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Evaluation of Silicon Concentrations and Modified Atmosphere Packing (MAP) on Behavior of Pioneer Plums under Two Different Storage Temperatures

[1]I. Samah Nasr, [2]Hassan M. Korkar and [3]A. Abd-El Hamid

[1]Ministry of Agriculture, Giza, Egypt
[2]Higher Institute for Agriculture Co-Operation, Cairo, Egypt
[3]Department of Horticulture, Faculty of Agriculture, Ain Shams University, Egypt

Abstract: The effect of different per storage potassium silicate concentration (0.0, 2500, 5000 and 10000 ppm) alone or combined with modified atmosphere packing (MAP) on extending storage life and reduction chilling injury symptoms of Pioneer plums under two different storage temperatures have been investigated. Results clearly indicated that, the lower concentration of potassium silicate (2500 and 5000 ppm) with packaging fruits in polyethylene under temperature (0 ±1 °C) and 5000 ppm potassium silicate application with or without packaging fruits under temperatures (20 ±2 °C) maintaining the fruit firmness, reduced weight loss% through out reducing respiration rate and recorded the high scores (excellent) for fruits color, juiciness and taste during sensory evaluation compared with the control and high concentration of potassium silicate (10000ppm). Moreover, 2500 and 5000 ppm potassium silicate treatments reduced the chilling injury symptoms i.e electrolyte lockage and flesh browning degree. The potential of Si to alleviate the chilling injury of plums may be due to the modification of cell membranes, reducing the membrane permeability and increasing membrane stability and integrity. Finally, the application of potassium silicate at 2500 and 5000 ppm either alone or in combination with MAP proved to be an safe and effective means of reducing chilling injury and extending postharvest storage life of Pioneer plums.

Key words: Pioneer plums · Potassium silicate · Silicon · Modified atmosphere packing · Storage

INTRODUCTION

Plums are mem bers of the Rosaceae family and include ‘Japanese plums’, belonging to the species *Prunus salicina* Lindell, native to China and domesticated in Japan 400 years ago; mainly used for fresh consumption. The plum is classified as a climacteric fruit, showing a peak in ethylene production and respiration during development. However, two distinct types of ripening behaviour have been observed for several cultivars [1, 2]. Those showing a typical climacteric behaviour and those considered suppressed climacteric [3]. Despite their different ethylene production rates, the suppressed climacteric cultivars were shown to be sensitive to ethylene and its analogues [1, 4]. Plums have a short postharvest life compared with the other climacteric temperate fruits such as apples and pears [5]. Refrigerate and low-temperature storage (0°C) are recommended to delay ripening and maintain plum fruit quality. However, the use of low-temperature storage has to be carefully managed in plum in order to avoid the incidence of chilling injury(CI) symptoms, usually manifested as translucency, red pigment accumulation (bleeding), flesh browning and/or failure to ripen, might develop [6, 5]. Many plum cultivars might develop chilling injury, depending on storage temperature [7, 1].

Cold storage, under modified atmosphere and controlled atmosphere (CA) improves flesh firmness and ground color retention and reduces shrivel in some plum cultivars. However, CA does not prevent chilling injury and may reduce the flavor after long-term storage, limiting its commercial use to extend plums storage life [8, 9]. Modified atmosphere (MA) storage has been shown to be effective in maintaining quality and they extend post-harvest life in many commodities, primarily apple (*Malus domestica* Borkh) and pear (*Pyrus communis* L.),

Corresponding Author: I. Samah Nasr, Ministry of Agriculture, Giza, Egypt.

although its application in many other fruits and vegetables has not been nearly as successful. In the case of plums, reduced decay incidence and delay of ground colour changes [5]. Modified atmosphere packaging (MAP) technology has been successfully used to maintain the postharvest quality and to prolong the storage period of many fruit and vegetables. By creating higher carbon dioxide (CO_2) and lower oxygen (O_2) concentrations in the surrounding atmosphere of the commodities, decay, respiration rate, ethylene production and enzymatic activity can be controlled, resulting in an increase in postharvest quality [10, 11]. MAP may also prevent weight loss and fruit shriveling by creating a higher relative humidity in the surrounding environment of the products. Wargo *et al*. [12] and Mustafa and Eski [13] reported that the success of MAP depends on several factors such as the physical properties of the film and the respiration rate of the product.

Silicon (Si) is the second abundant element in the crust of earth and in plants in which its content in plant is%0.1 to%10 of dry weight [14, 15]. Although silicon is not considered an essential element for plant nutrition, many authors report on beneficial effects when its supply to various cultivated plants is enhanced. In most cases, the favorable effects of Si on crop plants seem to originate from reinforcement of the cell walls due to deposition of Si in form of amorphous silica (SiO_2. nH_2O) and opal phytoliths [14, 16]. Moreover, the mechanical strength provided by Si to the plant tissues increases their resistance to several bacterial, fungi and insect diseases [17, 14]. Si has been reported to generally improve plant growth, a feature linked to the ability of Si to balance nutrient uptake or the general enhancement of nutrient transport and distribution by Si [18, 19]. Apart from the physical action of Si deposits in cells, Si can also associate with cell wall proteins, where it might exert an active biochemical function, possibly through production of defence compounds which could reduce pathogen attacks [20]. Therefore, Si applications could improve the postharvest fruit quality of avocado, not only through reducing pest and disease incidences but also by altering certain fruit parameters. Recently, silicon dips have an ability to reduce chilling injury symptoms in lemons; however low concentration should be used [19, 21].

The most commonly used from of Si in agricultural commodities is currently potassium silicate (K_2SiO_3), although other products, such as calcium ($CaSiO_3$) and sodium silicate (Na_2SiO_3) as well as NonTox-silica are available. However, as these products are either less soluble than KSil or, like Na, might affect fruit quality negatively [19]. The objectives of this study are to evaluate the use of permeable silicon and modified atmosphere packaging (MAP) to extend storability and reduce chilling injury of Pioneer plums during storage under two different temperatures (0 and 20 °C) also the effects on the sensory, physical, chemical and physiological characteristics were examined.

