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Research Article
Extending Storability of Egyptian Banzahir Lime Fruits by Aqueous Ozone Technology with Edible Coating

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Abstract

Background and Objective: The present research aims to study the influence of aqueous ozone technology with gum arabic on Egyptian Banzahir lime fruits to maintain postharvest quality during cold storage and be available for longer period during the season. **Materials and Methods:** During the two successive seasons 2016 and 2017, fruits were harvested from El-Menoufia Governorate, Egypt. Fruits treated with 0.3 ppm aqueous ozone for 5 and 10 min, edible coating with gum arabic at 10% and combination of aqueous ozone and gum arabic. Fruits were stored at 7°C±1 and 90-95% relative humidity (RH) for 60 days. After 30 and 60 days of cold storage fruits held for 3 days at ambient conditions (25-30°C and 60-70% RH) as marketing. **Results:** Fruits treated with aqueous ozone for 5 or 10 min then edible coating with gum arabic 10% during 3 days as marketing after 60 days of cold storage gave favorite characters from physiological view including fruit weight loss, decay, chilling injury, respiratory rate, skin hue color, fruit firmness, juice percentage and technological index. Moreover, this treatment reflecting an improvement in fruit chemical characteristics during storage including higher concentrations of TSS, TSS/acid ratio, total sugar, juice pH, reduced the decline of acidity and vitamin C while, reduced chlorophyllase activity. **Conclusion:** Generally, it could conclude that, for commercial range or the export market, it may be useful to treat Egyptian Banzahir lime fruits with aqueous ozone or mixture of aqueous ozone with gum arabic for maintaining quality and decreasing fruit losses accompanied by changes in various metabolic and physiological processes during cold storage.

Key words: Limefruits, ozone solution, gum arabic, edible coating, metabolic and physiological processes

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

There are different varieties of lemon cultivated in Egypt, while Egyptian Banzahir lime (*Citrus aurantifolia*) is the main variety. The cultivated area reached about 16324 ha produce 345929 ton (Annual Reports of Statistical Institute and Agricultural Economic Research in Egypt, 2016). Also, there are other varieties cultivated in Egypt such as Sweet Lime (*Citrus limettioides*) and Rough Lime (*Citrus limond*) but on small scale. There is a constant demand for lime fruits throughout the year for local consumption and for exportation. In general, the Egyptian Banzahir lime begins to appear in the market from August and extends to late November. The lime fruits are small rounded about 2.5-5 cm diameter, high acidity, juice citric acid about 7-8%. Beyond the usual natural season, growers treat the trees with special agricultural treatments such as the fasting systems to prolong the lime marketing period. The frequent fasting of trees especially in the system of "big fast" to tamper with them physiologically, which leads to deterioration and even shortens their relative life. So, cold storage of harvested fruits represented the most promising method for increase storage life of Egyptian Banzahir lime fruits to prolong their marketing period. While, lemon fruits are subtropical origin and known as susceptible to chilling injury during cold storage. Chilling injury is a physiological disorder which develops in citrus when they exposed to low temperature[1]. Various postharvest treatments have been shown to be helpful in eliminating the chilling injury and maintaining the quality of fruits. Moreover, increasing consumer health concerns led to the decline in the demand of fungicide treated fruits and the use of alternative friendly techniques to reduce decay incidence and enhancement fruits during cold storage.

Ozone is one of the cleanest technologies to maintain fruit safety and quality that leaves no toxic residue within the fruits. It is approval as a generally recognized as safe (GRAS) ingredient by United States Food and Drug Administration (USFDA) in 2001. Commodities can be exposed to continuous or intermittent gaseous ozone[2] in the storage chambers or can be subjected to dissolved ozone in aqueous phase used for the treatment[3]. Application of ozone (O3) has gained recognition as a sanitizing agent. It has an oxidizing potential 1.5 times greater than that of chlorine and is much effective than chlorine as it can significantly control a wider spectrum of microorganisms without leaving any harmful residue[4]. Ozone can be used as a pre-storage treatment in air or water and either as a continuous or intermittent atmosphere during the storage period to prevent fruit decay. The limit value-short term exposure established by the US Occupational Safety and Health Administration (US-OSHA) for ozone is 0.3 ppm. This is the level to which healthy individuals can be exposed for 15 min without suffering irritation or other acute effects[5]. Ozone is an effective treatment for decreasing fruit weight loss without leaves any toxic by-products or residues. Moreover, it does not affect healthy cells or alter its chemistry and is non carcinogenic. Ozone always reverts back to its original form oxygen.

The development of edible coatings using natural biopolymers presents many advantages for the quality characteristics of fruits. Also, this system alternative had a lower cost and easier application than modified or controlled atmospheres. Consequently, edible coatings may well be an effective alternative to synthetic materials in terms of edibility, biocompatibility, non toxicity and low cost. Edible coating generates a modified atmosphere by creating a semi permeable barrier against O_2, CO_2, moisture and solute movement. Thus reducing respiration rate, weight loss, water loss and oxidation reaction rates[6].

Gum arabic is polysaccharide natural secretion exudates from the stems or branches of *Acacia* species. It is the least viscous and most soluble of the hydrocolloids, used extensively in the industrial sector because of its emulsification, film forming and encapsulation properties[7]. Gum arabic is a complex mixture of arabinogalactan oligosaccharides, polysaccharides and glycoproteins. It is a branched neutral or slightly acidic substance. The backbone has been identified to consist of β (1→3) linked d galactopyranosyl units. The side chains are composed of 2-5 β (1→3) linked d galactopyranosyl units, joined to the main chain by 1,6 linkages[8]. Gum arabic has been studied by many authors as an edible coating to delay the postharvest ripening of many food products. It was used as edible coatings for sweet cherries in order to delay their ripening during postharvest storage at 2°C and 90-95% relative humidity for 15 days. Also, it was slowing down the gas exchange by reducing the CO_2 concentration of coated sweet cherry by reducing their ethylene production[9]. Maqbool *et al.*[10] proved that the application of a mixture of 10% gum arabic and 1% chitosan as edible coating reduced the color evolution, the respiration rate and the ethylene production of the coated banana fruits compared with the control.

Therefore, the presented research aimed to study the effect of some safe postharvest treatments such as aqueous ozone technology with gum arabic edible coating as supplementary refrigeration treatments for prolonging marketing period and maintaining quality of Egyptian Banzahir lime fruits during cold storage.

