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Research Article

Effect of pre-harvest application of salicylic acid, potassium silicate, and calcium chloride, on storability and quality attributes of table grape

Adel M.R.A. ABDELAZIZ[1], Samar A.M.A. SHAARAWI[2]*, Wael M. IBRAHIM[1]

[1]*Central Laboratory of Organic Agriculture, Agricultural Research Center (ARC), Giza, Egypt; dr.adel.organic@gmail.com ; dr.waelmohamed@gmail.com*
[2]*Fruit Handling Research Department, Horticulture Research Institute, ARC, Giza, Egypt; sshaarawi@hotmail.com (*corresponding author)*

Abstract

Pre-harvest application of potassium silicate, calcium chloride and salicylic acid as spraying treatments is a promising strategy for the management of fruit quality and exhibits a high potential in controlling post-harvest losses of horticultural crops. The aim of this study was to investigate the storability of 'ARAA18' cultivar after some pre-harvest treatments that were applied during two consecutive growing seasons. The 'ARRA 18' table grape variety is one of the 'ARRA' group varieties that have been recently introduced to Egypt. Treatments were applied as foliar sprays at three different stages during the growing season before harvest. The plants were sprayed with potassium silicate (K_2SiO_3), salicylic acid, and calcium chloride, while untreated vine trees sprayed with water served as control. Mature clusters were harvested, then placed in carton containers and stored in cold storage at 0±1 °C to study the storability of 'ARRA18'. Records of physical and chemical quality parameters were taken at 7-day intervals. All treatments reduced weight loss, berry softening and decay incidence comparing to control under storage conditions. K_2SiO_3 generally showed the highest significant effect compared to other treatments and control. Hence, the use of (K_2SiO_3) at both applied concentrations and (SA) at 100 ppm, significantly proved to be the most effective treatments in keeping the overall quality of stored grapes.

Keywords: 'ARRA18'; calcium chloride ($CaCl_2$); cold storage; potassium silicate (K_2SiO_3); salicylic acid (SA)

Introduction

Grape is one of the most widely-grown fruit crops in Egypt, the second most important after citrus. The 'ARRA 18' table grape variety is one of the 'ARRA' group varieties that have been recently introduced to Egypt. Growth pattern, nutritional requirements and storage behaviour were studied under the Egyptian conditions. Storability of newly introduced varieties was required to evaluate their ability under storage condition. The post-harvest life of table grapes is relatively short due to water loss, skin browning, rachis dehydration and

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browning, berry shatter, and fungal decay (Ranjbaran *et al*., 2011). Studies of alternative compounds of chemical but still relatively safe treatments to maintain the quality in the post-harvest life of table grapes is highly needed.

Pre-harvest application of potassium silicate, calcium chloride and salicylic acid as spraying treatment is a promising strategy for the management of fruit quality and exhibits a high potential in controlling post-harvest losses of horticultural crops (Asghari and Aghdam, 2010; Mohamed *et al*., 2017). Silicon (Si) is regarded as one of the most beneficial elements that increases plant resistance against various abiotic and biotic stresses (Schabl *et al*., 2020). It is one such nutritive element which is gaining increasing attention due to its observed properties, enhancing plant tolerance against biotic as well as abiotic stresses. Recent reports indicated some of the important roles that Si plays in plants, among which improving growth, yield and crop quality, photosynthesis, nitrogen fixation and providing tolerance against abiotic and biotic stresses such as extreme temperature, UV radiation, metal toxicity, nutrient deficiency, drought, salinity, pathogen and fungus attack (Zargar *et al*., 2019).

Potassium silicate, the most commonly used form of Si, according to Tarabih *et al*. (2014), was applied in order to investigate its effect on increasing the concentration of antifungal compounds and/or the enzyme PAL which in turn increases the concentration of phenolic compounds and, at later, ripening stages, thus decreasing disease incidence. Moreover, using of potassium silicate at pre- harvest stage has proved to be an effective method to control diseases for various fruit crops (Singh *et al*., 2020). In addition, potassium silicate is a source of highly soluble potassium and silicon. It is used in agricultural production systems primarily as a silica amendment, in addition to the benefit of supplying small amounts of potassium. The using of potassium silicate (K_2SiO_3) showed to be most beneficial to maintain avocado fruit quality, probably due to a suppression of respiration and a reduction in ethylene evolution (Kaluwa *et al*., 2010). 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.