MATERIALS AND METHODS

Commercially ripening plums (*Prunus salicina* L.) were hand- harvested at the maturity stage (SSC ≈13.00, TA ≈1.20, firmness ≈15.56 K.force, medium size (80 – 90 g) and red greenish of skin color in early July during 2012 – 2013 seasons from selected 8 years old cv Pioneer grafted on seedling rootstock located in a commercial orchard at El_Ghazoo Agriculture Society near Dina Farms, Giza Governorate. Fruits were selected for uniformity, shape, colour and size and any blemished or diseased fruits were discarded. The fruits were immediately transported on the same day to the postharvest laboratory at the Department of Horticulture, Ain Shames University Cairo, Egypt. The fruits were clipped and washed with distilled water to remove any dirt and dipped in four potassium silicate concentrations 0, 2500, 5000 and 10000 ppm (K_2SiO_3) solutions for 5 min to allow penetration of the solution alone or in combination with modified atmosphere packaging (MAP). MAP was carried out using polyethylene (PE) with a thickness of 30 μm, an O_2 permeability of 1614.32 mL (m^2 day atm)$^{-1}$ and a CO_2 permeability of 546.24 mL (m^2 day atm)$^{-1}$. The fruit were placed in small plastic crates and covered with PE bags as described above and closed tightly [13].

The Used Treatments Were: Control (0 K_2SiO_3 and no Packaging), 2500 ppm K_2SiO_3, 5000 ppm K_2SiO_3, 10000 ppm K_2SiO_3, polyethylene bags (MAP), 2500 ppm K_2SiO_3 + MAP, 5000 ppm K_2SiO_3 + MAP and 10000 ppm K_2SiO_3 + MAP.

Each treatment included 48 fruits and was replicated three times (16 fruit per each replicated). The fruits from each treatment and replicate were packed in perforated small plastic crates and stored at 0 ±1 °C with 90 ±5% or 20± 2 °C with 85±5% relative humidity (RH) for a 28 days

A sample of randomly selected fruits at the beginning of cold storage duration (0 day) and weekly (7 days) intervals was collected from each replication for all treatments during the storage period. The experiment was arranged in randomized complete blocks design.

Data on the following parameters was recorded.

Fruit Physical Properties

Weight Loss%: Plums were weighed at the beginning of the experiment just after treatments application and every seven days interval during the storage period. Weight loss was expressed as the percentage loss of the initial total weight.

Discarded Fruits%: The number of decayed fruits was periodically recorded and expressed as a percentage from the total fruit number.

Fruit Firmness (Kgf): Fruit firmness was measured on the equatorial zone of the both cheeks after removing fruit skin using Tester (GY-1, China) equipped with a 2-mm plunger tip a digital basic force gauge. Values were expressed in kilo gram force(Kgf).

Sensory Evaluation of Samples: Sensory quality for freshness, color, juiciness and taste hedonic of fruits was evaluated by a panel of eight assessors at the end of storage periods at both temperature (0 & 20°C), with descriptive terms on the left (lower anchor) and on the right (upper anchor), the panelists rated the intensity of each descriptor for each sample, being required to test the attributes in the following order: freshness plum appearance (unacceptable to excellent), red color (light to dark), juiciness (not juicy to very juicy), hedonic scale (dislike extremely to like extremely[22].

Fruit Chemical Properties

Soluble Solids Content and Titaratable Acidity: A homogeneous fruits sample was prepared for soluble solids content (SSC) and titaratable acidity. Soluble solids content (SSC) were measured as Brix% in fruit juice with a digital refractometer [23]. Titratable acidity (as malic acid) was determined in juice by titration with 0.1 N sodium hydroxide in the presence of phenolphthalein as indicator and the results were expressed as a percentage [24].

Respiration Rate (mg CO_2/kg fruit/hr): Carbon dioxide produced by plum fruits was determined after 10 hrs finished from treatments and then every 7 days during storage until experiment termination. The air-flow was passed through concentrated NaOH, to insure that air-flow is CO_2 free, before passing into 1-liter jar fruit container (fruit ambient) one fruit/jar was considered as one replicate. The out-coming air-flow was then passed into 100 ml NaOH of 0.1 N for 1 h. Such solution was then titrated against 0.1 N HCl and CO_2 levels produced by the fruits were then calculated as mg CO_2/kg fruits/h [23].

Anthocyanins Pigment Content (mg/100g F.wt): Total anthocyanins were extracted from one gram pulp fresh weight with 100 ml 0.1% methanolic HCL, the solution filtered and absorbency measured at 520 nm on Spekol 11 spectrophotometer [25].

Chilling Injury Symptoms (Electrolyte Leakage and Flesh Browning)

Electrolyte Leakage (% EC Leakage): Ten grams disks of the fruits tissues were placed in a 100-ml glass beaker containing 30 ml of deionized water and magnetic stirred for 15 min. Electrical conductivity (EC) of the stirrered solution was measured using electrical conductivity meter. Stirrered solution of each beaker was then replaced by equal volume (30 ml) of deionized water for homogenizing the disks in a blender and the aliquot was then used for measuring EC level as previously described. Percentage of solute leakage was then calculated as EC leakage using the following formula by Mirdehghan *et al*. [26]:

$$\text{EC leaking \%} = \frac{\text{EC of stirrered solution}}{\text{EC of stirrered solution} + \text{EC of homogenized disks}} \text{X } 100$$

The Browning Degree: (OD_{420}/gFW): The flesh sample was homogenized by 85% ethanol and the homogenates were centrifuged at 10,000×g for 15 min at 4°C and the absorbance of the supernatant was immediately measured at 420 nm, higher values of the absorbance at 420 nm correspond to higher browning of the tissue [27].

Statistical Analysis: Data were subjected to analysis of variance (ANOVA) using MSTAT-C software (MSTAT, Michigan University East Lansing). Duncan multiple rang test (LSR) was performed to determine any significant difference among various treatments. $p<0.05$ was selected as decision for significant differences) according to Steel *et al*. [28].

RESULTS AND DISCUSSION

Fruit Physical Analysis

Weight loss(%): Generally an observed increase in weight loss% with increasing time of storage with all treatments were noticed (Table 1) Potassium silicate (Si) concentrations (2500 and 5000 ppm) with packaging fruits in polyethylene line led to reduction of weight loss percentage under two different storage temperatures (0±1° C and 20 ±2°C).

