Production of Some Odor-active Volatiles by ‘McIntosh’ Apples following Low-ethylene Controlled-atmosphere Storage

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Additional index words. Malus domestica, respiration, flavor

Abstract. The effectiveness of some poststorage treatments in enhancing the flavor components of low-ethylene controlled-atmosphere (LCA) stored ‘McIntosh’ apples (Malus domestica Borkh.) was investigated. Fruits were stored for 9 months in LCA at 3.3C and then exposed to air at 20C and to air, simulated LCA, 100% O2, or light at 3.3C for up to 4 weeks. Respiration and ethylene production indicated that apples were still in the early stage of ripening after 9 months of storage in LCA. Gas chromatographic analysis for 13 odor-active volatiles revealed the presence of eight. Air at 20C after LCA significantly increased the production of some odor volatiles, while light for up to 3 weeks only slightly increased their concentration. Poststorage exposure to air or 100% O2 at 3.3C for up to 4 weeks was not effective in enhancing volatile formation.

Controlled atmosphere (CA) is an established method of prolonging the storage life of apples (Smock, 1979). Low-ethylene CA (LCA), where ethylene in the storage atmosphere is maintained at or below 1 ppm, is very effective in further prolonging the storage life of the fruit with minimum losses in flesh firmness, acidity, and soluble solids (Blanpied et al., 1985; Liu and Samelson, 1986; Yahia et al., 1985).

Williams (1979) indicated that flavor is an important quality attribute in CA-stored apples that are firm. Earlier studies (Kidd and West, 1936) concluded that the full characteristic flavor of CA-stored ‘Cox’s Orange Pippin’ apples developed after a short conditioning period in air at 12C. Hatfield (1975) reported that much of the loss of flavor in CA storage could be regained if the apples were kept at 5 to 15C after storage before being transferred to 20C. However, other studies indicated significant loss in flavor in CA-stored apples (Knee and Sharples, 1981; Streif and Bangerth, 1988; Yahia, 1989; Yahia et al., 1990b, 1985). The severity of CA suppression of flavor components depended on the atmospheric composition and the duration of storage. The lower the O2 concentration, the higher the CO2 concentration; and the longer the fruit was kept in CA storage, the greater was the suppression (Knee and Sharples, 1981; Lidster et al., 1983; Patterson et al., 1974; Yahia et al., 1990b, 1985).

Simulated LCA storage caused a greater suppression of flavor than conventional CA storage (Yahia, 1989; Yahia et al., 1990b, 1985).

Apple flavor is a complex combination of taste and odor sensations. Although taste and texture are important to apple quality, the presence of trace amounts of volatile components responsible for odor gives the fruit much of its character (Dimick and Hoskin, 1983). About 20 to 40 odor-active volatiles are responsible for apple aroma (Cunningham et al., 1986). These volatiles fall into three classes: the “apple peel-smelling” esters like ethyl 2-methylbutanoate, the lipid

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Fig. 1. Effects of poststorage treatments on respiration (A) and ethylene production (B) rates of ‘McIntosh’ apples following low-ethylene CA storage. Vertical bars represent LSD values at P = 0.05.
commercial LCA room. The room was filled on 22 to 26 Sept. 1984, sealed immediately, and held at 3.3C. The atmosphere in the room was monitored daily using an Orsat gas analyzer (Orsat, Fisher Scientific, Springfield, N.J.) and averaged 3.3% O2 and 4.6% CO2. Ethylene produced by the fruit was removed with KMnO4/alumina beads for the first 2 months and a Swintherm Heated Catalyst Ethylene Converter afterwards (Blanpied et al., 1985). Ethylene in the room was monitored at various intervals using gas chromatography and averaged 2.42 ± 1.39 μl-liter⁻¹. The room was opened on 22 June 1985. On 24 June, fruits were taken from the LCA room and placed under one of the following five treatments: air at 20C; air at 3.3C; simulated LCA at 3.3C; 100% O2 at 3.3C; and light at 3.3C.

