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Effect of exposure times of gaseous ozone on quality of strawberry fruits during cold storage

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ABSTRACT

Strawberry fruits (*Fragaria* × *ananassa*) of the cultivar "Festival" were harvested at 75% maturity on 5th and 9th February in 2017 and 2018 seasons, respectively from private farm in Bader Center, Behera Governorate, Egypt and transported to the postharvest Center, Faculty of Agriculture, Alexandria University, to evaluate the effect of exposure times (10, 20, 30, 40 and 50 min.) of ozone gas on quality attributes of strawberry fruits during storage at 0°C for 21 days. Results showed that all ozone treatments of strawberry fruits reduced weight loss and did not show any decay until the end of storage period. Strawberry fruits which exposed to ozone gas for 30 min. was the most effective treatment in maintaining fruit quality, it would reduce weight loss percentage and resulted in fruits with no decay and maintained fruit firmness, TSS, ascorbic acid content, anthocyanins content and total sugars and also gave fruits with good appearance after 21 days of storage at 0°C and 95 % RH as compared with the other treatments and untreated control.

***Keywords*:** strawberry, ozone, anthocyanins, decay, appearance, storability.

Introduction

Strawberries (*Fragaria* × *ananassa*) have high nutritional quality characterized by unique and highly desirable taste and flavor, relevant sources of bioactive compounds due to high levels of vitamin C and E, carotene and phenolic compounds such as anthocyanins, substances related to health benefits (Kuchi and Sharavani, 2019). On the other hand, many researchers found that strawberries have a very short shelf life due to their sensitivity to fungal attack and excessive texture softening caused by the natural ripening process. Also, it was found this is because strawberry is very susceptible to mechanical injury, water loss, decay and physiological deterioration after harvesting; this reduces its economic value. Moreover, quality attributes of fruits also deteriorates with time, thus rendering unsafe product for consumers (Han *et al.,* 2005, Ali *et al.,* 2011 and Stolfa *et al.,* 2014). Coelho *et al.* (2014) indicated that the strawberry is a small crop of great important in all around the world but has a high susceptibility to a large variety of phytopathogenic organisms, promoting considerable post-harvest losses. Thus, sanitizing step becomes important process to maintain fruit quality and proper fruit storage is an effective way to maintain the quality of fruits after harvest (Stolfa *et al.,* 2014). Hence the idea of using ozone as a postharvest treatment of strawberry fruits came up (Perez *et al.,* 1999). Ozone is a natural gas on earth. Naturally, it is produced by reaction of oxygen with ultraviolet light from sunlight or lightning (Suslow, 2004). The use of ozone increased significantly after it was deemed safe in the USA and approved as a recognized food additive by the US-FDA (U.S. FDA 1999). Guzel-Seydim *et al.* (2004) showed that ozone is one of the potential alternatives that can be used as a sanitizing agent for postharvest application. Compared to other gases that are used in postharvest treatment, ozone is generally easy to detect by distinct smell. Previously, ozone is well known for their highly antimicrobial activity due to its high oxidative properties that can kill most microbes. Palou *et al.* (2007) reported that ozone is very oxidative at high concentration and it is also easily decompose back to oxygen in a very short time leaving only oxygen and no other harmful by product. Karaca and Velioglu (2007) and Souza *et al.* (2018) found that ozone (O_3) is a powerful oxidant agent and concluded that ozone as gas can be

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used in vegetables without harming the quality. Zhang *et al.* (2011) indicated that the treatment of 4 ppm ozone could hindered the decrease of ascorbic acid, weight loss and the treatment delayed the senescence of strawberry, despite of significant respiration rate. They concluded that the ozone could be good treatment maintaining postharvest quality of strawberry and provide a longer storage life. Thaer *et al.* (2013) showed that ozone treatment plays a control effect on microorganism contamination and increases shelf life of strawberry. Coelho *et al.* (2014) illustrated that ozonated strawberry fruits at concentrations 0.2, 0.5 and 1.0 mg/L for 5 minutes showed superior performance in reducing postharvest phytopathogens, whereas the concentration of 0.5 mg/L for 5 minutes delayed and decreased the disease incidence in fruits. Morais *et al.* (2015) concluded that the application of ozone gas to maintain the physic-chemical and microbiological characteristics is efficient for storage of strawberry fruits for up to 10 days.

The present study was carried out to investigate the effect of exposure times of gaseous O_3 on the quality attributes of strawberry fruits during cold storage and to determine the optimum exposure time for the O_3 gas to maintain quality and storability of strawberry fruits.

