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The role of Potassium and Boron in Improving the Nutritional Status and productivity of Crimson grapevines grown in newly reclamation sandy soil

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Abstract: The present investigation was achieved during two consecutive seasons of 2023 and 2024, by using thirty uniforms in vigor, nine years old own rooted 'Crimson Seedless' grapevines. The chosen vines were grown in private vineyard orchard located at Beni Mazar district, El-Minia Governorate, Egypt. The soil texture in the farm was sandy loam and irrigated by using drip irrigation system. Ten treatments from Potassium citrate and Boric acid as well as their combination were examined. The obtained results indicated that foliar spraying of Potassium and Boron play an essential role in improving nutritional status and productivity of Crimson grapevines. The individual treatments with Potassium showed noticeable superiority over Boron treatments. Moreover, the combined application with Potassium and Boron surpassed the individual application of each one. In order to improve the nutritional status and vine productivity, it is recommended to spray Potassium in form of potassium citrate at 1.5% and Boron in form of boric acid at 150 ppm three times yearly.

Key words: Grape, Crimson Seedless, Potassium citrate, Boric acid, productivity, Nutritional Status.

1. Introduction

Grapevine (*Vitis vinifera L.*) conceded as one of the most widely cultivated fruit crops worldwide. However, the mineral nutrition of grapevines plays a crucial role in determining nutritional status and fruit quality (**Reynier, 2000**). Egypt is considered as one of the leading grape-producing countries in the Arab world and the Middle East countries. Egyptian grape exports exceeded 181 thousand tons in 2024. El-Minia Governorate is one of the leader rejoin of table grape cultivation (**FAO-stat, 2024**).

Crimson cultivar considered as one of the most important late-season red seedless table grapes *cvs* in worldwide. It is highly appreciated for its attractive bright red color, firm berries, sweet flavor, long shelf life, and excellent marketability (**Reynier, 2000**). This cultivar was developed in the United States and has gained wide commercial importance in many grape-producing countries, including Egypt (**Abd El-Razek *et al.*, 2011**).

Among essential nutrients, potassium (K) is considered a key element influencing both physiological and biochemical processes in grapevines (**Villette *et al.*, 2020**). It is the most abundant cation in plant cells and is involved in numerous physiological functions, including enzyme activation, osmoregulation inside plant cell (**Hu *et al.*, 2023**). Its mobility within plant tissues allows it to be redistributed depended on plant requirements. According to **Singh *et al.* (2024)**, potassium improves tolerance to abiotic stresses such as drought and hot, which are becoming more frequent in grape-growing regions (**Wang *et al.*, 2024**). The reviewed studies demonstrate that foliar potassium application improves nutritional status, and significantly increases flowering, fruit set, and yield. These effects are largely attributed to potassium's role in enzyme activation, photosynthesis, and assimilate translocation. Potassium contributes positively to both physical and chemical characteristics of grape berries.

Boron plays a pivotal role in the reproductive development of grapevines, particularly during flowering and fertilization stages. Its importance is primarily linked to its involvement in pollen viability, pollen tube growth, and successful fertilization. In grapevines, boron has been shown to exert a significant indirect influence on pigment synthesis, stability, and functionality through its effects on cellular integrity and metabolic regulation (**Marschner, 2012)**. In sandy soil Boron deficiency resulted in a significant decline in chlorophyll a, chlorophyll b, and total chlorophyll content in grapevine leaves (**Wei *et al.*, 2022**). Additionally, boron has been linked to the regulation of enzymatic activities involved in photosynthesis. Enzymes such as ribulose-1,5-bisphosphate Carboxylase/ Oxygenase (RuBisCO) are indirectly affected by boron availability through its influence on nitrogen metabolism and protein synthesis (**Khan *et al.*, 2021**).

2. Material and Methods

The current investigation was achieved during two consecutive seasons of 2023 and 2024 seasons, using thirty uniforms in vigor, nine years old 'Crimson Seedless' grapevines. The chosen vines were grown in private vineyard orchard located at Beni Mazar district, El-Minia Governorate – Egypt. The soil texture of orchard was sandy loam (Table 1). The farm has been irrigated by using drip irrigation system feeding from underground well water.

