Temperature and Propylene Effects on Ripening of Green and Black ‘Conservolea’ Olives

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Abstract. Ripening of detached mature-green and black-ripe olives (*Olea europaea* L., cv. Conservolea) was studied during storage at 0, 5, 10, or 20 °C in air or air plus 100–200 $\mu\text{L}\cdot\text{L}^{-1}$ propylene. Green olive skin h° remained unchanged after 24 days at 0 or 5 °C in air or air + propylene, while olives partially lost their green color at 10 °C and developed purple color at 20 °C together with a substantial flesh softening. Propylene partially delayed flesh softening only at 10 °C. Respiration of green and black olives increased with storage temperature. Black olives had higher respiration rate than green olives. Propylene had no substantial effect on green or black olive respiration rate, except for an increase in respiration and ripening rates of green olives kept at 20 °C. Ethylene production rate of air- or air + propylene-treated green olives was almost undetectable. Black olives had higher ethylene production rate than green olives and this rate significantly increased with storage temperature. Addition of propylene had only minor effect on ethylene production of black olives. No climacteric respiratory rise or autocatalytic ethylene production was observed in green and black olives.

‘Conservolea’ is the major Greek olive cultivar for production of green and natural black ripe table olives. There is no published information on fruit physiology of this cultivar and especially the effect of ethylene on ripening of cold-stored olive fruit. Research with other cultivars indicate that detached olives show no climacteric respiratory rise (Maxie et al., 1960). Green fruit produced only traces of ethylene, while black fruit produced significantly higher quantities but still very low compared to climacteric fruits (Kader et al., 1990). Ethylene at 150–250 $\mu\text{L}\cdot\text{L}^{-1}$ only slightly increased respiration rate of green olives at 20 °C, while it considerably increased respiration rates at 25 or 30 °C with a climacteric-type rise depending on cultivar (Maxie et al., 1960). The same scientists found no effect of ethylene on black olive respiration. Moreover, exposure of green olives to ethylene did not accelerate anthocyanin accumulation and softening (Maxie et al., 1960; Shulman et al., 1974). Propylene is known to mimic ethylene effects with 130 $\mu\text{L}\cdot\text{L}^{-1}$ propylene having similar effect to 1 $\mu\text{L}\cdot\text{L}^{-1}$ ethylene, a concentration that may be found in olive storage rooms. Propylene has been found to

accelerate autocatalytic ethylene production and ripening in apples and kiwifruit (Sfakiotakis and Dilley, 1973; Sfakiotakis et al., 1989), and it is a useful tool to study autocatalytic ethylene production.

Mature-green olives are chilling sensitive at temperatures below 10 °C depending on cultivar (Maxie, 1964). A positive correlation has been found between storage temperature and respiration rates of green and black olives and ethylene production rate of black olives for the major Californian and Spanish cultivars (Agar et al., 1999; Fernandez-Bolanos et al., 1997; Garcia and Streif, 1991; Garcia et al., 1995; Maxie et al., 1960).

In the present study, we investigated the physiology of ripening, mainly respiration and ethylene production rates, of fresh mature-green and black-ripe ‘Conservolea’ olives at chilling, optimal and ripening temperatures. We also studied the effect of propylene on ripening and autocatalytic ethylene production.

Materials and Methods

Olives (*Olea europaea* L., cv. Conservolea) were harvested from three farms (replicates) in Volos, Central Greece, during 1994 and 1995. Mature-green and black-ripe olives were harvested at the end of September and in mid-November, respectively. Fruit were transported

to the Postharvest Laboratory at the Aristotle Univ. of Thessaloniki, Greece, sorted, and put in 5-L jars (55 fruit per jar). Jars were kept in temperature regulated water baths (± 0.2 °C) at 0, 5, 10, and 20 °C for 24 (green fruit) or 10 d (black fruit). The jars were connected to a flow board, equipped with a flow-through system continuously supplying humidified air or air plus 100–200 $\mu\text{L}\cdot\text{L}^{-1}$ propylene (to mimic ethylene concentration of 1 $\mu\text{L}\cdot\text{L}^{-1}$) at a flow rate of ≈ 50 mL/min. Propylene was supplied from a pressurized cylinder and mixed with air before introduction to the flow board. There were three jar replicates per treatment and temperature. The outlets of all jars were connected after dehumidification to a CO₂ infrared gas analyzer and an O₂ paramagnetic analyzer. Gas analysis was performed and data were recorded automatically through custom-made software and a computer.

Gas samples were withdrawn with a hypodermic syringe from the outlet of each jar and ethylene and propylene concentrations were measured with a Varian gas chromatograph (model 3300, Varian Instruments, Walnut Creek, Calif.) equipped with FID and a 100 $\times$ 0.32 cm activated alumina column.

Respiration ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$) and ethylene production rates ($\text{nL}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$) were calculated based on the weight of fruit and flow rate of each jar. Respiratory quotient and Q10 values were also calculated.