MATERIALS AND METHODS

This study was conducted in seasons 2016 and 2017 to evaluate the effectiveness of aqueous ozone and edible coating with gum arabic for enhancing storability and the subsequent marketing of Egyptian Banzahir lime fruits (*Citrus aurantifolia* Swing). Fruits at green ripe stages were harvested from similar trees 18 years old grafted on sour orange rootstock, grown in sandy soil (5 x 5 m) apart in private orchard at El-Menoufia Governorate, Egypt. Fruit were selected according to size (50 mm diameter, ±3 mm) and color (intense green). The fruits were picked using small clippers at15th February and packed in plastic boxes and directly transferred to the laboratory. At the beginning of the experiments, samples of 50 fruits were taken to determine the initial fruits properties. Six sets of 180 fruits (30 fruits/replicate) free from physical damage and diseases with similar sizes, color and firmness were received the following treatments:

- Control (dipping fruit with tap water)
- Dipping fruits with 0.3 ppm aqueous ozone for 5 min
- Dipping fruits with 0.3 ppm aqueous ozone for 10 min
- Edible coating with gum arabic 10%
- Dipping fruits with 0.3 ppm aqueous ozone for 5 min, then edible coating with gum arabic 10%
- Dipping fruits with 0.3 ppm aqueous ozone for 10 min, then edible coating with gum arabic 10%

Ozone treatments: Ozone treatments were performed by passed oxygen through discharge generator (B6ATP, Euro Entech Co., LTD-Thailand, with a capacity of 2,500 mg h^{-1}). The generator was interconnected to a container filled with water (approximate volume of 30 L; the ratio between mass of the samples and volume of ozonated water was approximately 80 g/30 L), forming a closed circuit ring apparatus. The ozone generator operated production 0.3 ppm concentrations of dissolved O3. The concentration was maintained constant throughout treatment. Samples were immersed in ozonated water for 3 min.

Preparation of coating solutions: Gum arabic from *Acacia* trees was purchased from Sigma Aldrich. Coating solutions were prepared according to the method of Mahfoudhi and Hamdi[9]. Briefly, 10% (w/w) of gum arabic solutions was stirred at 40 for 60 min using a magnetic stirrer and then filtered to remove any undissolved impurities using a vacuum flask. After cooling to 20 glycerol monostearate (1.0%) (Sigma Aldrich, St. Louis, MO) was added as a plasticizer to improve the strength and flexibility of coating solutions. Fruits were immersed in gum solution for 3 min. then coating films were applied uniformly on the whole surface. Then, fruits were air dried for 1 h at ambient temperature, packed in plastic boxes.

For storage study, treated fruits were stored in perforated carton boxes in one layer at 7±1°C and 90-95% relative humidity (RH) for 60 days. After every period of cold storage fruits stored 3 days at ambient conditions (25-30°C and 60-70% RH) as marketing. Then, the data were recorded after 3 days at marketing conditions during both seasons. Fruit quality assessment was recorded as described below:

Determination of physical and chemical properties

Weight loss (%): It was determined according to the following equation:

$$\text{Loss in fruit weight (\%)} = \frac{\text{Initial weight-Weight at sampling date}}{\text{Initial fruit weight}} \times 100$$

Fruit decay (%): It was determined according to the following equation:

$$\text{Decay (\%)} = \frac{\text{Weight of rotted fruits}}{\text{Initial total fruit weight}} \times 100$$

Chilling injury index (%): Chilling injury symptoms were included pitting, staining and necrotic areas of fruit peel. CI was assessed as the percentage of affected fruit peel using 5 categories, according to the affected surface area, as follows: 0: 0%, 1:<5%, 2: 5-25%, 3: 25-50% and 4: >50% according to Lafuente *et al.*[1].

Respiration rate (CO_2 mg kg^{-1} h^{-1}): The respiratory rate was measured in 5 fruits of each treatment which were placed for 3 h in 3 L hermetic glass jars. A rubber septum was put on each lid and then gas samples were taken. A sample from each pot was collected with the aid of a 1 mL syringe and then analyzed through a CO_2 and O_2 analyzer. Carbon dioxide produced by lime fruits was determined according to AOAC[11].

Skin hue color (h): Skin color was evaluated through a hand-held colorimeter (CR-10; Minolta Co., Ltd., Osaka, Japan). Color changes from green to yellow were indicated by calculating the hue angle (h°), from (a*, b*) using the methods described by McGuire[12].

Fruit firmness (N): Fruits firmness was determined on the 2 opposite sides of fruit using a penetrating cylinder of 1 mm at 5 mm depth and the peak of resistance was recorded. The fruit firmness was measured as g cm^{-2} and converted to Newton value (g cm^{-2}* 9.81/1000) according to AOAC[13].

Juice (%): Content of juice was measured by squeezing 15 fruits for every treatment represent 3 replicates and then juice percentage was calculated (w/w).

Technological index (TI): It was calculated according to Kluge *et al.*[14] by the following equation:

$$\text{Technological index (\%)} = \frac{\text{Total soluble solids (TSS)}}{\text{Juice}} \times 100$$

Juice pH: The pH values were measured in triplicate in the pulp juice of lime with a digital pH meter (model HI 98107, Hanna Instruments Inc.; Woonsocket, RI, USA) by direct immersion of the electrode into the sample. Prior to each set of measurements, pH meter was calibrated using buffers of pH 4.0 and 7.0.

Total soluble solids (TSS %): Total soluble solids in fruit juice were measured using a Carl-Zeiss hand refractometer[13].

Total titratable acidity (TA %): It was determined in fruit juice by titration using 0.1 N sodium hydroxide and calculated as citric acid[13].

TSS/acid ratio: It was calculated by dividing the value of TSS over the value of titratable acidity of each sample.

Total sugar (%): The extract was prepared by taking 0.5 g of fresh pulp and extracting with 80% ethanol according to Ranganna[15].

Ascorbic acid (mg/100 g fresh weight): Ascorbic acid (vitamin C) was measured by the oxidation of ascorbic acid with using 2, 6-dichlorophenolindophenol and 2% oxalic acid as a substrate then the results were expressed as mg/100 g fresh weight according to Ranganna[15].

Chlorophyllase enzyme: For the enzyme assays, lime fruits 5 g was grounded with 50 mL of cold acetone concentrations of 80% for 5 min and then filtered on a Buchner funnel with paper filter Whatman No. 1. The residue was washed with cold diethyl ether until to white residue then dried at room temperature become to acetone powder[16]. The enzymatic activity was spectrophotometrically detected by chlorophyll a formation at 663 nm (unit mg^{-1} protein).

