Effect of Preservation Treatment, Light, and Storage Time on Quality Parameters of Spanish-Style Green Olives

Antonio H. Sánchez,* Alfredo Montaño, and Luis Rejano

Instituto de la Grasa (CSIC), Apartado 1078, 41012 Seville, Spain

The influence of acidity−salt level, pasteurization, light, and storage time on pH, titratable acidity, brine color, and firmness and color of the fruit was determined in packed green olives (whole, pitted, and stuffed with pepper paste). There was a significant increase in pH during storage, indicating microbiological instability, in the case of the nonpasteurized pitted olives with the lowest acidity−salt level (0.3−3.0%). In general, the pasteurized samples were less firm and had lower color index [$i = (4R_{635} + R_{590} - 2R_{560})/3$] and a darker brine (as measured by the parameter $A_{440} - A_{700}$) than the nonpasteurized samples. The color index was highly correlated with the parameter L^*. The samples stored in the presence of light had a paler brine, but higher values of i, than those stored in darkness. During storage the firmness degraded slowly, with the data fitting first-order kinetics well ($r > 0.90$). The color of the olives also degraded with time, mainly in the pasteurized samples stored in darkness. The repercussions on the product's shelf life are discussed.

Keywords: *Olives; storage; shelf life; firmness; color*

INTRODUCTION

The worldwide production of Spanish-style green olives is some 400 000 tons per year, with Spain being the main producer with some 120 500 tons/year (IOOC, 1996). The preparation of this product consists of treating the fruits with a dilute NaOH solution (1.8−2.5%, w/v) followed by one or two washes with water to remove the excess alkali. A solution of NaCl (10−13%, w/v) is then added, and a lactic acid fermentation takes place. Finally, the olives are packed in small containers with an acidified cover brine. There are various forms of presentation to the consumer: whole, pitted, stuffed, sliced, etc. The final packed product has the following physicochemical characteristics: pH, 3.2−4.1; titratable acidity, 0.4−0.6%, expressed as lactic acid; and NaCl, 5−7% (Fernández-Díez et al., 1985). There is a current tendency to use thermal treatments of pasteurization to stabilize the product, thus satisfying consumer demand for products with lower levels of acidity and salt, but without significantly affecting the color and firmness of the olives (Sánchez et al., 1991). The long-term effect of such treatment, however, is not known. At the same time, during marketing, the olives may be stored in the light (for example, in a shop window) or in darkness (for example, inside boxes); it is equally unknown how these storage conditions affect the quality parameters of the product.

Shelf life has not yet been determined for Spanish-style green olives, although some companies, because this is a fermented product of high acidity, indicate a time of 3 or 5 years on the packaging label. Shelf life studies must inevitably include, for each critical quality attribute, a knowledge of the level beyond which the product is considered unacceptable (Jones and Man, 1994). In the case of Spanish-style green olives, var. Manzanilla, it is known that a value of the color index (i) < 23.7 is related with a poor color of the fruit (Sánchez et al., 1985) and that a value of $A_{440} - A_{700}$ for the packing brine > 0.23 AU is considered unacceptable (Montaño et al., 1988).

The aims of the present work were to study the effect of different preservation treatments (distinct acidity−salt levels, pasteurization), storage conditions (storage in light or in darkness), and storage time on the physicochemical characteristics, firmness, and color of green olives for the three main forms of presentation (whole, pitted, and stuffed with pepper paste) and to make inferences about the shelf life in each case.

MATERIALS AND METHODS

Olives. The olives, *Olea europaea* L. cv. Manzanillo, were supplied by the firm Compañía Envasadora Loreto, S.A. (Espartinas, Sevilla) in the three forms of presentation to be studied (whole, pitted, and stuffed with pepper paste). These had the following values of firmness (expressed as N/g) and color (L^*, a^*, b^*, i): whole olives, 29.2 and 55.5, 4.0, 40.4, and 30.2; pitted olives, 33.4 and 50.4, 3.6, 34.4, and 25.8; and stuffed olives, 42.9 and 51.1, 3.5, 35.7, and 25.2.

Packing and Storage Conditions. The olives were packed in bucket-type glass containers with a fruit weight (grams)/cover liquor volume (milliliters) ratio of 163/100, 144/122, and 163/100 for whole, pitted, and stuffed samples, respectively. The cover liquor used was a brine acidified with lactic acid. The concentrations of acid and NaCl were calculated to give at osmotic equilibrium the following acidity (%)−salt (% NaCl) levels: level 1, 0.40−4.5, 0.30−3.0, 0.40−4.0; level 2, 0.50−5.5, 0.45−5.0, 0.50−5.5; and level 3, 0.65−6.5, 0.40−6.5, 0.60−6.5, for whole, pitted, and stuffed olives, respectively. Moisture contents of 60% for whole olives and 75% for pitted and stuffed olives were assumed. For each type of olive, 200 replicated jars were prepared for each level. Of these, after the jars were sealed, 100 were pasteurized for 9 min at 85 °C (Sánchez, 1989) and the other 100 were left unpasteurized. Half of the jars (50) of each series were kept in the light on an open shelf in the laboratory and close to a window; the other half were kept in darkness, inside sealed cardboard boxes in a covered industrial plant. Duplicate samples from each lot were analyzed the day after packing and after 3, 6, 12, 18, and 36 months of storage. The fruits were analyzed to measure firmness and color, and the packing brine was analyzed to determine the physicochemical parameters.

