Identification of optimum preprocessing storage conditions to maintain quality of black ripe 'Manzanillo' olives

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Abstract

Black-ripe olives (*Olea europaea* cv. 'Manzanillo'), used for processing into canned olives or oil were stored at 0, 2.2 and 5°C in air or 2 kPa O_2 (balance N_2). Olive samples were analyzed initially, and after 2, 4 and 6 weeks for fruit quality based on color, visual quality and fruit firmness, weight loss, water and oil content. Respiration rate, ethylene production and incidence of physiological disorders and decay were determined. Olive oil quality was evaluated based on titratable acidity, peroxide value, K_{232} and K_{270} coefficients, and fatty acid composition. Decay incidence increased with storage temperature and duration but it was lower in black-ripe olives kept in 2 kPa O_2 than in those kept in air. Fruit decay after 4 weeks storage in 2 kPa O_2 was 9.2, 8.2, and 7.7% in olives kept at 0, 2.2, and 5°C, respectively. No visual chilling injury symptoms were observed in any of the storage treatments. Storage time and atmospheres had no significant effect on olive color but visual quality scores of olives stored in 2 kPa O_2 at 0°C were generally higher than other treatments. Ethylene production and respiration rates were considerably higher at 5°C than at 0 or 2.2°C and in air than 2 kPa O_2. Fruit firmness declined markedly after 4 weeks storage in both the air and 2 kPa O_2 treatments, irrespective of storage temperature. There was no significant difference between the air and 2 kPa O_2 stored fruit. There were no significant differences in water and oil content among treatments. Oil obtained from olives stored at 0°C, was within the limit of 'extra' virgin quality in terms of acidity, irrespective of storage atmosphere after 4 weeks storage, whereas oils extracted from olives stored at 2.2°C in air and 2 kPa O_2 and olives stored at 5°C in 2 kPa O_2 were qualified as 'fine' virgin quality. K_{232} and K_{270} values were not surpassed in any of the treatments except oil obtained from olives stored at 20°C. Fatty acid composition was within the range required for 'extra' virgin olive oil, except for slightly higher linolenic acid. In conclusion, black-ripe 'Manzanillo' olives can be stored at 0–5°C in air or in 2 kPa O_2 for up to 4 weeks between harvesting and processing while maintaining fruit and oil quality. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

In many olive producing countries, processing of olives is not well synchronized with harvest due to the limited oil extraction capacities of the industrial facilities (Garcia and Streif, 1991; Gutierrez et al., 1992). Therefore after harvest olives might be piled in heaps and stored at ambient temperatures for up to several weeks before processing for oil extraction (Garcia et al., 1996a). The greatest amount of oil deterioration occurs during the harvest and processing procedures (Olias and Garcia, 1997). Pressure within the olive pile can damage the fruits and the fluid secretion from crushed olives may provide an optimum media for growth of fungi and bacteria (Olias and Garcia, 1997). Also heat produced by the olives respiratory activity may accelerate deterioration (Garcia and Streif, 1991). Oil extracted from these damaged olives can be high in acidity, low in stability (Garcia et al., 1996a), and high in volatile acids (acetic or butyric) which cause a musty smell (Gutierrez et al., 1992; Olias and Garcia, 1997).

'Manzanillo' is the most popular olive cultivar grown in California (Luh and Martin, 1996) and most of the production is destined for the processed, California-style 'black-ripe' market (Ferguson et al., 1991). Mature-green olives are often stored in brine until they are processed, but the wastewater disposal is a problem (Maxie, 1964; Kader et al., 1989). Storage of fresh olives is more desirable and could allow a more orderly flow to the processing plant (Kader et al., 1989). During the past few years there has been an increase in producing high quality olive oil from both green and black olives in California. The possibility of extending the storage time of olives before oil extraction could increase the yield of high quality product (Petruccioli and Parlati, 1987).

Storage of green 'Manzanillo' olives at temperatures below 5°C causes chilling injury (Kader et al., 1990) but black-ripe olives might tolerate lower temperatures without incidence of chilling injury, as found in avocado fruit (Kosiyachinda and Young, 1976). Kader et al. (1989) reported that 2 kPa O_2 retards fruit ripening and softening of green 'Manzanillo' olives kept at 5°C or lower.

Publications are available on the storage of mature-green fruit which have a green skin with reddish spots, commonly referred to as stage 2 (Garcia et al., 1996b). However, there is paucity of information on the storage of black-ripe fruit which have black skin with $> 50\%$ purple flesh, commonly referred to as stage 6 (Garcia et al., 1996b). Our study was conducted to identify the optimum preprocessing storage temperature and atmospheric composition to maintain fruit and oil quality of black-ripe 'Manzanillo' olives.

2. Materials and methods

2.1. Experimental material

Black-ripe olives (*Olea europea* cv. 'Manzanillo') were hand harvested from the University of California Davis Pomology Department experimental orchard and transported to the Postharvest Laboratory within 1 h. Olives were sorted to obtain fruit of uniform size and color and distributed randomly in 0.5-kg lots that were placed into 2-l glass jars as one replicate.