Materials and Methods

Strawberry fruits (*Fragaria* × *ananassa*) of the cultivar "Festival" were harvested at 75% maturity on 5th and 9th February in 2017 and 2018 seasons, respectively from private farm in Bader Center – Behera Governorate, Egypt and transported to the Postharvest Center, Faculty of Agriculture, Alexandria University, Egypt.

Ozone gas (100 ppm at air flow rate of 2.5L/ min with ozone output of 300 mg/hr) was used in this study and produced by a laboratory corona discharge ozone generator (Xetin Ozone Air &Water purifier, Model XT 301, Xetin Co. Ltd,Taiwan). The ozone generator was warmed up for 15 min before the experiment was conducted. (Osman, 2015).The ozonation process was carried out in closed foam box, 60 x 40 x 30 cm^3.

Fruits were packed in panetts and each panett contain 250 g as one replicate and divided into six following groups:-

1. Control (without treatment).
2. Fruits were exposed to O_3 gas for 10 min.
3. Fruits were exposed to O_3 gas for 20 min.
4. Fruits were exposed to O_3 gas for 30 min.
5. Fruits were exposed to O_3 gas for 40 min.
6. Fruits were exposed to O_3 gas for 50 min.

After ozonation, panetts were packed in polypropylene bags 30 µm thickness. The samples were arranged in complete randomized design with three replicates, each treatment consist of 21 panetts and stored at 0°C and 95 % RH for 21 days. Three replicates from each treatment were taken at random and examined immediately after harvest and every 3 days intervals for the following properties:-

1. The loss in weight percentage was calculated by the following equation: Loss in weight % =Initial weight of fruit – weight of fruit at sampling date / the initial weight of the fruit X 100.
2. Decay percentage was determined the number of decayed fruits due to fungus or any microorganism infection was recorded periodically (every 3 days) and calculated as a percentage from the total number of fruits using the following equation: FDP= number of decayed fruits/ total fruit number x100.
3. The general appearance was scaled from 9 to 1, where 9= excellent, 7=good, 5= fair, 3= poor and 1 = unsalable and fruits rating (5) or below were considered as unmarketable, as described by kader *et al.* (1973).
4. Fruit firmness was recorded using TA- 1000 texture analyzer instrument using a penetrating cylinder of 1mm diameter. Firmness was expressed as pound per square inch (Lb/in^2).
5. Total soluble solids percentage was determined by using PR- 101 digital refractometer.
6. Ascorbic acid content was determined by titration method using 2, 6 dicloro phenol indophenols as described by A.O.A.C (1990).

7. Anthocyanins content was spectrophotometrically determined by the method described by A.O.A.C (1990).
8. Total sugars were determined using Nelson's methods (Malik and Singh, 1980), which determined colorimetrically at wavelength of 520 nm (Sadasivam and Manickam, 2004).

Statistical Analysis:

Data were statistically analyzed using the analysis of variance described by Snedecor and Cochran (1980).The method of Duncan multiple range test was applied for comparison between means according to Waller and Duncan (1969).

Results and Discussion

Weight loss percentage:

Data in Table (1) showed that weight loss percentage of strawberry fruits was increased considerably and consistently with the prolongation of storage period in the two seasons. These results are in agreement with those obtained by Perez *et al.* (1999) and Atala (2015) on strawberry fruits. Normally, the weight loss occurs during the fruit storage due to respiratory process, the transference of humidity and some processes of oxidation (Wills *et al.,* 1998).

Concerning the effect of postharvest treatments, data revealed that there were significant differences between postharvest treatments and untreated control during storage. All postharvest treatments retained their weight during storage as compared with untreated control. Moreover, strawberry fruits which exposed to ozone gas for 30 min. was the most effective treatment in reducing weight loss% followed by fruits which exposed to ozone gas for 20 or 40 min. with significant differences between them in the two seasons. Fruits which exposed to ozone gas for 50 min. were the less effective treatment in this concern. The highest value of weight loss% was recorded with untreated control. These results were achieved in the two seasons and were in agreement with Skog and Chu (2001) and Zhang *et al.* (2011).

Table 1: Effect of ozone treatments on weight loss percentage of strawberry fruits during storage at 0°C in 2017 and 2018 seasons.

