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Impact of Different Rootstocks on Antioxidant Properties and Volatile Profile of Honeydew Melons (*Cucumis melo* L.) during Postharvest Storage

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Abstract: Two rootstock hybrids of sweet melons and watermelons ("Kickstart" and "Carnivor" *Cucurbita moschata* × *Cucurbita maxima*) grafted onto two watermelon cultivars (scions), "Honeygoal" and "Honeyval", were examined in this study to determine whether functional compounds, antioxidant properties, and volatile compounds were retained after five days of cold storage at 5 °C and 85% RH following harvest. An interaction exists between cultivars, rootstocks, and storage for total phenolic content, ascorbic acid, chlorophyll content, antioxidant activities, and volatile compounds. Generally, all functional compounds and antioxidant properties decreased during storage; however, "Honeygoal/Carnivor" in cold storage for 7 days retained the total phenols, ascorbic acid, chlorophyl contents, DPPH (15.47 IC_{50} mg/mL), ABTS (1.06 IC_{50} mg/mL) scavenging activities, and antioxidant power (IC_{50} mg/mL) higher than ungrafted, "Honeyval" or "Honeygoal/Kickstart", "Honeyval/Carnivor" or "Honeyval/Kickstart" melons. The heat map showed a higher abundance of volatile compounds in "Honeygoal/Carnivor" and "Honeyval/Carnivor" melons stored for 7 and 14 days while "Honeygoal/Kickstart" or "Honeyval/Kickstart" requires 14 days of storage. "Honeygoal/Carnivor" and "Honeyval/Carnivor" melons stored for up to 7 days in cold storage were preferred by panelists. Hence, grafting "Honeygoal" melons onto "Carnivor" rootstocks helped to improve the functional compounds, antioxidant properties, and volatiles during storage for 7 days after harvest.

Keywords: *Cucumis melo*; grafting; antioxidant activity; volatile compounds; organoleptic quality

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1. Introduction

Cucumis melo L., (melon), a member of the Cucurbitaceae family, is a fruit that is widely produced throughout the world. Melon is full of fiber, vitamins A and C, folic acid, and phytochemicals, which are all beneficial to health [1]. The World Health Organization (WHO) recommends consuming at least 400 g of fruits and vegetables per day as a minimum standard [2]. Honeydew melons (*Cucumis melo* L.) with green flesh exhibit slower softening, non-climacteric respiration, reduced aromatic compounds, and a longer shelf life [3].

Cucurbita family crops could benefit from grafting since it increases output, quality, intrinsic nutritional values, and shelf life of the fruit in addition to helping with pest management [4]. Grafting could lower the nutritional content of fruits, although the fruit size is frequently unaffected. The scion-rootstock combination might influence the quality characteristics of fruits depending on their compatibility [5]. However, grafting to specific rootstocks has been linked to potential disadvantages in flavor compounds, texture, and fruit size [6].The effect of grafting's have also been ascribed to an increase in the firmness of fruit flesh and extension of shelf life [7]. Therefore, the effect of grafting on the storage and shelf-life performances of melon fruits has gained importance.

Melons are often regarded as having good internal quality if their soluble solid content (SSC) value is between 9 and 10.99 percent or above [8]. Melons should be harvested at the proper stage of ripening [9], as the last stage (10 days before harvest) coincides with a sharp fall in acid levels and a large increase in sugar content. Fruit color, texture, flavor (including increased sugar content and decreased organic acid content), and aroma are all indicators of fruit quality [10]. According to Ramirez et al. [11], consumers' preferences for melons were strongly influenced by texture as well as flavor. To boost the marketability of melons, several breeding programs have prioritized increasing shelf-life potential at the cost of flavor contents [12]. On the other hand, customers stated that melons with a longer shelf life had poorer fruit quality, which led to low approval ratings [13]. A fruit's flavor is a complex combination of taste, aroma, and chemical sense perceptions that include both non-volatile (such as sugars and acids) and volatile substances produced by the fruit [14]. The ester compounds found in melons are particularly important in determining consumers' preferences, making improved fruit volatiles one of the most important breeding objectives. However, volatiles such as aldehydes, alcohols, and esters are degraded by senescence [15].

In our previous study, we examined the quality, phytonutrient composition, and volatile compounds of two rootstock hybrids of sweet melon and watermelon (*Cucurbita moschata* x *Cucurbita maxima*), "Kickstart" and "Carnivor," grafted onto four melon cultivars (cantaloupes; "Majestic" and "Hunter") and (Honeydew; "Honeygoal," and "Honeyval") [16]. Both "Kickstart" and "Carnivor" are rootstock crosses of sweet melon and watermelon (*Cucurbita maxima* and *Cucurbita moschata*). The "Carnivor" rootstock is known for its cold tolerance, ability to set fruit, and ability to produce heavier fruit [16]. Unlike Kickstart, which has stronger roots, matures earlier, and produces high-quality fruit [16]. Melons undergo grafting to handle stress factors such as soil-borne diseases such as Fusarium wilt, drought, and extreme temperatures and to increase plant productivity. However, there is less focus on the retention of nutraceutical properties of melons after postharvest storage. Higher demand for superior fresh produce requires a choice of rootstock-scion combinations that yield quality fruit with a long shelf life. Therefore, the purpose of the grafting program is to produce high-quality melon varieties that have nutraceutical properties and desirable volatile compounds after postharvest storage. Thus, the objective of this study was to see the influence of two rootstock hybrids of sweet and watermelon ("Kickstart" and "Carnivor") grafted onto two honeydew melon cultivars ("Honeygoal" and "Honeyval") in comparison to the un-grafted controls on quality, antioxidant properties, and volatile compounds after postharvest storage at 5 °C, 85% RH for 7 and 14 days.

2. Materials and Methods

Merck (Pty) Ltd., Westfield, Letthabong, South Africa, supplied all the chemicals used in the study.

2.1. Melon Fruits and Postharvest Storage

As described by Lecholocholo et al. [16], "Honeygoal" (control), "Honeyval" (control), "Honeyval/Carnivor", "Honeyval/Kickstart", "Honeygoal/Carnivor", and "Honeygoal/Kickstart" were harvested when the skin had turned from a creamy to white color under the non-temperature-controlled plastic tunnel at the Hygrotech experimental farm, Dewageningsdrift, Pretoria, South Africa. The geographical location of the experimental farm was 25.4580° S, 28.6411° E, and altitude 1214 m and fruits were harvested during summer (October to February) between 2020 and 2021 growing seasons [16]. The experiment was designed as a randomized complete block design with four replications. Each experimental unit consisted of ten plants with 2.5 plants per m^2.

The drip irrigation, fertilizer application, and pest control were implemented as described by Lecholocholo et al. [16]. Fruits were handpicked with pruning shears in the early morning hours and within 3 h of harvesting, and were transported into the laboratory at a holding temperature of 15 °C. Melons were then washed, disinfected for 3 min with

99.88 mg L^{-1} chlorine, and blotted with sterile paper towels. The study consisted of ten replicate boxes per treatment, each box providing five fruits. Afterwards, five fruits were packed into corrugated cardboard boxes (500 mm × 400 mm × 190 mm). The melons were stored at 5 °C and 90% RH for 7 and 14 days and kept for one day at room temperature (20 °C). Physicochemical properties, volatile profiles, and descriptive sensory analyses of melons were assessed at harvest (after one day at 20 °C) and at the end of storage for 7 and 14 days.

2.2. Melon Sample Preparation

Melons were cleaned in tap water and blot dry with sterile paper towel [16,17]. The fruits were peeled with a knife, the blossom and stem end of the fruits 2–3 cm) were cut. The fruit was then cut longitudinally, and the placental tissue and seeds were removed from each half and afterwards each half was cut into five slices.

2.3. Total Phenol Content

The Folin–Ciocalteu assay method as described by Managa et al. [18] was used to determine the total phenolic content in melons after juicing by crushing in a mortar and pestle. Aliquot (200 µL) of samples were homogenized in 10-fold diluted Folin–Ciocalteu reagent (1000 µL). A 7.5% of Na_2CO_3 solution was added to individual mixture of sample and Folin–Ciocalteu reagent and was incubated for 2 h. The spectrophotometer (SPECTROstar Nano; BMG LABTECH, Ortenberg, Germany) was used to measure the absorbance of the sample at 750 nm and a distilled water as the blank. The TPC concentration in melons were expressed in mg 100 mL−1 of samples and was calculated from a calibration curve generated with 1 µM gallic acid.

2.4. Ascorbic Acid Content

Ascorbic acid content was determined in melon juice obtained from ten longitudinal pieces of each replicate according to Mampholo et al. [19] using the 2,6-dichlorophenolindophenol titration method. The ascorbic acid content was quantified as mg of ascorbic acid per 100 g of melons.

2.5. Total Chlorophyl Content

The chlorophyll content of a melon samples was determined using the method described by Mampholo et al. [19]. Melon fresh cut samples (0.2 g) were macerated in 1 mL of 96% methanol and was transferred to a 96-well multi-titre plate. The multiplate reader was used to measure the chlorophyll content (chlorophyll a and chlorophyll b) at 663, 645, and 470 nm wavelengths. Results were reported as mg per 100 g of fresh weight melons.

2.6. Antioxidant Scavenging Activities

According to Phahlane et al. [20], the DPPH radical scavenging capacity of melon was measured by mixing 0.1 g of sample with 1 mL of 80% methanol, centrifuging at 3000× *g*, at 4 °C for 5 min. Serial dilutions of filtered supernatant, ranging from 0–10 mg mL^{-1}, were performed and 100 µL of sample from each concentration was combined with 200 µL of DPPH solution. A 96-well multiplate reader (BMG LABTECH, SpectroStar Nano, Ortenberg, Germany) was used at 25 °C to measure the color change at 517 nm and to calculate the inhibition percentage. The IC_{50} (mg mL^{-1}) of DPPH activities was calculated from the inhibition percentage versus concentration graph.

