Intermittent Warming of "Mexican" Lime to Reduce Chilling Injury during Cold Storage

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ABSTRACT

The present study was conducted on "Mexican" lime (*Citrus aurantifolia* Swing.) during 2004 and 2005 seasons. The purpose of the present study was to investigate the effect of intermittent warming (IW) of the "Mexican" lime to reduce chilling injury (CI) during cold storage. Fruits were submitted for storage; at 5°C or 12°C continuously and at 5°C with submitted to intermittent warming; at 12°C for one week every 2 weeks, at 20°C for 48 h every 2 weeks, at 12°C for one week every 3 weeks and at 20°C for 48 h every 3 weeks. The fruits were evaluated after 30 and 60 days plus 3 days at 20°C. The obtained results revealed that fruits kept continuously at 12°C did not show CI during storage periods. No visible symptoms of CI were observed in fruits until 30 days of storage but observed only after 60 days of storage at 5°C. The incidence of CI was 82–84 % for fruits kept continually at 5°C for both seasons, respectively. However, fruits intermittently warmed at 20°C for 48 h every 2 weeks did not show CI. Fruits kept at 20°C for 48 h every 2 weeks and at 20°C for 48 h every 3 weeks had greener skin after 60 days of storage but fruits kept continuously at 12°C showed degreeing after 30 days of storage in both seasons. Fruits stored continuously at 5°C, warmed to 12°C for one week every three weeks of storage at 5°C and continuously at 12°C had the highest weight loss. However, intermittently warmed fruits every two weeks of storage at 5°C to 12°C for one week or at 20°C for 48 h had the lowest weight loss after 60 days of storage in both seasons. No differences were found in the fruit quality after 60 days of storage period among fruits kept at 5°C and submitted to IW. Generally, the temperature of 5°C can be used for "Mexican" lime during 30 days of cold storage without risk of CI. Intermittent warming (IW) had been shown to be effective in reducing CI. Fruits intermittently warmed at 20°C for 48 h every 2 weeks had no injuries (CI), greener fruit skin fruit color, lowest weight loss and with no differences in the fruit quality after 60 days of storage period.

Key words: Intermittent warming -"Mexican" Lime- chilling injury.

INTRODUCTION

Lime fruits are subtropical origin and known to be susceptible to chilling injury (CI) development during cold storage (Paull, 1990; Kader & Arpaia, 2000). Storage at low temperature could prolong shelf life and maintain fruit quality by decreasing the rate of metabolism, delaying ripening and controlling growth of microorganisms. Chilling injury is a physiological disorder induced by low temperatures (below 10 -13°C) but above their freezing. At these chilling temperatures, the tissues weaken because they are unable to carry on normal metabolic processes. Various physiological and biochemical alterations and cellular dysfunctions occur in chilling sensitive species in response to chilling stress (Wang, 1993). When chilling stress is prolonged, these alterations and dysfunctions will lead to the development of a variety of chilling injury symptoms such as surface

lesions, internal discoloration, water soaking of the tissue and failure to normally ripen (Saltveit and Morris, 1990).

Several postharvest heat treatments have been reported to induce fruit tolerance to cold temperatures and to reduce the development of CI symptoms during cold storage (Wang, 1993; Lurie, 1998a, b; Schirra and Ben –Yehoshua, 1999, Paull and Chen, 2000). Such treatments include intermittent warming (IW), which consists of exposing fruits to one or more periods of warm temperature, during the cold storage (Wang, 1993). Intermittent warming increases fruit resistance to low temperatures, enabling fruit to be stored at temperatures below the ones normally recommended and maintains fruit quality for longer periods (Kluge *et al.*, 2003a). Intermittent warming has been shown to be effective to reduce CI in several citrus fruit cultivars. IW was tested for lemon (Cohen *et al.*, 1983; Cohen, 1988, Artés *et al.*, 1993), lime (Kluge *et al.*, 2003 a, b),"Olinda" orange (Schirra and Cohen, 1999),"Valencia" orange and grapefruit (Martinez Javega *et al.*, 1987) and "Clementine" mandarins (Martinez Javega and Cuquerella, 1984). They found considerable improvement of the fruit conservation period due to CI reduction in all mentioned studies. Beneficial effects of IW were observed in other commodities, such as peaches (Kluge *et al.*, 1996), pomegranates (Artés *et al.*, 2000) and plums (Kluge *et al.*, 1997). The greatest difficulty in creating optimum condition with intermittent warming (IW) storage lies in the need to operate with temperatures, duration and IW frequency that may greatly change from cultivar to cultivar, fruit maturity stage and growing condition.

