Effect of Mechanically Harvested Olive Storage Temperature and Duration on Oil Quality

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Additional index words. virgin olive oil, temperature, irrigation, mechanized harvest, polyphenols, free fatty acids, peroxide value

Summary. **Most newly planted olive (*Olea europaea* L.) orchards are irrigated and harvested mechanically. We assessed the effects of olive storage temperature and duration on the resultant oil's quality in three cultivars from modern orchards. Oil acidity increased with storage temperature and time, most markedly in 'Barnea' and least in 'Koroneiki'. In 'Koroneiki', after 9 days in cool storage (4 and 10 °C), free fatty acid (FFA) level remained constant. Polyphenol (PP) content behaved differently among cultivars: in 'Picual', it was relatively invariable; in 'Barnea', it decreased moderately; and in 'Koroneiki', it decreased sharply to half of its initial value in 4 °C storage and one-sixth its initial value in room temperature storage after 23 days. Peroxide value (PV) did not increase during the storage period and did not appear to be affected by temperature. Thus, different cultivars show different responses to storage, and fruit originated from modern orchards are not necessarily more sensitive to storage than those from traditional orchards.**

Olive has been grown traditionally for centuries in countries of the Mediterranean basin. However, the increase in olive oil consumption related to the perception of its health-related benefits (Waterman and Lockwood, 2007) has led, in the last two decades, to the intensification and expansion of olive cultivation, inside and outside of Mediterranean countries. According to the Food and Agriculture Organization of the United Nations (FAO), at present there are 9.4 million hectares of olive orchards in the world, most of which are still located in the Mediterranean basin (FAO, 2012). Traditionally, olives are not irrigated, but recently water application has been recognized as constructive to 1) increase yields of olives in regions with traditional rain-fed olive production (Moriana et al., 2003), 2) allow cultivation in high-density olive orchards, and 3) expand olive production into regions where there is not enough rainfall to support the crop (Connor, 2005). Today, 25% to 30% of the olive orchards supplying fruit to the oil extraction industry receive some level of irrigation (Lavee, 2011).

It has been claimed that the greatest deterioration of olive oil quality is due to poor handling of the olives between harvest and processing (Olias and García, 1997). These fruit may develop all kinds of degenerative processes in a short period of time. The resultant oils tend to show hydrolytic and oxidative deterioration, evident by their high FFA and PV content (García and Yousfi, 2006). Therefore, many studies have explored the proper way to store olives before processing to maintain good oil quality. Olive oil extraction is often not well synchronized with crop harvests because of limited labor and machinery available for harvest, and the number and size of oil extraction facilities (Agar et al., 1998). Therefore, short-term storage of olive fruit before oil extraction can provide a buffer which will enable more efficient use of both harvest facilities and the mill.

Several papers have been published on the effects of storage length and conditions on the resultant oil's quality. However, they generally examine manually picked fruit (Agar et al., 1998; Clodoveo et al., 2007; Dourtoglou et al., 2006; García et al., 1996; Kyriakidis and Dourou, 2002; Youssef et al., 2011) or give no indication of the harvest method (Inarejos-García et al., 2010; Kalua et al., 2008; Kiritsakis et al., 1998; Yousfi et al., 2009). Moreover, there is generally no indication of whether the fruit originated from rain-fed or irrigated orchards (Agar et al., 1998; Clodoveo et al., 2007; Dourtoglou et al., 2006; García et al., 1996; Inarejos-García et al., 2010; Kalua et al., 2008; Kiritsakis et al., 1998; Yousfi et al., 2009; Youssef et al., 2011), although we may speculate that those which are not indicated originated from rain-fed orchards. There are almost no such studies of fruit originating from modern, irrigated, and mechanically harvested orchards, although these are becoming more and more common in olive oil producing countries.

Olives from irrigated trees demonstrate an apparent sensitivity to mechanical wounding, which subsequently leads to increased free acidity and peroxide level, and decreased total phenol content in the oil (Ben-Gal et al., 2011; Dag et al., 2008; Patumi et al., 2002). Therefore, their storage capacity might be limited in comparison with fruit originated from traditional rain-fed, manually picked orchards. Olive storage is important to balance the rates of harvest with those of oil extraction in the mill. The objective of the current work was to evaluate the effect of storage temperatures and duration on extracted oil quality from commercial, mechanically harvested orchards.

