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Post-Cold Storage Shelf Life of Organic Chili Pepper (*Capsicum annum* cv. 'Superhot') Applied with Hot Water Dip and Active Packaging

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Abstract

Cold storage could increase shelf life of chili pepper (*Capsicum annum*) but too long a period of storage could adversely affect shelf life during subsequent holding at ambient. This study determined the effects of different durations of cold storage on the shelf life during subsequent ambient holding of organic chili cv. 'Superhot' applied with hot water dip and active packaging. Organic chili pepper at the full-red stage were dipped in 50°C water for 4 min and then packed in 32-34 µm-thick polyethylene (PE) bag with micro-perforations (Active PACK™). The fruit were cold-stored at 10°C with 95% RH for 4-16 days and then held at ambient (25°C, 75% RH) to simulate the distribution and marketing period. Cold storage of 12 days is the best duration in prolonging fruit shelf life at ambient by about four days more than that of the control. Longer duration of cold storage shortened the shelf life due to increased weight loss and decay.

Introduction

Chili pepper (*Capsicum annum* cv. 'Superhot') is an important domestic and export vegetable in Thailand. Chili peppers are usually harvested and marketed as whole fruit at the red ripe stage and have a short post-harvest life (7-10 days) even under proper temperature management due to decay, shriveling and softening (Rodoni et al., 2015). At temperatures below 7°C, peppers develop chilling injury (González-Aguilar et al., 2004).

Several postharvest techniques can be applied in combination in order to extend shelf life of fruit and vegetables including organic product which is a product that the market needs high due to the emphasis on environment-friendly food production and human healthcare. In organic green and red peppers, Rodoni et al. (2016) combined the use of hot water dip (HWD) and cold storage and found that HWD at 45°C for 3 min resulting in lower fruit spoilage than the control fruit. The treatment reduced soft rot, shriveling, weight loss, color changes and respiration rate; delayed pectin solubilization and softening; and prevented membrane leakage during storage at 4°C. It did not alter sugar content, acidity and antioxidant capacity. The research

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concluded that HWD is a simple and safe non-chemical approach to supplement low temperature management, extending the shelf life of organic peppers.

Modified atmosphere packaging (MAP) is another non-chemical method to improve shelf life of fruit and vegetables. It is exemplified by the use of polymeric films to create an atmosphere of low O_2, high CO_2 and high water vapor content which can effectively slow the rates of respiration, water loss and ripening or senescence (Kader & Watkins, 2000). In recent years, many research studies have focused on the application of active packaging on a broad array of food systems (Atar & Chiralt, 2016). In an earlier study in organic chili pepper cv. Superhot, active MAP using a propriety product (Active PAK™) of 32-34 µm-thick polyethylene (PE) bag with micro-perforations combined with HWD at 50°C for 4 min applied before packaging was found to effectively reduce weight loss and decay during 16-day cold storage (10°C, 95% relative humidity) as compared to passive MAP (62 µm-thick PE) combined with 45°C or 55°C HWD (Krongyut & Duangsi, 2015). However, fruit shelf life during subsequent holding at ambient conditions was not improved. The present study determined the duration of cold storage that could improve fruit shelf life during subsequent ambient holding.

Materials and methods

1. Preparation of fruit samples

Freshly harvested chili pepper cv. 'Superhot' at the full-red stage were obtained from a local organic farm in Ubon Ratchathani Province and brought to the Post-harvest Laboratory of the Faculty of Agriculture, Ubon Ratchathani Rajabhat University, Ubon Ratchathani, Thailand. The fruit were sorted and only defect-free and uniformly sized fruit were used as experimental samples.

2. Application of treatments

The fruit were treated first with HWD, followed by active packaging before cold storage and subsequent ambient holding. The chili pepper were dipped in 50°C water for 4 minutes and then air-dried at room temperature for 30 min (Krongyut & Duangsi, 2015). The HWD-treated fruit weighing 100 g per replicate were placed in a fruit tray and packed in active MAP using Active PAK™ from the National Metal and Materials Technology Center (MTEC), Thailand. The active MAP has micro-perforations and anti-fog agent to prevent water condensation and is essentially made of PE of 32-34 µm thickness and 8 x 12 inches size, with O_2 transmission rate of 10,000-12,000 cm^3/m^2/day·atm, CO_2 transmission rate of 29,000-32,000 cm^3/m^2/day·atm, and water vapor transmission rate of 10 g/m^2· day. The packed fruit were then stored in a cold chamber at 10°C temperature and 95% RH at different durations - 0 (control), 4, 8, 12 and 16 days. After cold storage, the fruit were transferred to a 25°C room with 75% RH for 5 days for ambient shelf life simulation.