Statistical analysis: The data of both seasons of the study were analyzed by the variance of (ANOVA). The differences among mean of treatments were statistically analyzed using Duncan's multiple tests at a level 0.05, using the CoStat V6.4 program.

RESULTS AND DISCUSSION

This work estimated the effect of aqueous ozone technology with arabic gum edible coating as supplementary refrigeration treatments for extending and maintaining fruit quality of Egyptian Banzahir lime fruits during cold storage.

Weight loss (%): A reduction in fruit weight during storage is primarily attributed to the loss of moisture during respiration and transpiration processes[17]. Data presented in Table 1 revealed that there was a significant increase in fruit weight loss percentage with the advanced storage periods. In addition, the results revealed that dipping Egyptian Banzahir lime fruits with 0.3 ppm aqueous ozone for 5 min+edible coating with arabic gum 10% gave the lowest decrease in fruit weight loss (6.60 and 6.80%) during 3 days as marketing after 60 days of cold storage compared to the other treatments or the control in both seasons. Also, all the applied treatments reduced the loss in fruit weight than the control. Since, the percent of loss in fruit weight of the untreated fruits were 15.90 and 16.00% during 3 days as marketing after 60 days of cold storage in both seasons, respectively.

Weight losses are the major problems of lime fruits which not only cause quantitative losses but it also result qualitative problems such as softening, shriveling and wilting[18]. Edible coating like gum arabic helped to improve the fruit quality and worked efficiently against exterior constituents. This might be due to coatings formed an excellent barrier around the fruits which resulted in decrease in water losses, gas exchange aroma, flavor and solute passage towards cuticle. The results corroborate with the findings of Zhang *et al.*[19], who reported that ozone treated strawberries maintained low physiological loss weight than untreated ones during cold storage. Ozone is also significantly better in reducing aging and weight loss of orange compared to the non-treated fruits[20]. Ozone can break down the ethylene gas and reduce the rate of senescence in fruits sensitive to ethylene production in mix-stored room.

Table 1: Effect of aqueous ozone technology with gum arabic as edible coating on weight loss (%), decay (%) and chilling injury (%) of Banzahir lime fruits for 3 days at marketing conditions after 30 and 60 days of cold storage during 2016 and 2017 seasons

	Loss weight (%)			Decay (%)			Chilling injury (%)		
		Marketing after cold storage			Marketing after cold storage			Marketing after cold storage	
Treatments	Initial	30 days	60 days	Initial	30 days	60 days	Initial	30 days	60 days
2016 season									
Control (dipping fruit with tap water)	0.00^{k}	8.00^{f}	15.90^{a}	0.00^{g}	0.00^{g}	10.12^{a}	0.00^{h}	11.50^{b}	16.50^{a}
Dipping fruits with 0.3 ppm aqueous ozone for 5 min	0.00^{k}	5.51^{h}	10.00^{c}	0.00^{g}	0.00^{g}	2.55^{c}	0.00^{h}	0.00^{h}	2.36^{e}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min	0.00^{k}	5.24^{ij}	10.35^{b}	0.00^{g}	0.00^{g}	2.05^{d}	0.00^{h}	0.00^{h}	3.11^{c}
Edible coating with gum arabic 10%	0.00^{k}	5.46^{h}	9.80^{d}	0.00^{g}	0.00^{g}	3.70^{b}	0.00^{h}	0.00^{h}	2.86^{d}
Dipping fruits with 0.3 ppm aqueous ozone for 5 min +gum arabic 10%	0.00^{k}	5.20^{j}	6.60^{g}	0.00^{g}	0.00^{g}	1.55^{f}	0.00^{h}	0.00^{h}	2.00^{g}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min +gum arabic 10%	0.00^{k}	5.29^{i}	8.20^{e}	0.00^{g}	0.00^{g}	1.95^{e}	0.00^{h}	0.00^{h}	2.24^{f}
2017 season									
Control (dipping fruit with tap water)	0.00^{k}	8.70^{e}	16.00^{a}	0.00^{g}	0.00^{g}	11.20^{a}	0.00^{h}	9.80^{b}	16.50^{a}
Dipping fruits with 0.3 ppm aqueous ozone for 5 min	0.00^{k}	5.71^{h}	10.40^{c}	0.00^{g}	0.00^{g}	1.95^{d}	0.00^{h}	0.00^{h}	3.20^{d}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min	0.00^{k}	5.44^{j}	10.55^{b}	0.00^{g}	0.00^{g}	2.37^{c}	0.00^{h}	0.00^{h}	4.20^{c}
Edible coating with gum arabic 10%	0.00^{k}	5.76^{h}	9.90^{d}	0.00^{g}	0.00^{g}	3.40^{b}	0.00^{h}	0.00^{h}	2.00^{f}
Dipping fruits with 0.3 ppm aqueous ozone for 5 min +gum arabic 10%	0.00^{k}	5.59^{i}	6.80^{g}	0.00^{g}	0.00^{g}	1.35^{f}	0.00^{h}	0.00^{h}	1.80^{g}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min +gum arabic 10%	0.00^{k}	5.60^{i}	8.40^{f}	0.00^{g}	0.00^{g}	1.80^{e}	0.00^{h}	0.00^{h}	2.10^{e}

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

Decay (%): It is clear from Table 1 that all treatments did not present any decayed fruits during 3 days as marketing after 30 days of cold storage through both seasons. Since, all treatments significantly reduced the percent of decayed fruits than the control during 3 days as marketing after 60 of cold storage in the both seasons, respectively. In our study, dipping Egyptian Banzahir lime fruits with aqueous ozone 0.3 ppm for 5 min+edible coating with gum arabic 10% produced the lowest significant decayed fruits (1.55 and 1.35%) during 3 days as marketing after 60 days of cold storage in both seasons, respectively. The highest percent of decayed fruits were obtained for the untreated fruits (10.12 and 11.20%) at the same period in the both seasons, respectively.

Overall, it is recognized that both coating and storage at lower temperature had a significant beneficial effect on delaying the ripening and extending the shelf life. Lower decay in ozone treated fruits might be due to the antimicrobial action of ozone. The oxidative nature of ozone interferes with protein synthesis and enzyme activity of the microbial cell and leads to production of free radicals that rupture the cell membrane leading to lysis of microbial cell[2]. Ozone oxidizes the metabolic products and neutralizes the odors generated during the ripening stage in storage of fruits. Ozone preserves the shelf life on fresh produce. Ozone enhances the taste of most perishables by oxidizing pesticides and by neutralizing ammonia and ethylene gases produced during ripening or decay. Also, Ozone is effective killing microorganisms through oxidation of their cell membranes and increases the shelf life and reduces shrinkage[21].