The radical scavenging capacity of ABTS was measured as described by Phahlane et al. [20]. A 420 mM ABTS stock solution was incubated for 12–16 h at 25 °C and allowed to react with 4.9 mM potassium persulfate at a ratio of 1:1 to produce the radical cation (ABTS+). Afterwards, 40 µL of the sample (different concentrations between 0 and 10 mg mL^{-1}) was pipetted into 200 µL of ABTS+. The decrease in absorption at 734 nm was measured after incubating at 37 °C for 10 min in a 96-well microtiter plate kept under the darkness. Based on the graph of inhibition percentage versus concentration, the IC50 (mg mL^{-1}) was determined. The ferric reducing

antioxidant potential (FRAP) assay following a method described by Phahlane et al. [20] was used. The FRAP solution contained 10 mL of 0.3 acetate buffer (pH 3.6), 1 mL of 10 mM 2,4,6-tris(2-pyridyl)-s-triazine (TPTZ) solution in 40 mM HCl (previously prepared), and 1 mL of 20 mM ferric chloride solution ($FeCl_3$ $6H_2O$). FRAP solution (150 µL) was combined with 20 µL of sample extract and incubated for 10 min. Thereafter, the absorbance was measured at 593 nm. Trolox was used as a standard for calibration. The antioxidant capacity (FRAP assay) was calculated as Trolox-equivalent antioxidant capacity (mM TEAC g^{-1}).

2.7. Volatile Compounds

Extraction of the volatile organic compounds (VOCs) was based on the method described by Lecholocholo et al. [16]. Melon sample (10 g) was juiced and 50 mL of butylated hydroxytoluene (1 mg mL) and sodium chloride (1 g) was added. After extraction of volatile organic compounds with n-hexane (2 mL) at 25 °C, the mixture was sonicated for 30 min at 300 °C (MRC Ultrasonic cleaner, Model DC-150H, Health Care Technologies, Cape Town, South Africa). Thereafter centrifugation was done for 10 min at 3420× *g* (Model Z326K, HermleLabortechnik, Wehingen, Germany), and the supernatant was collected. As previously described, the residue was rinsed three times in hexane and centrifuged. To prepare the samples for analysis, the supernatants were pooled, dried with sodium sulphate, filtered with a Whatman 1 filter paper, concentrated using stream of nitrogen gas, and stored at 50 °C. To analyze the volatile compounds in the melon samples, a gas chromatograph (Agilent, Santa Clara, CA, USA) combined with an Agilent 5975 C MSD with a Triple axis detector was utilized. The gas chromatograph setup, column conditions and the injection volume were similar to those described by Lecholocholo et al. [16]. Using pentadecane, pentanal, 1-octene, and methyl heptadecanoate as reference standards, VOCs were identified and quantified relative to C8-C22 n-alkanes by comparing with reference spectra available from the mass spectral library (NIST08). The standard curves, regression coefficients (R^2) generated, and CAS numbers are given in Supplementary Table S1A,B.

2.8. Sensory Analysis

Methods described by Farcuh et al. [12] and Lecholocholo et al. [16] were used to assess the sensory qualities of melons using 10 trained panelists. The sensory analysis involved male and female trained panellists, aged 25–50, and the sensory descriptors for the melon samples was as described by Lecholocholo et al. [16]. A scale of 0 to 15 cm rule was used with the exception of the color attributes, which ranged from pale to irregular. Panellists were presented with coded samples in replicates and in an unorganized manner. During this sensory evaluation, samples were served under white fluorescent light at 25 °C in booths with time intervals between individual treatments. To prevent misjudging from flavor interference, panelists were asked to rinse their mouths with water and provided plain crackers [16].

2.9. Statistical Analysis

Data analysis was performed using StataSoft, version 10. Three-way ANOVA was conducted to determine the interactions between cultivars × rootstocks × storage time for physicochemical parameters, antioxidant constituents and activity, and volatile compounds. MetaboAnalyst software was used to run principal component analysis (PCA), and heat maps to understand the relationship between rootstocks and fruit volatile composition.

3. Results and Discussion

3.1. Changes in Antioxidants in Grafted and Non-Grafted Honeydew Melons during Postharvest Storage

Table 1 shows the changes in total phenol, ascorbic acid, and total chlorophyll during postharvest storage in grafted and un-grafted honeydew melons. The results of this study indicate there is an interaction between cultivars, rootstocks, and storage of melons in terms of the total phenols, ascorbic acid, and chlorophyll content.

Table 1. Changes in total phenol, ascorbic acid and total chlorophyll of grafted and un-grafted honeydew melon cultivars during postharvest storage.

	TPC (mg/100 g)	% Loss (−)	AA (mg/100 g)	% Loss (−)	Total Chlorophyll (mg/mL)	% Loss (−)
Honeygoal × 0 d	24.14 ± 0.36 ^{i}		17.52 ± 1.15 ^{e}		1.94 ± 0.56 ^{d}	
Honeygoal × 7 d	19.41 ± 0.63 ^{j}	−19.6 ± 0.42 ^{d}	12.11 ± 0.78 ^{g}	−30.87 ± 1.08 ^{c}	1.47 ± 1.62 ^{f}	−24.22 ± 0.09 ^{f}
Honeygoal × 14 d	15.51 ± 0.85 ^{k}	−35.74 ± 0.86 ^{b}	9.20 ± 0.83 ^{h}	−47.48 ± 0.72 ^{a}	1.47 ± 1.62 ^{f}	−24.22 ± 0.62 ^{f}
Honeygoal/Carnivor × 0 d	32.04 ± 1.47 ^{a}		20.34 ± 1.05 ^{b}		3.31 ± 0.59 ^{a}	
Honeygoal/Carnivor × 7 d	30.97 ± 0.66 ^{b}	−3.33 ± 0.94 ^{i}	19.71 ± 0.61 ^{b}	−3.09 ± 1.23 ^{j}	3.11 ± 0.48 ^{b}	−6.04 ± 0.88 ^{i}
Honeygoal/Carnivor × 14 d	30.01 ± 0.32 ^{d}	−6.33 ± 1.08 ^{f}	19.08 ± 1.49 ^{c}	−6.19 ± 1.09 ^{i}	2.35 ± 1.26 ^{c}	−29.00 ± 0.94 ^{e}
Honeygoal/Kickstart × 0 d	30.38 ± 0.47 ^{c}		19.73 ± 0.69 ^{b}		2.23 ± 0.74 ^{c}	
Honeygoal/Kickstart × 7 d	28.32 ± 0.72 ^{f}	−6.78 ± 0.43 ^{f}	15.94 ± 0.52 ^{e}	−19.20 ± 0.43 ^{f}	2.16 ± 1.22 ^{c}	−3.13 ± 0.15 ^{j}
Honeygoal/Kickstart × 14 d	26.16 ± 0.73 ^{h}	−13.89 ± 0.63 ^{e}	13.62 ± 0.64 ^{f}	−30.96 ± 0.81 ^{c}	1.39 ± 0.55 ^{f}	−37.66 ± 0.12 ^{c}
Honeyval × 0 d	27.33 ± 1.10 ^{g}		17.02 ± 1.21 ^{e}		1.74 ± 0.09 ^{e}	
Honeyval × 7 d	21.33 ± 0.73 ^{i}	−21.95 ± 0.94 ^{c}	12.09 ± 0.83 ^{g}	−28.97 ± 1.32 ^{d}	1.13 ± 1.21 ^{g}	−35.05 ± 0.94 ^{b}
Honeyval × 14 d	12.70 ± 0.74 ^{l}	−53.53 ± 1.32 ^{a}	9.43 ± 0.66 ^{h}	−44.59 ± 1.72 ^{b}	0.64 ± 1.45 ^{h}	−63.21 ± 1.72 ^{a}
Honeyval/Carnivor × 0 d	31.24 ± 0.34 ^{b}		22.93 ± 0.89 ^{a}		3.32 ± 1.22 ^{a}	
Honeyval/Carnivor × 7 d	31.44 ± 1.01 ^{b}	−1.29 ± 0.92 ^{k}	22.50 ± 0.16 ^{a}	−1.87 ± 1.44 ^{k}	3.06 ± 1.04 ^{b}	−7.83 ± 0.83 ^{h}
Honeyval/Carnivor × 14 d	29.94 ± 0.81 ^{d}	−3.54 ± 1.04 ^{h}	18.93 ± 0.73 ^{c}	−17.44 ± 1.09 ^{h}	2.33 ± 1.06 ^{c}	−29.81 ± 0.12 ^{e}
Honeyval/Kickstart × 0 d	31.16 ± 0.68 ^{b}		22.52 ± 1.04 ^{a}		2.03 ± 0.48 ^{d}	
Honeyval/Kickstart × 7 d	30.37 ± 0.96 ^{c}	−2.53 ± 0.43 ^{j}	18.25 ± 1.02 ^{d}	−18.96 ± 1.73 ^{g}	1.78 ± 0.92 ^{e}	−12.31 ± 0.91 ^{g}
Honeyval/Kickstart × 14 d	29.25 ± 0.36 ^{e}	−6.12 ± 0.68 ^{g}	16.48 ± 0.61 ^{e}	−26.82 ± 0.14 ^{e}	1.42 ± 0.74 ^{f}	−30.04 ± 1.21 ^{d}
Cultivar × Rootstock × storage time	0.36 *		0.63 *		0.16 *	

Values are mean ± standard deviation of nine replicates, and values followed by the same letter within the column are not significantly different * = $p \leq 0.05$, Fisher's LSD. Day 0 (0 d), Day 7 (7 d), and Day 14 (14 d). Total phenolic content (TPC); ascorbic acid (AA).