Si is nowadays used by organic and biodynamic grape producers, since it is believed to be a more effective in increasing plant defense and fruit quality (Meunier *et al*., 2011). Moreover, silicon fertilizers produce several advantages in fruit quality, since it increases sugar content, enhanced hardness and pressure-resistance of grape and apple fruits, increases vitamin C and protein content of nectarine fruit and some vegetable crops (Jia *et al*., 2011). It has been also shown to improve plant cell wall strength and structural integrity, drought and frost resistance, decrease lodging potential (Currie and Perry, 2007), and boost plant natural pest and disease fighting systems (Rodrigues and Datnoff, 2007). Salicylic acid (SA) is a natural phenolic compound involved in the regulation of many processes in plant growth and development. Among them, it is noteworthy that SA exhibits a high potential in controlling post-harvest losses of horticultural crops (Asghari and Aghdam 2010). It has been also reported that SA application, either in pre- or post-harvest, reduced fungal decay in sweet cherry (Yao and Tian, 2005; Xu and Tian, 2008), strawberry (Babalar *et al*., 2007; Shafiee *et al*., 2010) and peach fruits (Wang *et al*., 2006). Malamy *et al*. (1990), stated that exogenous SA treatment may also induce the expression of pathogenesis-related proteins, and establish systemic acquired resistance (Gaffney *et al*., 1993, Beckers and Spoel, 2006). Terry and Joyce (2004) reported that SA can extend the shelf life of the harvested fruit by delaying the development of disease incidence through the induction of the defense resistance system and stimulation of antioxidant enzymes, as indicated also by Khademi and Ershadi (2013). On the other hand, Ranjbaran *et al*. (2011) and Asghari *et al*. (2013) demonstrated that the postharvest treatment of grape berries by SA has potential for increasing storage life of table grapes and maintaining their quality. For its action at minimal concentrations, SA is considered a plant hormone (Raskin, 1992), inhibiting ethylene biosynthesis and delaying fruit senescence (Khademi *et al*., 2012), and it is also considered as "Generally Recognized as Safe" (GRAS). In the same context, SA as a natural and relatively safe compound, has been reported to have a high potential in maintaining fruit quality and reducing fungal decay in harvested fruits (Amborabe *et al*., 2002).

The application of acetylsalicylic acid (a derivative of SA) slowed down the softening rate of kiwifruit by inhibiting ethylene production and maintaining higher endogenous SA levels (Zhang *et al*., 2003). Salicylic acid also prevented the softening of banana and kiwifruit during ripening (Srivastava and Dwivedi, 2000; Zhang *et al*., 2003). In addition, Shaarawi *et al*. (2016) reported that the use of salicylic acid and calcium chloride helped to keep a better overall quality of pomegranate arils at the end of the 12-day storage at 5±1 °C.

Calcium chloride ($CaCl_2$) proved to be an effective strategy for quality maintenance during post-harvest storage, while its foliar application of has been found to control physiological disorders of fruit with improved fruit quality (Bakshi *et al*., 2005). Pre- and postharvest applications of calcium (Ca) have been practiced commercially in many fruits for improving quality, and it is considered as a key plant nutrient that has a significant role in cell functions, including reducing softening, delaying senescence, reducing postharvest decay, and controlling the physiological disorder (Poovaiah, 1986; Conway *et al*., 1994; Barker; Pilbeam, 2015), with no detrimental effect on consumer acceptance. Ca regulates the ripening of fruits and stimulates their coloring, ethylene production, and flesh firmness (Gerasopoulos and Richardson, 1999). Grapes with optimum Ca concentrations had improved fruit quality (Cupta *et al*., 1980). Amiri *et al*. (2009) found that pre-harvest $CaCl_2$ improved quality components, including berry firmness, berry color, and appearance at harvest time; in the meantime, Ca sprays reduced berry drops and botrytis infection. Abbasi *et al*. (2020) reported that pre-harvest foliar sprays of different $CaCl_2$ concentrations significantly improved berry quality with increased berry length and diameter of 'Perlette' and 'King's Ruby' table grapes. They also indicated that postharvest biochemical quality of these cultivars was considerably improved with higher total soluble solids (TSS), titratable acidity (TA), ascorbic acid contents, sugars, total phenolic contents, and antioxidants under long term storage conditions at 0.5 ± 0.5 °C and 90% RH for four weeks.

The aim of the study was to investigate the storability and quality attributes of the 'ARRA 18' cultivar as affected by pre-harvest treatments with SA, K_2SiO_3, and $CaCl_2$, under cold storage conditions.

Materials and Methods

The current study was conducted during two consecutive seasons (2019-2020) on grapevine trees 'ARA-18' cultivar grown in a private farm located at el Sadat City-Desert Road, Egypt. Vines were planted on sandy soil cultivated at 1.5 x 3 m distance, trained with the Baron-h modified system, drip irrigated and vines were treated regularly as the breeder and MOA recommendations, receiving normal cultural practices adopted in the orchard.

Each treatment consisted of 3 trees in a randomized complete block design where a single tree represented the experimental unit. The experiment consisted of a total of 7 treatments (including the control) for each season. Trees of 'ARRA18' were sprayed twice during the growing season, at version stage, then followed with the second spray at 15 days before harvest date. Treatments were as follows: (i) K_2SiO_3 at concentration of 1500 and 2000 ppm, (ii) SA at 100 and 200 ppm, and (iii) $CaCl_2$ at 1% and 2%, while untreated vine trees sprayed with water served as control. Mature clusters were harvested, and were selected in uniformity of weight, size, and absence of physical injuries Clusters were then placed in carton containers and stored in cold storage at 0±1 °C to study the storability of 'ARRA18' cultivar. Records of physical and chemical quality parameters were taken at day 0, and then at seven- day intervals during storage.

Physical and chemical parameters

The following physical characteristics were evaluated:

Weight loss

Samples of each treatment were weighed at weekly intervals until the end of experiment. Weight loss (%) was calculated as follows:

Fruit weight loss (%) = [(initial weight – weight at sampling date / initial weight)] x 100.

Decay

The 'Decay percentage' was evaluated by type, as skin appearance, shrivelling, chilling injury and pathogenic rots. In every inspection date, decayed berries were discarded and the relative amount expressed as decay percentage.

Firmness

Berry 'Firmness' was measured using a handheld firmness tester (fruit firmness tester: FHP-802) with 3.5 mm diameter tip plunger.

The following chemical characteristics were evaluated:

Total Soluble Solids (TSS)

TSS was determined using digital pocket refractometer (model PAL 1, ATAGOTM, Tokyo Tech.) and expressed as percentage.