Physicochemical Analyses. The pH of samples was measured using a Metrohm 670 Titroprocessor. Acidity was

* Author to whom correspondence should be addressed (telephone 34-5-4691054; fax 34-5-4691262; e-mail ahiginio@cica.es).

S0021-8561(97)00251-3 CCC: $14.00

Table 1. Main Effects of Acidity−Salt Level,[a] Pasteurization Treatment, Light, and Storage Time on Quality of Spanish-Style Green Olives (Whole Olives)[b]

main effects	pH	acidity (as % lactic acid)	color brine ($A_{440} - A_{700}$)	firmness (N/g)	color index (i)[c]	L^*	a^*	b^*
acidity−salt level								
L1	3.04 a	0.45 a	0.104 a	20.6 a	28.5 a	55.0 a	3.5 a	39.8 a
L2	2.91 b	0.58 b	0.104 a	21.8 b	28.2 a	54.7 b	3.5 a	39.4 a
L3	2.81 c	0.72 c	0.097 b	22.2 c	28.0 a	54.5 b	3.7 a	39.6 a
pasteurization treatment								
untreated	2.92 a	0.59 a	0.098 a	22.3 a	28.7 a	55.1 a	3.7 a	40.6 a
treated	2.92 a	0.59 a	0.106 b	20.8 b	27.8 b	54.4 b	3.5 b	38.7 b
light								
presence	2.93 a	0.59 a	0.096 a	21.7 a	28.5 a	54.9 a	3.6 a	39.6 a
absence	2.91 b	0.58 b	0.107 b	21.4 a	28.0 b	54.5 b	3.6 a	39.7 a
storage time								
initial[d]	−[e]	−	0.050 a	26.5 a	28.4 a	54.3 ad	3.8 a	40.1 a
3 months	2.84 a	0.53 a	0.106 b	27.0 a	29.2 b	55.4 b	3.5 b	39.9 ab
6 months	2.86 b	0.57 b	0.108 b	21.5 b	28.5 a	55.2 bc	3.5 b	40.1 a
12 months	2.95 c	0.57 b	0.105 b	20.8 c	28.2 a	54.8 bcd	3.5 b	39.5 ab
18 months	2.90 d	0.60 c	0.122 c	17.7 d	27.5 c	54.5 ac	3.5 b	39.3 ab
36 months	3.04 e	0.67 d	0.129 d	13.8 e	27.3 c	54.0 ad	3.7 a	38.7 b

[a] Acidity (%)−salt (% NaCl) levels: L1, 0.40−4.5; L2, 0.50−5.5; L3, 0.65−6.5. [b] Means with different letters within a column for each effect are significantly different ($p < 0.05$). [c] Color index, $i = (4R_{635} + R_{590} - 2R_{560})/3$. [d] Initial = 24 h after packing. [e] −, not determined.

determined by titrating up to pH 8.3 with 0.2 N NaOH and expressed as percent (w/v) of lactic acid. Brine color was determined as the difference in absorbance at 440 and 700 nm ($A_{440} - A_{700}$), as described by Montaño et al. (1988).

Determination of Fruit Firmness and Color. Firmness was determined using a Kramer compression cell coupled to an Instron test device (Model 1011). The cross-head speed was 200 mm/min. The firmness of olives was expressed as the mean of 10 replicated measurements, each of which was performed on 4 olives (i.e. 40 olives/jar were used). In the whole olives, the pit was removed first using a manual machine. In the olives stuffed with pepper paste, the stuffing was removed before the measurements were made. Shear compression force was expressed as newtons per gram of product.

The measurements of fruit color were carried out using a Color-View Model 9000 spectrophotometer (BYK-Gardner, Inc., Silver Spring, MD) with a measurement area of 11 mm diameter, 45° circumferential illumination, and observation angle of 0°. All measurements were done on the CIE 1976 $L^*a^*b^*$ scale using illuminating conditions CIE type C, 10° observer. Results were expressed as the mean of 10 replicate measurements, each made on 1 olive. From the reflectance curve supplied by the apparatus, a color index, i, was obtained, as described by Sánchez et al. (1985):

$$i = (4R_{635} + R_{590} - 2R_{560})/3$$

R_{635}, R_{590}, and R_{560} are the values of reflectance at 635, 590, and 560 nm, respectively.

