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Effect of postharvest temperature on the muscat flavor and aroma volatile content in the berries of 'Shine Muscat' (*Vitis labruscana* Baily × *V. vinifera* L.)

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ABSTRACT

The muscat flavor of table grapes often decreases after harvest, but the contributions of post-harvest temperature to the flavor loss were unknown. In the present study, the effect of different postharvest temperatures on muscat flavor and the content of aroma volatiles was investigated at 0, 2, 5, and 10 °C for 12 weeks in the berries of 'Shine Muscat' (*Vitis labruscana* Baily × *Vitis vinifera Vitis vinifera* L.), which has a strong muscat flavor. Furthermore, after 2, 4, and 8 weeks of storage at 0 °C, the grapes were subjected to post-storage conditioning at 10 °C for 14 more days, and changes in the aroma volatile content were investigated. A sensory test showed that after 4 weeks of storage, the muscat flavor obviously decreased at 0 °C, but at 10 °C, the muscat flavor was maintained. Gas chromatography analysis of aroma volatiles showed that the content of linalool, which is one of the causative agents of muscat flavor, dramatically decreased at low temperatures (0, 2, and 5 °C) in comparison with that at 10 °C. During storage, the linalool content was much lower at 0 °C than at 10 °C in both the skin and the flesh. Interestingly, the linalool content, as well as muscat flavor, which decreased during storage at 0 °C, increased after the grapes were subjected to post-storage conditioning at 10 °C. The linalool content of the grape conditioned at 10 °C for 1–14 more days was higher than that of the grape continuously stored at 0 °C. These results indicated that muscat flavor is strongly influenced by postharvest temperature and that low-temperature storage enhances the loss of muscat flavor and the decrease in linalool content, but storage at 10 °C delayed and minimized them. Moreover, these results showed that post-storage conditioning at an increased temperature before consumption would be effective to increase the muscat flavor even after flavor loss during low-temperature storage at 0 °C.

1. Introduction

Postharvest handling temperature and storage length are important factors affecting the flavor quality of fruits and vegetables (Baldwin, 2002; Kader, 2008). In general, low-temperature storage has been used in an attempt to reduce decay and maintain the appearance of many crops (Thompson, 2002). Recent studies have reported that in several tomato and mandarin cultivars, storage at low temperature, which is currently used in commercial practice, sometimes induces flavor loss and generates an off-flavor (Maul et al., 2000; Obenland et al., 2011, 2013; Tietel et al., 2011). In these studies, researchers determined optimal and minimum safe temperatures for maintaining flavor quality and suggested that the postharvest handling temperature currently used in commercial practice is not always optimal for maintaining flavor quality. Thus, it is important to investigate the postharvest handling temperature that will maintain the flavor quality of fruits.

Muscat flavor is an important quality for table grapes and has been studied in many cultivars (Marais, 1983; Bhat et al., 2010). The berries of muscat cultivars contain a high concentration of aroma volatiles, such as terpene compounds, in comparison with non-muscat cultivars (Marais, 1983; Bhat et al., 2010). Ribéreau-Gayon et al. (1975) identified terpene compounds contained in muscat grapes and determined their flavor thresholds in sugar water. They reported that linalool, nerol, and geraniol are major compounds that contribute to a muscat flavor, and linalool has the lowest threshold among these compounds. The content and composition of these aroma volatiles vary among muscat cultivars, which contributes to their specific flavors (Marais, 1983; Bhat et al., 2010).

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The loss of muscat flavor has been studied during the making and storage of wine and grape juice (Ribéreau-Gayon et al., 1975; Marais, 1983). Under acidic conditions, linalool, nerol, and geraniol are converted to less aromatic compounds by acid-catalyzed transformation. Ribéreau-Gayon et al. (1975) reported that these chemical transformations are responsible for a loss of aroma during the making and storage of wine and grape juice.

On the other hand, in fresh table grapes, loss of muscat flavor during storage has scarcely been studied, though the muscat flavor of table grapes often decreases after harvest (Artés-Hernández et al., 2004; our personal observation). In an attempt to reduce decay and maintain appearance, the storage temperature of table grapes has been studied, and the recommended storage temperature is between −0.5 and 1 °C (Crisosto and Mitchell, 2002). However, to the best of our knowledge, little research has been conducted on the effect of different postharvest temperatures on changes in the muscat flavor quality of table grapes.

'Shine Muscat'is a table grape derived from *Vitis labruscana* Baily and *Vitis viniferaVitis vinifera* L. and is a major table grape cultivar in Japan (Yamada et al., 2008). This cultivar has a strong muscat flavor, large green berries, crisp flesh texture, high soluble solid concentration, low acidity, and the berries are edible with the skin on. However, the muscat flavor of the freshly harvested fruit decreases during storage.

The aim of the present study was to investigate the effect of postharvest temperature on muscat flavor and to identify the optimal handling procedure for maintaining the muscat flavor quality. In the present study, the effects of different postharvest temperatures (0, 2, 5, and 10 °C) on changes in the muscat flavor and aroma volatile content in the berries of 'Shine Muscat' after storage for 2, 4, 8, and 12 weeks have been evaluated. Furthermore, after storage at 0 °C for 2, 4, and 8 weeks, the grapes were subjected to post-storage conditioning at 10 °C for 14 more days and changes in the aroma volatile content were examined.

