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Volatile Compounds and Quality Characteristics of Fresh-Cut Apples and Mixed Fruits Coated with Ascorbic Acid during Cold Storage

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Abstract: Fresh-cut apples are commonly known as minimally processed agricultural products because of their convenience and ease of consumption. However, during storage, the quality of the apple rapidly changes after cutting due to enzymatic and non-enzymatic processes. This study aimed to monitor the quality changes and volatile compounds in fresh-cut apples at various temperatures using an electronic nose. The quality relationships of the product during distribution and storage using cold chain systems were also evaluated. The results showed that the total viable count initially differed between fresh-cut apples (2.59 Log CFU/g) and mixed fruits (apple 'Hongro', kumquat, and cherry tomatoes) (3.2 Log CFU/g) during the storage period ($p < 0.05$). There were no significant differences ($p > 0.05$) in the physicochemical properties except for the firmness, color values, browning index, whiteness index, and titratable acidity. The volatile compounds found in fresh-cut apples indicating apple fruit aroma were propyl propanoate and ethyl isovalerate, hexanol (freshness), and methanethiol and ethyl acetate (unpleasant off-odor), and these compounds could be used as markers for the deterioration process in fresh-cut apples during storage. Methanethiol and ethyl acetate were correlated with microbial growth (Pearson correlation of 0.81–0.98 for total viable microbe and 0.49–0.90 for coliform count). The limonene level was higher in the mixed fruits than in other treatments and gradually increased during storage due to the kumquat.

Keywords: ascorbic acid; cold chain systems; electronic nose; fresh-cut apple; mixed fruits; quality changes; storage; temperature; volatile compounds

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1. Introduction

Fresh agriculture products are well known for their high contents of essential nutrients for the human body and contain natural functional compounds such as phenols, antioxidants, flavonoids, and vitamins. Fresh-cut apples are minimally processed through washing, peeling, and cutting into practical shapes for consumption and packaged in convenient containers for easy handling [1,2]. However, during storage, the quality of fresh-cut apples quickly changes due to cell damage in the apple skin caused by cutting and slicing, which triggers enzymatic browning. This process produces undesirable attributes such as changes in taste, odor, texture, color, and nutritional value and a loss of economic importance [3,4].

Fresh-cut products can be preserved using various methods based on the end purpose. These techniques include modified atmosphere packaging that can maintain the firmness and limit ethylene production [5]; chitosan-−ascorbic acid coatings that can suppress enzymatic browning, maintain phenolic compounds, and retain firmness [6]; and pulsed electric field (PEF), which can induce metabolic stress and control the metabolic heat and respiration rate in fresh-cut apples [7]. Ascorbic acid is commonly used on fresh-cut apples

in Korean markets. Ascorbic acid use in fresh-cut apples effectively inhibits microbial growth and prevents browning during storage by increasing ascorbate peroxidase (APX) activity and inhibiting polyphenol oxidase (PPO) and peroxidase (POD) activities that can reduce the oxidation of flavonoids and total phenolics [8,9]. However, exogenous ascorbic acid (1% concentration application) can penetrate and stay in the intercellular space, potentially leading to cellular death and rapid oxidation due to oxygen exposure [10]. A cold chain is essential for maintaining quality and safety, including inhibiting microbial growth, in perishable products with short shelf lives, such as fresh-cut apples. In addition, apples are significantly affected by fluctuating temperatures [11]. By using a combination of ascorbic acid coatings and cold storage, the deterioration of fresh-cut apples can potentially be slowed in the long term [6]. During storage, fresh-cut apples can produce volatile compounds indicating off-flavor due to biochemical degradation [12–14].

The production of aroma-active compounds in apples is related to the harvest date, cultivar, and storage conditions. Via gas chromatography-flame ionization detection (GC-FID), ethyl 2-methyl butanoate, 2-methyl butyl acetate, and hexyl acetate have been identified and found to contribute to the characteristic aroma of 'Fuji' apples [15]. Using headspace solid-phase microextraction coupled with gas chromatography-mass spectrometry (HS-SPME-GC-MS), it was found that the essential variables that determine the apple cultivar are ethyl 2-methyl butyrate, 2-methyl-1-butanol, Z-3-hexenyl acetate, E-2-hexen-1-ol, linalool, and dodecanol [16]. Volatile profiles after mechanical damage have also been studied using gas chromatography-ion mobility spectrometry (GC-IMS), finding hexanal and ethyl acetate as potential volatile biomarkers to detect damaged apples [15]. An electronic nose is a fast analysis instrument for food quality monitoring in a small sample size in a short time that uses alpha MOS sensor technology to identify and expose the volatile compounds present in the headspace (HS) [17]. Limited studies exist on the combination of ascorbic acid coatings and cold storage for the preservation of fresh-cut apples during storage, and to the best of our knowledge, volatile compound formation in ascorbic-acid-coated fresh-cut apples during cold storage has yet to be evaluated. Therefore, the aim of this study was to evaluate the influence of ascorbic acid coatings and cold storage on fresh-cut apples and mixed fruits during storage to determine markers of freshness and off-odor in fresh-cut apples during storage at various temperatures. The contribution of other fruits in the products were also studied and quality changes monitored in real time using an electronic nose. We chose temperatures of 4 °C, 8 °C, and 15 °C (medium temperature) to study aroma compound production during distribution and storage. In addition, these temperatures were maintained constantly, and future studies under fluctuating temperature conditions, which represent the real-time conditions in the market, will be conducted. Furthermore, the relationships between the volatile compound characteristics of the samples were evaluated to describe the role of volatile compounds in quality degradation of fresh-cut apples in real-time simulations.

2. Materials and Methods

2.1. Sample and Material Preparation

Ascorbic acid (AA) solutions were prepared by mixing 1 mg of AA in 100 mL of distilled water. Fresh-cut apples and mixed fruits were coated by dipping them in AA solution with a concentration of 0.01% for 5 min and drained at room temperature for 2 min. The coated fresh-cut apple was packed and sealed in a 150 g polyethylene terephthalate (PET) cup with a thickness of 150 µm, an O_2 permeability of 1.47 mlm^{-2} MPa^{-1} per day, and a CO_2 permeability of 10 mlm^{-2} MPa^{-1} per day. In addition, mixed fruit containing 50% AA-coated fresh-cut apple (*Malus* × domestica Borkh cv Hongro), 25% kumquat or *Citrus japonica*, and 25% cherry tomato or *S. lycopersicum* var. *cerasiforme* was also prepared in a 150 g PET cup and stored at 4 °C to determine the external volatile compounds' influence (from kumquat and tomato) on fresh-cut apple products.

Before being placed in the storage room, the samples were firstly distributed via refrigerated container trucks at 8 °C for 10 h. This was conducted to monitor the tempera-

ture changes during the distribution of fresh-cut apples in real conditions, and an initial temperature check was performed before storage. After that, 21 cups of fresh-cut apples were stored at 15 °C for 10 days, 33 cups of fresh-cut apples were stored at 8 °C for 20 days, 33 cups of fresh-cut apples were stored at 4 °C for 30 days, and 33 cups of mixed fruits were stored at 4 °C for 30 days at the Korea Food Research Institute. The sampling interval time was 1 day for the samples stored at 15 °C, 2 days for those stored at 8 °C, and 3 days for those stored at 4 °C. The fresh-cut apples (450 g or 3 cups) were collected for quality and volatile compound analyses.

Real-time internal and surface temperatures of fresh-cut apples and environmental temperatures in the storage room were also recorded using a temperature recorder (TR-52i, T&D Corp., Nagano, Japan) with a flexible fluoropolymer-coated sensor (TR-5106, T&D Corp., Nagano, Japan) and a stainless protection sensor (TR-5320, T&D Corp., Nagano, Japan) to evaluate the temperature changes during distribution and storage.

2.2. Quality Analyses of Fresh-Cut Apples

2.2.1. Moisture Content and Total Soluble Solids

The moisture content of fresh-cut apples was determined using an oven-drying technique. The fresh-cut apple (50 g) was sliced into small pieces and mixed well. The weight of the mixed sample was 2 g, with three replications in an aluminum container, and it was dried in a dry oven (HK-D0134F, Hankuk S&I Co., Ltd., Hwaseong-si, Gyeonggi-do, Republic of Korea) for 3 h at 135 °C. The samples' moisture contents were calculated on a percentage wet basis using the following equation:

$$Moisture\ (wb)\ (\%) = \frac{initial\ sample\ weight\ (\mathrm{g}) - dried\ sample\ weight\ (\mathrm{g})}{inital\ sample\ weight\ (\mathrm{g})} \times 100 \quad (1)$$

For total soluble solids, the fresh-cut apple was blended using a kitchen blender (HMF600, Hanil Global Tech Co., Ltd., Sejong-si, Republic of Korea), 50 g of the sample was filtered through filter paper (Whatman No. 1, GE Healthcare UK Ltd., Buckinghamshire, UK), and 0.3 mL of the filtrate was placed on the prism of a refractometer (PAL-1, Atago Co., Ltd., Tokyo, Japan). Three replications of the analysis were performed. The total soluble solids (TSSs) of the sample were recorded as the brix percentage (%°Brix).

2.2.2. Titratable Acidity and pH

A sample of fresh-cut apples was blended using a fruit juicer (H-100-SBFA01, Hurom Corp., Seoul, Republic of Korea), and 10 g of fresh-cut apple juice was placed in a 50 mL glass beaker. The sample's pH value was obtained with three replications using a digital pH meter (TA-70, DKK-TOA Corp., Tokyo, Japan) [18]. The titratable acidity (TA) was determined via the acid-base titration method according to the addition of NaOH 0.1 N to 10 g of fresh-cut apple juice until a pH of 8.2 was reached. The TA value was calculated as percentage of malic acid (molas mass = 134.09 g/mol) using the following equation:

$$TA\ (\%\ malic\ acid) = \frac{Volume\ NaOH\ (\mathrm{mL}) \times 0.1\ N \times 134.09\ \mathrm{g/mol} \times 100}{10\ \mathrm{g} \times 1000} \quad (2)$$

2.2.3. Changes in Appearance and Color Value

The appearance of the fresh-cut apple was captured using a mobile camera (Galaxy S series, Samsung Electronics Co. Ltd., Suwon, Republic of Korea) with the specifications of 108 MP, f/1.8, 24 mm (wide), 1/1.33", 0.8 µm, PDAF, Laser AF, and OIS. The color of the fresh-cut apples was measured using an automatic colorimeter (CR-400, Konica Minolta Inc., Osaka, Japan) with six samples (25 g) and three replications. The color value was set as CIELAB color parameters L^* (lightness from black to white), a^* (green to red), and b^*

(yellow to blue). Total color difference (ΔE), browning index (BI), and whiteness index (WI) were obtained according to the following formulas [19,20]:

$$\Delta E^* = \sqrt{\left(L^*_{fresh} - L^*_{sample}\right)^2 + \left(a^*_{fresh} - a^*_{sample}\right) + \left(b^*_{fresh} - b^*_{sample}\right)} \quad (3)$$

$$BI = \frac{[100(x - 0.31)]}{0.172}, \text{ where } x = \frac{a^* + 1.75\ L^*}{5.645\ L^* + a^* - 3.012\ b^*} \quad (4)$$

$$WI = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}} \quad (5)$$

2.2.4. Texture Analysis

The fresh-cut apple's texture (firmness) during storage was determined using a texture analyzer (TA.XT PlusC, Stable Micro Systems Ltd., Vienna Court, UK) in Newtons (N). The analysis was conducted through pre-test, test, and post-test speed of 5 mm/sec with 10 replications of fresh-cut apples (25 g) using a single blade set (HDP/BS probe, Stable Micro Systems Ltd., Vienna Court, UK) [2].