Table 1: Effect of potassium silicate and MAP on weight loss percentage of pioneer plums under two different storage temperatures (0±1° C and 20±2°C) during 2012 and 2013 seasons.

	Days in cold storage (0±1°C)				Days in un-refrigerated storage (20 ±2°C)			
Treatments	7	14	21	28	7	14	21	28
Season 2012								
Control	0.79 a	1.47 a	2.25 a	3.07 ab	3.23 a	4.33 a	6.11 a	7.89 a
2500 ppm K_2SiO_3	0.59 b	1.05 b	1.67 b	2.19 c	1.73 c	2.49 c	3.45 d	4.92 de
5000 ppm K_2SiO_3	0.53 bc	1.00 b	1.48 bc	1.95 cd	1.54 c	2.39 c	3.30 d	4.23 e
10000 ppm K_2SiO_3	0.71 a	1.66 a	2.34 a	2.83 b	2.21 b	3.08 b	4.91 bc	6.11 bc
MAP	0.47 bc	0.81 bc	1.27 bc	1.78 cd	1.92 bc	2.54 c	4.20 c	5.79 cd
2500 ppm K_2SiO_3 + MAP	0.41 c	0.70 c	1.11 c	1.58 d	1.54 c	2.79 bc	3.90 cd	4.79 de
5000 ppm K_2SiO_3 + MAP	0.38 c	0.72 c	1.03 c	1.41 d	1.45 c	2.17 c	3.56 d	4.34 e
1000 ppm K_2SiO_3 + MAP	0.78 a	1.57 a	2.54 a	3.39 a	2.46 b	3.30 b	5.39 ab	7.04 ab
Season 2013								
Control	0.85 a	1.34 ab	2.61 a	3.97 a	3.17 a	5.86 a	6.54 a	8.10 a
2500 ppm K_2SiO_3	0.63 c	1.13 b	1.54 c	2.08 cd	1.96 b	2.45 c	3.70 c	5.04 cd
5000 ppm K_2SiO_3	0.62 c	1.29 ab	1.91 bc	2.17 bc	1.31 c	2.04 c	3.10 c	4.65 d
10000 ppm K_2SiO_3	0.70 bc	1.49 a	2.10 b	2.94 bc	2.00 b	3.36 b	4.19 b	6.04 b
MAP	0.56 cd	0.87 c	1.09 d	1.81 d	2.11 b	3.05 b	4.53 b	5.82 bc
2500 ppm K_2SiO_3 + MAP	0.48 d	0.73 c	0.90 d	1.36 d	1.77 c	2.26 c	3.13 c	4.96 cd
5000 ppm K_2SiO_3 + MAP	0.41 d	0.63 c	0.92 d	1.45 d	1.41 c	2.15 c	3.00 c	4.19 d
1000 ppm K_2SiO_3 + MAP	0.76 ab	1.40 a	2.75 a	3.11 ab	2.54 b	3.29 b	4.72 b	6.35 b

Values followed by the same letter (s) are not significantly different at 5% level

Table 2: Effect of potassium silicate and MAP on discarded fruits% of Pioneer plums under two different storage temperatures (0 ±1° C and 20 ±2°C) during 2012 and 2013 seasons

	Days in cold storage (0 ±1°C)				Days in un-refrigerated storage (20 ±2°C)			
Treatments	7	14	21	28	7	14	21	28
Season 2012								
Control	0.0	2.2 ab	11.0a	19.8a	0.0	13.2 a	22.0a	37.4a
2500 ppm K_2SiO_3	0.0	0.0b	0.0c	2.2d	0.0	4.4bc	11.0cd	13.2cd
5000 ppm K_2SiO_3	0.0	0.0b	2.2c	4.4d	0.0	0.0c	4.4e	8.8de
10000 ppm K_2SiO_3	0.0	2.2ab	11.0a	11.0bc	0.0	8.8b	15.4bc	26.4b
MAP	0.0	0.0b	4.4bc	8.8bc	0.0	6.6b	13.2c	19.8c
2500 ppm K_2SiO_3 + MAP	0.0	0.0b	0.0c	2.2d	0.0	2.2c	6.6de	13.2cd
5000 ppm K_2SiO_3 + MAP	0.0	0.0b	0.0c	6.6cd	0.0	0.0c	2.2e	6.6e
1000 ppm K_2SiO_3 + MAP	0.0	4.4a	8.8ab	13.2b	0.0	13.2a	19.8ab	33.0a
Season 2013								
Control	0.0	4.4a	15.4a	22.0a	0.0	15.4d	26.4a	39.2a
2500 ppm K_2SiO_3	0.0	0.0b	0.0c	0.0d	0.0	2.2c	8.8cd	13.2de
5000 ppm K_2SiO_3	0.0	0.0b	2.2c	4.4cd	0.0	0.0c	4.4d	11.0de
10000 ppm K_2SiO_3	0.0	0.0b	6.6b	13.2b	0.0	11.0b	17.6b	24.2bc
MAP	0.0	0.0b	2.2c	6.6c	0.0	8.8b	11.0c	17.6cd
2500 ppm K_2SiO_3 + MAP	0.0	0.0b	0.0c	2.2d	0.0	0.0c	4.4d	11.0de
5000 ppm K_2SiO_3 + MAP	0.0	0.0b	0.0c	4.4cd	0.0	0.0c	4.4d	8.8e
1000 ppm K_2SiO_3 + MAP	0.0	2.2ab	8.8b	15.4b	0.0	8.8b	19.8b	30.8b

Values followed by the same letter (s) are not significantly different at 5% level

Fruit fresh weight declined significantly faster in control and the highest concentration of Si than other Si-treated fruit, it is clear from data of the Table (7) which discussed letter an increase the respiration rate of these treatments. The 2500 and 5000 ppm Si application with packaging fruits in polyethylene under temperature (0 ±1°C) and 5000 ppm Si application with or without packaging fruits under temperatures (20±2°C) maintaining the highest weight. It is worth mentioning the lack respiratory rate of fruits in this treatment (Table 7 on respiration rate). When chilling injury occurs, the associated abnormal metabolism may be reflected in an increase in respiration rate of the damaged tissues causing microscopic cracks in the peel and pits. Such cracks enable a greater water loss from the fruit [29-31]