Statistical Analyses. The data were subjected to analysis of variance using the Statistica software (StatSoft Inc., 1996). Wherever F values were significant, Duncan's multiple range test was used to separate the means of mean effects. Kinetics of degradation of olive firmness was determined by regression analysis for each type of olive. Softening rate constants obtained for pasteurized and nonpasteurized samples were compared using the F^* statistic.

RESULTS AND DISCUSSION

Olives supplied for this work had different initial characteristics as mentioned under Materials and Methods. Since, for processing of Spanish-style green olives, fruit is normally picked when it has a green-yellow color, the observed differences in initial firmness and color can be attributed to different processing factors (i.e. alkaline treatment, washing system, fermentation, operations during the postfermentation stage) rather than to different grades of maturity of olives. After packing, the physicochemical quality of olives changed, as described below.

pH and Titratable Acidity of the Brines. The different levels of lactic acid added in cover brine significantly ($p < 0.05$) affected the titratable acidity and pH of the samples (Tables 1−3). The values of titratable acidity measured were generally slightly higher than expected, probably because the actual moisture content of olives was slightly different from that assumed, the greatest difference being in the case of whole olives. The influence of light on the titratable acidity and pH of the samples was negligible. For each acidity−salt level, the change in titratable acidity and pH of the pasteurized samples during storage was almost the same as that of the nonpasteurized samples (data not shown), except for the lowest level of acidity in pitted olives (Figure 1b). In this case, besides the increase in pH, a considerable sediment formation was observed in the jars of nonpasteurized samples. Sediment formation during storage of packed green olives has been correlated with the growth of propionic bacteria (Borbolla et al., 1975). It seems necessary that the initial pH is 3.3 or lower for nonpasteurized packed olives to be microbiologically stable during storage (Borbolla and Pellissó, 1972). The simultaneous increases in the titratable acidity and in the pH of brines during storage (Tables 1−3) are noteworthy. Fleming et al. (1988) found a similar evolution, without evidence of microbial spoilage, during storage of fermented cucumbers; however, no explanation of this finding was given. Degradation of pectins under acid conditions, likely responsible for olive softening, and solubilization of deesterified galacturonate residues into the brine may cause an increase in titratable acidity along with a change in the acid−base equilibrium of brine; as a result, an increase in pH brine may take place.

Brine Color. The pitted olives had darker brine colors (higher values of $A_{440} - A_{700}$) than did the whole and stuffed olives (Tables 1−3). In all three types of olive, the brine color of the pasteurized samples was darker than that of the nonpasteurized ones, which agreed with results by Brenes et al. (1989) for green olives packed with different cover brines. Darkening of brines due to pasteurization may be attributed to chemical oxidation of phenols. Although nonenzymic autoxidative phenolic browning reactions occur very

Table 2. Main Effects of Acidity−Salt Level,[a] Pasteurization Treatment, Light, and Storage Time on Quality of Spanish-Style Green Olives (Pitted Olives)[b]

main effects	pH	acidity (as % lactic acid)	color brine ($A_{440} - A_{700}$)	firmness (N/g)	color index (i)[c]	L^*	a^*	b^*
acidity-salt level								
L1	3.60 a	0.32 a	0.171 a	24.1 a	25.4 a	51.6 a	3.0 a	33.5 a
L2	3.10 b	0.50 b	0.158 b	23.3 b	26.3 b	51.1 b	3.5 b	33.2 a
L3	3.11 c	0.44 c	0.157 b	24.4 a	26.2 b	51.0 b	3.7 c	33.5 a
pasteurization treatment								
untreated	3.35 a	0.42 a	0.157 a	24.4 a	26.4 a	52.0 a	3.3 a	34.5 a
treated	3.19 b	0.42 a	0.168 b	22.5 b	25.6 b	50.5 b	3.5 b	32.3 b
light								
presence	3.27 a	0.42 a	0.151 a	24.4 a	26.5 a	51.6 a	3.4 a	33.6 a
absence	3.27 a	0.42 a	0.172 b	23.5 b	25.5 b	50.9 b	3.4 a	33.2 b
storage time								
initial[d]	–[e]	–	0.144 a	31.7 a	26.5 a	50.6 ad	3.6 a	32.6 a
3 months	3.12 a	0.39 a	0.164 b	28.6 b	27.1 a	51.8 bc	3.6 a	33.1 ab
6 months	3.22 b	0.42 b	0.170 b	22.0 c	26.3 a	51.5 bcd	3.4 a	33.4 ab
12 months	3.34 c	0.41 c	0.151 c	22.8 c	25.8 a	51.4 bcd	3.4 a	33.8 bc
18 months	3.26 d	0.43 b	0.188 d	19.4 d	24.4 b	51.0 acd	3.2 b	33.4 ab
36 months	3.40 e	0.45 d	0.169 b	16.9 e	24.9 b	51.0 acd	3.0 b	34.1 bc

[a] Acidity (%)−salt (% NaCl) levels: L1, 0.30−3.0; L2, 0.45−5.0; L3, 0.40−6.5. [b] Means with different letters within a column for each effect are significantly different ($p < 0.05$). [c] Color index, $i = (4R_{635} + R_{590} - 2R_{560})/3$. [d] Initial = 24 h after packing. [e] –, not determined.

