Physicochemical and Sensory Evaluation of 'Rocha' Pear Following Controlled Atmosphere Storage

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ABSTRACT: The effects of several processing factors (storage time, time in the open air at room temperature, and overhead concentrations of O_2 and CO_2) on color, firmness, polyphenol oxidase (PPO) activity, and sensory attributes of pears (cv. Rocha) grown in 2 locations were studied using a multiple linear regression model. Backward elimination ($F \geq 0.005$) was used to assess the significant factors. Extended storage time, long-time exposure at room temperature, and high O_2 concentration played major roles on color changes assessed instrumentally and further confirmed by a sensory panel. Firmness was strongly affected by storage time and by time in the open air at room temperature. Finally, PPO activity was dependent on the growing location.

Keywords: color, firmness, PPO, sensory analysis, modeling

Introduction

RECENT INCREASES IN THE PRODUCTION AND impact of the *Pyrus communis* L. cv. Rocha, a pear bearing an *Appélation d'Origine Protegée* status (and possessing excellent and unique sensory properties and good storability), along with attempts to optimize its storage conditions, were prompted by consumer demand. The 'Rocha' pear is characterized by a white, smooth, granular, sweet, nonacidic, and very juicy pulp. Pears are usually harvested between August and mid-September, so appropriate postharvest storage conditions are required to preserve fruit quality over a period of up to 9 mo.

Extensive information is available pertaining to recommended controlled atmospheres (CA) for storage of various pear varieties (for example, Chen and Varga 1997; Richardson and Kupferman 1997); however, the effects of CA are dependent on several internal and external parameters (Roelofs and Jager 1997; Lammertyn and others 2000; Watkins and Pritts 2001). Conversely, in the case of the Rocha cultivar, little information is found on the recommended gas composition for CA storage (Richardson and Kupferman 1997) or on the factors that can influence the associated quality loss (Veltman and others 2000). Several disorders have been associated with CA storage, such as the development of undesirable color and texture, and abnormal taste and flavor (Drake and others 2001), and some of these disorders have been directly correlated with improper postharvest storage practices. The formation of yellow and brown pigments was claimed to be a result of high levels of phenolic compounds and polyphenol oxidase (PPO) (Coseteng and Lee 1987; Amiot and others 1992), but the severity of this defect is cultivar-dependent (Amiot and others 1995). Browning incidence has recently been associated with antioxidant and ATP levels in the fruit (Veltman and others 1999; Saquet and others 2000). After storage and during the ripening period, firmness decays at a rate that is constrained by factors such as storage duration and temperature (Jonhston and others 2001). Good retention of firmness in pears is achieved under low O_2 content (Kader 1989), whereas firmness retention is enhanced in apples when stored under low O_2 and high CO_2 concentrations (Banks and others 1997). Maintenance of pear attributes is thus likely if storage under CA conditions is provided (Drake and Eisele 1999).

The 2 goals of this study were (1) to determine the effect of storage time, time of exposure to the open air at room temperature, and storage gas composition on quality parameters of pears (cv. Rocha) produced in distinct locations and (2) to empirically model the effect of those factors on the final quality of the pear.

Materials and Methods

Plant material

Pears (cv. Rocha) were harvested at a stage of commercial maturity in August 1998 in 2 different locations, Sobrena and Piçarra (Portugal).

Storage conditions

The pears were stored at 0 to 0.5 °C and 90 to 95% relative humidity in air (NA) or under CA conditions at Estação Nacional de Fruticultura Vieira Natividade (Alcobaça, Portugal). Four CA storage conditions were tested: 2% (v/v) O_2 + 0.5% (v/v) CO_2; 2% (v/v) O_2 + 1.5% (v/v) CO_2; 3% (v/v) O_2 + 0.5% (v/v) CO_2; and 3% (v/v) O_2 + 1.5% (v/v) CO_2.

After 4, 7, and 9 mo of storage, fruits selected at random were removed from each storage condition and transported to the Post-harvest Technology Laboratory at Escola Superior de Biotecnologia (Porto, Portugal), where they were allowed to ripen in air at room temperature (19 to 20 °C). Pears selected randomly from each storage condition were evaluated for physicochemical attributes at 1 and 6 d after removal from storage for Sobrena, and at 2 and 7 d after removal from storage for Piçarra.

Color assessment

The color of the pear flesh was assessed with a (hand-held) tristimulus reflectance colorimeter, model CR-300 (from Minolta, Ramsey, N.Y., U.S.A.). The skin of the pear was removed just before assaying to avoid flesh oxidation. Two replicates of 10 pears each were employed. Color was recorded using a CIE-L*a*b* uniform color space. The color parameters selected were a* and b* because they were the best indicators of the influence of the factors tested.

Firmness assessment

The texture measurements were performed with a universal testing machine,

Table 1—Second-order polynomial model for Hunter's a* value of 'Rocha' pears from 2 different growing locations, as a function of the relevant independent variables, and associated estimators of parameters.

Location	Model*	Parameter	Estimated value ± 95% confidence interval	Unit	R^2
Sobrena	$Y_1 = b_0 + b_1X_1 + b_3X_3 + b_{11}X_1^2 + b_{13}X_1X_3 + b_{22}X_2^2 + b_{33}X_3^2 + b_{34}X_3X_4$	b_0	−0.2 ± 0.5	dimensionless	0.80
		b_1	−0.6 ± 0.2	mo^{-1}	
		b_3	−0.4 ± 0.1	$(\%\ v/v)^{-1}$	
		b_{11}	0.04 ± 0.01	mo^{-2}	
		b_{13}	−0.014 ± 0.002	$mo^{-1} \times (\%v/v)^{-1}$	
		b_{22}	0.013 ± 0.002	d^{-2}	
		b_{33}	0.019 ± 0.004	$(\%v/v)^{-2}$	
		b_{34}	0.14 ± 0.03	$(\%v/v)^{-2}$	
Piçarra	$Y_1 = b_0 + b_1X_1 + b_{11}X_1^2 + b_{12}X_1X_2 + b_{14}X_1X_4 + b_{22}X_2^2 + b_{23}X_2X_3 + b_{24}X_2X_4$	b_0	−0.8 ± 0.5	dimensionless	0.84
		b_1	−0.7 ± 0.1	mo^{-1}	
		b_{11}	0.03 ± 0.01	mo^{-2}	
		b_{12}	0.020 ± 0.006	$mo^{-1} \times d^{-1}$	
		b_{14}	0.06 ± 0.01	$mo^{-1} \times (\%\ v/v)^{-1}$	
		b_{22}	0.010 ± 0.005	d^{-2}	
		b_{23}	−0.020 ± 0.001	$d^{-1} \times (\%\ v/v)^{-1}$	
		b_{24}	−0.05 ± 0.02	$d^{-1} \times (\%\ v/v)^{-1}$	

*including only the statistically significant parameters

Table 2—Second-order polynomial model for Hunter's b* value of 'Rocha' pears from 2 different growing locations, as a function of the relevant independent variables and associated estimators of parameters.

