Fruit Quality and Antioxidant Activities of Yellow-Skinned Apple Cultivars Coated with Natural Sucrose Monoesters

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Abstract: Yellow-skinned ‘Tsugaru’, ‘Summer King’, and ‘Shinano Gold’ apples (Malus × domestica Borkh.) were coated with a mixture of edible sucrose monoesters of fatty acid and ethanol that had never been applied in those apple fruits, for up to 28 days after room temperature storage (DAS) to evaluate their morphological characteristics, fruit qualities, and antioxidant concentrations. The coating treatment significantly reduced respiration rates of ‘Tsugaru’ and ‘Summer King’ apples at both 14 and 28 DAS, and ‘Shinano Gold’ at 28 DAS. The coated ‘Tsugaru’ and ‘Summer King’ apples were found in greater coverage with fragments of the sucrose esters than those of ‘Shinano Gold’, exhibiting greater skin greasiness and thickness. The coated ‘Tsugaru’ and ‘Summer King’ apples mostly maintained high fruit firmness, peel color, vitamin C, total polyphenol concentrations, and 1,1-diphenyl-2-picrylhydrazyl radical scavenging activity. The recent developed coating material contributed to improving shelf-life of the ‘Tsugaru’ and ‘Summer King’ apples and fruit defense systems as a novel post-harvest technology for sustainable food security.

Keywords: antioxidant; apple; coating; respiration; ‘Tsugaru’

1. Introduction

‘Tsugaru’ apples (Malus × domestica Borkh.) are an early-ripening popular cultivar for summer markets in East Asian countries [1–3]. However, they characteristically exhibit high acidity, astringency, and bitterness associated with a high tannin content, and so the ‘Summer King’ of apples was newly released in South Korea in 2010 as a substitute for ‘Tsugaru’ [1–3]. Recent global warming would have led to a higher production of yellow-skinned apples with accumulation of carotenoid pigments than of the red-color cultivars of the anthocyanin present in the skin required in low temperature conditions during harvest time [1,4]. ‘Tsugaru’, ‘Summer King’, and ‘Shinano Gold’ apples, a late-ripening cultivar, all have a distinctive smooth yellow-skin without need for red pigmentation but climacteric fruits associated with rapid increases in internal ethylene concentrations and respiration rates [5,6]. This has lead to the fast metabolism and fruit senescence and has been major concern toward those apple fruits.

Softening of ‘Summer King’ apples rapidly advanced between 10 and 15 days after harvest, reducing the primary parameter of internal fruit quality [5,6]. A large supply and bulk shipment of early-ripening apples often leaves fruit susceptible to mishandling through the lack of a suitable post-harvest treatment and leads to large quantities of fruit spoiling (more than 40%) during storage and processing in developing countries, from reductions in fruit metabolic rate and increased storage disorders [1,7,8]. A combination of 1-methylcyclopropene (1-MCP) and carnauba wax-based coatings resulted in preserving the shelf-life and fruit quality of red ‘Fuji’ apples [7,9], with limited information existing for the effects of coating on shelf-life extension and antioxidant value of yellow-skin apples. The biodegradable coating for fruits might be more attracted for recent consumers who are primarily concerned in environmental issues and food safety rather than those of 1-MCP-treated fruits [8,10–20].
Natural biodegradable edible coatings for fruits, such as those using polysaccharide, protein, and lipids, create a thin layer on the fruit surface and showed various effects favorable to extending shelf-lives of climacteric fruits, apples, bananas, pears, plums, and litchi or even within a cultivar due to their different anatomy reacting to a surface coating and associated rapid increase in respiration [8,10–19]. Bilayer composites have been shown to provide a physical moisture barrier through lipid coatings and a gas regulator through polysaccharide coatings [12,19], with little scientific data available for their effects on coated apples in room temperature storage. A mixture of sucrose monoesters with ethanol has been recently introduced as an alternative to modified atmosphere storage by reducing anaerobic conditions and off-flavors in pome fruits, as well as providing a barrier to gas exchange and water vapor permeability via its adherence [8,10–19]. This novel technology is also proved to be effective in foodborne disease outbreaks and degradation associated with preservation of the yellow-skin apples for concerns of public health [20].