Discarded Fruits (%): Data in Table (2) show an evident increase in discarded fruits% with prolonging the days in two different storage temperatures irrespective of the used treatments. The control treatment recorded the

Table 3: Effects of potassium silicate and MAP on fruit firmness (Kgf) of Pioneer plums under two different storage temperatures (0 ±1° C and 20 ±2°C) during 2012 and 2013 seasons

	Days in cold storage (0±1°C)				Days in un-refrigerated storage (20 ±2°C)			
Treatments	7	14	21	28	7	14	21	28
Season 2012								
Control	7.3 a	5.7 c	4.1 d	2.2 e	4.8 c	3.5 d	2.7 d	1.3 d
2500 ppm K_2SiO_3	7.8 a	7.3 ab	6.5 a	5.1 ab	6.0 bc	4.9 bc	3.6 c	3.1 c
5000 ppm K_2SiO_3	7.6 a	7.2 ab	6.8 a	5.0 ab	7.1 a	6.0 a	4.9 a	4.2 a
10000 ppm K_2SiO_3	7.0 a	6.6 b	5.7 b	3.3 d	6.1 b	5.1 b	4.0 bc	3.6 b
MAP	7.5 a	6.9 b	5.3 bc	4.2 c	5.2 c	3.5 d	2.9 d	2.6 c
2500 ppm K_2SiO_3 + MAP	8.0 a	7.7 a	6.9 a	5.7 a	6.4 ab	4.8 bc	3.6 c	3.0 cd
5000 ppm K_2SiO_3 + MAP	7.7 a	6.5 bc	5.8 b	4.8 bc	6.7 ab	5.2 b	4.3 b	3.8 ab
1000 ppm K_2SiO_3 + MAP	7.4 a	5.9 c	4.7 cd	2.8 e	5.8 bc	4.4 c	3.5 c	1.7 d
Season 2013								
Control	7.1 a	6.0 ab	3.7 d	2.4 d	4.4 d	3.1 d	2.5 e	1.1 d
2500 ppm K_2SiO_3	7.3 a	6.5 a	5.8 a	5.0 ab	5.8 bc	3.8 cd	2.7 de	3.2 b
5000 ppm K_2SiO_3	7.5 a	6.3 a	5.6 ab	5.1 ab	6.9 a	5.7 a	4.9 ab	4.0 a
10000 ppm K_2SiO_3	7.0 a	5.1 c	4.2 cd	3.1 cd	5.3 cd	4.6 bc	3.9 c	3.3 b
MAP	7.3 a	6.0 ab	5.1 b	4.0 c	5.3 cd	4.2 c	3.2 cd	2.4 c
2500 ppm K_2SiO_3 + MAP	7.6 a	6.3 a	5.9 a	5.5 a	6.7 ab	5.2 b	4.5 b	3.3 b
5000 ppm K_2SiO_3 + MAP	7.6 a	6.7 a	5.4 ab	4.8 b	7.3 a	6.1 a	5.5 a	4.2 a
1000 ppm K_2SiO_3 + MAP	7.0 a	5.4 bc	4.6 bc	3.2 cd	4.6 d	3.4 d	2.5 e	1.9 c

Values followed by the same letter (s) in each column are not significantly different at 5% level

highest percentage of discarded fruits. At the end of storage, the highest percentage of discarded fruits was obtained with untreated fruit where it reached to about 19.8, 37.4, 22.0 and 39.2% discarded fruits under (0 ±1°C and 20 ±2°C) during 2012 and 2013 seasons respectively.

No significant differences were detected between 2500 ppm potassium silicate application at 0±1°C and 5000 ppm Si at 20 ±2 °C with or without packaging fruits in polyethylene line (MAP) which gave values ranged from 2.2 to 8.8%. The mechanical strength provided by Si to the plant tissues increases their resistance to several bacterial, fungi and insect diseases [17, 31, 14].

Fruit Firmness: Data presented in Table (3) show the change in fruit firmness of Pioneer plums as affected by some storage treatments. After 7 days, no significant differences were noticed between different treatments of storage at 0 ±1°C where it was ranged from 7.3 to 8.0 kilo gram force in the first season and ranged from 7.1 to 7.6 kilo gram force in the second season. Whereas significant differences appeared during storage at 20±2°C which ranged from 4.8 to 7.1 Kgf in the first season and ranged from 4.4 to 7.3 Kgf in the second season. The end of storage duration, potassium silicate treatments at 2500 ppm at cold storage with polyethylene packed fruit (MAP) and 5000 ppm at un-refrigerated storage (20 ±2°C) with or without MAP, achieved the highest fruit firmness values which recorded (5.7 and 3.8 & 4.2 Kg force) at first season and (5.5 and 4.2 & 4.0 Kg/ force) at the second season in the end period of storage respectively.

In contrast untreated fruits and the highest concentration of potassium silicate plus MAP caused a sharp decrease in fruit firmness with no significant differences between them which reached (2.2 and 2.8 Kg/ force) at cold storage and (1.3 and 1.7 Kg/ force) at 20±2°C during 2012, season respectively. From these data, it could be concluded that low concentrations of potassium silicate (2500 and 5000 ppm) with polyethylene line packed fruit were effective in minimizing fruits softening and consequently extended marketing life. Flesh firmness can be used as an index together with SSC to determine the appropriate developmental stage at which fruit can be more tolerant to manipulation but without compromising fruit flavour [32].

Si treatments showed alterations in the cell membrane structure. In Si treatments the cell membrane seemed to be dislodged from the middle lamella, leaving a space which seemed to be filled out, possibly with Si or K_2SiO_3. The relatively hardness of silicates provides a physical barrier to any pathogen. Several authors have shown an increase presence of Si (amorph silica) in cell walls after Si application which results in increased mechanical cell strength and deterioration of cell membranes could be prevented by Si application. Provision of physical barrier when Si is deposited underneath the cuticle to form a cuticle-Si double layer, thereby reducing stress susceptibility has been reported. Si can also increase antioxidant defence systems, thus facilitating plant resistance to stress [33-35].