Location	Model*	Parameter	Estimated value ± 95% confidence interval	Unit	R^2
Sobrena	$Y_2 = b_0 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{33}X_3^2 + b_{34}X_3X_4 + b_{44}X_4^2$	b_0	10.2 ± 1.7	dimensionless	0.75
		b_2	−0.6 ± 0.2	d^{-1}	
		b_3	3.3 ± 0.9	$(\%\ v/v)^{-1}$	
		b_{11}	0.04 ± 0.07	mo^{-2}	
		b_{13}	0.02 ± 0.09	$mo^{-1} \times (\%v/v)^{-1}$	
		b_{23}	0.03 ± 0.01	$d^{-1} \times (\%v/v)^{-1}$	
		b_{24}	0.3 ± 0.1	$d^{-1} \times (\%v/v)^{-1}$	
		b_{33}	−0.15 ± 0.04	$(\%v/v)^{-2}$	
		b_{34}	−2.4 ± 0.7	$(\%v/v)^{-2}$	
		b_{44}	1.6 ± 0.9	$(\%v/v)^{-2}$	
Piçarra	$Y_2 = b_0 + b_{11}X_1^2 + b_{13}X_1X_3 + b_{22}X_2^2 + b_{33}X_3^2$	b_0	15.4 ± 0.5	dimensionless	0.65
		b_{11}	0.020 ± 0.009	mo^{-2}	
		b_{13}	0.06 ± 0.01	$mo^{-1} \times (\%\ v/v)^{-1}$	
		b_{22}	−0.040 ± 0.009	d^{-2}	
		b_{33}	−0.010 ± 0.003	$(\%\ v/v)^{-2}$	

*including only the statistically significant parameters

Table 3—Second-order polynomial model for firmness of 'Rocha' pears from 2 different growing locations, as a function of the relevant independent variables, and associated estimators of parameters.

Location	Model*	Parameter	Estimated value ± 95% confidence interval	Unit	R^2
Sobrena	$Y_3 = b_0 + b_1X_1 + b_{11}X_1^2 + b_{22}X_2^2 + b_{23}X_2X_3 + b_{24}X_2X_4$	b_0	14.4 ± 7.1	N	0.92
		b_1	16.4 ± 2.4	$N \times mo^{-1}$	
		b_{11}	−1.4 ± 0.2	$N \times mo^{-2}$	
		b_{22}	−0.66 ± 0.05	$N \times d^{-2}$	
		b_{23}	0.08 ± 0.02	$N \times d^{-1} \times (\%v/v)^{-1}$	
		b_{24}	−0.5 ± 0.2	$N \times d^{-1} \times (\%v/v)^{-1}$	
Piçarra	$Y_3 = b_0 + b_1X_1 + b_{11}X_1^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{22}X_2^2 + b_{23}X_2X_3 + b_{33}X_3^2 + b_{44}X_4^2$	b_0	−16.7 ± 8.1	N	0.87
		b_1	26.7 ± 2.6	$N \times mo^{-1}$	
		b_{11}	−1.9 ± 0.2	$N \times mo^{-2}$	
		b_{12}	−0.4 ± 0.1	$N \times mo^{-1} \times d^{-1}$	
		b_{13}	−0.08 ± 0.03	$N \times mo^{-1} \times (\%v/v)^{-1}$	
		b_{22}	−0.21 ± 0.08	$N \times d^{-2}$	
		b_{23}	0.05 ± 0.02	$N \times d^{-1} \times (\%v/v)^{-1}$	
		b_{33}	0.02 ± 0.01	$N \times (\%v/v)^{-2}$	
		b_{44}	−1.4 ± 0.6	$N \times (\%v/v)^{-2}$	

*including only the statistically significant parameters

model 4501 (from Instron, Canton, Mass., U.S.A.). The puncture probe (8-mm dia) was programmed to penetrate 5 mm in a normal direction, at a crosshead speed of 10 mm/min, using a 100-N load cell. For each fruit, the skin was removed from the test section, and the flesh was punctured twice on opposite sides in the equatorial area. Two replicates of 10 pears each were employed. Results were expressed as the maximum force to puncture the equatorial surface of the whole pear.

PPO activity assay

A few modifications were introduced on the extraction procedure initially described by Galeazzi and Sgarbieri (1981). A pear enzyme extract was prepared by homogenizing frozen pear samples with 0.2 *M* sodium phosphate buffer (pH 6.5) containing 2% (w/v) polyvinylpolypyrrolidone (PVPP) and 0.25% (v/v) Triton X-100, using an Ultra-Turrax model T 25 (IKA Labortechnik, Wilmington, N.C., U.S.A.) in an external ice bath, for 3 min at 1-min intervals. The homogenate was centrifuged at 4 °C and 16 000 × *g* for 30 min using a Sorvall RC-5C centrifuge (Instruments Dupont, Newtown, Conn., U.S.A.). The supernatant was then filtered through cheesecloth and its volume was measured.

The rate of increase in absorbance at 420 nm during 1 min at 25 °C was recorded using a UV/VIS Recording Spectrophotometer model UV-260 (Shimadzu, Kyoto, Japan). The reaction mixture consisted of the aforementioned supernatant (which was a crude enzyme extract) and catechol (which was used as substrate). The linear part of the absorbance/time curve was used to estimate the activity of the enzyme. One unit of enzymatic activity (U) was defined as the change of 0.001 units of absorbance under the aforementioned assay conditions. Triplicate assays were performed on each of the 3 pear extract replicates obtained at each storage condition.

Sensory analysis

Sensorial analyses were performed by 6 or 7 d of exposure to air at room temperature for Sobrena and Piçarra locations, respectively. Pears were evaluated in terms of firmness, yellow color, juiciness, and sweetness by 10 experienced panelists who had been selected previously on the basis of their interest, taste acuity, and ability to determine intensities. The sensory assessments were performed in a sensorial testing room, with individual booths and controlled lighting (white). Pear samples were cut into quarters and peeled just before evaluation, thus avoiding oxidation as

