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Modified atmosphere improves storage ability, controls decay, and maintains quality and antioxidant contents of Barhi date fruits

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Abstract

Full mature 'Barhi' date fruits *(Phoenix dactylifera*) were exposed to modified atmosphere storage conditions with three carbon dioxide concentrations (5, 10 or 20%) during storage at cold storage (0°C). The control fruits were stored at cold storage (0°C) under the common air components conditions (0.03% CO_2). Fruits storage ability, decay percentage, and physiochemical changes during the storage period were studied. High CO_2 concentrations extended fruit storage ability, retarded fruits decay, maintained fruit quality, prevented fruit softening, and reduced postharvest losses. Fruits stored at 0°C under 20% CO_2 showed significantly longer storage period (lasted for 26 weeks) than all other treatments (i.e. 5 and 10% CO_2 which lasted for 17 weeks) and the control (lasted for 7 weeks). Moreover, fruits stored under MA conditions showed lower decay and weight loss percentage. At the end of the experiment, MA treatment with 20% CO_2 prevented fruit darkening and maintained fruit color (as control fruit turned brown after only two months of storage), firmness, SSC%, total sugar content, and total tannins, which are the most dominant antioxidant compounds in date fruits. In addition, CO_2 treatment retarded significantly the degradation of caffeoylshikimic acid (CSA), which is one of the major phenolic compounds of date fruits. Sensory panelists rated fruits stored at 0°C in modified atmosphere contained 20% CO_2 firmer and identical to the fresh harvested fruits than fruits stored in 0.03%, 5%, or 10% CO_2. This study indicated that 'Barhi' date fruits could be stored under modified atmosphere conditions in cold storage (at 0°C) to achieve the longest possible storage period (more than 6 months, compared with 2 months for those stored at 0°C under common air composition) with the best fruit color and firmness, and most proper eating quality, which ultimately improves market ability.

Key words: Postharvest, modified atmosphere, date fruits, Barhi cultivar, *Phoenix dactylifera*, cold storage.

Introduction

Date palm, the tree of life, is the major fruit tree in most Arabian countries and it is widely grown in the middle east countries, and especially in the Kingdom of Saudi Arabia. According to a recent economics survey in the Kingdom of Saudi Arabia, in 2002 there were 18 million date palms producing annually almost 850,000 tons of dates fruits, which represents more than 14% of the world total production [2]. Moreover, the total acreages of date palm in Saudi Arabia expanded very rapidly during the last decade. Barhi is the most popular cultivar worldwide which could be marketed and consumed in full mature stage of development, however, when it ripens its economical value decreases sharply. Substantial quantities of 'Barhi' production are marketed at the time they are harvested at full mature stage, while surplus production usually ripens very rapidly and is to be sold at lower prices. Dates are highly competitive commodity. The future strategy for producers for exporting 'Barhi' dates to foreign market would necessitate the need for modern technology to handle and store 'Barhi' fruits at the full mature stage and to delay fruit ripening to be in a position to meet the international standards at a competitive price.

Many trials have been carried out to improve the storage period and maintain fruit quality throughout the storage period of date fruits. Some of the trials dealed with storage of fruits at relatively low temperatures [12], coating of fruits with polypropylene films [45] or storing them in polyethylene bags [23]. However, a very limited success has been achieved to maintain fruit quality throughout the storage period.

'Barhi' date fruits, at full mature stage of development, initially have a moisture content about 65% [21]. This moisture content is comparatively much higher than the critical value of 23% for yeast fermentation and fungal attack[39]. At this range of moisture, the CO_2 atmosphere had shown to be fungicidal. The use of modified atmosphere as a fungicidal agent is advantageous because it is economically competitive with chemical fumigation, and leaves no chemical residue on the fruit. In addition, date fruits at full mature stage are rich in antioxidants [1, 6-8, 18, 22, 25, 30, 35, 36, 37, 44] especially in phenol compounds [4]. Tannins, which are the most dominant phenol compounds in date fruits, are closely associated with fruit ripening process. The more advanced stage of ripening, the lower is the fruit tannin content [39, 41]. Sawaya et al.[42] reported that tannin values are high in the Khalal stage (full mature stage of development) and gradually decrease to reach minimum concentration in the ripe stage (Rutab).

