



Influence of cold storage prior to and after ripening on quality factors and sensory attributes of 'Hass' avocados[☆]



Mary Lu Arpaia^a, Sue Collin^a, James Sievert^a, David Obenland^{b,*}

^a Department of Botany and Plant Sciences, University of California, Riverside, CA 92521, United States

^b USDA, Agricultural Research Service, San Joaquin Valley Agricultural Sciences Center, 9611 South Riverbend Avenue, Parlier, CA 93648-9757, United States

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ABSTRACT

Partially-ripened avocados are often held in cold storage in an attempt to enable the consistent delivery of ripe fruit to food service or retail outlets. It is also common to hold fruit without any prior ripening for a few days to several weeks prior to ethylene treatment and final ripening. The purpose of this study was to determine the impact of these practices on ripening time and subsequent fruit quality. 'Hass' avocados were harvested from three different orchards on six harvest dates and placed at either 5 °C or 12 °C immediately after harvest or after ripening to average firmness values of either 80 N (partially ripe) or 19 N (near ripe). After storage the fruit were then ripened to eating firmness (4.4–6.7 N) and evaluated for quality parameters. A portion of the fruit at harvest firmness were stored for 0 d, 7 d, 14 d or 28 d and then treated with ethylene to ripen the fruit. Continual softening during storage resulted in fruit that had been ripened prior to storage being nearly at eating firmness at the end of 14 d, especially those stored at 12 °C. Stem end rot, body rot and pink staining of the vascular tissue occurred more frequently in the previously-ripened fruit after 14 d, the severity being greatest at 12 °C where the incidence exceeded 50% for both stem end rot and pink staining. Both harvest date and orchard influenced the amount of pink staining observed. Storage of firm fruit prior to ethylene treatment resulted in higher levels of both stem end rot and pink staining only when the storage time exceeded 14 d. In an additional study to assess the impact of the storage of partially-ripened fruit on both quality and sensory characteristics, 'Hass' avocados were harvested six times at monthly intervals, ripened to approximately 16 N firmness at 20 °C and then placed at either 1 °C or 5 °C for 7 d or 14 d. Following storage the fruit were ripened to eating firmness and evaluated. The occurrence of fruit quality defects was not affected by the timing of ripening. Sensory panelists liked fruit ripened prior to or after cold storage equally well and there were no differences among the ripening treatments, within a storage time, in the level of rich, nutty or grassy attributes that composed the fruit flavor. There were statistically-significant differences in the degree of textural creaminess among the ripening treatments, although these differences were inconsistent and slight. Storing partially ripe 'Hass' avocados for up to 4 d at either 1 °C, 5 °C or 12 °C does not greatly alter avocado quality, while storage for longer periods, such as 14 d, may be problematic due to enhanced development of decay and pink staining, especially at higher temperatures. Holding unripe avocados for longer than 14 d prior to ethylene treatment may predispose the fruit to the development of pink staining.

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* Corresponding author. Fax: +1 559 596 2803.

E-mail address: david.obenland@ars.usda.gov (D. Obenland).

1. Introduction

Consumers in the United States are generally supplied with avocados in the marketplace that have been ripened to a stage where they could be either readily consumed or eaten after a brief period of ripening. This is to a large degree a consequence of prior research demonstrating greatly enhanced consumer preference for pre-ripened fruit (Lee and Coggins, 1982) and the development of means to commercially implement the ripening process (Tokar, 2007). Not only is the consumer able to easily buy avocados that

can be readily consumed but also the fruit-to-fruit variability in ripening time is reduced. Food service organizations also prefer the convenience of using ripened avocados as it greatly reduces the effort needed to ready the fruit for consumption.

Avocados do not ripen on the tree and so an extensive period of ripening must occur before consumption. Commercial ripening of avocados in California is most commonly performed in distribution centers or other dedicated facilities where the fruit is ripened to different levels of firmness, depending on the needs of the customer, prior to shipping to retail or food service outlets. Ethylene, at a concentration of 10–100 $\mu\text{L L}^{-1}$, is used to facilitate the ripening, which requires from 8 h to 36 h, depending on temperature and maturity of the fruit (Eaks, 1966; Anon., 2013). Although ripening immediately prior to marketing is preferred, it may be that the fruit are ripened and then placed into cold storage for a prolonged time awaiting demand and/or transportation. Although this is a common practice, there is insufficient information available regarding its influence on avocado fruit quality.

Holding of unripe avocados for extended amounts of time in cold storage is also common as packers and distributors respond to market demand. In addition, a large proportion of the fruit marketed in the United States is foreign in origin, sometimes necessitating lengthy transit times (21–28 d) while the fruit are in an unripe state. Fruit during long distance shipment may either be pretreated with 1-MCP (SmartFreshSM) or shipped in controlled atmosphere equipped containers to prevent in-transit softening. These fruit will also benefit from ethylene ripening. Softening is known to occur in unripe avocados during cold storage (Zauberman et al., 1973; Eaks, 1976) and acts to reduce the time needed to achieve full ripeness after the fruit are warmed. Ethylene is often used during the time of final ripening to facilitate the ripening process. The impact of ethylene on fruit that have undergone such storage is, however, incompletely understood as are the effects on quality.