2.1. Soil and water analysis

A composite soil and irrigation water samples were collected and subjected to Physical and chemical analysis according **Chapman & Partt (1961)** and **Walsh & Beaton (1986)**. The obtained data are shown in Table (1)

Table (1). Physical and chemical analysis of orchard soil and irrigation water

Soil analysis		Water analysis	
Constituents	**Values**	**Constituents**	**Values**
Sand %	81.1	**E.C (mmhos/cm/25C)**	1.8
Silt %	14.1	**Hardness**	16.7
Clay %	4.8	**pH**	7.74
Texture	Sandy loam	**Ca (mg/L)**	40.1
EC (1:2.5 extract) mmhos/cm/ 25 C	2.2	**Mg (mg/L)**	20.8
Organic matter %	0.07	**K (mg/L)**	5.27
pH (1 : 2.5 extract)	8.02	**Na (mg/L)**	71.6
Active lime ($CaCO_3$ %)	9.92%	**Sum of Cations (mg/L)**	9.16
Total N %	0.07	**Alkalinity (mg/L)**	152
Available Phosphorus (ppm)	2.04	**Chlorides (mg/L)**	102
Available Ca (meq/100g)	22.1	**Nitrate (mg/L)**	10.0
Available Mg (meq/100g)	2.14	**Sulphates (mg/L)**	41.9
Available K (meq/100g)	0.49	**Sum of anions (mg/L)**	7.09

Except the treatments which practice during the experimental work of this investigation, (spraying potassium citrate and boric acid) the selected vines received the recommended horticultural practices that are commonly applied in the vineyard in Egypt.

2.2. Experimental work

For achieving the main objectives of this investigation, ten treatments from the two elements (Potassium in form of potassium citrate and Boron in form of Boric acid) as well as their combinations were implemented as the following: Control treatment (untreated vines); spraying Potassium citrate at 0.5 %; spraying Potassium citrate at 1.0 %, spraying Potassium citrate at 1.5 %, spraying Boric acid at 50 ppm, spraying Boric acid at 100 ppm, spraying Boric acid at 150 ppm, Spraying potassium citrate at 0.5% + Boric acid at 50 ppm, spraying potassium citrate at 1.0% + Boric acid at 100 ppm, and spraying potassium citrate at 1.5% + Boric acid at 150 ppm. Three replications were done by each treatment, one vine per each replicate. All potassium and boron as well as their combinations treatments were sprayed three times yearly (after burst bud "1st week of April", after berry setting "2nd week of May" and one month later.

2.3. Experimental design and statistical analysis

The present investigation was designed in Randomized Complete Block Design (RCBD) (**Gomez and Gomez, 1984)**. At the end of each season, the obtained data tabulated and subjected to statistical analysis, using new LSD at 5% for comparisons among the significance differences between treatments, according to (**Snedecor and Cochran, 1990**).

2.4. Various measurements and determinations

Leaf photosynthesis pigments determination

Main photosynthesis pigments (chlorophyll A, chlorophyll B, total chlorophylls and total carotenoids) of adult leaves were determined and presented as "mg/100 g FW'. Fresh and adult ten leaves / vine from those opposite of the first cluster were collected and cut into small pieces. Then a known sample weight (0.5 g) from each sample was taken, homogenized and extracted by using acetone 75% in presence of little amounts of celenium, pure sand and sodium carbonate, the sample was ground by using porcelain mortar, Filtrated and the filtration was conducted and the residue washed with acetone till the filtrate was colorless. Acetone 75% was used as a blank. The optical density of the filtrate was determined by using spectrophotometer at the wave length adjusted at 662, 644 and 440.5 nm to determine chlorophyll A, chlorophyll B and total carotenoids respectively (**Marten Previl *et al* 1984**).

Chlorophyll A = (9.784 x E662) – (0.99 x E644) = ……. mg/ g F.W.

Chlorophyll B = (21.426 x E644) – (4.65 x E662) = …… mg/ g F.W.

Total chlorophylls = Ch. A + Chl. B = …….. mg/ g F.W.

Total carotenoids = (4.965 x E 440.5) – 0.268 (Total chlorophyll)

Since E = Optical density at a given wave length.

