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QUALITY AND DISORDERS OF 'BALADY' LIMESDURING COLD STORAGE AT DIFFERENTTEMP ERATURES AND INTERMITTEN TWARMING

El-Shiekh, A. F.
Horticulture Dept., College of Agric., Suez Canal Univ., Ismailia, Egypt

ABSTRACT

'Balady' lime (*Citrus aurantifolia*, L.) fruits were exposed to postharvest continuous 5 and 12°C storage temperatures in the first season. Also, the fruits were analyzed every 10 days directly from cooler and after 2 days at room temperature. The continuous 5°C storage temperature was excluded in the second season from analysis every 10 days because of the high percentage of fruit disorders.

Another intermittent warming experiment was carried out in the two successive seasons. The intermittent warming treatments were in cycles and they were A) 2 days at 5°C + 1 day at room temperature B) 4 days at 5°C + 1 day at room temperature C) 6 days at 5°C + 1 day at room temperature D) 6 days at 5°C + 2 days at room temperature. For comparison, continuous 5 and 12°C storage temperatures were used also.

The objective for this study was to evaluate the effect of those storage conditions on 'Balady' lime fruit quality and disorders.

Increasing storage temperature from 5 to 12°C and also increasing storage duration resulted in higher 'L' and intensity colour values of fruit peel. In addition, leaving the fruits for two days at room temperature gave similar results which reflected the breakdown of the chlorophyll and the appearance of the yellow colour.

However, 'h' colour value decreased from the bluish-green area to the yellow area by increasing storage temperature and duration and also after leaving the fruits for 2 days at room temperature after cold storage.

Storage at continuous 5°C maintained peel green colour but the intensity colour value decreased because fruit disorders affected the readings.

Storage temperature had no effect on either fruit firmness, juice content or acidity. However, SSC, SSC/acid, and ascorbic acid decreased in fruits stored at 5°C and increased in fruits stored at 12°C. Firmness and ascorbic acid content decreased during storage for 60 days. However, SSC and SSC/acid ratio of the fruits increased.

Leaving the fruits for 2 days at room temperature after cold storage revealed no differences in firmness, juice content, SSC, and ascorbic acid. However, fruit acidity increased and SSC/acid decreased after storage at 12°C.

The intermittent warming treatment, 6 days at 5°C + 1 day at room temperature in cycles, helped in maintaining fruit firmness, juice content and ascorbic acid. However, that treatment resulted in higher fruit acidity and SSC.

Also, fruit disorders (%) after 60 days of storage were the lowest in comparison with the other storage conditions.

INTRODUCTION

Cold storage of lemons and limes at 10 - 12°C delayed fruit decay and prolonged fruit life without chilling injury (Castro-Lopez et al., 1981; Wild and Scott, 1983). During cold storage at 10-12°C of Balady' limes for 45 days, ascorbic acid, acidity, soluble solids content (SSC), juice (%) decreased (Mansour *et al.*, 1987). Etman *et al.* (1996) also found that acidity and ascorbic acid of 'Balady' limes fruit decreased by the end of cold storage at 10°C while SSC fluctuated.

Storage at < 10°C caused chilling injury (CI), including internal membranosis, peel pitting, and change in juice composition (Cohen and Schiffmann-Nadel, 1978). Long-term storage of lemons at 13°C for 3 months and longer resulted in a high incidence of rot. The remaining sound fruits became dry, overripe in colour, and therefore unmarketable (Cohen, 1988).

Storage different cultivars of lemons at 12-14°C usually induces physiological disorders (Artes and Carpena, 1977; Cohen *et al.*, 1983). Disorder severity is related to cultivar, environmental conditions at picking, fruit maturity, and postharvest treatments (temperature, relative humidity, ventilation, packinghouse treatments, and storage duration (Artes *et al.*, 1993).

Davis and Hoffmann (1973) suggested intermittent warming to reduce citrus fruit CI. Intermittent warming of 'Vill-Franka' lemons for 7 days at 13°C every 21 days during storage at 2 or 8°C eliminated membranosis, prevented rind pitting and reduced decay compared with storing lemons continuously at 2 or 8°C for 6 months (Cohen *et al.*, 1983) and prevented disorders in 'Fino' lemons (Artes *et al.*, 1990).

Several techniques have been applied to alleviate CI in lemons stored for 2-6 months in relative humidity > 90%. These techniques include using moderate temperatures (~ 13), intermittent fruits warming during cold storage, and some chemicals. Reduction in decay and physiological disorders was best with two cycles of 2 weeks at 2°C and 2 weeks at 13°C and relative humidity > 95% (Artes *et al.*, 1993). Under these storage condition, SSC, pH, acidity, and reducing sugars did not change relative to values at harvest, but concentration of ascorbic acid increased.

No intermittent warming treatments have been carried out on limes in Egypt to prolong the postharvest life of the fruits with good quality and maintain a moderate price of the fruits for longer time instead of having very low prices at the peak of the crop, then few weeks later the prices go up.

In this study, lime fruits, grown at Sharkia conditions, are harvested and then exposed to continuous low and moderate temperatures (5 and 12°C) in addition to intermittent warming to evaluate the effect of those storage conditions on limes quality and disorders.

MATERIALS AND METHODS

'Balady' limes were harvested from a 15-year-old orchard on Oct. 7, 2000 and Oct. 27, 2001 seasons in El-Salhia region, El-Sharkia Govemorate, Egypt and transported by car to the lab within 2 hrs. The fruits were sorted to eliminate defects. Sound fruits were washed using regular water and air dried.