Table 3. Main Effects of Acidity−Salt Level,[a] Pasteurization Treatment, Light, and Storage Time on Quality of Spanish-Style Green Olives (Stuffed Olives)[b]

main effects	pH	acidity (as % lactic acid)	color brine ($A_{440} - A_{700}$)	firmness (N/g)	color index (i)[c]	L^*	a^*	b^*
acidity−salt level								
L1	3.20 a	0.41 a	0.111 a	32.0 a	24.0 a	51.3 a	2.9 a	34.7 a
L2	3.02 b	0.53 b	0.099 b	30.7 a	24.1 a	51.2 a	3.1 b	35.1 a
L3	2.93 c	0.63 c	0.104 c	30.9 a	23.8 a	50.7 b	3.3 c	34.4 a
pasteurization treatment								
untreated	3.06 a	0.53 a	0.099 a	32.2 a	24.6 a	51.7 a	3.1 a	35.5 a
treated	3.04 a	0.52 a	0.110 b	30.2 b	23.4 b	50.4 b	3.0 b	33.9 b
light								
presence	3.06 a	0.53 a	0.098 a	31.9 a	24.1 a	51.1 a	3.1 a	34.5 a
absence	3.04 a	0.52 a	0.109 b	30.6 b	23.8 a	51.0 a	3.1 a	34.9 b
storage time								
initial[d]	–[e]	–	0.096 a	41.8 a	26.1 a	51.2 a	3.7 a	35.9 a
3 months	2.96 a	0.51 a	0.109 b	38.1 b	25.1 b	51.5 a	3.3 b	34.3 bc
6 months	2.99 a	0.53 b	0.103 a	29.9 c	23.9 c	51.1 a	3.1 c	34.7 bc
12 months	3.08 b	0.51 a	0.099 a	29.2 c	23.1 d	51.0 a	2.9 d	35.1 c
18 months	2.98 a	0.53 b	0.113 b	24.8 d	22.2 e	50.8 a	2.6 e	34.7 bc
36 months	3.19 c	0.55 c	0.112 b	20.3 e	22.3 e	50.6 a	2.6 e	33.7 b

[a] Acidity (%)−salt (% NaCl) levels: L1, 0.40−4.0; L2, 0.50−5.5; L3, 0.60−6.5. [b] Means with different letters within a column for each effect are significantly different ($p < 0.05$). [c] Color index, $i = (4R_{635} + R_{590} - 2R_{560})/3$. [d] Initial = 24 h after packing. [e] –, not determined.

rapidly in alkaline media, they can also take place under acid conditions (Cilliers and Singleton, 1989; Oszmianski et al., 1996). Rejano et al. (1995) observed a relationship between darkening of brines and oxidation of hydroxytyrosol in Spanish-style green olives packed in plastic pouches. The brine color of samples stored in the light was paler than that of olives stored in darkness (Tables 1−3). Brenes et al. (1990) found the same effect of light on the color of regenerated olive brines. The absence of pit in the case of the pitted and stuffed olives meant that the equilibrium between olive juice and cover liquor was reached rapidly, and so the change of color between 1 day and 3 months of storage was less marked than in the case of whole olives. The value of the parameter $A_{440} - A_{700}$ was always below the limit of 0.23 AU fixed for packed green olives, above which the brine color is considered unacceptable (Montaño et al., 1988).

Firmness. The acidity−salt level used for packing did not have a notable influence on fruit firmness, although in the case of whole olives the mean values of firmness increased with the acidity−salt level (Tables 1−3). The mechanisms by which NaCl and organic acids affect the olive firmness are not clear. Jiménez et al. (1997) suggest that there must be some locations in the cell wall that lead to firmness increases by electrostatic means (places that could be occupied by monovalent and divalent cations) and others that need divalent cations, because they constitute coordination complexes; at low pH (e.g. pH 3), the ionic locations are occupied by protons, so increasing amounts of protons and/or sodium have no effect on firmness. In accelerated softening assays at 80 °C, Brenes et al. (1994) found that NaCl concentration between 0 and 1.2 M did not have any effect on firmness of Spanish-style green olives, but the initial firmness declined as the pH decreased within the pH range 2.5−4.0. Light had no significant effect ($p < 0.05$) on firmness in whole olives, but in the case of pitted and stuffed olives the samples stored in darkness were less firm than those stored in light (Tables 1−3). The explanation of this effect is not readily apparent. Pasteurization resulted in a significant decrease in firmness in all three cases. Degradation by heat of texture of Spanish-style green olives can be modeled by first-order kinetics (Sánchez et al., 1991). Firmness decreased with storage time, and after 3 years