3.1.1. Total Phenols

At harvest, "Honeygoal/Carnivor" melons had the highest total phenolic content (32.04 mg/100 g) among honeydew cultivars. Although the total phenolic content decreased during cold storage, the "Honeygoal" and "Honeyval" melons grafted onto the rootstocks of "Carnivor", "Honeyval/Carnivor" (31.44 mg/100 g) and "Honeygoal/Carnivor" (30.97 mg/100 g) had the highest total phenolic content compared to "Honeygoal/Kickstart" and "Honeyval/Kickstart" melons and the un-grafted cultivars. Moreover, on day 14 of storage, "Honeygoal/Carnivor" (30.01 mg/100 g) and "Honeyval/Carnivor" (29.94 mg/100 g) melons had the highest concentrations of total phenols among the melons at day 14 of cold storage, compared to un-grafted honeydew cultivars. It was found that un-grafted "Honeygoal" and "Honeyval" melons stored for 7 and 14 days in cold storage retained significantly lower concentration of total phenols than those that had been grafted. The percent decrease in TPC was the lowest in "Honeyval/Carnivor" (−1.29%) and "Honeygoal/Carnivor" (−3.33%) stored for 7 days compared to the un-grafted and other grafted melons stored for 14 days. The reduction in total phenolic content in melons may be due to endogenous polyphenol oxidase reactions [21], especially on the 14th day of cold storage. The most abundant class of secondary metabolites in plants is the phenolic compounds and are responsible for the prevention of molecular damage in plants through their ability to inhibit the generation of reactive oxygen species [22]. Genetic and environmental factors (storage) affect the phenolic content in fruits [23] thus corroborating our observation of reduced TPC in honeydew melons after storage.

3.1.2. Ascorbic Acid Content

At harvest (0 days), the ascorbic acid (AA) concentrations in honeydew melons were highest in "Honeyval/Carnivor" (22.93 mg/100 g) and was not significantly different to "Honeyval/Kickstart" (22.52 mg/100 g) at harvest and "Honeyval/Carnivor" (22.50 mg/ 100 g) melons stored for 7 days ($p \geq 0.05$). However, at harvest "Honeyval/Carnivor" (22.93 mg/100 g) melon had higher ascorbic acid concentrations than "Honeygoal/Carnivor" melons (20.34 mg/100 g). Nevertheless, "Honeyval/Carnivor" melons on the 7th day of cold storage had similar ascorbic acid levels ($p > 0.05$) as melons harvested on day 0 and had the highest levels of ascorbic acid compared to other grafted and un-grafted cultivars. After day 7 of storage, "Honeygoal" or "Honeyval" melons grafted onto "Kickstart" rootstocks, "Honeygoal" and "Honeyval" (ungrafted melons)

lost 19.21%, 18.96%, 47.49%, and 44.59% of their AA concentrations, respectively, while "Honeygoal" and "Honeyval" grafted on the "Carnivor" rootstock showed less than 5% loss. In addition, grafted and un-grafted melons, and grafted "Honeygoal/Kickstart" and "Honeyval/Kickstart", showed significant decreases in ascorbic acid content with 14 days of cold storage compared to the "Honeygoal" or "Honeyval" grafted onto the "Carnivor" rootstock. The decrease in AA was 47.49%, 44.59%, 30.97%, and 26.65%, respectively, in ungrafted ("Honeygoal", "Honeyval"), and grafted ("Honeygoal/Kickstart" and "Honeyval/Kickstart"). Ascorbic acid concentrations in "Honeygoal" and "Honeyval" melons grafted onto "Carnivor" rootstock were 19.08 mg/100 g and 18.93 mg/100 g, respectively, after 14 days of cold storage, compared to freshly harvested (0 days) samples. Similar decline in ascorbic acid and total phenolic content have been reported in coated fresh-cut melons after storage [24]. It has been reported that ascorbic acid is the most susceptible to degradation during storage due to its inactive state or due to oxidation when exposed to prolonged time and temperature [25]. Food quality can be negatively affected by ascorbic acid degradation [26]. Furthermore, a higher ascorbic acid concentration in the grafted melons ("Honeygoal/Carnivor", "Honeyval/Carnivor", and "Honeyval/Kickstart") at harvest compared to un-grafted melons may be attributed to the effect of grafting that resulted in higher ascorbic acid retention. The observed higher ascorbic acid concentration could have been a consequence of the connection between scion and rootstock. Honeydews on Carnivor rootstock have an increased ascorbic acid concentration, which promotes a better flow of water and minerals, thus improving the photosynthetic process [27].

3.1.3. Total Chlorophyll Content

Compared to the un-grafted (controls) and "Honeyval" melons grafted onto "Kickstart" rootstock, "Honeygoal" and "Honeyval" melons grafted onto "Carnivor" rootstock had the highest chlorophyll content at harvest (0 days). Furthermore, on day 7 Honeygoal and Honeyval melons grafted onto Carnivor rootstock showed significant higher retention of chlorophyll content (3.11 mg/mL and 3.32 mg/mL respectively) compared to their un-grafted and grafted counterparts ("Honeygoal/Kickstart" and "Honeyval/Kickstart"). Despite a reduction in chlorophyll content with increased storage time, "Honeyval/Carnivor" and "Honeyval/Carnivor" retained a significantly higher chlorophyll content on day 14 than "Honeyval/Kickstart", "Honeygoal/Kickstart" and the un-grafted melons. High retention of chlorophyll content has been reported in chitosan-coated Bartlett pears after cold storage [28]. According to Ahlawat and Liu [29], low temperatures have a significant impact on slowing down the senescence of green vegetables. Changes in chlorophyll concentrations in chloroplasts, however, are indicative of senescence [30], typically occurring in green fruits or vegetables after harvest.

3.2. Changes in Antioxidant Activity of Grafted and Un-Grafted Honeydew Melons during Postharvest Storage

The changes in DPPH, ABTS scavenging activities, and antioxidant power in grafted and un-grafted honeydew melons during storage are shown in Table 2. An interaction exists between cultivars, rootstocks, and storage for DPPH, ABTS scavenging activities and antioxidant power. DPPH, ABTS scavenging activities, and antioxidant power (FRAP) were the highest in "Honeygoal/Carnivor" melons at harvest (0 days) compared to un-grafted and other grafted melons. The un-grafted "Honeyval" and "Honeygoal" stored for 14 days in cold storage displayed the lowest DPPH, ABTS scavenging activities and antioxidant power.

Table 2. Changes in antioxidant activities of grafted and un-grafted Honeydew melon cultivars during postharvest storage.

Cantaloupes	DPPH (IC_{50} mg/mL)	ABTS (IC_{50} mg/mL)	FRAP (μM TEAC/g)
Honeygoal × 0 d	17.37 ± 1.15 ^{g}	2.23 ± 0.39 ^{c}	2.59 ± 0.04 ^{f}
Honeygoal × 7 d	21.63 ± 0.06 ^{d}	2.94 ± 0.23 ^{b}	2.04 ± 0.04 ^{i}
Honeygoal × 14 d	28.87 ± 0.02 ^{a}	3.90 ± 0.62 ^{a}	1.22 ± 0.01 ^{k}
Honeygoal/Carnivor × 0 d	13.55 ± 0.57 ^{i}	0.94 ± 0.39 ^{h}	3.47 ± 0.15 ^{a}
Honeygoal/Carnivor × 7 d	15.47 ± 0.02 ^{h}	1.06 ± 0.22 ^{g}	3.22 ± 0.03 ^{c}
Honeygoal/Carnivor × 14 d	18.05 ± 0.01 ^{f}	1.15 ± 0.96 ^{f}	2.91 ± 0.03 ^{d}
Honeygoal/Kickstart × 0 d	13.84 ± 0.67 ^{i}	0.83 ± 0.50 ^{h}	2.72 ± 0.02 ^{e}
Honeygoal/Kickstart × 7 d	16.01 ± 0.08 ^{h}	1.01 ± 0.45 ^{g}	2.33 ± 0.06 ^{g}
Honeygoal/Kickstart × 14 d	18.41 ± 0.08 ^{f}	1.22 ± 0.33 ^{f}	2.02 ± 0.01 ^{i}
Honeyval × 0 d	18.70 ± 0.45 ^{e}	2.13 ± 0.51 ^{c}	2.76 ± 0.03 ^{e}
Honeyval × 7 d	22.87 ± 0.01 ^{c}	3.02 ± 0.40 ^{b}	1.74 ± 0.04 ^{j}
Honeyval × 14 d	28.42 ± 1.92 ^{a}	3.82 ± 0.61 ^{a}	1.13 ± 0.05 ^{l}
Honeyval/Carnivor × 0 d	16.54 ± 0.56 ^{h}	1.13 ± 0.40 ^{f}	3.30 ± 0.04 ^{b}
Honeyval/Carnivor × 7 d	18.42 ± 2.11 ^{f}	1.25 ± 0.62 ^{f}	3.01 ± 0.16 ^{d}
Honeyval/Carnivor × 14 d	22.22 ± 0.34 ^{c}	1.49 ± 0.50 ^{e}	2.35 ± 0.04 ^{g}
Honeyval/Kickstart × 0 d	16.62 ± 1.02 ^{h}	1.21 ± 0.46 ^{f}	3.20 ± 0.04 ^{c}
Honeyval/Kickstart × 7 d	19.12 ± 0.02 ^{e}	1.43 ± 0.74 ^{e}	2.75 ± 0.03 ^{e}
Honeyval/Kickstart × 14 d	23.46 ± 0.10 ^{b}	1.84 ± 0.50 ^{d}	2.22 ± 0.07 ^{h}
Cultivar × Rootstock × storage time	0.59 *	0.18 *	0.08 *

Values are mean ± standard deviation of 9 replicates, and values followed by the same letter within the column are not significantly different * = $p \leq 0.05$; Fisher's LSD. Day 0 (0 d); Day 7 (7 d); and Day 14 (14 d); 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity (DPPH); 2,2′-azinobis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS); Ferric reducing antioxidant power (FRAP); IC_{50}-Half maximal inhibitory concentration.