Leaf mineral nutritional status

At full blooming stage, sample including ten adult leaves were collected from those opposite to the basal clusters on shoot (According to **Martian – Prevel *et al.*, 1984 and Ibrahim, 2010**). The blades were separated and previously used in photosynthesis pigments determination, only the petioles were saved for determination of mineral macro-elements (NPK) and micro-nutrients elements (Zn, Fe, Mn, and B). Petioles were dried by using oven at 70 C^{o} until constant weight, then ground to fine powder and carefully kept until using in chemical analysis (**Ibrahim 2010**). Weight of 0.5 g was used for digesting using H_2SO_4 and H_2O_2 until clear solution, determinations of N, P and K as well as Fe, Zn, Mn and B were determined according to (**Martain Prevel *et al.*, 1984**).

- **Nitrogen content** was determined by using modified-microkeldahl method **Walsh & Beaton (1986)**.

- **Phosphorus content** was determined by using Olsen method by **Walsh & Beaton (1986)**.
- **Potassium content** was determined by using flame-photometre methods (according to **Chapman & Partt (1961)**.
- **Micronutrient determination:** Fe, Zn, Mn and B were determined by using atomic absorption methods **Chapman & Partt (1961)**.

2.5. Fruit set %

At the full blooming stage, four inflorescences per vine were bagged by using paper bags in this process. After berry set stage, the bags were removed, and the number of fallen flowers inside each bag as well as the number of successfully set flowers was counted. Then, the berries set percentage was calculated, and the average percentage of berries set calculated by dividing by four **(Ibrahim 2010)**.

$$\textbf{Berries set}\,\% = \frac{\textbf{Number of setting flowers}}{\textbf{Total numbers of flowers}} \boldsymbol{X}\ \mathbf{100}$$

The total numbers of flowers = setting flowers + fallen flowers

2.6. Yield and its components

Harvesting took place when TSS/ acid ratio in control berries reached at list 22: 1. This is compatible with the last week of August, during the two seasons. The number of clusters per vine was counted before harvesting and recorded**:** at harvesting, four clusters per each vine were harvested (two cluster from each side), and the average weight was recorded. The yield was mathematically calculated as e result of mutably average cluster weight (g) by the number of clusters per vine, and the yield expressed kg/vine.

3. Results and Discussion:

3.1. Effect of spraying potassium citrate and boric acid on leaf photosynthesis pigments

Effect on chlorophyll a and b

Data illustrated in Table (2) showed the effect of spraying Potassium and Boron at different concentrations as well as their combinations on adult leaves photosynthesis pigments (chlorophyll a and chlorophyll b) of ‘Crimson’ grapevines growing in sandy soil. The obtained data showed that, spraying potassium in form of Potassium citrate and Boron in form of boric acid were very effective in enhancing chlorophyll a and b in adult leaves in comparison to untreated vines (control). It is clear that adult leaves chlorophyll contents significantly increased parallel to increasing the potassium citrate from 0.5% to 1.0% and boric acid from 50 ppm to 150 ppm. However, the vines received potassium citrate presented higher chlorophyll contents rather than those received boric acid, during the two experimental seasons.

Furthermore, treated the Crimson vines with the combinations of potassium citrate and boric acids presented the higher chlorophyll contents in comparison to those received each compound alone. It is clear also that the vines sprayed with potassium citrate at 1.5% and boric 150 ppm produced the highest chlorophylls a and b, during the two experimental seasons. On the opposite side untreated vines presented the lowest chlorophylls a and b. These findings were true during the two experimental seasons respectively.

Effect on total chlorophyll and total carotenoid

he obtained data, Table (3) shows a range of clear effects of spraying Potassium citrate and Boron on adult leaves total chlorophyll and total carotenoids of ‘Crimson’ grapevine, during 2024 and 2025 seasons. It is clear that, spraying potassium in form of potassium citrate at different concentrations (0.5%, 1.0% and 1.5%) was combined with significant improvement of leaf total chlorophyll an total carotenoids (mg/100g F.W.). It is notable that, all individual treatments with potassium and boric acid were capable to increase the total chlorophyll and total carotenoids in adult leaves significantly, during the two experimental seasons, except the case of low concentration (0.5%) which failed to enhance leaves total carotenoids significantly in the first season. This increment was parallel with increasing the concentration used. However, the spring the highest potassium concentration (1.5%) produced the highest total chlorophyll (4.6 & 4.8 mg/100g F.W.) and total carotenoids (1.3 & 1.3 mg/100g F.W.) in 'Crimson' adult leaves in compared to other individual treatments. these findings were true during the two seasons respectively.

