MCP]) are effective in delaying fruit ripening and softening by reducing the respiration and ethylene production rates (Lim et al. 2016).

The firmness and weight loss of ‘Cheongsan’ hardy kiwifruit decreased after harvest in our study, with greater decreases in ‘harvest 1’ fruit than in ‘harvest 2’ fruit. Similar to our findings, Fisk et al. (2008) reported that the firmness of ‘Ananasnaya’ hardy kiwifruit rapidly decreased in the first few weeks of ripening; however, Lim et al. (2016) found that the softening of ‘Cheongsan’ hardy kiwifruit was delayed during storage at 1 °C when treated with 1-MCP. Studies have reported that the softening rate of fruit varies with species (White et al. 2005) and maturity stage (Krupa et al. 2011). Fisk et al. (2006) observed that ‘Ananasnaya’ hardy kiwifruit harvested at 8.7% SSC had significantly lower ($p < .05$) firmness than those harvested at 6.0% SSC, three weeks after ripening, unlike our results. The higher firmness in ‘harvest 2’ than in ‘harvest 1’ observed in the present study was not consistent with that reported previously. Latocha et al. (2014) reported that ‘Bingo’ fruit harvested at 6.5–8.0% SSC was firmer than fruit harvested at 8.0–9.5% SSC. Furthermore, the firmness of ‘Saehan’, ‘Daesung’, and ‘Chilbo’ hardy kiwifruits decreased with the increase of SSC, similar to fruit growing on the vine (Kim et al. 2014). The temperature and relative humidity in July
and August of 2018 was relatively hotter and more humid than usual according to the Korea Meteorological Administration (http://www.kma.go.kr). Moretti et al. (2010) noticed that the A. argute fruit qualities, such as firmness, SSC, TA, and fresh weight, could be strongly correlated with weather condition during the fruit ripening phase. Thus, it may be assumed that different vegetation season may influence the hardy kiwifruit firmness.

The increase of SSC in 'Cheongsan' hardy kiwifruit during ripening observed in this study is consistent with that reported previously (Fisk et al. 2006; Krupa et al. 2011; Latocha et al. 2014). Latocha et al. (2014) reported that hardy kiwifruit SSC increased to approximately 175–200% and 150–175% relative to the initial harvest value in ‘Ananasnaya’ and ‘Bingo’ cultivars, respectively, eight weeks after cold storage. Furthermore, a relatively high SSC was observed after storage in fruit harvested at 8.0–9.5% SSC compared with fruit harvested at 6.5–8.0% SSC. According to MacRae et al. (1992), the increase in SSC during storage is mainly due to the degradation of starch and conversion to sucrose by glucolytic enzymes. Langenkämper et al. (1998) reported that the activity of these enzymes increased as fruit matured, regardless of storage conditions; however, the activity was different between cultivars (Choudhury et al. 2009). The TA of ‘harvest 2’ fruit increased from 1.04% to 1.55% citric acid for up to three days after ripening, and then decreased to 0.84% at the end of ripening. After seven
days, ‘harvest 1’ and ‘harvest 2’ fruit lost ~14.0% and 19.1% of their acidity, respectively; however, these decreases were not statistically significant. A similar level (~0.5–1.1%) of TA has been previously reported (Latocha et al. 2014). They also observed a consistent decrease in the TA during ripening, regardless of fruit maturity, unlike our results. Our results indicated that the harvest of hardy kiwifruit at 8% SSC could significantly reduce weight loss and improve firmness during ripening, thus effectively extending shelf-life.

5. Conclusions

This study showed the physicochemical changes in ‘Cheongsan’ hardy kiwifruit of different harvest maturities, determined based on the SSC, during ripening. ‘Harvest 2’ fruit presented significantly reduced weight loss and high firmness during ripening compared with those of ‘harvest 1’ fruit. Additionally, ‘harvest 1’ fruit decayed seven days after days in ripening, and they were not of adequate fruit quality and spoiled before ripening. These data suggest that ‘Cheongsan’ hardy kiwifruit should be harvested when the SSC is higher than 8% to retain high quality fruit after ripening.

6. Disclosure statement

No potential conflict of interest was reported by the authors.

References

Atkinson RG, Sutherland PW, Johnston SL, Gunaseelan K, Hallett IC, Mitra D, Brummell DA, Schröder R, Johnston JW, Schaffer RJ. 2012. Down-regulation of POLYGALACTURONASE1 alters firmness, tensile strength and water loss in apple (Malus × domestica) fruit. BMC Plant Biol. 12(1):129.