The purpose of the present study was to investigate the effect of intermittent warming of the "Mexican" lime to reduce chilling injury during cold storage.

MATERIAL AND METHODS

The present study was conducted with "Mexican" lime (*Citrus aurantifolia* Swing.) during 2004 and 2005 seasons. Seven - year old orchard trees were budded on Volkamer lemon (*Citrus volkameriana* Ten) rootstock, grown in the Agricultural Experimental and Research Station (Deyrab) of the Faculty of Food and Agricultural Sciences – King Saud University, Riyadh. The trees received the same agro – technical practices.

Fruits were harvested randomly by the first week of September in both seasons, when commercially mature [35 mm diameter ± 2 mm and green color (Kader and Arpaia, 2000)]. Fruits were immediately delivered to the laboratory after harvest. Fruits were not washed and had no prestorage fungicide or wax treatments.

Defect-free lime fruits were selected and divided into six groups containing five boxes (replications) per group having 50 fruits each. Each group was submitted to one of the following treatments: [1]continuous storage at 12℃ (T1), [2]continuous storage at 5℃ (T2), [3] intermittently warmed to 12℃ for one week every two weeks of storage at 5℃ (T3), [4] storage at 5℃ and submission to warming at 20℃ for 48 h every two weeks (T4), [5] intermittently warmed to 12℃ for one week every three weeks of storage at 5℃ (T5) and [6] storage at 5℃ and submitted to warming at 20℃ for 48 h every three weeks (T6). These warming procedures consisted in transferring the fruits from storage at 5℃ to chambers set at the prescribed temperatures. Relative humidity (RH) in the storage room was maintained at 90 % and air change in the cold room was programmed automatically.

Samples of ten fruits for each replicate were evaluated at initial and at 30 & 60 days of storage periods (10 fruits × 5 replicates × 6 treatments) + 3 days at 20℃ (simulated shelf – life). Chilling injury (CI) was determined as the percentage of affected fruits and CI severity was evaluated. Fruits were evaluated for injury on the basis of the following subjective system according to the surface area affected as follows: 0 = 0 %, 1= < 5 %, 2 = ≥ 5 to < 25 %, 3= ≥25 to < 50 % and 4 = ≥50% (Kluge et al., 2003a). The skin color was evaluated by Minolta Chroma Meter CR -400 in CIE L* a* b* mode under CIE Standard Illuminant. Changes in hue angle (h°) and Chroma (C*) were calculated as $h° = \arctan (b^*/a^*)$ and $C^* = (a^{*2} + b^{*2})^{1/2}$ (McGuire, 1992). Two readings per fruit were taken on opposite. Weight loss percentage was measured during storage period for 10 fruit of each replicates (five replicates × six treatments) were numbered and weighted. The loss in weight was expressed as percent of the initial weight of the fruits. The juice was extracted from fruits with a motor-driven hand reamer (Ssntos, No.11). The juice content as percentage of fruit weight was recorded. The percentage of total soluble solids (TSS) was determined in fruit juice using BRX-242 digital refractometer. Juice acidity percentage (estimated as citric acid equivalent) was determined by titration with NaOH and phenolphthalein indicator. Ascorbic acid (Vitamin C) was determined by titration with 2,6 dichlorophenol-endophenol blue dye and expressed as ascorbic acid (ml per 100 ml of juice) (A.O.A.C. 1986).

The experimental design was completely randomized. Each treatment (six treatments) involved five replications of ten fruits each. All analyses were performed with SAS's personal computer software package version 6.03 (SAS Institute, 1988).