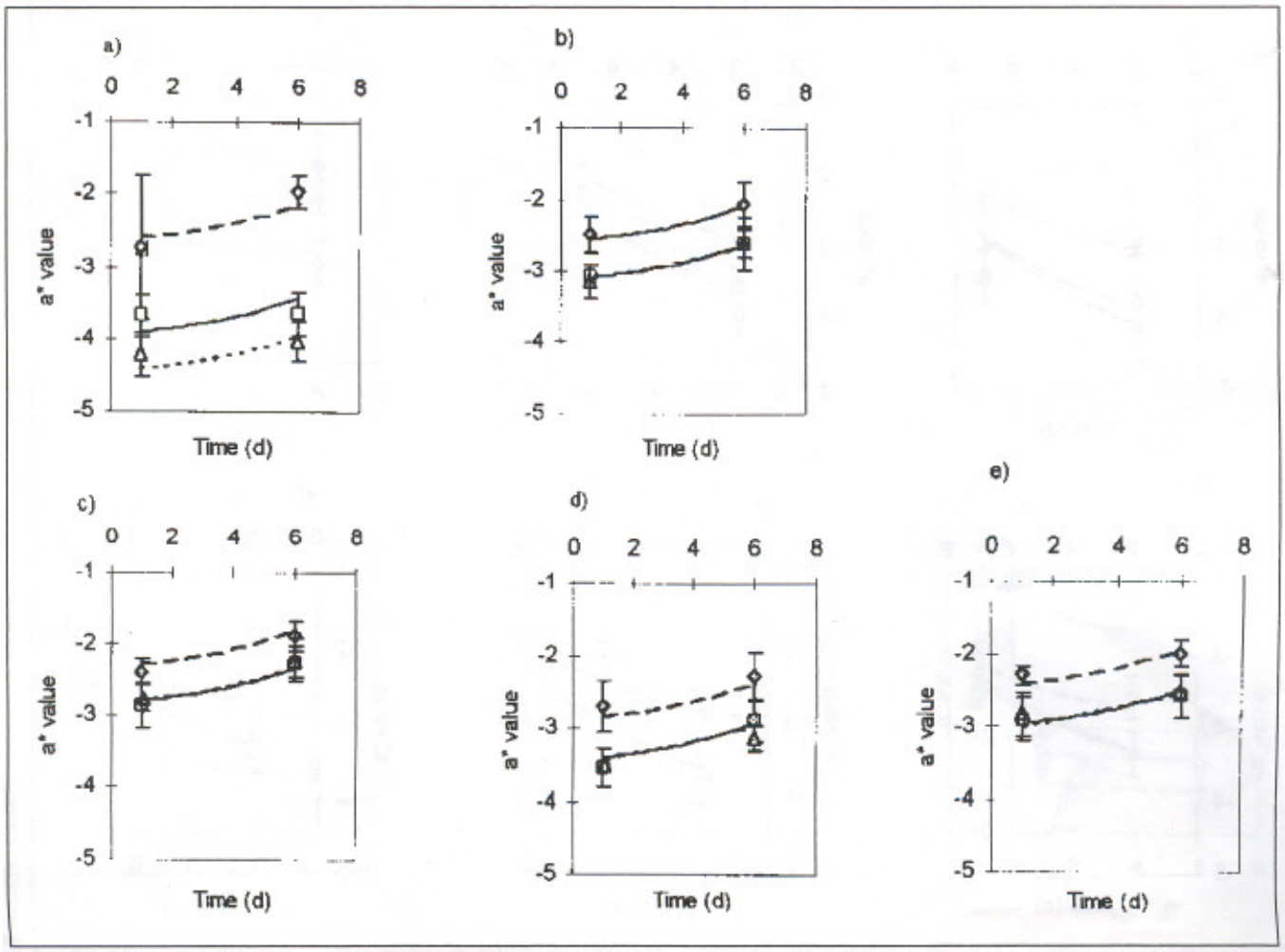

Figure 1—Hunter's a* values of 'Rocha' pears from the Sobrena location throughout time in the open air at room temperature after 4 (◇), 7 (□) and 9 (△) mo of storage under (a) air, (b) 2% (v/v) O_2 + 0.5% (v/v) CO_2, (c) 2% (v/v) O_2 + 1.5% (v/v) CO_2, (d) 3% (v/v) O_2 + 0.5% (v/v) CO_2, and (e) 3% (v/v) O_2 + 1.5% (v/v) CO_2. Points represent average of experimental values, bars standard deviation and lines fitted model (Eq. 1, Table 1).

much as possible. Five pear samples, corresponding to each storage condition, were simultaneously presented on individual coded plates. Panelists were asked to indicate their score by marking a 1 to 9 scale with 1 = none, 3 = slightly, 5 = moderately, 7 = strongly, and 9 = extremely intense, for firmness, yellow color, juiciness, and sweetness.

Statistical analysis

The influences of storage time (X_1), time in the open air at room temperature (X_2), concentration of oxygen (X_3), and concentration of carbon dioxide (X_4) in the CA were empirically modeled according to the following second-order polynomial, using as dependent variables Hunter's a* value (Y_1), Hunter's b* value (Y_2), and firmness (Y_3).

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_{11}X_1^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{22}X_2^2 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{33}X_3^2 + b_{34}X_3X_4 + b_{44}X_4^2 \quad (1)$$

In the above polynomial, b_0 is the intercept; b_1, b_2, b_3, and b_4 are linear parameters; b_{11}, b_{22}, b_{33}, and b_{44} are quadratic parameters; and b_{12}, b_{13}, b_{14}, b_{23}, b_{24}, and b_{34} are interaction parameters.

The experimental data were fitted to by Eq. 1 using stepwise backward regression with the software SPSS (version 9.0, SPSS Inst., Chicago, Ill., U.S.A.), using $F \geq 0.005$ as criterion of significance for the adjustable parameters. Data with associated residual values above 2 standard deviations were rejected as outliers. An analysis of variance (ANOVA) was performed to evaluate the influence of the storage conditions on the PPO activity and the sensorial attributes color, firmness, sweetness, and juiciness; Duncan's multiple range test was employed to detect significant differences.

Results and Discussion

Color

At harvest, the average and standard deviation of the initial values of a* for pears from the Sobrena location was –2.4 ± 0.5; after storage, the average experimental values ranged from –4.2 to –1.9. The value of a* decreased over storage time in pears under all conditions tested (Figure 1), and the decrease was more notorious from the 4th to the 7th mo, eventually becoming negligible from the 7th to the 9th mo of CA storage. When the pears were exposed to air at room temperature, the value of a* in-