The aim of this research was to identify the morphological characteristics, fruit qualities, antioxidant levels, and occurrence of physiological disorders of coated ‘Tsugaru’, ‘Summer King’, and ‘Shinano Gold’ apples, as well as to examine factors related to sucrose esters and storage time to consider commercial availability and sustainable food safety at each storage time.

2. Materials and Methods

2.1. Plant Material and Coating Treatment

Medium-sized, similarly colored apple fruits used in this study were randomly collected at a commercially mature stage (on the 30 July 2020, for ‘Tsugaru’ and ‘Summer King’, and on the 20 October 2020, for ‘Shinano Gold’) from private farms (Figure 1A,B) located in Cheongsong, South Korea (36° 26′ N/129° 3′ E). The daily temperature range and duration of sunshine were recorded on 13.8 °C and 1520 h from April to October during the growing season, respectively, which was favorable environmental condition to grow apple fruit trees [21]. The collected apples were pre-cooled in air storage at 2 °C for 24 h at an Agricultural Experiment Station at Daegu Catholic University in Gyeongsan, South Korea. The fruits were then treated as follows: (1) a control group (uncoated) and (2) application of 2.0% white powdery coating with a mixture of sucrose monoesters of fatty acid with ethanol (Naturcover Extra, Decco, Inc., Valencia, Spain) after randomly collecting 160-fruit from each cultivar. The coating material (Registry Numbers 84066-95-5) was composed of 5.0% (w/v) alpha-D-Glucopyranoside, beta-D-fructofuranosyl, and mixed palmitates and stearates, with 15.0% (w/v) ethanol and 2.0% water (w/v). The coating was applied by dipping fruits into the solution for five minutes, the fruits were then air-dried, and monitored for 28 days after storage (28 DAS) at 20–25 °C and 50–60% of relative humidity (RH).

Figure 1. Apple orchard views panel (A) and satellite photograph panel (B).
Control and coated fruits on each cultivar were examined at 14 DAS by checking the structure of the fruit peel (5 × 5 × 2 mm) under scanning electron microscopy (SEM; SU-3500, Hitachi Co., Ltd., Tokyo, Japan).

In total, three individual fruit per control and coated group from each cultivar were used to measure CO$_{2}$ concentration at both 14 and 28 DAS, as well as fruit quality at 0, 7, 14, 21, and 28 DAS. Additionally, three fruits per control and coated group of each cultivar were immediately removed at 0, 14, and 28 DAS, put into liquid nitrogen, and stored at −80 °C for antioxidant assays of vitamin C, total polyphenol, 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity (RSA).

2.2. Fruit Quality Measurements

Each fruit on each cultivar was sealed in a 3000-mL plastic container, with a digital CO$_{2}$ monitor (XE-2000 Multi-function, XEAST Co., Ltd., Shenzhen, China) inserted for one hour to detect fruit respiration rate.

Greasiness was assessed by rubbing fruit skin against the hand at 28 DAS and scoring the degree of greasiness as none (0), slight (1), moderate (2), or severe (3) as proposed by Dadzie et al. [22].

Fruit peel thickness was obtained with a digital caliper (Mitutoyo Corp., Takatsu-ku, Japan) through averaging three measured positions of each fruit peel at 28 DAS.

Fruit weight loss was recorded as a percentage on a fruit fresh weight basis ($\text{w/w}$) from each DAS.

Fruit peel color, L* (light), a* (red), b* (yellow), and hue, was determined at four points on the equatorial region using a digital colorimeter with an 8.0-mm measuring aperture color analyzer (FR-5105, X-Rite, Inc., Grand Rapids, USA).

The middle point of the fruit was thinly peeled to measure soluble solid contents (SSC), fruit acidity measured using a hand-held refractometer (GMK-706R, G-WON Hitech Co., Ltd., Seoul, Korea) and fruit firmness measured using a hand-held hardness tester with an 8.0-mm diameter tip (FR-5105, Lutron electronic enterprise Co., Ltd., Taipei, Taiwan).