Titratable Acidity (TA) percentage

According to A.O.A.C. (2003) the results were expressed as a percentage of tartaric acid (g of tartaric acid per 100 ml grape juice).

Total Anthocyanin Content (TAC)

The TAC (mg/100 ml) was colorimetrically quantified in the juice of berries as described by Hsia *et al*. (1965). Relative anthocyanin levels were spectrophotometrically quantified according to our previous method (Li *et al*., 2013).

Total sugars (TS)

TS was determined as described by A.O.A.C. (2003).

Statistical analysis

For experiments, complete factorial randomized designs were applied. Treatments were always replicated three times, and the obtained data were statistically analysed by ANOVA. Mean comparisons were performed by Duncan's Multiple range test at 5% level (Snedecor and Cochran, 1982).

Results and Discussion

Physical characteristics

Weight loss

Data reported in Table 1 illustrates that, irrespectively to treatments, weight loss percentage increased often significantly by the increasing of the storage period, and this was true for both studied seasons. These results are in accordance with those obtained by Al-Qurashi and Awad (2013), as they reported significant interaction effects on weight loss percentage between treatment and storage period. All treatments significantly reduced weight loss comparing to control under cold storage conditions. However, SA at 100 ppm, only in the first season, and K_2SiO_3 at the concentration of 2000 ppm in both seasons, significantly showed higher effect on weight loss reduction, compared to other treatments, meanwhile control fruits scored the highest significant

loss of weight in both studied seasons. Similarly, a significant reduction of fruit weight loss was marked in foliar sprayed 'Anna' apple fruits with K_2SiO_3 at 0.3% (Tarabih *et al*., 2014). This was in harmony with the results obtained by Levchenko *et al*. (2021) who mentioned that the natural loss in the mass of grapes is a projection of metabolic process intensity. Additionally, El Kholy *et al*. (2018) stated that K_2SiO_3 treated loquat fruits showed lower weight loss (%), and they explained that this low reduction in weight might be due to the suppression of the transpiration and respiration rates of fruits by closing the stomata.

Table 1. Weight loss: effect of pre-harvest application of SA, K_2SiO_3 and $CaCl_2$, on weight loss percentage of 'Arra18' table grape cultivar (2019-2020 seasons) during cold storage at 0±1°C.

Storage period (wks.) / Treatments	0	1	2	3	4	5	Mean
	1st season: 2019						
Control	0.00t*	3.45pq	7.50i-k	11.05d-f	13.43b	15.53a	8.49A
Ca Cl_2 (2%)	0.00t	2.95p-r	3.74op	5.48mn	7.07i-k	11.18de	5.07E
Ca Cl_2 (4%)	0.00t	2.02rs	4.99mn	6.70j-l	8.96h	11.16de	5.64D
SA (100 ppm)	0.00t	1.20s	2.86p-r	4.59no	7.01i-k	11.88cd	4.59F
SA (200 ppm)	0.00t	2.67qr	4.52no	9.49gh	10.94d-f	12.64bc	6.71B
K_2SiO_3 (1500 ppm)	0.00t	2.17r	5.91lm	7.67ij	10.12fg	11.59d	6.24C
K_2SiO_3 (2000 ppm)	0.00t	2.80p-r	4.50no	6.48kl	7.83i	10.38e-g	5.33DE
Mean	0.00F	2.47E	4.86D	7.35C	9.34B	12.05A	
	2nd season: 2020						
Control	0.00s	1.93n-p	5.97e-g	7.81d	10.79b	12.70a	6.53A
Ca Cl_2 (2%)	0.00s	1.32p-r	3.17k-m	5.14g-i	6.05ef	8.87c	4.09D
Ca Cl_2 (4%)	0.00s	0.57rs	1.97n-p	3.47kl	4.97hi	7.69d	3.11F
SA (100 ppm)	0.00s	0.73q-r	2.59l-n	4.33ij	5.30f-h	7.97d	3.49E
SA (200 ppm)	0.00s	2.38m-o	4.64hi	6.51e	7.55d	10.37b	5.24B
K_2SiO_3 (1500 ppm)	0.00s	1.58o-q	3.38jk	6.47e	7.43d	7.88d	4.49C
K_2SiO_3 (2000 ppm)	0.00s	0.67rs	1.74n-p	3.04k-m	4.60hi	6.60e	2.78G
Mean	0.00F	1.31E	3.38D	5.25C	6.67B	8.87A	

*Note: Different letters indicate significantly different values by ANOVA followed by Duncan test at P≤0.05 (small letters refer to values recorder in each season, different capital letters refer to mean values)

Decay %

In both seasons, decay percentages had progressive increment as the storage period increased (Table 2). All treatments reduced decay incidence comparing to control under storage conditions. K_2SiO_3 at 2000 ppm, and SA at 100 ppm followed by K_2SiO_3 at 1500 ppm, generally showed the highest significant effect on decay incidence in both studied seasons, compared to other treatments and control. Decay incidence started at the third week of the storage period, mainly on untreated fruits, and slightly increased up to 35 days of cold storage. Moreover, untreated fruits showed the highest significant decay incidence at the end of the storage period. These results are in agreements with the reports of Ranjbaran *et al*. (2011) who mentioned that the incidences of fungal decay were significantly affected by 4 mM SA treatment at 45+2 days of post-harvest life. However, there was no significant difference in decay incidence between treated and untreated grapes during cold storage. In the same context, results are in harmony with those obtained by Rodrigues *et al*. (2009), as they mentioned that foliar application of Si provided satisfactory disease control since the foliar application of K_2SiO_3 has great potential for reducing soybean rust intensity. Bowen *et al*. (1992) reported that thick KSi deposits coating a significant portion of the grape leaf cuticle prevented penetration by germinating ascospores of *Uncinula necator*. Results may be attributed to the fact that Si is regarded as one of the most beneficial elements that increases plant resistance against various abiotic and biotic stresses. It has been shown to improve plant cell wall strength and structural integrity, and to boost plant natural pest and disease fighting systems (Rodrigues and Datnoff, 2007). It was also reported that Si is associated with increasing in antioxidant defense mechanism of plants (Meena *et al*., 2014).