Consequently, "Honeygoal/Carnivor" melons stored for 7 days retained the highest DPPH (15.47 IC_{50} mg/mL), ABTS (1.06 IC_{50} mg/mL) scavenging activities and antioxidant power (IC_{50} mg/mL) than the un-grafted and "Honeyval/Kickstart" or "Honeygoal/Kickstart", "Honeyval/Carnivor" or "Honeyval/Kickstart" melon cultivars after cold storage for 7 days. However, among the grafted honeydew melons, "Honeygoal/Carnivor" melons had the highest DPPH, ABTS scavenging activities and antioxidant power after 7 or 14 days in cold storage. Hence, cultivar type, grafting and storage duration influenced the antioxidant activities of the melons similar to the assertion that the retention of antioxidant activity in melons is influenced by variation in cultivars [31]. Fruits and vegetables contain antioxidants such as phenolic compounds and ascorbic acids that have been associated with the bioactive functions such as the control of stress-related activities, including scavenging free radicals and acquiring resistance to pre-harvest factors and environments (cold storage). The decrease of antioxidant properties during cold storage can be attributed to the activity of polyphenol oxidase enzymes that oxidize the polyphenols to quinones [32] and also due to the degradation of ascorbic acid and carotenoids. Fruit storage decomposes ascorbic acid due to oxidation caused by enzymes and catalysts such as ascorbate oxidase, which could influence the observed low DPPH scavenging activities. Similar observation of a slight loss in antioxidant activity was reported in fresh watermelon cultivars; Giza, Mahdia, Local Sidi Bouzid and P P608 F1 stored at 5 °C for five days with a greater decrease in antioxidant activity after 10 days [31]. There was a relationship between rootstock type and antioxidant activity in peach fruit [32].

3.3. Volatile Compounds

Tables 3–5 provide information on changes in volatile compound concentrations during postharvest storage of un-grafted honeydew melons compared to grafted melons.

Based on a three-way ANOVA analysis, esters, alkanes, and aldehydes showed a significant interaction between honeydew melon cultivars and rootstocks. In all grafted cultivars, total volatile compounds increased after 7 and 14 days of storage. However, the most increase was observed after 14 days of storage in comparison to the un-grafted controls. Esters dominated the increased volatile compounds (Table 3). There was a greater concentration of volatile compounds (esters, alkanes, alkenes, ketones and aldehyde) in the grafted honeydew melons than in the un-grafted (controls). Nonane was not detected in un-grafted "Honeyval" melons at harvest and after storage for 7 and 14 days. "Honeygoal" melons stored for 14 days had the highest methyl-3- nonenoate (30.58 μg/g), ethyl hexanoate (38.51 μg/g), and methyl acetate (34.97 μg/g). On the other hand, "Honeyval" cultivar stored for 14 days had the highest hexyl acetate (68.32 μg/g), 2-methyl propyl acetate (42.52 μg/g), and propyl acetate (21.87 μg/g). Benzyl butanoate was highest in "Honeygoal/Carnivor" stored for 14 days (30.52 μg/g).

Nevertheless, alkanes, including hexadecane, decane, nonane, pentadecane, 2-methyl decane, and 2-methyl nonane were detected in all grafted honeydew melon cultivars (Table 4). The total alkane concentration was significantly increased after cold storage of grafted and un-grafted melon cultivars for 14 days ($p \leq 0.05$). In comparison to all other grafted melons and un-grafted controls, "Honeyval/Carnivor" had the highest concentration of hexadecane after cold storage for 7 (42.48 μg/g) or 14 days (42.37 μg/g) and were not significantly different to each other ($p \leq 0.05$). Moreover, "Honeygoal/Carnivor" melons stored for 7 days (8.56 μg/g) and 14 days (19.92 μg/g) had significantly high decane levels than their "Kickstart" grafted melons stored for respective 7 and 14 days and the un-grafted melons. Even though pentadecane concentration increased gradually over time during storage, "Honeygoal" un-grafted melons had the highest levels on day 14 (26.44 μg/g), followed by "Honeygoal/Carnivor" on days 7 and 14 (24.28 μg/g). "Honeygoal/Kickstart" melons at harvest (0 day) or stored for 7 or 14 days failed to show any significant increase in 2-methyl decane while it was highest in "Honeyval" melons (14.08 μg/g) at harvest. However, 2-methyl nonane improved during cold storage in grafted and un-grafted melons over time. Concentrations were highest in un-grafted "Honeyval" melons (65.83 μg/g), followed by "Honeyval/Kickstart" on day 14. The total alkane detected was highest in "Honeygoal/Carnivor" stored for 14 days (110 μg/g) and was not significantly different to "Honeygoal/Carnivor" stored for 7 days (94.79 μg/g), un-grafted "Honeyval" at harvest (98.58 μg/g), and "Honeyval/Kickstart" cultivar stored for 14 days (97.59 μg/g). The highest levels of 3-hydroxy-2-butanone (ketone), and 4,5 dimethyl -1-hexene (alkene) were found in stored un-grafted "Honeygoal" melons on day 14, followed by "Honeyval" on day 14 compared with other grafted melons (Table 5). Relative to other un-grafted and grafted melons, "Honeygoal/Carnivor" melons had the highest 4-methylundec-1-ene concentrations on day 14 (73.17 μg/g), followed by 7 (31.04 μg/g). Furthermore, cold stored "Honeygoal" melons at 14 days had the highest concentrations of 2-heptenal (12.76 μg/g), and benzaldehyde (25.03 μg/g) compared to the un-grafted "Honeygoal" and other grafted melons.

Increased storage time resulted in esters dominating the total volatile content [12] in all honeydew melon cultivars. Ethyl butanoate (35.39 μg/g), ethyl hexanoate (38.51 μg/g), propyl acetate (21.91 μg/g), and methyl-3- nonenoate (30.58 μg/g), were most abundant in "Honeygoal" melons stored for 14 days in comparison with harvest or 7 day samples, and other un-grafted and grafted melons. In contrast, "Honeyval" melons stored in cold storage for 14 days had the highest concentrations of hexyl acetate (68.32 μg/g), propyl acetate (21.87 μg/g), and methyl-3- nonenoate (42.52 μg/g), while "Honeygoal" grafted melons in cold storage for 7 and 14 days had the lowest levels of these compounds. Furthermore, "Honeygoal" melons grafted onto "Carnivor" rootstocks stored for 14 days at 5 °C displayed the highest concentrations of esters benzyl butanoate (27.37 μg/g), 2-ethyl hexyl acetate (39.85 μg/g), and total esters (262.3 μg/g) when compared to the other grafted and un-grafted melons stored for the same storage time.

Table 3. Changes in volatile compounds (Esters) of honeydew melon cultivars influenced by grafting and postharvest storage (μg/g).