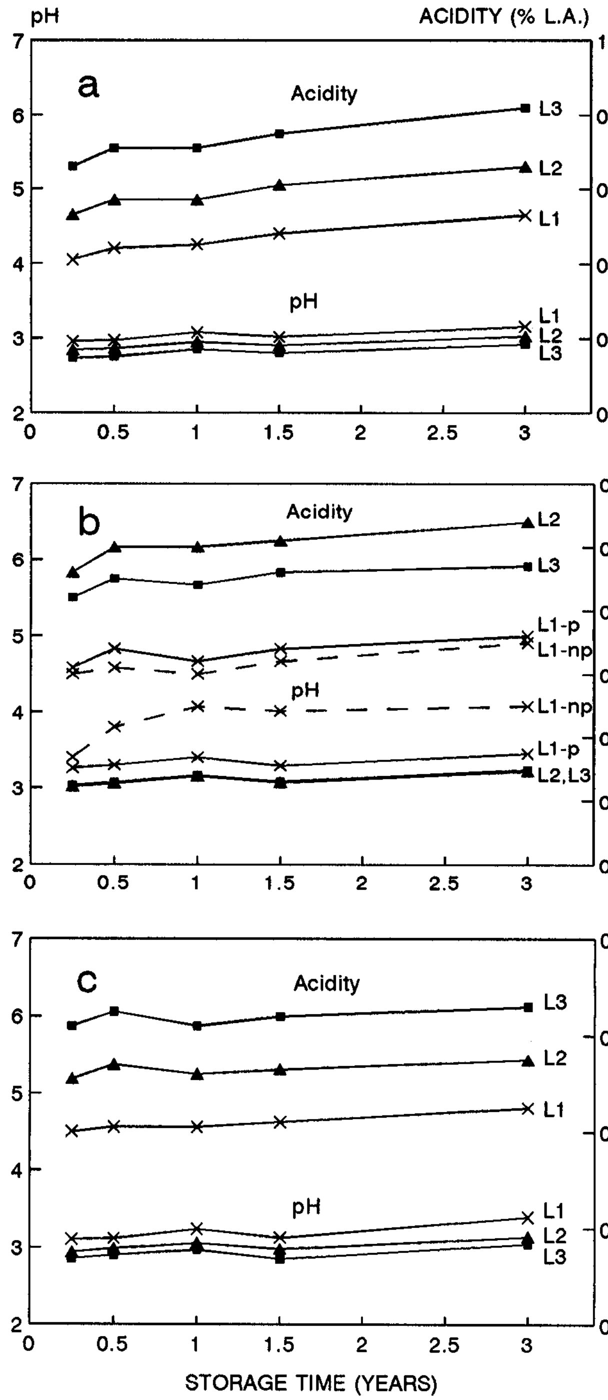

Figure 1. Changes in pH and titratable acidity of brine during storage of whole (a), pitted (b), and stuffed (c) Spanish-style green olives. Acidity (% lactic acid)−salt (% NaCl) levels: level 1 (L1), 0.40−4.5, 0.30−3.0, 0.40−4.0; level 2 (L2), 0.50−5.5, 0.45−5.0, 0.50−5.5; and level 3 (L3), 0.65−6.5, 0.40−6.5, 0.60−6.5, for whole, pitted, and stuffed olives, respectively. L1-p, level 1 and pasteurized; L1-np, level 1 and nonpasteurized. Each point represents the mean of eight (four samples × two replicates), except for L1-p and L1-np (two samples × two replicates).

was practically half the initial value. The decrease in firmness with time fitted first-order kinetics better than zero-order kinetics (data not shown). In whole and pitted olives, first-order softening rate constants were higher in the pasteurized samples than in the nonpasteurized ones, but the corresponding rate constants in stuffed olives were not significantly ($p < 0.05$) different (Table 4). Since rate constants for whole, pitted, and stuffed olives, all of them pasteurized, were not significantly ($p < 0.05$) different, among them a single pooled rate constant ($k = 0.0224$) can be used for all three types of pasteurized olive (Table 4). For a degradation with first-order kinetics, it is possible to calculate the shelf life, t_s, from the expression (Ellis, 1994)

$$t_s = (\ln F_0/F_l)/k$$

where F_0 is the initial firmness ($t = 0$) and F_l is the limit of firmness below which the olives are considered unacceptable. Although this limit has not yet been established from a correlation study with subjective evaluation on firmness, previous studies (unpublished data) indicate that $F_l \approx 10$ N/g. Thus, irrespective of the olive form, assuming initial firmness values of 40, 30, and 20 N/g, this yields shelf lives for pasteurized green olives of 63.0, 49.9, and 31.5 months, respectively.