2.2.5. Total Viable Count and Total Coliform Count

The total viable count (TVC) and total coliform (CC) were determined via the Petrifilm™ (Aerobic Count (AC), 3M™, St. Paul, MN, USA) plate method 6400/6403/6406/6442 and Coliform (Count Plate (CC), 3M™, St. Paul, MN, USA) plate method 6402/6412. Ten grams of fresh-cut apple was removed in a sterile environment and diluted 10-fold by 0.85% saline solution in a sterile filter bag. Furthermore, the sample was homogenized for one minute with four strokes per second using a 400 CC stomacher (BagMixer, Interscience Intl., Saint Nom la Bretêche, France). Each instance was removed and diluted with 9 mL of 0.85% saline solution. A particular dilution series (1 mL) was placed on Petrifilm plates and incubated at 35 °C ± 1 °C for 48 h ± 3 h (AC plate) and 32 °C ± 1 °C for 24 h (CC plate).

2.2.6. Analysis of Volatile Compounds

All volatile compounds (VOCs) were analyzed using a fast gas chromatography–flame ionization detection (GC-FID) instrument (Heracles II, Alpha M.O.S., Toulouse, France). An auto sampling system (HS100 autosampler, Alpha M.O.S., Toulouse, France) with two columns (MXT-5, Fisher Scientific Inc., Boston, MA, USA, and MXT-1701, Fisher Scientific Inc., Boston, MA, USA) and two flame ionization detectors was installed in the instrument to increase the performance of detection at different polarities. Two grams of fresh-cut apples were prepared in a 20 mL vial (with headspace) and injected into the e-nose, with 5 repeats of each sample based on sample type and storage treatment. Before the analysis, the method in [18] was selected and followed with some parameter modifications: the incubation time was set to 20 min at 40 °C with an agitation speed of 500 rpm, and the volume of injection was 1000 µL with a speed of 125 µL/s at 200 °C (initial conditions). The oven had an initial temperature of 40 °C, and this was increased to 250 °C gradually at rates of 1 °C/s and 3 °C/s with an acquisition duration of 110 s, an acquisition period of 0.01 s, and a detector temperature of 260 °C. Kovat's indices were used to measure the retention time of C6-C16, and the data were processed in Alpha-Soft software (V14.2, Alpha M.O.S, Toulouse, France). The VOCs were identified using the chemical compound library (AroChembase, Alpha MOS, Toulouse, France) using chemical compounds, formulas, CAS numbers, and odor descriptions [21].

2.3. Statistical Analysis

A one-way analysis of variance (ANOVA) was performed to analyze the experimental data, followed by Duncan's multiple range test at a 0.05 significance level. A variable correlation analysis (Pearson correlation) was also performed using GraphPad for Windows (GraphPad Prism version 10.0.3, GraphPad Software, Boston, MA, USA).

3. Results and Discussion

3.1. Physicochemical Properties

3.1.1. Moisture Content, Total Soluble Solids, pH, and Titratable Acidity

The moisture content in the fresh-cut apples was relatively stable during storage, regardless of whether they were stored at 15 °C, 8 °C, or 4 °C ($p > 0.05$) (Figure 1a). At 4 °C, with the prolongation of storage time, the cell shape gradually became irregular, and this became more severe over time. This cell decomposition can lead to the migration of moisture in the fresh-cut apple due to cell structure cleavage [22]. However, the plastic packaging used for fresh-cut apples in this experiment can prevent water loss for over 30 days at 4 °C. The pH value, TA, and TSSs of all treatments showed no remarkable changes from the initial day of storage until the final day of observation ($p > 0.05$) (Figure 1b–d). These results align with the previous studies, which showed no difference in physicochemical properties during storage at 4 °C [23–25]. At 8 °C and 15 °C, there was no change in the physicochemical properties due to the short experiment time; the vitamin C coating prevents quality degradation by suppressing browning and maintaining acidity and phenolic compounds, and the plastic cup plays a role in preventing water loss during storage [6,26,27]. Therefore, the physicochemical properties of fresh-cut apples coated with AA (0.01% concentration) in plastic packaging exhibited no significant changes.

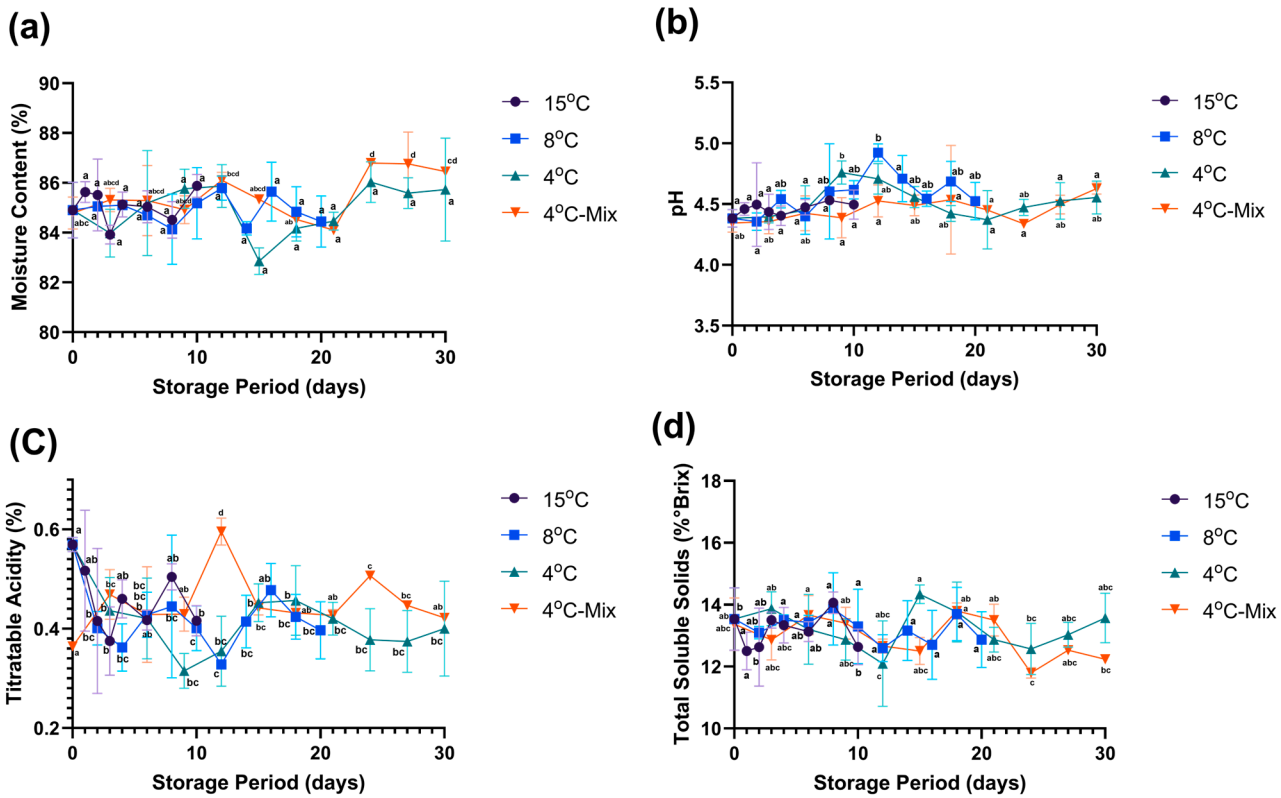

Figure 1. (**a**) Moisture content (%); (**b**) changes in pH value; (**c**) titratable acidity (TA); and (**d**) total soluble solids (%°Brix) of fresh-cut apples during storage at 15 °C, 8 °C, 4 °C, and 4 °C—mixed fruits (fresh-cut apple, cherry tomato, and kumquat). The data are expressed as means ± SE with $n = 3$. Superscripts with different letters (a–d) considered at the same temperature represent significant differences at $p < 0.05$.

3.1.2. Changes in Color and Appearance

Color change in fresh-cut apples is the most important parameter that indicates chemical and biochemical reactions during long-term storage. The color variable of fresh-cut apples, such as L^* (whiteness/darkness) and b^* (yellowness/blueness) in Figure 2a,c, showed no significant differences in all temperature treatments during storage, even though

the values on the initial and final days were different ($p > 0.05$). However, in mixed fruits at 4 °C, L^* significantly decreased during storage until the final day. This decrease in L^* can be attributed to the formation of browning pigment, which leads to the browning process [28]. AA is an effective inhibitor of enzymatic browning because of its ability to reduce quinones, but once the AA is completely oxidized, quinones can accumulate and start the browning process [29]. The a^* value, which represents redness/greenness, significantly increased ($p < 0.05$) from day 0 to day 30 of the experiment at 4 °C, from day 0 to day 20 at 8 °C, and from day 0 to day 10 at 15 °C (Figure 2b). Figure 2d illustrates the gradual change in total color change of fresh-cut apples from day 0 to day 10 at 15 °C, from day 0 to day 20 at 8 °C, and from day 0 to day 30 °C at 4 °C for fresh-cut apples and mixed fruits. According to the relevant literature, the a^* value gradually increases with the increase in storage duration, suggesting that the surface color of fresh-cut apples becomes redder [22].

