

DETERMINAREA MOMENTULUI OPTIM DE RECOLTARE LA SOIUL DE MĂR 'SUMMER KING' CULTIVAT ÎN REGIUNILE CU LATITUDINE RIDICATĂ DIN COREEA

DETERMINATION OF THE OPTIMAL HARVEST TIMING FOR 'SUMMER KING' APPLES CULTIVATED IN HIGH-LATITUDE REGION of KOREA

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Abstract

The apple cultivar 'Summer King' has gained popularity in Korea owing to its superior fruit quality and strong market competitiveness during the early harvest season. However, as climate change drives apple production toward higher latitudes such as Gangwon State, region-specific harvest guidelines have become increasingly necessary. This study aimed to determine the optimal harvest timing for 'Summer King' apples under high-latitude growing conditions. Three ten-year-old 'Summer King' trees were evaluated over two consecutive years, with fruit samples collected at 5-day intervals from 80 to 120 days after full bloom (DAFB). Key fruit quality parameters, including fruit weight, soluble solids content (SSC), titratable acidity (TA), firmness, peel coloration, and starch degradation, were measured. Fruit weight and SSC increased steadily with fruit maturation, stabilizing at approximately 110 DAFB. Although maximum SSC and fruit weight were observed after 115 DAFB, a concomitant sharp decline in TA and firmness suggested an increased risk of over-ripening. Fruits harvested around 110 DAFB exhibited a balanced profile of quality traits, indicating that approximately 110 DAFB is the optimal harvest window for 'Summer King' apples cultivated in high-latitude regions such as Gangwon State.

Cuvinte cheie: colorație, calitate fruct, *Malus domestica*, degradarea amidonului.

Key words: coloration, fruit quality, *Malus domestica*, starch degradation.

1. Introduction

In 2024, the apple (*Malus domestica* Borkh.) cultivation area in Korea reached approximately 33,298 hectares, with an estimated production volume of around 460,000 tons. Apples thus represent the leading fruit crop in Korea, highlighting their substantial importance within the national horticultural sector. The varietal landscape, however, remains relatively narrow, with 'Fuji' and 'Hongro'—both large-fruited cultivars—comprising 79.8% of the total cultivation area. Recent shifts in consumer preferences, alongside a marked increase in the proportion of single-person households, have intensified demand for small- and medium-sized apples suitable for daily consumption and distinct from traditional large-fruited varieties. In response, new cultivars have been developed domestically, including 'Ruby S' (small-fruited) and early-maturing, medium-fruited cultivars such as 'Summer King' and 'Green Ball' (Lee et al., 2018; Kwon et al., 2019; Kwon et al., 2023). Among these, 'Summer King' has garnered particular attention due to its superior fruit quality, early market availability, and strong price competitiveness, leading to its gradual expansion across production regions nationwide.

The ongoing impacts of climate change have prompted a northward shift in the optimal zones for apple cultivation, with Gangwon State emerging as a key production area (Lee et al., 2023). Given the colder climate of Gangwon State compared to mid- and low-latitude regions of Korea, variations in fruit development and quality characteristics are to be expected (Birtukan et al., 2025). Consequently, production strategies based solely on data from different climatic zones may not adequately support quality assurance or meet market expectations. Harvest maturity is a critical determinant of fruit quality (Wani et al., 2023), yet no established guidelines currently exist for assessing the optimal harvest timing of 'Summer King' apples grown under high-latitude conditions. This study was therefore undertaken to identify optimal harvest maturity indices for 'Summer King' in Gangwon State and to provide practical information to support quality management in high-latitude apple production.