Choudhury SR, Roy S, Sengupta DN. 2009. A comparative study of cultivar differences in sucrose phosphate synthase gene expression and sucrose formation during banana fruit ripening. Postharvest Biol Tec. 54(1):15–24.

Fisk CL, McDaniel MR, Strik BC, Zhao Y. 2006. Physicochemical, sensory, and nutritive qualities of hardy kiwifruit (Actinidia arguta ‘Ananasnaya’) as affected by harvest maturity and storage. J Food Sci. 71(3):S204–S210.

Fisk CL, Silver AM, Strik BC, Zhao Y. 2008. Postharvest quality of hardy kiwifruit (Actinidia arguta ‘Ananasnaya’) associated with packaging and storage conditions. Postharvest Biol Tec. 47(3):338–345.

Ghiani A, Onelli E, Aina R, Cocucci M, Citterio S. 2011. A comparative study of melting and non-melting flesh peach cultivars reveals that during fruit ripening endo-polygalacturonase (endo-PG) is mainly involved in pericarp textural changes, not in firmness reduction. J Exp Bot. 62(11):4043–4054.

Kim CW, Oh SI, Kim MJ, Park Y. 2014. Optimal harvest time by the seasonal fruit quality and ripening characteristics of hardy kiwifruit in Korea. J Korean Soc For Sci. 103(3):353–358.

Krupa T, Latocha P, Liwińska A. 2011. Changes of physicochemical quality, phenolics and vitamin C content in hardy kiwifruit (Actinidia arguta and its hybrid) during storage. Sci Hortic. 130(2):410–417.

Langenkämper G, McHale R, Gardner RC, MacRae E. 1998. Sucrose-phosphate synthase steady-state mRNA increases in ripening kiwifruit. Plant Mol Biol. 36(6):857–869.

Latocha P, Jankowski P, Radzanowska J. 2011. Genotypic difference in postharvest characteristics of hardy kiwifruit (Actinidia arguta and its hybrids), as a new commercial crop Part I. Sensory profiling and physicochemical differences. Food Res Int. 44(7):1936–1945.

Latocha P, Krupa T, Jankowski P, Radzanowska J. 2014. Changes in postharvest physicochemical and sensory characteristics of hardy kiwifruit (Actinidia arguta and its hybrid) after cold storage under normal versus controlled atmosphere. Postharvest Biol Tec. 88:21–33.

Lim S, Han SH, Kim J, Lee HJ, Lee JG, Lee EJ. 2016. Inhibition of hardy kiwifruit (Actinidia arguta) ripening by 1-methylcyclopentene during cold storage and anticancer properties of the fruit extract. Food Chem. 190:150–157.

MacRae E, Quick WP, Benker C, Stitt M. 1992. Carbohydrate metabolism during postharvest ripening in kiwifruit. Planta. 188(3):314–323.

Marsh K, Attanayake S, Walker S, Gunson A, Boldingh H, MacRae E. 2004. Acidity and taste in kiwifruit. Postharvest Biol Tec. 32(2):159–168.

Moretti CL, Mattos LM, Calbo AG, Sargent SA. 2010. Climate changes and potential impacts on postharvest quality of fruit and vegetable crops: a review. Food Res Int. 43(7):1824–1832.

Oh SI, Kim CW, Kim MJ. 2014. Changes of storability and quality characteristics of ‘Autumn Sense’ hardy kiwifruit according to ethylene treatment and storage condition. J Kor Soc For Sci. 103(3):368–374.

Oh SB, Muneer S, Kwack YB, Shin MH, Kim JG. 2017. Characteristic of fruit development for optimal harvest date and postharvest storability in ‘Skinny Green’ baby kiwifruit. Sci Hortic. 222:57–61.

Slinkard K, Singleton VL. 1977. Total phenol analysis: automation and comparison with manual methods. Am J Enol Viticult. 28(1):49–55.

Strik BC, Hummer KE. 2006. ‘Ananasnaya’ hardy kiwifruit. J Am Pom Sci. 60(3):106–112.

Wang Y, Xu F, Feng X, MacArthur RL. 2015. Modulation of Actinidia arguta fruit ripening by three ethylene biosynthesis inhibitors. Food Chem. 173:405–413.

White A, de Silva HN, Requejo-Tapia C, Harker FR. 2005. Evaluation of softening characteristics of fruit from 14 species of Actinidia. Postharvest Biol Tec. 35(2):143–151.