Chilling injury (CI): Chilling injury is a physiological disorder which develops in lime when they exposed to low temperature. Chilling injury incidence (CI) was increased gradually and significantly with prolonging of cold storage period (Table 1). Moreover, all treatments did not present chilling injury (CI) in lime fruits during 3 days as marketing after 30 days of cold storage through both seasons. Since, all applied treatments reduced chilling injury incidence compare to the control. Dipping Egyptian Banzahir lime fruits with aqueous ozone 0.3 ppm for 5 min+edible coating with gum arabic 10% significantly gave lower CI indexes (2.00 and 1.80) during 3 days as marketing after 60 days of cold storage in both seasons, respectively. Chilling injury (Cl) in citrus fruits can be described as small pitted areas and skin depressions irregularly distributed over the fruit surface. The primary cause of CI in fruits is through the damage of cell membranes. The damage of membrane causes a cascade of secondary reactions, which led to ethylene production, increase of respiration rate, accumulation of toxic compounds and alteration of the cellular structure[22]. O3 has a high oxidative potential, which can impact the physiological status of fruits and vegetables by reducing the size of stomata on fruit

Table 2: Effect of aqueous ozone technology with gum arabic as edible coating on respiratory rate, skin hue angle (h°) and pulp firmness (N) of Banzahir lime fruits for 3 days at marketing conditions after 30 and 60 days of cold storage during 2016 and 2017 seasons

	Respiratory rate (mL CO_2 kg^{-1} h^{-1})			Skin hue angle (h°)			Pulp firmness (N)		
		Marketing after cold storage			Marketing after cold storage			Marketing after cold storage	
Treatments	Initial	30 days	60 days	Initial	30 days	60 days	Initial	30 days	60 days
2016 season									
Control (dipping fruit with tap water)	21.45^{a}	16.41^{b}	14.36^{c}	91.00^{a}	88.00^{d}	80.20^{l}	8.68^{a}	5.60^{e}	5.10^{i}
Dipping fruits with 0.3 ppm aqueous ozone for 5 min	21.45^{a}	12.45^{e}	7.30^{i}	91.00^{a}	85.90^{g}	81.40^{k}	8.68^{a}	5.70^{d}	5.30^{h}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min	21.45^{a}	13.45^{d}	6.89^{j}	91.00^{a}	87.40^{e}	83.90^{j}	8.68^{a}	5.80^{c}	5.40^{g}
Edible coating with gum arabic 10%	21.45^{a}	11.69^{f}	5.23^{k}	91.00^{a}	89.70^{b}	84.20^{i}	8.68^{a}	5.80^{c}	5.40^{g}
Dipping fruits with 0.3 ppm aqueous ozone for 5 min +gum arabic 10%	21.45^{a}	11.38^{h}	5.14^{l}	91.00^{a}	89.00^{c}	86.00^{g}	8.68^{a}	5.90^{b}	5.80^{c}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min+ gum arabic 10%	21.45^{a}	11.57^{g}	5.20^{k}	91.00^{a}	87.00^{f}	85.70^{h}	8.68^{a}	5.90^{b}	5.50^{f}
2017 season									
Control (dipping fruit with tap water)	20.15^{a}	15.00^{b}	12.16^{d}	93.00^{a}	89.30^{e}	82.80^{j}	9.00^{a}	5.40^{g}	5.20
Dipping fruits with 0.3 ppm aqueous ozone for 5 min	20.15^{a}	10.05^{f}	7.12^{g}	93.00^{a}	90.00^{d}	83.00^{j}	9.00^{a}	5.60^{f}	5.40^{g}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min	20.15^{a}	12.40^{c}	6.49^{h}	93.00^{a}	92.00^{b}	84.66^{i}	9.00^{a}	5.70^{e}	5.60^{f}
Edible coating with gum arabic 10%	20.15^{a}	10.20^{e}	5.20^{i}	93.00^{a}	91.00^{c}	85.00^{h}	9.00^{a}	5.80^{d}	5.60^{f}
Dipping fruits with 0.3 ppm aqueous ozone for 5 min +gum arabic 10%	20.15^{a}	10.00^{f}	5.00^{k}	93.00^{a}	90.90^{c}	86.60^{f}	9.00^{a}	6.00^{b}	5.90^{c}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min +gum arabic 10%	20.15^{a}	10.10^{f}	5.11^{j}	93.00^{a}	92.00^{b}	86.00^{g}	9.00^{a}	5.90^{c}	5.70^{e}

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

surfaces and degrading a variety of substances that are harmful to cells and cause browning[23]. Ozone treatment of coriander suppressed PPO activity, which may be related to the ability of ozone to degrade substances that are harmful to cells and oxidize fruit metabolites such as ethylene, thus delaying senescence.

On the other hand, coated fruit exhibited significantly lower CI than untreated (uncoated) lime fruits. Low CI symptoms in coated fruits describe the ability of edible coatings to act as a semipermeable barrier, thereby providing extra protection to fruit against low temperature injury[24].

Respiratory rate (mL CO_2 kg^{-1} h^{-1}): With the progression of storage time, all treatments showed a declining trend in respiration rate (Table 2). During 3 days as marketing after 30 days of cold storage, fruits treated with aqueous ozone 0.3 ppm for 5 min+edible coating with gum arabic 10% significantly presented lower respiratory, since the peak values of CO_2 evolution were 5.14 and 5.00 mL (CO_2 kg^{-1} h^{-1}) during 3 days as marketing after 60 days of cold storage in both seasons, respectively. Peak CO_2 evolution rates of 14.36 and 12.16 mL (CO_2 kg^{-1} h^{-1}) were observed in control during 3 days as marketing after 60 days of cold storage in both seasons, respectively.

The edible coating besides blocking the action of ethylene decreases the respiratory rate. The lime is a non-climacteric fruit which frequently led to decline the respiration rate after harvest. Surface coating can modify the internal atmosphere of the fruit, thereby delaying senescence. Elevation of CO_2 level in the environment up to about 5% leads to a reduction in respiration rate[25]. The reduction of O_2 with the higher of CO_2 can be led to suppress biosynthesis of the C_2H_4. Produce respiration can also lead to some small loss in weight[26]. Ozone ions have strong penetrating power and can readily enter cells, where it can decompose endogenous ethylene and inhibit the activity of intracellular oxidase, thereby reducing the rate of plant metabolism. Ozone treatment has been reported to induce a lower respiration rate in kiwifruit throughout the ripening period[27].