	Storage period (days)								
Treatments(min)	**0**	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**Mean**
					2017				
Control	0.00z	0.86vx	2.40op	5.50j	12.53d	22.56c	28.66b	39.13a	13.95A
10	0.00z	0.60xy	1.26tu	1.80r	2.70no	3.46m	5.60ij	8.66f	3.01C
20	0.00z	0.40y	0.90vx	1.20tv	1.80r	2.26pq	3.80lm	6.33h	2.08E
30	0.00z	0.30yz	0.56xy	0.96uw	1.33t	1.70rs	2.63np	4.30k	1.47F
40	0.00z	0.43y	0.96u-w	1.3tu	1.93qr	2.40op	4.03kl	6.76g	2.22D
50	0.00z	0.63wy	1.36st	1.96qr	2.83n	3.63m	5.93i	9.63e	3.25B
Mean	0.00H	0.53G	1.24F	2.12E	3.85D	6.00C	8.44B	12.47A	
					2018				
Control	0.00y	0.80t-u	2.30no	4.50h	8.63d	17.40c	23.80b	35.70a	11.64A
10	0.00y	0.53v	1.10rs	1.66p	2.56lm	3.10k	5.36g	8.50d	2.85C
20	0.00y	0.36vx	0.83t	1.13rs	1.63p	2.10o	3.63ij	5.80f	1.93E
30	0.00y	0.23xy	0.53v	0.83t	1.13rs	1.43q	2.50mn	3.60ij	1.28F
40	0.00y	0.40vx	0.90st	1.20qr	1.73p	2.23o	3.83i	6.63e	2.11D
50	0.00y	0.56uv	1.26qr	1.73p	2.76l	3.56j	5.76f	8.63d	3.03B
Mean	0.00H	0.48G	1.15F	1.84E	3.07D	4.97C	7.48B	11.47A	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan's multiple rang test.

Minimizing weight loss from ozone treatment during storage may be due to ozone removes exogenous ethylene from atmosphere surrounding produce by oxidizing it to ethylene glycol, which later breaks into carbon dioxide (Skog and Chu, 2001), which decreased respiration rate (Zhang *et al.,*2011) and consequently reduced fresh weight loss. Also, Kim *et al.* (2010) illustrated that O_3 reduce weight loss because O_3 inhibition of enzymatic reaction can cause a decrease in fruit respiration leading to less weight loss.

In general, the interaction between postharvest treatments and storage periods was significant effect on weight loss percentage in the two seasons. After 21 days of storage, the lowest value of weight loss was recorded from strawberry fruits which exposed to ozone gas for 30 min. while the highest values of weight loss percentage were obtained from untreated control.

Decay percentage:

Data in Table (2) indicated that there were significant increases in decay percentage with the prolongation of storage period in the two seasons. These results were in agreement with those obtained by Perez *et al.* (1999) and Atala (2015) on strawberry fruits. This finding may be due to the continuous chemical and biochemical changes happened in fruits such as moisture concentration and transformation of complex compounds to simple forms of more liability to fungal infection such as solid protopectin to the soluble pectin form (Wills *et al.,* 1981).

There were significant differences in decay percentage between postharvest treatments and control. Strawberry fruits treated with ozone gas for different periods did not show any decay during all storage periods till 21 days of storage at 0°C in the two seasons, while untreated control gave the highest decay %. These results were achieved in the two seasons and were in agreement with Perez *et al.* (1999), Aday *et al.* (2014) and Kannaujia *et al.* (2019).

Suslow (1998) showed that ozone rapidly attacks bacterial cell walls and is more effective against the thick-walled spores of plant pathogens and animal parasites than chlorine, at practical and safe concentrations. Also, Thaer *et al.* (2013) show that ozone treatment plays a control effect on microorganism contamination and increases shelf life.

Table 2: Effect of ozone treatments on decay percentage of strawberry fruits during storage at 0°C in 2017 and 2018 seasons.

	Storage period (days)								
Treatments(min)	**0**	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**Mean**
					2017				
Control	0.00f	0.00f	1.96e	2.23e	4.86d	8.93c	18.10b	28.70a	8.10A
10	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00B
20	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00B
30	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00B
40	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00B
50	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00B
Mean	0.00E	0.00E	0.33DE	0.37DE	0.81CD	1.48C	3.01B	4.78A	
					2018				
Control	0.00f	0.00f	1.76e	2.10e	4.33d	8.70c	17.70b	26.76a	7.67A
10	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00B
20	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00B
30	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00B
40	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00B
50	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00f	0.00B
Mean	0.00E	0.00E	0.29DE	0.35DE	0.72D	1.45C	2.95B	4.46A	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan's multiple rang test.