2. Materials and methods

2.1. Plant materials and storage conditions

The grapes of 'Shine Muscat' (*Vitis labruscana* Baily × *V. vinifera* L.), in which total soluble solids (TSS) content was 18 and above, were harvested from vines at the National Institute of Fruit Tree Science, Akitsu (Hiroshima, Japan) in late August 2013 and 2014 and from vines at the Gunma Agricultural Technology Center (Gunma, Japan) in mid-September 2012. The storage experiment was repeated over 2 years. In the 2012 and 2013 seasons, the bunches were divided into 4 groups for different temperature treatments (0, 2, 5, and 10 °C) and incubated in the dark at 0, 2, 5, and 10 °C for up to 3 months. Three bunches were subjected to each treatment. At weeks 0, 2, 4, 8, and 12 after storage, 3 berries per bunch were picked from the top, the middle, and the tip of a bunch, mixed (Hagiwara and Ooi, 1987), and used for the sample of each bunch. During temperature treatments, bunches in each treatment were placed in desiccators with continuous ventilation by air pump with a relative humidity of 99%.

In the 2014 season, changes in the aroma volatile content during post-storage conditioning at 10 °C were examined after storage at 0 °C for 2, 4, and 8 weeks. Nine bunches were stored at 0 °C for 8 weeks, and 3 bunches were stored at 10 °C for a control group. After storage at 0 °C for 2, 4, and 8 weeks, 3 bunches were selected, and each bunch was cut into small bunches and divided into 2 groups. One group was stored continuously at 0 °C, and the other group was transferred to a post-storage condition of 10 °C and stored for 14 more days. After days 0, 1, 3, 7, and 14 of post-storage conditioning, berries were picked, mixed, and used for the sample of each bunch. The berries were manually peeled, and the skins were separated from the flesh. The skin and the flesh were immediately frozen in liquid nitrogen and stored at −80 °C until use.

2.2. Analysis of aroma volatiles

Flavor volatiles were extracted from the skin and flesh using solid-phase microextraction (SPME) in accordance with a method described previously, with slight modifications (Sánchez-Palomo et al., 2005). Skins and flesh stored at −80 °C were homogenized in liquid nitrogen. Aliquots (0.5 g of the flesh and 0.3 g of the skin) were placed in headspace vials (volume size 10 mL), 5 μL of 1-pentanol (100 $\mu L\,L^{-1}$ in water) was added as an internal standard, and a saturated aqueous solution of ammonium sulfate (0.5 mL for the flesh and 0.3 mL for the skin) was added to suppress enzymatic degradation. The sample vials were stored at −20 °C until analysis. The aroma volatiles were manually extracted from the headspace of vials by SPME using StableFlex fiber coated with a 65 μm layer of polydimethylsiloxane/divinylbenzene (PDMS/DVB) supplied by Supelco (Bellefonte, PA, USA). Before every extraction, the fiber was conditioned for 5 min at 250 °C in a gas chromatograph injector. Before analysis, the samples stored at −20 °C were thawed and kept on ice. Each sample was immersed in a 40 °C water bath, and the fiber was exposed to the headspace of the sample vial for 10 min. The volatiles extracted with the fiber were desorbed in a split/splitless injector at 250 °C for 1 min and analyzed with gas chromatography–mass spectrometry (GC–MS) or gas chromatography–flame ionization detection (GC–FID).

The aroma volatiles were identified by comparing GC–MS spectra and retention times with authentic standards using the US National Institute of Standards and Technology (NIST)'s Mass Spectral Library. Quantification was performed with GC–FID. Six aroma volatiles (linalool, hexanal, (*E*)-2-hexenal, hexanol, (*Z*)-3-hexene-1-ol, and nerol) were quantified by comparing their peak areas with those of authentic standards using an internal standard method. The aroma volatiles were quantified in $mg\,kg^{-1}$ with reference to standard curves, which were obtained by SPME of the standard solution. The defined amount of authentic standards dissolved in acetone was mixed with a synthetic must (grape juice) solution (10% glucose, 10% fructose, and 4% tartaric acid in water) and used as a standard solution (Sánchez-Palomo et al., 2005). Each analytical measurement was replicated twice. The results are given as the mean ± standard error of 3 bunches.

GC–MS analysis was performed on a Shimadzu GC2010 coupled to a model QP2010 mass spectrometer (Shimadzu, Kyoto, Japan). The aroma volatiles were separated on an Agilent DB-WAX capillary column (30 m × 0.25 mm i.d., 0.25-μm film thickness) (J&W Scientific, Folsom, CA, USA). The column oven temperature was held at 70 °C for 5 min, then ramped up to 150 °C at a rate of $5\,°C\,min^{-1}$, then 190 °C at a rate of $0.33\,°C\,s^{-1}$, and held at 190 °C for 5 min. The carrier gas was helium, set at $13\,\mu L\,s^{-1}$. The mass detector was in electron impact (EI) mode at 70 eV, with a source temperature of 200 °C, a mass scan range of 35–350, and a sampling scan rate of $1\,s^{-1}$. GC-FID analysis was performed on a Shimadzu GC14B (Shimadzu, Kyoto, Japan). Gas chromatography was performed under the same conditions used in the GC–MS analysis. A flame ionization detector was set at 250 °C.

2.3. Sensory evaluations

In the 2014 season, muscat flavor preference was evaluated by sensory evaluation. The sensory test was conducted prior to storage, after storage at 0 and 10 °C for 4 weeks, and after post-storage conditioning at 10 °C for 7 more days after 4 weeks of storage at 0 °C. Before sensory evaluation, the temperature of the berries stored at 0 and 10 °C was equilibrated at 20 °C for 2 h, and