Skin hue color: The external color is one of the most appreciated quality factors of citrus fruits[28]. The data presented in Table 2 indicated that, the h° value of the skin decreased during the storage period. Concerning the effect of treatments on color, the data showed slight differences between all treatments. The best preserved skin green coloration was fruits treated with aqueous ozone 0.3 ppm for 5 min+edible coating with gum arabic 10% (86 and 86.6 h°) during 3 days as marketing after 60 days of cold storage in both seasons, respectively. These fruits were still suitable for commercialization, despite presenting initial chilling symptoms. During 3 days as marketing after 60 days of cold storage, untreated fruits presented the lowest hue values ranged 80.20 and 82.80 h° in both seasons, respectively. The lower rate of color change in coated fruits may be related to the effect of coating in creating modified atmospheres within the fruit.

Moreover, Eskandari *et al.*[29] proved that coating sweet lemon fruit with 10% gum arabic mainly reduced the skin color changes during a storage period of 3 months. In general, the effect of gum arabic edible coatings as a barrier against gas exchange between inner and outer environments as well as against ethylene production (discussed in the section Edible films' thickness) which delayed the color evolution. Higher h° value in coated fruits describes the ability of edible coatings to delay the breakdown of chlorophyll. Green color change could be due to the conversion of chloroplasts to chromoplasts pertaining to changes in pigment content of fruit as ripening progresses.

Pulp firmness (N): Fruit firmness is an important criterion to assess the quality of lime fruits. Data in Table 2 revealed that the firmness of lime fruits was decreased gradually with prolonged storage period up to the end of storage period, among all treatments in 2 seasons. These findings may support the results of fruits weight loss. However, the treated fruits maintained relatively higher firmness compared with untreated fruits (control). The maximum value of firmness (5.80 and 5.90 N) was found in fruits treated with aqueous ozone 0.3 ppm for 5 min+edible coating with gum arabic 10% during 3 days as marketing after 60 days of cold storage in both seasons, respectively. While, the minimum value (5.10 and 5.20 N) was recorded in untreated fruits during the same period. In coated fruits, during fruit ripening, a decrease in pectinesterase and polygalacturonase activities is generally observed due to low oxygen and high carbon dioxide concentration regime therefore, degradation of insoluble protopectins to the more soluble pectic acid and pectin may be retarded to reduce water loss from the fruit surface and allowing firmness retention[30]. Ozone is oxidative in nature, which is responsible for inactivating fruit softening enzymes such aspect in methylesterase, which helps in maintaining fruit firmness during storage. Also ozone has been attributed to cause suppression of ethylene gas production that is responsible for fruit softening hence helping in better retention of firmness[31]. Moreover, Crisosto *et al.*[32] showed that the softening process depends on the increase in polygalacturonase, β-galactosidase and pectin methylesterase activities. This enzymatic activity depends on the respiration rate of the fruit during ripening. Therefore, the activity of these enzymes could be declined by the reduced O_2 internal and increased CO_2 concentrations.

Total soluble solids concentration (TSS %): Concerning to the effect on TSS, data from Table 2 showed that TSS contents obtained in fruit juice of Banzahir lime fruits tended to increase with storage duration in both seasons regardless of the used treatments.

In this respect, all treatments gave somewhat higher values of TSS in fruit juice than the control fruits. Since, fruits treated with aqueous ozone for 10 min+edible coating with gum arabic 10% produced higher TSS values in juice compared to other treatments conducted averaged 8.10 and 8.20% during 3 days as marketing after 60 days of cold storage in both seasons, respectively. The data also disclose that, untreated fruits gave less values of TSS which ranged 7.90% in both seasons during 3 days as marketing after 60 days of cold storage. In general, TSS increased and the titratable acidity decreased during storage. The concentrations of acid and sugars may be influenced with weight loss percentage, which affects the residual weight of lime fruits.

The gradual increase in the percentage of TSS with the increase of storage period could be due to the degradation of complex insoluble compounds to simple soluble compounds like sugars, which are the major TSS components.

Also, the increase in TSS percentage might be due to water loss by transpiration during storage period. In addition, the treatments used led to reduce respiration which contribute to maintain TSS. Moreover, Eskandari *et al.*[29] studied the effect of edible coatings of gum arabic on the shelf life of postharvest sweet lemon at concentrations of 5 and 10% and found that, soluble solids and vitamin C significantly increased while reduced pH substances and TA.

Titratable acidity (TA): A gradual decrease in titratable acidity was found with an increase in storage period irrespective in all treatments used from harvest until 3 days as marketing after 60 days of cold storage in both seasons. Also, as the period of storage prolonged the reduction became more obvious. Similar results were also found in a previous report where TA of fruits was decreased with extended storage conditions[18]. The reduction in acid content of fruits can be attributed to the conversion of organic acids to sugars during the process of respiration[33]. Data from Table 3 demonstrate that all treatments used reduced the percent of total acidity in fruit juice than the control during both seasons, respectively. Commonly, fruits treated with aqueous ozone 0.3 ppm for 5 min+edible coating with gum arabic 10% had the least significant TA (1.65 and 1.70%) compared with other treatments during both seasons, respectively. Furthermore, the acidity of fruit juice was significantly higher in the control

Table 3: Effect of aqueous ozone technology with gum arabic as edible coating on Juice TSS (%), Juice acidity (%) and TSS/acid ratio (%) of Banzahir lime fruits for 3 days at marketing conditions after 30 and 60 days of cold storage during 2016 and 2017 seasons