Concerning the combined treatments with potassium and boron, all combined treatments were capable to increase the leaf total chlorophyll and total carotenoids significantly rather than untreated vines, these findings were true during the two experimental seasons. Furthermore, the effect of combined Potassium and Boron was superior than spraying each one alone. The vines received the highest concentration of Potassium citrate (1.5%) and Boric acid (150 ppm) presented the highest leaf total chlorophyll (5.9 & 6.0 mg/100g F.W.) and total carotenoids (1.6 & 1.8 mg/100g F.W.) compared to other treatments or untreated vines, in both experimental seasons respectively. on the opposite side, untreated crimson vines produced the lowest total chlorophyll and total carotenoids, in both seasons.

Concerning the effect of potassium and boron on leaves chlorophyll contents of 'Crimson' grapevines, the obtained data was harmony with those obtained by **Masoud (2017); Villette *et al.*, 2020; Marcuzzo *et al.* (2021); Singh *et al.* (2024) and Wang *et al.* (2024)** on Potassium and **Wei *et al.* (2022); Hu *et al.* (2023); Nikolaou *et al.* (2023) and Lupo *et al.* (2025)** on Boron**.**

Table (2). Effect of spraying Potassium citrate and Boron at different concentration on photosynthesis pigments (mg/100g F.W) of Crimson grapevines adult leaves, during 2023 and 2024 seasons

Treatments	Chlorophyll A		Chlorophyll b		Total chlorophyll		Total carotenoids	
	2023	2024	2023	2024	2023	2024	2023	2024
Control	2.8	2.7	1.0	1.1	3.8	3.8	1.0	1.1
K Citrate 0.5 %	3.0	3.2	1.1	1.1	4.1	4.3	1.2	1.2
K Citrate 1.0 %	3.1	3.4	1.1	1.2	4.2	4.6	1.3	1.4
K Citrate 1.5 %	3.4	3.6	1.3	1.4	4.7	5.0	1.4	1.6
B 50 ppm	2.9	2.9	1.4	1.5	4.3	4.4	1.1	1.1
B 100 ppm	3.0	3.2	1.4	1.6	4.3	4.8	1.2	1.3
B 150 ppm	3.1	3.2	1.5	1.6	4.6	4.8	1.3	1.3
K Citrate 0.5% + B 50 ppm	3.6	3.7	1.6	1.8	5.2	5.5	1.4	1.5
K Citrate 1.0% + B 100 ppm	3.8	3.8	1.8	1.9	5.6	5.7	1.5	1.6
K Citrate 1.5% + B 150 ppm	4.0	4.1	1.9	1.9	5.9	6.0	1.6	1.8
Mean	**3.3**	**3.4**	**1.4**	**1.5**	**4.7**	**4.9**	**1.3**	**1.4**
New LSD at 5%	**0.3**	**0.3**	**0.2**	**0.2**	**0.3**	**0.4**	**0.2**	**0.3**

The recent studies have highlighted the increasing importance of potassium fertilization to resisting the abiotic stress especially in aired soil area, under changing climate conditions. **Singh *et al.* (2024)**, spraying potassium improves tolerance to abiotic stresses such as hot and drought stresses (**Singh *et al.*, 2024**), which are becoming more frequent in grape growing regions. This makes potassium management a critical factor in sustainable viticulture (**Mengel, 2001** and **Marschner, 2012**). Foliar application of potassium has gained attention as an effective method to quickly correct deficiencies and enhance plant performance. **Wang *et al.* (2024).** Although, numerous studies confirm the positive role of boron in pigment formation, the relationship is not always linear. Both deficiency and excess of boron can negatively impact pigment content and photosynthetic efficiency (**Reynier, 2000**). The dual nature of boron effects highlights the importance of precise nutrient management. While moderate boron levels enhance pigment synthesis and photosynthesis, imbalances can lead to oxidative stress, chlorophyll degradation, and reduced plant performance. Another important consideration is the interaction between boron and environmental factors such as light intensity, temperature, and water availability. These factors can modulate the impact of boron on pigment dynamics, leading to variability in experimental results.

3.2. Effect of spraying Potassium citrate and Boric acid on nutritional status of vines

A: Effect of spraying potassium citrate and boric acid on leaf macronutrients

The obtained data illustrated in Table (3) shows a range of clear effects of spraying Potassium citrate and Boric acid on leaf Nitrogen, Phosphorus, and Potassium contents of ‘Crimson’ grapevine, during 2024 and 2025 seasons. It is clear also that, spraying either compound individual or the two compounds in combination was very effective in leaf macro-nutrients (NPK) contents, during 2024 and 2025 seasons.