Modified atmosphere (MA) has been used widely for many years, and it is becoming a popular method of extending storage period for fruits and vegetables [31]. Elevated carbon dioxide during storage delays fruit ripening and reduces postharvest losses, which extends storage life and maintains quality [27]. The use of elevated CO_2 at storage atmosphere for preserving fruit quality and delaying fruit deterioration has been described [3, 9-11, 21, 34]. In addition, elevated concentrations of CO_2 inhibited decay and retarded softening without impairing the flavor of the strawberry[46]. Optimal MA combinations have been developed for different species, and even cultivars within the same species [26]. Very little work has been done on the effect of modified atmosphere

treatments on date fruits. Moreover, previous carbon dioxide treatments on date fruits have been focused on dried fruits only and on CO_2 as a potential treatment to control nitidulid beetles[32,33]. However, as far to our knowledge, no modified atmosphere researches have been conducted on soft full mature dates to delay their ripening processes and the response of 'Barhi' date fruits at full mature stage to MA is unknown.

Our objective was to determine the possible use of carbon dioxide postharvest treatment to extend the storage period without affecting soluble solids concentration (SSC), flesh firmness, skin color, or flavor of full mature 'Barhi' date fruits.

Materials and Methods

***Plant materials*:** Seven mature date trees of 'Barhi' cultivar, grown in the experimental research station, College of Agriculture, King Saud University, Buraidah, Al-Qassim, the Kingdom of Saudi Arabia, were selected for the study. All the trees were almost of the same age and uniform in growth. The trees were in good physical condition, free from insect damage and diseases and were subjected to the same management treatments.

Collection of fruit samples started in mid August. Date fruits were harvested according to skin color (yellow, and the yellowish green area should not exceed 10%) and soluble solids concentration (not less than 28%) [28]. Immediately after harvesting, the freshly collected fruits were transported to the postharvest laboratory at the horticulture department. Fruits similar in shape, color and degree of development were divided into groups and wiped free of dirt, weighed and stored under CO_2-enriched modified atmospheres.

***Carbon dioxide enrichment*:** Date fruits were stored in well sealed gas-tight containers equipped with inlet and outlet valves for gas exchange. Carbon dioxide gas injected from CO_2 gas cylinders. Each treatment received one of the following CO_2 concentrations: 5%,10%, or 20%. Supply and exhaust CO_2 gas composition was monitored using gas analyzer. Air storage was used as a control for all of the experiments. All the containers were stored at 0°C.

Quality evaluation: Ten date fruits per each replicate were removed every month for quality evaluations, including determination of fruit weight loss, fruit firmness, fruit decay percent, fruit skin color, total tannin content, total sugar content, non-reducing sugar contents, reducing sugar contents and fruit soluble solids content. At the end of the experiment a test panel was carried out to evaluate the fruit eating quality and overall visual quality.

Fruit firmness was measured on ten healthy fruits per replication by first removing the skin with a razor blade. Thereafter the force of penetration was measured in grams using a Wagner Instrument pressure tester, equipped with a 3-mm plunger. SSC was measured with a temperature compensated Abbe refractometer. Reducing, non-reducing, and total sugars were determined colorimetrically by using Perkin Elmer Ez301 spectrophotometer according to the method of Dubois [20].

Antioxidants determination: The antioxidant caffeoylshikimic acid (CSA) was determined using Shimadzu SCL-10 AVP HPLC equipped with Shim ODS column and SPD-10 AVP Shimadzu UV detector, whereas total tannins were determined according to the method of A.O.A.C. [13].