Fruit quality was evaluated at the beginning and end of each experiment. Fruit quality evaluation included skin color and flesh firmness. Skin color (L^* , a^* , b^*) was evaluated with a Minolta chromameter (model CR-200; Minolta Camera Co., Japan) (55 fruit per replicate) and hue angle (h° , true color) was calculated (McGuire, 1992). Flesh firmness was measured with a Chatillon penetrometer equipped with a 3-mm-diameter plunger (J. Chatillon and Sons, N.Y.) after careful removal of skin (15 fruit per replicate). Weight of olives in each jar was recorded at the beginning and end of each experiment and the difference was used to calculate percent weight loss. Appearance of decay was periodically evaluated with macroscopic observation of the olives in each jar. The experiments were terminated when mycelia developed on the fruit.

Analysis of variance (ANOVA) was performed over temperature and presence or absence of propylene with SPSS statistical package (SPSS 8.0, Chicago). As experiments during 1994 and 1995 were performed in the same way and the fruit quality data were similar for both years, statistical analysis for these data was performed over six replicates (2 years $\times$ 3 farms-replicates). Least significant differences (LSDs) at 5% level were calculated and Duncan’s multiple range test was performed to distinguish differences between the means, whenever necessary.

Results and Discussion

As storage temperature increased, weight losses of green and black olives increased. Storage at 0 °C resulted in <0.5% fresh weight

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loss. Weight losses were around 2% to 3% at 5 °C and 3% to 5% at 10 °C. Finally, weight losses at 20 °C were 17% after 24 d in storage (green olives) and 7.5% after 10 d in storage (black olives). Thus, storage at temperatures below 20 °C significantly reduced weight losses although the air used in all treatments was humidified by bubbling through water column. This was expected as, despite the humidification of air, water pressure deficit of air at 20 °C is at least double that of air at 10 °C or less. The rate of weight loss per day at 20 °C was similar between green and black olives, although mature-green fruit are expected to be more susceptible to weight loss than ripe fruit, which have more surface wax.

The storage experiments of black olives were terminated at 10 d as decay appeared on fruit at 10 and 20 °C, which could affect respiration and ethylene production rates. During 24 d in storage, green olives exhibited no decay. 'Conservolea' green olives did not show chilling injury symptoms (internal browning and pitting) during the experiments. This cultivar was found to be relatively chilling resistant.

Green olives did not change color (h°) during storage for 24 d at 0 or 5 °C (Table 1). They partially lost green color at 10 °C and developed purple color after 24 d at 20 °C. Similar color changes could be depicted with the a^* and b^* coordinates (data not shown). There were no differences in h° between air- or air + propylene-treated green olives at 0 or 5 °C (Table 1). Propylene-treated green olives exhibited faster purple color development at 20 °C than air-treated olives.

Flesh firmness of green olives decreased by $\approx 23\%$ and 27% after 24 d at 0 or 5 °C, respectively (Table 1). Substantial flesh softening was measured after 24 d at 10 and 20 °C, with 70% and 100% firmness loss, respectively. Addition of propylene resulted in slightly better firmness retention for green olives kept at 10 °C (Table 1). Black olives had no measurable flesh firmness, with the particular method used in this study, at harvest and after storage at any temperature tested.

From these quality indices, a positive correlation was found between green color loss and flesh firmness reduction ($R^2 = 0.91$), although green olives stored at 0 or 5 °C had significantly lower flesh firmness without any color changes compared to freshly harvested fruit. These two quality indices have previously been proposed as successful maturity indices for green olives destined to be processed with the Spanish method (Nanos et al., 1999).

As storage temperature increased, respiration of green olives also increased (Fig. 1). The overall respiratory quotient (RQ) was slightly above 1, indicating that carbohydrates are mainly used for respiration in green olives. Q10 values of green olives were around 2.0 and 1.8 for 0 to 10 °C and 10 to 20 °C, respectively.

Propylene did not influence respiration rate of green olives kept at 0, 5, or 10 °C (Fig. 1). Green olives kept in the presence of propylene at 20 °C had higher respiration rate than olives

Table 1. Skin color (h°) and firmness of mature-green 'Conservolea' olives kept for 24 d in air or air plus 100–200 $\mu\text{L}\cdot\text{L}^{-1}$ propylene at 0–20 °C. Values shown are the mean values of both years of experiments (six, 15-fruit replicates).

Storage temp. (°C)	Color (h°)			Firmness (N)		
	Init.	24 d Air	24 d Prop	Init.	24 d Air	24 d Prop
	119.4 a ^c			9.8 a		
0		118.0 a	118.3 a		7.2 b	7.8 b
5		116.2 a	117.2 a		6.8 b	7.5 b
10		106.4 b	113.3 ab		2.0 d	4.0 c
20		72.9 c	63.8 d		0 e	0 e

^cOverall mean separation by Duncan's multiple range test at $P \leq 0.05$.