Volatile compounds ([b] IUPAC Name)	Ethyl Butanoate	Ethyl Hexanoate	Hexyl Acetate	Methyl Acetate	Benzyl Butanoate	2-Ethyl hexyl Acetate	Propyl Acetate	Methyl-3-nonenoate	2-Methyl Propyl Acetate	Total Esters
[a] Calculated KI	799	1001	1007	523	1344	1160	712	1228	768	
Literature KI (DB-5)	800	1002	1008	522	1354	1159	713	1227	767	
Honeygoal × 0 d	2.42 ± 0.15 [i]	0.58 ± 0.35 [k]	8.96 ± 0.05 [n]	0.67 ± 0.29 [n]	3.49 ± 0.25 [h]	0.65 ± 0.44 [l]	3.66 ± 0.59 [k]	11.36 ± 1.08 [j]	4.96 ± 0.73 [m]	36.75
Honeygoal × 7 d	7.46 ± 0.30 [g]	33.04 ± 0.54 [b]	10.61 ± 0.10 [m]	7.59 ± 0.28 [h]	6.78 ± 0.73 [g]	4.98 ± 0.16 [i]	12.60 ± 1.09 [e]	18.83 ± 1.13 [i]	16.60 ± 0.99 [k]	118.49
Honeygoal × 14 d	35.39 ± 0.40 [a]	38.51 ± 0.79 [a]	21.58 ± 0.11 [g]	34.97 ± 1.69 [a]	8.56 ± 0.38 [f]	14.17 ± 0.07 [e]	21.91 ± 0.68 [a]	30.58 ± 0.57 [a]	29.62 ± 0.91 [b]	235.29
Honeygoal/Carnivor × 0 d	2.48 ± 0.33 [i]	13.78 ± 1.63 [e]	30.54 ± 0.58 [e]	21.97 ± 0.39 [d]	17.37 ± 0.46 [c]	24.21 ± 0.44 [c]	8.58 ± 0.52 [i]	24.66 ± 0.11 [e]	24.07 ± 1.31 [f]	167.66
Honeygoal/Carnivor × 7 d	4.38 ± 0.24 [h]	16.95 ± 0.52 [d]	44.19 ± 0.60 [c]	24.34 ± 0.83 [c]	27.37 ± 0.46 [b]	34.65 ± 1.00 [b]	10.05 ± 0.70 [g]	26.49 ± 0.75 [d]	26.92 ± 0.45 [d]	215.34
Honeygoal/Carnivor × 14 d	7.44 ± 0.39 [g]	29.15 ± 0.52 [c]	62.97 ± 1.68 [b]	25.02 ± 0.42 [c]	30.52 ± 0.18 [a]	39.85 ± 0.56 [a]	11.76 ± 0.46 [f]	27.55 ± 0.11 [c]	28.07 ± 0.54 [c]	262.33
Honeygoal/Kickstart × 0 d	0.37 ± 0.09 [k]	2.45 ± 0.26 [j]	14.54 ± 0.48 j	2.56 ± 0.29 [l]	11.04 ± 0.68 [e]	4.38 ± 0.36 [i]	6.47 ± 0.70 [j]	20.56 ± 0.76 [h]	21.26 ± 1.43 [j]	83.63
Honeygoal/Kickstart × 7 d	2.37 ± 0.09 [i]	7.80 ± 0.05 [g]	21.20 ± 0.12 [g]	4.38 ± 0.25 [j]	17.11 ± 0.45 [c]	9.15 ± 0.01 [h]	8.06 ± 0.49 [i]	22.39 ± 1.37 [g]	23.73 ± 0.54 [g]	116.19
Honeygoal/Kickstart × 14 d	7.37 ± 0.09 [g]	10.37 ± 0.29 [f]	28.85 ± 0.62 [f]	6.50 ± 0.31 [i]	15.44 ± 0.46 [d]	10.31 ± 0.44 [g]	10.42 ± 1.34 [g]	24.59 ± 0.53 [e]	26.44 ± 0.47 [d]	140.29
Honeyval × 0 d	1.09 ± 0.01 [j]	0.45 ± 0.33 [k]	8.65 ± 0.05 n	1.36 ± 0.05 [m]	ND	0.70 ± 0.14 [l]	2.58 ± 0.44 [l]	9.51 ± 0.45 [k]	8.37 ± 0.42 [l]	33.01
Honeyval × 7 d	4.48 ± 0.29 [h]	2.45 ± 0.33 [j]	42.28 ± 1.33 [d]	2.32 ± 0.20 [l]	ND	2.16 ± 0.32 [k]	10.87 ± 0.47 [g]	23.56 ± 2.27 [f]	30.20 ± 1.05 [b]	118.32
Honeyval × 14 d	26.46 ± 0.34 [b]	7.66 ± 0.28 [g]	68.32 ± 0.58 [a]	3.32 ± 0.20 [k]	ND	3.70 ± 0.33 [j]	21.87 ± 0.47 [a]	28.03 ± 0.76 [b]	42.52 ± 0.95 [a]	201.88
Honeyval/Carnivor × 0 d	8.40 ± 0.35 [f]	4.23 ± 0.20 [i]	10.38 ± 0.32 [m]	17.00 ± 0.54 [f]	ND	9.14 ± 0.25 [h]	7.99 ± 1.01 [i]	22.52 ± 1.05 [g]	22.44 ± 1.05 [i]	102.1
Honeyval/Carnivor × 7 d	11.28 ± 0.56 [d]	4.33 ± 0.19 [i]	13.52 ± 0.57 [j]	20.91 ± 0.03 [e]	ND	11.69 ± 1.02 [f]	9.62 ± 0.55 [h]	24.05 ± 1.02 [e]	25.19 ± 1.11 [e]	120.51
Honeyval/Carnivor × 14 d	14.38 ± 0.26 [c]	5.11 ± 0.31 [h]	16.60 ± 0.99 [i]	26.24 ± 0.61 [b]	ND	24.08 ± 1.23 [c]	11.36 ± 0.59 [f]	26.07 ± 0.36 [d]	27.99 ± 0.39 [c]	151.83
Honeyval/Kickstart × 0 d	4.22 ± 0.25 h	2.48 ± 0.19 [j]	11.65 ± 0.93 [l]	1.28 ± 0.18 [m]	ND	3.17 ± 0.55 [j]	15.36 ± 0.34 [d]	20.19 ± 0.34 [h]	20.96 ± 1.47 [j]	79.31
Honeyval/Kickstart × 7 d	8.80 ± 0.01 [f]	4.58 ± 0.30 [i]	12.93 ± 0.62 [k]	3.36 ± 0.29 l	ND	17.20 ± 1.22 [d]	16.96 ± 0.56 [c]	22.80 ± 0.82 [g]	23.28 ± 0.57 [h]	109.91
Honeyval/Kickstart × 14 d	9.44 ± 0.46 [e]	4.82 ± 0.07 [i]	19.36 ± 0.22 [h]	8.78 ± 0.23 [g]	ND	17.35 ± 0.99 [d]	19.38 ± 0.15 [b]	24.88 ± 0.56 [e]	25.32 ± 0.53 [e]	129.33
Cultivar × Rootstock × storage time	0.64 *	2.69 *	1.28 *	1.06 *	1.78 *	0.68 *	1.04 *	0.49 *	0.34 *	

Values are mean ± standard deviation of (n = 5) replicates, and values followed by the same alphabet letter within the column are not different at * = $p \leq 0.05$ Fisher's LSD. Day 0 (0 d), Day 7 (7 d), and Day 14 (14 d). [a] Calculated Kovats Indices on Zebron Guardian Capillary GC Column. [b] IUPAC, international union of pure and applied chemistry. All aroma descriptions were obtained from El Sayed. [33] and the NIST database http://www.nist.gov/index.html (accessed on 13 March 2022), Mahattanatawee, et al. [34].

Table 4. Changes in volatile compounds (alkanes) of honeydew melon cultivars influenced by grafting and postharvest storage (μg/g).

Volatile Compounds (IUPAC name)	Hexadecane	Decane	Nonane	Pentadecane	2-methyl Decane	2-methyl Nonane	Total Alkanes
Calculated (KI)	1601	1001	901	1499	1060	961	
Literature KI (DB-5)	1600	999	899	1500	1061	962	
Aroma description	Non-specific odor	Gasoline-like	Gasoline-like odor	Green citrus honey	Gasoline-like to odorles	Sharp	
Honeygoal × 0 d	1.25 ± 0.83 ^{i}	0.67 ± 0.29 ^{l}	0.7 ± 0.13 ^{e}	0.24 ± 0.31 ^{l}	0.24 ± 0.22 ^{k}	0.12 ± 0.21 ^{m}	3.22 ± 0.33 ^{e}
Honeygoal × 7 d	4.80 ± 0.68 ^{g}	2.32 ± 0.21 ^{k}	1.79 ± 0.12 ^{c}	4.24 ± 0.31 ^{j}	4.55 ± 0.19 ^{e}	2.18 ± 0.05 ^{i}	19.88 ± 0.26 ^{d}
Honeygoal × 14 d	5.38 ± 0.57 ^{f}	3.32 ± 0.20 ^{j}	5.06 ± 0.57 ^{a}	26.44 ± 0.46 ^{a}	11.27 ± 0.52 ^{b}	17.61 ± 0.54 ^{c}	69.08 ± 0.47 ^{bc}
Honeygoal/Carnivor × 0 d	1.23 ± 1.81 ^{i}	25.02 ± 0.42 ^{b}	0.42 ± 0.21 ^{f}	22.71 ± 0.66 ^{c}	0.74 ± 0.08 ^{i}	2.35 ± 0.25 ^{i}	52.47 ± 0.57 ^{c}
Honeygoal/Carnivor × 7 d	8.56 ± 0.65 ^{e}	54.97 ± 1.41 ^{a}	0.48 ± 0.67 ^{f}	24.28 ± 0.32 ^{b}	2.30 ± 0.12 ^{g}	4.20 ± 0.19 ^{g}	94.79 ± 0.56 ^{a}
Honeygoal/Carnivor × 14 d	19.92 ± 0.54 ^{c}	54.34 ± 0.83 ^{a}	0.57 ± 0.55 ^{e}	24.28 ± 0.81 ^{b}	3.77 ± 0.12 ^{f}	7.42 ± 0.36 ^{e}	110.3 ± 0.53 ^{a}
Honeygoal/Kickstart × 0 d	1.26 ± 0.12 ^{i}	2.56 ± 0.29 ^{k}	0.52 ± 0.13 ^{e}	1.29 ± 0.38 ^{k}	1.60 ± 0.12 ^{h}	4.34 ± 0.12 ^{g}	11.57 ± 0.19 ^{e}
Honeygoal/Kickstart × 7 d	5.03 ± 0.32 ^{f}	7.59 ± 0.28 ^{g}	0.44 ± 0.04 ^{f}	4.29 ± 0.38 ^{j}	1.24 ± 0.21 ^{h}	4.85 ± 0.69 ^{g}	23.44 ± 0.32 ^{d}
Honeygoal/Kickstart × 14 d	14.03 ± 1.12 ^{d}	15.91 ± 0.03 ^{e}	0.53 ± 0.10 ^{e}	9.69 ± 0.24 ^{g}	1.70 ± 0.34 ^{h}	5.69 ± 0.38 ^{f}	47.55 ± 0.38 ^{c}
Honeyval × 0 d	1.63 ± 0.33 ^{i}	1.28 ± 0.18 ^{l}	ND	1.54 ± 0.02 ^{k}	0.42 ± 0.11 ^{j}	0.97 ± 0.12 ^{k}	5.84 ± 0.16 ^{e}
Honeyval × 7 d	3.08 ± 0.01 ^{h}	4.38 ± 0.25 ^{i}	ND	6.04 ± 0.01 ^{i}	0.96 ± 0.29 ^{i}	1.69 ± 0.38 ^{j}	16.15 ± 0.19 ^{d}
Honeyval × 14 d	3.61 ± 0.37 ^{h}	6.50 ± 0.31 ^{h}	ND	8.56 ± 0.27 ^{h}	14.08 ± 0.58 ^{a}	65.83 ± 0.99 ^{a}	98.58 ± 0.50 ^{a}
Honeyval/Carnivor × 0 d	23.96 ± 1.21 ^{b}	3.97 ± 0.29 ^{i}	0.26 ± 0.21 ^{g}	13.30 ± 0.42 ^{f}	1.66 ± 1.31 ^{h}	0.30 ± 0.00 ^{l}	43.45 ± 0.57 ^{c}
Honeyval/Carnivor × 7 d	42.48 ± 0.34 ^{a}	8.78 ± 0.23 ^{f}	1.26 ± 0.21 ^{d}	14.53 ± 0.61 ^{e}	4.11 ± 0.49 ^{e}	3.41 ± 0.33 ^{h}	74.57 ± 0.33 ^{b}
Honeyval/Carnivor × 14 d	42.37 ± 2.12 ^{a}	26.24 ± 0.61 ^{b}	3.31 ± 0.21 ^{b}	19.55 ± 0.40 ^{d}	5.23 ± 0.01 ^{d}	10.97 ± 0.79 ^{d}	83.67 ± 0.65 ^{b}
Honeyval/Kickstart × 0 d	5.88 ± 0.57 ^{f}	1.36 ± 0.05 ^{l}	0.22 ± 0.01 ^{g}	9.11 ± 0.41 ^{g}	0.84 ± 0.21 ^{i}	0.69 ± 0.38 ^{k}	18.12 ± 0.27 ^{d}
Honeyval/Kickstart × 7 d	5.97 ± 0.39 ^{f}	17.00 ± 0.54 ^{d}	0.37 ± 0.22 ^{f}	9.24 ± 0.31 ^{g}	3.27 ± 0.04 ^{f}	5.79 ± 0.26 ^{f}	41.64 ± 0.29 ^{c}
Honeyval/Kickstart × 14 d	15.04 ± 0.79 ^{d}	21.97 ± 0.39 ^{c}	0.58 ± 0.42 ^{e}	15.08 ± 0.48 ^{e}	10.25 ± 0.51 ^{c}	34.67 ± 1.41 ^{b}	97.59 ± 1.32 ^{a}
Cultivar × Rootstock × storage time	0.23 *	0.64 *	0.26 *	1.05 *	0.28 *	0.49 *	4.58 *