RESULTS AND DISCUSSION

1 - Chilling injury (CI)

Results of chilling injury as affected by intermittent warming are presented in Table (1) and Figure (1) during 2004 and 2005 seasons. Fruits kept continuously at 12℃ (T1) did not show CI during storage. In addition, no visible symptoms of CI were observed on fruits of other treatments at 30 days of storage but observed only at 60 days of storage at 5℃. The CI was characterized by small black superficial pits on the fruit skin. The incidences of CI were 82 and 84% for fruits kept continuously at 5℃ (T2) for both seasons, respectively. Fruits intermittently warmed at 20℃ for 48 h every 2 weeks (T4) did not show CI. While, fruits kept at 5℃ and submitted to intermittent warming at 20℃ for 48 h every 3 weeks (T6) showed 23 and 24% of CI for both seasons, respectively. However, intermittent warmed to 12℃ for one week every two weeks of storage at 5℃ (T3), or one week every three weeks of storage at 5℃ (T5) showed 34 and 69% of CI in the first season, respectively. The corresponding values for the second season were 36 and 68 %, respectively. The present study showed that IW at 20℃ for 48 h every 2 or 3 weeks (T4 and T6) reduced CI at 60 days of storage. No injuries were observed at 30 days of refrigerated storage in any of the treatments used. The occurrence of chilling symptoms depends on both, the temperature and the exposure time to this temperature (Wang, 1993). In the present work, the 30 days exposure period at 5℃ was not enough to induce CI in fruits and thus the temperature of 5℃ can be used for "Mexican" lime during 30 days of cold storage without risk of CI. The IW had been shown to be effective in reducing CI in various sensitive citrus fruits cultivars. Cohen *et al.* (1983) has demonstrated that the occurrence of peel pitting in "Villa Franka" lemon after 4–5 months of storage at 2℃ was 54 – 59 %. Fruits warmed at 13℃ for 7 days after each 21 days periods reduced this percentage to 3 – 4 %. Schirria and Cohen (1999) have verified for "Olinda" orange that IW during storage, with cycles of 3 weeks at 3℃ by 2 weeks at 15℃ delayed the onset of CI by approximately 10 weeks and greatly enhanced resistance to CI development. Investigations on "Fortune" mandarins showed that IW at 10℃ for 3 days every 4 days at 2℃ retarded CI development as compared to constant storage at 2℃. Favorable effects of IW have also been seen for "Tahiti" lime at 20℃ for 48 hours every 7 or 14 days reduced CI at 60 days of storage (Kluge *et al.*, 2003a). There are several hypotheses concerning the mechanisms of IW.

Table (1): Effect of intermittent warming on affected fruits % of "Mexican" lime at 60 days during 2004 and 2005 cold storage periods.

Treatments*	Affected fruits %	Category (Percentage of fruits)				
		0 (0)	1 (1-4)	2 (5-24)	3 (25-50)	4 (> 50)
			2004			
T_1	0	100	0	0	0	0
T_2	82	18	34	22	26	0
T_3	34	66	0	2	0	0
T_4	0	100	43	0	0	0
T_5	69	31	23	21	5	0
T_6	23	77	1.28	0	0	0
$LSD_{0.05}$	1.22	0.93		0.93	1.81	
			2005			
T_1	0	100	0	0	0	0
T_2	84	16	36	20	28	0
T_3	36	64	36	0	0	0
T_4	0	100	0	0	0	0
T_5	68	32	40	20	8	0
T_6	24	76	24	0	0	0
$LSD_{0.05}$	1.26	0.96	1.26	0.89	1.41	

* Treatments; T_1= fruit stored continuously at 12 ℃; T_2= stored continuously at 5 ℃, T_3 = intermittently warmed to 12℃ for one week every two weeks of storage at 5℃, T_4= warming at 20℃ for 48 h every two weeks, T_5= warmed to 12℃ for one week every three weeks of storage at 5℃ and T_6= warming at 20℃ for 48 h every three weeks.

Figure (1): Chilling injury (CI) symptoms and fruit skin color as affected by intermittent warming (IW) of the "Mexican" lime after 60 days of cold storage. T1= fruits stored continuously at 12 ℃; T2= stored continuously at 5 ℃, T3 = intermittently warmed to 12℃ for one week every two weeks of storage at 5℃, T4= warming at 20℃ for 48 h every two weeks, T5= warmed to 12℃ for one week every three weeks of storage at 5℃ and T6= warming at 20℃ for 48 h every three weeks.