2.2. Storage treatments

The jars with olives were connected to continuous flow of humidified air (control), or 2 kPa O_2 (remainder nitrogen) in a flow-through-system at a flow rate of 500 ml min^{-1}. These were placed at 0, 2.2, and 5°C. Another group of olives were placed at 20°C only in air (control) to determine deterioration rate at a higher temperature. Three replicates were used per treatment and all data points represent the mean and SD of the three replicates. Quality evaluations were made initially and after 2, 4 and 6 weeks in storage.

2.3. Quality evaluation

2.3.1. Fruit quality

2.3.1.1. Decay incidence and physiological disorders. The percentages of decayed olives (with visible mycelial growth) and those exhibiting physiological disorders (mainly chilling injury) were determined.

2.3.1.2. Color and visual quality. External skin color (opposite sides) was measured with a chromameter (Minolta, Model CR-300, Minolta, Ramsey, NJ). Changes in hue angle (h°), calculated as $h = \arctan b*/a*$, which can be used effectively for visualizing the color of fruits (McGuire, 1992) was calculated. External color was measured on 20 olives for each replicate.

The visual quality in each replicate (20 olives) was determined based on the following hedonic scale: 1, poor (inedible); 3, fair, (limit of usability); 5, good (limit of marketability); 7, very good; and 9, excellent. A weighted average of individual olive quality scores was used to determine the mean visual quality score for each replicate.

2.3.1.3. Mass loss (%). Mass of olives in each replicate was recorded initially and after different treatments and storage durations and the difference was used to calculate percent mass loss.

2.3.1.4. Olive firmness. A momentum transfer generator (MTG) (Washington State University, Pullman, WA) was used for measuring the firmness of black olives. The device is a non-destructive impact sensor developed specifically for measuring firmness of sweet cherries and other soft fruits (Younce and Davis, 1995). Mitcham et al. (1998) reported that MTG is a more precise device for measuring firmness of sweet cherries than UC firmness tester equipped with an Ametek penetrometer. Two firmness measurements were recorded on opposite sides of each olive and 20 olives were measured for each replicate. Olive firmness is reported as MTG units.

2.3.1.5. Water and oil content. Ten olives from each replicate were placed in a petri dish and weighed before placing them in an oven at 105°C for 48 h until they reached a constant mass. Water content was determined from the difference of fresh and dry mass and expressed as percent. The dried olives were used to determine oil content in duplicate. Olives were ground by mortar and pestle and 10 g paste was filled in a Soxhlet cartridge and oil was extracted with 150 ml hexane at 70°C. After 6 h of extraction, hexane was collected and percent oil content was calculated on dry mass basis.

2.4. Fruit physiology

Carbon dioxide (CO_2) and ethylene (C_2H_4) production rates were monitored in triplicate during storage at 20°C and 101 kPa total pressure. An infrared CO_2 analyzer (model PIR-2000R, Horiba Instruments, Irvine, CA) and a gas chromatograph (model 211 Carle Instruments, Anaheim, CA) equipped with a FID detector were used to measure CO_2 and C_2H_4 concentrations, respectively.

2.5. Oil extraction

Olive oil was extracted using a procedure to imitate the industrial process (Garcia and Streif, 1991). About 400 g of black olives were triturated with mortar and pestle. After triturating, malaxation of the paste was done very slowly for 30 min. Then about 100 ml of water was added to 0.4 kg of paste to continue malaxation for additional 30 min. Paste was squeezed through four layers of cheesecloth. Extraction was continued by adding 50–100 ml more water and pressing again until all oil was extracted. The filtrate was centrifuged at $3000 \times g$ to separate the oil from the wastewater. Oil was collected by a Pasteur pipette under light vacuum, filtered through Watmann No. 2 filter paper, placed in dark glass bottles and flushed with nitrogen to eliminate O_2. The bottles were stored at $-20°C$ until analyses were performed.

2.6. Oil quality

2.6.1. Titratable acidity
Titratable acidity was determined in triplicate by the method described by Garcia et al. (1996a). The olive oil sample of 20 g was placed in an Erlenmeyer flask and 125 ml of a previously neutralized solvent mixture was added. The solvent mixture consisted of equal parts of ethanol and diethyl ether and phenolphthalein as an indicator (1% in ethanol) in the ratio of 2–125 ml v:v of the solvent mixture. When the sample was completely dissolved it was titrated with 0.1 N KOH to the first permanent pink color (persisting for at least 10 s) of the same intensity as the neutralized solvent prior to its addition to the sample. The

results were expressed as percent of free oleic acid present in the oil.

2.6.2. Peroxide value

Peroxide value was assayed according to Garcia et al. (1996a). A 5 g olive oil sample from each replicate was placed in a 250 ml Erlenmeyer flask which was previously purged with nitrogen, and then sample was shaken, dissolved in 25 ml of an acetic acid:chloroform solution (2:1, v/v) where O_2 was removed by bubbling N_2 through the solution. Subsequently, 1 ml of saturated potassium iodide (KI) solution was added. The mixture was placed in a darkness for 5 min, then 75 ml of distilled water was added to stop the reaction, and 0.5 ml of freshly prepared starch indicator solution (0.5% starch in distilled water) were added to each sample. Finally the mixture was titrated with 0.01 N sodium thiosulphate until the blue color disappears. The peroxide value was expressed in milliequivalents of oxygen per kg of oil.