Sensory evaluation: At the end of the experiment, a trained sensory panel evaluated fruits stored at 0°C under different CO_2 concentrations according to the procedures described by Reitmeier and Nonnecke [38]. The sensory evaluation focused on color, crunch, firmness, juiciness, sweetness, flavor and appearance of the fruits, and was carried out by a trained panel of 10 members. Panelists were screened for their acuity in perceiving date fruit quality. A grading scale for this test panel was established as follows: 1 bad, 2 satisfactory, 3 good, 4 very good or 5 excellent (exactly as the freshly harvested fruits).

***Statistical analysis*:** Data were statistically analyzed by using complete randomized block design with five replicates per treatment through Student-Newman-Keul's Test. The least significant differences were used to compare means at P d" 0.05 according to the procedure outlined by Snedecor and Cochran [43]. The experiment was repeated twice.

Results and Discussion

Fruit weight loss: A significant reduction in fruit weight loss occurred when carbon dioxide concentration in the storing containers was elevated (Fig. 1). There was an inversely proportional relationship between CO_2 concentration in the storing containers and the fruit weight loss percent. Highest fruit weight loss percent was observed in control fruits, followed by low CO_2 concentrations (5% and 10%, respectively), whereas lowest fruit weight loss percent was recorded in fruits received 20% CO_2. Al-Yahia reported that 'Barhi' fruit weight loss, which occurred during storage period, is most probably due to fruit water loss [12]. Subsequently, high CO_2 concentrations reduced tremendously fruit water loss. Moreover, Hegazi et al. [23], indicated that the rate of darkening of 'Deglet Noor' date fruits at full mature stage of development (Bisr stage) was accelerated with low moisture content in the fruits. These observations could explain our results which indicated that darkening in date fruits that received high CO_2 concentrations was minimal.

Fruit firmness: Date fruit firmness was affected significantly by both storage period and using modified atmosphere conditions during storage (Fig. 2). Fruit firmness showed an inversely proportional values to the storage period. Lowest fruit firmness values were observed in control fruits, which totally collapsed after 60 days of storage. Data indicated that fruit firmness was closely associated with fruit ripening process during the storage period, the more advanced stage of ripening, the lower the fruit firmness. Moreover, fruit firmness showed directly proportional values to CO_2 concentration used in the MA treatments. Fruits stored at MA supplied with 20% CO_2 showed significantly higher fruit firmness compared to all other treatments, which clearly indicated the positive effect of CO_2 treatment in retarding the fruit ripening process and subsequently maintain fruit quality and firmness. It was quite clear that carbon dioxide at high concentration (20%) significantly retarded fruit ripening, but did not cause fruit injury. A similar trend was observed with muskmelon [47] and strawberry [46].

Fruit decay percent: Fruit decay percent was significantly affected by MA treatments. The beneficial effect of high CO_2 on decay suppression was clearly demonstrated (Fig. 3). High CO_2 treatment

suppressed microorganism growth on 'Barhi' date fruits during the MA test. The percentage of fruit decay showed an inversely proportional relationship to the supplied CO_2 concentrations in the MA system. Lowest fruit decay percent was observed in fruits stored under MA conditions and supplied with 20% CO_2, as they remained totally decay free for more than 150 days, and the decay percent did not exceed 7.4% after 180 days of storage in the same fruits. On the other hand, decayed fruits exceeded 10% in the control fruits during the second month of the experiment and all control fruits were discarded during the third month of the storage.

Barhi' date fruits, at full mature stage of development, initially have a moisture content about 65% [12], which is comparatively much higher than the critical value of 23 % for yeast fermentation and fungal attack [40]. At this range of moisture, the CO_2 atmosphere had shown to be fungicidal. The use of modified atmosphere as a fungicidal agent is advantageous because it is economically competitive with chemical fumigation, and leaves no chemical residue on the fruit.