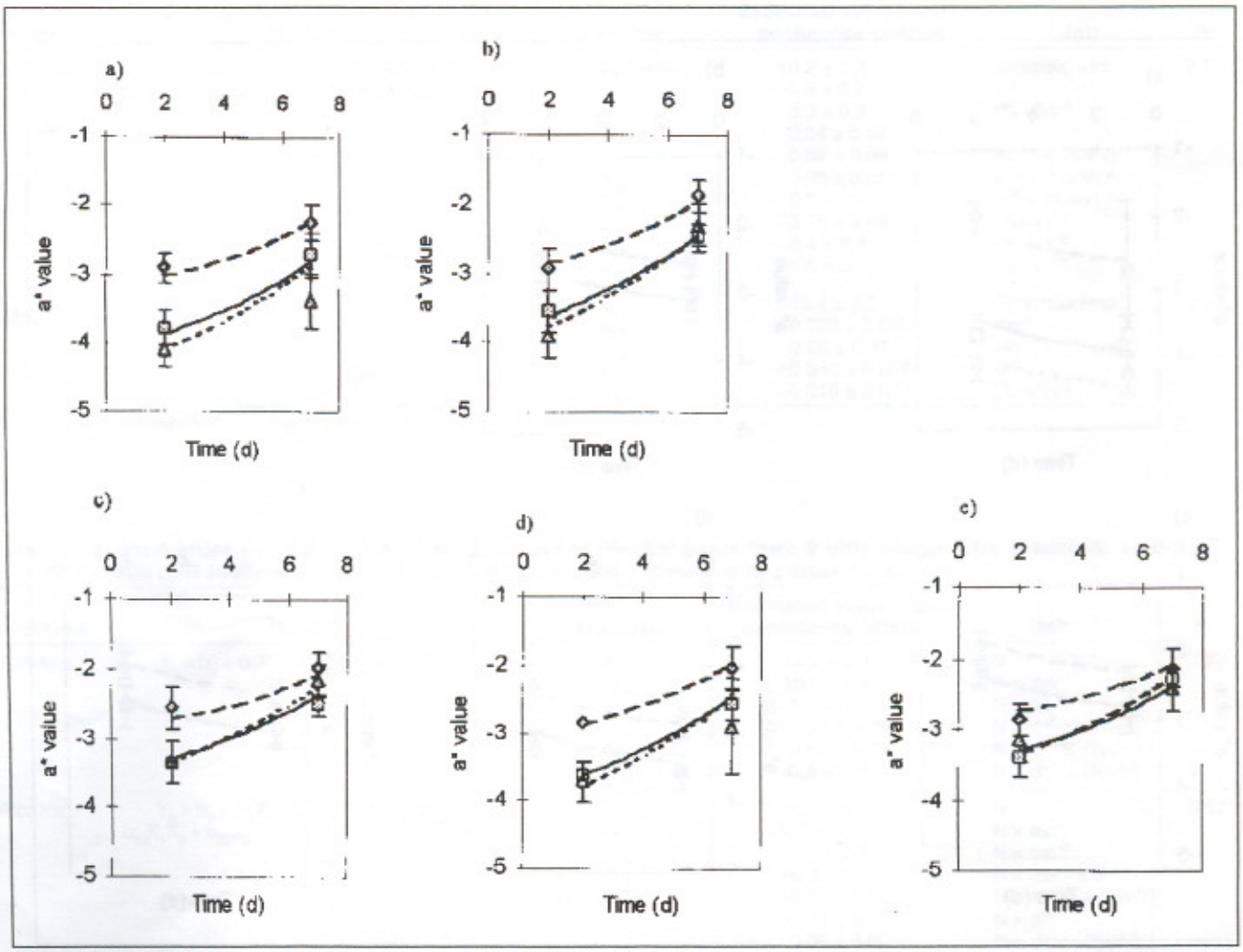

Figure 2—Hunter's a* values of 'Rocha' pears from the Piçarra location throughout time in the open air at room temperature after 4 (◇), 7 (□) and 9 (△) months of storage under (a) air, (b) 2% (v/v) O_2 + 0.5% (v/v) CO_2, (c) 2% (v/v) O_2 + 1.5% (v/v) CO_2, (d), 3% (v/v) O_2 + 0.5% (v/v) CO_2 and (e) 3% (v/v) O_2 + 1.5% (v/v) CO_2. Points represent average of experimental values, bars standard deviation and lines fitted model (Eq. 1, Table 1).

creased in pears from all storage conditions.

The decrease of a* as storage time elapsed, and its increase afterward throughout time in the open air at room temperature, were confirmed by the negative value of b_1 and the positive value of b_{22} (Table 1). Furthermore, the values of a* decreased with the concentration of O_2, as its interaction with the time of storage also yielded a negative parameter value. Hunter's a* value was positively influenced by the square of the concentration of O_2, as well as by the interaction between the concentrations of O_2 and CO_2.

At harvest, the average and standard deviation of the initial value of a* for pears from the Piçarra location was –2.4 ± 0.6; after storage, the average experimental values of a* ranged from –4.1 to –1.9. The value of this parameter showed a decrease with storage time that was confirmed by the negative value of b_1 (Table 1, Figure 2); such decrease was more apparent between the 4th and the 7th mo than between the 7th and the 9th mo of storage. When fruits were exposed to the open air at room temperature, the values of a* increased in pears from all storage conditions. A positive effect was found for the interaction of the time of exposure to the open air at room temperature and the storage time. The results of the regression model also indicate that color changes were negatively influenced by the interaction of the time of exposure to the open air at room temperature with either the concentration of O_2 or the concentration of CO_2. Conversely, there was a positive interaction of the storage time with the concentration of CO_2.

The value of b* at harvest for pears from the Sobrena location was 10.6 ± 1.3, in terms of average and standard deviation. Following storage, the experimental values of b* ranged from 11.9 to 20.0. This parameter increased in value during storage, as confirmed by the positive value of b_{11} (Table 2, Figure 3); such an increase was clearer for pears stored in the open air than under CA. When pears were exposed to air at room temperature, the value of b* decreased as dramatically shown by the negative value for b_2. The values of b* increased with the concentration of O_2 (b_3). Hunter's b* values were positively influenced by the interaction of the concentration of O_2 with the storage time and the interaction of the concentration of O_2 with the time of exposure to the open air at room temperature. The regression analysis