Fruits for air, simulated LCA, and 100% O2 were put into 19-liter glass jars with 50 fruits each. Air free from C2H4 and CO2, or a mixture of 3% O2 + 3% CO2 and 94% N2 was humidified and metered at 200 ml-min⁻¹ through each of the air or simulated LCA jars, respectively. Gas samples were collected three times per week from the outlet of each LCA jar, and O2 and CO2 contents were measured using an Orsat gas analyzer. The jars with 100% O2 were ventilated with humidified O2 at 200 ml-min⁻¹. Apples exposed to light were put for up to 3 weeks at 3.3C in a chamber composed of a box with nine high-output fluorescent tubes (F48 T12/WW/HO, General Electric) with an average intensity of 7560 lux. The side of the fruit exposed to light was random. Respiration rate was measured for all apples but those in simulated LCA or under light by detecting the CO2 concentration from the outlet of the jar using a calibrated Beckman Model IR 215 infrared gas analyzer (Beckman Instruments, Somerset, N.J.). Data were calculated as milliliters CO2 per kilogram per hour. Ethylene production was measured for all apples but those under light using a Varian Aerograph Model 3700 gas chromatograph (Varian Analytical Instruments, Sunnyvale, Calif.) equipped with a flame ionization detector and a 0.25 m × 2 mm column packed with activated aluminum oxide. Samples of 10 apples were taken initially and at weekly intervals for analysis of 13 volatile compounds (Table 1). These volatiles have all been shown to be odor-active in a combined apple extract of various cultivars, including ‘McIntosh’ (Cunningham et al., 1986). Volatiles were extracted as reported by Yahia et al. (1990a, 1990b). A gas chromatograph equipped with a flame ionization detector and a 12.5 m × 0.36 mm fused silica column coated with 0.53 μm crosslinked methyl silicone was used for volatile analysis. The column was held at 35C for 3 min, increased 4°C/min to 250C, and held there for 15 min. The retention indices (Kovats, 1965) of the 13 authentic standards were used to identify all volatiles and as a calibration for quantitative analysis. Retention indices were calculated using n-paraffin hydrocarbon standards containing n-heptane through n-octadecane. Statistical analysis for respiration and ethylene production rates was done using analysis of variance and least significant difference test at P = 0.05 was used for mean separation. Volatiles values represent one measurement of extract from 10 fruits.

Apples ripened in air at 20C had the highest rates of respiration (Fig. 1A). Apples kept in simulated LCA produced little ethylene (<1 μl-kg⁻¹-h⁻¹). Those kept in air at 3.3C or in 100% O2 at 3.3C had intermediate rates of ethylene production, and those kept in air at 20C had the highest rate (Fig. 1B).

Gas chromatographic analysis of odor-active volatiles revealed the absence of five volatiles, i.e., butyl-, phenyl-, and isopentyl acetate, and butyl propanoate and butyl pentanoate. Although these volatiles were found to be present in some apple cultivars (Dimick and Hoskin, 1983), they were consistently absent from ‘McIntosh’ and ‘Cortland’ apples (Yahia, 1989; Yahia et al., 1990a, 1990b, 1985). The total content of volatiles detected increased rapidly during fruit ripening in air at 20C but remained very low under other conditions and was the lowest under simulated LCA storage (Fig. 2). There were no large differences in the production of hexanal under the different storage conditions except for the unexplained peak in air at 20C at 7 days. (E)-2-hexenal was lowest in simulated LCA and in air at 3.3C, slightly higher under light and 100% O2, and highest in air at 20C. Hexanal generally decreased at a similar rate under all conditions, except for an increase in air at 20C at 14 days and in light at 21 days. Butyl hexanoate was not detected in simulated LCA and had increased by 3 weeks of light treatment and by 4 weeks of holding in air at 20C. Ethyl butanoate content was very low in apples from simulated LCA, slightly higher in those from air at 3.3C, light, or 100% O2, and very high in air at 20C (Fig. 3). Propyl butanoate was produced in small amounts in air at 20C but was nearly absent under all other conditions. Butyl butanoate was produced in small amounts in simulated LCA and in 100% O2, and in slightly higher amounts in air at 3.3C, light, or 100% O2, and very high in air at 20C. Ethyl 2-methylbutanoate was produced in small amounts under all conditions except in air at 20C.

The rates of CO2 and ethylene production indicated that apples were still in the early stage of ripening after 9 months of storage in LCA. The ability of LCA storage to slow ripening and senescence and to prolong the storage life of apples has been shown by others (Blanpied et al., 1985; Liu, 1985; Liu and Samelson, 1986).

Exposure of apples for 4 weeks to air at 3.3C after LCA storage was not effective in enhancing the flavor components of the fruit. Air at 20C significantly increased the production of some flavor volatiles. However, this temperature increases softening and acidity loss of apples (Liu, 1985; Liu and Samelson, 1986). The use of 100% O2 did not cause any significant stimulation in the production of odor-active volatiles. Frenkel (1978) used high levels of O2 to accelerate ripening in several fruits and storage organs. The use of high O2 in combination with eth-
Table 1. Odor-active volatiles analyzed.

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<tr>
<td>Butyl acetate</td>
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<td>Pentyl acetate</td>
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<td>Iso pentyl acetate</td>
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<td>Hexyl acetate</td>
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<td>Butyl propenoate</td>
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<td>Hexanal (E)-2-hexenal</td>
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<td>Ethyl butanoate</td>
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<td>Propyl butanoate</td>
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<td>Butyl butanoate</td>
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<td>Ethyl 2-methylbutanoate</td>
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<td>Butyl pentanoate</td>
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<td>Butyl hexanoate</td>
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3.3C for 3 to 4 weeks did not improve flavor of ‘McIntosh’ apples after storage in LCA for 9 months. Only the ripening temperature (20°C) stimulates the production of odor volatiles after storage in LCA. Further studies are needed to understand the mode of action of CA and to evaluate ethylene scrubbing systems for their effects on flavor volatiles.

Literature Cited