Effect on leaf Nitrogen content

The obtained data shows the response of leaves Nitrogen contents of ‘Crimson’ grapevines to spraying Potassium citrate or Boric acid each one alone or in combination during 2024 and 2025 seasons. It is clear from the obtained data that, during the first season all individual potassium and Boron treatments failed to enhance the leaf Nitrogen content significantly, except the case of spraying potassium citrate at highest concentration (1.5%) which exerted at significant promotion on leaf Nitrogen contents. Regarding the individual treatments of Potassium citrate and Boric acid in the second season, it is evident from this table that spraying the low concentrations of individual application of potassium citrate (0.5%) and Boric acid (50 & 100 ppm) failed to enhancing the leaf Nitrogen contents of ‘Crimson’ grapevine. Contrary, the highest concentration of Potassium citrate (1.0% & 1.5%) and Boric acid (150 ppm) succeeded to significantly increase the leaf Nitrogen content.

Concerning the combined application of both Potassium citrate and Boric acid together during the two experimental seasons, it is clear from the obtained data that all combined treatments was capable to significantly improve the leaves Nitrogen contents in both experimental seasons, except the case of low concentrations (0.5% Potassium citrate + 50 ppm Boric acid) in the first season. Furthermore, spraying the ‘Crimson’ vines with the highest combined concentrations (1.5% Potassium citrate + 150 ppm Boric acid) produced the highest Nitrogen content in adult leaves (1.94% & 2.04%) in compression to control or other treatments. Contrary, untreated vines produced the lowest leaves Nitrogen contents (1.52% and 1.48%). These findings were true during the two experimental seasons respectively.

Effect on leaf Phosphorus content

Adult leaves Phosphorus content (%) of ‘Crimson’ grapevine significantly varied among to spraying the Potassium citrate and Boric acid such individual or in combinations compared to untreated vines, during the two experimental seasons (Table 3). The obtained data showed that, spraying the two essential nutrients (K and B) individually increase leaf phosphorus contents significantly in both experimental seasons, compared to untreated vines. Furthermore, increasing the concentration used was parallel to increasing the leaf phosphorus contents. However, the vines received the highest concentration produced the highest phosphorus contents in leaves, in comparison to those received the low concentrations or untreated one.

It is clear from the same table that the combined application of Potassium citrate and Boric acid was more effective in enhancing leaf phosphorus content rather than the individual application of each one. However, the vines received Potassium citrate and Boric acid in combination at highest concentrations presented the highest leaf Phosphorus contents in comparison to the other treatments or control vines. On the other hand, untreated vines (control) presented the lowest phosphorus contents in adult leaves. These findings were true during the two experimental seasons respectively

Effect on leaf Potassium content

Data presented in Table (3) shows the effect of spraying potassium citrate and Boric acid on adult leaves Potassium content, during the two experimental seasons. It is worth to note that, all individual potassium citrate concentration was capable to increase the leaves Potassium contents during the two experimental seasons, except the case of law Potassium concentration (0.5%) only in the first season. On the other hand, all individual Boron treatments failed to increase the Potassium contents in adult leaves during the two experimental seasons, except the case of higher Boric acid concentration (150 ppm), only in the second season, which significantly improved leaves potassium contents.

Furthermore, all combined treatments with Potassium citrate and Boric acid significantly increased the leaves potassium contents during the two seasons. This increment was parallel with increasing the concentration used from each compound. However, the vines received the highest Potassium citrate (1.5%) and Boric acid (150 ppm) concentrations presented the highest potassium in their leaves. On the contrary, untreated vines presented the lowest Potassium contents in their leaves. These findings were true during the two seasons respectively.