The mechanical barrier formed by silicon polymerisation below the cuticle and in the cell, wall was also the first proposed hypothesis to explain how silicon reduces or impedes fungal penetration (Schabl *et al*., 2020). Rodrigues *et al*. (2015) suggested that silicon effects on plant resistance may also occur through mediated host plant resistance mechanisms against pathogen infection. They also mentioned that plants supplied with silicon exhibit potentiated activation of the phenylpropanoid pathway resulting in increased total soluble phenolics and lignin. The same authors added that only root applications of silicon potentiate plant defense responses, such as the activities of peroxidases, polyphenol oxidases, β-1,3-glucanases and chitinases. The transcription of defense-related genes occurs faster and with greater output, too. Similarly, several reports indicate that exogenous application of SA might induce the expression of many defense genes (Loake and Grant, 2007; Wang *et al*., 2006). Similar results on SA application have been obtained on peach (Wang *et al*., 2006), strawberry (Babalar *et al*., 2007) and sweet cherry (Xu and Tian, 2008). It has been documented that improved resistance in SA–treated fruit against fungal attack can be attributed to the induction of a defense resistance system (Chan and Tian, 2006). Role of SA in controlling fungi decay may be due to activation of antioxidant defense responses (Xu and Tian, 2008) or its direct antifungal effects on fungus development (Amborabe *et al*., 2002).

The effect of K_2SiO_3 my due to the fact that foliar application of Si provided satisfactory disease control, probably through a physical barrier of Si deposited on leaf surfaces, or through an osmotic effect of the silicate applied (Rodrigues *et al*., 2009).

Table 2. Decay: effect of pre-harvest application of SA, K_2SiO_3, and $CaCl_2$, on decay incidence percentage of 'Arra18' table grape cultivar (2019-2020 seasons) during cold storage at 0±1°C

Storage period (wks.) / Treatments	0	1	2	3	4	5	Mean
	1st season: 2019						
Control	0.00q*	0.00q	2.13mn	6.93de	8.43c	13.30a	5.13A
Ca Cl_2 (2%)	0.00q	0.00q	0.00q	3.80ij	6.64ef	9.04c	3.25B
Ca Cl_2 (4%)	0.00q	0.00q	0.00q	1.83m-o	4.21hi	7.63d	2.28C
SA (100 ppm)	0.00q	0.00q	0.00q	1.13op	2.51lm	5.67g	1.55E
SA (200 ppm)	0.00q	0.00q	0.00q	2.93kl	4.79h	10.90b	3.10B
K_2SiO_3 (1500 ppm)	0.00q	0.00q	0.00q	0.75p	4.87h	6.03fg	1.94D
K_2SiO_3 (2000 ppm)	0.00q	0.00q	0.00q	0.45pq	1.57no	3.37jk	0.90F
Mean	0.00E	0.00E	0.30D	2.55C	4.72B	7.99A	
	2nd season: 2020						
Control	0.00m	0.00m	3.63h	5.87e	9.07b	12.43a	5.17A
Ca Cl_2 (2%)	0.00m	0.00m	1.83jk	2.70i	6.10e	8.40c	3.17C
Ca Cl_2 (4%)	0.00m	0.00m	0.00m	2.10i-k	5.03f	6.43e	2.26D
SA (100 ppm)	0.00m	0.00m	0.00m	1.90jk	4.60fg	5.10f	1.93E
SA (200 ppm)	0.00m	0.00m	1.60k	4.10gh	7.03d	9.10b	3.64B
K_2SiO_3 (1500 ppm)	0.00m	0.00m	0.00m	2.07i-k	3.57h	5.93e	1.93E
K_2SiO_3 (2000 ppm)	0.00m	0.00m	0.00m	0.63l	1.85jk	2.40ij	0.81F
Mean	0.00E	0.00E	1.01D	2.77C	5.32B	7.11F	

*Note: Different letters indicate significantly different values by ANOVA followed by Duncan test at P≤0.05 (small letters refer to values recorder in each season, different capital letters refer to mean values)

Firmness

Fruit firmness is one of the most crucial factors in determining the post-harvest quality and physiology of fruits (Kirmani, *et al*., 2013). Obviously berry firmness showed a significant decrease as the storage period increased these effects, irrespective to the treatments. This is due to the breakdown of insoluble propectin into soluble pectin by hydrolysis of starch (Matto *et al*., 1975) or by cellular disintegration leading to increased membrane permeability (Oogaki *et al*., 1990).

