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Improving yield, quality, and storability of Thompson seedless grape by foliar application of potassium

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Abstract

This study was carried out during the two successive seasons 2022 and 2023 on 15-years-old "Thompson seedless grapes" grown at Assiut governorate, Egypt, to study the effect of four foliar spray treatments: control (spraying with water, T1), potassium nitrate (36% K_2O, T2), potassium citrate (40% K_2O, T3), and potassium thiosulfate (36% K_2O, T4) as preharvest on yield, berry quality, storability quality parameters, and enzyme activity of Thompson Seedless Grapes. All vines were sprayed three times during the growing season (end of May, mid-June, and first of July). Treated clusters were stored at 2±2°C and 85-90% RH for 5 weeks. The results showed that all treatments significantly improved the quantity and quality at harvest of "Thompson Seedless Grapes" potassium citrate or potassium thiosulfate treatment at 0.2% K_2O increased cluster weight, yield (kg/vine) and yield (ton/ha), berry weight, and berry diameter, while potassium nitrate increased leaf area (cm^2), juice weight %. Throughout cold storage at 2±2°C and 85-90% RH for 5 weeks, foliar application of different sources of potassium decreased weight loss %, shattering %, decay %, total loss % and maintained quality and increased antioxidant enzyme activities in the end storage period. The best potassium spray treatments were potassium citrate or potassium thiosulfate to improve the yield and quality at harvest, as well as reduce weight loss, shattering %, decay %, total loss % and the best quality during storage.

Keywords: antioxidant enzymes, grapes, malondialdehyde (MDA), potassium, storage.

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1. Introduction

Grapes are of great importance, both in terms of local consumption and exportation. The total area of vineyards in the world reached 11.0 million hectares with a total production of 90.0-million tons (FAO, 2019). In Egypt, it ranks third behind citrus and mango in terms of the cultivated area and the magnitude of the yield. The total area reached was 190,486 feddan, and the fruiting area was 174,715 feddan that produced about 1,594,781 tons of fruits, or about 9.128 tons per feddan. In addition, grapes are considered the most important export horticultural crop, and its export value is about 10% while the quantity is about 3% of total horticultural export (M.A.L.R., 2019). Thompson Seedless grapevines are a popular grape grown in Egypt. Increasing demand for grape production requires a new strategy. However, it is smaller in size. Also, numerous physiological and biochemical processes in the fresh grape, including nutrient intake, increased respiration, and water loss, cause the grape quality to decline during storage (Sabir and Sabir, 2013). Potassium intake is linked to human health. (Cowan *et al*., 2020). Adequate supply of potassium to crops is essential for the production of high-quality foods (Holland *et al*., 2019; Pettigrew, 2008; Valentinuzzi *et al*., 2018). Therefore, adequate supplies of K fertilizer are needed not only to produce foods with sufficient K^+ concentration for a balanced human diet (Holland *et al*., 2019; Valentinuzzi *et al*., 2018; Wu *et al*., 2014), but also to improve fruit quality, as potassium availability is associated with a rise in concentrations of sugars, soluble solids (Valentinuzzi *et al*., 2018), and antioxidants such as phenolics (Preciado-Rangel *et al*., 2018). In crops, K^+ maintains adequate leaf inclination by turgor control (Carroll *et al*., 1994), enhances photosynthetic assimilation, and improves nutrient uptake (Sustr *et al*., 2019). Thus, potassium has a key role in the mechanism that controls the transport of nutrients, water, and metabolites across plant tissues and organs. also, maintenance of osmotic homeostasis and plant defense against oxidative stresses (Cuin *et al*., 2018; Lu *et al*., 2016; Srivastava *et al*., 2019). Adequate K nutrition has been associated with increased shelf life, storage, and shipping quality of many horticultural crops (Geraldson, 1985; Lester *et al*., 2007). Previous studies have shown different effects of different forms of potassium on yield, fruit quality, and post-harvest traits, with different results depending on methods and frequency of application, as well as crop type and stages of fruit growth (Awad *et al*., 2014; Yousuf *et al*., 2018). However, no previous studies compared, among K sources, and K source could be applied to grapes. Based on the above, the aim of this paper is to study the physiological and levels of bioactive compounds effects of pre-harvest foliar application of different sources of potassium: potassium nitrate, potassium sulphate, and potassium citrate's effects on fruit yield, quality, and the storability of Thompson seedless grapes.

2. Materials and methods

2.1 Experimental site and treatments description

The field trial was conducted during two successive growing seasons, 2022 and 2023, at a private vineyard in Assiut, Egypt. The soil has a clay texture and is well drained, and a surface irrigation system was used to water the tested vineyard. The trial was conducted on a vigorous, fruitful 'Thompson Seedless' (*Vitis vinefera* L.) cultivar with a 10-year-old grapevine and was planted at a distance of 2 m along the row and 2.5 m between the row (2000 vines ha^{-1}).

2.2 Experimental design

The experiment was performed as a randomized complete block design with three replications, with each replicate consisting of two uniform grapevines. The experiment was set up with four foliar spray treatments: control (spraying with water, T1), potassium nitrate (36% K_2O, T2), potassium citrate (40% K_2O, T3), and potassium thiosulfate (36% K_2O, T4). The treatment solution was sprayed at the rate of 0.2% K_2O three times during the growing season (end of May, mid-June, and first of July).

2.3 Samples collections

At the harvest stage, clusters were collected from each replicate and picked up in the earlier morning and then transported to the Plant Physiology Laboratory, Faculty of Science, Assiut University, Egypt. The samples collected were divided into two groups. The first group consists of two clusters for each replicate to measure the quantity and quality parameters. While the second group was used for storage experiments.

2.4 Vegetative growth and yield parameters

The average leaf area (cm^2) was measured according to the equation reported by Ahmed and Morsy (1999). The sample consisted of 20 leaves for each grapevine from those opposite to basal clusters. At harvest time, the grapevine productivity was recorded (kg/vine). Two randomly selected clusters of each grapevine were selected to measure cluster weight (g), berry weight (g), and berry length and width (mm).

2.5 Storage experiment

In this experiment, five storage periods were done, and the duration of each storage period was one week. The harvested clusters were packed in perforated plastic bags and divided into two groups; the first group included two clusters for each replicate/storage period to measure physiological parameters. However, the second group consists of one cluster for each replicate/storage period to perform the biochemical analysis at each storage period. The prepared plastic bags were stored at 2±2 ºC and 85-90% RH.

2.5.1 Physiological parameters

Weight loss (%) = (Initial cluster weight - Final cluster weight / Initial cluster weight) × 100. The shattered berries were calculated by dividing the shattered berries weight by cluster weight before the shaking and expressed as percentage. Decayed berries were separated, weighted, and expressed as percentage per cluster weight. Total loss in cluster weight percentage was calculated by percentage sum of cluster weight loss, berry shatter, and decayed berries.