2.6.3. Specific extinction coefficient at 232 and 270 nm (K_{232} and K_{270})

An oil sample of 250 mg was placed in a 25 ml graduated flask and diluted to 25 ml with cyclohexane (spectrophotometer grade). The sample was homogenized using a vortex and the resulting solution was placed into a quartz cuvette. Absorbance at 232 and 270 nm was determined in a spectrophotometer (Shimadzu, Model 1601), using the pure cyclohexane as a blank (Garcia et al., 1996a).

2.7. Fatty acid composition

Oil extraction and fatty acid methyl esters (FAMEs) were done in one step according to the method of Garces and Mancha (1993). This method allows complete oil extraction and fatty acid trans-methylation in the same tube. Ten olives from each replicate and three replicates for each treatment were randomly selected and the olives were analyzed individually for their fatty acid composition. For oil extraction, a 100 mg of flesh was taken from each olive. Samples were heated at 80°C for 2 h with a reagent mixture, which consisted of methanol:heptane:benzene:2,2-dimethoxypropane:H_2SO_4 in the ratio of 37:36:20:5:2 by volume. Approximately 3 min after the extraction tubes were placed in a hot water bath, samples were shaken vigorously to form one phase. After 2 h, extraction tubes were cooled down to room temperature and two phases were formed. The upper phase containing the fatty acid methyl esters was transferred to smaller vials, flushed with nitrogen and capped.

The composition of FAMEs was determined by gas chromatography performed on a Hewlett Packard 5890 GC equipped with a HP 7673 autosampler, controller, a FID detector, fitted with a 30-m column (SP-2330, Supelco, Bellfonte, PA) having a 0.25 mm I.D. and a 0.2 μm film thickness. The FAMEs were identified based on R_f of known standards (Sigma). Injector and detector temperature was 220 and 250°C, respectively. Oven temperature was held at 190°C for 7 min, then increased to 210°C at 10°C min^{-1}, and held for 5 min at the final temperature. Column pressure was maintained at 11 psi.

2.8. Statistical analysis

Analysis of variance (ANOVA), followed by Duncan's multiple range test with a significance level of $P < 0.05$ were performed on all data (CoStat Statistical Software, Ver. 5.01, CoHort Software, Minneapolis, MN).

3. Results and Discussion

3.1. Effect of different temperatures and storage atmospheres on olive fruit quality

3.1.1. Decay incidence and physiological disorders

Decay incidence markedly increased with storage temperature and duration but it was lower in black-ripe olives stored in 2 kPa O_2 (Fig. 1(b)) than in those stored in air (Fig. 1(a)). This positive effect of low oxygen atmosphere on reducing decay in black-ripe 'Manzanillo' olives is contrary to results of Garcia et al. (1994) who reported that 5 kPa O_2 in the storage atmosphere had caused higher incidence of decay in mature-green 'Picual' olives than seen in air. Also Garcia and
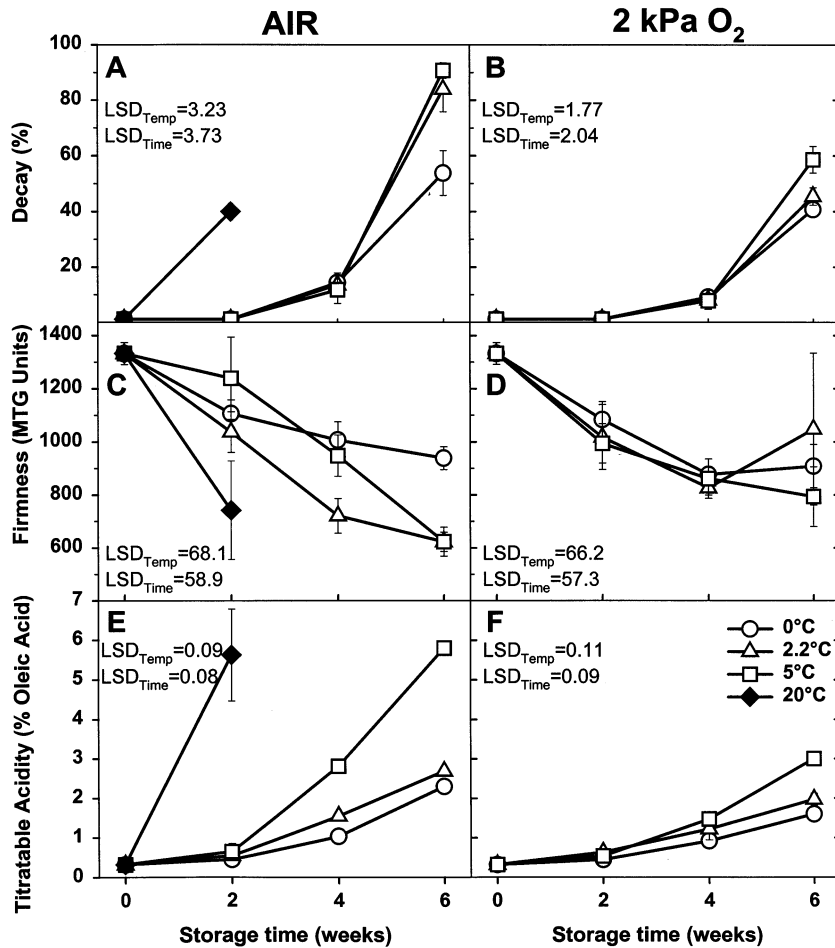
Fig. 1. Changes in the incidence of decay (a) and (b), fruit firmness (c) and (d) and titratable acidity (e) and (f) of black-ripe 'Manzanillo' olives stored at different temperatures in air or 2 kPa O_2. Each data point represents mean of three replicates $\pm$ SD. LSD at 5% level for temperature and time is shown for each figure.