Materials and methods

Samples. Olive fruit were obtained from irrigated commercial olive orchards in Israel: the Israeli cultivar Barnea and the Spanish cultivar Picual were obtained from Revivim olive farm (lat. 31.0500°N, long. 34.4103°E), and the Greek cultivar Koroneiki was from Gshur olive farm (lat. 32.7708°N, long. 35.7728°E). In Revivim, trees were at 7 × 3.5-m spacing, with irrigation of ≈800 mm per year, and in Gshur, trees were at 4 × 2-m spacing with irrigation of ≈600 mm per year.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1	ppm	$mg \cdot kg^{-1}$	1
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

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Fruit were collected immediately after commercial mechanical harvest on 16 Dec. 2009 and brought to the laboratory. Harvesting was performed with a commercial linear-vibrating trunk shaker (model D10; Dotan Technologies, Migdal HaEmek, Israel) in Revivim and with a commercial overhead mechanical harvester (model VX Braud; New Holland, Coex, France) in Gshur. The olives were randomly divided into 2-kg lots, which were placed in plastic baskets, each basket considered one replicate. Four replicates were used for each cultivar–storage duration–temperature combination. Maturity index (Uceda and Frías, 1975) was recorded and was 3.6 for 'Barnea', 2.6 for 'Picual', and 2.0 for 'Koroneiki'.

Storage treatments. Three different storage conditions were tested, two at 4 and 10 °C in refrigerated rooms and a third under ambient conditions (room temperature), with temperatures fluctuating between 12 and 25 °C, as recorded by data logging thermometer. Each storage condition was evaluated for five periods: 1, 5, 9, 16, and 23 d.

Oil extraction and characterization. Cold-pressed virgin olive oil was obtained with an "Abencor" system (MC2 Ingenieria y Sistemas, Seville, Spain) as described by Ben-David et al. (2010) for olives originated from irrigated orchards. Tested oil chemical quality parameters were: FFA content, PV, and total PP content. Determinations of FFA content and PV were carried out following International Organization for Standardization (ISO) analytical methods 660 and 3960, respectively. Free acidity (ISO 660), given as percentage of oleic acid, was determined by titration of a solution of oil in ethanol–ether (1:1, v/v) with ethanolic potassium hydroxide. PV (ISO 3960), expressed in milliequivalents active oxygen (O_2) per kilogram oil, was determined as follows: a mixture of oil and isooctane–acetic acid (3:2, v/v) was left to react in the dark with a potassium iodide solution and the free iodine was then titrated with sodium thiosulfate solution. Phenolic compounds were isolated from a solution of oil in hexane by triple extraction with methanol–water (60:40, v/v). Total PP, expressed as tyrosol equivalents (parts per million), were determined with a ultraviolet–visible spectrophotometer (Beckman Coulter, Fullerton, CA) at 735 nm using the Folin-Ciocalteu reagent (Swain and Hillis, 1959).

Results and discussion

To produce high-quality oil, it is generally recommended that the olives be processed within 12 to 24 h of harvest (Vossen, 2007). However, extension of this period by proper storage of the fruit would allow more efficient use of the harvest machinery on the one hand, and of the mill on the other. Here, we followed the effects of storage length and temperature on three major quality parameters in three different major olive oil cultivars grown in intensified orchards.

Influence of storage temperature on FFA level. Increased acidity after fruit storage correlates well with decay incidence (Gutiérrez et al., 1992). In general, the first action of a parasitic microorganism