General appearance (score):

Data in Table (3) showed that general appearance (score) of strawberries fruits was significant decreased with the prolongation of storage period in both seasons. These results were in agreement with those obtained by Ali *et al.* (2011) and Atala (2015). Such decrease in general appearance of fruits, mostly may be due to a slight dryness of the fruit surface, instead of translucency or macroscopic decay, as reported by Atress and Attia (2011).

Concerning the effect of postharvest treatments, data revealed that there were significant differences between postharvest treatments and untreated control during storage. Strawberry fruits treated with ozone treatments had significantly the highest score of appearance as compared with untreated control. However, strawberry fruits which exposed to ozone gas for 30 min. was the most effective treatment for maintaining general appearance, followed by fruits which exposed to ozone gas for 20, 40 min. with no significant differences between them in the two seasons, while untreated control recorded the lowest ones in this concern. These results were achieved in the two seasons and were in agreement with Perez *et al.* (1999), Thaer *et al.* (2013) and Aday *et al.* (2014).

Table 3: Effect of ozone treatments on general appearance (score) of strawberry fruits during storage at 0°C in 2017 and 2018 seasons.

	Storage period (days)								
Treatments(min)	**0**	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**Mean**
					2017				
Control	9.00a	8.33de	6.33de	5.66ef	4.33gh	3.66hi	3.00i	1.00j	5.16E
10	9.00a	9.00a	9.00a	8.33ab	7.66bc	7.00cd	5.66ef	5.00fg	7.58C
20	9.00a	9.00a	9.00a	9.00a	9.00a	8.33ab	7.00cd	6.33de	8.33B
30	9.00a	9.00a	9.00a	9.00a	9.00a	9.00a	8.33ab	7.00cd	8.66A
40	9.00a	9.00a	9.00a	9.00a	8.33ab	7.66bc	6.33de	5.66ef	8.00B
50	9.00a	9.00a	8.33ab	7.66bc	7.00cd	6.33de	5.00fg	4.30gh	7.08D
Mean	9.00A	8.88A	8.44B	8.11B	7.55C	7.00D	5.88E	4.88F	
					2018				
Control	9.00a	9.00a	7.00cd	6.33de	5.00fg	4.33g	3.00h	1.00i	5.58E
10	9.00a	9.00a	9.00a	8.33ab	7.66bc	7.00cd	5.66ef	5.00fg	7.58C
20	9.00a	9.00a	9.00a	9.00a	9.00a	8.33ab	7.00cd	6.33de	8.33B
30	9.00a	9.00a	9.00a	9.00a	9.00a	9.00a	8.33ab	7.66bc	8.75A
40	9.00a	9.00a	9.00a	9.00a	8.33ab	7.66bc	6.33de	5.66ef	8.00B
50	9.00a	9.00a	8.33ab	7.66bc	7.00cd	6.33de	5.00fg	4.33g	7.08D
Mean	9.00A	9.00A	8.55AB	8.22B	7.66C	7.11D	5.88E	5.00F	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan's multiple rang test.

Ozone maintaining postharvest quality of fruit by oxidizing ethylene produced and reduced the respiration rate during the ripening process. Reducing the ethylene level extending the shelf life of many ethylene sensitive fruits and vegetables and reduces the shrinking of product during storage (Jaksch *et al*., 2004 and Shalluf *et al*., 2007). Also, ozone treatment markedly reduction in respiration rate that retarded deterioration and maintained the keeping quality attributes for a longer period (Mshraky, 2017).

In general, the interaction between postharvest treatments and storage periods was significant in the two seasons. Results recorded that strawberry fruits which exposed to ozone gas for 30 min. showed the best appearance and did not show any changes in GA and showed excellent appearance until 18 days and rated good appearance at the end of storage period, while ozone treatment for 20 min. gave good appearance after 18 days of storage and dropped to fair appearance at the end of storage period. On the other hand, untreated control had the unsalable appearance after 21 days of storage at 0ºC.

Fruit firmness:

Data in Table (4) indicated that there was a significant reduction in fruit firmness of strawberry by the prolongation of storage period in the two seasons. Similar results were obtained by Ali *et al.* (2011), Thaer *et al.* (2013) and Atala (2015) on strawberry fruits. The decline in firmness may be due to the gradual breakdown of proto-pectin to lower molecular fractions which are more soluble in water and this directly correlated with the rate of softening of the fruits (Wills *et al.,* 1998). Nogata *et al.* (1993) cleared that the softening of strawberry is mainly due to the presence of polygalacturonase which solubilizes and degrades the cell wall polyuronides. Also, Koh and Melton (2004) found that softening of strawberry fruits is mainly due to loss of cell wall material.