Raising the temperature temporarily could induce higher metabolic activities, which would allow tissues to metabolize excess intermediates, and replenish deficiencies that developed during chilling. Warming of chilled tissues for short periods helps to repair damage of membranes, organelles, or metabolic pathways (Lyons and Breidenach, 1987). Warming and cooling of tissues (IW) maintain high level of phospholipids, increases the degree of unsaturation of fatty acids, increases the levels of Spermidine and Spermine, and stimulate the activities of free radical scavenging enzymes. Heat treatment induces heat shock proteins, suppresses oxidative activity, and maintains membrane stability (Wang, 2000). All of these processes can enhance chilling tolerance of tissues and alleviate chilling injury of fruits.

2 – Fruit skin color

The skin green color for the fruits kept at 12℃ (T1) had significantly greater losses as compared to those stored at 5℃ (T2 to T6) during 2004 and 2005 storage seasons (Tables 2 & 3 and Fig.1). Fruits stored at 12℃ had the lowest hue angle (h°) and higher Chroma (C*) values at 30 days of storage, that means they were less green (yellow). Hue angles deviating more from 90° represent greener fruit, whereas values nearer to 90°, represent yellowier fruit. Chroma defines the color intensity, presenting values around zero for neutral color (gray) and values around 60 for bright color (McGuire, 1992). In this way, as for the present work, higher Chroma values mean higher yellow color intensity. Treatment 4 and T6 had greener fruit at 60 days of storage, in both seasons. These findings agreed with those found by Kluge *et al.* (2003 a, b). Such results were expected, considering that the speed of metabolic reactions is directly related to the temperature at which it occurs. Goldschmidt (1997) stated that the chlorophyll degradation is an event that can be regulated by ethylene. Consequently, the loss of green skin color of "Mexican" lime could be blocked by inhibitors of ethylene action, when fruits were stored at chilling temperature (5℃).

3 – Weight loss %

It is evident from Table (4) that the rate of loss in fruit weight increased significantly with the storage period advancement. Fruits stored continuously at 5℃ (T2) or warmed to 12℃ for one week every three weeks of storage at 5℃ (T5) and continuously at 12℃ (T1) had the highest weight loss. However, intermittently warmed every two weeks of storage at 5℃ to 12℃ for one week (T3) or at 20℃ for 48 h (T4) had the lowest weight loss at 60 days of storage in both seasons. The period and temperature conditioning of IW treatments may decrease CI by inhibiting water loss. Purvis (1984) and McDonald, *et al.* (1993) concluded that water loss during low – temperature storage of grapefruit was a contributing factor to CI symptom development. Fruits kept at 5℃ and submitted to warming at 20℃ for 48 h every 2 weeks (T4) had lowest weight loss and affected fruit % (CI) in both seasons (Tables 1 & 4). These results agreed with those found by Kluge *et al.* (2003 a).

4 – Juice %

The data presented in Table (5) revealed no differences in the juice % among fruits kept at 5℃ and submitted to IW treatments (T2 to T6) in both seasons. However, fruits kept continuously at 12℃ (T1) had slight increase in the juice %.The results found by Kluge *et al.* (2003 a, b) and Schirria and Cohen (1999) seemed to be in general agreement with those obtained in this study.

Table (2): Effect of intermittent warming on hue angle of "Mexican" lime during 2004 and 2005 cold storage periods.

Treatments*	Storage period (days)			Mean
	0	30	60	
		2004		
T_1	106.43	91.33	90.54	96.10
T_2	106.43	102.56	99.33	102.77
T_3	106.43	102.56	99.64	103.01
T_4	106.43	103.43	101.54	103.80
T_5	106.43	101.65	99.43	102.50
T_6	106.43	102.76	101.24	103.48
Mean	106.43	100.78	98.62	
$LSD_{0.05}$	T = 0.48	P = 0.38	T*P = 0.83	
		2005		
T_1	105.95	92.33	91.21	96.50
T_2	105.95	102.72	99.34	102.67
T_3	105.95	102.10	98.23	102.10
T_4	105.95	102.54	100.38	102.96
T_5	105.95	101.27	98.48	101.91
T_6	105.95	102.54	100.35	102.95
Mean	105.95	100.58	98.00	
$LSD_{0.05}$	T = 0.44	P = 0.31	T*P = 0.76	

* As in Table (1).

Table (3): Effect of intermittent warming on chroma of "Mexican" lime during 2004 and 2005 cold storage periods.