2.5.2 Biochemical analysis

The following biochemical analyses were performed at harvest time and at each storage period. Soluble solid contents (TSS) of berry juice were measured using the hand refractometer apparatus and expressed as a percentage. Titratable acidity was determined as mg of tartaric acid equivalent using NaOH (0.1 N) in 100 ml of berry juice according to A.O.A.C. (2000). TSS: acid ratio was calculated.

2.5.3 Determination of malondialdehyde

Malondialdehyde (MDA), a reactive metabolite of 2-thiobarbituric acid (TBA), was used to measure the amount of lipid peroxidation in the grapes fruit tissues. In short, 2.5 ml of 0.1% w/v trichloroacetic acid (TCA) was used to homogenize 0.45 g of samples. This was followed by 5 minutes of centrifugation at 2400 g. Four milliliters of 20% w/v TCA containing 0.5% w/v TBA were combined with an aliquot of supernatant (1 mL). An ice bath was used to quickly chill the mixture after it had been heated to 95°C for 30 minutes. The mixture was centrifuged for 15 minutes at 2400 g, and the supernatant's absorbance was measured at 450, 532, and 600 nm. The following equation (Hodges *et al*., 1999) was used to express the MDA concentration as µmol g^{-1} DW.

2.5.4 Determination of antioxidant enzymes

After homogenizing fresh weight in potassium phosphate buffer (50 mM, pH 7) with polyvinylpyrrolidone and ethylenediamine tetra acetic acid (0.2 mM), centrifugation at 4800 g for 20 minutes was performed. Ascorbate peroxidase, peroxidase, and catalase were all quantified using the supernatant. The Lowry technique was used to determine the extract's protein content (Lowry *et al*., 1951). The activity of catalase (CAT, EC 1.11.1.6) was determined using Aebi's technique (Aebi, 1984). 100 µL of the enzymatic extract and 2.85 mL of phosphate buffer (PB) (50 mM, pH 7) made up the reaction media. 50 µL of 10 mM H_2O_2 was added to start the reaction, and the absorbance at 240 nm decreased for 60 seconds. The rate at which ascorbic acid is oxidized in a hydrogen peroxide-dependent manner is known as ascorbate peroxidase (APX, EC 1.11.1.11) activity (Nakano and Asada, 1987). 2.85 mL of PB (50 mM, pH 7) was combined with 100 µl of enzyme extract, H_2O_2 (100 µL, 5 mM), Na_2-EDTA (0.1 mM), and ascorbic acid (50 µL, 0.5 mM) in the reaction mixture. The decrease in absorbance at 290 nm for 60 seconds was used to determine the amount of ascorbic acid that was oxidized. The rate at which guaiacol dehydrogenates at 436 nm was used to calculate the activity of peroxidase (POD) (Pütter, 1974). 3 mL of PB (50 mM, pH 7) was combined with 50 µL of guaiacol (20 mM), 30 µL of H_2O_2 (12 mM), and 100 µl of enzyme extract in the reaction mixture.

2.6 Statistical analysis

To check the significance of differences among treatments, the obtained data of both seasons were subjected to analysis of variance using Statistix 8.1 software (Analytical Software, 2005). Means were compared for significant differences using the Tukey test at P = 0.05. Data were presented as the means ± standard deviations.

3. Results

3.1 Vegetative growth and yield parameters

3.1.1 Vegetative growth (Leaf area, cm^2)

It is clear from the data in Figure (1) that foliar application of different sources of potassium significantly resulted in an obvious promotion on the leaf area (cm^2). Similar results were announced during both seasons. The maximum values recorded on vines that sprayed with K-nitrate were 203.33 and 206.00 cm^2 during both seasons, respectively. Also, there was no significant difference or effect between spraying grape vines with potassium thiosulfate and potassium citrate in both seasons of the study. On the other hand, the minimum values of these traits were recorded on spraying vine with water (control) at 184.00 and 186.33 cm in the two studied seasons, respectively.

3.1.2 Cluster and yield traits: cluster weight (g), yield per vine (kg), and yield per ha (ton)

Figure (2) shows that spraying K-nitrate, K-citrate, or K-thiosulfate significantly with improved the yield expressed in cluster weight (g), yield (kg/vine), and yield (ton/ha) of Thompson Seedless Grapes in the 2022 and 2023 seasons. The experimental results showed the highest values for yield parameters, *viz*., cluster weight (442 and 451.67 g), yield (kg/vine) (11.49 and 12.20 kg/vine), and yield (ton/ha) (22.98 and 24.39 ton/ha) in vines that were sprayed with K-citrate during the 1st and 2nd seasons, respectively, compared to other treatments. The lowest cluster weight (348.00 and 350.67 g), yield (kg/vine) (9.05 and 9.47 kg/vine), and yield (ton/ha) (18.10 and 18.94 ton/ha) were recorded in the control in the first and second seasons, respectively. The highest increase percentage of yield (ton/ha) compared to control was observed when grapes vines were treated with K-citrate, which was 27.01 and 28.80%, then treated with K-thiosulfate, which amounted to (25.48 and 25.76%), followed by treated with K-nitrate (18.20 and 18.63%) in the first and second seasons, respectively.

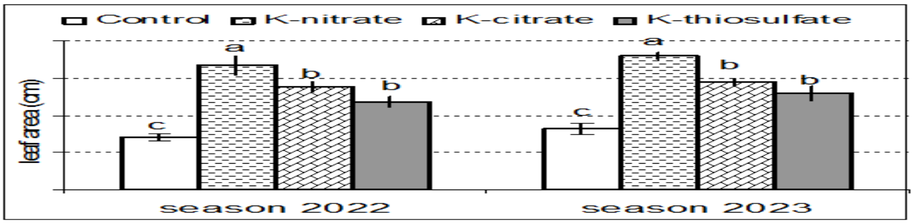

Figure (1): Influence of foliar application of different sources of potassium on leaf area (cm^2) of Thompson seedless grapes in the 2022 and 2023 seasons. Data were presented as means ± SDs, and the different upper letters indicate significant differences at the *P*<0.05 level according to the Tukey test.