2.3. Extraction of Antioxidants

‘Tsugaru’, ‘Summer King’, and ‘Shinano Gold’ apples were randomly picked from storage at 0, 14, and 28 DAS to examine antioxidants.

Vitamin C in the fruit tissue was analyzed via the method of Phillips et al. [23], widely applied in the analysis in various fruit, avocado, grapes, blackberries, blueberries, cantaloupe, watermelon, plums, and apples. The 1.0 g of dried fruit samples was digested in 50.0 mL of 5.0% meta-phosphoric acid, which was then homogenized and centrifuged at 3000 g for 10 min. The supernatant was fixed with distilled water up to 100.0 mL and was then colorimetrically measured using high performance liquid chromatography (Waters Alliance 2695, Waters Co., Ltd., Manchester, UK).

In total, 1.0 g of dried tissue sample of each fruit was then digested in 100.0 mL of 99.9% ethanol in a mortar for one hour. To determine the total polyphenolic contents, 2.0 mL of extract was mixed with 2.0 mL Folin–Dennis’ reagent for three minutes, shaken with 2.0 mL of 10.0% Na$_{2}$CO$_{3}$ for one hour, and measured colorimetrically using a UV-visible spectrophotometer (Optizen 3220UV, Mecasys Co., Daejeon, Korea) at 700 nm [24]. The 2.0 mL of extract was also mixed with 1.0 mL of 0.2 mM DPPH for 30 min at 37 °C and colorimetrically analyzed using a UV-visible spectrophotometer (Optizen 3220UV, Mecasys Co., Daejeon, Korea) at 517 nm to examine scavenging activity according to the Blois’ method [25].

2.4. Statistical Analysis

Experiment of each fruit cultivar was separately performed in replicated three times per treatment at different dates with a completely randomized design. Each dependent variable in this experiment was performed by one-way analysis of variance using the SAS (Version 8.02; SAS Institute, Cary, NC, USA) to analysis the significant differences in all
3. Results and Discussion

3.1. Fruit CO\textsubscript{2} and Morphological Characteristics

The coating treatment significantly reduced the respiration rates for 'Tsugaru' and 'Summer King' apples at both 14 and 28 DAS, and 'Shinano Gold' at 28 DAS (Figure 2A–C), possibly because of acting as a barrier to CO\textsubscript{2} and O\textsubscript{2} exchange [7,8,10–14,18]. The respiration rates increased for all the fruits from 14 to 28 DAS, which was mostly associated with increasing internal ethylene concentrations accelerating the ripening process [12,26]. Similar results have been reported in other studies that 'Tsugaru' and 'Summer King' apples treated with 1-MCP in the pre-climacteric significantly disrupted production of ethylene and respiration rates at 20 °C for four weeks [6,27].

The epidermal cells of the fruit peel were observed on all the control and coated fruits at 14 DAS using an SEM analysis (Figure 3A–F). The surface peel was remarkably covered with small fragments of a mixture of sucrose monoesters in 'Tsugaru' and 'Summer King' fruits (Figure 3B,D), which was in line with the stomatal apertures of bananas coated with sucrose monoester alone [28]. Sucrose esters remained on the peel surface of apples, pears, and bananas during their 30-day storage at 17 °C [11]. However, poor adhesion of the coating was observed on the 'Shinano Gold' apples (Figure 3F), probably due to the varying porosity and composition of the fruit peel [10,12]. 'Shinano Gold' apples showed greater greasiness and skin thickness than that observed in 'Tsugaru' and 'Summer King' fruits (Figure 4A,B), with the reason for the mechanism unclear. The late ripening apples were likely to show increases in skin thickness and the accumulation of cuticular waxes, liquid aliphatic compounds, during storage [29,30].