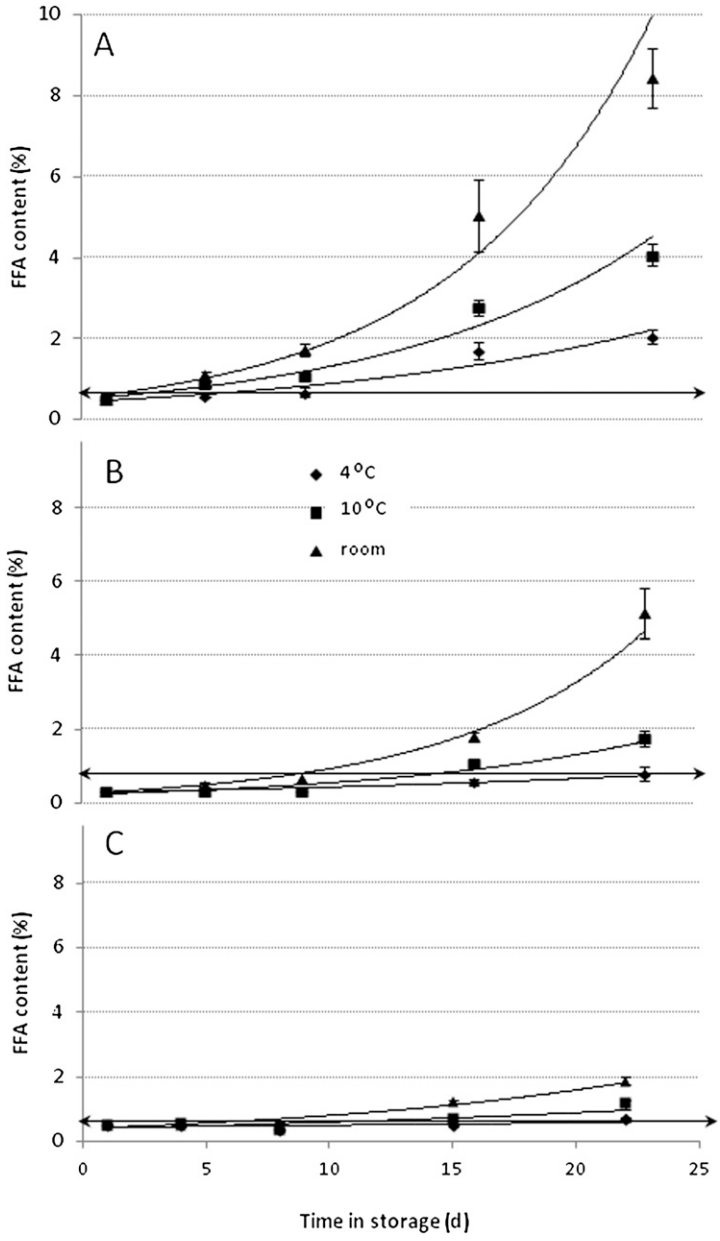

Fig. 1. Changes in free fatty acid (FFA) content (percent oleic acid) of oils obtained from olives stored at different temperatures (4 °C, 10 °C, and room temperature) for different periods of time (1, 5, 9, 16, and 23 d). (A) 'Barnea', (B) 'Picual', and (C) 'Koroneiki'. Data points represent means of four replicates ± SD. An arrow line is inserted at 0.8% to indicate the maximal accepted level for extravirgin olive oil; (1.8 × °C) + 32 = °F.

in an oil-rich tissue is the induction of hydrolytic activity by lipases, which leads to the release of fatty acids from the triacylglycerol molecules of the oil (Clodoveo et al., 2007). Lower storage temperatures delay the appearance of decay incidence (Agar et al., 1998). The different cultivars responded differently to storage time: 'Barnea' appeared to have the strongest response (Fig. 1A), followed by 'Picual' (Fig. 1B) and 'Koroneiki', which provided the most stable oil (Fig. 1C). Increased storage temperature resulted in an accelerated increase in FFA, as has been reported previously (Clodoveo et al., 2007; García et al., 1996; Gutiérrez et al., 1992; Inarejos-García et al., 2010; Kiritsakis et al., 1998). In 'Barnea', only the 4 °C storage conditions for up to 9 d resulted in oil that satisfies the extra virgin olive oil (EVOO) standard (FFA ≤ 0.8%). In 10 °C and room temperature storage, a rapid increase in oil acidity started immediately and after 9 d, and it was no longer acceptable as virgin oil (FFA > 2%) (Fig. 1A). A tendency toward elevated FFA levels in 'Barnea' from irrigated orchards has been recently reported by Ben-Gal et al. (2011). In 'Picual', the increase in FFA was slow under all storage conditions (including room temperature), and oil FFA content was reasonable for up to 5 d in storage, not rising above 0.65%. In 4 °C storage, the oil FFA level only reached the upper limit for EVOO (0.8%) after 23 d. 'Picual' oil is considered to have remarkably high stability, which is attributed to its high total PP content (Pardo et al., 2011). However, this high PP level refers to fruit originating from rain-fed conditions. In the current study, the PP levels were extremely low [around 120 mg·kg^{-1} oil vs. ≈800 mg·kg^{-1} oil in Pardo et al.'s (2011) study]. We presume that the reduced PP content is a result of irrigation (Ben-Gal et al., 2011; Tovar et al., 2002). Therefore, we speculate that the better stability of 'Picual' oil is due to some other factor, for example, its relatively high level of oleic acid (Mailer et al., 2010), which is expected to contribute to its oxidative stability and slow increase in FFA (Frankel, 2010) despite the relatively low PP content. 'Koroneiki' showed a remarkably slow increase in FFA content. In fact, at 9 d in the cold (4 and 10 °C), its FFA level was still constant (Fig. 1C). Even at room temperature, FFA content rose by only 0.04% during that period. At the lower temperature during the 23 d of storage, FFA of the 'Koroneiki' oil increased by only 0.2%. When stored at 10 °C, FFA content remained at an acceptable level (0.67%) for up to 16 d in storage. Kiritsakis et al. (1998) reported that oil obtained from 'Koroneiki' fruit stored for 30 d at 5 °C is of reasonable quality. Similarly, a slow increase in FFA levels during storage of 'Koroneiki' olives originated from a traditional rain-fed orchard was reported by Kyriakidis and Dourou (2002). The 'Koroneiki' oil is well known for its high PP content (Vossen, 2007). Similarly, in the current study, its initial (day 1) PP levels were much higher [≈5-fold (Fig. 2C)] than those of 'Barnea' (Fig. 2A) and 'Picual' (Fig. 2B). This further suggests the importance of PP in enabling long periods of storage for that cultivar.