Table (3). Effect of spraying potassium citrate and boron at different concentrations on leaves NPK (%) of Crimson grapevines, during 2023 and 2024 seasons

Treatments	Nitrogen %		Phosphorus %		Potassium %	
	2023	2024	2023	2024	2023	2024
Control	1.52	1.48	0.18	0.19	1.22	1.24
K Citrate 0.5 %	1.62	1.66	0.22	0.23	1.39	1.43
K Citrate 1.0 %	1.72	1.79	0.23	0.23	1.46	1.60
K Citrate 1.5 %	1.83	1.94	0.24	0.25	1.55	1.64
B 50 ppm	1.57	1.65	0.21	0.23	1.28	1.30
B 100 ppm	1.67	1.69	0.22	0.24	1.31	1.35
B 150 ppm	1.62	1.78	0.24	0.25	1.36	1.44
K Citrate 0.5% + B 50 ppm	1.79	1.85	0.25	0.27	1.55	1.62
K Citrate 1.0% + B 100 ppm	1.86	1.89	0.28	0.30	1.61	1.64
K Citrate 1.5% + B 150 ppm	1.94	2.04	0.31	0.32	1.69	1.72
Mean	**1.71**	**1.77**	**0.24**	**0.25**	**1.44**	**1.49**
New LSD at 5%	**0.3**	**0.3**	**0.03**	**0.04**	**0.17**	**0.19**

B: Effect of spraying potassium citrate and boric acid on leaf micro-nutrients

Data illustrated in Table (4) showed the effect of spraying Potassium Citrate (at 0.5%, 1.0% and 1.5%) and Boric acid (at 50, 100 and 150 ppm) on Fe, Zn, Mn, and B ppm) of 'Crimson' grapevine adult leaves, grown in sandy soil under Minia Governorate conditions, during 2023 and 2024 seasons.

Effect on Fe contents

It is clear from the obtained data that spraying Potassium at 0.5%, 1.0% and 1.5% and Boron at 50, 100, and 150 ppm significantly improved the Fe (ppm) in the adult leaves of Crimson cultivar during the two experimental seasons.

Concerning the individual treatments with potassium citrate and boric acid, increasing the concentration of Potassium citrate from 0.5% to 1.5% was parallel to increasing leaves Fe contents. However, the vines received 1.5% Potassium citrate present higher and significant Fe contents (66 & 70 ppm) rather than control or those received the lower concentrations (0.5% and 1.0%). These findings were true during the two seasons respectively. On the same context increasing boric acid concentration from 50 to 150 ppm was accompany with significant increment in leaves Fe contents. However, the vines received 150 ppm boric acid produced higher and significant Fe in there leaves (65 & 69 ppm) rather than those received the lower concentrations or control.

Regarding the combined application of Potassium citrate and Boric acid, all combined treatments was capable to increase the leaves Fe contents significantly in both seasons (2023 and 2024). However, the vines received the higher concentrations (1.5% potassium citrate + 150 ppm boric acid) presented the highest Fe in there leaves in comparison to other single or combined treatments as well as control treatment. On the opposite side, untreated vines (control) present the lowest Fe contents. These findings were true during the two experimental seasons respectively.

Effect on Zn contents

It is clear from the obtained data (Table4) that all Potassium and Boron individual treatments were capable to significantly increased the adult leaves Zn contents (ppm) of Crimson cultivar, during the two experimental seasons. Except, the case of lower boric acid concentration, it failed to increase leaves Zn contents significantly, neither in the first season nor in the second one. Concerning the individual treatments, increasing the concentration of Potassium citrate from 0.5% to 1.5% and boric acid from 50 ppm to 150 ppm was parallel to gradual and significant increase in leaves Zn contents. However, the vines received 1.5% Potassium citrate present higher and significant Zn contents (ppm) rather than control or those received 0.5% and 1.0%. Similarly, the vines revived the highest boric acid concentration (150 ppm) present higher and significant Zn contents in there leave (ppm). These findings were true during the two seasons respectively. These results were true during the two seasons respectively. Regarding the combined application, all combined (K and B) treatments were capable to enhancing the leaves Zn contents significantly in both experimental seasons. However, the vines received the concentrations (1.5% potassium citrate + 150 ppm boric acid) produced the highest Zn in there leaves in comparison to other single or combined treatments as well as control one. On the opposite side, untreated vines (control) present the lowest Zn contents (41 and 43 ppm). These findings were true during the two experimental seasons respectively.