Table 4. First-Order Softening Rate Constants Obtained for Different Types of Spanish-Style Green Olives, Pasteurized and/or Nonpasteurized

olives[a]	pasteurization treatment	k[b] (month^{-1})	confidence interval at 95% level	r
W	untreated	0.0176	± 0.0009	0.976
P	untreated	0.0178	± 0.0033	0.909
S	untreated	0.0225	± 0.0019	0.941
W	treated	0.0207	± 0.0011	0.975
P	treated	0.0233	± 0.0019	0.946
S	treated	0.0232	± 0.0014	0.968
W	untreated + treated	0.0193[c]	± 0.0008	0.972
P	untreated + treated	0.0206[c]	± 0.0014	0.923
S	untreated + treated	0.0228[d]	± 0.0012	0.954
W + P + S	untreated	0.0193[c]	± 0.0010	0.934
W + P + S	treated	0.0224[d]	± 0.0009	0.960

[a] W, whole olives; P, pitted olives; S, stuffed olives. [b] First-order softening rate constant obtained from the equation $\ln(F/F_0) = -kt$, where F = firmness, F_0 = initial firmness, and t = time in months. [c] The single pooled rate constant cannot be used instead of the separate rate constants as indicated by F^* statistic ($\alpha = 0.05$). [d] The single pooled rate constant can be used instead of the separate rate constants as indicated by F^* statistic ($\alpha = 0.05$).

Table 5. Correlations between Color Index (*i*) and Different Color Parameters of Spanish-Style Green Olives

color parameter	r	intercept	slope
L^*	0.839	−28.0	1.031
a^*	0.655	14.83	3.37
b^*	0.652	6.8	0.535
a^*/L^*	0.455	18.08	125.0
a^*L^*	0.795	13.53	0.0716
a^*b^*/L^*	0.713	15.14	4.77
b^*/L^*	0.419	6.2	28.9
b^*L^*	0.728	10.98	0.00796
a^*/b^*	0.289	21.42	49.6

Fruit Color. Of the color parameters determined, the most useful in the present study of shelf life is the index *i*, as it is known to be well correlated with a visual scale (Sánchez et al., 1985). This parameter correlated well with various expressions of color (Table 5), but the highest correlation was obtained with the parameter L^* (lightness).

Color parameters L^* and b^* (yellowness) and color index *i* were lower in the pasteurized samples than in the nonpasteurized ones (Tables 1−3). Sánchez et al. (1991) found that thermal treatments of pasteurization necessary to guarantee the product's stability did not degrade the fruit color in a critical manner. However, because the stuffed olives had not very good color prior to packing, a significant degradation by pasteurization of color occurred in this type of olive. Darkening of