3. Data measurement

Peel color was measured using a CR-300 Chromameter (Minolta, Hong Kong) taking the a* (reddening) and L* (lightness) values. Surface color was taken from each 10 fruit samples, recording the average of five readings from the middle part of the fruit.

Weight loss was determined as percentage of the initial weight.

Decay incidence was obtained by taking the number of fruit that showed sign of decay which was then expressed as percentage of the total number of fruit samples per replicate.

Titratable acidity (TA) was analyzed using the titration method. Pulp tissues (10 g) were homogenized using a blender with 40 ml of distilled water. The mixture was then filtered through cotton wool. The filtrate (5 ml) was added with one to two drops of 0.1% phenolphthalein indicator and was titrated using 0.1 N NaOH to an endpoint of faint pink color (pH 8.1). The results were expressed as percentage citric acid per 100 g fresh weight.

Shelf life was determined as the number of days to reach the limit of marketability based on the visual quality of the fruit scored by eight trained panelists using a 5-point hedonic scale as previously described (Gonzalez-Aguilar et al., 2004).

4. Statistical analysis

The experiments were conducted in a completely randomized design (CRD) with three replications. Results were analyzed by performing the analysis of variance (ANOVA) and treatment mean comparison by the Least Significant Difference (LSD) test at 95% confidence intervals using Statistica 7 software (StatSoft, Tulsa, OK, USA). All data reported as means ± standard deviations (SD).

Results and discussion

Peel red color (a* values) during ambient holding for five days was not significantly affected by the duration of cold storage (Table 1). In general, a* values ranged from 21.4-24.4 regardless of the holding period at ambient. Data measurement was terminated earlier in some treatments because the fruit became unmarketable. Similarly, surface lightness (L* values) was not significantly affected by the duration of cold storage and ranged from 39.5-41.4 throughout the five-day ambient holding period (Table 2).

Table 1 Peel color a* values during ambient storage of hot water-treated and active MAP-held organic chili pepper subjected to different durations of cold storage.

Cold storage duration (days)	Days at ambient					
	0^{ns}	1^{ns}	2^{ns}	3^{ns}	4^{ns}	5
0	23.75±0.32	22.69±1.56	22.49±0.29	ND	ND	ND
4	24.12±0.75	22.42±1.67	22.49±0.29	22.20±0.36	21.99±1.08	21.45±0.99
8	23.40±0.50	22.81±1.25	22.48±1.62	22.09±1.33	21.78±0.81	ND
12	23.31±0.20	22.43±0.11	22.44±0.45	22.18±0.14	22.20±0.09	ND
16	23.34±0.12	22.87±0.65	22.50±1.16	22.29±0.91	ND	ND

Remark: Each value is presented as mean standard deviation (n=3).
The letters ns are displayed in column. There was no significant different (p>0.05).
ND is not detectable.

Table 2 Peel color L* values during ambient storage of hot water-treated and active MAP-held organic chili pepper subjected to different durations of cold storage.

Cold storage duration (days)	Days at ambient					
	0^{ns}	1^{ns}	2^{ns}	3^{ns}	4^{ns}	5
0	40.78±0.46	40.41±0.41	40.11±0.49	ND	ND	ND
4	40.78±1.12	40.67±1.11	40.52±0.99	39.95±0.56	39.87±0.54	39.77±0.55
8	41.38±1.45	41.13±1.78	40.55±1.19	39.49±0.62	39.57±0.49	ND
12	40.31±0.95	40.43±0.98	40.32±0.91	39.49±0.62	39.90±0.71	ND
16	40.82±0.72	40.08±0.28	39.85±1.12	39.65±1.11	ND	ND

Remark: Each value is presented as mean standard deviation (n=3).
The letters ns are displayed in column. There was no significant different (p>0.05).
ND is not detectable.