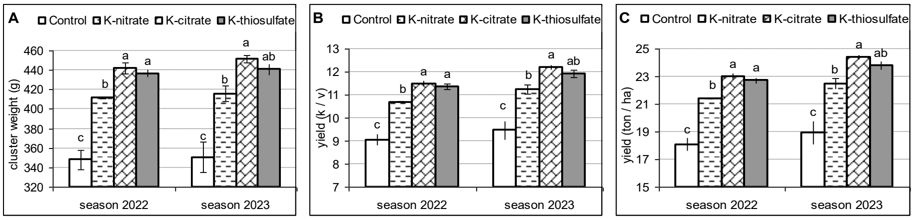

Figure (2): Influence of foliar application of different sources of potassium on (A) cluster weight (g), (B) yield (kg/vine), and (C) yield (ton/ha) Thompson seedless grapes in the 2022 and 2023 seasons. Data were presented as means ± SDs, and the different upper letters indicate significant differences at the *P*<0.05 level according to the Tukey test.

3.1.3 Physical properties of berries (berry weight (g), length (mm), diameter (mm), and juice weight (%)

As shown in the data presented in Figure (3), all treatments increased significantly berry weight, length, diameter, and juice weight % compared to control (water sprayed), The highest significant values were 1.70 and 1.74 g for berry weight and 14.93 and 15.17 mm for berry diameter recorded due to spraying with K-citrate in the two examined seasons, respectively. Likewise, the significantly lowest values of 1.37 and 1.37 g for berry weight and 12.00 and 11.87 mm for berry diameter were recorded for the control of the two seasons, respectively. The lowest values were recorded in berry length (13.57 and 13.47 mm) with unsprayed grape vines. On the other side, spraying K-nitrate (58.77 and 58.40) was significantly preferable to using the other two sources of potassium, followed by K-citrate (58.44 and 56.86). While the lowest treatments for spraying potassium in juice weight are K-thiosulfate (56.20 and 55.57). The lowest values were recorded in juice weight (53.85 and 53.56) in both seasons, respectively.

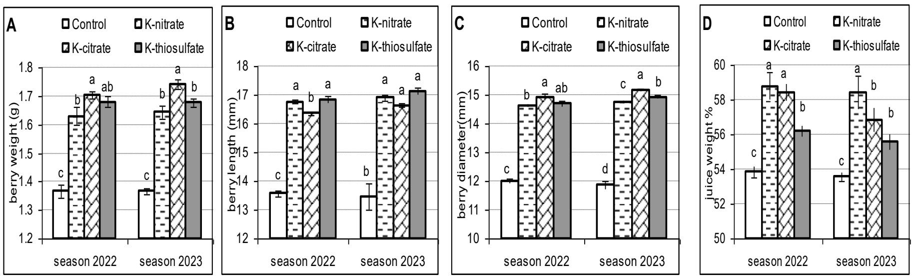

Figure (3): Influence of foliar application of different sources of potassium on (A) Berry weight (g), (B) length (mm), (C) diameter (mm), and (D) juice weight % of Thompson seedless grapes in the 2022 and 2023 seasons. Data were presented as means ± SDs, and the different upper letters indicate significant differences at the *P*<0.05 level according to the Tukey test.

3.1.4 Chemical properties of berries (TSS, TA, and TSS/TA)

Data listed in Table (1) show that foliar application of sources of potassium was significantly very effective in improving fruit quality in terms of increasing T.S.S. % and TSS/TA and reducing total acidity % in relative to the control treatment. Spraying K-thiosulfate was significantly preferable to using the other two sources of potassium in improving fruit quality. As it gave the highest values TSS/TA (47.03 and 48.68) in both seasons, respectively. On the other hand, the control treatment gave the lowest values of TSS/TA (37.48 and 40.94) in the first and second seasons, respectively.

Table (1): Influence of foliar application of different sources of potassium on (TSS%), acidity (%) and TSS/acid ratio of Thompson seedless grapes in the 2022 and 2023 seasons.

Treatments	(TSS %)		Acidity (%)		TSS /Acid ratio	
	Season 2022	Season 2023	Season 2022	Season 2023	Season 2022	Season 2023
Control	20.47±0.50 [c]	21.27±0.46[c]	0.55±0.02[a]	0.52±0.02[a]	37.48±1.98[c]	40.94±1.77[c]
K-nitrate	23.67±0.42[a]	24.33±0.58[a]	0.50±0.0[b]	0.50±0.01[ab]	41.11±6.28[b]	43.26±5.18[b]
K-citrate	22.30±0.10[b]	22.60±0.20[b]	0.42±0.0[d]	0.41±0.01[c]	44.37±4.30[a]	45.96±6.14[a]
K-thiosulfate	23.27±0.64[ab]	23.80±0.20[a]	0.47±0.01[c]	0.47±0.01[b]	47.03±1.35[ab]	48.68±1.49[b]

Data were presented as means ± SDs, and the different upper letters indicate significant differences at the *P*<0.05 level according to the Tukey test.

3.2 Storage period evaluation

3.2.1 Weight loss percentage

Data presented in Figure (4) clear a continued increase in weight loss percentage as the cold storage period increased. As a result, the highest percentage of weight loss % was obtained at the end of the storage period (after five weeks). In Figure (4), clusters treated with different sources of potassium were less in weight loss % than those untreated during different cold storage periods. Moreover, the percentage of weight loss was lower when sprayed with K-citrate. Compared to other potassium spray treatments (10.33 and 9.41% in 1st and 2nd seasons, respectively) at five weeks.

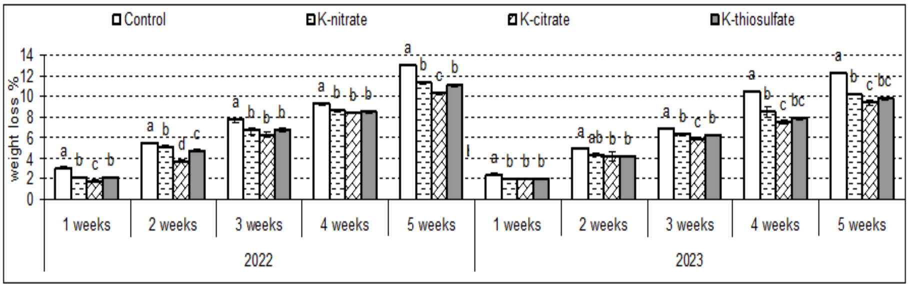

Figure (4): Influence of foliar application of different sources of potassium on weight loss% of Thompson seedless grapes during storage at (2±2 ºC) and 85 - 90% RH in 2022 and 2023 seasons. Data were presented as means ± SDs, and the different upper letters indicate significant differences at the *P*<0.05 level according to the Tukey test.