Table 3 illustrates that all treatments reduced berry softening comparing to control under storage conditions. All treatments recorded significantly higher firmness than control fruits, however K_2SiO_3 at 2000

ppm, $CaCl_2$at 4% and SA at 100 ppm, in this order, recorded the highest significant firmness values, since berries firmness were highly maintained by these treatments compared to control berries and other treatments. These results are in harmony with those recorded by Bassiony *et al*. (2018), as they mentioned that foliar spray applications of calcium and silicon had a positive effect in enhancing berry firmness. Also, Kirmani *et al*. (2013) found that the firmest fruits of 'Santa Rosa' plum at harvest time were obtained from trees receiving pre-harvest application of $CaCl_2$ at 0.5%. In accordance with these results, Aguayo *et al*. (2012) reported that $CaCl_2$ treatments kept a better firmness of pomegranates fruits than control arils. In addition, Ranjbaran *et al*. (2011) indicated that the analysis showed slightly higher berry firmness in SA–treated clusters after 45 days at 0 °C and exposed for 2 days of shelf life, in comparison to those of control. In addition, they reported that the application of SA delayed ripening and reduced fruit softening rate. On the other hand, Peyro *et al*. (2017) also reported that the firmness of berries increased in the treatment with 1 mmol SA and 20% Aloe vera gel. This could be explained considering that, in fruits, SA delays fruit softening by affecting major enzymes activity that causes cell wall degradation like polygalacturonase, xylanase and cellulase (Srivastava and Dwivedi, 2000) through the reduction of ethylene production. The results of Si application are in accordance with those obtained by Tarabih *et al*. (2014), as they confirmed that all K_2SiO_3 treatments significantly reduced the loss in apple fruit firmness than the control at all storage conditions.

The desired effect of $CaCl_2$ may be due to the calcium binding to free carboxyl groups of polygalacturonate polymer, stabilizing and strengthening the cell wall (Rees, 1975) Strengthened tissue becomes more resistant to hydrolytic enzyme activity, where Ca inhibits the polygalacturonase activity in cell walls (Buescher and Hobson, 1982).

Table 3. Firmness: effect of pre-harvest application of SA, K_2SiO_3, and $CaCl_2$, on firmness (lb/in^2) of 'Arra18' table grape cultivar (2019-2020 seasons) during cold storage at 0±1°C

Storage period (wks.) / Treatments	0	1	2	3	4	5	Mean
	1st season: 2019						
Control	2.47k*	2.00op	1.50t	0.97u	0.67v	0.30w	1.32G
Ca Cl_2 (2%)	3.33c	3.10ef	2.73i	2.23lm	1.93pq	1.67s	2.50E
Ca Cl_2 (4%)	3.77a	3.27cd	2.90gh	2.60j	2.13mn	1.93pq	2.77B
SA (100 ppm)	3.57b	3.00fg	2.87h	2.60j	2.23lm	1.77rs	2.67C
SA (200 ppm)	2.87h	2.60j	2.47k	1.90pq	1.40t	1.03u	2.04F
K_2SiO_3 (1500 ppm)	3.37c	3.07ef	2.90gh	2.50jk	2.07no	1.87qr	2.63D
K_2SiO_3 (2000 ppm)	3.83a	3.30c	3.17de	2.93gh	2.60j	2.27l	3.02A
Mean	3.31A	2.90B	2.65C	2.25D	1.86F	1.55F	
	2nd season: 2020						
Control	2.70m	2.13qr	1.90u	1.60w	0.83y	0.50z	1.61G
Ca Cl_2 (2%)	3.33e	2.93ij	2.60n	2.37p	2.07rs	1.77v	2.51E
Ca Cl_2 (4%)	3.87b	3.20f	2.87jk	2.77lm	2.37p	2.00st	2.84B
SA (100 ppm)	3.57cd	3.10g	2.87jk	2.83kl	2.40p	1.87u	2.77C
SA (200 ppm)	3.03gh	2.40p	2.40p	2.17q	1.93tu	1.37x	2.22F
K_2SiO_3 (1500 ppm)	3.60c	2.97hi	2.73m	2.57no	2.40p	2.07rs	2.72D
K_2SiO_3 (2000 ppm)	4.00a	3.50d	3.23f	3.07g	2.73m	2.50o	3.17A
Mean	3.44A	2.89B	2.66C	2.48D	2.10E	1.72F	

*Note: Different letters indicate significantly different values by ANOVA followed by Duncan test at P≤0.05 (small letters refer to values recorder in each season, different capital letters refer to mean values)

Chemical characteristics

Total soluble solids TSS %

Regarding the storage period data, Table 4 shows that, irrespective to treatments, TSS percentage was slightly affected by the storage duration, in harmony with what reported by Ranjbaran *et al*. (2011) who mentioned that the soluble solid content (SSC) increased with storage in all treated and untreated clusters. SSC increased significantly with storage time and coincided with the increase in water loss. It is most likely that

the increased SSC is due to the concentration of juice during storage. In this context, Cirami *et al*. (1992) explained that grapes are non-climacteric type of fruit, and show very low respiration rates. Therefore, there is low consumption of sugar for respiration during postharvest life in grapes. TSS content was markedly influenced by the treatments with K_2SiO_3 at 2000 ppm it significantly recorded the highest TSS values, followed by SA at concentration of 100 ppm, in both the tested seasons. These results are in harmony with those mentioned by Peyro *et al*. (2017) as they stated that the application of 2 mmol SA increased the content of total soluble solids to the highest level of 428.43 g/100 g fruit juice. On the contrary, Ranjbaran *et al*. (2011) stated that SSC in berries were not significantly affected by SA treatments.