Streif (1991) reported noticeable decay in mature-green 'Gordal' olives stored in 1 kPa O_2 at 5°C and commented that possibly the 1 kPa O_2 atmosphere can increase the sensitivity of olives to cold temperature and induce anaerobiosis, which may be followed by fungal infection. More than 40% of the olives stored at 20°C (ambient) decayed after 2 weeks (Fig. 1(a)) whereas no decay was observed in any of the treatments at lower temperatures during this period. The percent decay after 4 weeks was 14.4, 13.6 and 11.9% in air and 9.2, 8.2 and 7.9% in 2 kPa O_2 in olives kept at 0, 2.2 and 5°C, respectively. After 6 weeks in all treatments decay exceeded 25%, rendering them

unacceptable from a commercial point of view. Garcia et al. (1996a) reported more than 25 and 80% decay in mature-green 'Picual' olives after 1 and 2 weeks, respectively, which were stored at ambient temperature, whereas percent decay reached 25% after 6 weeks storage at 5°C. Similarly Garcia et al. (1996b) stated that a level of 20% decay for mature-green olives ('Villalonga' and 'Blanqueta') was reached in 60 days when stored at 5°C for 60 days, while olives stored at ambient temperatures exceeded 20% decay after only 20 days. Our results on decay of black-ripe 'Manzanillo' olives stored in ambient are consistent with the results of Garcia et al. (1996a,b).
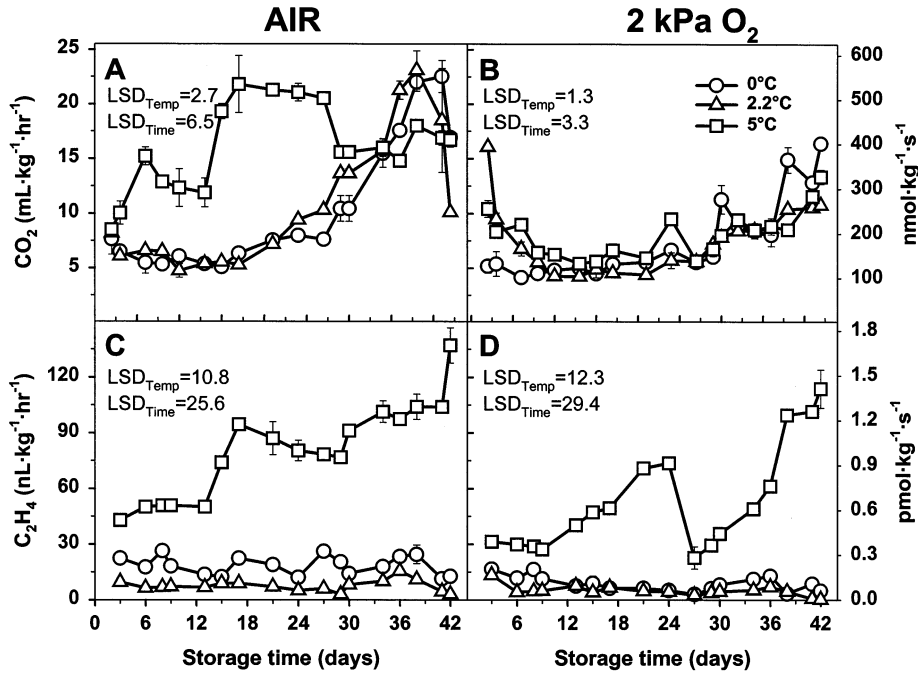
Fig. 2. Respiration (a) and (b) and ethylene production (c) and (d) rates of black-ripe 'Manzanillo' olives stored at different temperatures in air or 2 kPa O_2. Each data point represents mean of three replicates $\pm$ SD. LSD at 5% level for temperature and time is shown for each figure.

In our experiments there was no visual chilling injury (CI) symptoms as described by Kader (1996) in any of the storage treatments. But slightly higher ethylene production rates at 0°C (Fig. 2(c)) might indicate a mild chilling damage. Kader et al. (1990) observed CI in mature-green 'Manzanillo' olives when stored at 0 and 2.5°C after 2 and 5 weeks respectively, whereas when those stored at 5–7.5°C had no visible symptoms of CI. Our results support the thesis that ripe fruits of the same cultivar tolerate lower temperatures than mature-green fruits.

3.1.2. Color and visual quality

'Manzanillo' olives stored at 20°C had significantly poorer color than fruit from the other treatments. The differences between the rest of the treatments were minimal. Storage time and atmospheres had no significant effect on color (data not shown).

Visual quality of black-ripe 'Manzanillo' olives from 2 kPa O_2 and 0°C were generally rated

higher than air and other two temperatures. Nevertheless olives kept for 4 weeks in 2 kPa O_2 at 0, 2.2 and 5°C were rated as 7, 6 and 5, respectively, which indicates that they were still marketable to very good (data not shown).