There have been a limited number of studies that have examined the effect of cold storage of ripened or partially-ripened fruit on subsequent fruit quality, but previous work has focused on susceptibility to chilling injury, principally discoloration of the skin or flesh, and thus has been limited in the type of quality evaluations that were performed. Zauberman et al. (1973) demonstrated that soft or semi-soft fruit can be stored for 4 weeks at temperatures ranging from 0 °C to 6 °C without the danger of chilling injury. Subsequently, Kosiyachina and Young (1976) established that avocados are most sensitive to chilling injury when the fruit are at the climacteric rise or peak stage of ripening, but are much less sensitive following the climacteric. In a more recent study, Marques et al. (2011) again addressed the issue of the effects on avocado fruit quality of storing fruit that had been partially ripened. This and prior research have not provided any information regarding its potential impact on sensory quality and have not investigated the interaction of this practice with fruit maturity. The main objective of our research was to provide a more detailed view of the impact of cold storage of partially-ripened avocados on fruit quality across the harvest season, including influences of the

practice on sensory characteristics. Another objective was to examine the effect of ethylene on the time needed to achieve ripeness and quality of unripe fruit that have previously undergone various durations of cold storage.

2. Materials and methods

2.1. Avocado harvest (Tests 1A and 1B, 2006 season)

For Test 1 'Hass' avocados were harvested from three separate orchards in Ventura County, CA on six different harvest dates (January 23 (H1), March 20 (H2), April 24 (H3), June 5 (H4), July 17 (H5) and August 24 (H6)). Size 48 fruit (212–268 g) were utilized, with 500 fruit per orchard being harvested. Harvests H1, H3, and H5 were used for the experiments to determine the influence of partial ripening prior to storage on ripening time and fruit quality (part A). The remaining three harvests (H2, H4, and H6) were used to investigate the impact of cold storage prior to ethylene treatment and ripening on the same quality parameters (part B). Fruit for all of the tests were harvested in the morning and transported by air-conditioned vehicle to the Kearney Agricultural Center (KAC) in Parlier, CA. The fruit were held overnight at 12 °C, then sorted and assigned to the appropriate treatments on the following day. Care was taken to exclude blemished fruit.

2.2. Avocado harvest (Test 2, 2011 season)

For Test 2, 'Hass' avocados were obtained monthly during the avocado season in California beginning in March and ending in August from a commercial grove near Fillmore, CA (Table 1). At each harvest 450 avocados (size 48) were picked from 8 to 10 trees, the same trees being utilized each time. Care was taken to obtain fruit free of external blemishes. After harvest the fruit were transported in an air-conditioned vehicle to the Kearney Agricultural Center (KAC) in Parlier, CA. Upon arrival the fruit were randomized and placed into separate bins corresponding to the various treatments and the fruit placed at 5 °C and 90% RH. Average fruit weights and dry weights, a measurement of fruit maturity, were determined from 10 individual fruit from each of the harvests.

2.3. Ripening and storage treatments (Tests 1A and 1B)

To examine the effect of ripening prior to cold storage on subsequent fruit quality (part A) avocados were placed into cold storage either immediately after harvest (average firmness = 200 N) or following treatment with 25 $\mu\text{L L}^{-1}$ ethylene and ripening at 20 °C until the fruit were either partially ripe (average firmness = 80 N) or near ripe (average firmness = 19 N). In each case firmness was determined by use of a penetrometer (U.C. firmness tester, 8 mm tip). Fruit were stored at either 5 °C or 12 °C at 95% RH for either 4 d or 14 d. The storage times were selected to represent common avocado commercial handling practices in the United States, with 4 d or 14 d being typical short- or long-term storage durations, respectively. A temperature of 5 °C is used by the

Table 1
Average 'Hass' avocado fruit weight, dry weight and minimum and maximum dry weights for the five harvests for Test 2.

Harvest date	Average fruit weight (g) ^x	Average dry weight (%) ^x	Minimum dry weight (%)	Maximum dry weight (%)
15-Mar-11	219.3b	19.8c	18.0	21.4
27-Apr-11	242.3ab	23.5b	18.9	27.2
8-Jun-11	249.6ab	27.9a	23.1	31.8
13-Jul-11	281.1a	29.1a	26.6	31.3
17-Aug-11	278.6 a	29.2a	26.0	34.4

^x Average fruit weights and dry weights determined on 10 individual fruit per harvest. Mean separation based on the 0.05% level using Tukey's test.

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