Titratable Acidity (TA %)

Data of Table 5 shows that acidity decreased gradually along with the increasing of the storage period, and this was true for both studied seasons, regardless of treatments and in accordance with Ball (1997). It has been suggested that total acidity decreases in fruits as a result of breakup of acids to sugars during respiration. Lowest percentage of TA was recorded on berries treated with 2000 ppm of K_2SiO_3, followed by the treatments of SA at 100 ppm, and 4% of $CaCl_2$. In the meantime, SA at 200 ppm showed the highest significant TA percentages, comparing to control and other treatments; this trend was observed in both the studied seasons, in accordance with what was observed by Darshani and Dilshan (2015). The obtained results were in agreements also with those recorded by El Kholy *et al*. (2018) who mentioned that pre-harvest sprays of K_2SiO_3, reduced relatively the TA. In addition, Hoda *et al*. (2018) mentioned that foliar spray treatments with SA and K_2SiO_3 decreased the percentage of citrus fruit acidity content as compared with control treatment. Tripathi *et al*. (2013) illustrated that application of Si enhances the growth, yield, and fruit quality. Low acidity content may due to the increase in total soluble solids in the fruits. (Bhavya, 2010; Hanumanthaiah *et al*., 2015).

Table 4. TSS: effect of pre-harvest application of SA, K_2SiO_3, and $CaCl_2$, on TSS percentage of 'Arra18' table grape cultivar (2019-2020 seasons) during cold storage at 0±1 °C

Storage period (wks.) / Treatments	0	1	2	3	4	5	Mean
	1st season: 2019						
Control	17.30w*	18.40rs	18.73pq	18.87o-q	16.57x	15.47y	17.57G
Ca Cl_2 (2%)	17.97u	18.70q	18.97no	19.23lm	19.40kl	21.20e	19.24F
Ca Cl_2 (4%)	18.23st	18.67q	19.53jk	20.17h	21.00f	22.53c	20.02D
SA (100 ppm)	18.10tu	18.87o-q	19.67ij	19.83i	21.37v	22.97b	20.13C
SA (200 ppm)	17.73v	18.93n-p	19.27lm	19.63ij	19.80i	20.97f	19.39E
K_2SiO_3 (1500 ppm)	18.23st	19.13mn	20.13h	20.77g	21.30e	22.87b	20.41B
K_2SiO_3 (2000 ppm)	18.47r	19.80i	20.60g	21.73d	22.77b	23.87a	21.21A
Mean	18.00F	18.93E	19.56D	20.03C	20.31B	21.41A	
	2nd season: 2020						
Control	16.73x	18.20u	19.23r	20.47lm	16.37y	15.40z	17.73G
Ca Cl_2 (2%)	17.67w	19.60q	20.13o	21.33i	21.77g	22.53e	20.51E
Ca Cl_2 (4%)	18.00v	19.70pq	20.27no	21.87g	22.83d	23.57b	21.04C
SA (100 ppm)	18.10uv	19.63pq	20.63k	21.87g	22.93cd	23.70b	21.14B
SA (200 ppm)	17.77p	18.92s	19.30r	19.77p	20.60kl	21.47hi	19.64F
K_2SiO_3 (1500 ppm)	18.17u	18.83s	20.40mn	21.53h	22.27f	23.00c	20.70D
K_2SiO_3 (2000 ppm)	18.40t	19.20r	21.00j	21.90g	22.53e	24.53a	21.26A
Mean	17.83F	19.15E	20.14D	21.25C	21.33B	22.03A	

*Note: Different letters indicate significantly different values by ANOVA followed by Duncan test at P≤0.05 (small letters refer to values recorder in each season, different capital letters refer to mean values)

Anthocyanin (mg/100 ml)

Anthocyanins are responsible for the desirable red colour of many other red-coloured fruit juices (Li *et al*., 2010). Table 6 shows that anthocyanin content significantly decreased throughout the storage periods in both the seasons, and this was regardless the applied treatments. It should be noted that berries treated with

K_2SiO_3 at 2000 ppm at initial time soon after harvest showed the highest significant values of anthocyanin content, comparing to control and other treatments. These results are in accordance with those of Caleb *et al*. (2013) and Arendse et al. (2014) who reported a significant effect of storage duration on the total anthocyanin content of pomegranates, with a general trend of a decrease in total anthocyanin content as the storage time increases. The decrease in phenolic concentration, including anthocyanin, could be attributed to the change of enzyme activities resulting to phenolic degradation (Fawole and Opara, 2013). Furthermore, loss of anthocyanin could be attributed to many other factors, such as pH and acidity, phenolic compounds, sugars and sugar degradation products, oxygen, ascorbic acid, fruit maturity and thawing time (Withy *et al*., 1993; García-Viguera *et al*., 1998).