3.2.2 Shatter %

Data presented in Table (2) show a continued increase in shatter percentage as the cold storage period increased. As a result, the highest percentage of shatter % was obtained at the end of the storage period (after five weeks). The highest percentage of shatter % was obtained from the control treatment compared with other treatments, which were 0.93 and 0.64% at 1st week, 1.32 and 0.74% at 2nd week, 2.46 and 1.85% at 3rd week, 5.65 and 4.36% at 4th week; however, at 5th weeks, it was 11.19 and 10.52% in both seasons, respectively. From Table (2), the results also show spraying grape vines with potassium nitrate, potassium citrate, and potassium thiosulfate to reduce the shatter percentage during storage at 2±2 ºC and 85-90 % RH in the 2022 and 2023 seasons. In addition, the difference between spraying treatments was very little significant.

3.2.3 Decay %

The effect of foliar application of different sources of potassium on the percentage decay of Thompson seedless grapes at different time samplings during storage was presented in Table (3). In general, decay % was gradually increased with the advancing cold storage periods in both seasons. But no decayed berry was observed in foliar application with K-citrate or K-thiosulfate in the first week of 2022 season and also in the first and second weeks of the 2023 season. We also note as in Table (3) that all potassium spraying treatments reduce the percentage of decay berries compared to the control during different storage periods. Control treatment recorded the maximum percentage of decay, which were 5.82 and 4.92% during the 2022 and 2023 seasons, respectively, at 5th week. Moreover, treatment of K-citrate or K-thiosulfate showed the highest reduction percentage in decayed percentage during the 2022 and 2023 seasons.

Table (2): Influence of foliar application of different sources of potassium on shatter % of Thompson seedless grapes during storage at (2±2 ºC) and 85-90% RH in the 2022 and 2023 seasons.

Treatment	2022					2023				
	1 weeks	2 weeks	3 weeks	4 weeks	5 weeks	1 weeks	2 weeks	3 weeks	4 weeks	5 weeks
Control	0.93 ± 0.05^{a}	1.32 ± 0.12^{a}	2.46 ± 0.36^{a}	5.65 ± 0.60^{a}	11.19 ± 0.14^{a}	0.64 ± 0.01^{a}	0.74 ± 0.09^{a}	1.85 ± 0.13^{a}	4.36 ± 0.29^{a}	10.52 ± 0.19^{a}
K-nitrate	0.40 ± 0.07^{b}	0.93 ± 0.05^{b}	1.59 ± 0.10^{b}	3.93 ± 0.02^{b}	9.97 ± 0.25^{b}	0.11 ± 0.20^{b}	0.55 ± 0.09^{ab}	1.33 ± 0.12^{b}	3.14 ± 0.08^{b}	8.65 ± 0.29^{b}
K-citrate	0.47 ± 0.09^{b}	0.64 ± 0.10^{c}	1.05 ± 0.15^{b}	2.94 ± 0.50^{c}	9.35 ± 0.25^{b}	0.13 ± 0.11^{b}	0.21 ± 0.03^{c}	1.08 ± 0.12^{b}	2.03 ± 0.44^{c}	8.64 ± 0.27^{b}
K-thiosulfate	0.44 ± 0.07^{b}	0.73 ± 0.13^{bc}	1.31 ± 0.08^{b}	3.40 ± 0.08^{bc}	10.22 ± 0.5^{b}	0.27 ± 0.24^{ab}	0.41 ± 0.07^{b}	1.12 ± 0.06^{b}	2.88 ± 0.23^{b}	9.53 ± 0.40^{b}

Data were presented as means ± SDs, and the different upper letters indicate significant differences at the *P*<0.05 level according to the Tukey test.

Table (3): Influence of foliar application of different sources of potassium on decay % of Thompson seedless grapes during storage at (2±2 ºC) and 85-90% RH in the 2022 and 2023 seasons.

Treatment	2022					2023				
	1 weeks	2 weeks	3 weeks	4 weeks	5 weeks	1 weeks	2 weeks	3 weeks	4 weeks	5 weeks
Control	0.52 ± 0.11^{a}	1.23 ± 0.09^{a}	1.87 ± 0.10^{a}	3.22 ± 0.12^{a}	5.82 ± 0.85^{a}	0.00±0.00	0.80 ± 0.06^{a}	1.22 ± 0.15^{a}	2.77 ± 0.12^{a}	4.92 ± 0.35^{a}
K-nitrate	0.30 ± 0.01^{b}	0.62 ± 0.09^{ab}	1.25 ± 0.25^{b}	2.25 ± 0.29^{b}	4.88 ± 0.07^{ab}	0.00±0.00	0.49 ± 0.06^{b}	0.84 ± 0.10^{b}	1.91 ± 0.06^{b}	4.36 ± 0.10^{ab}
K-citrate	0.00 ± 0.00^{c}	0.33 ± 0.29^{b}	0.55 ± 0.02^{c}	1.04 ± 0.10^{d}	2.97 ± 0.21^{c}	0.00±0.00	0.00 ± 0.00^{c}	0.33 ± 0.13^{c}	0.73 ± 0.06^{d}	2.90 ± 0.36^{c}
K-thiosulfate	0.00 ± 0.00^{c}	0.39 ± 0.34^{b}	0.95 ± 0.14^{bc}	1.68 ± 0.06^{c}	3.77 ± 0.76^{bc}	0.00±0.00	0.00 ± 0.00^{c}	0.61 ± 0.10^{bc}	1.19 ± 0.08^{c}	3.79 ± 0.09^{b}

Data were presented as means ± SDs, and the different upper letters indicate significant differences at the *P*<0.05 level according to the Tukey test.

3.2.4 Total loss %

Effects of K-nitrate, K-citrate, and K-thiosulfate on total loss were shown in Figure (5). Clusters treated with different sources of potassium were less in total loss % than those untreated during different cold storage periods. Moreover, data also showed that the foliar application of different sources of potassium decreased total loss compared to the water sprayed (control). The best treatment concerned total loss was using K-citrate treatment, which gave the lowest values of 22.65 and 20.95%, followed by K-thiosulfate, which gave 25.08 and 23.12, followed by K-nitrate, which gave 26.13 and 23.26 at the end of the storage period during the 2022 and 2023 seasons, respectively. Data also showed that the total loss increased with the progression of the cold storage period during the two studied seasons. The highest values of total loss were recorded at the end of the storage period.

3.2.5 Juice weight %

Data presented in Table (4) show all spraying treatments with potassium reduced the percentage decrease in juice weight compared to the control. The highest rate of decrease in the percentage of juice weight at clusters untreated (control), where the percentage of juice weight decreased from 53.85 and 53.56 to 40.84 and 41.53 at the end of the storage period, *i.e*., a decrease rate of 24.16 and 22.45%. Wile, the lowest rate of decrease in the percentage of juice weight was at clusters treated with K-citrate, where the percentage of juice weight decreased from 58.44 and 56.86 to 48.25 and 47.70 at the end of the storage period, *i.e*., a decrease rate of 17.43 and 16.10% compared to the treatments of the other potassium spraying, which decreased rate of 17.88 and 17.44% at clusters treated with K-thiosulfate (18.95 and 17.47%) at clusters treated with K-nitrate after five weeks during the two studied seasons, respectively.