For the continuous storage temperature (5 and 12°C), 960 fruits were randomized into perforated colourless plastic 36.5 x 24.5 cm bags (7 mm in diameter hole per 16 cm2 bag area), 30 fruits in each. All bags were divided into two groups. One group of 16 bags was stored at 5°C and the other group was stored at 12°C and 75-85% RH. Fruits were sampled at harvest and at

10-day intervals. At each sampling time, two bags (60 fruits) were taken out of the cooler and 30 fruits were analyzed directly while the other 30 fruits were analyzed after 2 days at room temperature (22 ± 3°C). In the second season and because of the high percentage of the disordered fruits, low storage temperature (5°C) was eliminated from the continuous storage and sampling periods and was used only as a comparative continuous temperature in the intermittent warming experiment.

For the intermittent warming experiment (in both seasons), treatments were: A) 60 days at continuous 5°C, B) 60 days at continuous 12°C, C) 2 days at 5°C + 1 day at room temperature (RT), D) 4 days at 5°C + 1 day at RT, E) 6 days at 5°C + 1 day at RT, and F) 6 days at 5°C + 2 days at RT. Treatments C - F were in cycles.

For each intermittent warming treatment, 150 fruits in three perforated bags (50 in each) were used. At the end of the experiment, 60 days, the fruits were analyzed.

Parameters measured:

They were 'L', 'h', and intensity colour values of fruit peel, firmness, juice volume, soluble solids content (SSC), titratable acidity, and ascorbic acid content. Also, at the end of the experiment, fruit disorders were evaluated.

Colour values:

'L' colour value, which measures relative white (100) to black (0) colour, hue ('h', arctangent b/a) angle, which measures the red-purple (0°), yellow (90°), and bluish-green (180°) (as recommended by Little, 1975) and intensity {(a2+b2)m} of fruit peel were measured using a Minolta CR 10 Chromameter (Minolta Crop, Japan). Then average values were determined for individual fruit for subsequent statistical analyses.

Firmness:

It was measured on one side of the fruits using Effegi penetrometer (McCormick, Yakima, Washington) with 0.7 cm plunger, after peeling the fruits.

Juice volume:

Extractable juice obtained by squeezing was calculated as the percentage of juice to fresh weight.

SSC:

It was determined in the juice using Milton Roy (Japan) refractometer.

Acidity:

It was determined by titrating 5ml of lime juice using 0. IN NaOH until pH 8.0 and expressed as percent citric acid.

Ascorbic acid:

It was determined by the Association of Official Analytical Chemists (AOAC, 1984) titrating methods.

Fruit disorders (%):

It was also calculated at the end of the experiment for each treatment when brown pitting of the rind was observed. These disorders included discrete, depressed lesions, several mm across and sometimes surrounded by a diffuse brown halo.

Statistical analyses:

Two models were used. The first one was applied between storage temperature treatments (5°C, 5°C + 2 days at room temperature, 12°C, and 12°C +2 days at room temperature), sampling periods and their interactions for the parameters measured in the first season. In the second season, 5°C storage temperature was excluded and 12°C and 12°C + 2 days at room temperature was included. The second model contained the intermittent warming treatments.

The experimental design was completely randomized with a factorial arrangement of treatments and sampling periods (Steel and Torrie, 1980). Analyses of variance and means comparison (LSD, 5%) were performed using Statistix 4.1 (Analytical Software, Inc., Tallahassee, FL).

For percent fruit disorders, Chi-square contingency tests were used to compare each pair of treatments under each storage condition in each season.

RESULTS AND DISCUSSION

Effect of cold storage.

Fruit colour:

Interaction of storage temperatures (ST) x sampling periods (SP) revealed significant differences in the first season for 'L', 'h', and intensity colour values (Table 1). However, in the second season the interactions for the same parameters did not show significant differences.

In the first season, and at each sampling periods, the 'L' colour value of the fruits stored at 12°C or 12°C + 2 days at room temperature (2D) was significantly higher than that of the fruits stored at 5°C or 5°C + 2D. However, in the second season, no major differences were noticed between fruit stored at 12°C and fruit left for 2D after storage at 12°C.

The composite effect of storage temperatures revealed that the 'L' colour value increased significantly with increasing storage temperature from 5°C to 12°C (in the first season) and also increased after leaving the fruits for two days at room temperature and the increases were more pronounced in the first season (breakdown of the chlorophyll and the appearance of the yellow pigments). Similarly, the 'L' colour value increased significantly during storage (composite effect of sampling periods) and the maximum values were obtained after 40 and 20 days of storage in the first and the second seasons, respectively.

In the first season, at each sampling period, 'h' value was higher for the fruits stored at 5°C or 5°C + 2D than fruit stored at 12°C or 12°C + 2D. In the second season, no major differences were noticed between fruits analyzed directly from cooler and fruits left for 2 days at room temperature.

The 'h' angle was decreased significantly from the bluish- green area to the yellow area by increasing storage temperature (composite effect of storage temperatures) and as a result of leaving the fruits for 2 days at room temperature in both seasons. Also, the 'h' value decreased from 108 and 106 to 94 and 84 after 60 days of storage (composite effect of sampling periods) in the first and second seasons, respectively.

