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Physiological and Pathological Impacts of Potassium Silicate on Storability of Anna Apple Fruits

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ABSTRACT

Exogenous application of silicon (Si) in the form of potassium silicate at different concentrations (0.1, 0.2 and 0.3%) were investigated for maintaining quality and control disease development caused by *Penicillium expansum* on Anna apple fruits stored 60 days at 0°C±1 with 90-95% R.H (Experiment 1) and held for 6 days at room temperature conditions at 28°C±2 with 65-70% R.H (Experiment 2). It was noticed that the reduction in linear growth and dry weight were positively correlated to the increase in potassium silicate concentrations. So, potassium silicate at 0.3% treatment indicated complete inhibition of the linear growth and dry weight of *P. expansum.* The disease infection decreased as storage period advanced at cold storage and under marketing conditions. The lowest significant values of disease infection percentage of *P. expansum* were recorded by dipping fruit at potassium silicate at 0.3% after 60 days of cold storage and 6 days at marketing in the two seasons. Generally, significant changes were observed in potassium silicate at 0.3% which reduced the loss of weight, decay, total loss, respiration rate and PPO activity with respect to the other treatments or the control. Meanwhile, potassium silicate at 0.2% gave a higher fruit firmness. In addition, all silicon treatments reduced SSC, acidity, SSC/acid ratio and total sugar compare to the untreated fruits. The values of hue angle increased with the progress of potassium silicate concentration. These results show that potassium silicate can be used to delay ripening, keep quality and control disease development caused by *P. expansum* on apple fruits.

Key words: Anna apple, potassium silicate, cold storage, marketing conditions, *Penicillium expansum*, respiration rate

INTRODUCTION

Anna apple variety is considered as a hybrid between Red Hadassiya and Golden Delicious. Anna is one of the leading apple cultivars in Egypt, considered the standard in low-chilling apples. The limited shelf-life of the fruits is related to rapid softening and also to the tendency to bruise and brown easily. Postharvest pathogens cause major losses in apple production. More than 90 fungal species have been described as causative agents of apple decay during storage (Pianzzola *et al*., 2004).

Blue mould caused by *P. expansum* is destructive postharvest disease of apples. This disease causes shortage of shelf-life and economic loss of apple. The use of synthetic fungicides is a primary

method of control for this disease. However, concerns about public health and the development of resistant pathogens have increased the need to search for alternative methods (Gholamnejad *et al*., 2009).

Silicon (Si) is the second richest element found on the surface of the earth's crust and its content in plants is 0.1-10% of their dry weight (Liang *et al*., 2008). Silicon applications might become an alternative to currently used fungicides. Silicon has been used to minimize the adverse effects of biotic and abiotic stresses on various fruit crops by stimulating defense reaction mechanisms (Brecht *et al*., 2003). Also, excess of Si has no toxic reports so far (Ma and Yamaji, 2006).

The concentrations of silicon especially combination with hot water, affects apple's responses towards *P. expansum* and it could be an important method for control of apple blue mould (Etebarian *et al*., 2013).

There is much experimental evidences suggesting that Si affects the activity of major antioxidant enzymes, involved in plant stress defense systems (Epstein, 2009). Depositions of Si into epidermal cells may form an effective mechanical barrier against fungal penetration. Plants harden physically as a result of Si accumulation resulting in additional protection, preventing fungi from entering plant cells (Bosse *et al*., 2011). Farahani *et al*. (2012), used three concentrations of silicon (Si) at 0.1, 0.3 and 0.5% against apple blue mould caused by *P. expansum* and proposed two mechanisms for Si-enhanced resistance to diseases, inwhich Si can act as a physical barrier as it is deposited beneath the cuticle to form a cuticle-Si double layer, while it also acts as a modulator of host resistance to pathogens.

Potassium silicate the most commonly used form of Si was therefore applied in order to determine whether such practice could increase the concentration of antifungal compounds and/or the enzyme PAL to be able to increase the concentration of phenolic compounds present at later ripening stages in order to decrease disease incidence.

Potassium silicate is a source of highly soluble potassium and silicon. It is used in agricultural production systems primarily as a silica amendment and has added the benefit of supplying small amounts of potassium.

Kaluwa *et al*. (2010) used different sources of silicon (potassium silicate, Nontox-silica, calcium silicate, sodium metasilicate and Biosilicate) as post-harvest dips at 2940 ppm on avocado fruits and found that potassium silicate seem to be most beneficial to maintain avocado fruit quality, probably due to a suppression of respiration and a reduction in ethylene evolution. Moreover, recent post-harvest studies on avocado have proved, Si to be a safe and effective antioxidant source (Tesfay *et al*., 2011). Mditshwa *et al*. (2013) investigated the ability of K_2SiO_3 dips at 50, 150 and 250 mg L^{-1} solutions for 30 min to reduce fruit weight loss and enhance the phenolic content in order to reduce the incidence of chilling injury in lemon fruit.

The objective of this study was to evaluate the use of potassium silicate to extend storability, delay ripening, maintain fruit quality and enhance systemic resistance of Anna apple fruits during cold storage and marketing at room temperature. Also, the effects on the sensory, physical, chemical, pathological and physiological characteristics were examined.