Table 4: Effect of potassium silicate and MAP on sensory evaluation of Pioneer plums under two different storage temperatures (0 ±1° C and 20 ±2°C) during 2012 and 2013 seasons

	The end of cold storage (0 ±1°C)				The end un-refrigerated storage (20 ±2°C)			
Treatments	Freshness	Colour	Juiciness	hedonic Scale	Freshness	Colour	Juiciness	hedonic Scale
Season 2012								
Control	2.1 d	2.3 c	1.7 d	2.6 c	1.5 d	4.1 b	1.6 d	3.1 c
2500 ppm K_2SiO_3	4.4 ab	3.6 b	4.0 b	4.4 b	3.2 a	4.0 bc	3.6 b	4.0 ab
5000 ppm K_2SiO_3	4.0 bc	3.9 ab	4.2 b	4.7 ab	4.2 a	4.6 a	4.0 a	4.4 ab
10000 ppm K_2SiO_3	1.9 d	2.1 c	2.0 d	2.6 c	2.4 cd	3.9 c	2.2 d	2.4 d
MAP	3.7 c	3.7 ab	3.1 c	2.9 c	3.1 b	3.5 cd	2.9 c	1.9 d
2500 ppm K_2SiO_3 + MAP	4.6 a	4.0 ab	4.8 a	4.8 a	3.0 b	4.6 a	3.7 ab	3.7 b
5000 ppm K_2SiO_3 + MAP	4.0 bc	4.1 a	4.6 b	4.6 ab	3.9 a	4.4 ab	4.6 a	4.6 a
1000 ppm K_2SiO_3 + MAP	1.6 d	1.7 c	2.0 d	2.0 d	1.9 cd	3.0 d	1.6 d	1.8 d
Season 2013								
Control	2.0 d	2.5 c	1.8 c	2.8 b	1.6 d	4.3 ab	1.7 d	3.0 c
2500 ppm K_2SiO_3	4.5 ab	3.8 b	4.3 a	4.5 a	3.0 b	4.1 bc	3.4 c	4.2 ab
5000 ppm K_2SiO_3	4.2 bc	4.1 ab	4.0 a	4.5 a	4.5 a	4.7 a	4.2 ab	4.5 ab
10000 ppm K_2SiO_3	1.7 d	2.3 c	1.9 c	2.4 bc	2.3 c	4.0 bc	2.0 d	2.1 d
MAP	3.5 c	4.0 ab	3.3 b	3.0 b	3.3 b	3.4 cd	3.1 c	2.0 d
2500 ppm K_2SiO_3 + MAP	4.7 a	4.0 ab	4.5 a	4.7 a	3.2 b	4.4 ab	3.9 b	4.0 b
5000 ppm K_2SiO_3 + MAP	4.2 b	4.4 a	4.2 a	4.5 a	4.1 a	4.4 ab	4.5 a	4.7 a
1000 ppm K_2SiO_3 + MAP	1.8 d	2.0 c	1.6 c	1.9 c	2.0 cd	3.1 d	1.8 d	1.7 d

Values followed by the same letter (s) in each column are not significantly different at 5% level

Table 5: Effect of potassium silicate and MAP on soluble solids content of Pioneer plums under two different storage temperatures (0 ±1° C and 20 ±2°C) during 2012 and 2013 seasons

	Days in cold storage (0±1°C)				Days in un-refrigerated storage (20±2°C)			
Treatments	7	14	21	28	7	14	21	28
Season 2012								
Control	11.3 a	11.8 a	11.1 b	10.8 c	13.1 a	14.2 a	12.7 c	11.2 c
2500 ppm K_2SiO_3	10.9 a	11.6 a	12.7 a	13.6 a	12.6 ab	13.9 ab	15.1 a	15.0 a
5000 ppm K_2SiO_3	11.1 a	11.5 a	12.4 a	13.1 ab	12.1 ab	13.6 ab	15.1 a	15.3 a
10000 ppm K_2SiO_3	11.1 a	11.2 a	10.7 b	10.5 c	11.9 bc	12.6 bc	13.0 bc	12.8 b
MAP	11.5 a	11.9 a	12.6 a	12.0 b	12.0 bc	13.1a-c	14.3 ab	13.2 b
2500 ppm K_2SiO_3 + MAP	11.6 a	12.1 a	13.0 a	14.1 a	12.0 bc	13.2a-c	14.0 ab	15.1 a
5000 ppm K_2SiO_3 + MAP	11.4 a	11.8 a	12.7 a	13.1 ab	11.3 c	12.8 bc	14.2 ab	14.9 a
1000 ppm K_2SiO_3 + MAP	11.2 a	11.0 a	11.0 b	10.3 c	11.6 bc	12.3 c	12.0 c	11.8 c
Season 2013								
Control	11.9 a	12.5 a	12.1 bc	11.0 c	12.9 a	13.8 a	12.1b	10.9 c
2500 ppm K_2SiO_3	11.5 a	11.9 a	12.8 ab	13.7 a	12.5 a	13.0 ab	14.1 a	14.8 a
5000 ppm K_2SiO_3	11.5 a	11.8 a	12.5 ab	13.7 a	12.3 a	13.6a	14.6 a	15.1 a
10000 ppm K_2SiO_3	11.6 a	11.8 a	11.6 c	11.0 c	12.0 a	12.3b	11.8 b	11.6 bc
MAP	11.4 a	12.0 a	12.3 bc	12.3 b	12.0 a	13.1ab	12.6 b	12.2 b
2500 ppm K_2SiO_3 + MAP	11.7 a	12.1 a	13.5 a	13.9 a	12.1 a	13.1ab	14.3 a	15.3 a
5000 ppm K_2SiO_3 + MAP	11.5 a	12.0 a	13.1 ab	13.6 a	12.8 a	13.8a	15.0 a	15.6 a
1000 ppm K_2SiO_3 + MAP	11.3 a	11.5 a	11.4 c	10.1 c	12.1 a	12.4b	11.8 b	11.3 bc

Values followed by the same letter (s) in each column are not significantly different at 5% level

Sensory Evaluation: It is clear from data in (Table 4) that, sensory evaluation greatly affected by some storage treatments and temperature of plum fruits. The MAP fruits combination with 2500 ppm Si at cold storage or Si at 5000 ppm in (20 ±2°C), recorded the high (scores excellent) for fruits color, juiciness and taste during sensory evaluation compared with MAP plus treated fruits with high concentration of Si (10000ppm) under two temperatures which achieved moderate values without significant differences between them. The wrapped fruits alone exhibited the unacceptable for sensory evaluation i,e: desiccated fruits with brown tough peel, brown color, low juiciness and becoming dry appearance.