It is remarkable to observe that control fruits recorded the highest weight loss (Fig.1) and least fruit firmness (Fig. 2) as well as the highest fruit decay percent (Fig. 3). These three characters are firmly connected to each other and they usually have a common effect on each other. Fruit weight loss during storage period is accompanied by some disruption of the fruit tissues, which may facilitate the penetration of the decaying organisms. The attack of fungi and other microorganisms would result in more destruction of the tissues which in turn would cause softness and reduction in fruit firmness. Baraka et al.[15], reported that date fruits deterioration could be attributed to the activity of the fungus in producing pectinolytic and cellulolytic enzymes. However, work is still needed to elucidate the mode of action of fungicidal atmospheres.

Total tannin content: Modified atmosphere conditions prevented significantly tannin degradation in date fruits during storage (Table 1). Fruit total tannin content showed an inversely proportional values to the storage period. At the end of the second month, lowest fruit tannin content values were observed in control fruits. Data indicated that fruit total tannin content was closely associated with fruit ripening process during the storage period, the more advanced stage of ripening, the lower the fruit tannin content. Tannin contents of date fruits were at maximum concentration in the Khalal stage (full mature stage of development) and gradually decreased to reach minimum concentration in the ripe stage (Rutab). At the beginning of the experiment, 'Barhi' date fruits in the Khalal stage contained 4.2% tannins on dry weight basis. However, during the first 60 days of storage, tannins in control fruits decreased very rapidly where it recorded only 2.8%, whereas during the same period no changes in tannin content occurred in all MA-treated fruits. Moreover, fruit tannin contents showed directly proportional values to CO_2 concentration used in the MA treatments. Fruits stored at MA and supplied with 20% CO_2 showed significantly higher fruit tannin content compared to all other treatments and maintained, after 180 days of storage, the same tannin values as it was at the beginning of the experiment, which clearly indicated the positive effect of CO_2 treatment in retarding the fruit ripening process and subsequently maintain fruit quality and tannin contents. These findings are in harmony with those of Rouhani and Bassiri [39] and Sawaya et al. [41].

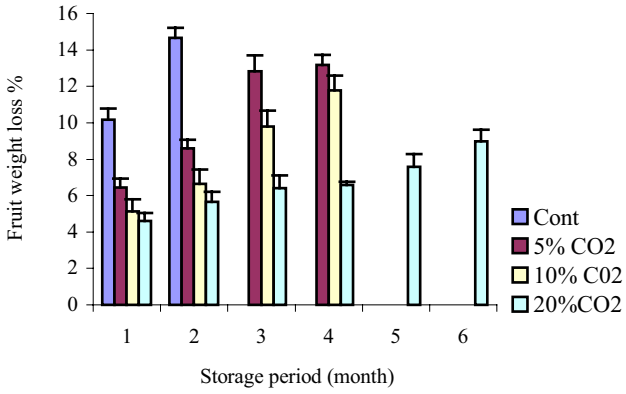

Figure 1. Effect of carbon dioxide concentrations on fruit Weight loss% at different storage periods. Vertical bars show standard errors of five replicates.

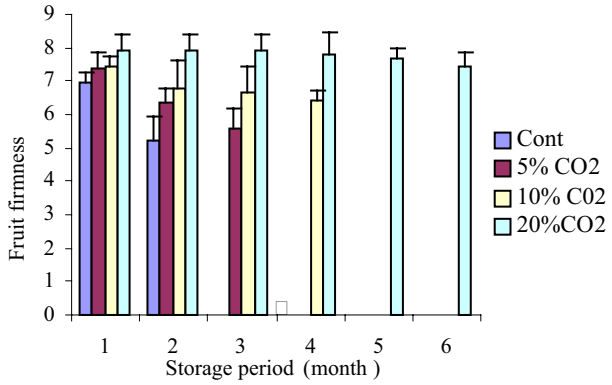

Figure 2. Effect of carbon dioxide concentrations on fruit firmness At different storage periods. Vertical bars show standard errors of five replicates.