Concerning the effect of postharvest treatments, data revealed that all ozone treatments had a significant effect on fruit firmness as compared with untreated control during storage in the two seasons. However, strawberry fruits which exposed to ozone gas for 30 min. gave the highest value of fruit firmness during storage, followed by ozone treatments for 20 and 40 min. with no significant differences between them, while the other treatments were less effective in this concern. The lowest value of fruit firmness was obtained from untreated control. These results were achieved in the two seasons and were in agreement with those obtained by Perez *et al.* (1999), Aday *et al.* (2014) and Kannaujia *et al.* (2019).

Several studies demonstrated that ozone treatments may reduce the activity of firmness-related enzymes generally enhanced during postharvest life of fruit and vegetable (Costa *et al*., 2006). In general, ozone treatment inhibited PAL activity and increased cell wall phenolic compounds (An *et al.,* 2006).

In general, the interaction between postharvest treatments and storage periods was significant in the two seasons. After 21 days at 0°C, strawberry fruits which exposed to ozone gas for 30 min. were the most obvious in maintaining fruit firmness at the end of storage period. The lowest value of fruit firmness was obtained from untreated control at the same period in the two seasons.

Table 4: Effect of ozone treatments on fruit firmness (Lb/in2) of strawberry fruits during storage at 0°C in 2017 and 2018 seasons.

	Storage period (days)								
Treatments(min)	**0**	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**Mean**
				2017					
Control	5.86a	5.36d-f	4.90g-i	4.40lm	3.76p-r	3.23s	2.60t	1.76u	3.98D
10	5.86a	5.46bd	5.10f-h	4.80hk	4.50km	4.23mo	3.96op	3.63qr	4.69C
20	5.86a	5.63ad	5.43ce	5.13eg	4.83gj	4.56jl	4.33l-n	4.06np	4.98B
30	5.86a	5.76ab	5.70ac	5.56ad	5.46bd	5.33df	5.13eg	4.93gi	5.47A
40	5.86a	5.53bd	5.40ce	5.06fh	4.73ik	4.50km	4.26lo	4.00op	4.92B
50	5.86a	5.40ce	5.03gi	4.73ik	4.40lm	4.20mo	3.83pq	3.50rs	4.62C
Mean	5.86A	5.52B	5.26C	4.95D	4.61E	4.34F	4.02G	3.65H	
				2018					
Control	5.93a	5.40d-i	5.13i-k	4.46o-r	3.80vx	3.26y	2.73z	1.80A	4.06D
10	5.93a	5.56c-f	5.36e-i	5.00j-l	4.70mo	4.36p-s	4.06t-v	3.76wx	4.84C
20	5.93a	5.73ac	5.50cg	5.30f-i	5.03j-l	4.80l-n	4.50oq	4.20r-t	5.12B
30	5.93a	5.86ab	5.76ac	5.66ad	5.56c-f	5.43dh	5.20hk	5.00j-l	5.55A
40	5.93a	5.60be	5.43dh	5.23g-j	4.93km	4.70mo	4.40ps	4.16s-u	5.05B
50	5.93a	5.53c-f	5.33e-i	4.93km	4.60np	4.26q-t	3.90uw	3.56x	4.75C
Mean	5.93A	5.61B	5.42C	5.10D	4.77E	4.47F	4.13G	3.75H	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan's multiple rang test.

Total soluble solids percentage:

Data in Table (5) indicated that total soluble solids of strawberry fruits were significantly decreased with the prolongation of storage period in both seasons. Similar results were obtained by Mishra and Kar (2014) on strawberry fruits. The loss of total soluble solids during the storage period is natural, as sugars are the primary constituent of the soluble solid contents of product, consumed by respiration and used for the metabolic activities of the fruits (Wills *et al.,* 1998).

Regarding the effect of postharvest treatments, data revealed that there were significant differences between postharvest treatments and untreated control in TSS % of strawberry fruits during storage. Strawberry fruits which exposed to ozone gas for 30 min. retained more TSS %, followed by ozone treatments for 20 and 40 min. with no significant differences between them in the second season. Untreated control gave the lowest value of TSS %. These results were achieved in the two seasons and were in agreement with those obtained by Perez *et al.* (1999), Aday *et al.* (2014) and Kannaujia *et al.* (2019).