	TSS (%)			Acidity (%)			TSS/acid ratio (%)		
		Marketing after cold storage			Marketing after cold storage			Marketing after cold storage	
Treatments	Initial	30 days	60 days	Initial	30 days	60 days	Initial	30 days	60 days
2016 season									
Control (dipping fruit with tap water)	6.30^{f}	6.90^{e}	7.90^{abc}	3.59^{a}	1.95^{b}	1.89^{de}	1.75^{l}	3.85^{k}	4.18^{f}
Dipping fruits with 0.3 ppm aqueous ozone for 5 min	6.30^{f}	7.30^{de}	7.90^{abc}	3.59^{a}	1.80^{h}	1.83^{gh}	1.75^{l}	4.05^{g}	4.31^{d}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min	6.30^{f}	7.40^{cde}	7.90^{abc}	3.59^{a}	1.85^{fg}	1.80^{h}	1.75^{l}	3.95^{i}	4.38^{c}
Edible coating with gum arabic 10%	6.30^{f}	7.50^{bcd}	8.00^{ab}	3.59^{a}	1.92^{bcd}	1.70^{i}	1.75^{l}	3.90^{j}	4.70^{b}
Dipping fruits with 0.3 ppm aqueous ozone for 5 min +gum arabic 10%	6.30^{f}	7.60^{abcd}	8.10^{a}	3.59^{a}	1.93^{bc}	1.65^{j}	1.75^{l}	3.93^{i}	4.90^{a}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min +gum arabic 10%	6.30^{f}	7.60^{abcd}	8.00^{ab}	3.59^{a}	1.90^{cde}	1.87^{ef}	1.75^{l}	4.00^{h}	4.27^{e}
2017 season									
Control (dipping fruit with tap water)	6.70^{i}	7.70^{f}	7.90^{d}	3.77^{a}	2.00^{b}	1.91^{ef}	1.77^{i}	3.86^{h}	4.13^{d}
Dipping fruits with 0.3 ppm aqueous ozone for 5 min	6.70^{i}	7.50^{h}	8.10^{b}	3.77^{a}	1.85^{g}	1.88^{fg}	1.77^{i}	4.03^{e}	4.30^{c}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min	6.70^{i}	7.50^{h}	8.00^{c}	3.77^{a}	1.92^{de}	1.86^{g}	1.77^{i}	3.90^{gh}	4.30^{c}
Edible coating with gum arabic 10%	6.70^{i}	7.60^{g}	8.10^{b}	3.77^{a}	1.95^{cd}	1.80^{h}	1.77^{i}	3.89^{h}	4.50^{b}
Dipping fruits with 0.3 ppm aqueous ozone for 5 min +gum arabic 10%	6.70^{i}	7.80^{e}	8.20^{a}	3.77^{a}	1.98^{bc}	1.70^{i}	1.77^{i}	3.94^{fg}	4.82^{a}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min +gum arabic 10%	6.70^{i}	7.70^{f}	8.20^{a}	3.77^{a}	1.96^{c}	1.90^{ef}	1.77^{i}	3.95^{f}	4.31^{c}

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

compared to the other treatments, whereas it declined with storage time which may be attributed to the use of such acids as substrates for respiration.

The decrease in acidity in citrus fruits during storage with the progress in maturity might be due to enhancement of sugar concentrations as a result to boost respiratory rate. So, the decrease in titratable acidity during storage led fruits to be more suitable for consumption due to suitable taste[34].

Total soluble solids (TSS)/acid ratio: Considering to the effect on TSS/acid ratio, data in Table 3 reveal that the values of TSS/acid ratio were progressively increased by the storage period advanced from harvest till 3 days as marketing after 60 days at cold storage. Results illustrate that, significant declining trend in juice TA contents while, significant rising trend in TSS/acid ratio were observed with the advancement of storage period in the both seasons. Since, control treatment produced a lower value of TSS/acid ratio during 3 days as marketing after 60 days of cold storage since the values averaged about 4.18 and 4.13% during the 2 seasons, respectively. Moreover, fruits treated with aqueous ozone 0.3 ppm for 5 min+edible coating with gum arabic 10% gave higher values of TSS/acid ratio (4.90 and 4.82%) during the two seasons, respectively.

TSS and TA determine the flavor and nutritional status of fruit. On the other hand, postharvest application of edible coatings retained higher TSS/acid ratio, as compared to control. Since, TSS/acid ratio decrease in uncoated fruits could be due to the increased respiration and oxidation of organic acids. Our results are in confirmation with the findings of Khaliq *et al.*[35], who found that gum arabic exhibited higher TSS/acid ratio by preventing degradation of organic acids in fruits during cold storage.

Juice (%): Data in Table 4 revealed the effect of postharvest treatments on juice percentage in both studied seasons. The juice present of lime fruit is considered one of the most important qualities parameter in juicy fruits like lime. In the present study, juice percentage of lime fruits gradually decreased with an increase in storage period in all treatments from harvest till 3 days as marketing after 60 days of cold storage. The maximum juice percent (32.29 and 33.50) was obtained from fruits treated with aqueous ozone 0.3 ppm for 10 min+edible coating with gum arabic 10% during 3 days as marketing after 60 days of cold storage, respectively. The reason for high juice content in this treatment is the minimum loss of water from the fruit surface. While, minimum juice (26.00 and 27.40%) was obtained from untreated fruits (control) during 3 days as marketing after 60 days of cold storage during both seasons, respectively. These results indicated a direct correlation between fresh fruit weight and juice percentage. Erkan and Pekmezci[36] reported that juice content of Washington Navel orange fruits increased at the beginning then showed a steady decrease (6%) during storage at 5°C+shelf-life. Maintaining juice (%) in treated

Table 4: Effect of aqueous ozone technology with gum arabic as edible coating on juice (%), technological index (TI) and juice pH of Banzahir lime fruits for 3 days at marketing conditions after 30 and 60 days of cold storage during 2016 and 2017 seasons

Treatments	Juice (%) Initial	Juice (%) Marketing after cold storage 30 days	Juice (%) Marketing after cold storage 60 days	Technological index (TI) Initial	TI Marketing after cold storage 30 days	TI Marketing after cold storage 60 days	Juice pH Initial	Juice pH Marketing after cold storage 30 days	Juice pH Marketing after cold storage 60 days
2016 season									
Control (dipping fruit with tap water)	40.00a	34.00f	26.00j	2.52e	2.58cd	2.05h	2.65h	3.00c	3.21a
Dipping fruits with 0.3 ppm aqueous ozone for 5 min	40.00a	36.40c	27.50i	2.52e	2.65b	2.17g	2.65h	2.92d	3.16a
Dipping fruits with 0.3 ppm aqueous ozone for 10 min	40.00a	35.80d	26.20j	2.52e	2.65b	2.07h	2.65h	2.85ef	3.06b
Edible coating with gum arabic 10%	40.00a	35.00e	30.46h	2.52e	2.62bc	2.43f	2.65h	2.81fg	2.94d
Dipping fruits with 0.3 ppm aqueous ozone for 5 min +gum arabic 10%	40.00a	37.00b	32.29g	2.52e	2.81a	2.61bc	2.65h	2.77g	2.90de
Dipping fruits with 0.3 ppm aqueous ozone for 10 min +gum arabic 10%	40.00a	36.90b	32.00g	2.52e	2.80a	2.55de	2.65h	2.79g	2.94d
2017 season									
Control (dipping fruit with tap water)	42.00a	36.00g	27.40m	2.81cd	2.77de	2.15h	2.70g	3.17b	3.30a
Dipping fruits with 0.3 ppm aqueous ozone for 5 min	42.00a	37.40f	29.30l	2.81cd	2.80cd	2.37g	2.70g	3.12c	3.20b
Dipping fruits with 0.3 ppm aqueous ozone for 10 min	42.00a	37.80e	29.60k	2.81cd	2.83bc	2.36g	2.70g	2.97d	3.16b
Edible coating with gum arabic 10%	42.00a	38.00d	32.40i	2.81cd	2.88b	2.62f	2.70g	2.87e	2.99d
Dipping fruits with 0.3 ppm aqueous ozone for 5 min +gum arabic 10%	42.00a	39.00b	33.50h	2.81cd	3.04a	2.74e	2.70g	2.80f	2.95d
Dipping fruits with 0.3 ppm aqueous ozone for 10 min +gum arabic 10%	42.00a	38.70c	32.20j	2.81cd	3.00a	2.64f	2.70g	2.88e	2.98d