Treatments*	Storage period (days)			Mean
	0	30	60	
		2004		
T_1	43.24	55.32	58.26	52.27
T_2	43.24	42.10	43.03	42.79
T_3	43.24	43.45	47.32	44.75
T_4	43.24	43.28	44.68	43.61
T_5	43.24	44.21	46.53	44.04
T_6	43.24	43.65	47.40	44.47
Mean	43.24	45.34	47.40	
$LSD_{0.05}$	T = 0.72	P = 0.40	T*P = 0.98	
		2005		
T_1	43.67	54.18	57.57	51.81
T_2	43.67	41.21	43.25	42.71
T_3	43.67	43.94	50.15	45.92
T_4	43.67	43.56	44.83	44.02
T_5	43.67	44.29	44.71	44.23
T_6	43.67	43.28	46.18	44.44
Mean	43.67	45.08	47.78	
$LSD_{0.05}$	T = 0.68	P = 0.48	T*P = 1.17	

* As in Table (1).

Table (4): Effect of intermittent warming on weight loss % of "Mexican" lime during 2004 and 2005 cold storage periods.

Treatments*	Storage period (days)			Mean
	0	30	60	
		2004		
T_1	0	7.43	14.13	10.78
T_2	0	7.58	15.26	11.42
T_3	0	6.03	9.60	7.81
T_4	0	5.48	9.94	7.70
T_5	0	6.94	15.40	11.17
T_6	0	6.43	11.40	8.94
Mean	0	6.64	12.63	
$LSD_{0.05}$	T = 0.25	P = 0.14	T*P = 0.35	
		2005		
T_1	0	7.91	13.86	10.88
T_2	0	7.88	15.61	11.74
T_3	0	6.16	9.93	8.05
T_4	0	5.47	10.72	8.09
T_5	0	6.93	15.80	11.37
T_6	0	6.43	11.97	9.20
Mean	0	6.79	12.98	
$LSD_{0.05}$	T = 0.08	P = 0.04	T*P = 0.11	

* As in Table (1).

Table (5): Effect of intermittent warming on juice % of "Mexican" lime during 2004 and 2005 cold storage periods.

Treatments*	Storage period (days)			Mean
	0	30	60	
		2004		
T_1	50.59	51.23	51.73	51.18
T_2	50.59	48.96	48.76	49.44
T_3	50.59	49.59	50.83	50.33
T_4	50.59	48.94	51.24	50.25
T_5	50.59	49.25	50.14	50.16
T_6	50.59	50.29	50.45	50.44
Mean	50.59	49.71	50.52	
$LSD_{0.05}$	T = 1.07	P = 0.71	T*P = 1.74	
		2005		
T_1	50.63	51.98	53.30	51.97
T_2	50.63	52.03	48.85	50.83
T_3	50.63	51.45	51.53	50.80
T_4	50.63	50.43	50.88	50.64
T_5	50.63	50.03	49.75	50.13
T_6	50.63	53.13	47.68	50.48
Mean	50.63	51.50	50.30	
$LSD_{0.05}$	T = 0.83	P = 0.59	T*P = 1.44	

* As in Table (1).

5 - Total soluble solids % (TSS)

Concerning the juice TSS, it is clear from the data presented in Table (6) that the treatments T1, T2, T3 and T4 did not have significant effects on TSS values in both studied seasons. However, T5 and T6 had slight decrease in the fruit TSS contents with significant difference when compared with T1 and T3 in both seasons. These results partially agreed with that found by Kluge *et al.* (2003 a) on lime and Schirria and Cohen (1999) on orange who found that TSS were not significantly affected by IW.

6 - Juice acidity %

The data given in Table (7) showed that acidity % decreased during the storage periods in both seasons. Fruits kept at 5℃ (T2; T3, T4, T5 and T6) did not have any significant effects on acidity % values in both studied seasons. These results agreed with that found by Kluge *et al.* (2003 a) on lime and Schirria and Cohen (1999) on orange. Who found that acidity % values were not significantly affected by IW.

Table (6): Effect of intermittent warming on TSS % of "Mexican" lime during 2004 and 2005 cold storage periods.