In the first season, colour intensity at each sampling period was higher for fruits stored at 12°C or 12°C + 2D than fruits stored at 5°C or 5°C + 2D. In the second season, colour intensity increased after leaving the fruits for 2D after storage at 12°C but the increases were not significant. Colour intensity values increased significantly with increasing storage temperature (composite effect of storage temperatures) from 5°C to 12°C in the first season and by leaving the fruits for two days at room temperature after storage at 5°C (in the first season) or 12°C in both seasons. Also, colour intensity increased significantly during cold storage (composite effect of sampling periods) in both seasons.

Storage at 5°C helped in maintaining peel green colour up to 50 days as indicated by 'L' colour value. The intensity colour value decreased after 50 days because chilling injury symptoms (dark brown colour) affected the readings. Also, keeping the fruits for 2 days at room temperature after storage at 5°C (in the first season) or 12°C (in both seasons) accelerated the loss of green colour and the appearance and/or the formation of the carotenes. High storage temperature and long storage duration accelerated the loss of green pigmentation, altered colour by producing yellow colour. Similarly, Hulme (1971) stated that the green colour of lemons is dominated by chlorophyll. As chlorophyll disappears during storage, the yellow pigments become evident.

Firmness and juice percentage:

The interaction of ST x SP for both firmness and juice (%) were not significant (Table 2).

Storage temperature (composite effect) had no significant effect on fruit firmness in both seasons. However, firmness decreased during storage (composite effect of sampling periods) but data failed to show significant differences in the first season while the reduction was significant in the second season.

Storage temperature had no significant effect on fruit juice content. In addition, fruit juice percentage was maintained during storage, composite effect of sampling periods.

Leaving the fruits for 2 days at room temperature after cold storage revealed no differences in firmness or juice content.

Table 1. Effect of postharvest storage temperature and sampling periods on peel colour ('L', 'h', and intensity) of 'Balady' limes in 2000 and 2001 seasons.

Parameters	Storage temperature (ST, °C)	Sampling periods (SP, days) 0[1] 2000	0[1] 2001	10 2000	10 2001	20 2000	20 2001	30 2000	30 2001	40 2000	40 2001	50 2000	50 2001	60 2000	60 2001	CEST[x] 2000	CEST[x] 2001
'L'[z]	5°C	48.64	NA[y]	47.20	NA	44.90	NA	53.20	NA	54.52	NA	51.07	NA	46.65	NA	49.45	NA
	5°C + 2D[2]	48.64	NA	56.98	NA	57.34	NA	55.28	NA	61.16	NA	62.90	NA	65.90	NA	58.31	NA
	12°C	48.64	53.78	49.92	70.48	52.83	73.18	56.18	72.34	65.46	73.78	61.92	72.78	72.88	72.02	58.26	69.77
	12°C + 2D	48.64	53.78	61.52	74.48	68.57	72.98	68.15	73.32	71.60	72.36	70.14	74.34	70.76	70.52	65.63	70.25
CESP[w]		48.64	53.78	53.91	72.48	55.91	73.08	58.20	72.83	63.19	73.07	61.51	73.56	64.05	71.27		
LSD 5% ST																1.91	1.04
										2000	2001						
	SP									2.52	1.94						
	ST x SP									5.05	3.35						
'h'	5°C	108.1	NA	107.7	NA	110.0	NA	104.9	NA	103.3	NA	106.0	NA	108.7	NA	107.0	NA
	5°C + 2D	108.1	NA	102.1	NA	102.1	NA	102.3	NA	98.9	NA	96.3	NA	97.9	NA	101.1	NA
	12°C	108.1	106.0	105.7	93.1	104.5	89.2	100.9	86.9	94.0	86.5	82.6	87.8	86.0	85.1	97.4	90.6
	12°C + 2D	108.1	106.0	99.5	89.0	74.9	87.4	88.7	86.0	86.5	85.8	85.6	86.4	84.2	83.1	89.6	89.1
CESP		108.1	106.0	103.8	91.1	97.8	88.3	99.2	86.4	95.7	86.1	92.6	87.1	94.2	84.1		
LSD 5% ST																2.5	1.0
										2000	2001						
	SP									3.3	1.8						
	ST x SP									6.6	2.6						
Intensity	5°C	41.64	NA	37.20	NA	33.38	NA	43.36	NA	43.38	NA	43.07	NA	34.75	NA	39.54	NA
	5°C + 2D	41.64	NA	46.02	NA	47.88	NA	44.14	NA	50.04	NA	53.37	NA	54.50	NA	48.23	NA
	12°C	41.64	42.50	42.06	56.38	43.87	55.74	45.83	59.10	56.92	58.10	53.18	59.28	62.88	60.42	49.48	55.93
	12°C + 2D	41.64	42.50	51.34	55.46	57.27	58.58	59.15	58.42	60.40	58.98	59.24	60.52	61.36	62.50	55.77	56.71
CESP		41.64	42.50	44.16	55.92	45.60	57.16	48.12	58.76	52.69	58.54	52.21	59.90	53.37	61.46		
LSD 5% ST																1.96	1.36
										2000	2001						
	SP									2.59	2.54						
	ST x SP									5.19	3.58						

[z] 'L' = Colour value; indicates the relative white (100) to black (0) colour.
'h' = Hue angle (arctangent b/a); indicates the red-purple (0°), yellow (90°), and bluish-green (180°). Intensity = $\{(a^2 + b^2)^{1/2}\}$
[y] Not available; in the second season, 5°C storage temperature was excluded because of the high fruit disorders percentage.
[x] Composite effect of storage temperature. [w] Composite effect of sampling periods.
[1] Harvest time. [2] 2D= Two days at room temperature (22±3°C).