2. Materials and methods

This study was conducted in 2022 and 2023 using three 10-year-old 'Summer King' apple trees planted at the Fruit Research Field of the Gangwon State Agricultural Research and Extension Services,

located in Chuncheon, Gangwon State, Korea. The trees were spaced at 3 m between rows and 2 m within rows and trained in a slender spindle system. To determine the optimal harvest timing for 'Summer King' apples, fruit samples were collected at 80, 85, 90, 95, 100, 105, 110, 115, and 120 days after full bloom (DAFB) over a two-year period. At each time point, ten fruits were randomly harvested and evaluated for fruit weight, soluble solids content (SSC), titratable acidity (TA), fruit firmness, skin coloration, and starch degradation (iodine staining index). Fruit weight was measured to the nearest gram using an electronic balance. SSC and TA were determined using a digital refractometer-acidimeter (SAM-706AC, G-Won Hightech, Seoul, Korea), with SSC expressed in °Brix and TA in percentage. Fruit firmness was measured in Newtons (N) using a penetrometer (Compac-100II, Sun Scientific, Tokyo, Japan) fitted with an 11.3 mm plunger after removing the peel at the equatorial region of the fruit. Skin color was assessed using a colorimeter (CR-400, Minolta, Tokyo, Japan), and the Hunter a value was recorded at the equator of the fruit to evaluate the degree of red coloration. Starch degradation was evaluated using an iodine staining method. Iodine solution was prepared by mixing 1 g of iodine (I) and 5% potassium iodide (KI). The equatorial section of each harvested fruit was cut transversely, immersed in the iodine solution for 10 seconds, and then air-dried. The degree of starch degradation was quantified by measuring the lightness (L value) using the colorimeter. All data were analyzed using ANOVA, with Duncan's multiple range test applied at $p < 0.05$ to determine significant differences.

3. Results and discussions

The results of fruit characteristics observed over a two-year period according to the developmental stages after full bloom (DAFB) of 'Summer King' apples are presented in Table 1. The average fruit weight was 134.1 g at around 80 DAFB, gradually increased over time, and plateaued at approximately 240 g from 110 DAFB onward. Similarly, the average soluble solids content (SSC) increased continuously from the lowest level of 11.3 °Brix (around 80 DAFB) and stabilizing above 14 °Brix after 115 DAFB. In contrast, titratable acidity (TA) showed a continuous decreasing trend as DAFB progressed. TA fell below 0.25% after 115 DAFB, which may indicate that the fruits had entered an overripe stage. Fruit firmness also declined steadily with increasing DAFB and exhibited a sharp decrease to below 59.8 N after 115 DAFB, mirroring the acidity trend. Skin coloration, as assessed by Hunter a value, increased consistently as the fruit skin turned redder with fruit maturation. The starch index, quantified by L value, also showed a rising trend with advancing DAFB, reflecting the progressive conversion of starch into sugars within the fruit flesh.

According to Kwon et al. (2023), 'Summer King' is recommended to be harvested before full red coloration, while the skin still exhibits significant green areas. In Gunwi, a mid-latitude region of Korea, the cultivar is reported to be optimally harvested around 100 DAFB, which corresponds to late July. At this stage, the fruits reportedly exhibit an average weight of 265 g, SSC of 13.7 °Brix, and TA of 0.43%. However, in the present study, fruits harvested around 100 DAFB did not fully express the characteristic quality attributes described by the original breeders. This suggests that 100 DAFB may be suboptimal for harvesting 'Summer King' in high-latitude regions such as Gangwon State. Although the highest fruit weight and SSC values were recorded after 115 DAFB, the sharp declines in acidity and firmness observed at this stage may compromise consumer acceptance and postharvest storability. Therefore, around 110 DAFB appears to be the most suitable harvest timing in high-latitude regions, as fruit weight, SSC, TA, and firmness were all expressed at appropriate levels. These findings indicate that 110 DAFB can be considered the optimal harvest window for 'Summer King' apples cultivated in high-latitude areas such as Gangwon State.

4. Conclusions

This study provides fundamental information to assist apple growers in high-latitude regions of Korea in determining the optimal harvest timing for 'Summer King' apples. The findings emphasize that fruit quality characteristics can vary considerably depending on the cultivation environment, underlining the need for region-specific management practices. Information generated under differing environmental conditions should be applied with caution, and the stable and optimal utilization of apple cultivars requires the establishment of localized cultivation guidelines based on targeted research efforts.