3.2. Fruit Quality

The coating mostly maintained high levels of fruit firmness for 'Tsugaru' and 'Summer King' apples stored at 50–60% RH conditions at room temperature (Figure 5A,C). Application of sucrose polyesters, ProLong®, was effective in maintaining flesh firmness and weight in 'Tsugaru' apples during cold storage at 85–95% RH, commonly recommended as the standard storage humidity for fresh fruits, but was not effective during marketing under relatively low RH conditions [8,14]. Flesh weight loss of 'Tsugaru' and 'Summer King' apples was retarded by the coating treatment at later parts of the storage period (Figure 5B,D). Both fruits would have had the large difference in water potential between the fruit flesh and air minimized through the application of a mixture of sucrose monoesters, palmitate (C16:0), and stearate (C18:0), with ethanol. The palmitate coating in the previous research uniformly formed small fragments on banana surfaces, leading to increased stomatal blockage, and an extended shelf-life of the fruits [28]. Coating with volatile compounds has also been shown to reduce post-harvest deterioration and prolong storage life of strawberries by effectively inhibiting fungal growth and decay [31]. Wax compounds substantially accumulated on the fruit surface of 'Shinano Gold' apples and contributed to the formation of a water-vapor barrier, affecting similar fruit softening and weight loss observed for control and coated fruits (Figure 5E,F).

Fruit juice SSC and acidity were varied widely in coated fruit during storage for all the fruit cultivars (Figure 6A–F), probably due to the relatively brief storage time although they were critical internal quality parameters in the apples [1].

The a* values in flesh tissue increased for all fruits during storage time, with declined values observed for h*, in particular for control 'Tsugaru' apples, approximately 10 of which increased in a* and 15 decreased in h* (Figure 7A–F). Coated fruits more effectively retained their green color, producing cohesive films for lenticel and stomata in the fruit peel, which was consistent with the prior reports in pears coated with sucrose esters and carboxymethyl cellulose [32] and bananas coated with a sucrose monoester alone [28].
Anthocyanin pigmentation of apples with yellow skins would have contributed to the increase in \( a^* \) values and the decline in \( h^* \) values [1].

**Figure 2.** Respiration rates in ‘Tsugaru’ panel (A), ‘Summer King’ panel (B), and ‘Shinano Gold’ panel (C) apples either control (uncoated) or coated with sucrose monoesters, respectively, at 14 and 28 days after room temperature storage (DAS). Bars represent error of the means (S.E.M; \( n = 3 \)), when larger than the dimension of the symbol. ns, *, and ** indicate nonsignificant and significant differences between control and coating treatments, respectively, at \( p < 0.05 \) and \( p < 0.01 \).
Figure 3. Scanning electron microscopic views of epidermal cells at 100 magnification of peel surface of ‘Tsugaru’ (control for panel (A) and coating for panel (B)), ‘Summer King’ (control for panel (C) and coating for panel (D)), and ‘Shinano Gold’ (control for panel E and coating for panel F).
3.3. Antioxidants

The coating treatment led to increased vitamin C content at 14 DAS in ‘Tsugaru’ and ‘Summer King’ and total polyphenol concentration at 14 DAS and 28 DAS but not for ‘Shinano Gold’ apples (Figure 8A–F). In particular, total polyphenols in the flesh tissue rapidly increased from 2.0 to 11.2 mg·g\(^{-1}\) at 14 DAS and remained at high levels of 12.2 mg·g\(^{-1}\) at 28 DAS for ‘Tsugaru’ apples. The vitamin C and polyphenols in ‘Tsugaru’ and ‘Summer King’ apples would have been synthesized by enzymatic activation caused by oxidative stress under room temperature storage or coating treatment [33,34]. Previous research showed that fruit stored under high concentrations of CO\(_2\) decreased in total phenols and anthocyanin due to the oxidation of ascorbic acid [31], which could partially explain the increase in antioxidant compounds in the coated fruits with suppressed respiration. However, none of the fruit cultivars showed incidences of physiological disorder, such as browning, involving the overproduction of free radicals, and reactive oxygen species metabolism (data not shown). The edible coating for fruits would be more contributed to reducing environmental concerns by preventing the deterioration and fruit waste than those of other addition of chemical preservatives, 1-MCP [8,10–20]. The lack of significant differences in antioxidant levels observed in ‘Shinano Gold’ apples was mostly likely related to the small effect of fruit senescence in the coating treatment [31]. The decrease in RSA observed in all fruits at 28 DAS (Figure 9A–C) might be attributed to the degradation of the antioxidant compounds [33].
Figure 5. Fruit firmness and weight loss in ‘Tsugaru’ panels (A, B), ‘Summer King’ panels (C, D), and ‘Shinano Gold’ panels (E, F) apples either control (uncoated) or coated with sucrose monoesters, respectively, at 0, 7, 14, 21, and 28 days after room temperature storage (DAS). Bars represent error of the means (S.E.M; n = 3), when larger than the dimension of the symbol. ns and * indicate nonsignificant and significant differences between control and coating treatments, respectively, at p < 0.05.
Figure 6. Fruit soluble solid contents and acidity in ‘Tsugaru’ panels (A,B), ‘Summer King’ panels (C,D), and ‘Shinano Gold’ panels (E,F) apples either control (uncoated) or coated with sucrose monoesters, respectively, at 0, 7, 14, 21, and 28 days after room temperature storage (DAS). Bars represent error of the means (S.E.M; n = 3), when larger than the dimension of the symbol. ns and * indicate nonsignificant and significant differences between control and coating treatments, respectively, at $p < 0.05$. 