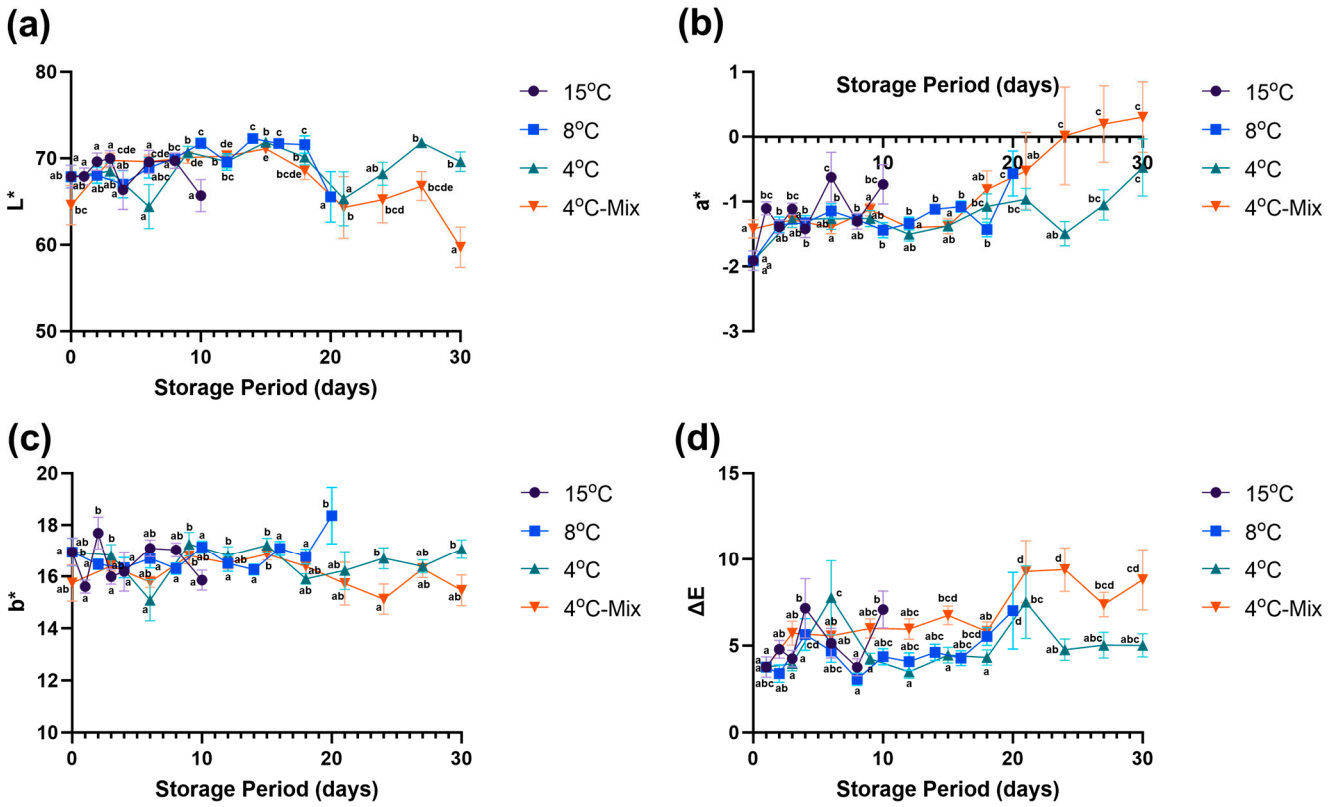

Figure 2. Changes in (**a**) L^*, (**b**) a^*, and (**c**) b^* and (**d**) ΔE of fresh-cut apple during storage at 15 °C, 8 °C, 4 °C, and 4 °C (mixed fruits: fresh-cut apple, cherry tomato, and kumquat). The data are expressed as means ± SE, with $n = 18$. Superscripts with different letters (a–e) considered at the same temperature represent significant differences at $p < 0.05$.

The browning index (BI) indicates the brown color purity during browning via an enzymatic or non-enzymatic reaction [30]. Meanwhile, a higher whiteness index (WI) corresponds to a lower browning intensity [31]. The results indicate that these color parameters gradually changed compared to the beginning of the observations (Figure 3). AA can prevent browning for 12 days under covered films [29]. The BI tended to increase to 25.61, the average value of fresh products. On the other hand, the WI significantly decreased ($p < 0.05$) for all treatments from the initial value of 64.59. Figure 4 shows the changes in fresh-cut apple appearance during storage under various temperatures; the fresh-cut apple stored at 15 °C slightly changed after day 10, and the browning process was initiated after day 18 at 8 °C. In addition, the color of fresh-cut apples significantly changed ($p < 0.05$) after 30 days of storage at 4 °C. On the other hand, after 21 days of storage at 4 °C, the mixed fruits deteriorated nine days earlier than the fresh-cut apple only.

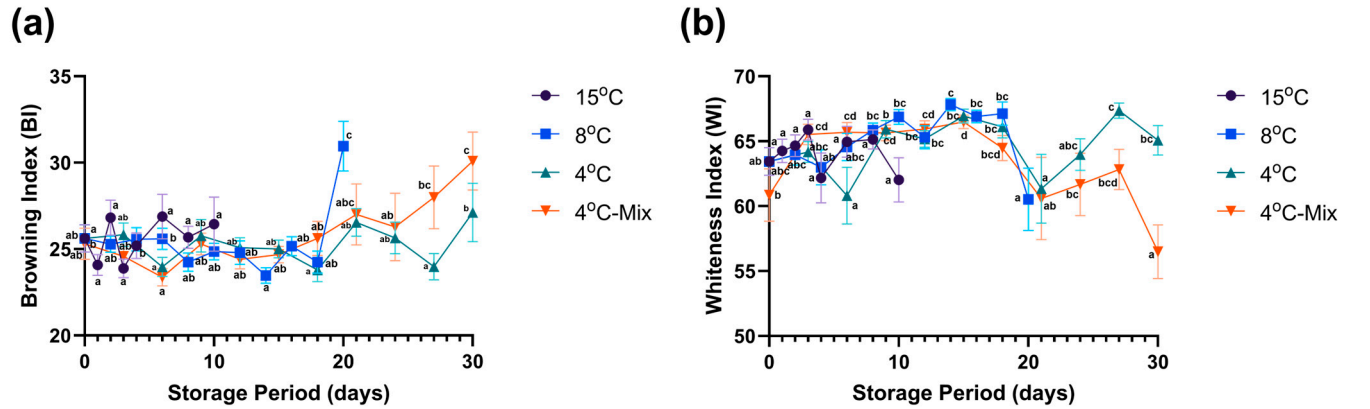

Figure 3. Changes in the (**a**) browning index and (**b**) whiteness index of fresh-cut apple during storage at 15 °C, 8 °C, 4 °C, and 4 °C (mixed fruits: fresh-cut apple, cherry tomato, and kumquat). The data are expressed as means ± SE with $n = 18$. Superscripts with different letters (a–d) considered at the same temperature represent significant differences at $p < 0.05$.

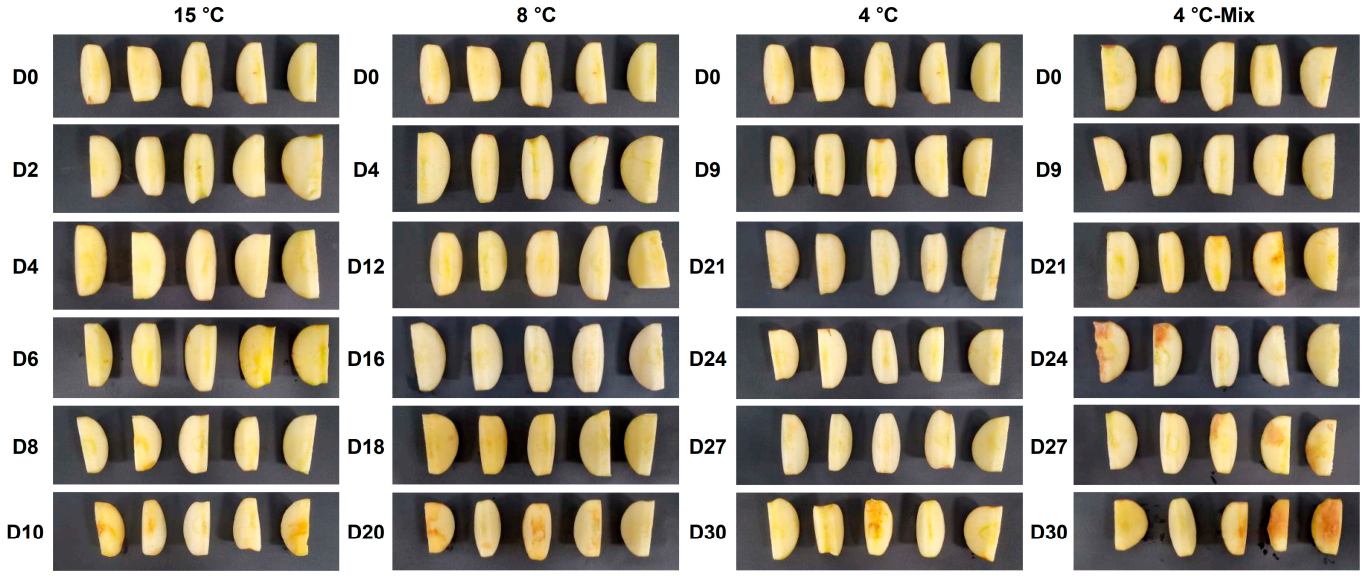

Figure 4. Changes in the appearance of fresh-cut apples during storage at different temperatures for 10 days at 15 °C, 20 days at 8 °C, 30 days at 4 °C, and 30 days at 4 °C (mixed fruits: fresh-cut apple, cherry tomato, and kumquat).

3.1.3. Texture Analysis (Firmness)

According to relevant studies, a loss of firmness can occur during postharvest and postproduction as a result of pectin breakdown through enzyme activities [32,33]. The firmness changes of fresh-cut apples after different treatments are shown in Figure 5. It can be seen that the initial force value was 76.28 N (fresh-cut apples only) and 77.91 N (mixed fruits), which decreased significantly to 48.13 N at 15 °C, 52.83 N at 8 °C, 56.58 N at 4 °C, and 41.52 N at 4 °C (mixed fruits). Texture changes in fruits are related to the transformation of cell wall polymers due to non-enzymatic and enzymatic reactions and high-pressure processing [23,34]. The microstructure of apples has a direct impact on the changes in textural properties due to compression forces, cell ruptures, and osmotic dehydration [35,36].