Table 2. Effect of postharvest storage temperature and sampling periods on firmness and percent juice of 'Balady' limes in 2000 and 2001 seasons.

Parameters	Storage temperature (ST, °C)	Sampling periods (SP, days) 0[1]		10		20		30		40		50		60		CEST[Y]	
		2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001
Firmness (N)	5°C	91.36	NA[Z]	86.48	NA	93.45	NA	80.49	NA	84.71	NA	87.01	NA	86.00	NA	87.07	NA
	5°C + 2D[2]	91.36	NA	76.64	NA	88.71	NA	87.16	NA	93.75	NA	87.00	NA	93.00	NA	88.23	NA
	12°C	91.36	98.57	95.52	98.30	92.56	84.14	87.97	82.31	93.52	73.64	79.89	77.81	78.49	84.64	88.47	85.63
	12°C + 2D	91.36	98.57	94.22	82.31	88.49	79.65	80.72	67.48	94.90	69.15	85.58	70.81	93.61	82.48	89.84	78.64
CESP[X]		91.36	98.57	88.22	90.30	90.80	81.90	84.08	74.89	91.72	71.40	84.87	74.31	87.77	83.56	4.91	8.97
LSD 5% ST								2000	2001								
	SP							6.49	16.78								
	ST x SP							12.99	23.03								
Juice (%)	5°C	49.04	NA	47.52	NA	49.19	NA	50.62	NA	53.92	NA	50.08	NA	51.64	NA	50.29	NA
	5°C + 2D	49.04	NA	46.92	NA	50.91	NA	50.71	NA	51.68	NA	48.28	NA	42.96	NA	48.64	NA
	12°C	49.04	44.11	52.56	48.52	49.74	47.79	49.81	46.97	54.14	46.85	52.84	45.98	52.57	47.59	51.53	46.83
	12°C + 2D	49.04	44.11	48.65	46.14	52.13	46.80	53.74	46.48	52.96	47.86	54.45	47.38	51.46	46.87	51.77	46.52
CESP		49.04	44.11	48.91	47.33	50.49	47.29	51.22	46.72	53.18	47.36	51.41	46.68	49.65	47.23	2.22	2.31
LSD 5% ST								2000	2001								
	SP							2.94	4.33								
	ST x SP							5.65	4.36								

[Z] Not available; in the second season, 5°C storage temperature was excluded because of the high fruit disorders percentage.
[Y] Composite effect of storage temperature.
[X] Composite effect of sampling periods.
[1] Harvest time.
[2] 2D= Two days at room temperature (22±3°C).

Acidity and SSC percentages:

The interaction of ST x SP for acidity and SSC were significant in the first season and was not significant in the second one (Table 3).

In the first season, acidity maintained up to 40 days at 5°C and at 5°C + 2D in the first season after which the acidity decreased significantly. However, storage at 12°C or 12°C +2 days at room temperature maintained fruit acidity up to 60 days.

In the second season, acidity increased significantly after 20 days of storage at 12°C or 12°C + 2D then maintained thereafter up to 50 days.

The composite effect of storage temperature on acidity revealed no significant differences between fruit acidity at 5°C or 12°C in the first season. Leaving the fruit for 2 days at room temperature resulted in higher acidity for 12°C storage temperature in the first season only.

The composite effect of sampling periods revealed significant reduction in fruit acidity after 40 days of storage in the first season. However, in the second season, acidity was maintained relative to value at harvest.

Fruit SSC decreased significantly after 50 days of storage at 5C while it increased significantly during storage at 12°C. Leaving the fruit for 2 days at room temperature after storage at either 5 or 12°C had no significant effect on fruit SSC.

The composite effect of storage temperature on fruit SSC revealed significant increment of fruit SSC at 12°C than at 5°C. Leaving the fruits for 2 days at room temperature after storage at low temperature revealed no significant changes.

The composite effect of sampling periods showed significant increases in SSC after 30 and 40 days of storage in the first and second seasons, respectively.

Etman *et al.* (1996) found that SSC of 'Balady' limes fluctuated during cold storage at 10°C. However, acidity decreased.

SSC/acid ratio and ascorbic acid percentage:

The interaction effect of ST x SP was significant in the first season for SSC/acid while it was not significant in the second one. The interaction effect of ST x SP was not significant for ascorbic acid in both seasons (Table 4).

Storage at 5°C resulted in increasing SSC/acid ratio after 50 days of storage while at 12°C the ratio increased significantly after 20 days of storage in the first season and 60 days of storage in the second season. Leaving the fruits for 2 days at room temperature after storage at 5°C resulted in significant increases in SSC/acid ratio at 60 days of storage in the first season. However, fruit left for 2 days at room temperature after storage at 12°C had lower SSC/acid ratio at 50 days of storage in the first season while higher ratio was obtained in the second one.

The composite effect of ST revealed higher ratio when the fruits were stored at 12°C than at 5°C. Fruit left for 2 days at room temperature after storage at 12°C had lower ratio in the first season only.

The composite effect of SP showed significant increases in SSC/acid ratio at 30 and 60 days of storage in the first and second seasons, respectively.

Table 3. Effect of postharvest storage temperature and sampling periods on acidity (%) and SSC (%) of 'Balady' limes in 2000 and 2001 seasons.