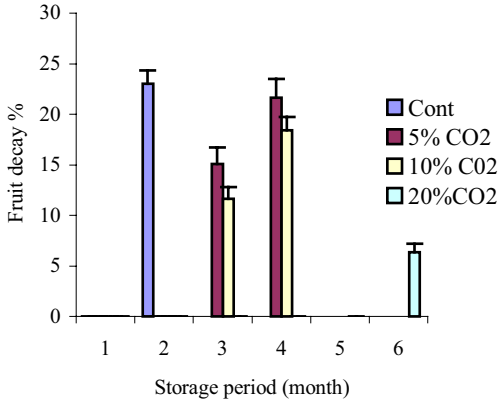

Figure 3. Effect of carbon dioxide concentrations on fruit decay percent at different storage periods. Vertical bars show standard errors of five replicates.

***Total sugar content*:** The total sugar content in 'Barhi' date fruits at the beginning of the experiment was 75.29% on a dry weight basis (Table 3). Evidently, after 30 days of storage, a slight increase was observed in fruit total sugar content. This increment occurred in all treatments under study but with different rates. Highest rate of total sugar increment during storage period occurred in control fruits, followed by those stored under MA with 5% CO_2. On contrary, lowest rate of total sugar increment was observed in fruits stored under MA with 20% CO_2. A clear relationship was

Table 1. Changes in percentage of total tannin contents (in dry weight) in Barhi date fruits stored at 0°C under different carbon dioxide concentrations.

Storage period (Days)	Carbon dioxide concentration								
	0.03% CO_2		5% CO_2		10% CO_2		20% CO_2		LSD^Z for for total tannins
	Total tannins	Reduction (%)	Total tannins	Reduction (%)	Total tannins	Reduction (%)	Total tannins	Reduction (%)	
1	4.2	0	4.2	0	4.2	0	4.2	0	NS
30	3.7	11.9	4.2	0	4.2	0	4.2	0	0.135
60	2.8	34.8	4.2	0	4.2	0	4.2	0	0.113
90	ND^Y	ND	4.2	0	4.2	0	4.2	0	NS
120	ND	ND	3.1	26.1	3.5	16.6	4.2	0	0.125
150	ND	ND	ND	ND	ND	ND	4.2	0	
180	ND	ND	ND	ND	ND	ND	4.2	0	
LSD^X	0.173		0.195		0.181		NS		ND

Each value in the table is the mean of three replicates, and three measurements were conducted for each replicate.
[Z] Least significant difference (LSD) for means in the same row ($P \leq 0.05$).
[Y] Not determined
[X] Least significant difference (LSD) for means in the same column ($P \leq 0.05$).

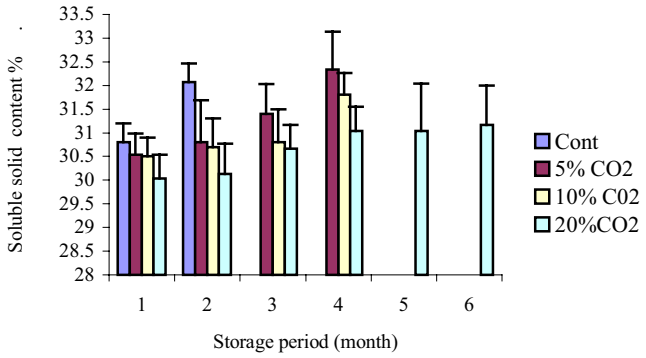

Figure 4. Effect of carbon dioxide concentrations on fruit soluble solid content % at different storage periods. Vertical bars show standard errors of five replicates.