Fruit Chemical Analysis

Soluble Solid Content: Data in Table 5 show the change in soluble solid contents as affected by potassium silicate, MAP and storage temperatures. The soluble solid contents of all treated samples increased at the beginning of storage, reached a peak value later, however in some

Table 6: Effect of potassium silicate and MAP on titratable acids (Malic acid) of Pioneer plums under two different storage temperatures (0 ±1° C and 20 ±2°C) during 2012 and 2013 seasons

	Days in cold storage (0 ±1°C)				Days in un-refrigerated storage (20±2°C)			
Treatments	7	14	21	28	7	14	21	28
Season 2012								
Control	1.62 a	1.53 a	1.40a-c	1.46a	1.10b	0.82c	0.79a-c	0.94a
2500 ppm K_2SiO_3	1.63 a	1.44ab	1.31bc	1.10bc	1.20ab	0.96a-c	0.71c	0.67cd
5000 ppm K_2SiO_3	1.65 a	1.42b	1.26c	1.17bc	1.29ab	1.10a	0.70c	0.63d
10000 ppm K_2SiO_3	1.61 a	1.54a	1.56a	1.50a	1.29ab	0.98a-c	0.85ab	0.86ab
MAP	1.60 a	1.48ab	1.33bc	1.20b	1.16b	0.92bc	0.77bc	0.84b
2500 ppm K_2SiO_3 + MAP	1.65 a	1.41b	1.20c	1.07c	1.27ab	1.03ab	0.82b	0.67cd
5000 ppm K_2SiO_3 + MAP	1.62 a	1.46b	1.28c	1.13bc	1.34a	1.14a	0.80ab	0.72c
1000 ppm K_2SiO_3 + MAP	1.62 a	1.56a	1.49ab	1.51a	1.18b	0.87bc	0.89a	0.86ab
Season 2013								
Control	1.38 a	1.23ab	1.01c	1.30a	1.16b	0.90b	0.96a	1.05a
2500 ppm K_2SiO_3	1.33 a	1.11b	0.97c	0.91c	1.20ab	1.03ab	0.82bc	0.72cd
5000 ppm K_2SiO_3	1.40 a	1.21ab	1.05bc	0.97c	1.34a	0.97ab	0.90ab	0.65d
10000 ppm K_2SiO_3	1.35 a	1.30a	1.30a	1.26a	1.30ab	1.10a	0.87ab	0.90b
MAP	1.37 a	1.20ab	1.17ab	1.12b	1.20ab	0.93ab	0.90ab	0.85b
2500 ppm K_2SiO_3 + MAP	1.31 a	1.15b	0.96c	0.90c	1.16b	0.95ab	0.83bc	0.71cd
5000 ppm K_2SiO_3 + MAP	1.30 a	1.23ab	1.05bc	0.90c	1.21ab	0.91b	0.79c	0.74c
1000 ppm K_2SiO_3 + MAP	1.36 a	1.30a	1.24a	1.17b	1.17b	1.03b	0.89ab	0.92b

Values followed by the same letter (s) in each column are not significantly different at 5% level

treatments finally decreased. The soluble solid content for treatment peaked with silicon application at 2500 and 5000 ppm increased quickly during two storage days. Respiration is a major factor contributing to post-harvest losses, which converts stored soluble solid (sugar mainly) into energy in the presence of an oxygen substrate [36].

Titratable Acidity: The main acid present in plum is malic acid and its level decreases during ripening. TA plays a significant role in consumer acceptance [37].

Data tabulated in Table (6) show that, generally, it could be noticed that titratable acidity decreased in all treatments under two storage temperatures even up to 21 days. The end of storage period,TA content was heights in control and 10000 ppm Si treated fruit plus MAP than other treated fruits in both storage temperatures, this may strongly due to the accumulation of middle respiratory metabolite. The lowest values of TA (1.07 and 0.72%) in first season detected in fruits treated with Si at 2500 and 5000 ppm plus MAP at 0 ±1° C and 20 ±2°C. Regarding the second season, the obtained results were similar to those found in the first one.

Respiration rate (mg CO_2/kg fruit/hr): The changes in respiration rates of Pioneer plums stored in MAP with and without silicon at 0±1° C or 20±2°C were shows in Table (7). The initial respiration rates were high, reaching 10.57 mg CO_2/kg/h, followed by lower levels that lasted 7 days at cold storage. Meanwhile respiration rate of plums stored at 20 ±2°C increased with storage time. The increase in the respiration rates at cold storage was likely a result of the chilling injury where noticed with untreated and treated fruit by Si at 10000 ppm ± MAP which gave the high rate without significances differences among them.The rate of oxidation relative to glycolysis which may lead to the accumulation of an intermediate respiratory substances to toxic levels or fermentation causing chilling injury development [31].

Plums stored in MAP alone or treated with silicon exhibited the lowest values of respiration rate while maintaining the high quality. Regarding the un-refrigerated storage (20 ±2°C) the results showed that untreated or Si treated fruits by 10000 ppm ± MAP exhibited an increase in respiration rate whereas treated fruits with silicon at 5000 ppm with or without MAP recorded the least respiration rate and the lowest electrolyte leakage

Anthocyanins Pigment Content (mg/100g fresh weight): It is clear that, anthocyanins content was increased gradually through storage in treated or untreated fruits (Table 8). Clear changed were observed during the two storage temperatures (0 and 20°C) among all used treatments. However, untreated fruit and Si- treated fruit at 10000 ppm alone or plus MAP recorded the lest values of anthocyanins content which give (40.6 & 46.8 and 50.1

Table 7: Effect of potassium silicate and MAP on respiration rate (mg CO_2/kg fruit/hr) of Pioneer plums under two different storage temperatures (0 ±1° C and 20 ±2°C) during 2012 and 2013 seasons