MATERIALS AND METHODS

Isolation and identification of the pathogen: *Penicillium expansum* was isolated from naturally infected Anna apple fruits. This isolate was the most aggressive one in our collection and produced the largest lesions on inoculated fruits. These fungi were purified and maintained on Potato Dextrose Agar (PDA) and stored at 4°C, with periodic transfers through citrus fruits to maintain its aggressiveness. Seedless grape were ready for examination under a stereoscopic binocular microscope (6-50 X) for the presence of fungi and to study their habit characters. When

necessary the compound microscope was used for confirming the identification after examining the morphology of conidia and conidiophores. Fungi were identified by means of comparison with the description sheets of Commonwealth Mycological Institute, Kew, Surrey, England (CMI), Danish Government Institute of Seed Pathology (DGISP) publications as well as publications of Ellis (1971) and Singh *et al.* (1991).

Effect of potassium silicate on growth of fungi isolated from Anna apple fruits and disease infection percentage

Linear growth: Potassium silicate was tested *in vitro* on the linear growth of the pathogenic fungi. Different concentrations were added to 10 mL of sterilized PDA before solidification and then poured in sterile petri-dishes. After solidification, the plates were inoculated with fungal disc (5 mm) in the center of the plate and incubated at 27±1°C. Three plates for each particular treatment for each fungus were used as replicates; three plates were prepared to serve as control for each fungus. Linear growth was observed daily and diameter of fungal colonies were recorded when plates of any treatment were filled with the fungal growth.

Dry weight: One hundred milliliter of liquid PD medium in 250 mL Erlenmeyer flasks were amended with different concentrations of the tested compounds after autoclaving. Each flask was inoculated using two discs of 0.6 mm in diameter of fungal culture and then incubated at 20±2°C for 7 days. Control flasks without any concentration of these compounds. Three replicates were used for each concentration. At the end of incubation period, the mycelium was filtered off and washed several times with distilled water, then dried in an oven at 80°C for 48 h till constant weight (El-Morsy, 1993).

Field study: This study was carried out during the two successive seasons of 2012 and 2013 on Anna apple fruits to evaluate the effect of potassium silicate as a post-harvest treatment for keeping quality of Anna apple fruits under cold storage condition and marketing at room temperature. Fruits were picked from trees about five years old, grown in sandy soil in a private orchard at EL-Khatatba city, Monifia, Governorate. These trees were healthy and similar in their vigor as possible and were treated with common agriculture practices in both seasons. Mature apple fruits were picked when the red color reached over 50%, fruit firmness was about 11-12% according to Drake and Kupferman (2000). Selected fruits were directly transported to the Laboratory and defective fruits were almost equal in size and apparently insect and pathogen injury free. At the beginning of the experiments, samples of 15 fruits were taken to determine the initial fruit properties and then received the following treatments:

- Dipping fruit with potassium silicate (K_2SiO_4) 0.1% for 5 min
- Dipping fruit with potassium silicate (K_2SiO_4) 0.2% for 5 min
- Dipping fruit with potassium silicate (K_2SiO_4) 0.3% for 5 min
- Control (Dipping fruits in tap water) for 5 min

Fruits of all treatments were sorted to remove any infected and damaged and then stored in perforated plastic bags (each contain 5 fruits). All bags with fruits were weighted and every three bags were put in ventilated carton box.

Experiment 1: For storage study, fruits of each treatment were stored 60 days at 0±1°C with 90-95% R.H and then the fruits were taken 20 days intervals to determine fruits characteristics.

Experiment 2: For marketing study, fruits for each treatment were held 6 days at room temperature conditions at 28±2°C with 65-70% R.H and then fruits were taken 2, 4 and 6 days intervals to determine the following parameters.

Disease infection: It was determined according to the following equation:

$$\text{Disease infection } (\%) = \frac{\text{No. of naturally infected fruits}}{\text{No. of total fruits}} \times 100$$

Effect of potassium silicate on Anna apple fruits quality: It was determined by the follwing factors.

Loss in fruit weight: It was determined according to the following equation:

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

Decay: It was determined according to the following equation:

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

Total loss in fruit (%): Following equation is used to determine the percentage of total loss in fruits:

$$\text{Total loss in fruit } (\%) = \text{Loss weight } (\%) + \text{Decayed fruits weight } (\%)$$

Respiration rate (mg CO_2 kg^{-1} h^{-1}): Carbon dioxide produced by apple fruits was determined as mg CO_2 kg^{-1} h^{-1} according to AOAC (1970).

Skin hue color: Skin color was measured using 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 (1992).

Fruit firmness (Ib $inch^{-2}$): It was determined on the two opposite sides of fruit using a hand Effegi-Penetrometers and the average was estimated as Ib $inch^{-2}$.

Soluble solids content (SSC%): Soluble solids content in fruit juice was measured using a Carl-Zeiss hand refractometer according to AOAC (2005).

Titratable acidity (TA%): It was determined in10 mL of fruit juice as a percentage of malic acid according to AOAC (2005).

SSC/acid ratio (%): It was calculated by dividing the value of SSC over the value of titratable acidity of each sample.

Polyphenol oxidase (PPO): The specific activity was expressed as unit per milligram according to Meng *et al.* (2008).

Total sugar (%): The extract was prepared by taking 0.5 g of fresh pulp and extracting with 80% ethanol according to Ranganna (1979).

Total starch: Starch content was calculated with starch-iodine test according to Generic chart scores (1-8), where 1 represents the least and 8 the highest starch scores.