Table 5. Acidity: effect of pre-harvest application of SA, K_2SiO_3, and $CaCl_2$, on titratable acidity percentage of 'Arra18' table grape cultivar (2019-2020 seasons) during cold storage at 0±1°C

Storage period (wks.) / Treatments	0	1	2	3	4	5	Mean
	1st season: 2019						
Control	1.73a*	1.37cd	1.123f-h	0.87lm	0.67p-r	0.43s	1.03C
Ca Cl_2 (2%)	1.43bc	1.33d	1.17e-g	0.97jk	0.80mn	0.70o-q	1.07B
Ca Cl_2 (4%)	1.33d	1.17e-g	1.03ij	0.90kl	0.77no	0.63qr	0.97D
SA (100 ppm)	1.37cd	1.07hi	0.97jk	0.93kl	0.73n-p	0.60r	0.94D
SA (200 ppm)	1.47b	1.23e	1.13f-h	1.03ij	0.97jk	0.80mn	1.11A
K_2SiO_3 (1500 ppm)	1.33d	1.20ef	1.10g-i	1.07hi	0.73n-p	0.67p-r	1.02C
K_2SiO_3 (2000 ppm)	1.20ef	0.97jk	0.90kl	0.80mn	0.63qr	0.47s	0.83E
Mean	1.41A	1.19B	1.06C	0.94D	0.76E	0.61F	
	2nd season: 2020						
Control	1.37a	1.17b	0.90f-i	0.80i-k	0.33o	0.20p	0.79F
Ca Cl_2 (2%)	1.13bc	1.10bc	0.97d-g	0.93e-h	0.90f-i	0.83h-k	0.98B
Ca Cl_2 (4%)	1.00d-f	1.00d-f	0.90f-i	0.83h-k	0.80i-k	0.77j-l	0.88D
SA (100 ppm)	0.93e-h	0.93e-h	0.93e-h	0.87g-j	0.77j-l	0.63m	0.84E
SA (200 ppm)	1.30a	1.10bc	1.03c-e	0.97d-g	0.90f-i	0.87g-j	1.03A
K_2SiO_3 (1500 ppm)	1.13bc	1.07b-d	1.00d-f	0.90f-i	0.80i-k	0.73kl	0.94C
K_2SiO_3 (2000 ppm)	0.83h-k	0.83h-k	0.77j-l	0.73kl	0.67lm	0.53n	0.73G
Mean	1.10A	1.03B	0.93C	0.86D	0.74E	0.65F	

*Note: Different letters indicate significantly different values by ANOVA followed by Duncan test at P≤0.05 (small letters refer to values recorder in each season, different capital letters refer to mean values)

Generally, all treatments showed an impactful effect on fruit anthocyanin content compared to control. However, at the end of the storage period, K_2SiO_3 at both concentrations and SA at 100 ppm maintained significantly highest anthocyanin content. In the meantime, K_2SiO_3 at 2000 ppm showed the highest significant mean values of anthocyanin concentrations, followed by SA at 100 ppm and K_2SiO_3 at 1500 ppm, while untreated grapes (control) exerted an opposite trend and this was true in both the studied seasons. The results are in agreement with those obtained by Shaarawi *et al*. (2016), as they reported that SA at 2 mM maintained the highest value of anthocyanin after 12 days of storage of pomegranate arils. They are also in accordance with Sayyari *et al*. (2011) who showed that SA maintains high levels of bioactive compounds, such as total anthocyanin. Singh *et al*. (2020) examined the effect of potassium silicate treatments on anthocyanin content, reporting that total anthocyanins in grapevines treated with 0.05% potassium compared to control sample demonstrated the highest value of total anthocyanins. In addition, anthocyanin of Hibiscus roselle calyces were significantly and gradually increased with the foliar spray of potassium silicate (Abdou *et al*., 2022). The effect K_2SiO_3 may due to enhancing the physiological response of plant leaves by increasing the photosynthetic pigments, compatible solutes, and enzyme activity (El-Sheery, 2017).

Table 6. Anthocyanin: effect of pre-harvest application of SA, K_2SiO_3, and $CaCl_2$, on anthocyanin concentration (mg/100g) of 'Arra18' table grape cultivar (2019-2020 seasons) during cold storage at 0±1°C

Storage period (wks.) / Treatments	0	1	2	3	4	5	Mean
	1st season: 2019						
Control	1.53l*	1.94k	2.21ij	2.39g-i	1.51l	0.77m	1.73F
Ca Cl_2 (2%)	2.32h-j	2.51f-h	2.57c-g	2.62b-f	2.65b-f	2.68b-f	2.56D
Ca Cl_2 (4%)	2.54e-g	2.63b-f	2.65b-f	2.67b-f	2.69b-f	2.75a-f	2.65C
SA (100 ppm)	2.68b-f	2.73a-f	2.76a-f	2.78a-e	2.80a-d	2.82ab	2.76B
SA (200 ppm)	2.13jk	2.24ij	2.52f-h	2.58b-g	2.63b-f	2.65b-f	2.46E
K_2SiO_3 (1500 ppm)	2.57d-g	2.68b-f	2.71a-f	2.71a-f	2.76a-f	2.82a-c	2.71BC
K_2SiO_3 (2000 ppm)	2.93a	2.93a	2.94a	2.94a	2.94a	2.95a	2.94A
Mean	2.39E	2.52CD	2.62AB	2.67A	2.57BC	2.49D	
	2nd season: 2020						
Control	1.59r	1.72qr	1.83q	2.44m-o	1.74qr	0.81s	1.69E
Ca Cl_2 (2%)	2.38no	2.46l-o	2.54k-o	2.60j-m	2.65h-l	2.69g-k	2.55D
Ca Cl_2 (4%)	2.58j-n	2.62i-m	2.65i-l	2.59j-n	2.78b-j	2.80a-j	2.67C
SA (100 ppm)	2.74f-k	2.76c-j	2.79a-j	2.82a-i	2.83a-i	2.87a-g	2.80B
SA (200 ppm)	2.16p	2.36o	2.43m-o	2.58j-n	2.66g-l	2.72g-k	2.49D
K_2SiO_3 (1500 ppm)	2.75e-k	2.76d-j	2.77c-j	2.79a-j	2.87a-h	2.94a-f	2.81B
K_2SiO_3 (2000 ppm)	2.95a-e	2.63i-m	2.97a-d	2.98a-c	2.98ab	2.99a	2.92A
Mean	2.45C	2.47C	2.57B	2.69A	2.65A	2.54B	