Parameters	Storage temperature (ST, °C)	Sampling periods (SP, days) 0[1] 2000	0[1] 2001	10 2000	10 2001	20 2000	20 2001	30 2000	30 2001	40 2000	40 2001	50 2000	50 2001	60 2000	60 2001	CEST[Y] 2000	CEST[Y] 2001
Acidity (%)	5°C	7.98	NA[Z]	7.94	NA	7.94	NA	7.85	NA	7.64	NA	7.25	NA	6.90	NA	7.64	NA
	5°C + 2D[2]	7.98	NA	8.24	NA	8.24	NA	7.98	NA	7.81	NA	7.13	NA	6.70	NA	7.72	NA
	12°C	7.98	6.70	7.64	7.34	7.51	7.68	7.51	7.81	7.55	7.77	7.68	7.34	7.94	6.57	7.69	7.31
	12°C + 2D	7.98	6.70	7.94	7.68	7.68	7.94	7.77	7.30	7.85	7.17	8.11	6.87	8.28	6.66	7.94	7.19
CESP[X]		**7.98**	**6.70**	**7.94**	**7.51**	**7.84**	**7.81**	**7.78**	**7.55**	**7.71**	**7.47**	**7.54**	**7.10**	**7.45**	**6.61**		
LSD 5%	**ST**															**0.17**	**0.22**
								2000	**2001**								
	SP							**0.23**	**0.42**								
	ST x SP							**0.45**	**0.59**								
SSC (%)	5°C	9.07	NA	9.00	NA	8.80	NA	9.00	NA	8.93	NA	8.67	NA	8.60	NA	8.87	NA
	5°C + 2D	9.07	NA	9.20	NA	8.53	NA	9.13	NA	9.10	NA	9.00	NA	9.05	NA	9.01	NA
	12°C	9.07	8.73	9.13	9.17	9.20	9.00	10.00	9.13	9.67	9.47	10.13	9.47	10.13	9.87	9.62	9.26
	12°C + 2D	9.07	8.73	9.27	9.27	9.13	9.13	10.00	9.20	9.93	9.47	9.93	9.80	9.80	9.73	9.59	9.33
CESP		**9.07**	**8.73**	**9.15**	**9.22**	**8.92**	**9.07**	**9.53**	**9.17**	**9.41**	**9.47**	**9.43**	**9.63**	**9.40**	**9.80**		
LSD 5%	**ST**															**0.15**	**0.20**
								2000	**2001**								
	SP							**0.20**	**0.37**								
	ST x SP							**0.39**	**0.52**								

[Z] Not available; in the second season, 5°C storage temperature was excluded because of the high fruit disorders percentage.
[Y] Composite effect of storage temperature.
[X] Composite effect of sampling periods.
[1] Harvest time.
[2] 2D= Two days at room temperature (22±3°C)

Table 4. Effect of postharvest storage temperature and sampling periods on SSC/acid and ascorbic acid content of 'Balady' limes in 2000 and 2001 seasons.

Parameters	Storage temperature (ST, °C)	Sampling periods (SP, days) 0[1] 2000	2001	10 2000	2001	20 2000	2001	30 2000	2001	40 2000	2001	50 2000	2001	60 2000	2001	CEST[Y] 2000	2001
SSC/acid	5°C	1.14	NA[Z]	1.14	NA	1.11	NA	1.15	NA	1.17	NA	1.20	NA	1.25	NA	**1.16**	**NA**
	5°C + 2D[2]	1.14	NA	1.12	NA	1.04	NA	1.15	NA	1.17	NA	1.26	NA	1.35	NA	**1.17**	**NA**
	12°C	1.14	1.31	1.20	1.26	1.23	1.17	1.33	1.17	1.28	1.22	1.32	1.29	1.28	1.50	**1.25**	**1.28**
	12°C + 2D	1.14	1.31	1.17	1.21	1.19	1.15	1.29	1.26	1.27	1.32	1.23	1.43	1.19	1.47	**1.21**	**1.31**
CESP[X]		**1.14**	**1.31**	**1.15**	**1.24**	**1.14**	**1.16**	**1.23**	**1.22**	**1.22**	**1.27**	**1.25**	**1.36**	**1.27**	**1.48**	**0.03**	**0.05**
LSD 5% ST									**2000**	**2001**							
	SP								**0.04**	**0.09**							
	ST x SP								**0.08**	**0.12**							
Ascorbic acid (mg/100ml juice)	5°C	38.33	NA	39.67	NA	37.00	NA	38.67	NA	35.67	NA	36.00	NA	30.33	NA	**36.52**	**NA**
	5°C + 2D	38.33	NA	37.00	NA	37.33	NA	39.00	NA	36.00	NA	35.67	NA	30.00	NA	**36.19**	**NA**
	12°C	38.33	43:33	39.00	39.33	39.00	38.67	41.00	36.00	40.00	31.33	40.00	36.33	38.33	33.33	**39.38**	**36.91**
	12°C + 2D	38.33	43.33	39.67	38.00	39.00	34.00	39.67	31.00	38.00	31.67	37.33	33.67	40.00	32.00	**38.86**	**34.81**
CESP		**38.33**	**43.33**	**38.83**	**38.67**	**38.08**	**36.33**	**39.58**	**33.50**	**37.42**	**31.50**	**37.25**	**35.00**	**34.67**	**32.67**	**1.67**	**2.30**
LSD 5% ST									**2000**	**2001**							
	SP								2.21	4.31							
	ST x SP								3.82	6.10							

[Z] Not available; in the second season, 5°C storage temperature was excluded because of the high fruit disorders percentage.
[Y] Composite effect of storage temperature.
[X] Composite effect of sampling periods.
[1] Harvest time.
[2] 2D= Two days at room temperature (22±3°C).