Statistical analysis: Data of both seasons of the study were analyzed using Analysis of Variance (ANOVA) technique. Differences among treatment means were statistically compared using Duncan's multiple range tests at a level of 0.05 using the CoStat v6.4 program.

RESULTS

Effect of potassium silicate on linear growth (cm), dry weight (g) of fungi isolated from Anna apple fruits and percentage disease infection as post-harvest treatments: Data in Table 1 indicated that the effect of treatments by dipping with potassium silicate on linear growth and dry weight of *P. expansum* isolated from Anna apple fruits. It was also noticed that the reduction in linear growth and dry weight were positively correlated to the increase in potassium silicate concentrations. Potassium silicate at 0.3% treatment showed complete inhibition of the linear growth and dry weight of *P. expansum*.

The disease infection at cold storage and 6 days during marketing are presented in Table 2. The data showed that, the disease infection decreased as storage period advanced under cold storage

Table 1: Effect of potassium silicate on linear growth (cm) and dry weight (g) of fungi isolated from Anna apple fruits

	Penicillium expansum	
Treatments	Linear growth (cm)	Dry weight (g)
Potassium silicate 0.1%	5.63b	0.71b
Potassium silicate 0.2%	2.96c	0.39c
Potassium silicate 0.3%	0.00d	0.00d
Control (water)	9.00a	1.86a

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

Table 2: Effect of potassium silicate on disease infection during cold storage and under market conditions during 2012 and 2013 seasons

	Cold storage (days)				Marketing 6 days at room temperature			
Treatments	0	20	40	60	0	2	4	6
Season 2012								
Potassium silicate 0.1%	0.00n	2.96l	7.69h	11.61f	0.00n	4.02k	9.17g	13.77d
Potassium silicate 0.2%	0.00n	2.18m	4.60j	6.53i	0.00n	2.35lm	4.98j	7.93h
Potassium silicate 0.3%	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n
Control	0.00n	4.52jk	12.94e	26.57b	0.00n	6.14i	15.28c	29.67a
Season 2013								
Potassium silicate 0.1%	0.00m	2.58l	5.71i	9.13f	0.00m	3.47k	7.91g	11.87d
Potassium silicate 0.2%	0.00m	2.08l	4.34j	5.70i	0.00m	2.03l	4.29j	6.84h
Potassium silicate 0.3%	0.00m	0.00m	0.00m	0.00m	0.00m	0.00m	0.00m	0.00m
Control	0.00m	3.96jk	10.29e	23.87b	0.00m	5.29i	13.18c	25.58a

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

and during marketing at room temperature. Thus, all the applied treatments reduced the disease infection than the control. Since, the percentage of disease infection of the untreated fruits were 26.57 and 23.87% after 60 days of cold storage and reached 29.67 and 25.58% as marketing in the both seasons, respectively. The lowest significant values of disease infection percentage of *P. expansum* were recorded by dipping fruit at potassium silicate at 0.3% ranged 0.00% in both seasons after 60 days of cold storage and 6 days of marketing in the two seasons.

Effect of potassium silicate on characteristics of Anna apple fruits under cold storage and through marketing at room temperature

Loss in fruit weight percentage: The loss in weight of Anna apple fruits at cold storage and 6 days during marketing are presented in Table 3. The data reveal that, the loss in fruit weight increased as storage period advanced under cold storage and in the second experiment, at room temperature. Thus, 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 10.22 and 11.04% after 60 days of cold storage and it were 6.73 and 6.79% in the second experiment, after six days as marketing in both seasons, respectively. The lowest significant values of weight loss percentage were recorded by dipping fruits in potassium silicate at 0.3% ranged 3.20 and 3.90% after 60 days of cold storage and it were 2.91 and 3.10% after 6 days of marketing in the two seasons, respectively.

Decay percentage: It is clear from Table 1 that all dipping treatments did not present any decayed fruits till 20 days of cold storage through both seasons. Since, all treatments significantly reduced the percentage of decayed fruits than the untreated fruits either after 60 days of cold storage or 6 days during marketing in the second experiment at room temperature in both seasons. Thus, the percentage of decayed fruits for the control were 27.23 and 28.41% after 60 days of cold storage but it reached about 18.94 and 19.10% through marketing in the second experiment in both seasons. Yet, dipping Anna apple fruits in potassium silicate at 0.3% significantly reduced decay percentage than all treatments applied after 60 days of cold storage (5.10 and 5.54%) however it were 6.00 and 6.20% during marketing in both seasons, respectively.

Total loss (%): Total loss in fruit weight is mainly due to loss in fruit weight and decay percentages are presented in Table 1. It is clear from this table that dipping Anna apple fruits in potassium silicate at 0.3% significantly reduced the percentage of total loss in fruit weight in both seasons than the other treatments or the control. Since, potassium silicate at 0.3% presented about 8.30% and 9.44%, respectively, after 60 days of cold storage whereas, the loss percentage reached 8.91 and 9.30% after 6 days at room temperature in the second experiment as mean of two seasons, respectively.

Moreover, the percentage of total loss in fruit weight was gradually increased during cold storage or at marketing as storage period advanced. Since, the percentage of total loss of the untreated fruits were about 37.45 and 39.45% after 60 days of cold storage but reached 25.67 and 25.89% when held 6 days at room temperature in the second experiment as mean of both seasons.