3.1.3. Mass loss, water and oil content

Mass loss increased with storage time and temperature in black-ripe 'Manzanillo' olives (data not shown). Mass loss was twice as high in air compared to 2 kPa O_2, but still did not exceed 5% after 6 weeks in storage. No visible signs of shriveling were observed in olives stored at 0–5°C, irrespective of storage atmosphere. On the other hand olives stored at 20°C for 2 weeks lost 3% of their mass. Higher mass loss might be also a consequence of fungal decomposition of olives resulting in the leakage of cell fluids (Castellano et al., 1993).

There were no significant differences in water or oil content of black-ripe 'Manzanillo' olives either over storage time or among treatments (data not

shown). Water content at harvest averaged 60.5% and ranged between 59.1 and 61.2%. Oil yield averaged 36.6% (on dry mass basis) and ranged from 36.0 to 38.7%, irrespective of storage temperature and atmosphere after 6 weeks storage. Oil content of olives stored at 20°C was 29.9%, which is lower than that of fruit stored at 0–5°C. Similarly Gutierrez et al. (1992) also found lower oil contents in olives stored at ambient temperatures.

3.1.4. Fruit firmness

Olive firmness decreased as ripening progressed from 1392 MTG units at harvest to 728 MTG units in air and to 794 MTG units in 2 kPa O_2. No differences were noted among the two storage atmospheres tested, whereas the effect of storage period was significant. Fruit firmness declined by 24.4–45.9% in air (Fig. 1(c)) and 34.2–38.0% in 2 kPa O_2 (Fig. 1(d)) depending on the storage temperatures after 4 weeks storage. Olive fruit firmness was not significantly different at 0 and 5°C in both the air- and 2 kPa O_2-atmospheres. Our results on the effect of 2 kPa O_2 on firmness retention are contrary to results on mature-green olives whose firmness retention was better when olives stored under 5 or 2 kPa O_2 olives (Kader et al., 1990; Castellano et al., 1993). On the other hand Garcia and Streif (1991) found a reduction in firmness in mature-green 'Gordal' olives stored in 1 kPa O_2 at 5°C. Firmness of black-ripe olives kept at 20°C decreased by 44.3% within first 2 weeks, and was much lower than any of the other treatments (Fig. 1(c)). This is in agreement with previous reports (Garcia et al., 1996a,b) that low temperatures delay both softening caused by endogenous activity of the enzymes involved in fruit ripening and that caused by exogenous action of the pathogens.

3.2. Effect of different temperatures and storage atmospheres on olive fruit physiology

Respiration rate (Fig. 2(a) and (b)) and ethylene production (Fig. 2(c) and (d)) increased with storage time and temperature and was significantly affected by storage atmosphere. Ethylene and CO_2 production rates of black-ripe 'Manzanillo' olives were much higher in air than in 2 kPa O_2 and at 5°C than at 0 and 2.2°C. The difference in respiration rate was reflected in the deterioration rate of olives stored in air at higher temperatures. Ethylene production at 0°C was higher than at 2.2°C irrespective of storage atmosphere, which might be an indication of slight chilling injury (Kader, 1996).

Initial respiration rate of black-ripe 'Manzanillo' olives at 20°C was 80 ml kg^{-1} h^{-1} and declined with time to 29 ml kg^{-1} h^{-1} at the end of 2 weeks. Ethylene production rates at 20°C were also 5-fold higher than the initial value of olives stored at 5°C in air and declined to about the same level reached by olives stored for 6 weeks at 5°C in air. These results on olive physiology are in general accordance with previous reports (Garcia and Streif, 1991; Kader et al., 1990).

3.3. Effect of different temperatures and storage atmospheres on olive oil quality

3.3.1. Titratable acidity

Virgin olive oil contains 98% neutral lipids, mainly triglycerides (96–97%) followed by small quantity of diglycerides (1%) and a variable quantity of free fatty acids which are used as a marker of oil quality (Olias and Garcia, 1997).