Values are mean ± standard deviation of (n = 5) replicates, and values followed by the same letter within the column are not different at * = $p \leq 0.05$., Fisher's LSD. Day 0 (0 d), Day 7 (7 d), and Day 14 (14 d).

Table 5. Changes in ketone, alkenes, and aldehydes of honeydew melon cultivars influenced by grafting and postharvest storage (μg/g).

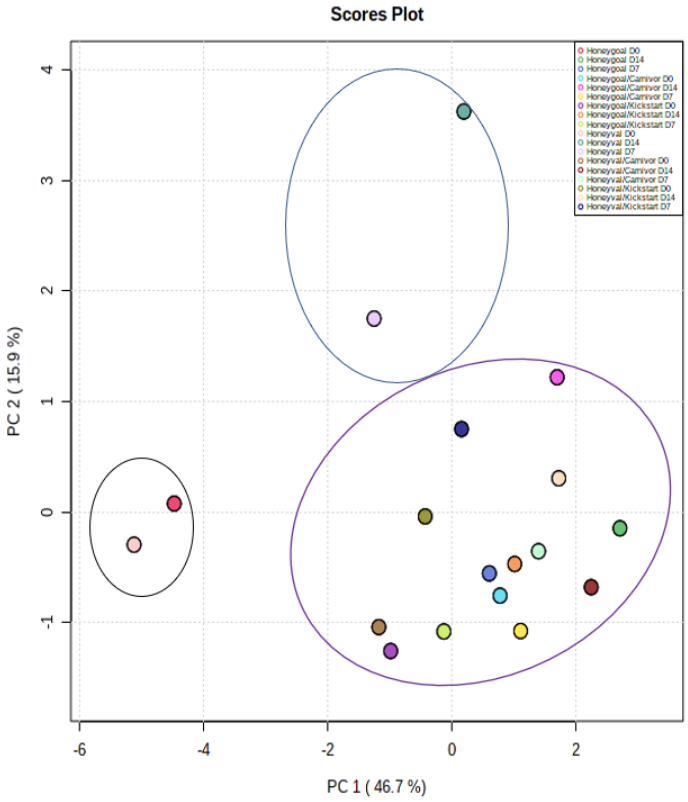
	Ketone	**Alkene**		**Total Alkene**	**Aldehyde**			**Total Aldehyde**
Volatile compounds (IUPAC name)	3- Hydroxybutan-2-one	4,5 Dimethyl -1-hexene	4-methylundec-1-ene		2-Heptenal (Z)	Benzaldehyde	Pentanal	
Calculated KI	719	747			951	963	701	
Literature KI (DB-5)	718				952	961	699	
Aroma description	Pleasant, buttery	Green fruity sweet fatty fresh apple pear			Fatty and fruity	Powerful sweet	Musty, apricot like	
Honeygoal × 0 d	0.80 ± 0.52 ^{l}	0.93 ± 0.34 ^{k}	0.94 ± 0.13 ^{h}	2.67	2.64 ± 0.25 ^{g}	2.71 ± 0.19 ^{j}	0.94 ± 0.16 ^{j}	6.29 ± 0.19 ^{i}
Honeygoal × 7 d	28.72 ± 0.76 ^{c}	1.67 ± 1.03 ^{k}	2.55 ± 0.25 ^{g}	32.94	4.28 ± 0.14 ^{e}	5.98 ± 0.77 ^{h}	2.55 ± 0.05 ^{h}	12.81 ± 1.16 ^{g}
Honeygoal × 14 d	60.52 ± 0.29 ^{a}	38.60 ± 1.24 ^{a}	5.49 ± 0.77 ^{e}	104.61	12.76 ± 0.07 ^{a}	25.03 ± 0.13 ^{a}	5.49 ± 0.39 ^{f}	43.28 ± 2.08 ^{c}
Honeygoal/Carnivor × 0 d	3.02 ± 0.35 ^{k}	6.38 ± 0.33 ^{h}	7.59 ± 0.40 ^{d}	16.99	5.23 ± 0.02 ^{d}	9.77 ± 0.24 ^{f}	7.59 ± 1.75 ^{e}	22.59 ± 1.30 ^{e}
Honeygoal/Carnivor × 7 d	4.46 ± 0.26 ^{j}	11.09 ± 0.01 ^{f}	31.04 ± 0.12 ^{b}	46.59	6.40 ± 0.58 ^{c}	15.61 ± 0.51 ^{d}	31.04 ± 0.70 ^{b}	53.05 ± 3.62 ^{b}
Honeygoal/Carnivor × 14 d	17.07 ± 0.07 ^{e}	13.69 ± 0.64 ^{d}	73.17 ± 0.73 ^{a}	103.93	8.39 ± 0.38 ^{b}	15.61 ± 0.08 ^{d}	73.17 ± 0.46 ^{a}	97.17 ± 2.64 ^{a}
Honeygoal/Kickstart × 0 d	1.29 ± 0.02 ^{l}	0.47 ± 0.38 ^{l}	0.67 ± 0.13 ^{h}	2.43	3.61 ± 0.36 ^{f}	9.26 ± 0.06 ^{f}	0.67 ± 0.38 ^{jk}	13.54 ± 0.68 ^{g}
Honeygoal/Kickstart × 7 d	3.60 ± 0.31 ^{k}	2.35 ± 0.35 ^{j}	3.34 ± 1.03 ^{f}	9.29	5.38 ± 0.43 ^{d}	15.66 ± 0.43 ^{d}	3.34 ± 0.55 ^{h}	24.38 ± 0.34 ^{e}
Honeygoal/Kickstart × 14 d	22.54 ± 0.57 ^{d}	5.67 ± 0.55 ^{i}	9.34 ± 1.10 ^{d}	37.55	8.38 ± 0.43 ^{b}	17.79 ± 0.77 ^{c}	9.34 ± 0.55 ^{d}	35.51 ± 0.18 ^{d}
Honeyval × 0 d	2.04 ± 0.23 ^{k}	0.87 ± 0.50 ^{k}	ND	2.91	2.12 ± 0.03 ^{g}	4.48 ± 0.05 ^{i}	0,87 ± 0.23 ^{j}	7.47 ± 0.10 ^{i}
Honeyval × 7 d	4.03 ± 0.34 ^{j}	12.29 ± 0.21 ^{e}	4.36 ± 0.40 ^{f}	20.68	6.50 ± 0.57 ^{c}	8.27 ± 0.13 ^{g}	4.36 ± 0.21 ^{g}	19.13 ± 0.22 ^{f}
Honeyval × 14 d	32.28 ± 1.07 ^{b}	28.33 ± 0.20 ^{b}	6.46 ± 1.15 ^{d}	67.07	8.13 ± 0.76 ^{b}	15.60 ± 0.50 ^{d}	6.46 ± 0.36 ^{f}	30.19 ± 0.54 ^{d}
Honeyval/Carnivor × 0 d	2.64 ± 0.51 ^{k}	3.45 ± 0.32 ^{j}	1.16 ± 0.50 ^{h}	7.25	4.77 ± 0.57 ^{e}	12.13 ± 0.01 ^{e}	1.16 ± 0.02 ^{j}	18.06 ± 1.42 ^{f}
Honeyval/Carnivor × 7 d	5.75 ± 0.54 ^{i}	4.73 ± 0.11 ^{i}	6.16 ± 0.42 ^{d}	16.64	6.12 ± 0.03 ^{c}	18.27 ± 0.45 ^{c}	6.16 ± 0.59 ^{f}	30.55 ± 2.04 ^{d}
Honeyval/Carnivor × 14 d	6.62 ± 0.03 ^{h}	5.08 ± 0.44 ^{i}	25.09 ± 2.92 ^{c}	36.79	8.82 ± 0.15 ^{b}	25.09 ± 0.48 ^{a}	25.09 ± 0.56 ^{c}	59.0 ± 1.55 ^{b}
Honeyval/Kickstart × 0 d	9.84 ± 0.36 ^{g}	2.76 ± 0.11 ^{j}	2.21 ± 0.70 ^{g}	14.81	2.45 ± 0.24 ^{g}	5.27 ± 0.13 ^{h}	2.21 ± 0.11 ^{hi}	9.93 ± 0.29 ^{h}
Honeyval/Kickstart × 7 d	12.79 ± 0.55 ^{f}	8.87 ± 0.50 ^{g}	6.25 ± 0.52 ^{d}	27.91	6.34 ± 0.27 ^{c}	12.50 ± 0.28 ^{e}	6.25 ± 0.52 ^{f}	25.09 ± 0.26 ^{e}
Honeyval/Kickstart × 14 d	17.20 ± 0.58 ^{e}	25.06 ± 0.39 ^{c}	7.64 ± 0.63 ^{d}	49.9	8.16 ± 0.16 ^{b}	21.65 ± 0.89 ^{b}	7.64 ± 0.27 ^{e}	37.45 ± 0.19 ^{d}
Cultivar × Rootstock × storage time	0.87 *	1.20 *	1.05 *		0.61 *	1.50 *	1.02*	2.90*