Respiration rate (mg CO_2 kg^{-1} h^{-1}): Results of Table 4 show that, all evaluated treatments succeeded in reducing respiration rate of Anna apple fruits during durations in comparison with

Table 3: Effect of potassium silicate on weight loss, decay and total loss percentage of Anna apple fruits during cold storage and under market conditions during 2012 and 2013 seasons

Treatments at different storage periods (days)	Cold storage			Marketing 6 days at room temperature		
	Loss weight (%)	Decay (%)	Total loss (%)	Loss weight (%)	Decay (%)	Total loss (%)
Season 2012						
Potassium silicate 0.1%						
0	0.00l	0.00g	0.00l	0.00j	0.00l	0.00l
20	2.11j	0.00g	2.11j	2.00h	5.21i	7.21i
40	3.93f	5.13f	9.06f	3.70e	10.13f	13.83f
60	6.13c	13.00d	19.13d	4.41c	12.19d	16.60d
Potassium silicate 0.2%						
0	0.00l	0.00g	0.00l	0.00j	0.00l	0.00l
20	2.29i	0.00g	2.29i	2.10g	5.10j	7.20i
40	4.17e	6.27e	10.44e	3.95d	10.24e	14.19e
60	7.00b	15.12b	22.12b	4.60b	12.90c	17.50c
Potassium silicate 0.3%						
0	0.00l	0.00g	0.00l	0.00j	0.00l	0.00l
20	1.96k	0.00g	1.96k	1.72i	0.00l	1.72k
40	2.34i	0.00g	2.34i	2.09gh	4.49k	6.58j
60	3.20h	5.10f	8.30g	2.91f	6.00h	8.91h
Control						
0	0.00l	0.00g	0.00l	0.00j	0.00l	0.00l
20	3.58g	0.00g	3.58h	3.00f	9.18g	12.18g
40	6.02d	14.27c	20.29c	4.33c	10.04b	18.37b
60	10.22a	27.23a	37.45a	6.73a	18.94a	25.67a
Season 2013						
Potassium silicate 0.1%						
0	0.00m	0.00h	0.00k	0.00k	0.00l	0.00l
20	2.24k	0.00h	2.17i	2.00i	5.44i	7.44i
40	4.40f	8.90e	13.30e	4.48e	9.54f	14.02f
60	6.59c	13.39d	19.98d	4.63d	13.10d	17.73d
Potassium silicate 0.2%						
0	0.00m	0.00h	0.00k	0.00k	0.00l	0.00l
20	2.49j	0.00h	2.49h	2.16h	5.10j	7.26j
40	4.48e	8.73f	13.21e	4.74c	10.10e	14.84e
60	7.30b	15.43b	22.73b	4.79c	13.45c	18.24c
Potassium silicate 0.3%						
0	0.00m	0.00h	0.00k	0.00k	0.00l	0.00l
20	2.00l	0.00h	2.00j	1.83j	0.00l	1.83k
40	2.60i	0.00h	2.60h	2.97g	4.23k	7.20j
60	3.90h	5.54g	9.44f	3.10f	6.20h	9.30h
Control						
0	0.00m	0.00h	0.00k	0.00k	0.00l	0.00l
20	3.99g	0.00h	3.99g	3.10f	8.48g	11.58g
40	6.45d	14.91c	21.36c	6.70b	14.22b	20.92b
60	11.04a	28.41a	39.45a	6.79a	19.10a	25.89a

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

the control treatment. Whereas, fruits dipping in potassium silicate at 0.3% proved to be the most efficient treatment (13.91 and 13.32 mg CO_2 kg^{-1} h^{-1}) till 60 days under cold storage and (12.93 and 12.70 mg CO_2 kg^{-1} h^{-1}) 6 days during marketing in the second experiment

through both seasons, respectively. On the other hand, the highest respiration rate were obtained by treatment of control (15.11 and 14.95 mg CO_2 kg^{-1} h^{-1}) till 60 days under cold storage and (14.45 and 14.40 mg CO_2 kg^{-1} h^{-1}) 6 days during marketing in both seasons, respectively.

Firmness (lb inch^{-2}): Data from Table 4 show clearly that, fruit firmness was reduced as storage period advanced under cold storage or through marketing at room temperature. The data also confirm that all treatments used significantly reduced the loss in fruit firmness than the control at cold storage or marketing in the second experiment at room temperature through the two seasons. Thus, fruit firmness for the control treatment was 6.55 and 6.79 lb inch^{-2} after 60 days of cold storage but it reached about 6.00 and 6.10 lb inch^{-2} through marketing in both seasons. Furthermore, treated fruits with potassium silicate at 0.3% showed a higher fruit firmness (8.10 and 8.29 lb inch^{-2}) after 60 days of cold storage while, reached 7.90 and 8.33 lb inch^{-2} from fruits held 6 days at room temperature in the second experiment of the two seasons, respectively.

Polyphenol oxidase (PPO unit mg^{-1}): The great relationship among the rate of respiration, firmness and PPO activity of Anna apple fruits during cold storage and through marketing at room temperature, as soon as increasing the fruit respiration rate resulting decrease in fruits firmness and PPO activity was observed.