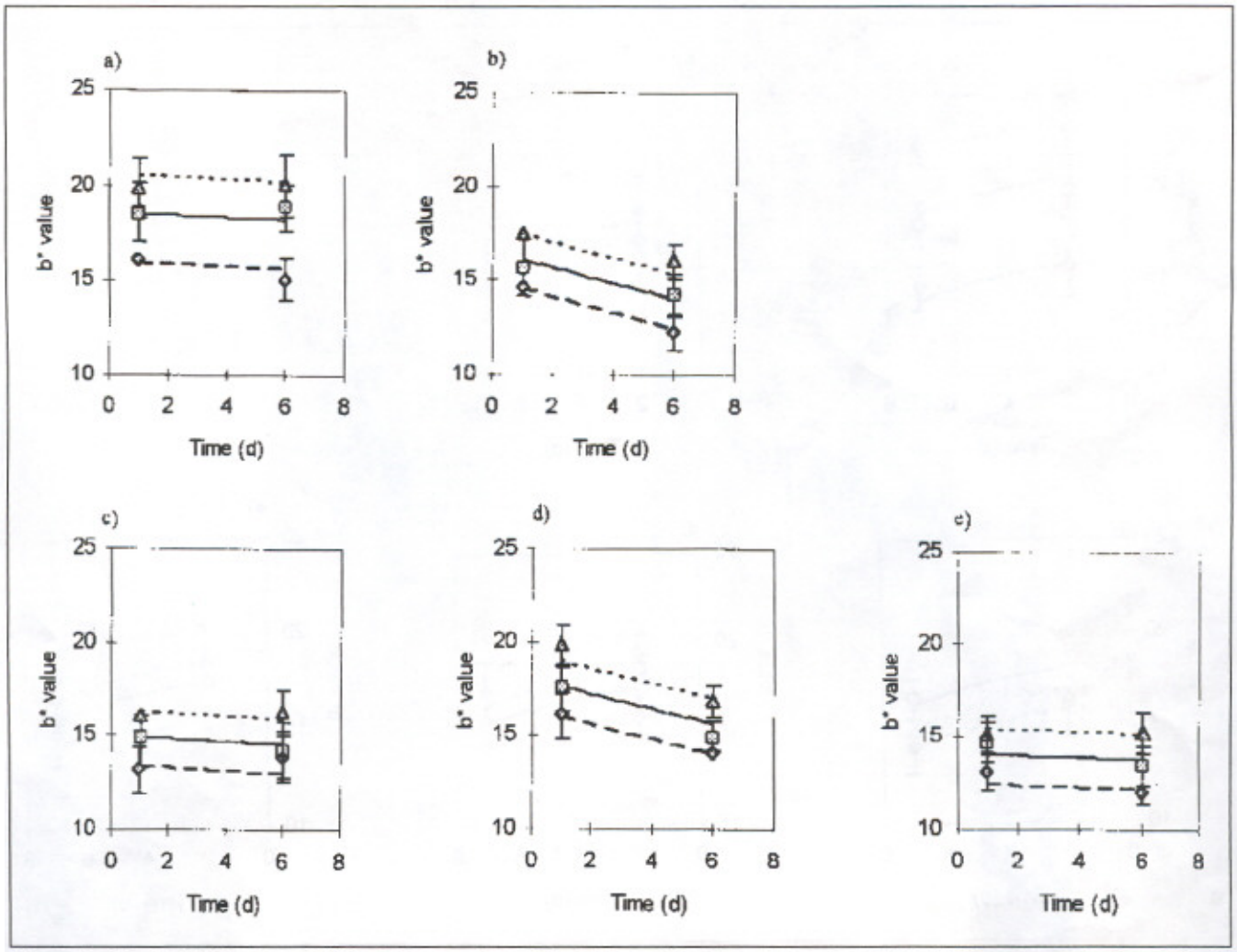

Figure 3—Hunter's b* values of 'Rocha' pears from the Sobrena location throughout time in the open air at room temperature after 4 (◇), 7 (□) and 9 (△) mo of storage under (a) air, (b) 2% (v/v) O_2 + 0.5% (v/v) CO_2, (c) 2% (v/v) O_2 + 1.5% (v/v) CO_2, (d) 3% (v/v) O_2 + 0.5% (v/v) CO_2, and (e) 3% (v/v) O_2 + 1.5% (v/v) CO_2. Points represent average of experimental values, bars standard deviation and lines fitted model (Eq. 1, Table 2).

showed that there are positive effects associated with the square of the concentration of CO_2 and with its interaction with the time of exposure to the open air at room temperature, whereas a negative effect can be ascribed to the interaction of the concentrations of O_2 and CO_2.

The value of b* at harvest was 10.8 ± 1.1 for pears from the Piçarra location; the experimental values of b* after storage ranged from 14.1 to 23.2. The changes of the values of b* unfolded an increase during storage, which was confirmed by the positive value of b_{11} (Table 2, Figure 4). When pears were exposed to the open air at room temperature, the values of b* decreased. The interaction of the storage time with the concentration of O_2 had a positive effect, whereas a negative one was observed in terms of the square of that concentration.

Firmness

At harvest, the firmness of pears from the Sobrena location was 52.3 ± 7.1 N (average ± standard deviation). By the end of the storage period, the firmness ranged in 18.7 to 60.1 N. The experimental data indicated that the firmness decreased throughout storage time (Figure 5); the firmness increased slightly from the 4th to the 7th mo of storage, and decreased sharply thereafter. Regarding the empirical model postulated, it was characterized by a positive value of b_1 and a negative value of b_{11} (Table 3). The firmness also decreased during the time of exposure to the open air at room temperature. The stepwise regression analysis indicated that firmness changes were positively affected by the interaction of the time of exposure to the open air at room temperature with the concentration of O_2, and negatively affected by the interaction of the time of exposure to the open air at room temperature with the concentration of CO_2.

The average firmness (and standard deviation) of pears from the Piçarra location was 53.6 ± 8.9 N at harvest; after storage the firmness was between 22.0 and 64.7 N. The firmness of the pears was influenced by storage time, as well as by the time of exposure to the open air at room temperature (Table 3, Figure 6). There was a clear negative influence by the interaction of the storage time with the time of exposure to the open air at room temperature, positive influences by the square of the concentration of O_2 and the interaction of the concentration of O_2 with the time of exposure to the open air at room temperature, and negative influences by the square of the concentration of CO_2 and the interaction of the concentration of O_2 with the storage time.