The positive effect on total soluble solids by ozone treatment may be due to the delaying of metabolic activity and reduced respiration rate and vital process, this reflected to reducing the loss of TSS during storage and degradation of fruits and over senescence (Shalluf *et al*., 2007).

In general, the interaction between postharvest treatments and storage periods was significant in the two seasons. After 21 days at 0°C, strawberry fruits which exposed to ozone gas for 30 min. resulted in significantly higher TSS %, followed by ozone treatments for 20 or 40 min. with no significant differences between them, while untreated control gave the lowest ones in the same period. These results were achieved in the two seasons.

Table 5: Effect of ozone treatments on total soluble solids (%) of strawberry fruits during storage at 0°C in 2017 and 2018 seasons.

Treatments (min)	Storage period (days) 0	3	6	9	12	15	18	21	Mean
					2017				
Control	12.53a	11.53gi	10.56lo	9.63r	8.33s	7.16t	6.00u	5.00v	8.84F
10	12.53a	11.96ce	11.46hj	10.90kl	10.30np	9.70q-r	8.66s	7.43t	10.37D
20	12.53a	12.26ac	11.86dg	11.40hj	10.90kl	10.50mo	10.26op	9.70qr	11.17B
30	12.53a	12.40ab	12.16bd	11.86dg	11.63eh	11.43hj	11.13jk	10.46mo	11.70A
40	12.53a	12.13bd	11.60fh	11.16jk	10.63ln	10.36np	10.00pq	9.50r	10.99C
50	12.53a	11.90df	11.23ik	10.76lm	10.06pq	9.46r	8.60s	7.26t	10.22E
Mean	12.53A	12.03B	11.48C	10.95D	10.31E	9.77F	9.11G	8.22H	
					2018				
Control	12.60a	11.90e-g	10.90kl	9.80st	8.43v	7.53x	6.26y	5.13z	9.07E
10	12.60a	12.06c-e	11.53hi	10.96kl	10.40op	10.16p-r	9.33u	7.96w	10.62C
20	12.60a	12.43ab	11.93e-f	11.63g-i	11.00jk	10.56m-o	10.46op	10.03q-s	11.33B
30	12.60a	12.46ab	12.26b-d	12.00cf	11.70f-h	11.50h-j	11.20jk	10.50no	11.77A
40	12.60a	12.30a-c	11.90d-g	11.56hi	10.83l-m	10.43op	10.36op	9.90r-t	11.23B
50	12.60a	11.96d-f	11.36ij	10.80l-n	10.30o-q	9.70t	9.16u	7.70wx	10.45D
Mean	12.60A	12.18B	11.65C	11.12D	10.44E	9.98F	9.46G	8.53H	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan's multiple rang test.

Ascorbic acid content:

Data in Table (6) showed that ascorbic acid content of strawberry fruits was significantly decreased with the prolongation of storage period in both seasons. Similar results were obtained by Lee and Kader (2000), Mishra and Kar (2014) and Atala (2015) on strawberry fruits. The reduction in ascorbic acid contents during storage may be due to the higher rate of sugar loss through respiration than the water loss through transpiration (Wills *et al.,* 1998).

Table 6: Effect of ozone treatments on ascorbic acid content (mg/100g FW) of strawberry fruits during storage at 0°C in 2017 and 2018 seasons.

Treatments (min)	Storage period (days) 0	3	6	9	12	15	18	21	Mean
					2017				
Control	95.83a	93.43r	89.23y	80.93z	68.03A	56.03B	43.13C	30.23D	69.60F
10	95.83a	95.36ef	95.03h	94.63kl	94.23op	93.43r	92.33u	90.50w	93.90D
20	95.83a	95.63bc	95.33ef	95.03h	94.73jk	94.33no	93.63q	92.53t	94.63B
30	95.83a	95.73ab	95.53cd	95.23fg	94.93i	94.73jk	94.63kl	94.33no	95.12A
40	95.83a	95.43de	95.13gh	94.86ij	94.53lm	94.13p	93.43r	91.63z	94.37C
50	95.83a	95.33ef	94.93i	94.53lm	94.10p	93.26s	92.23u	90.33x	93.82E
Mean	95.83A	95.15B	94.20C	92.53D	90.09E	87.65F	84.90G	81.59H	
					2018				
Control	96.33a	93.63op	90.23y	85.50z	78.23A	62.73B	50.63C	31.03D	73.54F
10	96.33a	95.93b-d	95.63hi	95.23m	94.53pq	93.73r	92.83t	91.73x	94.49D
20	96.33a	96.03b	95.83c-e	95.43kl	95.03n	94.73o	93.73r	92.83t	94.99B
30	96.33a	96.23a	96.03b	95.80d-f	95.53jk	95.23m	95.00n	94.63op	95.60A
40	96.33a	95.96bc	95.73e-g	95.33lm	94.93n	94.63op	93.66rs	92.13v	94.84C
50	96.33a	95.86f-h	95.43kl	94.93n	94.43q	93.56s	92.63u	91.03x	94.27E
Mean	96.33A	95.61B	94.81C	93.70D	92.11E	89.10F	86.41G	82.23H	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan's multiple rang test.