During the initial 2 weeks of storage, acidity values of the olives from all the treatments were lower than 1%, which is the limit set for 'extra' quality virgin olive oil as determined by International Olive Oil Council (IOOC). In contrast, acidity of olives stored at 20°C increased to 5.7%, which represents a 18-fold increase relative to the initial value during the same period. After 4 weeks of storage, acidity of oil obtained from olives which were stored at 0°C, was still within the limit of 'extra' virgin quality irrespective of storage atmosphere (Fig. 1(e) and (f)). Oils extracted from olives stored at 2.2°C in air and in 2 kPa O_2 and olives stored at 5°C in 2 kPa O_2 were qualified as the second best category (virgin olive oil 'fine') where 1–2% acidity is allowed. Oil extracted from olives stored at 5°C in air fall into the third category, virgin olive oil 'semi-fine' (< 3.3% acidity). The increase in titratable acidity of an oil during storage is positively related to increasing
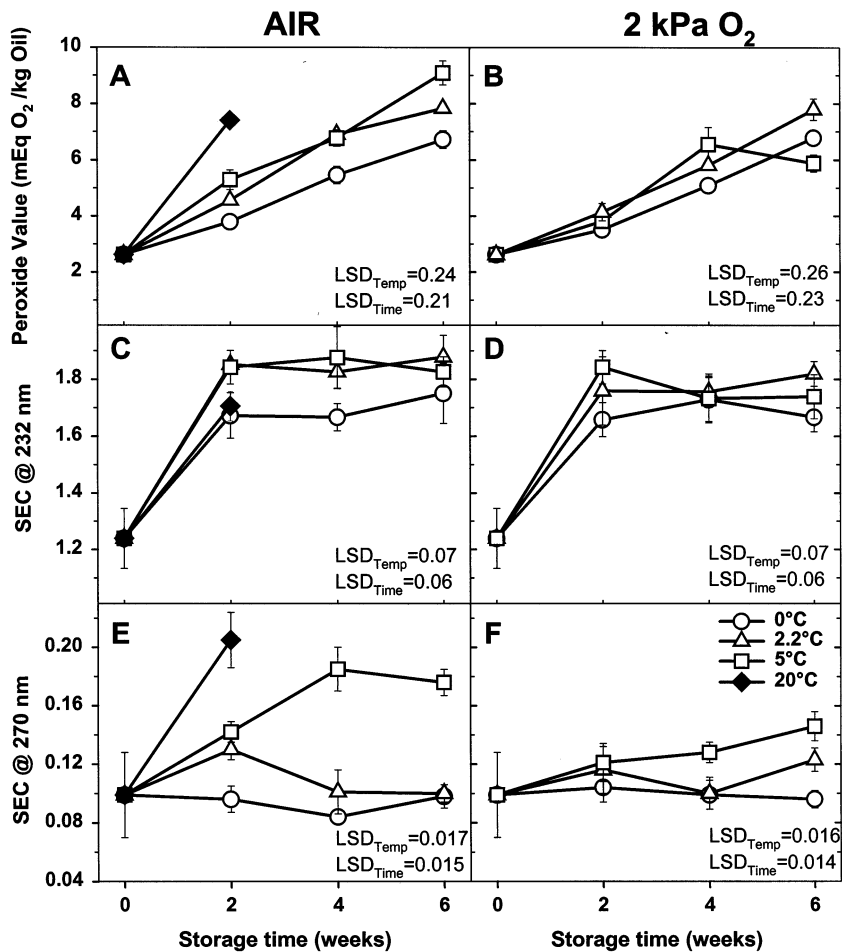
Fig. 3. Changes in the peroxide value (a) and (b), specific extinction coefficient (SEC) at 232 nm (c) and (d) and SEC at 270 nm (e) and (f) of black-ripe 'Manzanillo' olives stored at different temperatures in air or 2 kPa O_2. Each data point represents mean of three replicates $\pm$ SD. LSD at 5% level for temperature and time is shown for each figure.

storage temperature (Gutierrez et al., 1992; Garcia et al., 1994). Similarly, the percentage of decayed olives in the lot from which it was extracted increased with storage temperature (Garcia et al., 1996b). Titratable acidity was also affected by the storage atmosphere. Black-ripe 'Manzanillo' olives kept in air had 1.5-fold higher titratable acidity compared to olives stored in 2 kPa O_2. Similar beneficial effects of low oxygen atmospheres on titratable acidity were reported by Garcia and Streif (1991), Gutierrez et al. (1992).

The increase of acidity in oils extracted from fruit stored at 20°C (5.7% oleic acid) (Fig. 1(e)) correlated well with decay incidence as has been

reported by Gutierrez et al. (1992). Although percent decay increased sharply in all the treatments after 6 weeks of storage, oil from olives kept in 2 kPa O_2 at 0 and 2.2°C was still in the second best category 'fine' whereas oil from air-stored fruits fell into the third category 'semifine'.

3.3.2. Peroxide value

Cold storage of olives in air and especially in 2 kPa O_2 significantly delayed the rise in peroxide value of the oils, which is another indication of oxidation (Fig. 3(a) and (b)). Lower peroxide values for fruit held in 2 kPa O_2 may be a result of prevented oxidation of unsaturated fatty acids

(Garcia and Streif, 1991). However, Gutierrez et al. (1992) found that the reduction of O_2 concentration to 5 kPa showed no significant decrease in the peroxide value compared to air stored mature-green 'Picual' olives at the same temperature for 60 days.

Garcia et al. (1996a,b) found an increase in peroxide value of mature-green 'Picual', 'Blanqueta' and 'Villalonga' olives stored at ambient and at 8°C whereas olives from 5°C had the lowest level of peroxides. It is noteworthy that although percent decay reached 80% in ambient-stored olives, peroxide level was 14 mEq of oxygen per kg of oil and within the limits for 'extra' quality virgin olive oil. Garcia and Streif (1991) reported a marked increase in peroxide value of oils obtained from mature-green 'Gordal'olives stored in 1 kPa O_2.

Oil obtained from olives stored at 20°C for 2 weeks exhibited a sharp increase and reached 7.4 mEq of oxygen per kg (Fig. 3(a)) whereas all the other treatments reached that peroxide level after 6 weeks of storage. In our study none of the oils analyzed exceeded the limit of 20 mEq of oxygen per kg of oil, which is accepted as the limit for 'extra' quality virgin olive oil.