Treatments*	Storage period (days)			Mean
	0	30	60	
		2004		
T_1	7.65	7.85	7.78	7.76
T_2	7.65	7.78	7.82	7.74
T_3	7.65	7.95	7.80	7.80
T_4	7.65	8.10	7.75	7.83
T_5	7.65	7.47	7.55	7.55
T_6	7.65	7.45	7.48	7.53
Mean	7.65	7.76	7.70	
$LSD_{0.05}$	T = 0.17	P = 0.12	T*P = 0.30	
		2005		
T_1	7.65	8.68	8.33	8.22
T_2	7.65	8.08	8.20	7.98
T_3	7.65	8.33	8.45	8.14
T_4	7.65	8.23	7.65	7.84
T_5	7.65	7.80	7.50	7.65
T_6	7.65	7.80	7.50	7.65
Mean	7.65	8.15	7.94	
$LSD_{0.05}$	T = 0.39	P = 0.09	T*P = 0.23	

* As in Table (1).

Table (7): Effect of intermittent warming on titratable acidity % of "Mexican" lime during 2004 and 2005 cold storage periods.

Treatments*	Storage period (days)			Mean
	0	30	60	
		2004		
T_1	6.19	6.38	6.07	6.21
T_2	6.19	5.96	5.79	5.98
T_3	6.19	6.05	5.85	6.03
T_4	6.19	6.05	5.61	5.95
T_5	6.19	5.72	5.76	5.89
T_6	6.19	5.90	5.74	5.95
Mean	6.19	6.01	5.80	
$LSD_{0.05}$	T = 0.20	P = 0.14	T*P = 0.35	
		2005		
T_1	6.55	6.78	5.63	6.32
T_2	6.55	6.48	5.47	6.17
T_3	6.55	6.36	5.63	6.18
T_4	6.55	6.54	5.65	6.25
T_5	6.55	6.60	5.42	6.19
T_6	6.55	6.25	5.68	6.19
Mean	6.55	6.50	5.58	
$LSD_{0.05}$	T = 0.12	P = 0.08	T*P = 0.21	

* As in Table (1).

7- Vitamin C

It is evident from Table (8) that the vitamin C significantly decreased with the storage period advancement. At 30 days of storage, the reduction percentages in vitamin C were 26.15 and 27.12% in both seasons, respectively. While, from 30 to 60 days were 3.82 and 7.63% in both seasons, respectively. The differences in vitamin C were not significant between treatments; T2, T3, T5, and T6 in the first season and between T2, T5 and T6 in the second season (fruits kept at 5°C). These results partially agreed with those reported by Kluge *et al.* (2003 a) on lime and Schirria & Cohen (1999) on orange.

Table (8): Effect of intermittent warming on vitamin C % of "Mexican" lime during 2004 and 2005 cold storage periods.

Treatments*	Storage period (days)			Mean
	0	30	60	
		2004		
T_1	32.24	25.32	27.29	28.28
T_2	32.24	22.30	20.93	25.16
T_3	32.24	21.98	22.59	25.60
T_4	32.24	27.45	23.23	27.64
T_5	32.24	22.30	21.45	25.31
T_6	32.24	23.56	21.88	25.87
Mean	32.24	23.81	22.90	
$LSD_{0.05}$	T = 0.75	P = 0.53	T*P = 1.30	
		2005		
T_1	34.15	26.23	22.98	27.78
T_2	34.15	22.83	22.82	26.60
T_3	34.15	24.25	23.38	27.26
T_4	34.15	27.23	22.30	27.89
T_5	34.15	23.58	22.95	26.89
T_6	34.15	25.23	21.98	27.12
Mean	34.15	27.89	22.73	
$LSD_{0.05}$	T = 0.54	P = 0.38	T*P = 0.94	

* As in Table (1).

CONCLUSION

The results of the present experiment have shown that the temperature of 5℃ can be used for "Mexican" lime during 30 days of cold storage without risk of CI. Intermittent warming (IW) had been shown to be effective in reducing CI. Fruits that intermittently warmed at 20℃ for 48 h every 2 weeks (T4) did not cause injuries (CI), and had greener fruit skin color, lowest weight loss without differences in the fruit quality after 60 days of storage period.

REFERENCES

A.O.A.C. 1986. Association of Official Agricultural Chemists. Official and Tentative Methods of Analysis. 13th ed. Association of Official Agricultural Chemists, Washington, D.C., USA.