The inactivation and reactivation of PPO residual activity in the flesh of Anna apple juice subjected to potassium silicate treatments for 60 days was showed in Table 4. The activity of PPO in Anna apple juice of fruits treated by potassium silicate at 0.3% showed a statistically significant decrease with the advanced storage period, the residual activity of PPO was 0.390 and 0.393 U mg^{-1} after 60 days under cold storage and 6 days during marketing (0.361 and 0.377 U mg^{-1}) in the second experiment of two seasons, respectively. The higher residual activity of PPO was 0.430 and 0.433 U mg^{-1} after 60 days under cold storage and 6 days at marketing in the second experiment (0.423 and 0.429 U mg^{-1}) at the untreated ones during the two seasons, respectively.

Soluble solids content (SSC%): Concerning to the effect on SSC, data from Table 5 showed that soluble solids content in fruit juice of Anna apple was gradually increased as storage period prolonged either after cold storage or during shelf life at room temperature. It would be expected that increased weight loss in control fruits would lead to the increase of SSC due to disappearance of water from the fruits and concentration of soluble solids. Since, all treatments gave significantly lower values of SSC in fruit juice than the control fruit which ranged 14.15 and 13.90% after 60 days of cold storage and it were 14.90 and 14.69% after six days, marketing in both seasons under the study.

Titratable acidity (TA%): From Table 5, its clear that the content of total acidity in fruit juice was decreased with the progress in storage period from harvest till 60 day at cold storage or during marketing at room temperature. Since, all treatments gave significantly higher values of SSC in fruit juice than the control fruit. The highest value was obtained with potassium silicate at 0.3% (0.654 and 0.678%) after 60 days of cold storage and it was 14.90, 0.520 and 0.540% after six days, marketing in both seasons under the study. Moreover, control treatment produced lower significant acidity after 60 days of cold storage (0.630 and 0.654%), while after 6 days as marketing in the two seasons ranged 0.490 and 0.505% in the two seasons, respectively.

Table 4: Effect of potassium silicate on respiration rate (mg CO^2 kg^{-1} h^{-1}), firmness (lb $inch^{-2}$) and polyphenol oxidase (PPO) U mg^{-1} of Anna apple fruits during cold storage and under market conditions during 2012 and 2013 seasons

Treatments at different stroage periods (days)	Cold storage			Marketing 6 days at room temperature		
	Respiration rate	Firmness	Polyphenol oxidase	Respiration rate	Firmness	Polyphenol oxidase
Season 2012						
Potassium silicate 0.1%						
0	12.10g	10.70a	0.631a	12.20e	10.70a	0.633a
20	12.00gh	9.56b	0.629a	12.49d	9.90c	0.551c
40	13.20e	8.20d	0.542c	12.85c	8.00f	0.443h
60	14.33b	6.97f	0.421fg	13.36b	7.12i	0.405jk
Potassium silicate 0.2%						
0	12.10g	10.70a	0.631a	12.20e	10.70a	0.633a
20	11.91hi	9.70b	0.629a	12.55d	9.90c	0.539d
40	13.13e	8.83c	0.530d	12.96c	8.00f	0.456g
60	14.20c	7.11f	0.418g	13.25b	7.23h	0.396k
Potassium silicate 0.3%						
0	12.10g	10.70a	0.631a	12.20e	10.70a	0.633a
20	11.95hi	9.74b	0.625a	12.21e	10.00b	0.512e
40	12.92f	9.00c	0.510e	12.43d	8.95e	0.411j
60	13.91d	8.10d	0.390h	12.93c	7.90g	0.361l
Control						
0	12.10g	10.70a	0.631a	12.20e	10.70a	0.633a
20	11.83i	9.00c	0.630a	12.89c	9.10d	0.579b
40	13.83d	7.65e	0.587b	13.24b	7.88g	0.469f
60	15.11a	6.55g	0.430f	14.45a	6.00j	0.423i
Season 2013						
Potassium silicate 0.1%						
0	12.00g	10.93a	0.639a	12.00h	10.93a	0.639a
20	11.90hi	9.61c	0.631ab	12.20fg	10.00c	0.567c
40	13.00e	8.27f	0.554d	12.33ef	8.55f	0.458h
60	13.82b	7.03i	0.427fg	13.20b	7.73i	0.418j
Potassium silicate 0.2%						
0	12.00g	10.93a	0.639a	12.00h	10.93a	0.639a
20	11.82ij	9.70c	0.626b	12.29ef	9.95c	0.544d
40	12.92e	8.98e	0.540e	12.40e	8.60f	0.469g
60	13.57c	7.23h	0.421g	12.98c	7.90h	0.403k
Potassium silicate 0.3%						
0	12.00g	10.93a	0.639a	12.00h	10.93a	0.639a
20	11.93gh	10.11b	0.623b	12.13gh	10.15b	0.524e
40	12.79f	9.43d	0.560d	12.22fg	9.10e	0.428i
60	13.32d	8.29f	0.393h	12.70d	8.33g	0.377l
Control						
0	12.00g	10.93a	0.639a	12.00h	10.93a	0.639a
20	11.80j	9.10e	0.631ab	12.60d	9.70d	0.588b
40	13.61c	8.00g	0.593c	13.10bc	7.90h	0.483f
60	14.95a	6.79j	0.433f	14.40a	6.10j	0.429i

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

SSC/acid ratio (%): Considering the effect on SSC/acid ratio, data in Table 5 reveal that the values of SSC/acid ratio were progressively increased by the storage period advanced from harvest till 60 days either at cold storage or during marketing at room temperature.