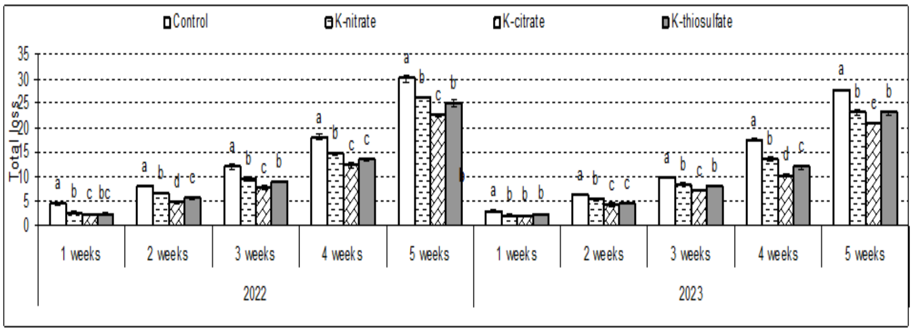

Figure (5): Influence of foliar application of different sources of potassium on Total loss % of Thompson seedless grapes during storage at (2±2 ºC) and 85-90% RH in the 2022 and 2023 seasons. Data were presented as means ± SDs, and the different upper letters indicate significant differences at the *P*<0.05 level according to the Tukey test.

Table (4): Influence of foliar application of different sources of potassium on juice weight % of Thompson seedless grapes during storage at 2±2 ºC and 85-90% RH in the 2022 and 2023 seasons.

Treatment	2022					2023				
	1 weeks	2 weeks	3 weeks	4 weeks	5 weeks	1 weeks	2 weeks	3 weeks	4 weeks	5 weeks
Control	50.90±0.10^{c}	48.53±0.16^{d}	46.73±0.24^{c}	44.81±0.22^{c}	40.84±0.14^{c}	51.22±0.10^{d}	48.79±0.22^{d}	47.02±0.07^{d}	43.23±0.24^{d}	41.53±0.25^{d}
K-nitrate	57.05±0.65^{a}	53.72±0.07^{b}	52.12±0.07^{a}	50.22±0.10^{a}	47.64±0.15^{a}	56.43±0.06^{a}	54.21±0.25^{a}	52.21±0.09^{a}	49.91±0.08^{a}	48.20±0.11^{a}
K-citrate	56.70±0.10^{a}	54.72±0.04^{a}	52.22±0.07^{a}	50.03±0.07^{a}	48.25±0.05^{a}	54.97±0.04^{b}	52.83±0.10^{b}	51.14±0.14^{b}	49.36±0.05^{b}	47.70±0.28^{b}
K-thiosulfate	54.14±0.17^{b}	51.47±0.05^{c}	49.22±0.07^{b}	47.75±0.05^{b}	46.15±1.02^{b}	53.73±0.10^{c}	51.43±0.06^{c}	49.24±0.66^{c}	47.75±0.06^{c}	45.88±0.13^{c}

Data were presented as means ± SDs, and the different upper letters indicate significant differences at the *P*<0.05 level according to the Tukey test.

3.2.6 TSS %

Data in Table (5) show the influence of foliar application of different sources of potassium on the content of the total soluble solids during storage at 2±2 ºC and 85-90% RH in the 2022 and 2023 seasons. The percentage of TSS at one, two, three, four, and five weeks during cold storage was measured (Table 5).

Obtained data revealed that TSS was gradually increased with the advancement of cold storage duration in the 2022 and 2023 seasons. The results also show that all potassium spraying treatments had higher values of TSS than the control during different storage periods. The minimum value of TSS was recorded in the juice of Thompson Seedless Grapes untreated (control), which were 20.57, 20.80, 20.97, 21.50, and 22.60 in the 1st seasons and 22.07, 22.83, 22.97, 24.83, and 25.20 at one, two, three, four and five weeks in the 2nd seasons, respectively. However, K-nitrate treatment showed the highest TSS content, which were 23.83, 24.03, 24.13, 24.20 and 24.83 in the 1st seasons and 24.57, 24.83, 25.43, 25.67, and 26.60 in the 2nd seasons at one, two, three, four, and five weeks, respectively. However, the rate of increase in TSS values was higher in the control (9.44 and 15.61%) compared to the rest of the treatments, and the lowest rate of increase was in treatment with K-citrate (3.32 and 6.87%) from harvest until the end of the storage period in the two studied seasons, respectively.

Table (5): Influence of foliar application of different sources of potassium on TSS % of Thompson seedless grapes during storage at 2±2 ºC and 85-90% RH in 2022 and 2023 seasons.

Treatment	2022					2023				
	1 weeks	2 weeks	3 weeks	4 weeks	5 weeks	1 weeks	2 weeks	3 weeks	4 weeks	5 weeks
Control	20.57±0.06^{d}	20.80±0.10^{d}	20.97±0.06^{d}	21.50±0.50^{c}	22.60±0.20^{d}	22.07±0.50^{b}	22.83±0.15^{c}	22.97±0.06^{c}	24.83±0.15^{ab}	25.20±0.20^{c}
K-nitrate	23.83±0.06^{a}	24.03±0.15^{a}	24.13±0.12^{a}	24.20±0.10^{a}	24.83±0.06^{a}	24.57±0.12^{a}	24.83±0.29^{a}	25.43±0.81^{a}	25.67±0.58^{a}	26.60±0.10^{a}
K-citrate	22.43±0.06^{c}	22.53±0.15^{c}	22.77±0.15^{c}	22.93±0.21^{b}	23.07±0.15^{c}	23.70±0.26^{a}	23.80±0.20^{b}	24.07±0.12^{bc}	24.17±0.06^{b}	24.27±0.06^{d}
K-thiosulfate	23.50±0.10^{b}	23.57±0.06^{b}	23.77±0.06^{b}	24.00±.00^{a}	24.13±0.06^{b}	24.07±0.12^{a}	24.37±0.15^{ab}	24.67±0.15^{ab}	24.80±0.20^{ab}	25.67±0.12^{b}

Data were presented as means ± SDs, and the different upper letters indicate significant differences at the *P*<0.05 level according to the Tukey test.

3.2.7 TA %

Data in Figure (6) show the influence of foliar application of different sources of potassium on acidity %. The obtained results indicated that total acidity % (TA %) gradually decreased with increasing storage period during the two studied seasons. The unsprayed clusters (control) recorded the highest total acidity values at the end of storage periods (0.43 and 0.41) compared to the clusters sprayed with potassium, except for the clusters sprayed with K-nitrate (0.44 and 0.43%) in 1st and 2nd seasons, respectively.