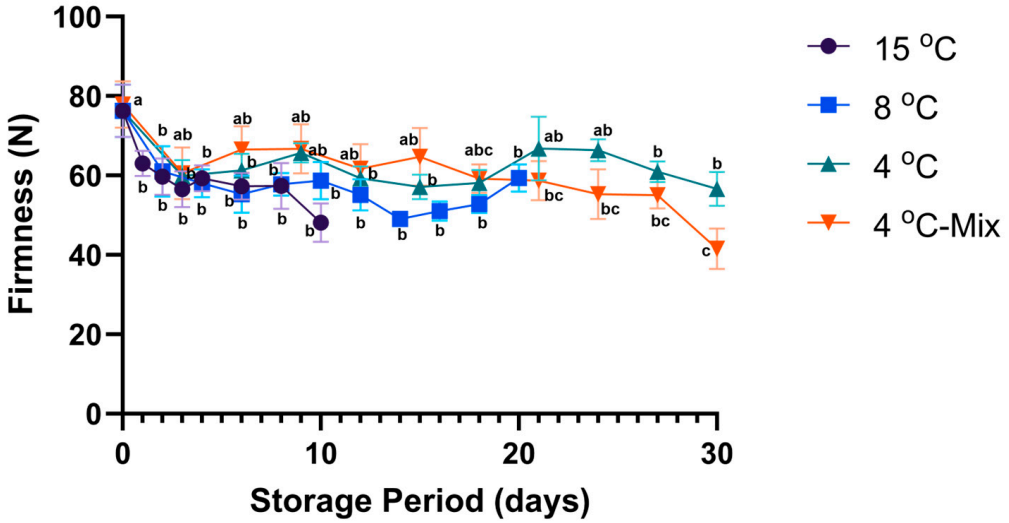

Figure 5. Changes in firmness (N) of fresh-cut apples during storage at 15 °C, 8 °C, 4 °C, and 4 °C (mixed fruits: fresh-cut apple, cherry tomato, and kumquat). The data are expressed as means ± SE, n = 10, with $p < 0.05$ considered significantly different. Superscripts with different letters (a–d) considered at the same temperature represent significant differences at $p < 0.05$.

3.2. Temperature Changes and Microbial Growth

Microbial growth was evaluated during storage and can be observed in Figure 6. This assessment was conducted to assess the food handling and safety regarding the producer's sanitation practices and equipment in the case of potential contamination of apples, either washed or unwashed, by external factors [37,38]. The TVC on the initial day was 2.59 Log CFU/g and 3.2 Log CFU/g (mixed fruits). The number of microbes significantly increased to the maximum values of 7.98 Log CFU/g at 15 °C, 7.69 Log CFU/g at 8 °C, 7.62 Log CFU/g at 4 °C, and 7.69 Log CFU/g at 4 °C (mixed fruits). In addition, the CC of fresh-cut apples during storage increased significantly ($p < 0.05$) from the initial values of 1.74 Log CFU/g and 2.88 Log CFU/g (mixed fruits), Figure 6a. The CC increased to 7.77 Log CFU/g at 15 °C, 7.49 Log CFU/g at 8 °C, 6.85 Log CFU/g at 4 °C, and 7.06 Log CFU/g at 4 °C (mixed fruits) (Figure 6b). The increase in microorganisms can be explained by mechanical damage to tissue cells and temperature conditions that could lead to enzyme and substrate mixing [22,39]. This mixing is ideal for microorganism growth [40]. It can be seen that storage at 4 °C can better prevent the growth of microbes compared to other temperatures.

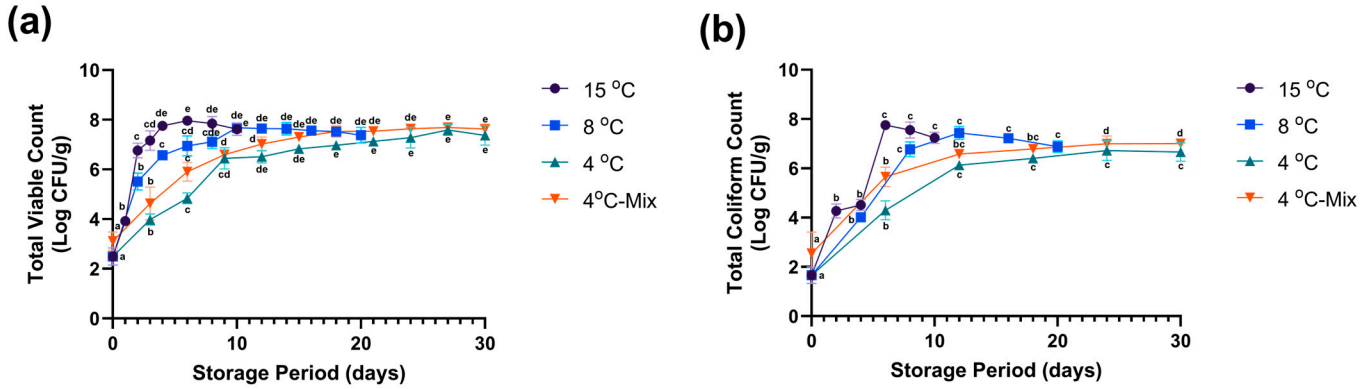

Figure 6. Increase in (**a**) total viable count (TVC) and (**b**) total coliform count (CC) of fresh-cut apples during storage at 15 °C, 8 °C, 4 °C, and 4 °C (mixed fruits: fresh-cut apple, cherry tomato, and kumquat). The data are expressed as means ± SE with n = 3. Superscripts with different letters (a–d) considered at the same temperature represent significant differences at $p < 0.05$.

The effectiveness of refrigerated storage as a preservation method depends on the initial quality of the raw material and the time/temperature conditions [41]. In Figure 7, the internal temperature of fresh-cut apple products was recorded during distribution as 9.84 ± 1.03 °C, categorized as exotic chill (≈10 °C) [42]. The internal temperature (Figure 7g) of fresh-cut apple decreased when the sample moved from distribution temperature conditions to the 4 °C storage room, with a cooling rate of 1.13 °C per hour. This condition could prevent the growth of microbes during distribution and minimize the initial number of microbes in storage. In addition, the operating temperatures and cooling rates of the cooling techniques must be properly applied and controlled to ensure food safety [43]. The temperature (inside, surface, and outside) of the fresh-cut apple products gradually changed during storage and was constantly maintained at the controlled temperatures (15 °C, 8 °C, 4 °C, and 4 °C—mixed fruits) until the end of monitoring demonstrated by recorded temperature of 15.65 ± 0.25 °C, 8.69 ± 0.20 °C, 4.39 ± 0.23 °C, and 4.34 ± 0.21 °C, respectively. Under these conditions, the temperature contributed to halting and controlling the growth of the microorganisms initially present in the products. The storage temperatures of 15 °C and 8 °C improperly extended the shelf-life of fresh-cut apple products.

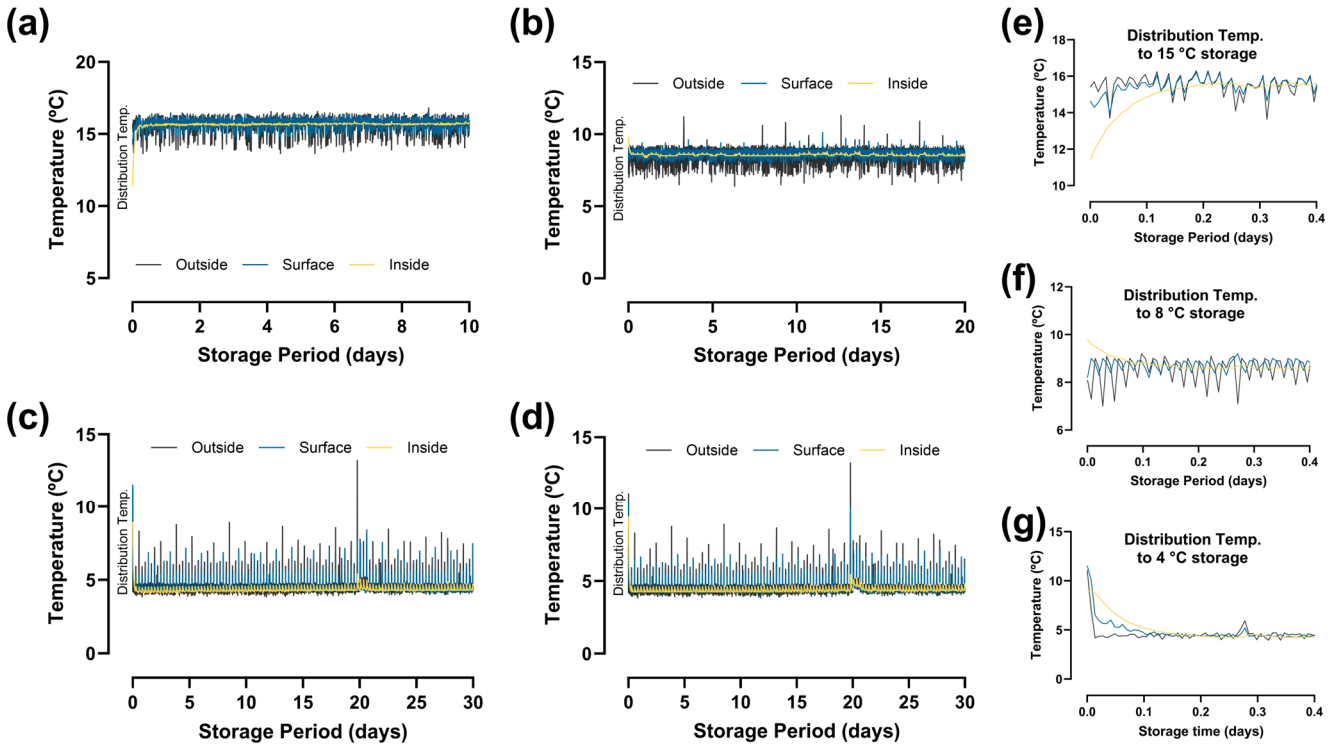

Figure 7. Temperature of fresh-cut apples during distribution (10 °C) and storage at (**a**) 15 °C, (**b**) 8 °C, (**c**) 4 °C, and (**d**) 4 °C (mixed fruits (fresh-cut apple, cherry tomato, and kumquat)) on the outside, surface, and inside of the product packaging; (**e**–**g**) temperature changes during 9 h of distribution. The data are expressed as means, with $n = 2$.