Table 5: Effect of potassium silicate on SSC (%), acidity (%) and SSC/acid ratio (%) of Anna apple fruits during cold storage and under market conditions during 2012 and 2013 seasons

Treatments at different storage periods (days)	Cold storage			Marketing 6 days at room temperature		
	SSC (%)	Acidity (%)	SSC/acid ratio (%)	SSC (%)	Acidity (%)	SSC/acid ratio (%)
Season 2012						
Potassium silicate 0.1%						
0	12.90h	0.750a	17.19j	12.90h	0.750a	17.19j
20	13.00gh	0.725c	17.92gh	13.39f	0.712c	18.80h
40	13.39d	0.680e	19.68e	13.83de	0.612fg	22.59f
60	13.85b	0.639g	21.67b	14.24b	0.500i	28.48b
Potassium silicate 0.2%						
0	12.90h	0.750a	17.19j	12.90h	0.750a	17.19j
20	12.97h	0.732bc	17.72hi	13.10g	0.719bc	18.21i
40	13.26e	0.682de	19.44e	13.99cd	0.620f	22.56f
60	13.61c	0.641g	21.23c	14.00c	0.509i	27.50c
Potassium silicate 0.3%						
0	12.90h	0.750a	17.19j	12.90h	0.750a	17.19j
20	12.93h	0.741ab	17.44ij	12.92h	0.724b	17.84i
40	13.10fg	0.694d	18.87f	13.69e	0.632e	21.66g
60	13.24e	0.654f	20.24d	13.79e	0.520h	26.52d
Control						
0	12.90h	0.750a	17.19j	12.90h	0.750a	17.19j
20	13.15ef	0.720c	18.26g	13.44f	0.700d	19.20h
40	13.69c	0.670e	20.43d	14.17b	0.603g	23.50e
60	14.15a	0.630g	22.45a	14.90a	0.490j	30.41a
Season 2013						
Potassium silicate 0.1%						
0	12.63f	0.776a	16.27g	12.63i	0.776a	16.27m
20	12.75ef	0.765ab	16.66fg	13.00g	0.713d	18.23j
40	13.00c	0.710cd	18.31d	13.65d	0.629f	21.83f
60	13.43b	0.663fg	20.25b	14.10b	0.519i	27.16b
Potassium silicate 0.2%						
0	12.63f	0.776a	16.27g	12.63i	0.776a	16.27m
20	12.70ef	0.765ab	16.59g	12.90gh	0.729c	17.69k
40	12.97cd	0.719c	18.03de	13.40e	0.631f	21.23g
60	13.32b	0.669ef	19.91b	13.92c	0.526i	26.46c
Potassium silicate 0.3%						
0	12.63f	0.776a	16.27g	12.63i	0.776a	16.27m
20	12.68f	0.761b	16.65fg	12.81h	0.741b	17.28l
40	12.83de	0.720c	17.82e	13.19f	0.649e	20.32h
60	13.00c	0.678e	19.16c	13.63d	0.540h	25.23d
Control						
0	12.63f	0.776a	16.27g	12.63i	0.776a	16.27m
20	12.96cd	0.760b	17.05f	13.26f	0.709d	18.70i
40	13.33b	0.705d	18.90c	14.00bc	0.616g	22.72e
60	13.90a	0.654g	21.24a	14.69a	0.505j	29.08a

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

With regard to the effect of these treatments on SSC/acid ratio the data reveal that, control treatment produced a higher value of SSC/acid ratio at cold storage, since

the values averaged about 22.45 and 21.24% while, in the second experiment after 6 days in marketing ranged 30.41 and 29.08% during the two seasons, respectively.

Moreover, after 60 days during cold storage potassium silicate at 0.3% treatment gave a lower values of SSC/acid ratio (20.24 and 19.16%) while, after 6 days as marketing ranged 26.52 and 25.23% during the two seasons, respectively.

Skin hue color (h°): The decline in hue angle (change in color from green to red) occurred rapidly with storage period advanced during cold storage or under room temperature. From Table 6 data presented that all applied treatments had a delay in the development of fruits skin color when compared with the untreated fruits. The loss of the green color in apple skin was expressed as lower hue angle (h°). The values of hue angle increased with the progress of potassium silicate concentrations. In control fruit, hue angle decreased rapidly during storage, indicated a losing green color, either at cold storage (72.33 and 68.40 h°) or during marketing in the second experiment (64.30 and 61.54 h°). Furthermore, the values of hue angle (h°) during marketing were almost lower than those obtained at cold storage during the both seasons of study.

Moreover, potassium silicate at 0.3% produced a higher hue angle (h°) than all treatments or the control after 60 days of cold storage and 6 days during marketing in both season. The increment due using these treatments reached about 79.40 and 76.85 h° after 60 days of cold storage, respectively during both seasons. While, after 6 days during marketing in the second experiment the values averaged 69.90 and 66.50 h° in both seasons, respectively.

Total sugar (%): Concerning to the effect on total sugar, Data from Table 6 showed that total sugar content in fruit juice of Anna apple fruits was gradually increased as storage period prolonged either after cold storage or during marketing at room temperature.

Since, the untreated fruits produced higher significant values of total sugar in apple fruits than all treatments which ranged 13.76 and 13.55% after 60 days of cold storage and it were 14.30 and 14.05% after six days as marketing in the second experiment during both seasons under the study. The data also disclose that, application of potassium silicate at 0.3% presented lower values of total sugars compare to the applied treatments averaged 13.32 and 13.27% after 60 days of cold storage and it were 13.71 and 13.63% after six days as marketing in both seasons, respectively.