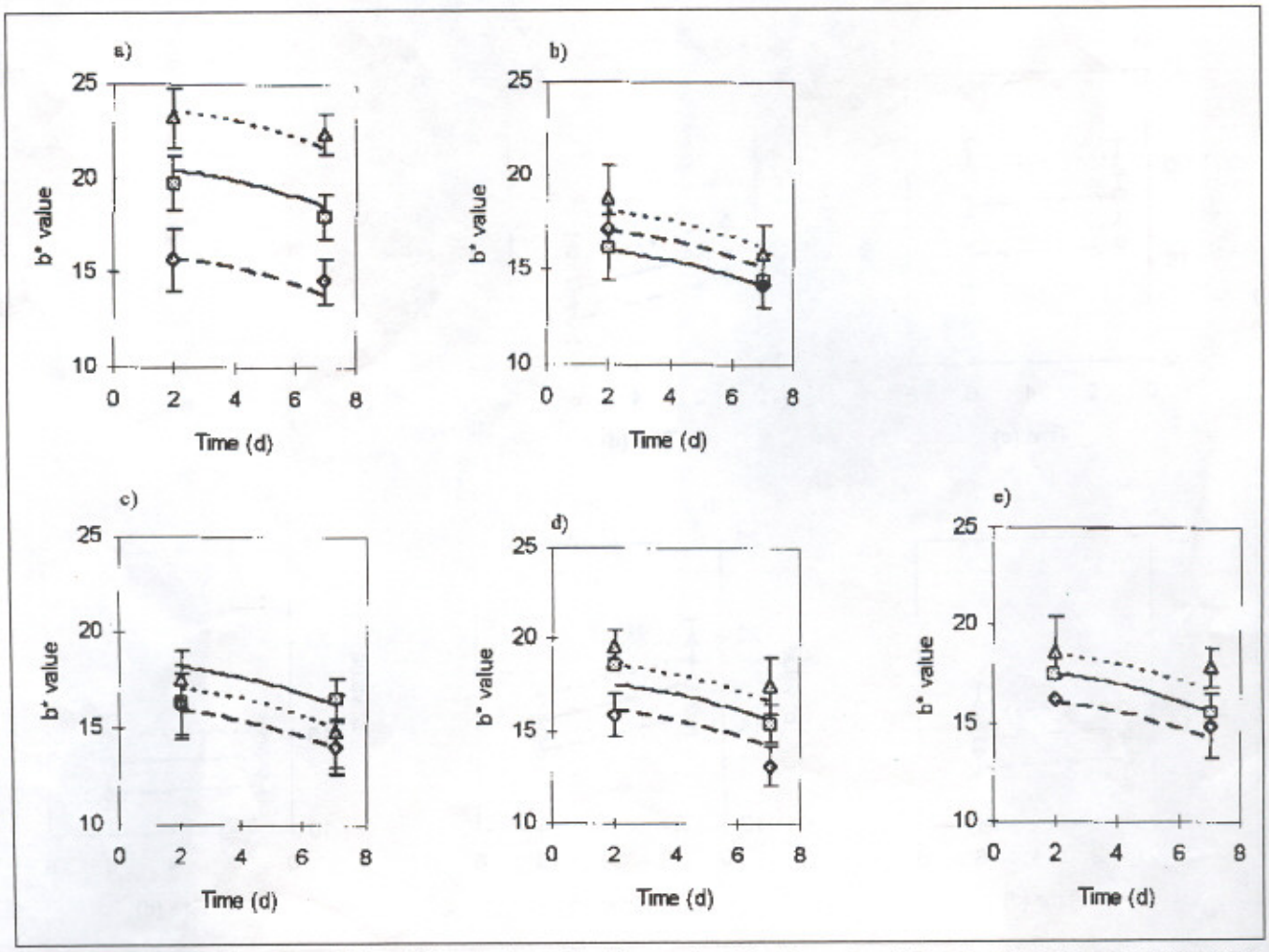

Figure 4—Hunter's b* values of 'Rocha' pears from the Piçarra location throughout time in the open air at room temperature after 4 (◇), 7 (□) and 9 (△) mo of storage under (a) air, (b) 2% (v/v) O_2 + 0.5% (v/v) CO_2, (c) 2% (v/v) O_2 + 1.5% (v/v) CO_2, (d) 3% (v/v) O_2 + 0.5% (v/v) CO_2, and (e) 3% (v/v) O_2 + 1.5% (v/v) CO_2. Points represent average of experimental values, bars standard deviation and lines fitted model (Eq. 1, Table 2).

Table 4—Effect of storage conditions on PPO activity (U/g/min) of 'Rocha' pears from the Sobrena location over the time of exposure to the open air at room temperature

	Overhead atmosphere composition				
Time (d)	Air	2% (v/v) O_2 + 0.5% (v/v) CO_2	2% (v/v) O_2 + 1.5% (v/v) CO_2	3% (v/v) O_2 + 0.5% (v/v) CO_2	3% (v/v) O_2 + 1.5% (v/v) CO_2
1	814.1 cd[z]	901.4 bc	1014.8 ab	726.1 d	1135.3 a
6	576.5 b	410.4 c	750.4 a	424.4 c	469.0 bc

[z]Mean separation within columns in the same line by Duncan's multiple range test ($P = 0.05$); significantly different means are followed by different letters (a, b, c, d)

Table 5—Effect of storage conditions on PPO activity (U/g/min) of 'Rocha' pears from the Sobrena location over the storage time

	Overhead atmosphere composition				
Storage time (mo)	Air	2% (v/v) O_2 + 0.5% (v/v) CO_2	2% (v/v) O_2 + 1.5% (v/v) CO_2	3% (v/v) O_2 + 0.5% (v/v) CO_2	3% (v/v) O_2 + 1.5% (v/v) CO_2
4	530.2 d[z]	660.0 bc	1354.6 a	680.5 bc	860.4 b
7	605.3 ab	503.1 b	752.6 a	544.1 ab	582.2 ab
9	950.6 a	804.6 b	540.6 c	501.1 c	963.9 a

[z]Mean separation within columns in the same line by Duncan's multiple range test ($P = 0.05$); significantly different means are followed by different letters (a, b, c, d)

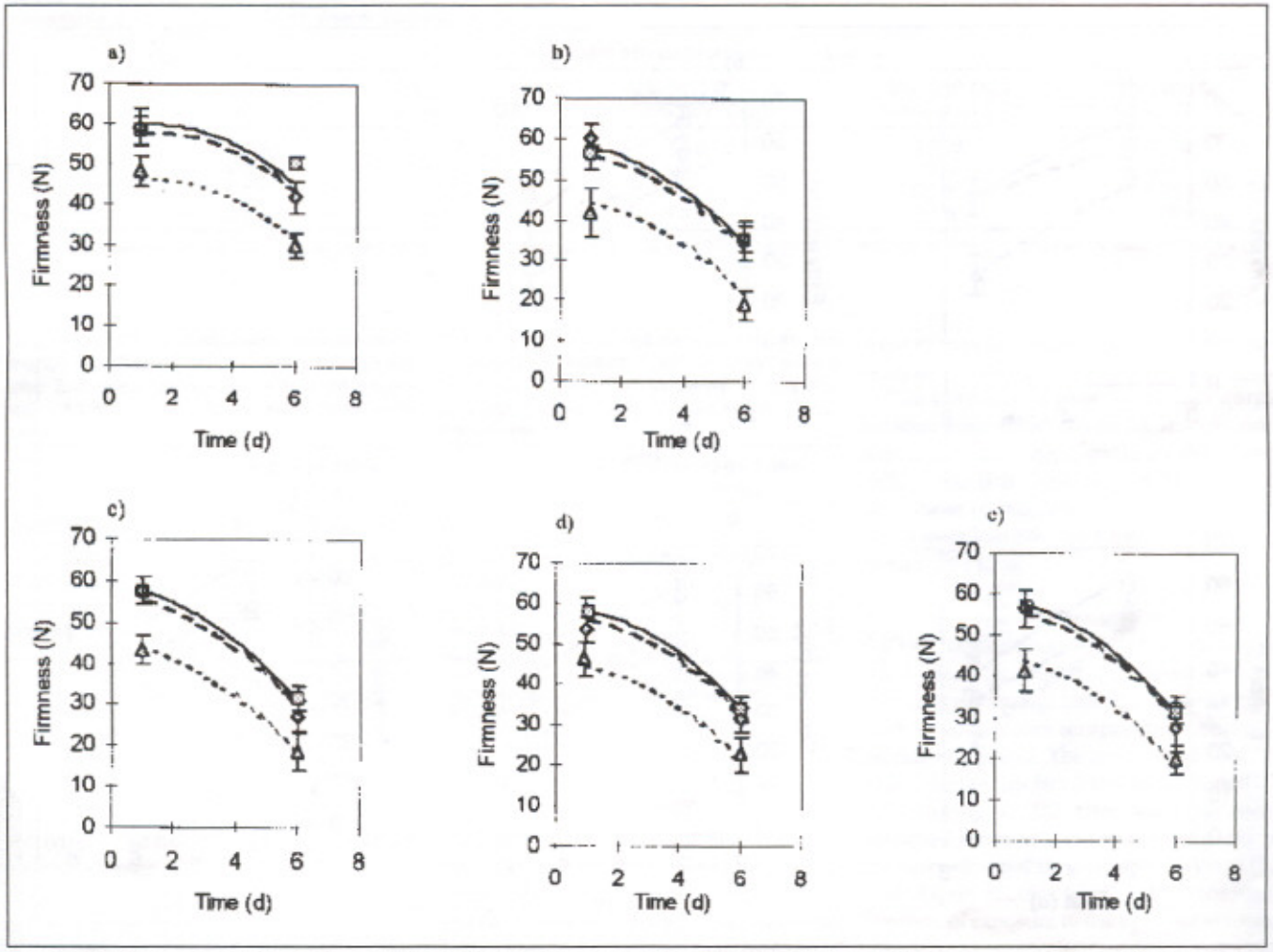

Figure 5—Firmness of 'Rocha' pears from the Sobrena location throughout time in the open air at room temperature after 4 (◇), 7 (□) and 9 (△) mo of storage under (a) air, (b) 2% (v/v) O_2 + 0.5% (v/v) CO_2, (c) 2% (v/v) O_2 + 1.5% (v/v) CO_2, (d) 3% (v/v) O_2 + 0.5% (v/v) CO_2, and (e) 3% (v/v) O_2 + 1.5% (v/v) CO_2. Points represent average of experimental values, bars standard deviation and lines fitted model (Eq. 1, Table 3).