Table 5. Effect of intermittent warming during postharvest cold storage (2 months) on peel colour of 'Balady' limes in 2000 & 2001 seasons.

Treatments	Peel colour [Y]					
	'L'		'h'		Intensity	
	2000	2001	2000	2001	2000	2001
1[Z]	48.64	53.78	108.14	106.00	41.64	42.50
2	69.42	71.90	89.38	89.77	58.92	61.17
3	66.18	67.27	93.98	92.40	54.96	56.17
4	67.70	68.80	92.52	90.50	55.02	57.57
5	70.36	70.30	86.88	87.33	60.66	59.87
6	46.65	70.33	108.65	87.13	34.75	57.87
7	72.88	72.02	86.04	85.06	62.88	60.42
LSD 5%	**4.23**	**3.89**	**3.28**	**3.55**	**4.37**	**4.74**

[Z] 1= Harvest time. 2= 2 days at 5°C + 1 day at room temperature (22±3°C)
3= 4 days at 5°C + 1 day at room temperature 4= 6 days at 5°C + 1 day at room temperature
5= 6 days at 5°C + 2 days at room temperature 6= Continuous storage at 5°C
7= Continuous storage at 12°C; treatments 2-5 were in cycles

[Y] 'L' = Colour value; indicates the relative white (100) to black (0) colour.
'h' = Hue angle (arctangent b/a); indicates the red-purple (0°), yellow (90°), and bluish-green (180°).
Intensity = $\{(a^2 + b^2)^{1/2}\}$.

Table 6. Effect of intermittent warming during postharvest cold storage (2 months) on quality properties and disorders of 'Balady' limes in 2000 and 2001 seasons.

Treatments	Firmness (N)		Juice (%)		Acidity (%)		SSC (%)		Sugar/acid ratio		Ascorbic acid (mg/100ml juice)		Fruit disorders[Y] (%)	
	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001
1[Z]	91.36	98.57	49.04	44.11	7.98	6.70	9.07	8.73	1.14	1.31	38.33	43.33	-----	-----
2	63.46	82.65	52.85	43.44	8.66	7.64	9.67	9.60	1.12	1.27	33.33	42.00	42.31 ab[X]	39.59 ab
3	78.12	88.09	51.83	44.17	8.28	7.12	9.87	9.80	1.19	1.39	42.67	42.00	30.77 bc	34.89 b
4	96.64	91.86	53.06	44.72	8.32	7.25	9.33	9.40	1.12	1.12	36.33	43.00	14.82 d	10.67 c
5	96.71	90.65	52.03	43.03	7.85	7.37	9.93	9.27	1.27	1.28	34.33	40.00	47.92 ae	54.99 ad
6	86.00	92.00	51.64	43.86	6.90	5.95	8.60	9.80	1.25	1.65	30.33	33.00	59.58 e	63.63 d
7	78.49	84.64	52.57	47.59	7.94	6.57	10.13	9.87	1.28	1.50	38.33	33.33	22.48 cd	18.27 c
LSD 5%	**16.34**	**13.87**	**4.29**	**5.46**	**0.34**	**1.47**	**0.42**	**0.73**	**0.07**	**0.19**	**5.47**	**9.60**		

[Z] 1= Harvest time. 2= 2 days at 5°C + 1 day at room temperature (22±3°C)
3= 4 days at 5°C + 1 day at room temperature 4= 6 days at 5°C + 1 day at room temperature
5= 6 days at 5°C + 2 days at room temperature 6= Continuous storage at 5°C
7= Continuous storage at 12°C; treatments 2-5 were in cycles

[Y] Included discrete, depressed lesion, several mm across and sometimes surrounded by a diffuse brown halo.

[X] Treatments within coloumns in each separate year, not followed by the same letter are different according to Chi-square contingency tests ($p \leq 0.05$).

Storage at 5°C resulted in a reduction of ascorbic acid at 60 days of storage in relation to value at harvest. Storage at 12°C revealed a reduction in ascorbic acid at 30 days of storage in the second season only. No significant differences were obtained in fruit ascorbic acid as affected by leaving them for 2 days at room temperature.

The composite effect of storage temperature on fruit ascorbic acid showed significant increases in fruit stored at 12°C over fruit stored at 5°C. However, ascorbic acid was maintained as a result of leaving the fruits for 2D after storage at either 5 or 12°C.

The composite effect of SP revealed a reduction in fruit ascorbic acid at 60 and 10 days of storage in the first and second seasons, respectively.

Similar results on ascorbic acid and acidity were obtained by Mansour *et al.*, 1987 who found that during cold storage of 'Balady' , limes for 45 days, ascorbic acid and acidity decreased. However, the data reported herein showed an increase in SSC and maintenance of fruit juice (%) during storage while they reported a reduction in SSC and juice content. Conditions of storage temperatures, relative humidity, storage duration, time of harvest, and preharvest management could be responsible for the conflicting results. In our finding, acidity and SSC was lower at 5°C than at 12°C and this may be due to the stress upon the fruits under the low storage temperature (5°C) which might result in increasing the respiration rate of the fruits which in turn consumes the SSC and the acids.