INFLUENCE OF STORAGE TEMPERATURE ON PV. PV is a measure of primary oxidation. Surprisingly, PV was not consistently affected by either storage time or temperature (Fig. 3). In 'Barnea', PV (reported in milliequivalents O_2 per kilogram oil) ranged between 3.0 and 5.3 (Fig. 3A);

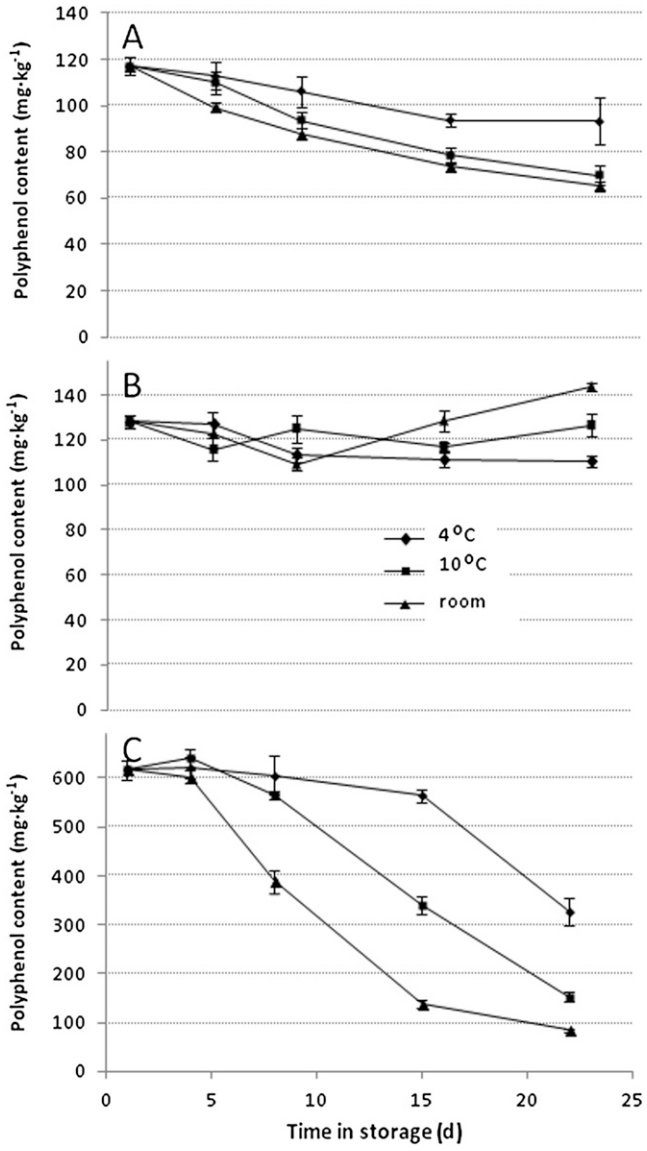

Fig. 2. Changes in polyphenol content of oils obtained from olives stored at different temperatures (4 °C, 10 °C, and room temperature) for different periods of time (1, 5, 9, 16, and 23 d). (A) 'Barnea', (B) 'Picual', and (C) 'Koroneiki'. Data points represent means of four replicates ± SD; (1.8 × °C) + 32 = °F, 1 kg = 2.2046 lb.