	Days in cold storage (0 ±1°C)				Days in un-refrigerated storage (20 ±2°C)			
Treatments	7	14	21	28	7	14	21	28
Season 2012								
Control	2.75 a	3.11 a	3.75 a	5.08 a	9.4 a	11.30 a	12.60 a	14.11ab
2500 ppm K_2SiO_3	2.00 bc	2.05bc	2.19 c	2.75 c	8.7 a	9.25 c	10.30bc	11.67c
5000 ppm K_2SiO_3	1.94 c	2.51 ab	2.82 b	2.65 c	9.05 a	9.20 c	9.18 c	9.64 d
10000 ppm K_2SiO_3	2.11 a	2.11 bc	3.04 ab	4.20 b	9.41 a	10.56ab	12.70 a	14.64ab
MAP	1.85 c	1.82 c	1.97 c	2.13 c	8.39 a	9.16 c	12.86 a	13.20bc
2500 ppm K_2SiO_3 + MAP	1.74 c	1.92 bc	2.23 bc	2.25 c	9.22 a	9.94 bc	10.45 b	11.40c
5000 ppm K_2SiO_3 + MAP	1.96 c	2.14 bc	2.70 b	2.61 c	9.08 a	9.73 bc	9.90 bc	9.10d
1000 ppm K_2SiO_3 + MAP	2.67 ab	2.60 ab	3.58 a	4.79 ab	9.62 a	11.20 a	13.15 a	15.20a
Season 2013								
Control	3.14a	2.98ab	3.59ab	4.68ab	9.80ab	11.73ab	14.16a	15.32ab
2500 ppm K_2SiO_3	2.56bc	2.74ab	2.60c	3.25c	9.51ab	10.08c	10.56bc	10.84c
5000 ppm K_2SiO_3	2.68ab	2.81ab	2.80bc	3.06c	9.12b	9.67c	10.43bc	11.11c
10000 ppm K_2SiO_3	2.96a	3.10a	3.97a	4.15b	9.83ab	10.76bc	13.11a	15.36ab
MAP	2.32bc	2.40b	2.26c	2.49c	9.43ab	9.20c	11.92b	13.87b
2500 ppm K_2SiO_3 + MAP	2.10c	2.65ab	2.93bc	2.89c	9.20b	10.50bc	11.00bc	11.06c
5000 ppm K_2SiO_3 + MAP	2.00c	2.54b	2.91bc	2.95c	9.11b	9.63c	10.22c	10.36c
1000 ppm K_2SiO_3 + MAP	2.76ab	2.96ab	3.76a	5.32a	10.31a	12.16a	14.20a	16.10a

Values followed by the same letter (s) in each column are not significantly different at 5% level

Table 8: Effect of potassium silicate concentrations and MAP on anthocyanins pigment content of pioneer plums under two different storage temperatures (0 ±1° C and 20 ±2°C) during 2012 and 2013 seasons

	Days in cold storage (0±1°C)				Days in un-refrigerated storage (20±2°C)			
Treatments	7	14	21	28	7	14	21	28
Season 2012								
Control	28.1 a	33.4 bc	41.6 c	47.6 c	40.5 ab	73.2 a	87.6 a	71.9 d
2500 ppm K_2SiO_3	26.6 a	35.6 b	49.7 b	60.8 ab	34.8 cd	60.8 b	71.4 cd	91.5 a
5000 ppm K_2SiO_3	25.4 a	31.7 c	52.8 ab	62.5 ab	34.0 cd	57.5 bc	67.8 d	90.4 a
10000 ppm K_2SiO_3	26.7 a	32.0 c	39.1 c	46.8 c	31.4 d	40.7 e	53.9 e	70.0 d
MAP	27.3 a	40.0 a	50.8 ab	57.1 b	41.7 a	67.5 a	83.6 a	76.5 c
2500 ppm K_2SiO_3 + MAP	28.4 a	40.5 a	53.3 a	64.3 a	36.1 bc	52.7 c	76.3 bc	90.1 a
5000 ppm K_2SiO_3 + MAP	28.6 a	41.6 a	50.1 ab	60.7 ab	32.9 cd	46.5 d	77.8 b	92.3 a
1000 ppm K_2SiO_3 + MAP	27.0 a	32.9 bc	42.7 c	50.1 c	30.6 d	41.0 de	59.4 e	68.7 d
Season 2013								
Control	30.0 a	34.1 c	38.7 d	50.1 c	42.5 a	67.5 a	80.4 a	73.6 cd
2500 ppm K_2SiO_3	27.4 a	33.8 c	45.9 c	67.1 a	35.6 bc	58.7 bc	75.3 ab	93.1 a
5000 ppm K_2SiO_3	27.1 a	40.1 a	47.6 bc	63.9 a	33.4 c	53.8 cd	70.9 c	94.5 a
10000 ppm K_2SiO_3	29.6 a	35.6 c	41.7 d	48.3 d	39.1 ab	49.6 d	61.5 d	68.5 d
MAP	28.4 a	36.8 bc	50.4 ab	60.1 b	40.8 a	59.6 b	78.9 ab	80.5 b
2500 ppm K_2SiO_3 + MAP	28.7 a	33.7 c	49.6 ab	65.5 a	35.9 bc	55.7 bc	70.3 c	94.7 a
5000 ppm K_2SiO_3 + MAP	27.8 a	38.9 ab	51.5 a	63.8 a	33.7 c	56.8 bc	72.8 bc	90.5 a
1000 ppm K_2SiO_3 + MAP	27.6 a	34.0 c	45.8 c	53.2 c	38.5 ab	48.1 d	61.4 d	74.4 c

Values followed by the same letter (s) in each column are not significantly different at 5% level

Table 9: Effects of potassium silicate and MAP on electrolyte leakage% (EC) of Pioneer plums under two different storage temperatures (0 ±1° C and 20 ±2°C) during 2012 and 2013 seasons