Weight loss increased with increasing period of ambient holding (Table 3). The duration of cold storage had a significant effect (Table 3). After one day of ambient holding, the fruit that was not held under cold storage (0 day, control) and those cold-stored for 16 days had markedly higher weight loss of 1-2% than fruit cold-stored for 4-12 days which had less than 1% weight loss. After three days of ambient holding when only cold-stored fruit remained, fruit cold-stored for 16 days had much higher weight loss (about 4%) than fruit cold-stored for 4-12 days (less than 2%). Differences in weight loss of fruit cold-stored for 4-12 days were not significant.

Decay set in faster in the control fruit than in fruit subjected to cold storage (Table 4). After 2 days of ambient holding, more than 20% of control fruit had decay while cold-stored fruit had less than 20% decay. Among cold-stored fruit, fruit stored for 16 days had significantly higher decay incidence after 1-3 days of ambient holding than fruit stored for 4-12 days. Fruit held in cold storage for 12 days had the lowest decay after 3 days of ambient holding.

Table 3 Weight loss (%) during ambient storage of hot water-treated and active MAP-held organic chili pepper subjected to different durations of cold storage.

Cold storage duration (days)	Days at ambient					
	0	1	2	3	4^{ns}	5
0	0.00	1.14±0.47^{b}	1.93±0.02^{a}	ND	ND	ND
4	0.00	0.76±0.18^{b}	1.30±0.07^{b}	1.38±0.01^{b}	1.73±0.76	1.76±0.77
8	0.00	0.65±0.35^{b}	1.79±0.18^{a}	1.69±0.06^{b}	1.91±0.08	ND
12	0.00	0.67±0.05^{b}	1.34±0.03^{b}	1.75±0.60^{b}	1.80±0.56	ND
16	0.00	1.96±0.03^{a}	1.94±0.05^{a}	3.98±0.10^{a}	ND	ND

Remark: Each value is presented as mean standard deviation (n=3).
Mean with ns in the same column are not significantly different (p>0.05).
Mean with a-b in the same column are significantly different (p≤0.05).
ND is not detectable.

Table 4 Decay (%) during ambient storage of hot water-treated and active MAP-held organic chili pepper subjected to different durations of cold storage.

Cold storage duration (days)	Days at ambient					
	0	1	2	3	4	5
0	0.00	14.67±0.58^{a}	22.67±2.52a	ND	ND	ND
4	0.00	6.33±0.58^{c}	12.67±0.58^{c}	15.41±0.52^{c}	17.24±0.41^{b}	18.41±0.52
8	0.00	6.87±0.32^{c}	13.15±0.26^{c}	17.00±0.23^{b}	18.13±0.23^{a}	ND
12	0.00	6.50±0.62^{c}	11.22±1.01^{c}	13.67±1.53^{d}	17.34±0.59^{b}	ND
16	0.00	10.66±0.77^{b}	16.12±0.19^{b}	20.16±0.06^{a}	ND	ND

Remark: Each value is presented as mean standard deviation (n=3).
Mean with a-c in the same column are significantly different (p≤0.05).
ND is not detectable.

Titratable acidity (TA) slightly increased during ambient holding and was significantly affected by the treatments only after 3 days at ambient when only cold-stored fruit remained marketable (Table 5). However, TA did not widely vary as it ranged only from 0.20-0.24% citric acid regardless of the duration of cold storage.

Ambient shelf life was shortest (less than two days) in control fruit (no cold storage) (Fig. 1). Cold storage increased shelf life but prolonged storage for 16 days shortened the shelf life at ambient to less than three days. This was apparently caused by the higher weight loss and decay than that of fruit cold stored for 4-12 days which lasted for more than three days at ambient. Based on the results, cold storage of 4-12 days is a safe holding period that has no adverse effect on shelf life of chili pepper during subsequent holding at ambient.

Table 5 Titratable acidity (%) during ambient storage of hot water-treated and active MAP-held organic chili pepper subjected to different durations of cold storage.

Cold storage duration (days)	Days at ambient					
	0^{ns}	1^{ns}	2^{ns}	3	4^{ns}	5
0	0.16±0.04	0.19±0.01	0.20±0.01	ND	ND	ND
4	0.16±0.00	0.18±0.00	0.24±0.04	$0.22±0.01^{ab}$	0.21±0.01	0.19±0.00
8	0.18±0.01	0.19±0.01	0.25±0.02	$0.24±0.02^{a}$	0.23±0.02	ND
12	0.16±0.04	0.21±0.02	0.22±0.01	$0.23±0.01^{a}$	0.22±0.02	ND
16	0.15±0.05	0.20±0.03	0.22±0.01	$0.20±0.01^{b}$	ND	ND

Remark: Each value is presented as mean standard deviation (n=3)
Mean with ns in the same column are not significantly different (p>0.05).
Mean with a-b in the same column are significantly different (p≤0.05).
ND is not detectable.