Values are mean ± standard deviation of (n = 5) replicates, and values followed by the same letter within the column are not different at * = $p \leq 0.05$. Fisher's LSD. Day 0 (0 d), Day 7 (7 d), and Day 14 (14 d).

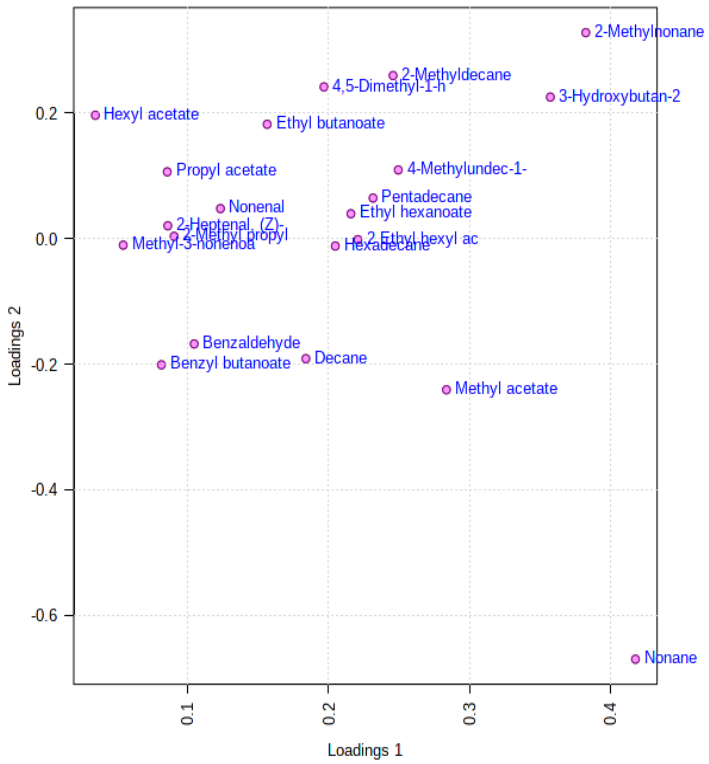
According to Obando-Ulloa et al. [15] in senescent climacteric fruit, acetate and non-acetate esters account for a significant proportion of the total aroma profile than at harvest especially, propyl acetate, hexyl acetate and ethyl butanoate. Although the honeydew melons are not categorized as non-climacteric [35,36] similar observation was noted in this study. Additionally, Obando-Ulloa et al. [36] found that during senescence, non-climacteric aldehydes near isogenic lines were reduced or not detected while the esters remained unchanged. Honeydew melon, however, does not contain 2-ethylfuran or isobutyl acetate, which are referred to as the ethylene-independent aroma compounds by Obando-Ulloa et al. [15]. Various esters have been associated with sweet and fruity attributes of fruit [37]. Stored honeydew melons, exhibited a continuous increase in ethyl acetate similar to observation in fresh cut climacteric melons after storage [38]. Cold storage of the melons for fourteen days, probably increased the production of ethylene, thus affecting fruit physiology. The loss of acetate esters would reduce freshness, and consumers acceptability of such melons after a prolong time of storage [15,39]. As compared with their un-grafted controls, the levels of the acetate esters, especially hexyl acetate, methyl acetate, ethyl hexyl acetate and methyl propyl acetate, increased significantly with storage in grafted melons which will invariably improve its acceptability by consumers. According to Lignou et al., [13], cultivars with a longer shelf-life produce fewer esters. Alternatively, high levels of aldehydes observed in Table 5 may be caused by senescence or off-flavors [40], and the differences observed in the aldehyde concentrations in grafted and un-grafted cultivars could be due to the differences in lipoxygenase, hydroperoxide lyase activities.

3.4. Multivariate Analysis

Chromatography, spectrophotometry, and multivariate analysis are the most commonly used analytical tools when discriminating a set of treatments. PCA simplifies high dimensional data so that the data can be visualized. Various cultivars of honeydew melon were subjected to principal component analysis (PCA). The PCA of rootstocks, cultivars, and volatile compounds are presented in Figure 1A. PC1 and PC2 explain 62.6% of the total variance (PC1: 46.7%, PC2: 15.9%). According to the PCA, there were three distinct clusters, with cluster 1 consisting of the un-grafted "Honeyval" melons stored for days 7 and 14 in cold storage. Cluster 2 contained the un-grafted "Honeygoal" and "Honeyval" melons at harvest (0 day). Cluster 3 included all other grafted and un-grafted cultivars stored for 7 and 14 days in cold storage. Even though most volatile compounds loaded positively on PC1, 2-methyl nonane as well as 3- hydroxyl butanone (Figure 1B) assisted in the separation of cluster 3 from clusters 1 and 2 (Figure 1A). Heat map visualization displays the intensity of VOCs during postharvest storage of honeydew melons at 5 °C after 7 and 14 days. The heat map (Figure 2) demonstrated that grafting with rootstocks "Carnivor" or "Kickstart" resulted in improvement of volatile compounds in honeydew melons compared to the un-grafted "Honeyval" and "Honeygoal" at harvest. Furthermore, "Honeyval" and "Honeygoal" melons grafted on to "Carnivor" rootstocks cold stored up to 7 days had higher volatile compounds levels than those grafted on to "Kickstart" rootstocks. Using the heat map, two cluster groups appear based on the concentration of volatile compounds; cluster 1 consists of the higher concentrations of volatile compounds for "Honeygoal/Carnivor" day 7, "Honeygoal/Carnivor" day 0, "Honeygoal/Carnivor" day 14, "Honeygoal/Carnivor" day 7, "Honeyval/Carnivor" day 7, and "Honeyval/Kickstart" day 14. Cluster 2 includes; "Honeygoal" day 0, "Honeyval" day 0, "Honeyval" day 0, "Honeyval/Kickstrat" day 7, "Honeyval" day 14, "Honeyval" day 7, "Honeygoal" day 7, "Honeyval/Carnivor" day 0, "Honeyval/Kickstart" day 0, "Honeyval/Kickstart" day 0, "Honeyval/Kickstrat" day 0, and "Honeygoal/Kickstrat" day 7. Hence, grafting "Honeyval" or "Honeygoal" melons onto "Carnivor" rootstocks helped to improve volatiles during storage after harvest.



(**A**)



(**B**)

Figure 1. (**A**) Principal component analysis of honeydew rootstocks, cultivars, and volatile compounds after postharvest storage. (**B**) PLS-DA score plot showing the loadings of volatile components of grafted and un-grafted honeydew melons.