3.3.3. Specific extinction coefficient at K_{232} and K_{270}

K_{232} value is an indication of conjugation of polyunsaturated fatty acids whereas K_{270} is an indication of carbonylic compounds (aldehydes and ketones) in olives (Garcia et al., 1996b). UV specific extinction determination permits an approximation of the oxidation process in unsaturated oils (Gutierrez et al., 1992).

K_{232} values of oils from all the treatments increased after 2 weeks storage and remained approximately the same for up to 6 weeks storage (Fig. 3(c) and (d)). Lower K_{232} values were obtained in olives kept at lower temperatures especially at 0°C and in 2 kPa O_2 (Fig. 3(d)). Olives stored at 20°C resulted in a higher K_{232} value of 1.7 after 2 weeks (Fig. 3(c)). A K_{232} value of 2.40, which is the limit of 'extra' virgin olive oil, was not exceeded irrespective of storage atmosphere and temperature. These results are similar to those of Gutierrez et al. (1992) who observed no differences between olives stored at 5°C in 5 kPa O_2 or in air, but found a higher K_{232} values in mature-green 'Picual' olives stored at ambient temperature. On the contrary, Garcia and Streif (1991) reported that oil obtained from mature-green 'Gordal' olives stored under 1 kPa O_2 had a higher K_{232}. Garcia et al. (1996b) also found no significant differences between the two cultivars they studied between ambient and 5°C in terms of K_{232}. In general, oils obtained from olives at advanced stages of ripening might have a higher K_{232} (Garcia et al., 1996c).

Storage temperature and 2 kPa O_2 affected the K_{270} of oils (Fig. 3(e) and (f)); 0.20 (limit for 'extra' virgin olive oil) was not surpassed in any of the treatments except oil obtained from olives stored at 20°C (0.21) (Fig. 3(e)). Our results on the content of carbonylic compounds indicated by K_{270} values are in accordance with previous reports (Gutierrez et al., 1992; Garcia et al., 1996a).

3.3.4. Fatty acid composition

The saturated fatty acids found in black-ripe 'Manzanillo' olives are palmitic followed by stearic and arachidic acids (Table 1). Palmitic acid content was 15.2% at harvest and ranged between 13.7 and 14.9% during 6 weeks storage. Stearic acid ranged between 3.8 and 5.3% in air-stored olives and 3.8–4.6% in olives stored in 2 kPa O_2. Arachidic acid declined from 0.9% at harvest to between 0.2 and 0.7% irrespective of storage temperature and atmosphere.

Oleic acid (66.1–70.4%) is the main monounsaturated fatty acid in olives which also contain low amounts of palmitoleic acid (1.3–1.9%) and traces of eicosenoic acid.

Polyunsaturated fatty acids are very important for human nutrition as they are considered essential. Linoleic acid was the dominant polyunsaturated fatty acid in 'Manzanillo' olives ranging from 9.1 to 11.5%, while linolenic acid ranged from 0.9 to 1.4%.

There was no significant effect of storage temperature or atmosphere on fatty acid composition except for linolenic acid, which was slightly lower in air-stored fruit. Storage time had a greater effect on fatty acid composition of black-ripe 'Manzanillo' olives than temperature or atmosphere.

Table 1
Changes in the fatty acid composition (as percentage of total fatty acids) of black-ripe 'Manzanillo' olives stored at different temperatures in air or 2 kPa O$_2$