Figure 7. Color a* and h* values of flesh tissue in ‘Tsugaru’ panels (A,B), ‘Summer King’ panels (C,D), and ‘Shinano Gold’ panels (E,F) apples either control (uncoated) or coated with sucrose monoesters, respectively, at 0, 7, 14, 21, and 28 days after room temperature storage (DAS). Bars represent error of the means (S.E.M; n = 3), when larger than the dimension of the symbol. ns and * indicate nonsignificant and significant differences between control and coating treatments, respectively, at $p < 0.05$. 
Figure 8. Vitamin C and total polyphenols of ‘Tsugaru’ panels (A,B), ‘Summer King’ panels (C,D), and ‘Shinano Gold’ panels (E,F) apples either control (uncoated) or coated with sucrose monoesters, respectively, at 0, 14, and 28 days after room temperature storage (DAS). Bars represent error of the means (S.E.M; n = 3), when larger than the dimension of the symbol. ns and * indicate nonsignificant and significant differences between control and coating treatments, respectively, at p < 0.05.
Figure 9. 1,1-diphenyl-2-picrylhydrazyl radical scavenging activity (RSA) of ‘Tsugaru’ panel (A), ‘Summer King’ panel (B), and ‘Shinano Gold’ panel (C) apples either control (uncoated) or coated with sucrose monoesters, respectively, at 0, 14, and 28 days after room temperature storage (DAS). Bars represent error of the means (S.E.M; n = 3), when larger than the dimension of the symbol. ns and * indicate nonsignificant and significant differences between control and coating treatments, respectively, at $p < 0.05$.

4. Conclusions

Highly perishable ‘Tsugaru’ and ‘Summer King’ apples are distributed, displayed, and consumed or stored typically under room temperature at 50–60% RH conditions, a widely used storage method at the post-harvest stage in developing countries, but one which leads to sharply declining fruit solidity and growers’ economic returns. A mixture of edible sucrose monoesters with volatile compounds could be favorable in extending shelf-life
without compromising in physiological deterioration and oxidative damage to apple flesh for up to 28 days by producing a semi-permeable modified atmosphere. The novel coating for fruits was more sustainable and convenient for appropriate post-harvest handling than those of the 1-MCP application, most widely used in developing countries, requiring for 24 h in a sealed container. Further research should consider the other yellow-skinned apple cultivars applied with the various types of combined coatings and temperatures of dipping solution to maximize coverage with small fragments of sucrose monoesters. Additional consideration for research in future should propose creating cost-benefit analysis as well as require extensive trial of the novel technology at industrial scale.