Total starch: Starch iodine index indicates the gradual change of starch to sugars in the fruit. Considering to the effect on total starch, data from Table 6 showed that total starch content in fruit pulp of Anna apple fruits were gradually decreased as storage period prolonged either after cold storage or during marketing at room temperature. The maximum starch score (6.31 and 6.49) recorded in fruit dipping at potassium silicate at 0.3% after 60 days of cold storage and it were 4.79 and 4.97% after six days as marketing in the second experiment of both seasons, respectively. While, the minimum starch score (5.86 and 6.21) recorded in control fruit after 60 days of cold storage and it were 4.34 and 4.65% after six days as marketing in the second experiment of both seasons, respectively.

DISCUSSION

The reduction in linear growth and dry weight were positive correlated to the increase in potassium silicate concentrations. Potassium silicate at 0.3% treatment showed complete inhibition of the linear growth and dry weight of *P. expansum*. This result is in agreement with the findings

Table 6: Effect of potassium silicate on hue angle (h°), sugar (%) and starch (iodine index) of Anna apple fruits during cold storage and under market conditions during 2012 and 2013 seasons

Treatments at different storage periods (days)	Cold storage			Marketing 6 days at room temperature		
	Hue angle	Total sugar	Total starch	Hue angle	Total sugar	Total starch
Season 2012						
Potassium silicate 0.1%						
0	95.15a	13.16g	8.06a	95.13a	13.16g	8.00a
20	91.50bc	13.03i	7.20d	84.95d	13.30f	6.17c
40	84.60ef	13.25e	6.94e	76.30h	13.68d	5.30f
60	74.93i	13.61b	6.00g	65.00l	14.09b	4.40j
Potassium silicate 0.2%						
0	95.15a	13.16g	8.06a	95.13a	13.16g	8.00a
20	92.20b	13.10h	7.23d	85.90c	13.27fg	6.23c
40	86.00e	13.23ef	7.16d	79.45g	13.50e	5.36f
60	76.53h	13.54c	6.19f	67.44k	13.86c	4.59i
Potassium silicate 0.3%						
0	95.15a	13.16g	8.06a	95.13a	13.16g	8.00a
20	93.73a	13.03i	7.41c	89.44b	13.23fg	6.44b
40	89.64d	13.19fg	7.59b	82.63f	13.33f	5.77e
60	79.40g	13.32d	6.31f	69.90j	13.71d	4.79h
Control						
0	95.15a	13.16g	8.06a	95.13a	13.16g	8.00a
20	90.40cd	13.10h	7.13d	83.60e	13.33f	6.00d
40	84.30f	13.30d	6.80e	74.73i	13.79cd	5.16g
60	72.33j	13.76a	5.86g	64.30m	14.30a	4.34j
Season 2013						
Potassium silicate 0.1%						
0	92.20a	13.02a	8.20a	92.20a	13.05I	8.22a
20	89.81c	13.00a	7.53d	82.33d	13.23gh	6.37d
40	80.31g	13.14a	7.19g	72.00h	13.46de	5.50h
60	72.37k	13.49a	6.30k	63.10l	13.90b	4.75l
Potassium silicate 0.2%						
0	92.20a	13.02a	8.20a	92.20a	13.05I	8.22a
20	89.90c	13.01a	7.68c	84.50c	13.21gh	6.49c
40	83.10f	9.79b	7.29f	73.40g	13.40ef	5.59g
60	74.10j	13.41a	6.39j	64.90k	13.82b	4.83k
Potassium silicate 0.3%						
0	92.20a	13.02a	8.20a	92.20a	13.05I	8.22a
20	90.99b	12.96a	7.80b	90.00b	13.15hi	6.70b
40	86.73e	13.09a	7.43e	78.13f	13.29fg	5.86f
60	76.85i	13.27a	6.49i	66.50j	13.63c	4.97j
Control						
0	92.20a	13.02a	8.20a	92.20a	13.05I	8.22a
20	87.40d	13.00a	7.47de	80.75e	13.29fg	6.28e
40	78.50h	13.18a	7.08h	71.25i	13.55cd	5.36i
60	68.40l	13.55a	6.21l	61.54m	14.05a	4.65m

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

of Tian *et al.* (2005) and Etebarian *et al.* (2013) on blue mould caused by *P. expansum* in apple, the results of *in vitro* studies showed that silicon in concentrations of higher than 0.6% inhibited the

growth of pathogen completely. Also, Si at concentration above 0.6% w/v inhibited the growth of the both isolates P1 and P2 completely, while Si at 0.2% had the least effect on the both isolates. There were no significant differences between 0.6, 0.8 and 1% w/v (Farahani *et al.*, 2012). Furthermore, Li *et al.* (2009) found that Si at 200 mL mol^{-1} inhibited the germination and *in vitro* mycelial growth of *P. expansum*.

Etebarian *et al.* (2013) showed *in vivo* experiments that, the lesion diameters in apples which were immersed in hot water at 40 or 50°C after inoculation with pathogen and then treated with silicon at concentrations of 0.2, 0.4, 0.6 and 1% in wounds were less than pathogen control after 15 and 45 days incubation at 20 and 4°C, respectively. In another experiment, the lesion diameters in apples which were immersed in hot water at 40 or 50°C after inoculation with pathogen and then treated with silicon were from 0-4.99 mm compared to 12.5 mm in pathogen control.