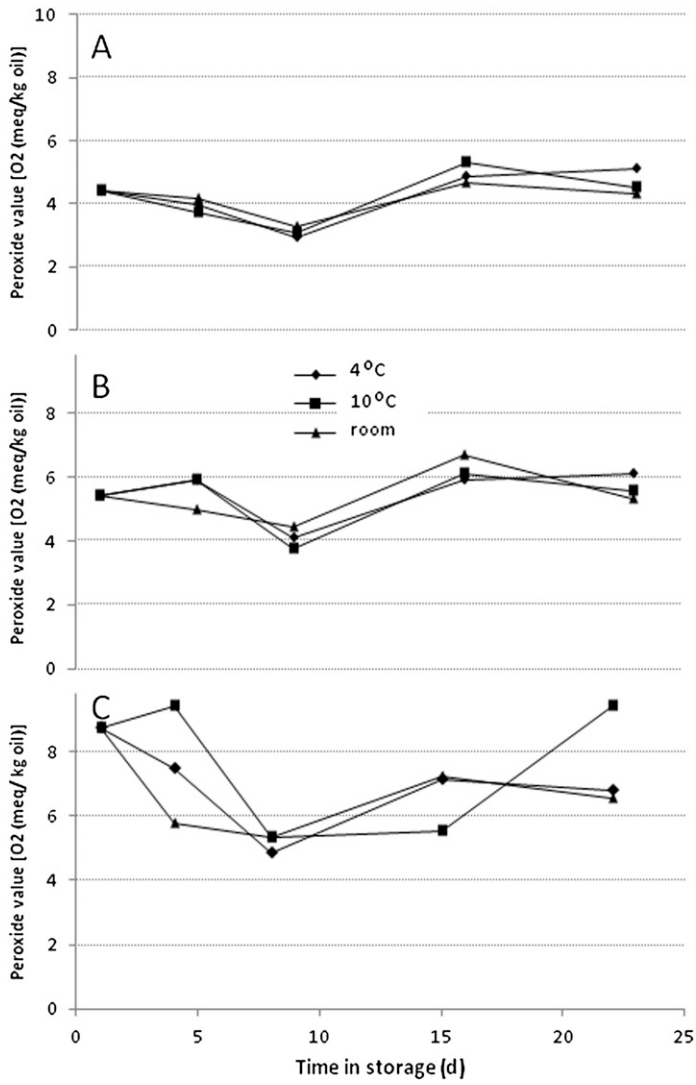

Fig. 3. Changes in peroxide values [milliequivalents active oxygen (O_2) per kilo gram oil] of oils obtained from olives stored at different temperatures (4 °C, 10 °C, and room temperature) for different periods of time (1, 5, 9, 16, and 23 d). (A) 'Barnea', (B) 'Picual', and (C) 'Koroneiki'. Data points represent means of four replicates; (1.8 × °C) + 32 = °F, 1 kg = 2.2046 lb.

in 'Picual', the values were a bit higher, between 3.7 and 6.7 (Fig. 3B); and in 'Koroneiki', they were highest, between 4.9 and 9.4 (Fig. 3C). However, even the highest PV was far below the upper limit for EVOO (≤20). García et al. (1996) reported constant PV for the first week of 'Picual' storage, followed by a sharp increase (from 4 to 14 at ambient temperature after 30 d), which might be a result of the larger containers they used compared with the current study, as this can affect the degradation process (Inarejos-García et al., 2010). In large containers, the weight of the olives damages the tissue of the drupe, resulting in the secretion of fluids from the fruit which favors the growth of undesirable microorganisms. Clodoveo et al. (2007) found the PV of oil obtained from olives stored at 20 °C for 15 d to be double its baseline values; however even after 30 d, the oil did not exceed the maximum PV for EVOO. Other studies did not find a consistent increase in PV with increasing storage time (Kiritsakis et al., 1998; Yousfi et al., 2008), in line with our findings.