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References
1. Musacchi, S.; Serra, S. Apple fruit quality: Overview on pre-harvest factors. Sci. Hortic. 2018, 234, 409–430. [CrossRef]
2. Ban, S.H.; Yun, W.H.; Kim, G.H.; Kwon, S.I.; Choi, C. Genetic identification of apple cultivars bred in Korea using simple sequence repeat markers. Hort. Environ. Biotechnol. 2014, 55, 531–539. [CrossRef]
3. Lee, E.H.; Cho, E.B.; Kim, B.O.; Jung, H.Y.; Lee, S.Y.; Yoo, J.G.; Kang, I.K.; Cho, Y.J. Functional properties of newly-bred ‘Summer King’ apples. Hort. Sci. Technol. 2020, 38, 405–417.
4. Fukuda, H. A possibility of workload saving on apple cultivations. Agric. Hortic. 2006, 81, 1286–1292.
5. Iwanami, H.; Moriya, S.; Kotoda, N.; Takahashi, S.; Abe, K. Storability in cold temperatures can be evaluated based on changes in fruit quality in apple genotypes under shelf life conditions. HortScience 2008, 43, 655–660. [CrossRef]
6. Yoo, J.G.; Kang, I.K. Effect of cold storage and 1-methylcyclopropene treatment on fruit storage potential of ‘Summer Prince’ and ‘Summer King’ apples. Korean. J. Food Preserv. 2020, 27, 137–144. [CrossRef]
7. Chen, H.Y.; Jiang, L.F.; Zeng, J.H.; Huo, Y.R.; Li, Y.X. Combination of carnauba wax-based coating and 1-methylcyclopropene (1-MCP) maintains better “Fuji” apple qualities during storage at low temperature. J. Food Process. Preserv. 2020, 44, 921–925. [CrossRef]
8. Flores-López, M.L.; Cerqueira, M.A.; de Rodriguez, D.J.; Vicente, A.A. Perspectives on utilization of edible coatings and nano-laminate coatings for extension of postharvest storage of fruits and vegetables. Food Eng. Rev. 2016, 8, 292–305. [CrossRef]
9. Martínez-Romero, D.; Bailén, G.; Serrano, M.; Guillén, F.; Valverde, J.M.; Zapata, P.; Castillo, S.; Valero, D. Tools to maintain postharvest fruit and vegetable quality through the inhibition of ethylene action: A review. Crit. Rev. Food Sci. Nutr. 2007, 47, 543–560. [CrossRef]
10. Bai, J.; Baldwin, E.A.; Hagenmaier, R.D. Coating selection for apples other than ‘Delicious’. Postharvest Biol. Technol. 2003, 28, 381–390. [CrossRef]
11. Bhardwaj, C.L.; Jones, H.F.; Smith, L.H. A study of the migration of externally applied sucrose esters of fatty acids through the skin of banana, apple and pear fruits. J. Sci. Food Agric. 1984, 35, 322–331. [CrossRef]
12. Dhall, R.K. Advances in edible coatings for fresh fruits and vegetables: A review. Crit. Rev. Food Sci. Nutr. 2013, 53, 435–450. [CrossRef]
13. Drake, S.R.; Fellman, J.K.; Nelson, J.W. Postharvest use of sucrose polyesters for extending the shelf-life of stored ‘Golden Delicious’ apples. J. Food Sci. 1987, 52, 1283–1285. [CrossRef]
14. Hwang, Y.S.; Lee, J.C.; Chun, J.P. Effect of fruit coatings on the marketable quality in ‘Tsugaru’ apples during storage and simulated marketing. J. Agri. Sci. 1992, 19, 136–144.
15. Kaewchana, R.; Techavuthiporn, C.; Kanlayanarat, S. Sucrose fatty acid coating retards pericarp browning of litchi cv. ‘Hong Huay’. Acta Hortic. 2006, 712, 579–584. [CrossRef]
16. Nimitkeatkai, H.; Srilaong, V.; Kanlayanarat, S. Effect of edible coating on pineapple fruit quality during cold storage. Acta Hortic. 2006, 712, 643–648. [CrossRef]
17. Thakur, R.; Pristijono, P.; Golding, J.B.; Stathopoulos, C.E.; Scarlett, C.J.; Bowyer, M.; Singh, S.P.; Vuong, Q.V. Development and application of rice starch based edible coating to improve the postharvest storage potential and quality of plum fruit (*Prunus salicina*). *Sci. Hortic.* 2018, 237, 59–66. [CrossRef]

18. Xuan, H.; Streif, J. Effect of pre- and postharvest application of ‘Biofresh’ coating on the keepability of apple fruits. *Acta Hortic.* 1987, 251, 483–492.