3.3. Changes of Volatile Compounds

Ten VOCs, including methanol, methanethiol, ethyl acetate, s(-)2-methyl-1-butanol, propyl propanoate, ethyl isovalerate, 1-hexanol, acetaldehyde, ethyl butyrate, and limonene, were identified in fresh-cut apples and are summarized in Table 1. The presence of methanol indicates a pungent odor; methanethiol leads to a sulfurous and fishy odor; ethyl acetate indicates an acidic and sweet odor; s(-)2-methyl-1-butanol is fruity and malty; propyl propanoate and ethyl isovalerate are related to apple aroma and critical odorant compounds in apples [44,45]; 1-hexanol gives a floral and fruity odor; acetaldehyde represents an ethereal and pungent odor; ethyl butyrate indicates a banana-like and caramelized odor;

and limonene imparts a citrus- and orange-like odor to the products. Figure 8 shows the peak changes in the chromatograms of fresh-cut apples during storage at 15 °C from day 0 to day 10 and highlights an increase in VOCs that have low molar masses and boiling points, such as methanol, methanethiol, and ethyl acetate. Furthermore, Figure 9 describes the peak changes in the chromatograms of fresh-cut apples and fresh-cut apples mixed with kumquat and cherry tomatoes during storage at 4 °C on day 0 and day 30. On day 0, there was no significant difference between fresh-cut apples only and the mixed fruits. However, in the mixed fruits on day 30 (Figure 9d), a limonene (RT = 73.31 s) peak was identified in either the MXT-5 or MXT-1701 columns, which indicates the contribution and influence of kumquat in the overall aroma of fresh-cut apple products. Limonene is classified as a monoterpene with colorless characteristics. It has an orange scent and two optical isomers, D-limonene and L-limonene [46].

Table 1. Identified volatile compounds (VOCs) in fresh-cut apples during storage with their CAS number, chemical formula, and odor descriptions.

Chemical Compound	CAS [1]	Formula	Odor Description [2]
Methanol	67-56-1	CH_4O	Pungent Odor
Methanethiol	74-93-1	CH_4S	Cheese, Fishy, Garlic, Rotten Egg, Rotten Cabbage, and Sulfurous
Ethyl Acetate	141-78-6	$C_4H_8O_2$	Acidic, Butter, Caramelized, Fruity, Pineapple, and Sweet
S(-)2-Methyl-1-Butanol	1565-80-6	$C_5H_{12}O$	Fruity and Malty
Propyl Propanoate	105-54-4	$C_6H_{12}O_2$	Apple and Pineapple Odor
Ethyl Isovalerate	108-64-5	$C_7H_{14}O_2$	Anise, Apple, Blackcurrant, Cashew, Fruity, and Sweet
1-Hexanol	111-27-3	$C_6H_{14}O$	Floral, Fruity, Grassy, Green, Mild Woody, Sweet, and Toasty
Acetaldehyde	75-07-0	C_2H_4O	Ethereal, Fresh, Fruity, and Pungent
Ethyl Butyrate	105-54-4	$C_6H_{12}O_2$	Banana, Bubblegum, Caramelized, Strawberry, and Sweet
Limonene	5989-27-5	$C_{10}H_{16}$	Citrus, Fruity, Minty, Orange, and Peely-like

[1] CAS is abbreviation for chemical abstracts service number, which assigns the number of chemical substances.
[2] Source: The odor descriptions were confirmed using the AroChemBase library (Alpha MOS, France).

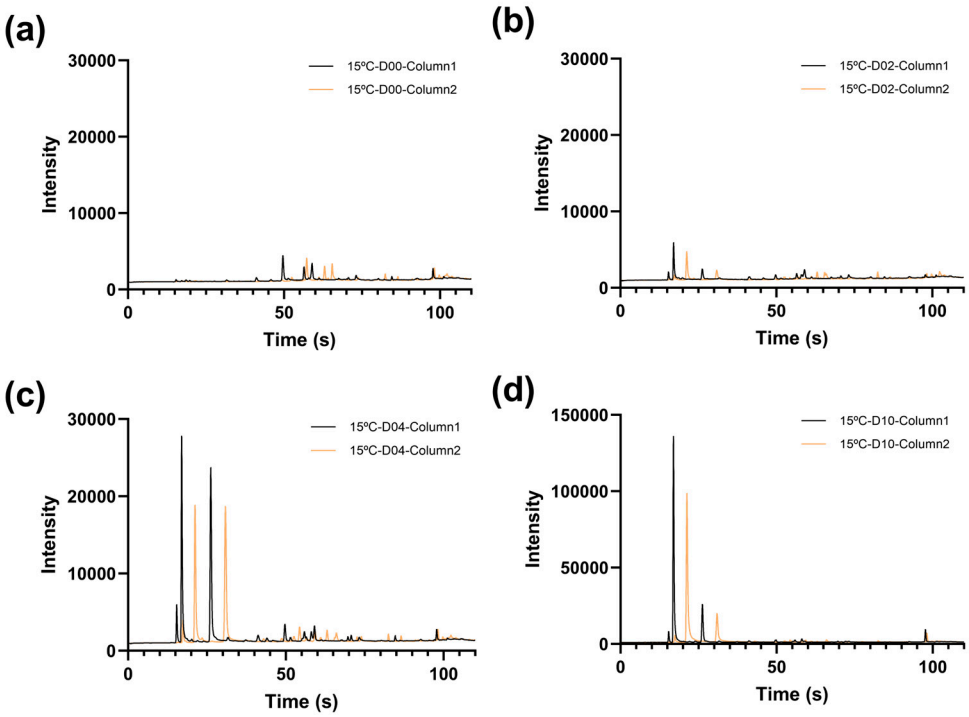

Figure 8. Chromatograms of fresh-cut apples during storage at 15 °C on (**a**) day 0, (**b**) day 2, (**c**) day 4, and (**d**) day 10. Column 1: MXT-5; Column 2: MXT-1701.

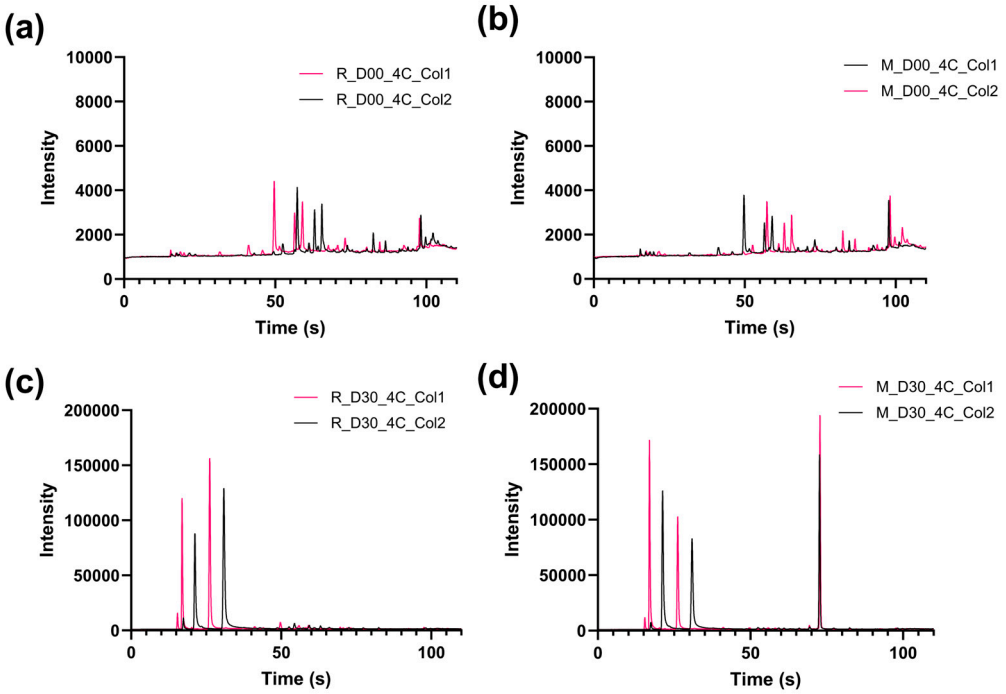

Figure 9. Chromatograms of fresh-cut apples during storage at 4 °C on (**a**) day 0; (**b**) day 0—mixed fruits; (**c**) day 30; and (**d**) day 30—mixed fruits. Column 1: MXT-5; Column 2: MXT-1701.

Detailed changes in the VOCs of fresh-cut apples can be found in Figure 10, which shows the relative abundance of odorous compounds at different temperatures and sample conditions during storage. The figure demonstrates a clear shift from the initial profile, with prevalent apple and fruit aroma compounds (e.g., propyl propanoate and ethyl isovalerate) with fresh notes (hexanol), to an unpleasant, off-odor (e.g., methanethiol and ethyl acetate). In general, ethyl acetate is described favorably as a fruity aroma compound (Table 1), but elevated ethyl acetate levels are associated with an off-odor in apples [14,47]. This shift occurred early during the shelf life, depending on the storage temperature. The aroma shift day can be defined as the end of the product's "flavor life" (postharvest life based on flavor), which is typically shorter than the life based on appearance and textural quality [48]. At 15 °C, the flavor life was just 1 day, and at 8 °C, it was less than 4 days, according to the decrease in propyl propanoate and the accumulation of methanethiol. Meanwhile, at 4 °C, the flavor life was less than 9 days. Based on the appearance of the fresh-cut apple in this experiment, the shelf-life was 30, 18, and 10 days for the sample stored at 4, 8, and 15 °C, respectively, whereas, for the sample of fresh-cut apple stored at 4 °C with kumquat and tomato, the shelf-life was 3 weeks. At 4 °C, 8 °C, and 15 °C, the methanethiol and ethyl acetate production in fresh-cut apples gradually increased until the last experiment. In the mixed fruits, the limonene level increased until day 30 of storage, matching the increases in methanethiol and ethyl acetate.