3.2.8 TSS/acid ratio

Data illustrated in Table (6) show that the TSS/acid ratio increased with an increased storage period. Regarding the effect of foliar spray treatments on the TSS/acid ratio (Table 6), it was significantly affected in both tested seasons. All treatments of foliar application of different sources of potassium result in an increase in values of TSS/TA during different storage periods compared to the control.

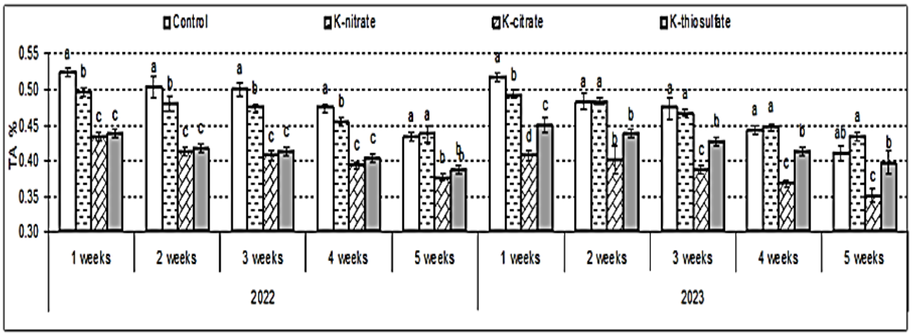

Figure (6): Influence of foliar application of different sources of potassium on TA% of Thompson Seedless Grapes during storage at 2±2 ºC and 85-90% RH in the 2022 and 2023 seasons. Data were presented as means ± SDs, and the different upper letters indicate significant differences at the *P*<0.05 level according to the Tukey test.

Table (6): Influence of foliar application of different sources of potassium on TSS/acid ratio of Thompson seedless grapes during storage at 2±2 ºC and 85-90% RH in the 2022 and 2023 seasons.

Treatment	2022					2023				
	1 weeks	2 weeks	3 weeks	4 weeks	5 weeks	1 weeks	2 weeks	3 weeks	4 weeks	5 weeks
Control	39.30±0.54^{c}	41.35±1.44^{d}	41.95±0.94^{c}	45.42±0.64^{c}	52.16±0.37^{c}	42.71±1.03^{d}	47.26±1.45^{c}	48.55±1.46^{d}	56.02±1.01^{c}	61.50±1.99^{b}
K-nitrate	47.99±0.51^{b}	50.09±1.28^{c}	50.99±0.54^{b}	53.39±0.50^{b}	56.90±1.55^{b}	49.80±0.72^{c}	51.38±0.61^{bc}	54.51±2.22^{c}	57.47±1.79^{bc}	61.39±0.62^{b}
K-citrate	51.78±0.76^{a}	54.53±1.06^{b}	55.99±0.95^{a}	58.32±1.36^{a}	61.25±1.10^{a}	58.29±1.48^{a}	59.58±2.48^{a}	62.25±0.83^{a}	65.92±0.89^{a}	69.37±1.84^{a}
K-thiosulfate	53.82±0.92^{a}	56.57±0.65^{a}	57.51±0.74^{a}	59.51±0.84^{a}	62.42±0.87^{a}	53.50±1.21^{b}	55.81±0.43^{ab}	57.82±1.09^{b}	60.01±1.27^{b}	64.78±2.81^{ab}

Data were presented as means ± SDs, and the different upper letters indicate significant differences at the *P*<0.05 level according to the Tukey test.

3.2.9 Malondialdehyde (MDA), and specific activities of catalase (CAT), ascorbate peroxidase (APX), peroxidase (POD), and total soluble protein

The MDA level in the grapes was found to be somewhat impacted by the foliar application of various K-salts, although there were no appreciable variations between the various K-salts when compared to the control, which was applied foliar with water. For the seasons 2022 and 2023, the same response was seen (Figure 7). Conversely, the antioxidant enzyme's reaction varies depending on the potassium salt found in the foliar application. When compared to the control, POD, APX, and CAT (Figure 8, 9 and 10) activities showed noticeably greater values at the various treatments. Over the course of two seasons, the usage of potassium nitrate, citrate, and thiosulfate significantly increased the activities of APX, POD, and CAT. At thiosulfate, nitrate, and citrate, the antioxidant enzymes (APX and CAT) showed the greatest increase of their activity compared with the control. When compared to the control, foliar administration of K-thiosulfate and K-citrate salts induced almost the same improved rate of POD activities, which are more than enhanced as detected by K-nitrate at two seasons (2022 and 2023) as follows: (0.041, 0.0497, 0.0559, 0.0571 U/mg protein/g FW/min) at season 2022 and (0.04, 0.048, 0.058, and 0.058 U/mg protein/g FW/min) at season 2023, respectively (Figure 11). During the 2022 season, CAT activities were approximately 48% higher in the foliar containing K-thiosulfate than in the control group (Figure 10). In the first season, potassium salts (K-thiosulfate, nitrate, and citrate) applied topically resulted in increased APX activities of 35%, 13%, 11%, 28%, 11% and 16% as compared to the control (foliar application with water), respectively (Figure 9). The foliar spray of several K-salts improved the protein concentration in the grapes; nevertheless, there were notable variations between the treatments. In the first season of 2022, the rate of protein enhancement was measured at the various K-salts, k-nitrate, k-thiosulfate, and k-citrate in the following order as compared to the control (foliar with water): 12.4, 11.07, 9.4, and 7.6 mg/g Fw, respectively. The responses from the two seasons of 2022 and 2023 were almost identical. Comparing the protein content to the control, potassium nitrate, thiosulfate, and citrate increased it to around 64, 46 and 23.5%, respectively (Figure 11).

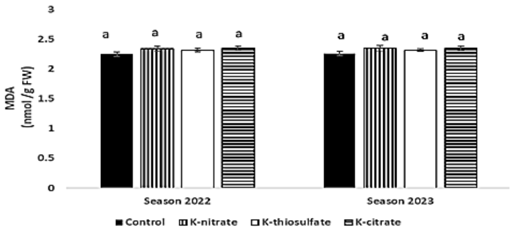

Figure (7): Variations in malondialdehyde (MDA) under different potassium salts treatments. Different letters over columns indicate significant differences at the *p*<0.05.

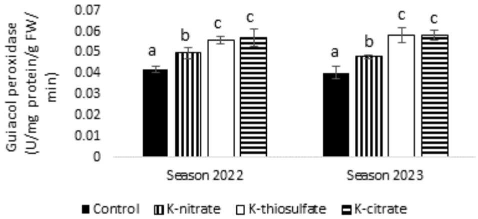

Figure (8): Specific activities of guicacol peroxidase (POD) under different potassium salt treatments. Different letters over columns indicate significant differences at *p*<0.05.