19. Tharanathan, R.N. Biodegradable films and composite coatings: Past, present and future. *Trends Food Sci. Technol.* 2003, 14, 71–78. [CrossRef]

20. Ma, L.; Zhang, M.; Bhandari, B.; Gao, Z. Recent developments in novel shelf life extension technologies of fresh-cut fruits and vegetables. *Trends Food Sci. Technol.* 2017, 64, 23–38. [CrossRef]

21. KMA. *Statistical Analysis of Climate*; Korea Meteorological Administration: Seoul, Korea, 2020.

22. Dadzie, B.; Banks, N.; Hewett, E.; Cleland, D. Reduced greasiness of ‘Granny Smith’ apples washed in tween 20 solution. *N. Z. J. Crop Hortic. Sci.* 1995, 23, 219–222. [CrossRef]

23. Phillips, K.M.; Tarrago-Trani, M.T.; Gebhardt, S.E.; Exler, J.; Patterson, K.Y.; Haytowitz, D.B.; Pehrsson, P.R.; Holden, J.M. Stability of vitamin C in frozen raw fruit and vegetable homogenates. *J. Food Compos. Anal.* 2010, 23, 253–259. [CrossRef]

24. Slinkard, K.; Singleton, V.L. Total phenol analysis: Automation and comparison with manual methods. *Am. J. Enol. Vitic.* 1977, 28, 49–55.

25. Blois, M.L. Antioxidant determination by the use of a stable free radical. *Nature* 1958, 181, 1199–1224. [CrossRef]

26. Song, J.; Bangerth, F. The effect of harvest date on aroma compound production from ‘Golden Delicious’ apple fruit and relationship to respiration and ethylene production. *Postharvest Biol. Technol.* 1996, 8, 259–269. [CrossRef]

27. Jung, S.K.; Lee, J.M. Effects of 1-methylcyclopropene (1-MCP) on ripening of apple fruit without cold storage. *J. Hortic. Sci. Biotech.* 2009, 84, 102–106. [CrossRef]

28. Momen, M.N.; Tatsumi, Y.; Shimokawa, K. Effects of coating treatment with sucrose fatty acid esters on the ripening of Cavendish banana. *Food Preserv. Sci.* 1997, 6, 315–320. [CrossRef]

29. Homutová, I.; Blažek, J. Differences in fruit skin thickness between selected apple (Malus domestica Borkh.) cultivars assessed by histological and sensory methods. *Hortic. Sci.* 2006, 33, 108–113. [CrossRef]

30. Yang, Y.; Zhou, B.; Zhang, J.; Wang, C.; Liu, C.; Liu, Y.; Zhu, X.; Ren, X. Relationships between cuticular waxes and skin greasiness of apples during storage. *Postharvest Biol. Technol.* 2017, 131, 55–67. [CrossRef]

31. Wang, S.Y.; Gao, H. Effect of chitosan-based edible coating on antioxidants, antioxidant enzyme system, and postharvest fruit quality of strawberries (*Fragaria x aranassa* Duch.). *LWT-Food Sci. Technol.* 2013, 52, 71–79. [CrossRef]

32. Hasan, S.M.K.; Nicolai, B. Quality of pears with permeability of bio-freshTM edible coatings. *Afr. J. Food Sci.* 2014, 8, 410–418.

33. Galani, J.H.Y.; Mankad, P.M.; Shah, A.K.; Patel, N.J.; Acharya, R.R.; Talati, J.G. Effect of storage temperature on vitamin C, total phenolics, UPLC phenolic acid profile and antioxidant capacity of eleven potato (*Solanum tuberosum*) varieties. *Hortic. Plant J.* 2017, 3, 73–89. [CrossRef]

34. Lee, J.H.; Min, S.C.; Song, K.B. Effects of edible coating on the quality change in ‘Hongro’ apples during storage. *J. Appl. Biol. Chem.* 2015, 58, 61–64. [CrossRef]