Artés, F.; A.J. Escriche and J. G. Marin, 1993. Treating "Primofiori" lemon in cold storage with intermittent warming and carbon dioxide. Hort Science 28: 819-821.

Artés, F.; J. A. Tudela, and R. Villaesscusa, 2000. Thermal postharvest treatments for improving pomegranate quality and shelf life. Postharvest Biol. Techno. 18 (3): 245-251.

Cohen,E., 1988. Commercial use of long-term storage of lemon with intermittent warming. Hort Science, 23: 400

Cohen, E.; M. Shuali and Y. Shalom, 1983. Effect of intermittent warming on the reduction of chilling injury of "Villa Franka" lemon stored at cold temperature. J. Hort. Sci., 58: 593- 598.

Goldschmidt, E. E., 1997. Ripening of citrus and other nonclimateric fruits :a role for ethylene . Acta Hort. 463: 325 – 334.

Kader, A. A. and M.L. Arpaia, 2000. Postharvest handling systems : subtropical fruit. In; Kader, A.A. (Ed), Postharvest Technology of Horticultural Crops. Regents of the University of California, Division of Agricultural and Natural Resources. pp. 375 – 384.

Kluge, R. A.; L.L Maria- Jomori, A.P. Jacomino, D.v. Maria-Carolina and D.C.Vitt, 2003a. Intermittent warming of "Tahiti" lime to prevent chilling injury during cold storage. Braz. Sci. agric., 60 (4): 609- 614.

Kluge, R. A.; L.L. Maria- Jomori, A.P. Jacomino, D.V. Maria-Carolina and M. Padula 2003b. Intermittent warming in "Tahiti" lime treated with an ethylene inhibitor. Postharvest Biol. Technol., 29: 195- 203.

Kluge, R.A.; A. Hoffmann ,J.C. Nachtigal, A. B. Bilhalava and J.C. Fachinello, 1996. Intermittent warming in "BR-6" peaches cold stored . Pesq. Agrop. Bras., 31: 543-547.

Kluge, R. A.; R.F. Cantillano and A.B. Bilhalva, 1997. Internal braekdown of Santa Rosa plum stored at different temperature regimes. Rev. Braz. Agrosci., 3: 125-130.

Lurie, S., 1998a. Postharvest heat treatment of horticultural crops. Hort. Rev. 22: 91 – 121.

Lurie, S., 1998b. Postharvest heat treatments. Postharvest. Biol. Technol. 14: 257-269.

Lyons, J.M. and R.W. Breidenbach, 1987. Chilling injury, In: J. Weichmann (Ed). Postharvest Physiology of Vegetable, Marcel Dekker, New York. p.305 – 326.

Martinez Javega, J. M. and J. Cuquerella, 1984. Factors affecting of Spanish oranges and mandarins. Pro. Ist. Sos. Citriculture 1: 511-514.

Martinez Javega, J.M.; M. Mateos , J. Cuquerella and P. Navarro, 1987. Improving live of citrus fruits by temperature management. XVIIth Int. Congr. Refrig., 3: 321-326.

McDonald, R. E.; T. G. McCollum and H. E. Nordby, 1993. Temperature conditioning and surface treatments of grapefruit affect expression of chilling injury and gas diffusion. J. Amer. Soc. Hort. Sci. 118 (4): 490 – 496.

McGuire, R. G., 1992. Reporting of objective color measurements. Hort science, 27: 1254 - 1255.

Paull, R.E., 1990. Chilling injury of crops of tropical and subtropical origin. In: Wang, C.Y. (Ed), chilling Injury of Horticultural Crops. CRC Press, Boca Raton , FL, pp.17 – 36.

Paull, R.E., and N.J. Chen, 2000. Heat treatment and fruit ripening Postharvest Biol. Technol. 21: 21-38.

Purvis, A. C.,1984. Importance of water loss in the chilling injury of grapefruit stored at low temperature. Sci. Hort. 23: 261–267.

Saltveit, M. E. and L. L. Morris, 1990. 0verview on chilling injury of Horticultural crops. In : Wang, C.Y.(Ed), chilling Injury of Horticultural Crops. CRC Press, Boca Raton, FL, pp.3-15.

SAS Institute,1988. SAS/STAT User' Guide, Release 6.03,SAS Inst., Cary, NC.