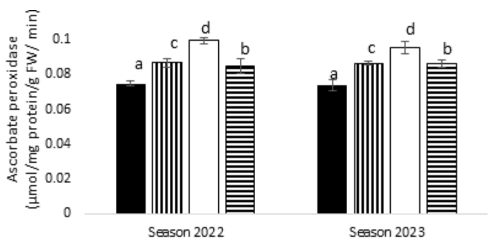

Figure (9): Specific activities of ascorbate peroxidase (APX) under different potassium salt treatments. Different letters over columns indicate significant differences at *p*<0.05.

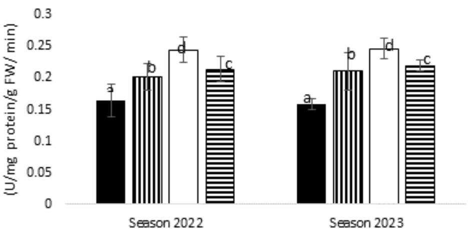

Figure (10): Specific activities of catalase (CAT) under different potassium salt treatments. Different letters over columns indicate significant differences at *p*<0.05.

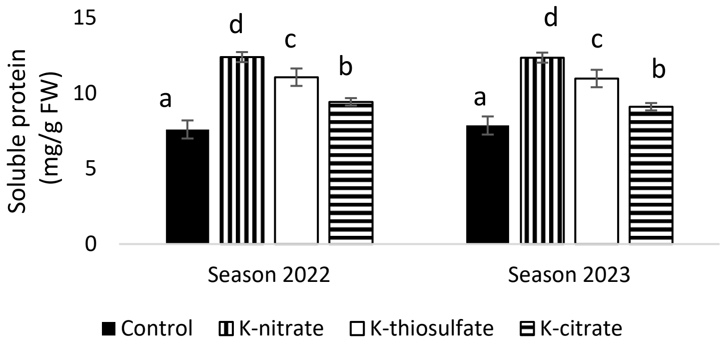

Figure (11): Total soluble protein under different potassium salt treatments. Different letters over columns indicate significant differences at $p<0.05$.