In addition, Hulme (1970) mentioned that ascorbic acid may be oxidized easily in the presence of oxygen so when the cellular disorganization occurs, as a result of senescence or disorders, the enzymes which may be responsible for the oxidative destruction of ascorbic acid do their oxidative activities.

Effect of intermittent warming

Fruit colour;

Fruit colour values ('L', 'h', and intensity) as affected by different intermittent warming treatments are shown in Table 5. In the first season, significant increases in 'L' colour value were obtained from the different treatments over the values at harvest except for the fruit stored at continuous 5°C (treatment 6) for 60 days where 'L' colour value did not change significantly over the value at harvest. The highest 'L' value was obtained from: Treatment 2 (2 days at 5°C + 1 day at room temperature), treatment 4 (6 days at 5°C + 1 day at room temperature), treatment 5 (6 days at 5°C + 2 days at room temperature), and treatment 7 (continuous 12°C).

The highest 'h' value (green colour) was obtained from fruit at harvest and fruit exposed to treatment 6 for 60 days. Treatments 2-4 almost maintained the 'h' value around 90 - 94 (yellow –bluish green). Treatment 5 and 7 kept the 'h' value low (86 - 87) which is dark yellow.

Colour intensity increased significantly with the treatments over the values at harvest while treatment 6 had the lowest colour intensity (chilling injury affected the readings).

In the second season, 'L' colour value and colour intensity increased significantly with the treatments while 'h' value decreased. In harmony with the first season, 'L' value of the fruit exposed to treatment 7 was the highest (light yellow colour).

Treatment 6 maintained the 'h' peel colour value (108) similar to the value at harvest (green) but the peel disorders were high. Treatments 2-4 maintained the 'h' value between 90 - 92 while treatments 5-7 showed 85 - 87 'h' value. Treatments 2, 5 and 7 revealed the highest colour intensity (59 - 63) in the first season while it was 60-61 in the second season. Treatments 3 and 4 had 66.18 and 67.7 'L' colour value, respectively, in the first season while the values were 67.3 and 68.8, respectively, in the second season.

Also, 'h' value was 93.98 and 92.5 2 for treatments 3 and 4, respectively, in the first season and 92.4 and 90.5, respectively, in the second season. This indicates that the intermittent warming with 4 days at 5°C + 1 day at room temperature and 6 days at 5°C + 1 day at room temperature gave better results where the peel colour was not fully yellow (greenish-yellow) and the colour intensity was moderate in comparison with the other treatments.

Firmness:

In the first season, firmness of the fruits was maintained with the different treatments in relation to the values at harvest but treatment 2 had the lowest fruit firmness (Table 6). The data in the second season showed similar trends where treatment 2 had the lowest firmness followed by treatment 7. No significant differences were obtained from the other treatments.

Juice percentage:

No significant differences were noticed in fruit juice content as affected by the different treatments in both seasons.

Acidity percentage:

The highest fruit acidity was obtained from treatments 2 - 4 in the first season and treatments 2 - 5 in the second season over the values at harvest. The lowest fruit acidity in both seasons was obtained from fruit stored continuously at 5°C. Storage at 5°C reduced fruit acidity in comparison to fruit acidity at harvest while storage at 12°C maintained the acidity. Fruit acidity increased as a result of the intermittent warming treatments in both seasons.

SSC percentage:

Fruit SSC increased with the intermittent warming treatments in both seasons. Storage at continuous 5°C resulted in a reduction in fruit SSC in the first season.

SSC/acid ratio:

In the first season, fruit SSC/acid ratio increased by 5 – 7 intermittent warming treatments while no significant differences were obtained from treatments 2-4 over the fruit at harvest.

In the second season, the ratio increased by 6 and 7 treatments while the 2 - 5 treatments maintained the ratio.

Ascorbic acid (%):

Fruit ascorbic acid decreased significantly by storage at continuous 5°C and 12°C in the second season while it was decreased significantly in the first season as affected by 5°C storage temperature. Intermittent warming treatments 3 and 4 and treatments 2-5 maintained fruit ascorbic acid in the first and the second seasons, respectively.

Fruit disorders (%):

Intermittent warming treatment 4 (6 days at 5°C + 1 day at room temperature) had the lowest fruit disorders (%) in both seasons followed by treatment 7 (continuous 12°C storage temperature). The highest fruit disorders were obtained from intermittent warming treatments 2 and 5 in both seasons followed by treatment 6 (continuous 5°C storage temperature).

In consistent to our finding, Castro-Lopez et al. (1981); Wild and Scott (1983) found that continuous cold storage of lemons and limes at 10 - 12°C delayed fruit decay and prolonged fruit life without chilling injury.

Artes *et al.* (1993) found that reduction in decay and physiological disorders was best with two cycles of 2 weeks at 2C and 2 weeks at 13C and relative humidity > 95%. Under these storage condition, SSC, acidity, and reducing sugars did not change relative to value at harvest but ascorbic acid concentration increased.

In contrary, Attia *et al.* (1996) reported that the percentage of the unmarketable 'Balady' limes after 8 and 12 weeks of storage at 10°C reached 6 and 78%, respectively, in the first season and 12 and 72%, respectively, in the second season.