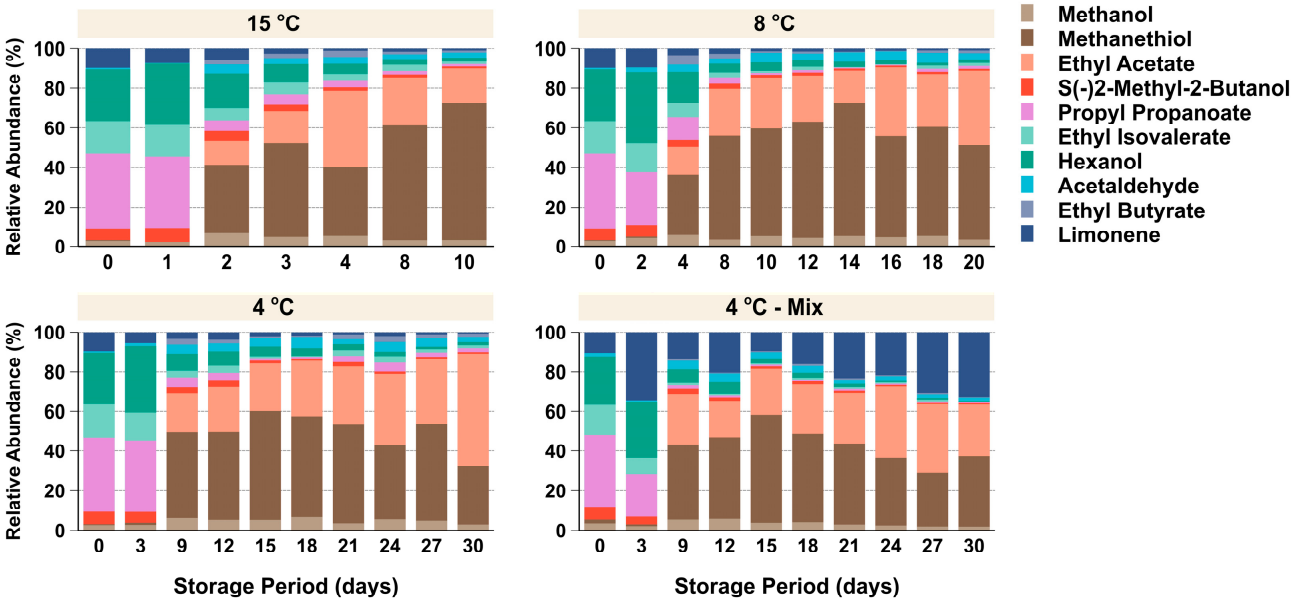

Figure 10. Changes in the relative abundance (%) of odor (volatile) compounds observed in fresh-cut apples under different temperature conditions for 10 days at 15 °C, 20 days at 8 °C, 30 days at 4 °C, and 30 days at 4 °C (mixed fruits: fresh-cut apple, cherry tomato, and kumquat).

3.4. Statistical and Variables Correlation Analysis during Storage

The Pearson correlation coefficient (r) determines the linear relationship between variables and contains a numerical code for grouping the variables from the weakest to the most substantial relation (–1 to 1) [49]. Figure 11 shows the Pearson correlation among all fresh-cut apple samples (variables) during storage at different temperatures. At 15 °C, the variables that had medium to high correlation with the storage time were pH (0.64), firmness (–0.66), TVC (0.75), and CC (0.90). At 8 °C, TVC and CC were the most correlated with storage time (0.73 and 0.84, respectively). Similarly to 8 °C, the most highly correlated variables to the storage period at 4 °C were TVC (0.88) and CC (0.87). Furthermore, the variables of the mixed fruits stored at 4 °C were significantly correlated to time, pH (0.60), firmness (–0.60), TVC (0.86), and CC (0.82). TVC and CC were highly correlated and contributed to changes in the physicochemical properties of fresh-cut apples. This result is similar to [50], in which the counts of microbes on the fresh-cut apples are correlated with the physicochemical properties. During storage at 15 °C, TVC was correlated to changes in TA and firmness. In addition, at 8 °C, TVC is correlated to pH, TA, and firmness changes. However, at 4 °C, TVC levels are correlated with decreases in TA (0.66) and pH (0.6) for mixed fruits. The CC is in line with the increase in pH, and a^* was negatively correlated with TA (–0.59) at 15 °C. The CC contributes to increased pH and L^* levels and decreased TA, TSS, delta E, and firmness levels at 8 °C. Variation in CC at 4 °C leads to a decrease in TA, b^*, and the firmness of mixed fruits during storage.

Using the Pearson correlation approach, Figure 12 shows the relationships of identified VOCs with microbial growth at different temperatures. Limonene was negatively correlated with the storage time at 15 °C, 8 °C, and 4 °C (−0.79, −0.83, and −0.87, respectively). Conversely, the mixed fruits were positively correlated with the storage time (0.40), indicating that the citrus odor from external factors influenced the characteristics of fresh-cut apples over time. Methanethiol and ethyl acetate could be used to determine fresh-cut apple deterioration during storage. At 15 °C, methanethiol was highly correlated, at 0.89, and medium correlation at 0.54 for ethyl acetate. Meanwhile, at 8 °C, 4 °C, and 4 °C (mixed fruits), ethyl acetate had the highest correlation at 0.88, 0.93, and 0.85 during storage. *T. gamsii*, *Bacillus* sp., or *Brassica oleracea* L. were potential microbe sources contributing to methanethiol production in fresh-cut apples, which is a VOC containing sulfur and indicating an off-odor [51,52]. Ethyl acetate was formed biologically by yeast (*S. cerevisiae*)

and *E.coli* through esterification of acyl-CoA and ethanol through endogenous alcohol acetyl-transferase (ATT) catalysts [53]. The relationships between microbes (TVC and CC) and VOCs (ethyl acetate and methanethiol) were positively correlated at 15 °C, 8 °C, 4 °C, and 4 °C—mixed fruits (0.88, 0.87, 0.88, and 0.81 for methanethiol and TVC; 0.96, 0.98, 0.89, and 0.92 for methanethiol and CC; 0.82, 0.76, 0.86, and 0.89 for ethyl acetate and TVC; 0.49, 0.90, 0.84, and 0.88 for ethyl acetate and CC, respectively).

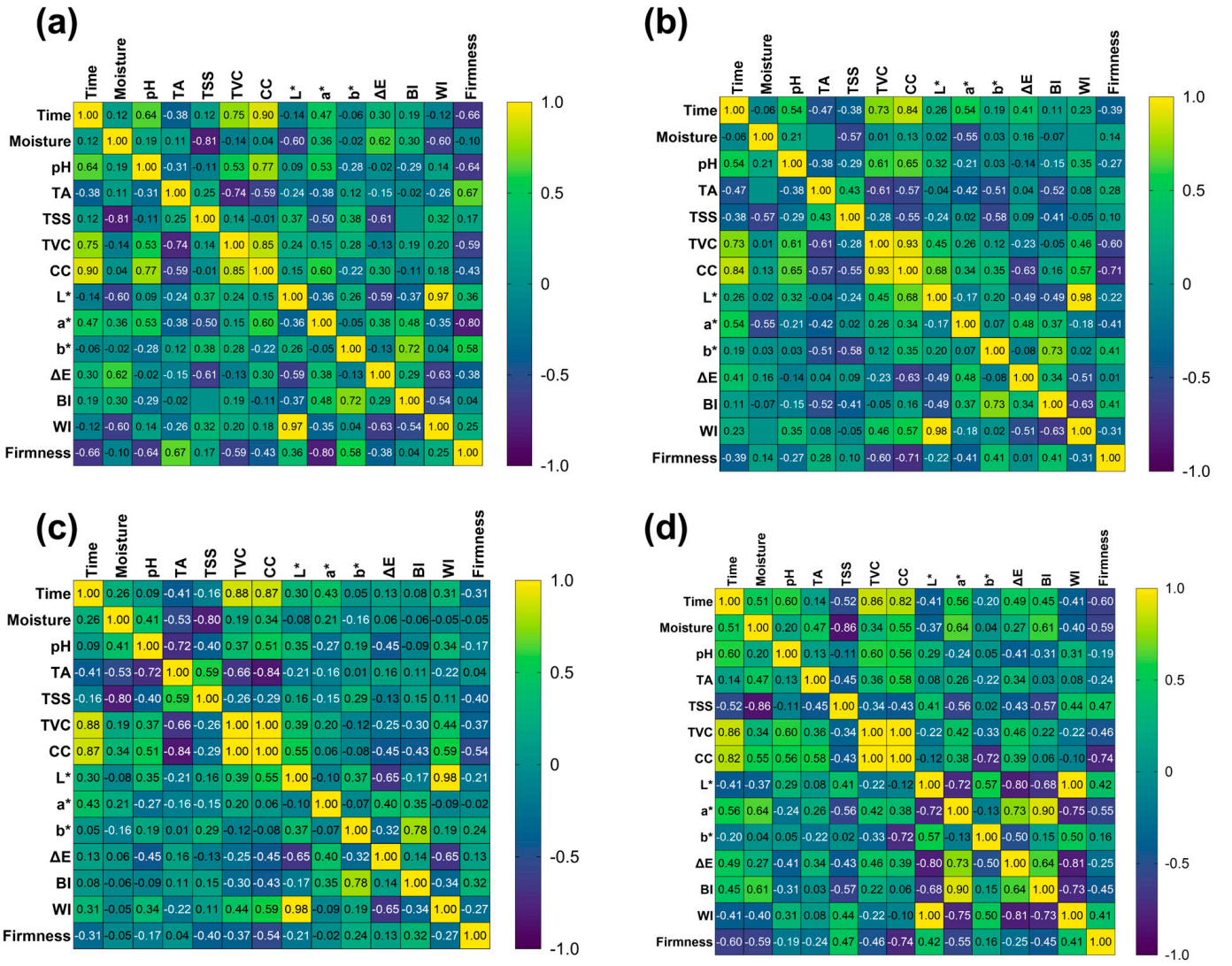

Figure 11. Pearson correlation among variables of fresh-cut apple stored at (**a**) 15 °C, (**b**) 8 °C, (**c**) 4 °C, and (**d**) 4 °C—mixed fruits (fresh-cut apple, cherry tomato, and kumquat). Note: time = storage time (days); moisture = moisture content (%); pH = pH value; TA = titratable acidity (%); TSSs = total soluble solids (%°Brix); TVC = total viable count (log CFU/g); CC = coliform count (log CFU/g); *L* a* b** = color value; ΔE = color difference; BI = browning index; WI = whiteness index; Firmness = texture of sample (N).