4. Discussion

Grapes are considered one of the most significant fruits in the world. Thompson Seedless Grapes is one of the most important varieties of seedless grapes, popular in Egypt. Thompson seedless grape is attracting huge interest for its better. Eating quality and higher returns to the grower, but it is smaller in berry size. Also, the grape quality is reduced during storage due to many physiological and biochemical reactions in the grape, including consumption of nutrients, increased decay, and water loss. Potassium (K) is an essential macronutrient that is known to be required for higher plants. In cell expansion, stomatal movements, and turgor-driven movements, it is essential for maintaining osmoregulation. Additionally, plants that are subjected to a wide range of biotic and abiotic challenges benefit from potassium (Hakerlerler *et al*., 1997; Johnson *et al*., 2022; Marschner, 1995; Sanyal *et al*., 2020; Sardans and Penuelas, 2021; Wang *et al*., 2013). High K levels were also found to strengthen plant defenses. Potassium has many positive effects on fruit cultivation. In addition, the application of K promotes the increase of fruit weight, fruit diameter, fruit length, and fruit yield. Also, it is improving fruit quality and disease resistance, as well as improving storability. Its role is well documented in increasing enzyme activity, improving the synthesis of protein, carbohydrates, and fats, translocating of photosynthates, enhancing their ability to resist pests and diseases, and also potassium is considered a major osmotically active cation of the plant cell (Mehdi *et al*., 2007). Adequate K nutrition has been associated with increased fruit yield, fruit weight, fruit size, increased soluble solids and ascorbic acid concentrations, increased shelf life, storage, and shipping quality of many horticultural crops (Geraldson, 1985; Lester *et al*., 2007). Our results showed that all spraying treatments with potassium led to an increase in leaf area, and the best treatment in this regard was treatment with potassium nitrate. The increase in leaf area of Thompson Seedless grapes can be attributed to the physiological role of K in carbohydrate formation, which is translocation and accumulation within the organs of the plant and the turgor pressure of cells (Meyer and Anderson, 1970). K also contributes to the growth of meristematic cells, the stimulation of the young tissue, and cell enlargement (Mengel and Kirkby, 1987). In addition to the synergistic effect between potassium and indole acetic acid (IAA) and the enhancement of K on the effect of gibberellin and cytokinin on plant growth (Cocucci and Rosa, 1980). The effect of K in increasing the growth of leaf area was confirmed by Gowda *et al*. (2022). The obtained results indicated that foliar application of different sources of potassium appeared to have the greatest effect on berry weight, length, diameter, increased cluster weight, and increased yield in comparison to the control trees. Moreover, the maximum cluster weight and yield were produced from grape vines treated with potassium citrate or potassium thiosulfate, followed by potassium nitrate treatment. An increase in weight of berry with potassium application might be due to the fact that potassium plays an important role in translocation of photo-assimilates to sink organs (fruits), thus resulting in changes to osmosis inside these organs, which allow the continuous import of carbohydrates and water to fruits, leading to higher fruit weight. Another probable explanation for these increases in weight of berries is higher fruit water content (juice weight %) in the potassium treatments. According to our results, it was observed that alteration in fruit water content is closely associated with the fruit's growth development (Haggag *et al*., 2013). The positive effect of potassium citrate is either due to the role of K in photosynthesis and osmoregulation, allowing an import of the assimilates from source to fruits, which in turn leads to increased fruit weight, or due to the role of citric acid in respiration pathways and the production of important energy (ATP synthesis) for all vital reactions inside the cell (Taiz *et al*., 2002). The results presented in our research were similar to (Alebidi *et al*., 2021; Baiea *et al*., 2015; Ben Mimoun *et al*., 2013; Bibi *et al*., 2019; Chidananda et *al*., 2020; Fattahi *et* al., 2021; Gowda *et al*., 2022; Haggag *et al*., 2016; Jadhav et al., 2019; Jawandha *et al*., 2017; Shen *et al*., 2016; Shinde *et al*., 2018; Solhjoo *et al*., 2017; Vijay *et al*., 2017; Yousuf *et al*., 2018; Zayan *et al*., 2016), which show that treatment with potassium leads to an increase in fruit weight and yield. Our results also show that all potassium treatments led to an increase in TSS and TSS/TA and a decrease in TA at harvest. It might be because k is known to enhance photophosphorylation and some reactions of photosynthesis, resulting in increased accumulation of carbohydrates. Also, the higher sugar content of fruits might be due to the role of potassium in translocation of sugars from leaves to fruits and maybe be because of the higher assimilating power of leaves over a long period, resulting in increased availability of sugars in the fruits. The high percentage of sugar in fruits is often the main reason for the increasing percentage of TSS. Generally, all forms of potassium applications resulted in a reduced fruit acidity at harvest in comparison to control. This may be attributed to the role of potassium in neutralizing acids and reducing fruit acidity (Habib, 1998), while the increase in fruit acidity caused by the potassium nitrate's application being a source of nitrogen, which caused an increase in fruit acidity %, as a result of increased synthesis of amino acids, proteins, and other metabolites as well as their subsequent translocation to the fruits (Mohit *et al*., 2017). These findings are in conformity with those obtained by (Abou El-Wafa *et al*., 2020; Alebidi *et al*., 2021; Aly *et al*., 2020; Baiea *et al*., 2015; Bibi *et al*., 2019; Chidananda *et al*., 2020; Fattahi *et al.,* 2021; Gowda *et al*., 2022; Haggag *et al*., 2016; Hamouda *et al*., 2015; Jadhav *et al*., 2019; Khayyat *et al*., 2012; Manivannan *et al*., 2015; Kumar *et al*., 2011; Pandey and Singh., 2016; Sindhe *et al*., 2018; Tehranifar and Tabar, 2009; Yousuf *et al*., 2018). Regarding the TSS during storage at 2±2 ºC and 85-90% RH in the 2022 and 2023 seasons., in most cases, the TSS was increased as the storage period prolonged; this increase may be due to the solubilization of compounds other than carbohydrate to sugars. On the other hand, results showed a decrease in acidity, which was caused by the use of acids in fruits as a source of energy and the conversion of organic acids to sugars (Wills *et al*., 1998). It may also be due to the loss of water from the berry, and this is consistent with what we found in this study, where the percentage of juice decreases with progress in the storage period. Similar results were seen by several researchers (Jawandha *et al*., 2017; Nireshkumar *et al*., 2020; Okba *et al*., 2021; Prasad *et al*., 2015; Shen *et al*., 2016). Also, this study shows that applying several foliar treatments of potassium salts (nitrate, citrate, and thiosulfate) to grape plants has a beneficial effect. This is achieved at all foliar potassium treatments by an increase in the total soluble protein content. The protein content was increased by potassium nitrate, thiosulfate, and citrate to approximately 64, 46, and 23.5%, respectively, of the control (water foliar). K is responsible for a number of critical biological functions, including the stabilization of protein synthesis, neutralization of negative charges on proteins, and enzyme activation (Ragel *et al*., 2019; Saadati *et al*., 2021). Because the synthesis of polypeptides in ribosomes demands a high concentration of potassium, the synthesis of protein increased with the usage of K under stress (Jones and Pollard, 1983; Saadati *et al*., 2021). In cell expansion, stomatal movements, and turgor-driven movements, it is essential for maintaining osmoregulation (Hakerlerler *et al*., 1997; Johnson *et al*., 2022; Marschner, 1995; Sanyal *et al*., 2020; Sardans and Penuelas, 2021; Wang *et al*., 2013). According to the current investigation, all K-salts had a neglected impact on grape MDA during the two seasons. This study is compatible with Hernandez *et al*. (2012), which recorded that potassium treatments enhance plant development while lowering lipid peroxidation. Grapes with K-salts have higher levels of antioxidant enzymes on their foliar. During the first season of 2022, K-thiosulfate had the greatest enhancement of the antioxidant enzymes APX, POD, and CAT, followed by K-citate and K-nitrate. The availability of K-salts can act as a form of defense against biotic and abiotic stress as well as oxidative damage. It has been discovered that potassium applied foliar improves grapes' antioxidant defense system by lowering reactive oxygen species (ROS) and activating antioxidant enzymes. This result is compatible with the research conducted by García-Martí *et al*. (2019), which demonstrated that elevated potassium buildup in plant cells can mitigate oxidative stress by increasing the activities of key antioxidant enzymes like NADPH oxidase reduction, dehydroascorbate reductase (DHAR), glutathione reductase (GPX), superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), peroxidase (POX), and ascorbate reductase (APX). Potassium (K) is an essential macronutrient that plays important roles in plant development, stress adaptation, cotransport of sugars, osmoregulation, and membrane potential regulation (Johnson *et al*., 2022; Sanyal *et al*, 2020; Sardans and Penuelas, 2021). According to Johnson *et al*. (2022), potassium is essential for the upregulation of K+, which lowers the generation of ROS in plants. In these results, K+ lowers the production of ROS through increasing the antioxidant enzymes activities, which lowers lipid peroxidation, which was also recorded by Cakmak (2005) and García-Martí *et al*. (2019). Foliar application of different sources of potassium reduced the weight loss % and values tended to be statistically equal in most cases. The weight loss is due to the loss of water, and this can be confirmed by looking at the percentage of juice, as it also decreases during the storage period. Earlier studies showed that the pre-harvest potassium salt sprays decreased the weight loss per cent (Nireshkumar *et al*., 2020; Okba *et al*., 2021; Venkatachalam, 2015). Regarding the fruit decay % during storage at 2±2 ºC and 85-90% RH in 2022 and 2023 seasons, in most cases, all potassium sources recorded a lower percentage of decay than the control treatment, which registered the highest value. Decrease in the percentage of fruit decay in most potassium treatments, which showed significant differences with the control, may be due to their effective role in limiting lipid peroxidation by reducing fruit MDA content, either after harvest or at the end of the storage period (Kanpure *et al*., 2019; Okba *et al*., 2021). The positive effect of potassium citrate in decreasing fruit decay % may be attributed to the role of citric acid in minimizing the reduction of totalphenolics

(Abbasi *et al*., 2013; Venkatachalam *et al*., 2015) in loquat and longkong fruits, which is considered anti-microbial (Pandey and Rizvi, 2009), and additionally its role in suppressing the activities of oxidoreductase enzymes (PPO and POD) which cause the fruit's surface to become more fragile (Venkatachalam *et al*., 2015) and susceptible to cold injury, while the positive effect of potassium nitrate on reducing the percentage of decay in Thompson seedless grapes may be through several factors; potassium accumulation in tissues in combination with increase the nitrogen uptake and induction of defense genes. Increasing potassium in tissues, which has a good role in disease resistance by enhanced silicification of cell walls (Prabhu *et al*., 2007), or due to its direct role in inhibiting the growth of mycelium of the fungus (Sugimoto *et al*., 2009). Our results are in line with the findings of Kanpure *et al*. (2019).

5. Conclusion

As a whole, it is recommended to spray potassium citrate and potassium thiosulfate in Thompson seedless grapes farms to obtain a high yield and high quality, maintaining the quality of the clusters during storage.

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