Influence of storage temperature on PP content. As already noted, olive oil originated from irrigated orchards generally has relatively low PP content compared with that from rain-fed orchards (Dag et al., 2008). This is probably because the trees' water status affects phenol production in olive fruit and consequently, phenol content in the olive paste (Pardo et al., 2011). Alternatively, it has been claimed that rather than being produced at low rates, phenolic compounds are partitioned during the olive oil extraction process and removed with the wastewater separated from oil in the mill; since the water content in fruit from irrigated orchards is higher, there is more wastewater washing the PP out and consequently reducing its content in the oil (Rodis et al., 2002). Clodoveo et al. (2007) reported decreasing PP content with longer storage period, while lower temperatures and carbon dioxide (CO_2) slowed the process. Yousfi et al. (2008) indicated that reduced PP content following fruit storage is a positive characteristic that may assist in reducing the intensity of sensor-evaluated bitterness for markets accustomed to the milder taste of refined oil. However, Dourtoglou et al. (2006), working with green olives, reported increases in PP content in oil from fruit stored for up to 5 d, which was even more pronounced in an enriched CO_2 environment. In the current study, we did not observe any increase in PP content. However, we found different responses for the different cultivars: in 'Picual', in general, there were minor changes in PP content during storage, with values ranging between 110 and 140 $mg \cdot kg^{-1}$ oil (Fig. 2B); in 'Barnea', we found a moderate reduction, from around 120 to 65 $mg \cdot kg^{-1}$ oil (Fig. 2A), whereas in 'Koroneiki' (Fig. 2C), we observed the strongest reduction, from 600 to 100 $mg \cdot kg^{-1}$ oil. The high initial PP content in 'Koroneiki' might be a result of cultivar characteristics as well as the relatively low ripeness index of the fruit in comparison with the other cultivars. In 'Barnea' and 'Koroneiki', the higher the storage temperature, the stronger the reduction in PP content; that is, ambient temperature resulted in the lowest final PP content while the cold storage conditions (4 °C) resulted in the highest levels. However, in 'Picual', the trend was reversed: the "room temperature" treatment resulted in higher PP levels than the 4 °C treatment, 144 vs. 111 $mg \cdot kg^{-1}$ oil, respectively, for the longest storage period of 23 d. These different trends in total PP content between cultivars might reflect different PP profiles: while phenolic compounds such as oleuropein

and ligstroside derivatives progressively decrease during storage, other, simple phenolic compounds such as hydroxytyrosol and tyrosol are formed from the hydrolysis of high-molecular-weight molecules (Kalua et al., 2008).

Conclusion

In general, it is better to extract oil from fruit shortly after harvest; however, when needed, fruit can be stored before oil extraction. From the results of the present study, we can conclude that despite the possible relative sensitivity of fruit from irrigated orchards to deterioration and to potential damage during mechanical harvesting, they can be stored before oil extraction without much reduction in oil quality. 'Koroneiki' olives can be stored for up to 9 d at 4 and even 10 °C with no reduction in PP content and no increase in FFA content; PV even improved during this time period. Even after 24 d, oils obtained from 'Koroneiki' fruit stored at 4 °C had FFA values suitable for the EVOO category; however, their PP content was about half of their initial content, which is expected to affect the oil's shelf life and organoleptic properties. García et al. (1996) recommended 5 °C as the most suitable temperature for obtaining the best oil quality after prolonged fruit storage. They further stated that storage temperatures above 8 °C must be avoided. Our data show that 'Picual' and 'Koroneiki' olives can be stored at 10 °C or even at room temperature for 9 d without much reduction in oil quality. However, it might be that other chemical and organoleptic quality parameters, which were not tested in the current study, are reduced during this time. In general, mills extract oil from olive orchards that have maintained similar cultivars and cultivation practices for years. Olive storage feasibility can be evaluated in those mills, using a small-scale mill (such as Abencor) to define, for their conditions, each cultivar's storage capacity in accordance with the cultivation practices in the region. A comparison of our results with those of García et al. (1996) shows that, at least for 'Picual', modernization of olive cultivation (i.e., irrigation and mechanical harvest) does not reduce the olive's capacity for storage before oil extraction. In addition to better flexibility in harvest and mill operations, fruit storage might increase the extraction efficiency of oil in the mill (Kalua et al., 2008). This is particularly relevant for irrigated orchards, where the high water content of the fruit reduces the extraction efficiency (Grattan et al., 2006). Fruit storage might also have a beneficial effect in reducing oil bitterness (Yousfi et al., 2008) for markets accustomed to milder-flavored oils.

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