Schirra, M., and S. Ben-Yehoshua, 1999. Heat treatments: a possible new technology in citrus handling challenges and prospects. In: Schirra,M, (Ed), Advances in postharvest Diseases and Disorders of Citrus Fruit. Research Signpost, Trivandrm, pp. 133-147.

Schirra, M. and E. Cohen, 1999. Long term storage of Olinda oranges under chilling and intermittent warming temperatures. Postharvest Biol. Technol. 16:63- 69.

Wang, C.Y., 1993. Approaches to reduce chilling injury of fruits and vegetables. Hort. Rev. 15: 63 – 95.

Wang, C.Y., 2000. Postharvest techniques for reducing low temperature injury in chilling – sensitive commodities, In : Artés, F; M.I. Gil and M.A. Conesa (Ed). Improving postharvest technology of fruits, Vegetables and Ornamentals, IIR conference Murcia, Spain, pp 467-473.

الملخص العربي

التدفئة المتقطعة لليمون "المكسيكي" لتقليل أضرار البرودة أثناء التخزين المبرد

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أجريت الدراسة خلال موسمي ٢٠٠٤ و٢٠٠٥م على ثمار الليمون المالح " المكسيكي" لدراسة تأثير التدفئة المتقطعة لتقليل أضرار البرودة أثناء التخزين المبرد. حصدت الثمار في مرحلة النضج البستاني من أشجار بالغة بعمر٧سنوات و مطعمة علي أصل ليمون فولكاماريانا و نامية بمزرعة محطة الأبحاث و التجارب الزراعية – ديراب . أجريت ست معاملات: التخزين باستمرار علي درجة ١٢°م، التخزين باستمرار علي درجة ٥°م ، التخزين على درجة ٥°م و كل أسبوعين تخضع لتدفئة لمدة أسبوع علي درجة ١٢°م ، التخزين علي درجة ٥°م و كل أسبوعين تخضع لتدفئة لمدة ٤٨ ساعة على درجة ٢٠°م ، التخزين علي درجة ٥°م و كل ثلاثة أسابيع تخضع لتدفئة لمدة أسبوع على درجة ١٢°م و التخزين على درجة ٥°م و كل ثلاثة أسابيع تخضع لتدفئة لمدة ٤٨ ساعة على درجة٢٠°م و تم تقييم تأثيرها على أضرار البرودة و صفات جودة الثمار. أشارت النتائج إلى عدم ظهور أعراض أضرار البرودة على الثمار خلال ٣٠ يوما الأولى من التخزين المبرد على درجة ٥°م كذلك المخزنة باستمرار علي درجة ١٢°م. وأظهرت تأثيراً معنوياً للتدفئة المتقطعة على نسبة الإصابة بأضرار البرودة و لون قشرة الثمار والفاقد في الوزن، حيث أن الثمار المخزنة باستمرار على درجة ٥°م أعطت أعلى نسبة لكل من الثمار المصابة ٨٢ – ٨٤٪ ونسبة الفاقد في الوزن خلال موسمي الدراسة. بينما الثمار المخزنة على درجة ٥°م و كل أسبوعين تخضع لتدفئة لمدة ٤٨ ساعة على درجة٢٠°م لم تظهر عليها أعراض أضرار البرودة و أعطت أقل نسبة من الفاقد في الوزن و احتفظت باللون الأخضر خلال فترة ٦٠ يوماً للتخزين. ولكن الثمار المخزنة باستمرار على درجة ١٢°م اختفى لونها الأخضر و اكتسبت اللون الأصفر بعد ٣٠ يوماً. كما لم تؤثر التدفئة المتقطعة على صفات جودة الثمار. عموماً يمكن تخزين ثمار الليمون المالح " المكسيكي" على درجة ٥°م لمدة ٣٠ يوماً دون حدوث أضرار للبرودة. لم تظهر على الثمار المخزنة علي درجة ٥°م و كل أسبوعين تخضع لتدفئة لمدة ٤٨ ساعة علي درجة٢٠°م أعراض البرودة و أعطت اقل نسبة من الفاقد في الوزن و احتفظت بلونها الأخضر دون نقص واضح في صفات جودة الثمار خلال فترة ٦٠ يوماً للتخزين المبرد .