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References

1. Geleta B.T., Abebe A.M., Heo J.Y., 2025. Effect of genotype \times environment interactions on apple fruit characteristics in a high latitude region of Korea. *Appl. Fruit Sci.* 67: 14.
2. Kwon S.I., Kim J.H., Kim S.A., Kwon Y.S., Lee J., 2019. 'RubyS', a Small Apple. *HortScience*. 54: 2067-2069.
3. Kwon Y.S., Kim J.H., Park J.T., Kwon S.I., Choi C., 2023. 'Summer King': an Early Maturing Apple Cultivar in Korea. *HortScience*. 58: 1306-1308.
4. Lee E., Kim Y., Kwon S.I., Kim J.H., Kang I.K., Kim B.O., Cho Y., 2018. Functional properties of newly bred Green ball apple (*Malus pumila* Mill.). *Food Sci. Preserv.* 25: 837-845.
5. Lee J.C., Park Y.S., Jeong H.N., Kim J.H., Heo J.Y., 2023. Temperature changes affected spring phenology and fruit quality of apples grown in high-latitude region of South Korea. *Horticulturae*. 9: 794.
6. Wani N.R., Hussain S.Z., Bej G., Naseer B., Beigh M., Fayaz U., Dey T., Pal A., Akuli A., Ghosh A., Dhekale B.S., Wani F.J., 2023. Predicting the optimum harvesting dates for different exotic apple varieties grown under North Western Himalayan regions through acoustic and machine vision techniques. *Food Chem X*. 19: 100754.

Tables and Figures

Table 1. Changes in fruit characteristics of 'Summer King' apples according to days after full bloom (DAFB) in 2023–2024 (n = 10)

DAFB (days)	Fruit weight (g)	Soluble solids content (°Brix)	Titratable acidity (%)	Flesh firmness (N)	Peel color (Hunter a value)	Starch Degradation (Hunter L value)
80	134.1d ^z	11.3d	0.52a	88.5a	-18.07g	37.83d
85	150.3d	12.4cd	0.42b	88.2a	-17.16fg	36.01d
90	162.3d	12.0cd	0.43b	87.1a	-14.14ef	45.44c
95	194.1c	12.0cd	0.40b	77.8b	-14.41e	49.21c
100	210.9bc	13.1bc	0.31c	77.5b	-12.19de	45.74bc
105	220.5abc	13.6ab	0.33c	75.4b	-10.78d	48.15bc
110	246.7a	13.6ab	0.32c	77.6b	-4.84c	53.64b
115	241.5a	14.2a	0.25d	59.8c	0.63b	60.58a
120	239.1ab	14.6a	0.21d	52.9c	3.73a	62.66a

^z Mean separation within each columns by Duncan's multiple range test, 5% level.

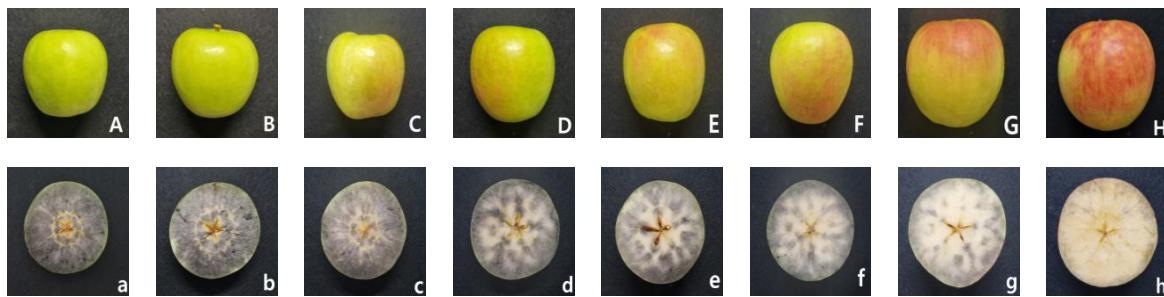


Fig. 1. Changes in peel coloration (A–H) and starch degradation patterns (a–h) of 'Summer King' apples according to harvest timing.

A–H: Fruit images at 80 to 115 days after full bloom (DAFB) at 5-day intervals.
a–h: Iodine-starch staining reactions corresponding to 80 to 115 DAFB.