Table 6—Effect of storage conditions on PPO activity (U/g/min) of 'Rocha' pears from the Piçarra location over the time of exposure to the open air at room temperature

	Overhead atmosphere composition				
Time (d)	Air	2% (v/v) O_2 + 0.5% (v/v) CO_2	2% (v/v) O_2 + 1.5% (v/v) CO_2	3% (v/v) O_2 + 0.5% (v/v) CO_2	3% (v/v) O_2 + 1.5% (v/v) CO_2
2	849.2 d[z]	1209.2 ab	1053.6 bc	937.9 cd	1309.1 a
7	841.2 b	677.6 c	859.4 b	608.7 c	1282.7 a

[z]Mean separation within columns in the same line by Duncan's multiple range test ($P = 0.05$); significantly different means are followed by different letters (a, b, c, d)

PPO activity

At harvest, the PPO activity ± standard deviation in pears from the Sobrena location was 467.0 ± 11.0 U/g/min and in pears from the Piçarra location was 295.9 ± 8.2 U/g/min. The PPO of pears from the Sobrena location was significantly ($P < 0.05$) affected by the storage time, the time in the open air at room temperature, and the storage conditions. In particular, the PPO activity decreased in pears from all storage conditions over the time of exposure to the open air at room temperature (Table 4). By 6 d of exposure to the open air at room temperature, pears stored under the 2 conditions of 0.5% (v/v) CO_2 presented lower enzyme activity than those under 2% (v/v) O_2 + 1.5% (v/v) CO_2. Pears under air presented an increase of the PPO activity over storage time, but no clear effect was observed under CA (Table 5). The PPO activity of pears from the Piçarra location was significantly ($P < 0.05$) affected by the storage conditions and the time in the open air at room temperature; a noticeable decrease in PPO activity in the pears stored under the 2 conditions of 0.5% (v/v) CO_2 over time was observed (Table 6). Despite the significant effect that the storage conditions have on PPO

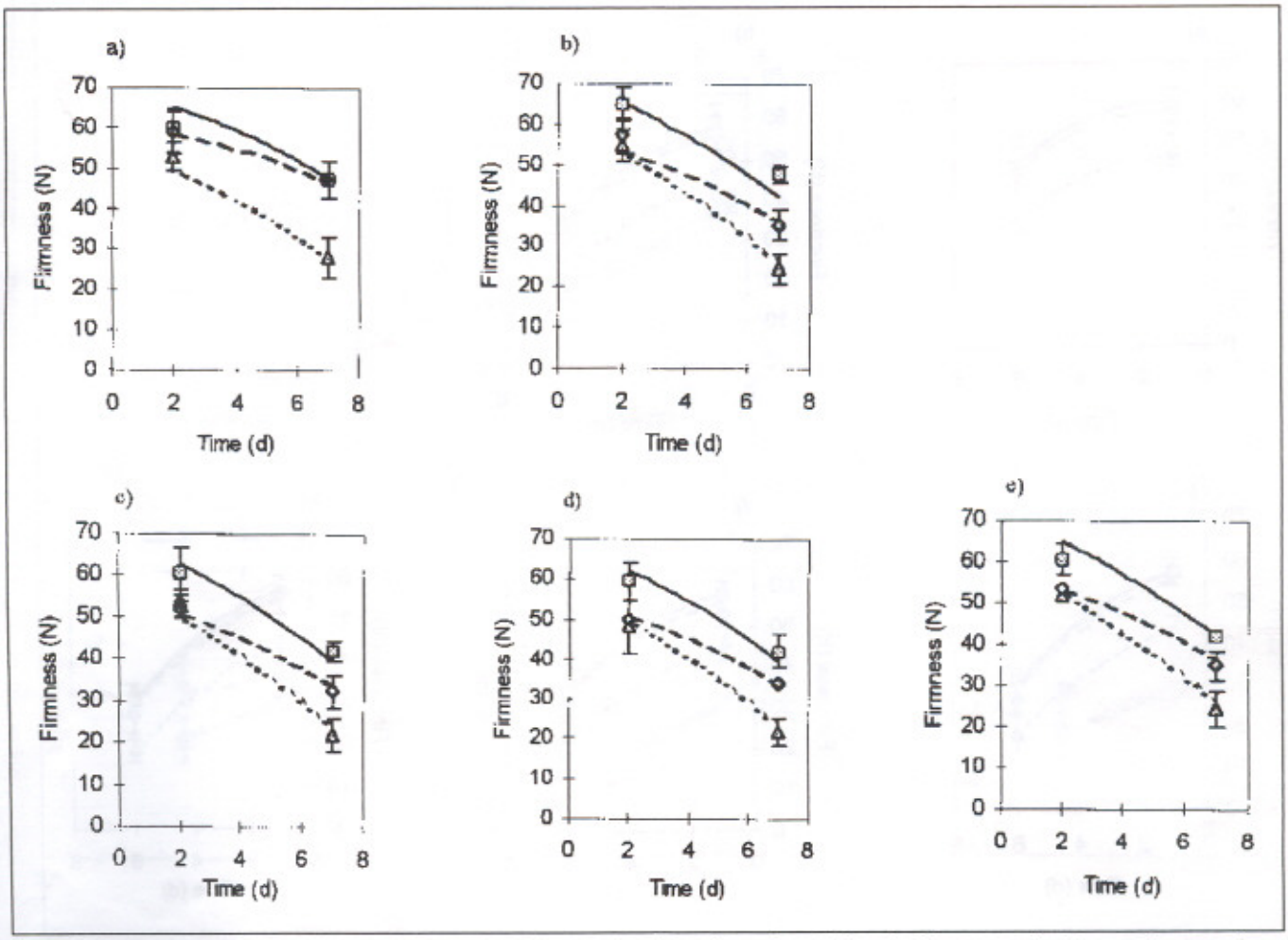

Figure 6—Firmness of 'Rocha' pears from the Piçarra location throughout time in the open air at room temperature after 4 (◇), 7 (□) and 9 (△) mo of storage under (a) air, (b) 2% (v/v) O_2 + 0.5% (v/v) CO_2, (c) 2% (v/v) O_2 + 1.5% (v/v) CO_2, (d) 3% (v/v) O_2 + 0.5% (v/v) CO_2, and (e) 3% (v/v) O_2 + 1.5% (v/v) CO_2. Points represent average of experimental values, bars standard deviation and lines fitted model (Eq. 1, Table 3).