As a recommendation for limes storage, intermittent fruit warming for 6 days at 5°C + 1 day at room temperature in cycles helped in maintaining fruit firmness, juice (%), and ascorbic acid while acidity and SSC were increased. Also, this intermittent warming treatment (4) kept the fruit disorders (%) at the lowest level. If the continuous storage temperature was the only way available for storage limes, 5°C is not recommended.

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جودة ثمار الليمون البلدى والأضرار التى تحدث لها أثناء التخزين المـــبرد علـــى درجات حرارة مختلفة وكذلك التدفئة المتقطعة

أحمد فتح الله الشيخ
قسم البساتين – كلية الزراعة – جامعة قناة السويس – الإسماعيلية – مصر

تم تخزين ثمار الليمون البلدى تحت درجات حرارة مستمرة ٥°م ، ١٢°م فى الموسم الأول وتحـت الحرارة ١٢° م المستمرة فى الموسم الثانى كذلك تم تحليل الثمار المخزنة تحت هذه الظروف فور خروجـــها من الثلاجة وكذلك بعد ٢ يوم على حرارة الغرفة وذلك فى كل ١٠ أيام ولقد تم استبعاد درجة حرارة ٥°م من التخزين المستمر والتحليل كل ١٠ ايام فى الموسم الثانى حيث أنه من البيانات فـــى الموســم الأول اتضــح ارتفاع نسبة أضرار الثمار نتيجة التخزين على هذه الدرجة .

كذلك فقد تم إجراء تجارب تخزين بتدفئة متقطعة فى نفس الموسمين المتتالين وكان التخزين فـــى دورات كما يلى :

أ- ٢ يوم على درجة حرارة ٥° + ١ يوم على درجة حرارة الغرفة .
ب- ٤ يوم على درجة حرارة ٥° + ١ يوم على درجة حرارة الغرفة .
ج- ٢ يوم على درجة حرارة ٥° + ١ يوم على درجة حرارة الغرفة .
د - ٦ يوم على درجة حرارة ٥° + ٢ يوم على درجة حرارة الغرفة .

كذلك فقد استخدم التخزين المستمر على درجتى ٥ ، ١٢° م كمقارنة لهذه المعاملات المتقطعة

وكان الهدف من الدراسة هو تقييم هذه الظروف التخزينية على جـــودة ثمـــار الليمـــون البلـــدى والأضرار التى تحدث له.

اتضح من البيانات أن زيادة درجة حارة التخزين من ٥ إلى ١٢° وكذلك زيادة فترة التخزين نتـــج عنه زيادة فى قيم "L" وكثافة لون قشرة الثمرة وتبين أن ترك الثمار على درجة حرارة الغرفة لمـــدة يوميـــن بعد التخزين المبرد نتج عنه نتائج مماثلة وهذا يبين أنه حدث تحلل للكلوروفيل وظهور اللون الأصفـــر ولكـــن بنسبة لقيمة الليمون "h" فإنها انخفضت بحيث تحول اللون من الأخضر الزرق إلى الأصفر وذلك بزيـــادة درجة الحرارة وفترة التخزين وكذلك بعد ترك الثمار لمدة يومين على درجة حرارة الغرفـــة بعـــد التخزيـــن المبرد .

التخزين المستمر على درجة حرارة ٥° م ساعد فى المحافظة على اللون الأخضر لقشـــرة ثمـــار الليمون ولكن كثافة اللون انخفضت بسبب الأضرار التى ظهرت على الثمار من تأثير الحرارة المنخفضة مما أثر على القراءات .

لم يكن للتخزين المستمر على درجة حرارة ٥ أو ١٢° م تأثير على كل من صلابة الثمار ، نســـبة العصير ، الحموضة ولكن حدث انخفاض فى محتوى المواد الصلبة الذائبة وكذلـــك نســـبة محتـــوى المـــواد الصلبة الذائبة إلى الحموضة وأيضاً محتوى الثمار من حامض الأسكوربيك نتيجة لتخزين الثمار على درجـــة حرارة ٥° بينما زادت فى الثمار التى تم تخزينها على درجة حرارة ١٢°م .

حدث انخفاض فى صلابة الثمار وكذلك محتواها من حامض الأسكوربيك عندما وصلـــت فـــترة التخزين ٦٠ يوماً . ولقد لوحظ أن محتوى الثمار من العصير والحموضة لم يتغير أثناء التخزين المبرد ولكن حدث زيادة فى المحتوى من المواد الصلبة الذائبة وكذلك نسبة المواد الصلبة الذائبة إلى الحموضة .

ترك الثمار لمدة يومين على درجة حرارة الغرفة بعد التخزين المبرد أظهر عدم تغير فى صلابـــة الثمار ، نسبة العصير ، المواد الصلبة الذائبة ، حامض الأسكوربيك بينما زادت نسبة الحموضة وانخفضـــت نسبة المواد الصلبة إلى الحموضة فى الثمار التى خزنت على ١٢° م .

أظهرت تجارب التخزين بالتدفئة المتقطعة أن المعاملة ٦ يوم على درجة حـــرارة ٥°م + ١ يـــوم على درجة حرارة الغرفة فى دورات أنها ساعدت فى المحافظة على صلابة الثمار ، نسبة العصير ، نســـبة حامض الأسكوربيك بدون تغير لمدة ٦٠ يوماً بينما زادت نسبة المواد الصلبة الذائبة والحموضة كذلك فـــإن هذه المعاملة أظهرت أقل نسبة من أضرار الثمار بعد ٦٠ يوم من التخزين بالمقارنة بالمعاملات الأخرى .