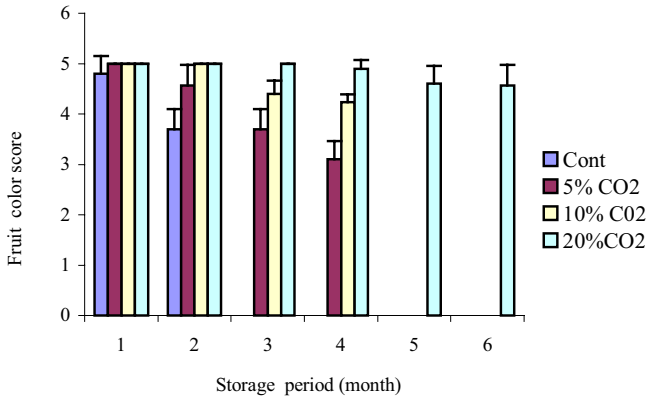

Figure 5. Effect of carbon dioxide concentrations on fruit color score at different storage periods. Vertical bars show standard errors of five replicates

observed between fruit stage of development and total sugar content. The more advanced stage of fruit development and ripening, the higher the sugar content. In general, there was an increase in fruit total sugar content as the fruits passed from the Khalal to Rutab (full ripen fruits) stage. These findings are similar to those reported earlier by other workers on various date cultivars[19, 24, 48].

Non-reducing sugar content: At the beginning of the storage period, non-reducing sugar content in 'Barhi' fruits was relatively

Table 2. Average storage period of Barhi date fruits stored at 0°C under different carbon dioxide concentrations.

Carbon dioxide concentrations	Storage period (Weeks)	Percent of extension
0.03% CO_2	7 a	0
5% CO_2	17 b	242.8
10% CO_2	17 b	242.8
20% CO_2	26 c	371.4

Means in the same column with different letters are significantly different ($P \leq 0.05$). Each value in the table is the mean of three replicates, and three measurements were conducted for each replicate.

low at Khalal stage (6.5% on dry weight basis), followed by a slight decrease (for all treatments) during the first month of storage (Table 4). As the storage period proceeded, non-reducing sugar concentration dropped very rapidly in control fruits to reach its minimal value at the Rutab stage (0% on dry weight basis). The rate of non-reducing sugar decrement in MA treated fruits varied according to CO_2 concentration. The lowest rate of decrement of non-reducing sugar content was observed in fruits stored under MA with 20% CO_2 followed by 10% and 5% CO_2, respectively. This drop which occurred in non-reducing sugar concentration during the ripening process of date fruits (conversion from Khalal to Rutab stages) could be due to the conversion of non-reducing sugar (mainly sucrose) in the fruits into reducing sugar (mainly glucose and fructose) which increased sharply at this stage of development (Table 5). Similar trend was observed with Khudari and Sullaj date cultivars [41].

Reducing sugar content: The relative amounts of the reducing sugars, on the other hand, increased rapidly when date fruits were converted from Khalal to Rutab stages (Table 5). The highest rate of increment of reducing sugar content values was observed in control fruits after 60 days of storage. On contrary, fruits stored under MA conditions showed significantly lower reducing sugar content. The lowest rate of increment in reducing sugar content during the storage period was in fruit stored under MA conditions with 20% CO_2 followed by 10% and 5% CO_2, respectively.

As it is known, the decrease in the sucrose content at the later stage of maturity and the increase in the reducing sugars are synchronized with the rising activity of the invertase enzyme which is characteristic of all date cultivars. The conversion of sucrose to glucose and fructose by the invertase is usually carried out to

Table 3. Changes in total sugar contents in Barhi date fruits stored at 0°C under different carbon dioxide concentrations.

Storage period (Days)	Carbon dioxide concentration			
	0.03% CO_2	5% CO_2	10% CO_2	20% CO_2
0	74.1	74.1	74.1	74.1
30	75.3	74.3	74.3	74.7
60	79.6	77.4	77.7	74.8
90	ND	78.2	77.8	76
120	ND	78.1	78.2	77.5
150	ND	ND	ND	76.8
180	ND	ND	ND	76.9

Each value in the table is the mean of three replicates, and three measurements were conducted for each replicate. The least significant difference (LSD) for means was 4.158 ($P \leq 0.05$).

Table 4. Changes in non-reducing sugar contents in Barhi date fruits stored at 0°C under different carbon dioxide concentrations.