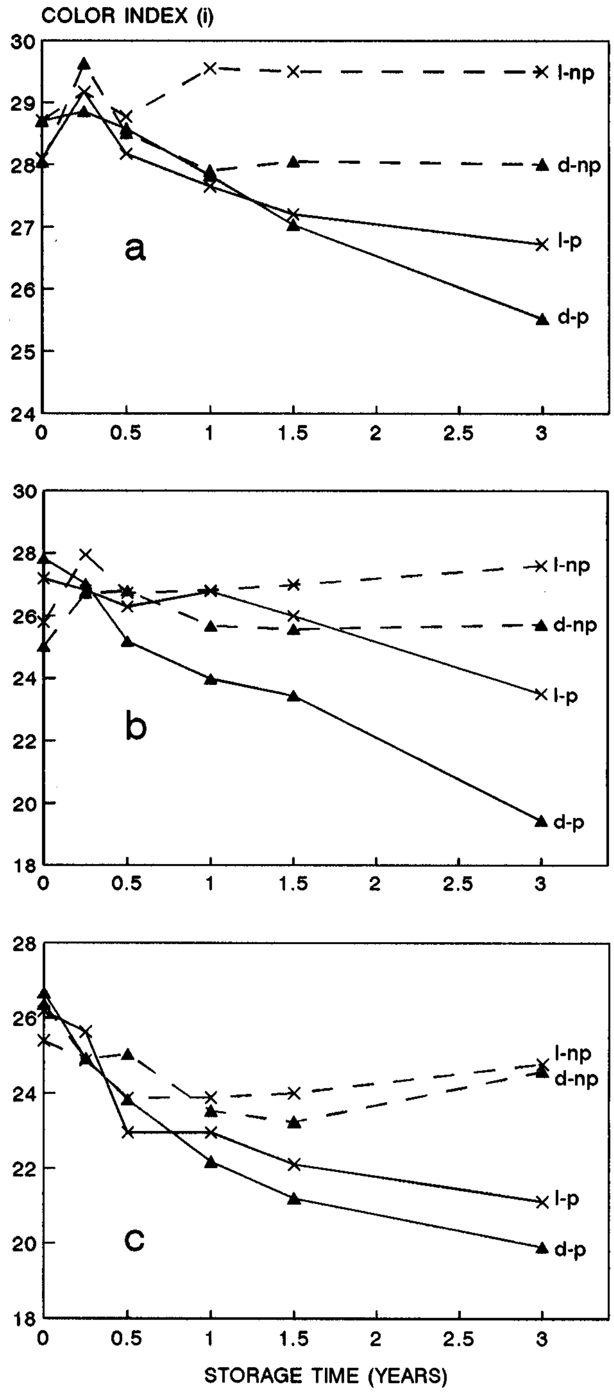

Figure 2. Changes in color index [$i = (4R_{635} + R_{590} - 2R_{560})/3$] during storage of whole (a), pitted (b), and stuffed (c) Spanish-style green olives. l-p, light and pasteurized; l-np, light and nonpasteurized; d-p, darkness and pasteurized; d-np, darkness and nonpasteurized. The slopes of the regression lines of color index change during storage for samples l-p and d-p were significant ($p < 0.05$) in all three types of olives. Each point represents the mean of six (three samples × two replicates).

olives due to pasteurization may be related to chemical oxidation of phenols, as suggested in the case of brines. The samples stored in the light had values of *i* and L^* higher than those of olives stored in darkness (Tables 1−3). It may be related to degradation by light of chlorophyll derivatives present in olives. A good correlation with negative slope for the regression line has been found between the color index *i* and the content of chlorophyll derivatives of Spanish-style green olives (Mínguez et al., 1987). Of these derivatives, pheophytin *a* has been found to be the major compound (Mínguez et al., 1991). In virgin olive oil stored under artificial light, pheophytin *a* has been shown to degrade to noncolored products in a few days (Gutiérrez et al., 1992). During storage time mean values of *i* and a^* (redness) decreased (Tables 1−3). Statistical analysis showed that there was a significant ($p < 0.05$) interaction of pasteurization × storage time and light × storage time on color index in all three types of olive. There was no significant color change during storage for nonpasteurized samples stored in the presence or absence of light, but the color index of pasteurized samples stored in the presence or absence of light changed significantly during storage (Figure 2). The most rapid decrease of *i* occurred in the pasteurized samples stored in darkness. It seems as if the pasteurization treatment provides the necessary energy to initiate the reaction of browning (nonezymic autoxidation). This should be investigated further. Since neither the pitted nor stuffed olives had very good color before packing, the color degradation of packed product during storage resulted in the critical value of *i* (i.e., $i = 23.7$) being reached before 3 years of storage. As shown in Figure 2, this occurred after 18 months of storage for pasteurized pitted olives in darkness and around 6 months for pasteurized stuffed olives in the presence or absence of light.

Conclusions. This work confirms that to achieve physicochemical quality of packed olives, without the need of a pasteurization treatment, the pH must be below 3.2−3.3 units. In spite of the initial differences in firmness and color, the influence of pasteurization, light, and storage time on quality parameters was very similar in the three olive types studied. When the microbiological stability is ensured, by means of a low pH or pasteurization, the criteria for fixing shelf life are based on color (by determination of the index *i*) and/or firmness of the olives. The results obtained show that a longer shelf life is achieved by packing olives of the highest quality, that is, those having relatively high indices of color and firmness, especially if they are going to be pasteurized. For a more exact determination of the shelf life of this product, a scale should be established, in collaboration with industrial experts, to classify olives by their firmness.

ABBREVIATIONS USED

A_{440}, absorbance of brine at 440 nm; A_{700}, absorbance of brine at 700 nm; AU, absorbance unit; d-np, darkness and nonpasteurized; d-p, darkness and pasteurized; *F*, firmness; F_0, initial firmness; F_l, critical firmness; *i*, color index of olives; *k*, first-order softening rate constant; l-np, light and nonpasteurized; l-p, light and pasteurized; L1, level 1 of acidity−salt; L2, level 2 of acidity−salt; L3, level 3 of acidity−salt; L1-np, level 1 of acidity−salt and nonpasteurized; L1-p, level 1 of acidity−salt and pasteurized; P, pitted olives; R_{560}, reflectance of olives at 560 nm; R_{590}, reflectance of olives at 590 nm; R_{635}, reflectance of olives at 635 nm; S, stuffed olives; W, whole olives.

LITERATURE CITED

Borbolla, J. M. R.; Pellissó, F. G. Studies on packaged green olives. XI. Sediment inhibition. *Grasas Aceites* **1972**, *23*, 107−117.

Borbolla, J. M. R.; Rejano, L.; Vega, M. N. Propionic acid formation during the conservation of table green olives. *Grasas Aceites* **1975,** *23*, 153−160.