*Note: Different letters indicate significantly different values by ANOVA followed by Duncan test at P≤0.05 (small letters refer to values recorder in each season, different capital letters refer to mean values)

Total sugars (%)

Total sugar content showed a marked increase as the storage period increased (Table 7). All treatments significantly resulted in higher content of total sugar comparing to control. However, the treatment of K_2SiO_3 at 2000 ppm significantly recorded the highest content of total sugars, and was followed by both treatments of $CaCl_2$ at 4% and SA at 100 ppm in both the studied seasons. Untreated berries showed the lowest significant total sugar content.

Table 7. Total sugar: effect of pre-harvest application of SA, K_2SiO_3, and Ca Cl_2, on total sugar percentage of 'Arra18' table grape cultivar (2019-2020 seasons) during cold storage at 0±1°C.

Storage period (wks.) / Treatments	0	1	2	3	4	5	Mean
	1st season: 2019						
Control	12.25s*	14.72n-q	14.88k-p	15.14h-o	13.25r	10.37t	13.44D
Ca Cl_2 (2%)	13.45r	14.96i-o	15.17h-o	15.39h-k	15.49g-i	16.61d	15.18C
Ca Cl_2 (4%)	14.24q	14.93j-o	15.44g-j	15.59gh	16.21d-f	17.59gh	15.67B
SA (100 ppm)	14.29q	14.83m-p	15.28h-m	15.57gh	16.16d-f	17.79ab	15.65B
SA (200 ppm)	13.33r	14.81m-p	14.98i-o	15.37h-l	15.51gh	16.15d-f	15.03C
K_2SiO_3 (1500 ppm)	14.40pq	14.80m-p	15.07h-o	15.53gh	16.10ef	17.25c	15.52B
K_2SiO_3 (2000 ppm)	14.64o-q	14.85l-p	15.20h-n	15.93fg	16.47de	18.23a	15.89A
Mean	13.80E	14.84D	15.15C	15.50B	15.60B	16.28A	
	2nd season: 2020						
Control	12.56u	14.08s	15.36no	15.81j-m	13.36t	11.65v	13.80E
Ca Cl_2 (2%)	13.51t	15.35no	16.11i-k	16.38hi	17.07f	17.69cd	16.02D
Ca Cl_2 (4%)	14.30rs	15.49mn	16.21ij	16.96fg	17.65cd	18.52b	16.52B
SA (100 ppm)	14.48qr	15.71k-n	15.97j-l	17.23ef	17.85c	18.51b	16.62B
SA (200 ppm)	13.67t	14.55qr	15.57l-n	15.81j-m	16.61gh	17.33d-f	15.59E
K_2SiO_3 (1500 ppm)	14.54qr	15.07op	15.73k-n	16.63gh	17.81c	18.40b	16.36C
K_2SiO_3 (2000 ppm)	14.77pq	15.36no	16.00i-k	17.52c-e	18.36b	19.17a	16.86A
Mean	13.98F	15.09E	15.85D	16.62C	16.96B	17.33A	

*Note: Different letters indicate significantly different values by ANOVA followed by Duncan test at P≤0.05 (small letters refer to values recorder in each season, different capital letters refer to mean values)

The higher sugar contents in treated grapes may due to the fact that cell walls contain large amounts of polysaccharides, mainly pectin and cellulose, and this was in line with Srivastava and Dwivedi (2000) who hypothesized that polysaccharides were digested due to the activity of the cell wall-degrading enzymes, leading to a significant increase in TSS content. Similarly, Shaarawi *et al*. (2016) demonstrated higher sugar contents in SA- and $CaCl_2$-treated wonderful pomegranate arils. Results are also consistent with the findings obtained on 'Bengaluru blue' grapes (Bhavya, 2010), and banana (Hanumanthaiah *et al*., 2015) after foliar treatments with Si and potassium that helped in the synthesis of more sugars in the fruits. The effect of $CaCl_2$ was reported by Ashour (2000), as this Author found that foliar application of Ca gave higher average of total sugars in fruits than control. Similar findings have been also reported when some apple cultivars were sprayed with $CaCl_2$ as sugars in fruit were increased during storage (Ramdane, 2002). Meanwhile, Raja *et al*. (2015) stated the contrary, since they indicated that the minimum total sugar content was obtained in fruits treated with $CaCl_2$ at 1.5%, while the maximum was recorded in untreated fruits.

Conclusions

In this study, treatments were applied as foliar sprays at three different stages during the growing season before harvest. 'ARRA18' trees were sprayed with K_2SiO_3, SA, and $CaCl_2$, while untreated vine trees sprayed with water served as control. Mature clusters were harvested, then placed in carton containers and stored in cold storage at 0±1 °C to study the storability of 'ARRA18', and records of physical and chemical quality parameters were taken at 7-day intervals. Based on the obtained data one can conclude that overall quality parameters were markedly maintained by all treatments, compared to control. The use of K_2SiO_3 at both applied concentrations, and particularly at 2000 ppm, SA at 100 ppm, significantly proved to be the most effective treatments in keeping the overall quality of stored grapes.

Authors' Contributions

All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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