The results of initial Si experiments indicate that silicon affects plant growth and crop quality, stimulates photosynthesis, reduces transpiration rate and enhances plant resistance to a series of both abiotic and biotic stresses such as water and chemical stresses, nutrient imbalances, metal toxicities, diseases and pest's problems (Zhou *et al.*, 2002). Liang *et al.* (2008) reviewed that silicon can stimulate the antioxidant system in plants and affect the structure of the plasma membrane so as to alleviate abiotic stresses. Recently, there has been an increased interest for sustainable crop production and Si can contribute to that direction with its prophylactic properties and promotion of plant health. Silica accumulation in cell walls was believed to be physically responsible for plant disease resistance it has a potential signal that activates defense mechanisms. Bekker *et al.* (2007) suggested that the positive effect of Si on plant growth and performance is only evident when plants are under some stress. So, Si has been found to offer protection against fungal infections by strengthening cell walls, thus making it more difficult for the fungi to penetrate and colonize the plant.

Si may enhance activity of chitinases, peroxidases and polyphenyloxidases and increased formation deposition of callose and hydrogen peroxide (Shetty *et al.*, 2012). Wei *et al.* (2004) reported that soluble silicon application stimulated the activity of the enzymes PAL, PPO and POD in hydroponically grown Chinese white-flowered gourd and increased silicon content by 1.43 times. Therefore, by increasing PAL activity by the addition of potassium silicate in these experiments, the fruit's resistance to disease can be increased. This may be especially important as fruit softens.

Zhu *et al.* (2004) indicated that silicon induced stress tolerance in plants may be caused, at least in part, by increased antioxidant enzymes activity, which in turn decrease oxidative damage to membrane and enzyme activity. Mditshwa *et al.* (2013) reported that chilling injury was exacerbated by 150 and 250 mg L^{-1} K_2SiO_3. This was probably caused by the glassy characteristics of Si that can potentially damage the cell hence increasing fruit water loss. The reduced fruit weight loss and electrolyte leakage following treatment with Si also showed the potential of Si to retard stress. The reduction in fruit weigh loss at 50 mg L^{-1} K_2SiO_3 was probably due to the modification of cell membranes after Si application that led to reduction of water loss and subsequently reduced fruit weight loss (Epstein, 2009).

It is also a known fact that treating plants with soluble Si enhances fungal resistance, inhibits fungal diseases through modifications of the epidermal layer of the leaves and fruits as well as by increasing presence of low-molecular-weight metabolites (Gillman *et al.*, 2003).

Texture is one of the most important factors affecting apple quality. Sugar and acid ratio is also deemed important as long as the acidity does not decline too far. During ripening, acidity and

firmness decline concurrently. Apple skin color results from the blending of chlorophyll, carotenoid and anthocyanin pigments, with anthocyanins being primarily responsible for the red color (Lancaster and Dougall, 1992). The storage durations significantly affected the starch content of apple. Since starch is the major storage carbohydrates in apple fruit, it is converted to sugars at the onset of ripening and during storage to meet the respiratory demand of the fruit (Crouch, 2003). Maksimovic *et al.* (2007) found increment in flavonoid and phenolic content in plants after silicon application. Covering fruit with a silicon layer seemed to increase gas exchange (respiration) at the two lower Si concentrations, thereby potentially hastening the ripening process (Tesfay *et al.*, 2011). The contents of total solid solutes of the fruit were significantly increased by Si in the form of K_2SiO_3, also enhanced the fruit firmness and vitamin C in the tomato fruits (Stamatakis *et al.*, 2003). The Si has beneficial effects on plant metabolism as increased contents of malic acid while, sucrose, glucose and fructose were reduced (Wang and Galletta, 1998). Jamali and Rahemi (2011) was confirmed that the inhibitory effect of Si on ethylene production increases the postharvest quality and longevity of carnations.

Kaluwa *et al.* (2010) concluded that post-harvest applications of 2940 ppm Si in the form of KSi seem to be most beneficial in suppressing respiration, reduction in ethylene evolution and would result in a slower decrease in the plant's carbon reserve compounds. The Si concentration applied had, however, no effect on the deposition of Si in the mesocarp tissue but the amount of Si found in the exocarp was higher in fruit treated with high Si concentrations. It would also be beneficial to investigate if Si increases antioxidant and total phenolics accumulation in the fruit, thereby increasing the stress-relieving ability of the fruit, producing fruit with a higher ability to withstand long-term storage.

CONCLUSION

The above results show that, dipping Anna apple fruits in potassium silicate has a great potential to enhance quality during cold storage (at 0±1°C with 90-95% R.H) and through marketing at room temperature. All silicon treatments has an ability to inhibit the radial mycelial growth of *Penicillium expansum* development, reduced SSC, acidity, SSC/acid ratio and total sugar compare to the untreated fruits. The present study showed that, potassium silicate at 0.3% gave the best results for reduced loss weight, decay, total loss weight, respiration rate and PPO activity than the other treatments or the control. Therefore, from this study the treatment with potassium silicate as a promising material to maintain the quality of the apples during storage and marketing for the longest possible period was found.

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