Brenes, M.; García, P.; Garrido, A. Influence of reusing regenerated brines on some characteristics of the packing green olives. *Grasas Aceites* **1989**, *40*, 182−189.

Brenes, M.; Montaño, A.; Garrido, A. Ultrafiltration of green table olive brines: influence of some operating parameters and effect on polyphenol composition. *J. Food Sci.* **1990**, *55*, 214−217.

Brenes, M; García, P.; Garrido, A. Influence of salts and pH on the firmness of olives in acid conditions. *J. Food Qual.* **1994**, *17*, 335−346.

Cilliers, J. J. L.; Singleton, V. L. Nonenzymic autoxidative phenolic browning reactions in a caffeic acid model system. *J. Agric. Food Chem.* **1989**, *37*, 890−896.

Ellis, M. J. The methodology of shelf life determination. In *Shelf Life Evaluation of Foods*; Man, C. M. D., Jones, A. A., Eds.; Chapman & Hall: London, 1994.

Fernández-Díez, M. J.; De Castro, R.; Fernández, A. G.; Cancho, F. G.; Pellissó, F. G.; Vega, M. N.; Moreno, A. H.; Mosquera, M. I. M.; Rejano, L.; Quintana, M. C. D.; Roldán, F. S.; García, P. G.; De Castro, A. *Biotecnología de la Aceituna de Mesa*; CSIC: Madrid, Spain, 1985.

Fleming, H. P.; McFeeters, R. F.; Daeschel, M. A.; Humphries, E. G.; Thompson, R. L. Fermentation of cucumbers in anaerobic tanks. *J. Food Sci.* **1988**, *53*, 127−133.

Gutiérrez, F.; Garrido, J.; Gallardo, L.; Gandúl, B.; Mínguez, M. I. Action of chlorophylls on the stability of virgin olive oil. *J. Am. Oil Chem. Soc.* **1992**, *69*, 866−871.

IOOC (International Olive Oil Council). Yearly report on table olive production and consumption. 75th Session of the International Olive Oil Council, Madrid, Spain, 1996.

Jiménez, A.; Heredia, A.; Guillén, R.; Fernández-Bolaños, J. Correlation between soaking conditions, cation content of cell wall, and olive firmness during "Spanish green olive" processing. *J. Agric. Food Chem.* **1997**, *45*, 1653−1658.

Jones, A. A.; Man, C. M. D. Ambient-stable sauces and pickles. In *Shelf Life Evaluation of Foods*; Man, C. M. D., Jones, A. A., Eds.; Chapman & Hall: London, 1994.

Mínguez, M. I.; Rejano, L.; Garrido, J.; Sánchez, A. H. Quantification of carotenoids and chlorophyl derivatives as a quality index for measuring the colour of green table olives. In *Proceedings of Euro Food Chem IV on Rapid Analysis in Food Processing and Food Control*, Loen, Norway, June 1987; Baltes, W., Baardseth, P., Norang, R., Søyland, K., Eds.; Norwegian Food Research Institute: Ås, Norway, 1987.

Mínguez, M. I.; Gandúl, B.; Montaño, A.; Garrido, J. Determination of chlorophylls and carotenoids by high-performance liquid chromatography during olive lactic fermentation. *J. Chromatogr.* **1991**, *585*, 259−266.

Montaño, A.; Sánchez, A. H.; Rejano, L. Method for determination of brine color in table green olives. *Alimentaria* **1988**, *193*, 79−83.

Oszmianski, J.; Cheynier, V.; Moutounet, M. Iron-catalyzed oxidation of (+)-catechin in model systems. *J. Agric. Food Chem.* **1996**, *44*, 1712−1715.

Rejano, L.; Brenes, M.; Sánchez, A. H.; García, P.; Garrido, A. Brine recycling: its application in canned anchovy-stuffed olives and olives packed in pouches. *Sci. Aliments* **1995**, *15*, 541−550.

Sánchez, A. H. Pasteurization of pickled green olives. Ph.D. Dissertation, University of Seville, 1989.

Sánchez, A. H.; Rejano, L.; Montaño, A. The determination of the colour in pickled green olives of the variety Manzanillo. *Grasas Aceites* **1985**, *36*, 258−261.

Sánchez, A. H.; Rejano, L.; Montaño, A. Kinetics of the destruction by heat of colour and texture of pickled green olives. *J. Sci. Food Agric.* **1991**, *54*, 379−385.

StatSoft, Inc. *Statistica for Windows* (computer program manual); Tulsa, OK, 1996.

Received for review March 31, 1997. Accepted July 17, 1997.[⊗] This work is part of a research project, ALI94-0980-CO2-01, supported by the Spanish Government through CICYT.

JF9702510

[⊗] Abstract published in *Advance ACS Abstracts*, September 1, 1997.