Storage period (Days)	Carbon dioxide concentration			
	0.03% CO_2	5% CO_2	10% CO_2	20% CO_2
1	6.5	6.5	6.5	6.5
30	5.8	6.1	6.3	5.9
60	0	5.2	4.9	5.8
90	ND	3.2	4.8	5
120	ND	1.5	3.1	5
150	ND	ND	ND	4.8
180	ND	ND	ND	4.6

Each value in the table is the mean of three replicates, and three measurements were conducted for each replicate. The least significant difference (LSD) for means was 0.955 ($P \leq 0.05$).

Table 5. Changes in reducing sugar contents in Barhi date fruits stored at 0°C under different carbon dioxide concentrations.

Storage period (Days)	Carbon dioxide concentration			
	0.03% CO_2	5% CO_2	10% CO_2	20% CO_2
1	67.6	67.6	67.6	67.6
30	69.5	68.2	68.0	68.8
60	79.6	72.2	72.8	69
90	ND	75	73.	71
120	ND	76.6	75.1	72.5
150	ND	ND	ND	72
180	ND	ND	ND	72.3

Each value in the table is the mean of three replicates, and three measurements were conducted for each replicate. The least significant difference (LSD) for means was 3.565 ($P \leq 0.05$).

completion or near completion in soft date cultivars [40]. These results are compatible with results reported by Hussein [24].

Soluble solids content: No clear differences were observed in date fruit soluble solids between all treatments (Fig. 5). Soluble solids content in date fruits seemed to be not significantly affected by fruit ripening, as the differences in SSC between full mature fruits and ripe ones were very slight. At the third and fourth month of the storage period, a very slight increase in SSC occurred in most treatments. This increment in SSC could be due to the conversion of some insoluble compounds into soluble compounds (such as the conversion of proto- pectin into pectin). Moreover, Thompson and Abboodi [45] reported that higher weight loss of date fruits caused a lower moisture contents and subsequently higher SSC. These results are in line with a considerable body of published work [14, 23].

Storage period: A great deal of extension had occurred in the storage period of full mature 'Barhi' date fruits stored under modified atmosphere conditions (Table 2). Data revealed that modified atmosphere treatments retarded effectively ripening and senescence of 'Barhi' full mature date. All CO_2 enriched treatments significantly improved the storage ability of the fruits. Evidently, elevating CO_2 concentration inside the storing containers to 20% resulted in extending the stored period of the date fruits 3.71 times the control fruits. Control fruits started to loose their eating quality after 7 weeks from storing, and were discarded totally after two months. On contrary, fruits stored under modified atmosphere contained 20% CO_2 maintained their quality and showed longer storage ability achieved 26 weeks.

Longest storage period occurred when date fruits were stored under MA containing 20% CO_2, followed by those containing 10% and 5% CO_2, respectively. On contrary, shortest storage period was observed in the control fruits. A clear relationship was observed between CO_2 concentration inside the storing containers and the storage ability of the fruits. The higher the CO_2 concentration, the longer the storage period.

Elevated carbon dioxide during storage delays fruit ripening

Table 6. Average of sensory evaluation of Barhi date fruits stored for 180 days at 0°C under different carbon dioxide concentrations. At the beginning of the experiment, fruits were at Khalal stage, but they varied at the evaluation time between Khalal and Rutab stages.

Carbon dioxide concentration	Average score of sensory evaluation of fruit overall quality [z]
Control	1.0 [y] a
5% CO_2	1.3 b
10% CO_2	1.5 b
20% CO_2	5.0 c

[z] The sensory evaluation focused on color, crunch, firmness, juiciness, sweetness, flavor, and appearance of the fruits. A grading scale for this test panel was established as follows: 1 bad, 2 satisfactory, 3 good, 4 very good, or 5 excellent (exactly as the freshly harvested fruits).
[y] Means in the same column with different letters are significantly different ($P \leq 0.05$).
Each value in the table is the mean of three replicates, and three measurements were conducted for each replicate.

and reduces respiration rate of the fruits, which extends storage life and maintains quality. The use of elevated CO_2 at storage atmosphere for preserving fruit quality, reducing respiration rate of the fruits and delaying fruit deterioration has been described [3, 9, 10, 11, 21, 34].