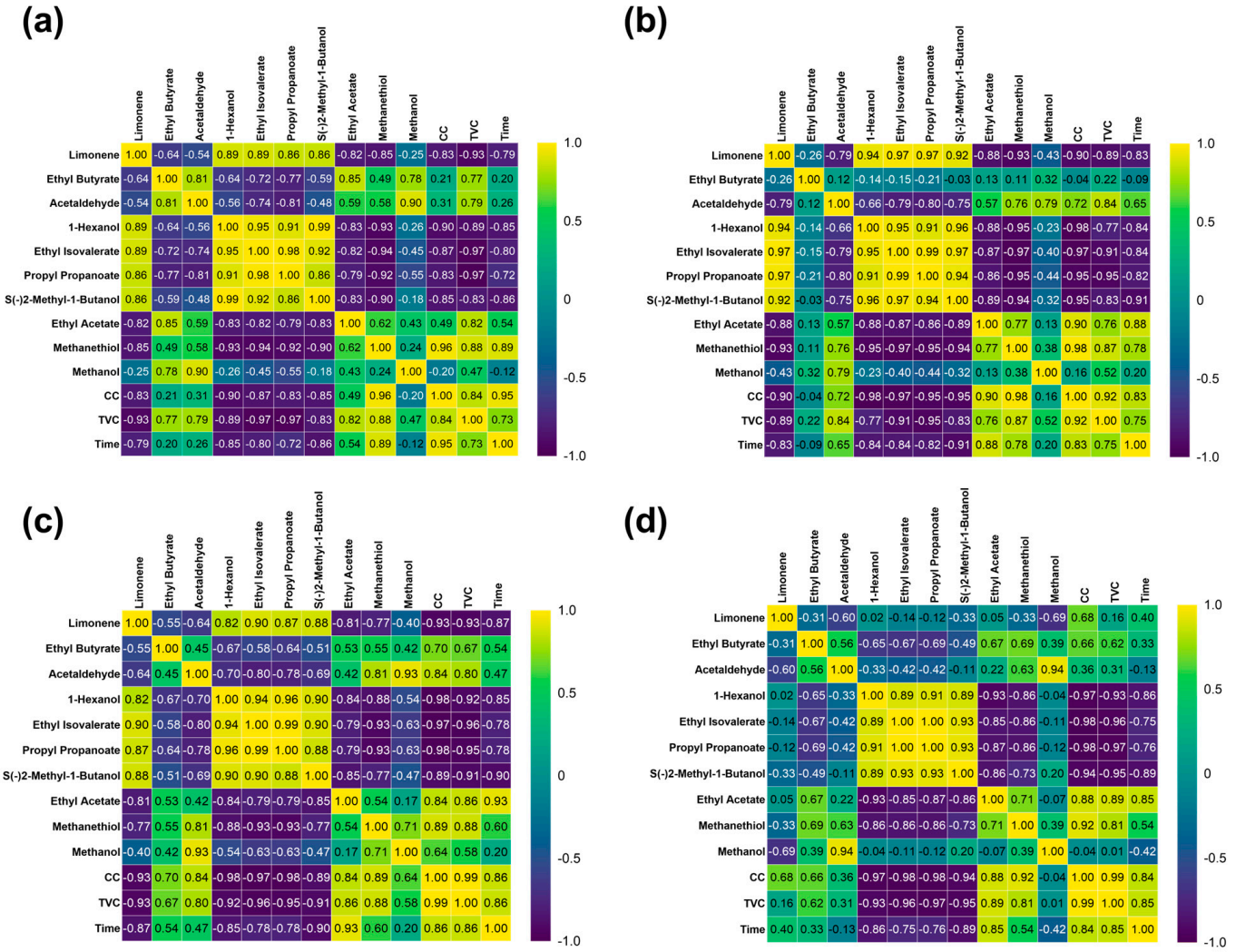

Figure 12. Pearson correlation of microbial growths and identified volatile compounds in fresh-cut apple during storage at **a**) 15 °C, (**b**) 8 °C, (**c**) 4 °C, and (**d**) 4 °C—mixed fruits (fresh-cut apple, cherry tomato, and kumquat). Note: time = storage time (days); TVC = total viable count (log CFU/g); CC = coliform count (log CFU/g).

4. Conclusions

This study evaluated the effects of storage temperature on the volatile compound characteristics and overall qualities of fresh-cut apples coated with AA in plastic cups. Samples containing both fresh-cut apples only and fresh-cut apples with kumquat and cherry tomato (mixed fruits) were studied. The fresh-cut apples stored at 15 °C, 8 °C, and 4 °C exhibited no significant differences in physicochemical properties, except for the BI, WI, color values, firmness, and TA, which are related and correlated to microbial growth parameters such as the TVC and CC. VOCs were identified in fresh-cut apples at 15 °C, 8 °C, and 4 °C, including methanol, methanethiol, ethyl acetate, s(-)2-methyl-1-butanol, propyl propanoate, ethyl isovalerate, 1-hexanol, acetaldehyde, ethyl butyrate, and limonene. In detail, these identified VOCs that are found in fresh-cut apples can indicate an apple fruit's aroma (propyl propanoate and ethyl isovalerate), freshness (hexanol), or an unpleasant off-odor (methanethiol and ethyl acetate). In the food industry, methanethiol and ethyl acetate can be used to monitor the quality of fresh-cut apples during storage as markers for deterioration. Furthermore, an electronic nose can potentially be used as a fast analysis instrument for product and external contributor identification in food products. The simultaneous application of AA followed by cold storage (at 4 °C) after packaging can

potentially be used to prolong the fresh-cut apple shelf life. These data may increase the reliability of quality enhancement and food safety of fresh-cut apples from production to storage and improve the sustainability of the products in the market via rising economic competitiveness.

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References

1. Dar, A.H.; Bashir, O.; Khan, S.; Wahid, A.; Makroo, H.A. Fresh-Cut Products: Processing Operations and Equipments. In *Fresh-Cut Fruits and Vegetables*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 77–97, ISBN 978-0-12-816184-5.
2. Perinban, S.; Orsat, V.; Raghavan, V. Influence of Plasma Activated Water Treatment on Enzyme Activity and Quality of Fresh-Cut Apples. *Food Chem.* **2022**, *393*, 133421. [CrossRef]
3. Mahajan, P.V.; Caleb, O.J.; Gil, M.I.; Izumi, H.; Colelli, G.; Watkins, C.B.; Zude, M. Quality and Safety of Fresh Horticultural Commodities: Recent Advances and Future Perspectives. *Food Packag. Shelf Life* **2017**, *14*, 2–11. [CrossRef]
4. He, Q.; Luo, Y. Enzymatic Browning and Its Control in Fresh-Cut Produce. *Stewart Postharvest Rev.* **2007**, *3*, 1–7. [CrossRef]
5. Cortellino, G.; Gobbi, S.; Bianchi, G.; Rizzolo, A. Modified Atmosphere Packaging for Shelf Life Extension of Fresh-Cut Apples. *Trends Food Sci. Technol.* **2015**, *46*, 320–330. [CrossRef]
6. Özdemir, K.S.; Gökmen, V. Effect of Chitosan-Ascorbic Acid Coatings on the Refrigerated Storage Stability of Fresh-Cut Apples. *Coatings* **2019**, *9*, 503. [CrossRef]
7. Dellarosa, N.; Tappi, S.; Ragni, L.; Laghi, L.; Rocculi, P.; Dalla Rosa, M. Metabolic Response of Fresh-Cut Apples Induced by Pulsed Electric Fields. *Innov. Food Sci. Emerg. Technol.* **2016**, *38*, 356–364. [CrossRef]
8. Plesoianu, A.M.; Nour, V.; Tutulescu, F.; Ionica, M.E. Quality of Fresh-Cut Apples as Affected by Dip Wash Treatments with Organic Acids and Acidic Electrolyzed Water. *Food Sci. Technol.* **2022**, *42*, e62620. [CrossRef]
9. Wen, Y.; Liang, Y.; Chai, W.; Wei, Q.; Yu, Z.; Wang, L. Effect of Ascorbic Acid on Tyrosinase and Its Anti-browning Activity in Fresh-cut Fuji Apple. *J. Food Biochem.* **2021**, *45*, e13995. [CrossRef]
10. Tappi, S.; Velickova, E.; Mannozzi, C.; Tylewicz, U.; Laghi, L.; Rocculi, P. Multi-Analytical Approach to Study Fresh-Cut Apples Vacuum Impregnated with Different Solutions. *Foods* **2022**, *11*, 488. [CrossRef]
11. Chen, L.; Pan, Y.; Jia, X.; Wang, X.; Yuan, J.; Li, X. Constant Storage Temperature Delays Firmness Decreasing and Pectin Solubilization of Apple during Post-harvest Storage. *J. Food Process. Preserv.* **2021**, *45*, e15655. [CrossRef]
12. Guarrasi, V. Monitoring the Shelf-Life of Minimally Processed Fresh-Cut Apple Slices by Physical Chemical Analysis and Electronic Nose. *Agrotechnology* **2014**, *3*, 126. [CrossRef]
13. Lin, M.; Chen, J.; Wu, D.; Chen, K. Volatile Profile and Biosynthesis of Post-Harvest Apples Are Affected by the Mechanical Damage. *J. Agric. Food Chem.* **2021**, *69*, 9716–9724. [CrossRef] [PubMed]
14. Schmidt, S.F.P.; Schultz, E.E.; Ludwig, V.; Berghetti, M.R.P.; Thewes, F.R.; Anese, R.D.O.; Both, V.; Brackmann, A. Volatile Compounds and Overall Quality of 'Braeburn' Apples after Long-Term Storage: Interaction of Innovative Storage Technologies and 1-MCP Treatment. *Sci. Hortic.* **2020**, *262*, 109039. [CrossRef]
15. Echeverría, G.; Fuentes, T.; Graell, J.; Lara, I.; López, M.L. Aroma Volatile Compounds of 'Fuji' Apples in Relation to Harvest Date and Cold Storage Technology. *Postharvest Biol. Technol.* **2004**, *32*, 29–44. [CrossRef]
16. Wu, X.; Bi, J.; Fauconnier, M.-L. Characteristic Volatiles and Cultivar Classification in 35 Apple Varieties: A Case Study of Two Harvest Years. *Foods* **2022**, *11*, 690. [CrossRef] [PubMed]
17. Loutfi, A.; Coradeschi, S.; Mani, G.K.; Shankar, P.; Rayappan, J.B.B. Electronic Noses for Food Quality: A Review. *J. Food Eng.* **2015**, *144*, 103–111. [CrossRef]