Table 7—Effect of storage conditions on PPO activity (U/g/min) of 'Rocha' pears from the Piçarra location over the storage time

Storage time (mo)	Overhead atmosphere composition				
	Air	2% (v/v) O_2 + 0.5% (v/v) CO_2	2% (v/v) O_2 + 1.5% (v/v) CO_2	3% (v/v) O_2 + 0.5% (v/v) CO_2	3% (v/v) O_2 + 1.5% (v/v) CO_2
4	822.9 b[z]	1197.5 a	746.8 b	719.3 b	1404.3 a
7	911.5 c	1099.9 b	1000.1 c	512.5 d	1226.9 a
9	801.2 c	532.6 b	1121.3 b	1088.3 b	1256.4 a

[z]Mean separation within columns in the same line by Duncan's multiple range test ($P = 0.05$); significantly different means are followed by different letters (a, b, c, d)

Table 8—Effect of storage conditions on sensorial attributes of 'Rocha' pears from the Sobrena location by 6 d of exposure to the open air at room temperature

Attribute	Overhead atmosphere composition				
	Air	2% (v/v) O_2 + 0.5% (v/v) CO_2	2% (v/v) O_2 + 1.5% (v/v) CO_2	3% (v/v) O_2 + 0.5% (v/v) CO_2	3% (v/v) O_2 + 1.5% (v/v) CO_2
Yellow color	5.9 a[z]	3.9 bc	3.7 bc	3.1 c	4.4 b
Firmness	4.4 bc	5.3 a	4.6 ab	5.0 ab	3.6 c
Juiciness	5.2 bc	5.8 abc	6.2 a	5.0 c	6.0 ab
Sweetness	3.6 c	5.7 a	5.9 a	4.6 b	5.7 a

[z]Mean separation within columns in the same line by Duncan's multiple range test ($P = 0.05$); significantly different means are followed by different letters (a, b, c)

Table 10—Effect of storage conditions on sensorial attributes of 'Rocha' pears from the Piçarra location by 7 d of exposure to the open air at room temperature.

Attribute	Overhead atmosphere composition				
	Air	2% (v/v) O_2 + 0.5% (v/v) CO_2	2% (v/v) O_2 + 1.5% (v/v) CO_2	3% (v/v) O_2 + 0.5% (v/v) CO_2	3% (v/v) O_2 + 1.5% (v/v) CO_2
Yellow color	5.8 a[z]	4.2 b	3.9 b	4.9 ab	4.2 b
Firmness	4.2 b	5.7 a	5.1 a	5.3 a	5.0 a
Juiciness	4.6 c	6.5 a	6.3 ab	5.5 b	6.3 ab
Sweetness	3.7 c	6.2 a	5.0 b	5.1 b	5.7 ab

[z]Mean separation within columns in the same line by Duncan's multiple range test ($P = 0.05$); significantly different means are followed by different letters (a, b, c)

Table 9—Effect of storage time on sensorial attributes of 'Rocha' pears from the Sobrena location by 6 d of exposure to the open air at room temperature.

Attribute	Storage time (mo)		
	4	7	9
Yellow color	3.9 b[z]	4.2 ab	4.6 a
Firmness	5.5 a	4.4 b	3.8 c
Juiciness	5.6 ab	5.2 b	6.1 a
Sweetness	4.7 a	5.3 a	5.3 a

[z]Mean separation within columns in the same line by Duncan's multiple range test ($P = 0.05$); significantly different means are followed by different letters (a, b, c)

Table 11—Effect of storage time on sensorial attributes of 'Rocha' pears from the Piçarra location by 7 d of exposure to the open air at room temperature.

Attribute	Storage time (mo)		
	4	7	9
Yellow color	4.7 ab[z]	3.9 b	5.2 a
Firmness	5.0 a	5.2 a	4.9 a
Juiciness	5.4 b	6.1 a	6.0 a
Sweetness	5.2 ab	5.5 a	4.7 b

[z]Mean separation within columns in the same line by Duncan's multiple range test ($P = 0.05$); significantly different means are followed by different letters (a, b, c)

activity, it did not follow a specific trend during storage (Table 7).

Sensory analysis

The yellow color and sweetness of pears from the Sobrena location were considerably influenced by the storage conditions, whereas the firmness and juiciness were influenced to a lesser extent. Sensorial data revealed that the fruits stored in air were more yellow and less sweet than those stored under CA (Table 8); pears were also firmer and whiter by 4 mo than by 9 mo of storage (Table 9), as expected. Note that pears more yellow and less sweet are considered as lower-quality fruits; the yellow color may in fact indicate a higher susceptibility to browning.

The attributes of pears from the Piçarra location were influenced by the storage conditions as well. Fruits stored in air were more yellow, less firm, less juicy, and less sweet than those stored under CA (Table 10). The pears were less juicy by 4 mo than by 9 mo of storage (Table 11).

Conclusions

THE CHANGES IN COLOR OF PEARS FROM THE 2 growing locations considered were affected by the storage time, the time of exposure to air at room temperature, and the storage conditions. The concentration of O_2 was an important factor toward evolution of color during storage. After pears had been removed from storage, there was still a memory effect of the concentrations of O_2 and CO_2 upon color, which interacted with the time of exposure to the open air at room temperature to accelerate color decay. Color differences were confirmed by the sensorial tests; pears stored under air were more yellow than those subjected to CA storage.

The firmness of pears originating from the 2 locations was highly influenced by the time of storage and the time of exposure to the open air at room temperature. Fruits under all storage conditions tended to be firmer between 4 mo and 7 mo of storage, but firmness decreased by 9 mo of storage. The substantial decrease observed between 7 mo and 9 mo of storage could be a consequence of the loss of membrane integrity (Ben-Arie and others 1979). As expected, the metabolism in the pear tissues was re-established after storage, thus allowing pears to soften. During the ripening period, a regular firmness decrease took place, which is caused by solubilization of pectin via action of various adventitious hydrolases (Bartley and others 1982). The effect of the overhead gas during storage was not confirmed by sensorial tests, which did not reveal significant differences in terms of firmness; however, Galvis-Sánchez and Morais (2002) reported previously that 'Rocha' pears under CA storage undergo normal textural changes.

The PPO activity was dependent on the CA composition, but its response to storage time was apparently different for pears from the 2 growing locations. Watkins and Pritts (2001) claimed that cultivar location affects the susceptibility of a commodity to injury by CO_2; whether PPO activity is affected or not by storage conditions (Kader 1989) or whether high or low PPO activity causes browning in pears still remains uncertain (Veltman and others 1999). Our results indicated that the PPO activity at harvest was already different in pears from the 2 growing locations. This realization might account for the different response of PPO activity to storage factors.

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MS 20020064 Submitted 1/29/02, Revised 7/11/02, Accepted 6/24/02, Received 7/16/02

This research was partially funded by project PAMAF 6034, by INIA (Portugal). Author A.C. Galvis-Sánchez acknowledges personal financial support from PRAXIS XXI, by FCT (Portugal) via a Ph.D. fellowship (ref. BD/18392/98).

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