Sensory evaluation and overall quality: Sensory evaluation and overall quality acceptapility of 'Barhi' date fruits after 180 days of storage under MA atmosphere conditions revealed significant differences between control fruits and MA treated ones (Table 6, Figs 5-7). At the beginning of the experiment, fruits were at Khalal stage, but they varied at the evaluation time between Khalal and Rutab stages. After 180 of storage, control fruits, as well as fruits stored in MA at both 5% or 10% CO_2, were moldy and were not analyzed. Sensory panelists rated fruits stored in 20% CO_2 as the freshly harvested fruits. Best sensory evaluation score was recorded for fruits stored under MA and supplied with 20% CO_2, as they at the end of the experiment (after 180 days) looked and tasted exactly as the freshly harvested fruits (Table 6, Fig.5) followed by 5% and 10%, respectively. On the contrary, lowest fruit quality was observed in control fruits. Moreover, clear differences were observed among different MA treatments. There was a positive proportional relationship between CO_2 concentration in the storing containers and fruit overall quality.

Conclusions

A significant improvement in postharvest storage period of 'Barhi' date fruits occurred when full mature fruits (Khalal stage) were stored under modified atmosphere conditions. MA supplied with high CO_2 concentrations increased fruit storage ability by up to 300 %. There was an inversely proportional relationship between CO_2 concentration in the storing containers and both fruit weight loss % and fruit decay %. When carbon dioxide concentration in the storing containers was elevated to 20%, a significant reduction occurred in fruit weight loss % and fruit decay %. The beneficial effect of high CO_2 on decay suppression was clearly demonstrated. On the contrary, MA conditions maintained fruit firmness, skin color, tannin contents, eating quality and overall visual quality of the fruits. All over the storage period which lasted for six months fruits looked and tasted exactly as the freshly harvested fruits. A positive proportional relationship between CO_2 concentration and both fruit quality and storage ability was recorded. In this respect, a modified atmosphere system could be developed for 'Barhi' full mature date fruits that can effectively retard ripening and senescence, and allow shipping of the this fruit to distant markets with acceptable quality.

Table 7. Changes in the antioxidant caffeoyl shikimic acid (CSA) contents (μmol g^{-1} dry weight) in Barhi date fruits stored at 0°C under different carbon dioxide concentrations.

Storage period (Days)	Carbon dioxide concentration								
	0.03% CO_2		5% CO_2		10% CO_2		20% CO_2		LSD[Z] for CSA contents
	CSA	% of reduction	CSA	% of reduction	CSA	% of reduction	CSA	% of reduction	
1	2.1	0	2.1	0	2.1	0	2.1	0	NS
30	1.9	9.5	2.1	0	2.1	0	2.1	0	0.335
60	0.2	90.5	2.1	0	2.1	0	2.1	0	0.313
90	ND[Y]	ND	2.1	0	2.1	0	2.1	0	NS
120	ND	ND	0.7	66.6	1.5	28.6	2.1	0	0.425
150	ND	ND	ND	ND	ND	ND	2.1	0	
180	ND	ND	ND	ND	ND	ND	2.1	0	
LSD[X]	0.162		0.173		0.131		NS		ND

Each value in the table is the mean of three replicates, and three measurements were conducted for each replicate.
[Z] Least significant difference (LSD) for means in the same row ($P \leq 0.05$).
[Y] Not determined
[X] Least significant difference (LSD) for means in the same column ($P \leq 0.05$).

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Figure 6. Barhi date fruits stored at 0°C under modified atmosphere condition (20% CO_2) for 180 days with (at right) or without strands (at left).

Figure 7. Control Barhi date fruits stored at 0°C under common air condition (0.03% CO_2) for 180 days with (at right) or without strands (at left).