Regarding the effect of postharvest treatments, data showed that all ozone treatments were significantly effective in preventing ascorbic acid degradation during storage as compared with untreated control. Moreover, strawberry fruits which exposed to ozone gas for 30 and 20 min. were the most effective treatments in maintaining ascorbic acid content with significant differences between them, followed by ozone treatments for 40 or 10 min. with significant differences between them. The lowest values resulted in untreated control. These results were achieved in the two seasons and were in agreement with those obtained by Perez *et al.* (1999), Aday *et al.* (2014) and Kannaujia *et al.* (2019).

Perez *et al*. (1999) revealed that changes in vitamin C content of strawberry fruits treated with ozone can be attributed to the activation of an antioxidative system that promotes the biosynthesis of vitamin C from the carbohydrate pool.

In general, the interaction between postharvest treatments and storage periods was significant in the two seasons. After 21 days at 0°C, strawberry fruits which exposed to ozone gas for 30 min. resulted in significantly higher ascorbic acid content, followed by ozone treatments for 20 or 40 min. with significant differences between them, while untreated control gave the lowest ones in the same period in the two seasons.

Anthocyanins content:

Data in Table (7) demonstrate that anthocyanins content of strawberry fruits were significantly increased with prolongation of storage period till the end of storage in both seasons. These results are in agreement with those obtained by Kalt and McDonald (1996) and Atala (2015) on strawberry fruits. The increase in anthocyanins concentration during strawberry storage due to continuous synthesis of this pigment (Almenar *et al.,* 2007).

Concerning the effect of postharvest treatments, data revealed that there were significant differences between ozone treatments and untreated control during storage. However, strawberry fruits which exposed to ozone gas for 30 min. gave the lowest values in anthocyanins content during storage followed by ozone treatments for 20 or 40 min. with significant differences between them while, the other treatments were less effective in this concern. The highest value of anthocyanins content was obtained from untreated control. These results were achieved in the two seasons and were in agreement with those obtained by Perez *et al.* (1999), Aday *et al.* (2014) and Kannaujia *et al.* (2019).

Table 7: Effect of ozone treatments on anthocyanins (mg/100g F W) of strawberry fruits during storage at 0°C in 2017 and 2018 seasons.

	Storage period (days)								
Treatments (min)	**0**	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**Mean**
				2017					
Control	78.68g	79.23g	81.32d-g	83.26c-f	84.15cd	85.92bc	88.32b	97.60a	84.81A
10	78.68g	78.86g	79.13g	79.57g	79.91f-g	80.24e-g	81.13d-g	83.35c-f	80.11C
20	78.68g	78.83g	78.95g	79.17g	79.32g	79.68g	79.93fg	81.11d-g	79.46E
30	78.68g	78.73g	78.83g	78.95g	79.13g	79.34g	79.56e-g	79.98fg	79.15F
40	78.68g	78.86g	78.97g	79.21g	79.38g	79.71g	79.97fg	81.34d-g	79.51D
50	78.68g	78.93g	79.22g	79.65e-g	79.96fg	80.43e-g	81.63d-g	83.57c-e	80.26B
Mean	78.68H	78.91G	79.40F	79.97E	80.31D	80.89C	81.75B	84.49A	
				2018					
Control	78.32j	79.21h-j	e-i80.94	e-g81.72	83.84cb	bc85.31	b86.26	96.56a	84.02A
10	78.32j	78.62j	78.90ij	79.04h-j	79.31h-j	g-j79.66	g-j80.12	82.42ef	79.55C
20	78.32j	78.51j	78.61j	78.87ij	79.15h-j	79.29h-j	79.73g-j	80.87e-i	79.17E
30	78.32j	78.39j	78.45j	78.53j	78.75ij	78.95h-j	79.12h-j	g-j79.76	78.78F
40	78.32j	78.54j	78.65j	78.96h-j	79.26h-j	79.47h-j	79.87g-j	81.13e-h	79.27D
50	78.32j	78.64j	78.95h-j	79.22h-j	79.52g-j	79.75g-j	80.22f-j	82.63de	79.65B
Mean	78.32H	78.65G	79.08F	79.39E	79.97D	80.40C	80.89B	83.89A	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan's multiple rang test.