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

fruits with gum arabic is probably due to the reduction of water loss from the fruits as compared to other treated fruits[29].

Technological index (TI): Considering to the effect on technological index, data in Table 4 reveal that TI was significantly decreased in most treatments from harvest till 3 days as marketing after 60 days of cold storage, except fruits treated with aqueous ozone either 0.3 ppm for 5 or 10 min+edible coating with gum arabic 10% in the first season under the study. It is obvious that, fruits treated with aqueous ozone 0.3 ppm for 5 min+edible coating with gum arabic 10% produced the highest TI (2.61 and 2.74) during 3 days as marketing after 60 days of cold storage compared with untreated fruits (%) produced the lowest TI (2.05 and 2.15) in the 2 seasons, respectively. Higher values of TI are an indicator of maturity and can also be used as indicator of fruit quality[37].

Juice pH: From Table 4 it is clear that, all applied treatments showing increment in pH values with prolonging cold storage period till 3 days as marketing after 60 days of cold storage. The data given clearly indicates that best treatment is storing lime with aqueous ozone 0.3 ppm for 5 min+edible coating with gum arabic 10% (2.90 and 2.95)which the pH value is of already de-greened lime. The highest value (3.21 and 3.30) was recorded in untreated fruits during 3 days as marketing after 60 days of cold storage. However, changing of pH value of lime fruit is directly related to the peel color, which increases with the de-greening process. When the color is changed from green to yellow, pH value is also increased concurrently. The deteriorated fruits (fruits in brown color) having the highest pH values[38]. Thereafter, it slowly goes down with the beginning of de-greening process and as a result of that pH of the fruits is gradually moving up. Moreover, the linear increase in pH might be ascribed to biochemical, structural and physiological alterations taking place during respiration. The increase in pH could be attributed to the accumulation of dry matter content and depolymerization of fruits polysaccharides under cold storage.

Total sugar (%): Data in Table 5 indicated that total sugar percent in fruit juice of lime fruits was gradually increased as storage period prolonged during cold storage. Since, the untreated fruits produced lower significant values of total sugar in the fruits than all treatments which ranged 1.52 and 1.58% during 3 days as marketing after 60 days of cold storage in both seasons under the study. The data also disclose that, treated fruits with aqueous ozone 0.3 ppm for 10 min+edible coating with gum arabic 10% presented higher values of total sugars compare to the applied treatments averaged 1.77 and 1.80% during 3 days as marketing after 60 days of cold storage in both seasons, respectively.

Table 5: Effect of aqueous ozone technology with gum arabic as edible coating on Juice TSS (%), Juice acidity (%) and TSS/acid ratio (%) of Banzahir lime fruits for 3 days at marketing conditions after 30 and 60 days of cold storage during 2016 and 2017 seasons

	Total sugar (%)			Juice vitamin C (mg/100 mL juice)			Chlorophyllase activity (unit mg^{-1} protein)		
		Marketing after cold storage			Marketing after cold storage			Marketing after cold storage	
Treatments	Initial	30 days	60 days	Initial	30 days	60 days	Initial	30 days	60 days
2016 season									
Control (dipping fruit with tap water)	1.39^{g}	1.47^{f}	1.52^{def}	40.40^{a}	36.00^{g}	32.00^{j}	0.14^{e}	0.65^{c}	0.86^{a}
Dipping fruits with 0.3 ppm aqueous ozone for 5 min	1.39^{g}	1.50^{ef}	1.54^{de}	40.40^{a}	37.20^{e}	35.00^{i}	0.14^{e}	0.56^{d}	0.78^{b}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min	1.39^{g}	1.55^{de}	1.62^{c}	40.40^{a}	37.90^{d}	35.30^{h}	0.14^{e}	0.55^{d}	0.78^{b}
Edible coating with gum arabic 10%	1.39^{g}	1.61^{c}	1.65^{c}	40.40^{a}	38.30^{c}	36.90^{f}	0.14^{e}	0.53^{d}	0.77^{b}
Dipping fruits with 0.3 ppm aqueous ozone for 5 min +gum arabic 10%	1.39^{g}	1.56^{d}	1.66^{c}	40.40^{a}	39.40^{b}	38.00^{d}	0.14^{e}	0.50^{d}	0.70^{c}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min +gum arabic 10%	1.39^{g}	1.71^{b}	1.77^{a}	40.40^{a}	39.20^{b}	37.40^{e}	0.14^{e}	0.52^{d}	0.71^{c}
2017 season									
Control (dipping fruit with tap water)	1.46^{f}	1.54^{e}	1.58^{de}	42.00^{a}	36.80^{j}	33.00^{m}	0.15^{h}	0.65^{d}	0.89^{a}
Dipping fruits with 0.3 ppm aqueous ozone for 5 min	1.46^{f}	1.56^{de}	1.60^{d}	42.00^{a}	37.70^{h}	35.70^{l}	0.15^{h}	0.58^{e}	0.80^{b}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min	1.46^{f}	1.60^{d}	1.69^{c}	42.00^{a}	38.40^{f}	35.90^{k}	0.15^{h}	0.56^{ef}	0.80^{b}
Edible coating with gum arabic 10%	1.46^{f}	1.68^{c}	1.75^{b}	42.00^{a}	38.90^{d}	37.00^{i}	0.15^{h}	0.54^{f}	0.79^{b}
Dipping fruits with 0.3 ppm aqueous ozone for 5 min +gum arabic 10%	1.46^{f}	1.60^{d}	1.74^{b}	42.00^{a}	39.90^{b}	38.60^{e}	0.15^{h}	0.51^{g}	0.71^{c}
Dipping fruits with 0.3 ppm aqueous ozone for 10 min +gum arabic 10%	1.46^{f}	1.78^{ab}	1.80^{a}	42.00^{a}	39.50^{c}	37.90^{g}	0.15^{h}	0.55^{f}	0.73^{c}