Atmosphere	Temperature (°C)	Storage period (weeks)	Saturated			Monounsaturated			Polyunsaturated	
			Palmitic (16:0)	Stearic (18:0)	Arachidic (20:0)	Palmitoleic (16:1)	Oleic (18:1)	Eicosenoic (20:1)	Linoleic (18:2)	Linolenic (18:3)
Air		Initial	15.2 ± 0.3[a]	4.0 ± 0.2	0.5 ± 0.2	1.9 ± 0.2	65.9 ± 1.0	0.2 ± 0.1	10.5 ± 0.5	1.3 ± 0.3
	0	2	13.7 ± 0.6	3.9 ± 0.3	0.3 ± 0.0	1.4 ± 0.1	70.4 ± 1.1	0.2 ± 0.0	9.2 ± 0.6	0.9 ± 0.1
		4	14.5 ± 0.3	3.8 ± 0.5	0.4 ± 0.1	1.5 ± 0.1	69.0 ± 1.8	0.1 ± 0.0	9.6 ± 1.5	1.1 ± 0.1
		6	14.2 ± 0.4	4.4 ± 0.6	0.3 ± 0.1	1.3 ± 0.1	67.8 ± 0.7	0.1 ± 0.0	10.6 ± 0.8	1.2 ± 0.2
	2.2	2	14.2 ± 0.8	4.8 ± 0.8	0.3 ± 0.0	1.6 ± 0.4	67.4 ± 4.6	0.1 ± 0.1	10.6 ± 2.8	1.0 ± 0.1
		4	14.9 ± 0.3	4.4 ± 0.3	0.4 ± 0.0	1.9 ± 0.1	66.9 ± 1.5	0.1 ± 0.0	10.3 ± 1.0	1.1 ± 0.0
		6	14.7 ± 0.4	4.7 ± 0.5	0.2 ± 0.1	1.8 ± 0.1	66.6 ± 1.3	0.2 ± 0.1	10.4 ± 1.3	1.4 ± 0.1
	5	2	13.7 ± 0.5	3.9 ± 0.1	0.3 ± 0.1	1.5 ± 0.1	70.1 ± 1.2	0.1 ± 0.1	9.4 ± 0.5	0.9 ± 0.1
		4	14.4 ± 0.4	4.3 ± 0.9	0.4 ± 0.2	1.6 ± 0.1	68.9 ± 0.5	0.1 ± 0.1	9.2 ± 0.7	1.1 ± 0.1
		6	13.8 ± 0.4	5.3 ± 0.3	0.2 ± 0.1	1.4 ± 0.1	69.1 ± 0.7	0.1 ± 0.0	9.1 ± 0.3	1.0 ± 0.2
	20	2	14.1 ± 0.7	4.1 ± 0.7	0.3 ± 0.1	1.5 ± 0.2	68.8 ± 2.3	0.2 ± 0.0	10.4 ± 2.0	0.8 ± 0.0
	LSD (5%) temperature		0.36	0.39	0.12	0.14	1.44	0.05	0.95	0.15
	LSD (5%) time		0.41	0.45	0.14	0.16	1.67	0.06	1.09	0.18
2 kPa O$_2$ (balance N$_2$)		Initial	15.2 ± 0.3	4.0 ± 0.2	0.5 ± 0.2	1.9 ± 0.2	65.9 ± 1.0	0.2 ± 0.1	10.5 ± 0.5	1.3 ± 0.3
	0	2	14.0 ± 0.4	4.1 ± 0.3	0.3 ± 0.0	1.4 ± 0.2	69.2 ± 2.3	0.2 ± 0.0	9.7 ± 1.5	1.0 ± 0.1
		4	14.7 ± 0.3	4.0 ± 0.9	0.4 ± 0.0	1.8 ± 0.0	66.4 ± 2.1	0.1 ± 0.0	11.5 ± 1.0	1.2 ± 0.3
		6	14.4 ± 0.3	3.8 ± 0.3	0.4 ± 0.1	1.5 ± 0.1	68.3 ± 0.8	0.2 ± 0.0	10.1 ± 0.8	1.1 ± 0.0
	2.2	2	14.6 ± 0.3	4.5 ± 0.4	0.4 ± 0.1	1.7 ± 0.2	66.1 ± 3.3	0.1 ± 0.1	11.3 ± 2.2	1.3 ± 0.2
		4	14.6 ± 0.5	4.0 ± 0.2	0.4 ± 0.1	1.8 ± 0.2	67.6 ± 1.0	0.1 ± 0.0	10.2 ± 0.8	1.3 ± 0.1
		6	14.2 ± 0.4	4.1 ± 0.2	0.3 ± 0.2	1.6 ± 0.1	68.2 ± 1.4	0.2 ± 0.1	10.2 ± 0.9	1.2 ± 0.1
	5	2	13.7 ± 0.1	4.5 ± 0.7	0.4 ± 0.1	1.6 ± 0.1	68.7 ± 1.8	0.1 ± 0.0	9.8 ± 1.3	1.2 ± 0.1
		4	14.5 ± 0.3	4.6 ± 0.3	0.7 ± 0.5	1.7 ± 0.1	66.6 ± 1.0	0.2 ± 0.1	10.3 ± 0.2	1.4 ± 0.3
		6	14.3 ± 0.4	4.4 ± 0.5	0.4 ± 0.2	1.5 ± 0.1	67.9 ± 1.0	0.1 ± 0.0	10.0 ± 0.6	1.3 ± 0.4
	LSD (5%) temperature		0.29	0.36	0.17	0.14	1.38	0.05	0.89	0.20
	LSD (5%) time		0.34	0.41	0.20	0.16	1.60	0.06	1.02	0.23

[a] Data are the means of three replicates ± SD.

Fatty acid profile of black-ripe 'Manzanillo' olives (Table 1) is in the range to fulfill the requirements of 'extra' virgin olive oil, except for linolenic acid. Maximum limit allowed by IOOC in 'extra' virgin olive oil is 0.9% linolenic acid (Raina, 1995; Spiller, 1996). We measured higher concentrations (up to $1.4 \pm 03\%$) for linolenic acid than those reported by Luh and Ferguson (1994). Although this might not be a problem for olives destined for table consumption, it may be a factor in olives destined for oil extraction. Interestingly, in all the articles cited in this paper authors used only oil quality criteria such as acidity, peroxide value and K_{232} and K_{270} values. Moreover, industry is using acidity as the sole indicator for olive quality, probably because it is easier to measure.

Oil of black-ripe 'Manzanillo' cultivar can be blended with oils from other cultivars to decrease the linolenic acid to 0.9% or lower. In California 'extra' virgin olive oil is made from 'Mission' and 'Manzanillo' olives which are blended after pressing the oil for obtaining better flavor. Linolenic acid concentration of 'Manzanillo' olives destined for oil, and the effect of storage temperatures and atmospheres on sensory attributes merit more investigation.

4. Conclusions

Storage of black-ripe 'Manzanillo' olives at 0–5°C in air or in 2 kPa O_2 is possible for up to 4 weeks and can be useful in synchronizing harvest and processing.

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