Fig. 1. Respiration rate of mature-green 'Conservolea' olives harvested late Sept. 1995 and stored in air or air plus 100–200 $\mu\text{L}\cdot\text{L}^{-1}$ propylene at various temperatures. Each point is the mean of three replicates and overall LSD at 5% is shown.

kept in air, especially during the first 17 d of storage. RQ values were similar in propylene- or air-treated green olives at around 1. Q10 values of olives kept in the presence of propylene were higher during the first 15 d of the experiment and lower thereafter than the values of olives kept in air.

Respiration rate of black olives was higher than that of green olives at each temperature tested. Overall respiration rates of black olives increased at 5 or 10 °C compared to 0 °C, and even further at 20 °C (Fig. 2). Respiration rate of air-stored black olives increased with temperature. RQ was close to 1 in 1994, but around 1.5 in 1995, probably due to fruit overproduction (1995 was an 'on' year in the area). The Q10 values of black olives were around 2 and 1.7 for 0 to 10 °C and 10 to 20 °C, respectively.

Exposure of black olives to propylene did not affect the respiration rate at each temperature tested compared to air-treated olives (Fig. 2). RQ levels were similar for air- or propylene-treated black olives. Q10 values of propylene-treated black olives were slightly lower than the values of air-treated fruit.

Ethylene production rate was almost undetectable in air- or propylene-treated green olives for the duration and temperatures tested. Ethylene production rate of black olives was significantly higher than that of green olives at

each temperature tested, except 0 °C. Overall ethylene production rate increased with temperature but without significant differences between 0 and 5 °C (Fig. 3). Ethylene production rate increased at least 10 fold between 0 and 10 °C, indicating that the critical temperature for ethylene synthesis is below 10 °C.

Ethylene production of propylene-treated black olives was similar to air-treated olives (Fig. 3). Q10 values for ethylene production of propylene-treated black olives were lower than the values of air-treated olives, especially at 0 to 10 °C.

Black 'Conservolea' olives had higher respiration and ethylene production rates than green ones, as has been found for cultivars grown in California, Italy, and Spain (Fernandez-Bolanos et al., 1997; Kader et al., 1990; Maxie et al., 1960; Ranalli et al., 1998). Black olives are more prone to deterioration (rotting and oil quality loss) than green olives, due to high respiration and ethylene production rates, and, possibly, loss of resistance to fungi.

Storage of olives at chilling temperatures (0 and 5 °C) resulted in very low respiration and ethylene production rates and no chilling injury after 24 d. Storage at 5 °C caused visible chilling injury symptoms to green 'Conservolea' olives after 50 d of storage (G.D. Nanos, unpublished data). Future re-

Fig. 2. Respiration rate of black-ripe 'Conservolea' olives harvested mid-Nov. 1995 and stored in air or air plus 100–200 $\mu\text{L}\cdot\text{L}^{-1}$ propylene at various temperatures. Each point is the mean of three replicates and overall LSD at 5% is shown.

Fig. 3. Ethylene production rate of black-ripe 'Conservolea' olives harvested mid-Nov. 1995 and stored in air or air plus 100–200 $\mu\text{L}\cdot\text{L}^{-1}$ propylene at various temperatures. Each point is the mean of three replicates and overall LSD at 5% is shown.

search could focus on the respiration and ethylene production rates of chilled for various durations and nonchilled olives after transfer to nonchilling temperatures.

The Q10 values of green or black 'Conservolea' olives were similar (close to 2) to most fruits. Similar Q10 values have been previously reported for mature-green olives kept at 10 to 35 °C (Maxie et al., 1960). RQ values calculated in this study agree with values found previously (Rugini et al., 1982), although RQ values of ripe olive fruit close to 1.5, when carbohydrates and organic acids are almost absent, can not be easily explained.

At 0 or 5 °C, propylene had no effect on olive fruit ripening. Propylene effect on green olive ripening at 10 °C was variable, while it

slightly accelerated ripening (including respiration) at 20 °C. Maxie et al. (1960) also reported, for mature green olives, acceleration of respiration at 25 or 30 °C, but only slight increase at 20 °C, in the presence of 150–250 $\mu\text{L}\cdot\text{L}^{-1}$ ethylene. In our work, propylene had no effect on black olive respiration and ethylene production rates, even at 10 or 20 °C. Thus, olives kept at temperatures below 10 °C are insensitive to low concentrations of ethylene. No respiratory climacteric rise was observed in green or black olives in the presence or absence of propylene at concentrations equivalent to 1 $\mu\text{L}\cdot\text{L}^{-1}$ ethylene.

In conclusion, detached mature-green or black-ripe olive fruit kept at temperatures up to 20 °C behave as a nonclimacteric fruit.

Typical nonclimacteric fruit, when treated with ethylene at 20 °C, show a transient increase of respiration rate (Tucker and Grierson, 1987). A slight increase in respiration rate was observed in propylene-treated green 'Conservolea' olives kept at 20 °C in our study and in green olives in California treated with high ethylene concentrations at 25 and 30 °C, but only slightly at 20 °C (Maxie et al., 1960). However, propylene had no effect on respiration and ethylene production rates of black olives.

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