	Days in cold storage (0±1°C)				Days in un-refrigerated storage (20±2°C)			
Treatments	7	14	21	28	7	14	21	28
Season 2012								
Control	9.0 a	19.7 a	25.8 ab	35.1 a	16.9 a	25.4 a	33.5 a	40.5 a
2500 ppm K_2SiO_3	8.9 a	13.4 c	17.2 cd	18.3 de	13.0 bc	19.1 bc	22.6 bc	30.0 bc
5000 ppm K_2SiO_3	8.5 a	14.0 c	16.1 cd	19.7 de	11.7 c	18.0 bc	21.0 bc	27.0 c
10000 ppm K_2SiO_3	9.2 a	17.5 ab	23.6 b	30.4 b	13.5 bc	20.7 b	32.7 a	40.5 a
MAP	8.7 a	15.4 bc	20.0 c	25.2 c	15.2 ab	23.6 a	30.7 a	34.3 b
2500 ppm K_2SiO_3 + MAP	9.0 a	12.2 c	14.5 d	17.6 e	14.0 bc	19.0 bc	23.8 b	26.9 c
5000 ppm K_2SiO_3 + MAP	8.6 a	13.0 c	16.8 cd	22.7 cd	12.6 bc	16.9 c	20.5 c	25.3 d
1000 ppm K_2SiO_3 + MAP	8.9 a	20.1 a	28.4 a	33.2 ab	13.2 bc	25.7 a	30.6 a	43.7 a
Season 2013								
Control	9.3 a	16.5 ab	27.3 a	36.7 a	17.5 a	23.9 a	38.7 a	45.1 ab
2500 ppm K_2SiO_3	9.0 a	14.1 bc	16.5 de	20.1 cd	12.9 cd	18.8 bc	21.5 c	30.6 d
5000 ppm K_2SiO_3	9.1 a	13.8 bc	17.1 de	20.5 cd	10.5 d	16.3 cd	19.8 c	24.9 e
10000 ppm K_2SiO_3	9.0 a	16.7 ab	22.5 bc	28.7 b	14.1 bc	24.4 a	35.7 a	42.5 b
MAP	9.0 a	15.0 ab	20.1 cd	24.8 c	16.0 ab	20.9 b	28.0 b	36.7 c
2500 ppm K_2SiO_3 + MAP	8.9 a	12.1 c	13.9 e	18.6 d	13.1 bc	17.6 cd	20.3 c	29.1 de
5000 ppm K_2SiO_3 + MAP	9.0 a	14.8 bc	20.8 c	24.1 c	11.3 cd	15.6 d	19.2 c	27.5 de
1000 ppm K_2SiO_3 + MAP	9.2 a	17.9 a	25.0 ab	30.7 b	14.0 bc	26.5 a	36.0 a	46.8 a

Values followed by the same letter (s) in each column are not significantly different at 5% level

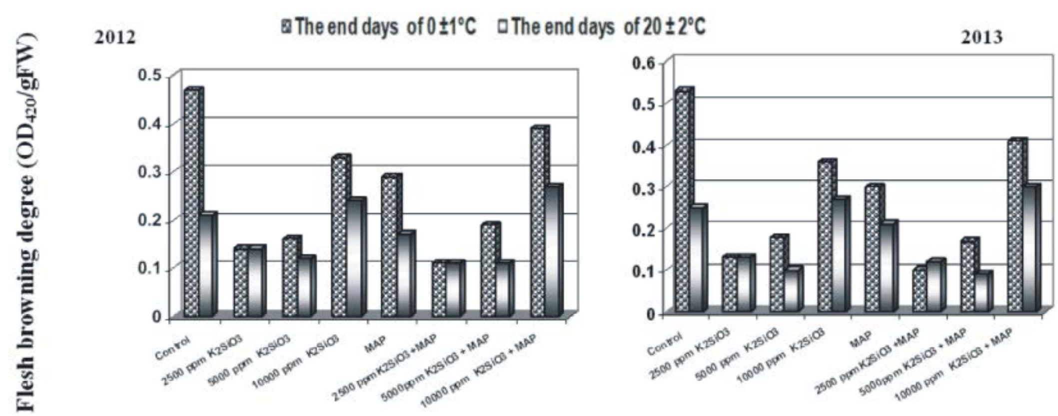

Fig. 1: Effect of potassium silicate concentrations and MAP on flesh browning degree of Pioneer plums at the end of storage (28 days) at (0 ±1° and 20 ±2°C) during 2012 and 2013 seasons

mg/100g F.wt) and (71.9 & 70.0 and 68.7 mg/100g F.wt) at 0 and 20°C, respectively. Dipping fruit for 2500 ppm Si plus packed of cold storage and dipped fruit for 2500 and 5000 ppm Si ± packed of un-refrigerated storage (20±2°C) gave the highest values of pigment anthocyanins content.

Chilling Injury Symptoms

Electrolyte Leakage% (EC): Storage at 0 ±1°C increases the manifestation of CI symptoms probably because the symptoms observed are associated with fruit physiological responses that could still at a relatively high temperature during storage at 20 ±2°C [6].

The leakage increased with the increasing storage time for all treatments, suggesting that membrane systems became more vulnerable to leakage. Tao *et al*. [38].

Storage temperature and the absence of silicon contributed to increases in the relative electrolyte leakage, which were also observed by Nourian *et al*. [36].

The relative cell membrane permeability in untreated and treated fruit with Si at 10% ± MAP during cold storage increased considerably from the 14^{th} storage day until the end of storage most likely due to chilling injury. Chilling injury is associated with changes in proteins [39]. and membrane structure that lead to increased permeability and ion leakage [40-42].

Plums stored in MAP without silicon caused physiological damage, which can explain that the relative cell membrane permeability higher than plum stored in MAP with 2500 and 5000 ppm silicon recorded the lower value of solute leakage. The relative cell membrane permeability of plums stored at cold storage had the fastest increase, whereas fruits stored at(20 ±2°C) had the slowest increase.

Cell membrane is a chilling sensitive compounded of the fruit cell. Several metabolic enzymes are membranes bound. When fruit chilled, membrane deteriorate and a sudden drop in the activity of membrane bound enzyme will be obtained as a result, the substrate of such enzymes (middle metabolites) will accumulate causing chilling injury development. With chilling injury, membrane permeability considerably increased due to its deterioration allowing more solute leakage. Electrolyte leakage increased significantly in chilled fruits [43, 44]. The chilling of sensitive fruit has increased membrane permeability [45].

Browning Degree (OD_{420}/gFW): The browning degree had a sharp increase with control and Si at 10000 ppm but decreased in MAP packaged fruits. The lowest level of browning degree was noticed by Si at 2500 and 5000 ppm ± MAP packaging under two storage temperatures.

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