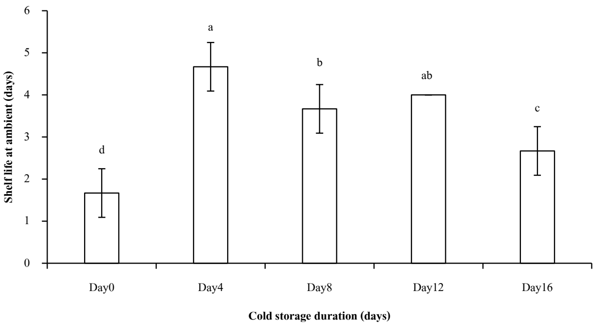

Fig. 1 Shelf life at ambient of hot water-treated and active MAP-held organic chili pepper subjected to different durations of cold storage. Error bars indicated standard deviation from mean values (n=3). Bar with different letters are significantly different (p≤0.05) according to the Least Significant Difference (LSD) test.

Chili peppers have a very short postharvest life and proper temperature management in combination with other techniques is important to improve the shelf life. In the present study, fruit shelf life without cold storage was less than two days because of high weight loss indicating rapid water loss and high decay incidence indicating rapid rotting and tissue breakdown associated with fruit senescence. Cold storage remarkably increased shelf life. Using 12-day cold storage duration, shelf life increased to 16 days, i.e. 12 days in cold storage plus 4 days at ambient. Extending the cold storage duration to 16 days had detrimental effect as it shortened ambient shelf life to less than three days due to high weight loss and decay, thereby limiting post-cold storage distribution and marketing at ambient. This supported earlier results in which 16-day cold storage did not improve ambient shelf life of organic red chili despite the application of HWD and active MAP (Krongyut & Duangsi, 2015) which were similarly applied in the present study.

Cold storage for at most 12 days seemed to maintain normal metabolism which was sustained during subsequent ambient holding. The rate of metabolic processes after cold storage for 4-12 days and during ambient holding was slowed as the fruit lasted for more than three days at ambient whereas fruit held immediately at ambient (without cold storage) lasted for less than two days. Prolonged cold storage for 16 days seemed to induce non-visible chilling damage as there was no chill-induced fruit discoloration seen based on peel color parameters. This non-visible chilling injury may include alteration in physicochemical processes leading to more rapid quality loss at ambient evidenced as high weight loss and decay. Cold-induced injury could increase the susceptibility of fruit to decay. The cold-induced metabolic alteration seemed to be physical in nature as TA analysis did not suggest abnormality in chemical composition of the fruit. Chilling injury is known to be a result of physical alteration of cell membranes and chili peppers developed visible chilling injury such as peel discoloration at temperatures below 10°C (González-Aguilar et al., 2004). The development of chilling injury in chili peppers and other tropical produce is a major limitation of cold storage which is considered as the single most effective method in prolonging postharvest life of fruit and vegetables (Rodoni et al., 2015).

It is recommended to elucidate the mechanism underlying the adverse effect of longer cold storage duration (e.g. 16 days) on ambient shelf life of organic chili pepper. Changes in cell membrane structure and enzymes associated with chilling injury development can be determined. Understanding these changes can provide clues to maximize the utility of cold storage without compromising ambient shelf life of the fruit. Other safe techniques to increase the resistance of the fruit to chilling storage can be tested, such as calcium treatment (pre- and/or post-harvest application) and surface coating. It is also worth applying conditioning treatments, such as gradual exposure to ambient temperature, in order to improve fruit shelf life at ambient. Alternatively, higher temperatures (e.g. 13°C) that will not induce chilling injury can be used and supplemented with other postharvest techniques that can prolong shelf life during and after cold storage.

Conclusion

Cold storage for 12 days was the most effective and longest duration that did not adversely affect subsequent shelf life at ambient of chili pepper pre-treated with HWD and then packed in active MAP. Longer cold storage duration seemed to induce non-visible chilling injury which consequently shortened ambient shelf life thereby limiting post-cold storage marketing and holding at ambient.

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