In general, the interaction between postharvest treatments and storage periods was significant effect on anthocyanins content in the two seasons. After 21 days of storage at 0°C, the lowest values of anthocyanins content were recorded from all ozone treatments of strawberry fruits while the highest ones were obtained from untreated control.

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Total sugars:

Data in Table (8) revealed that total sugars content of strawberry fruits were significantly affected by storage period. There was a significant reduction in total sugars by the prolongation of storage period in both seasons. These results were in agreement with those obtained by Castro *et al.* (2002) and Atala (2015) on strawberry fruits. The decrease of total sugars content is probably due to the consumption of sugars through respiration (Wills *et al.,* 1981).

Table 8: Effect of ozone treatments on total sugar (mg/100g F W) of strawberry fruits during storage at 0°C in 2017 and 2018 seasons.

	Storage period (days)								
Treatments(min)	**0**	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**Mean**
				2017					
Control	5.63a	5.06d-g	4.43lm	3.80op	3.43r	2.93s	2.26t	1.33u	3.61D
10	5.63a	5.40a-c	5.06d-g	4.76g-k	4.43lm	3.96no	3.76oq	3.46q-r	4.56C
20	5.63a	5.53ab	5.40a-c	5.13c-f	4.96e-i	4.83f-j	4.60j-l	4.06no	5.02B
30	5.63a	5.56a	5.50ab	5.46a-b	5.23b-e	5.06d-g	4.96e-i	4.56jm	5.25A
40	5.63a	5.50ab	5.33a-d	5.06d-g	4.93e-i	4.73h-l	4.50km	3.90op	4.95B
50	5.63a	5.33a-d	5.03d-h	4.70i-l	4.26mn	3.90op	3.60pr	3.36r	4.47C
Mean	5.63A	5.40B	5.12C	4.82D	4.54E	4.23F	3.95G	3.45H	
				2018					
Control	5.83a	5.13g-j	4.60l-n	4.10o-q	3.56r	3.06s	2.40t	1.50u	3.77D
10	5.83a	5.56a-e	5.30d-g	4.96h-k	4.76k-m	4.43m-o	4.06pq	3.60r	4.81C
20	5.83a	5.66a-c	5.50a-f	5.26e-h	5.16g-j	4.93h-l	4.73k-m	4.33n-p	5.17B
30	5.83a	5.70ab	5.66a-c	5.60a-d	5.50a-f	5.36c-g	5.16g-j	4.96h-k	5.47A
40	5.83a	5.63a-d	5.43b-g	5.20f-i	5.10g-j	4.86j-l	4-60l-n	4.16o-q	5.10B
50	5.83a	5.43b-g	5.26e-h	4.90i-l	4.66k-n	4.36n-p	3.96q	3.53r	4.74C
Mean	5.83A	5.52B	5.29C	5.00D	4.79E	4.50F	4.15G	3.68H	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan's multiple rang test.

Concerning the effect of postharvest treatments, data revealed that there were significant differences between all ozone treatments and untreated control in total sugars content of strawberry fruits during storage. Strawberry fruits which exposed to ozone gas for 30 min. retained more total sugars content, followed by ozone treatments for 20 and 40 min. with no significant differences between them in the two seasons. However, ozone treatments for 10 and 50 min. were less effective in this concern. The lowest value of total sugars content was obtained from untreated control. These results were achieved in the two seasons and were in agreement with those obtained by Perez *et al.* (1999), Aday *et al.* (2014) and Kannaujia *et al.* (2019).

In general, the interaction between postharvest treatments and storage periods was significant effect on total sugars content in the two seasons. After 21 days of storage at 0°C, strawberry fruits treated with all ozone treatments had the highest values of total sugars content as compared with untreated control, which gave the lowest values at the same period.

Conclusion

From the previous results, it could be conclude that strawberry fruits which exposed to ozone gas for 30 min. was the most effective treatment in maintaining fruit quality, it would reduce weight loss percentage and gave fruits without decay and maintaining fruit firmness, TSS, ascorbic acid content, anthocyanins content and total sugars and gave fruits with good appearance after 21 days of storage at 0ºC and 95 % RH.

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