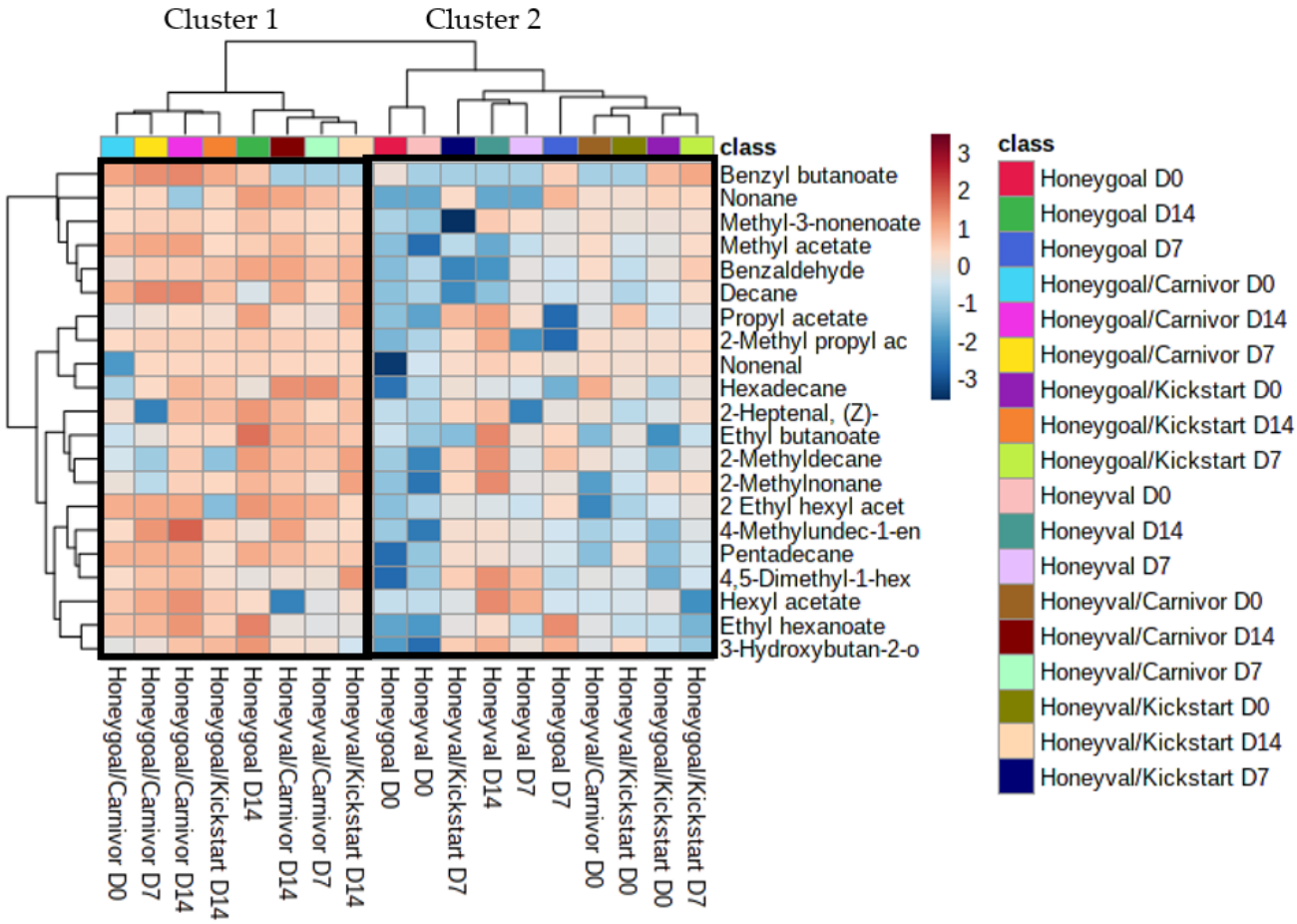


Figure 2. Heat map pattern of volatiles from grafted and un-grafted honeydew melons after postharvest storage.

3.5. Sensory Attributes

Genotype varieties significantly affect the perception of sweet aroma, sweetness, firmness, and juiciness of melon cultivars after cold storage [41–43]. Sensory descriptors (Supplementary Table S2) for appearance, texture, taste, and aroma were used to describe the sensory properties of the melon samples at harvest and after 7 and 14 days of storage. The color characteristics of honeydew cultivars ranged from moderate and uniform (5.5) to a more even apple peel color (8.95) as shown in Figure 3. The color attributes of honeydew melons were not significantly affected by cultivar type, grafting, nor storage period. Melons stored for 14 days were only slightly different from the fresh samples at harvest while the 7 days stored melons were not significantly different from the 14 days stored melons with regards to the color. The highest score for "color" in honeydew cultivars was observed in "carnivore" grafted on "Honeygoal" or "Honeyval" stored for 7 d and 14 d respectively. The perception of juiciness in the honeydew melons increased with increased storage days and was highest in the 14 days stored melons. However, grafting improved the fruit firmness in honeydew melons compared to the non-grafted similar to our observation in the pre-harvest study [16]. The length of storage could have contributed to the decreased texture (firmness) of the melons after storage.

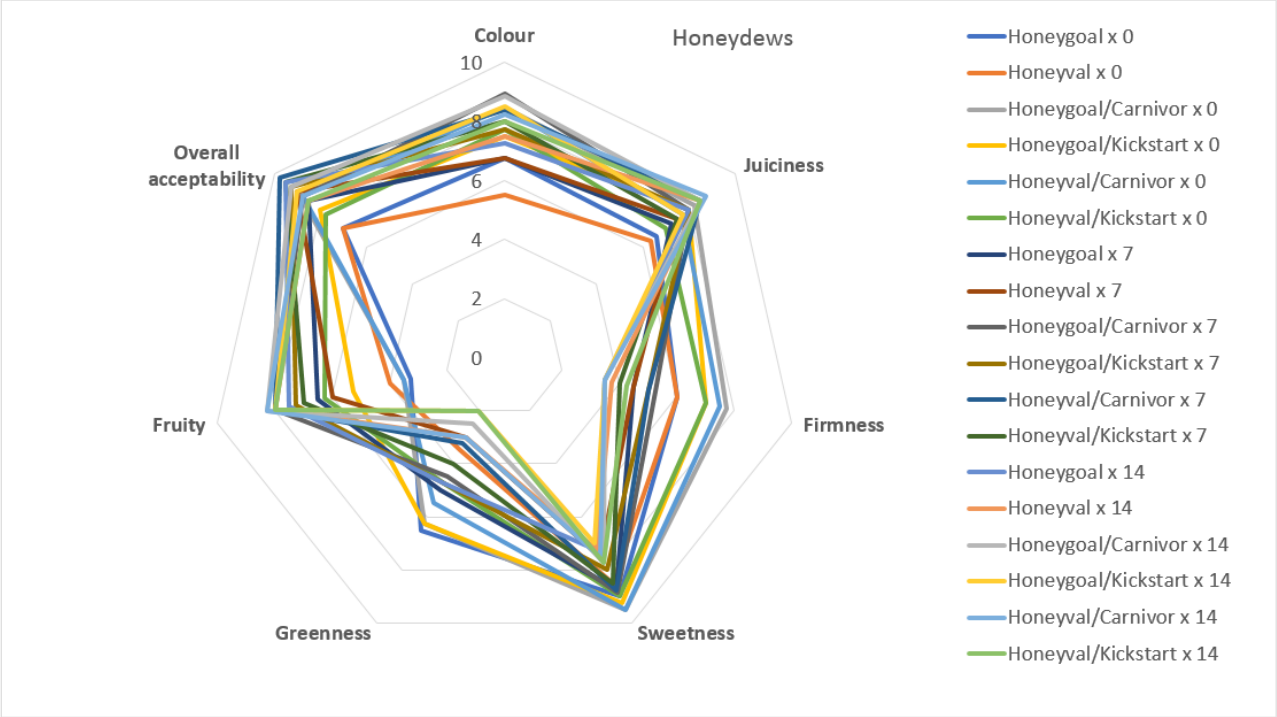


Figure 3. Sensory quality of grafted and un-grafted honeydew melons after cold storage.

In terms of juiciness and firmness, neither "Honeygoal" nor "Honeyval" melons grafted onto "Carnivor" or "Kickstart" rootstocks significantly differed from the non-grafted melons after 14 days of storage. Moreover, melons were characterized with reduced firmness after storage for 14 days with the highest in "Honeygoal/Carnivore" (7.75) at harvest. A similar significant decrease in melon firmness was reported in melons stored for 5 days at 10 °C [42] thus indicating the occurrence of senescence in the fruit. Melons lost their green taste significantly with increasing days of storage ($p \leq 0.05$). After storage for 14 days, "Honeygoal/Kickstart" and "Honeyval/Kickstart" melons (2.0) had the least perception of green taste. Neither grafting nor cultivar type affected the loss of green taste, but rather storage duration.

Fruity attribute perception ranged from 3.25 to 8.5 in honeydew cultivars. Perception of fruity taste was highest in "Honeyval/Carnivor" stored for 14 days and was lowest in "Honeygoal" sample at harvest. Storage of melons for 14 days significantly increased the development of fruity taste in the samples ($p \leq 0.05$) with higher perception in the grafted melons stored for 14 days. Sugar contents in fresh-cut fruits are known to decrease during storage with an increase in titratable acidity [43]. Contrary to the observation of the loss in fruity taste in Honeydew melons stored for 7 days at 10 °C by Bett-Garber et al. [43], there was an increase in the perception of fruity taste which correlates to the sweet taste perception in melons with increased storage days. In addition to the carbohydrates, solids such as water soluble amino acids could have contributed to the loss of sweetness during storage [44]. The increase in fruity taste might be associated with the increased rate of respiration causing the degradation of the cell carbohydrates and its conversion into simple sugar due to the accumulation of CO_2 thereby causing senescence in the melons. Storage for 7 days improves the overall eating quality of the melons. Fresh "Honeygoal" and "Honeyval" melons had the lowest acceptability, while "Honeyval" and "Carnivor" melons stored for 7 days had the highest acceptability. The acceptability of melons increased on day 7 of storage and was not significantly different from the samples at harvest ($p \geq 0.05$) while a decrease at 14 days of storage across cultivars was observed. There has been a decrease in sensory properties reported in fresh-cut melons after 6 days of storage [45–47]. After 14 days of storage, the acceptability of melons was moderately like, and the sensory quality was maintained after 7 days of storage. However, similar to our observation in

this study, Amaro et al. [48,49] have reported an early increase in volatiles of melons after storage but decreased after prolonged storage. According to Kappel and Mozafarian [50], storage temperatures affect postharvest quality more than Scion/rootstock combinations.

4. Conclusions

In light of impact of different rootstocks on antioxidant properties and volatile profile of Honeydew melons (*Cucumis melo* L.) during postharvest storage, storage of "Honeygoal/Carnivor" melons for 7 days did not significantly affect the ascorbic acid content. Grafting of melons improves the total phenolic content of honeydew melons, while the volatile concentration in grafted and un-grafted melons increased with prolonged cold storage. The grafting of "Honeygoal" melons onto "Carnivor" rootstocks can be recommended to retain the functional and volatile compounds, antioxidant properties, and sensory quality during postharvest storage at 5 °C, 85% RH for 14 days. A combination of scion-rootstock "Honeygoal/Canivor" is recommended for melon growers and marketers for increased accessibility of consumers to quality and health promoting components of honeydew melon.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy12102498/s1, Table S1: (A) The equations for the standard curves, regression coefficient (r2), (B) The Chemical Abstracts Service (CAS) number for the aroma volatiles detected in cantaloupe and honeydew melons, Table S2: Definition of attributes and reference scales used in the sensory analysis of melons.

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