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

Geransayeh *et al.*[39] found that treated 'Bidaneh Qermez' grape fruits by ozone soluted at 0.3 ppm concentration with three treatment times (5, 10 and 15 min), had a significant increase in reducing sugars and storage quality compared to controls. In general, it has been shown that due to the high oxidative capacity of O3 and its ability to generate toxic agents, they elicit plant defense reactions such as the production of phytoalexins including resveratrol in grapes. The increase in reducing sugars can enhance plant resistance against pathogens, because it can affect the total antioxidant content of fruit. However, fruits coated with gum arabic exhibited a lower increase in sugar content, which may be described due to its ability to delay the ripening process and maintained lower sugar levels in fruits[10].

Vitamin C (mg/100 mL juice): Vitamin C (VC) is among the most important quality parameters for fruits. In the present investigation (Table 5) it could be noticed that there was a significant decrease in ascorbic acid with the advanced storage periods. Concerning the effect of different treatments on ascorbic acid concentration, the obtained results indicated that fruits treated with aqueous ozone 0.3 ppm for 5 min+ edible coating with gum arabic 10% during 3 days as marketing after 60 days of cold storage has the highest positive vitamin C content (38.00 and 38.60 mg 100 mL^{-1} juice) when compared with the other treatments used during 2 seasons under the study.

The minimum vitamin C content (32.00 and 33.00 mg 100 mL^{-1} juice) was found in untreated fruits during 3 days as marketing after 60 days of cold storage in the 2 seasons under the study, respectively. Vitamin C content offered a gradual decrease, while pH was increased with the progress in ripening during cold storage. The decrease in ascorbic acid could be attributed to the increased respiration and oxidation of acids into sugars. Gum arabic treatment might have reduced oxidation of acids, thus resulting in higher values of vitamin C content[40].

Moreover, the decline in vitamin C content seems to be caused by the oxidation of ascorbic acid by enzymes; surface coating treatments might have triggered the action of the enzymes during storage[18]. In this respect, treated strawberry fruits with O3 led to higher vitamin C content, since O3-treatment activated antioxidative mechanism and promote vitamin C biosynthesis from carbohydrate reserves[41].

Lower respiration rate and ethylene production in fruits improved vitamin C retention. Since, the higher vitamin C retention after coating treatment may be due to the ability of coating a gas barrier to reduce the O_2 tension in the fruit tissue[42]. Moreover, the decline in vitamin C is related with the increment in pH.

Chlorophyllase activity (unit mg^{-1} protein): Chlorophyllase enzyme is present in chloroplast and undergoes degradation before and during maturation and color change in the fruits peel. Moreover, chlorophyllase enzyme is catalyzed chlorophyll by removing the phytol group, which results in chlorophyllide formation.

Data presented in Table 5 showed that, chlorophyllase activity in fruit juice of lime fruit gradually increased during cold storage in both seasons. Fruits treated with aqueous ozone 0.3 ppm for 5 min+edible coating with gum arabic 10% during 3 days as marketing after 60 days of cold storage had a lower chlorophyllase activity (0.70 and 0.71 unit mg^{-1} protein) than other treatments and control fruit from beginning to end storage in both seasons, respectively.

The chlorophyllase activity increased in the control treatment (0.86 and 0.89 unit mg^{-1} protein) throughout the storage time and remained high at the end of storage in both seasons, respectively. Lime fruits have changed color from green to yellow during storage. Changing the color of lime is mainly due to the use of ethylene to stimulate the decomposition of chlorophyll. The results, according to Drazkiewicz[43] found that the decomposition of chlorophyll is influenced by the production of ethylene through the intermediary of chlorophyllase enzyme system to synthetic of enzyme chlorophyllase.

The lowering of O_2 and elevation of CO_2 following coating treatment has already been demonstrated to be beneficial in preventing chlorophyll degradation[42]. Ozone treatment is suppressed the postharvest quality deterioration in horticultural plants by maintaining the physical appearance of the harvested crops and suppressed both the respiration rate and polyphenol oxidase activity. Moreover, O3 treatment inhibited the decline in chlorophyll content and inhibited the activity of the chlorophyll degrading enzymes such as chlorophyllase, chlorophyll degrading peroxidase and pheophytinase. Thus, treatment with ozone may be a useful approach for maintaining the quality and extending the shelf life of crops through its regulation of antioxidant and chlorophyll degrading enzyme activity.

CONCLUSION

Generally, fruits treated with aqueous ozone at 0.3 ppm for 5 or 10 min then edible coating with gum arabic 10% during 3 days as marketing after 60 days of cold storage gave favorite characters from physiological view including fruit weight loss, decay, chilling injury, respiratory rate, skin hue color, fruit firmness, juice (%) and technological index. Moreover, this treatment reflecting an improvement in fruit chemical characteristics during storage including higher concentrations of TSS, TSS/acid ratio, total sugar, juice pH, reduced the decline of acidity and vitamin C while, reduced chlorophyllase activity. Thus, it could conclude that, for commercial range or the export market, it may be useful to treat lime fruits with aqueous ozone or mixture of aqueous ozone and edible coating with gum arabic for extending and maintaining fruit quality of Egyptian Banzahir lime fruits during cold storage.

SIGNIFICANCE STATEMENT

This study discovered the possible effect of aqueous ozone technology with gum arabic as edible coating that can be beneficial for maintaining quality during commercial range or the export market of Egyptian Banzahir lime fruits. This study will help the researchers to uncover the critical areas of maintaining quality and decreasing fruit losses accompanied by changes in various metabolic and physiological processes during marketing that many researchers were not able to explore. Thus a new theory of aqueous ozone and with gum arabic are promising examples that are beginning to be adopted on a commercial scale which may be arrived at retain quality of lime fruits after 60 days of cold storage and held for 3 days at ambient conditions as marketing.

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