18. Laksana, A.J.; Choi, Y.-M.; Kim, J.-H.; Kim, B.-S.; Kim, J.-Y. Real-Time Monitoring the Effects of Storage Conditions on Volatile Compounds and Quality Indexes of Halal-Certified Kimchi during Distribution Using Electronic Nose. *Foods* **2022**, *11*, 2323. [CrossRef]
19. Palou, E.; Lopez-Malo, A.; Barbosa-Canovas, G.V.; Welti-Chanes, J.; Swanson, B.G. Polyphenoloxidase Activity and Color of Blanched and High Hydrostatic Pressure Treated Banana Puree. *J. Food Sci.* **1999**, *64*, 42–45. [CrossRef]
20. Zha, Z.; Tang, R.; Wang, C.; Li, Y.; Liu, S.; Wang, L.; Wang, K. Riboflavin Inhibits Browning of Fresh-Cut Apples by Repressing Phenolic Metabolism and Enhancing Antioxidant System. *Postharvest Biol. Technol.* **2022**, *187*, 111867. [CrossRef]
21. Yimenu, S.M.; Kim, J.Y.; Kim, B.S. Prediction of Egg Freshness during Storage Using Electronic Nose. *Poult. Sci.* **2017**, *96*, 3733–3746. [CrossRef]
22. Yang, H.; Cheng, S.; Lin, R.; Wang, S.; Wang, H.; Wang, H.; Tan, M. Investigation on Moisture Migration, Microstructure and Quality Changes of Fresh-cut Apple during Storage. *Int. J. Food Sci. Tech.* **2021**, *56*, 293–301. [CrossRef]
23. Wu, Z.S.; Zhang, M.; Wang, S. Effects of High Pressure Argon Treatments on the Quality of Fresh-Cut Apples at Cold Storage. *Food Control* **2012**, *23*, 120–127. [CrossRef]
24. Rocha, A.M.C.N.; Morais, A.M.M.B. Shelf Life of Minimally Processed Apple (Cv. Jonagored) Determined by Colour Changes. *Food Control* **2003**, *14*, 13–20. [CrossRef]
25. Osuga, R.; Koide, S.; Sakurai, M.; Orikasa, T.; Uemura, M. Quality and Microbial Evaluation of Fresh-Cut Apples during 10 Days of Supercooled Storage. *Food Control* **2021**, *126*, 108014. [CrossRef]
26. Liu, X.; Ren, J.; Zhu, Y.; Han, W.; Xuan, H.; Ge, L. The Preservation Effect of Ascorbic Acid and Calcium Chloride Modified Chitosan Coating on Fresh-Cut Apples at Room Temperature. *Colloids Surf. A Physicochem. Eng. Asp.* **2016**, *502*, 102–106. [CrossRef]
27. Ayón-Reyna, L.E.; Ayón-Reyna, L.G.; López-López, M.E.; López-Angulo, G.; Pineda-Hidalgo, K.V.; Zazueta-Niebla, J.A.; Vega-García, M.O. Changes in Ascorbic Acid and Total Phenolics Contents Associated with Browning Inhibition of Pineapple Slices. *Food Sci. Technol.* **2019**, *39*, 531–537. [CrossRef]
28. Dumitru Velești, I.; Nicoleta Rațu, R.; Arsenoaia, V.-N.; Roșca, R.; Marian Cârlescu, P.; Țenu, I. Research on the Process of Convective Drying of Apples and Apricots Using an Original Drying Installation. *Agriculture* **2023**, *13*, 820. [CrossRef]
29. Perez-Gago, M.B.; Serra, M.; Río, M.A.D. Color Change of Fresh-Cut Apples Coated with Whey Protein Concentrate-Based Edible Coatings. *Postharvest Biol. Technol.* **2006**, *39*, 84–92. [CrossRef]
30. Horison, R.; Sulaiman, F.O.; Alfredo, D.; Wardana, A.A. Browning Inhibition of Fresh-Cut Apple by Coating Carrageenan/Ascorbic Acid/ZnO Nanoparticles. *Food Res.* **2022**, *6*, 368–373. [CrossRef]
31. Joshi, A.P.K.; Rupasinghe, H.P.V.; Pitts, N.L.; Khanizadeh, S. Biochemical Characterization of Enzymatic Browning in Selected Apple Genotypes. *Can. J. Plant Sci.* **2007**, *87*, 1067–1074. [CrossRef]
32. Ornelas-Paz, J.D.J.; Quintana-Gallegos, B.M.; Escalante-Minakata, P.; Reyes-Hernández, J.; Pérez-Martínez, J.D.; Rios-Velasco, C.; Ruiz-Cruz, S. Relationship between the Firmness of Golden Delicious Apples and the Physicochemical Characteristics of the Fruits and Their Pectin during Development and Ripening. *J. Food Sci. Technol.* **2018**, *55*, 33–41. [CrossRef]
33. Matabura, V.V. Modelling of Firmness Variability of Jonagold Apple during Postharvest Storage. *J. Food Sci. Technol.* **2022**, *59*, 1487–1498. [CrossRef]
34. Sila, D.; Duvetter, T.; De Roeck, A.; Verlent, I.; Smout, C.; Van Loey, A. Texture Changes of Processed Plant Based Foods: Potential Role of Novel Technologies. *Trends Food Sci. Technol.* **2007**, *19*, 309–319. [CrossRef]
35. James, B.; Fonseca, C. Texture studies and compression behaviour of apple flesh. *Int. J. Mod. Phys. B* **2006**, *20*, 3993–3998. [CrossRef]
36. Salvatori, D.; Andrés, A.; Albors, A.; Chiralt, A.; Fito, P. Structural and Compositional Profiles in Osmotically Dehydrated Apple. *J. Food Sci.* **1998**, *63*, 606–610. [CrossRef]
37. Garcia, L.; Henderson, J.; Fabri, M.; Oke, M. Potential Sources of Microbial Contamination in Unpasteurized Apple Cider. *J. Food Prot.* **2006**, *69*, 137–144. [CrossRef]
38. Lang, M.M.; Ingham, S.C.; Ingham, B.H. Verifying Apple Cider Plant Sanitation and Hazard Analysis Critical Control Point Programs: Choice of Indicator Bacteria and Testing Methods. *J. Food Prot.* **1999**, *62*, 887–893. [CrossRef] [PubMed]
39. Quiles, A.; Hernando, I.; Pérez-Munuera, I.; Lluch, M.Á. Effect of Calcium Propionate on the Microstructure and Pectin Methylesterase Activity in the Parenchyma of Fresh-cut Fuji Apples. *J. Sci. Food Agric.* **2007**, *87*, 511–519. [CrossRef]
40. Chiabrando, V.; Giacalone, G. Effect of Chitosan and Sodium Alginate Edible Coatings on the Postharvest Quality of Fresh-Cut Nectarines during Storage. *Fruits* **2016**, *71*, 79–85. [CrossRef]
41. Andrés, S.C.; Giannuzzi, L.; Zaritzky, N.E. The Effect of Temperature on Microbial Growth in Apple Cubes Packed in Film and Preserved by Use of Orange Juice. *Int. J. Food Sci. Tech.* **2004**, *39*, 927–933. [CrossRef]
42. Ndraha, N.; Hsiao, H.-I.; Vlajic, J.; Yang, M.-F.; Lin, H.-T.V. Time-Temperature Abuse in the Food Cold Chain: Review of Issues, Challenges, and Recommendations. *Food Control* **2018**, *89*, 12–21. [CrossRef]
43. Coorey, R.; Ng, D.S.H.; Jayamanne, V.S.; Buys, E.M.; Munyard, S.; Mousley, C.J.; Njage, P.M.K.; Dykes, G.A. The Impact of Cooling Rate on the Safety of Food Products as Affected by Food Containers. *Comp. Rev. Food Sci. Food Safe* **2018**, *17*, 827–840. [CrossRef]
44. Li, R.; Shi, J.; Li, C.; Ren, X.; Tao, Y.; Ma, F.; Liu, Z.; Liu, C. Characterization of the Key Odorant Compounds in 'Qinguan' Apples (*Malus* × *Domestica*). *LWT* **2023**, *184*, 115052. [CrossRef]

45. Spaho, N.; Gaši, F.; Leitner, E.; Blesić, M.; Akagić, A.; Žuljević, S.O.; Kurtović, M.; Ratković, D.Đ.; Murtić, M.S.; Akšić, M.F.; et al. Characterization of Volatile Compounds and Flavor in Spirits of Old Apple and Pear Cultivars from the Balkan Region. *Foods* **2021**, *10*, 1258. [CrossRef] [PubMed]
46. Nikfar, S.; Behboudi, A.F. Limonene. In *Encyclopedia of Toxicology*; Elsevier: Amsterdam, The Netherlands, 2014; pp. 78–82, ISBN 978-0-12-386455-0.
47. Wright, A.H.; Delong, J.M.; Arul, J.; Prange, R.K. The Trend toward Lower Oxygen Levels during Apple (*Malus* × *Domestica* Borkh) Storage. *J. Hortic. Sci. Biotechnol.* **2015**, *90*, 1–13. [CrossRef]
48. Kader, A.A. Flavor Quality of Fruits and Vegetables. *J. Sci. Food Agric.* **2008**, *88*, 1863–1868. [CrossRef]
49. Hahs-Vaughn, D.L. Foundational Methods: Descriptive Statistics: Bivariate and Multivariate Data (Correlations, Associations). In *International Encyclopedia of Education*, 4th ed.; Elsevier: Amsterdam, The Netherlands, 2023; pp. 734–750, ISBN 978-0-12-818629-9.
50. Zhao, Q.; Tang, S.; Fang, X.; Wang, Z.; Jiang, Y.; Guo, X.; Zhu, J.; Zhang, Y. The Effect of Lactiplantibacillus Plantarum BX62 Alone or in Combination with Chitosan on the Qualitative Characteristics of Fresh-Cut Apples during Cold Storage. *Microorganisms* **2021**, *9*, 2404. [CrossRef]
51. Forney, C.F.; Hildebrand, P.D.; Saltveit, M.E. Production of methanethiol by anaerobic broccoli and microorganisms. *Acta Hortic.* **1993**, *343*, 100–104. [CrossRef]
52. Wang, K.; Ke, S.; Fang, W.; Liu, F.; Zhang, Z. Agroactive Volatile Organic Compounds from Microbes: Chemical Diversities and Potentials of Application in Crop Protection. *Adv. Agrochem.* **2023**, *2*, 39–57. [CrossRef]
53. Zhang, S.; Guo, F.; Yan, W.; Dong, W.; Zhou, J.; Zhang, W.; Xin, F.; Jiang, M. Perspectives for the Microbial Production of Ethyl Acetate. *Appl. Microbiol. Biotechnol.* **2020**, *104*, 7239–7245. [CrossRef]

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