Effect on Mn contents

The perusal of data reveals that, all treatments with potassium citrate had a significant effect on improving leaf Mn contents, during the two experimental seasons (Table 4). While, spraying the lowest Boric acid concentration (50 ppm) failed to enhance the adult leaves Mn contents, neither in the first season nor in the second one. Contrary, the higher concentrations of boric acid (100 and 150 ppm) significantly improve the Mn contents in ‘Crimson’ adult leaves. These data were true during the two seasons. In addition, spraying Potassium in form of potassium citrate and Boron in form of boric acid together was more effective in enhancing the Mn contents in leaves than using each compound alone. This increment was function to the concentration used. Furthermore, the vines received the highest concentrations of Potassium citrate (1.5%) and Boric acid (150 ppm) produced the highest Mn contents. On the contrary, untreated vines presented the lowest Mn contents (40 and 43 ppm) in there leaves, during the two seasons respectively.

Effect on B contents

The results pertaining to the effect of spraying potassium citrate and boric acid at different concentrations, as well as its combination on the adult leaves Boron contents are presented in Table (4). The perusal of data reveals that, all potassium citrate and Boric acid treatments had a significant effect on improving leaf B contents, these findings were true during the two experimental seasons. It is clear that, increasing the concentrations used from Potassium citrate or Boric acid each one alone was parallel to increasing the leaf B contents in both seasons (2023 and 2024). In addition, spraying potassium citrate and boric acid in combination was more effective in enhancing leaf B contents than using each compound alone. This increment was parallel to increasing concentration used. Furthermore, the vines received the highest concentrations of Potassium citrate (1.5%) and Boric acid (150 ppm) produced the highest B contents in their leaves. On the opposite side, untreated vines presented the lowest B contents in there leaves, during the two seasons respectively.

Table (4). Effect of spraying potassium citrate and Boron at different concentrations on leaf micro-nutrients (ppm) of Crimson grapevines, during 2023 and 2024 seasons

Treatments	Fe Ppm		Zn Ppm		Mn Ppm		B Ppm	
	2023	2024	2023	2024	2023	2024	2023	2024
Control	54	58	41	43	40	43	20	19
K Citrate 0.5 %	59	58	48	52	44	49	22	24
K Citrate 1.0 %	61	65	50	59	55	57	23	26
K Citrate 1.5 %	66	70	60	69	58	59	28	30
B 50 ppm	54	57	44	47	42	42	23	24
B 100 ppm	61	66	50	52	47	49	23	26
B 150 ppm	65	69	52	55	50	52	25	28
K Citrate 0.5% + B 50 ppm	72	76	66	62	55	59	28	31
K Citrate 1.0% + B 100 ppm	76	79	67	71	60	64	31	32
K Citrate 1.5% + B 150 ppm	80	82	72	77	66	68	31	33
Mean	**65**	**68**	**55**	**59**	**52**	**54**	**25**	**27**
New LSD at 5%	**5.0**	**6.0**	**4.0**	**6.0**	**3.0**	**4.0**	**2.0**	**4.0**

It well known that, Potassium plays a crucial role in improving nutrient uptake and internal nutrient balance in grapevines. **Hu *et al.* (2023)** confirmed that potassium fertilization enhances the absorption of essential nutrients such as nitrogen and phosphorus by improving root activity and nutrient transport mechanisms. **Villette *et al.* (2020)** demonstrated that potassium contributes to maintaining ionic balance within plant tissues, which is critical for nutrient homeostasis. In addition, potassium facilitates the redistribution of nutrients via the phloem, ensuring adequate supply to actively growing organs (**Villette *et al.*, 2020** and **Hu *et al.*, 2023**). **Zhang *et al.* (2023)** remarked that potassium application significantly affects metabolic pathways related to nutrient assimilation, particularly carbohydrate and organic acid metabolism, and confirmed that potassium enhances enzymatic activity involved in nutrient transformation and storage. Additionally, foliar application of potassium improved overall nutritional status and increased nutrient use efficiency in grapevines **Singh *et al.* (2024)**. This was attributed to potassium's ability to regulate physiological processes and enhance nutrient mobility within the plant.

Boron enhances micronutrient uptake through its effects on root growth and membrane stability (**Marshnear, 2012**). Healthy root systems exhibit greater nutrient absorption capacity, especially for iron, manganese and zinc (**Marshnear 2012**). According to **Brown *et al.* (2002)** boron improves the movement of sugars and organic compounds within plants. These compounds may act as chelating agents that facilitate Macro and micro-nutrient transport and availability. Boron also influences the activity of plasma membrane enzymes responsible for nutrient transport. Improved membrane integrity reduces nutrient leakage and enhances nutrient utilization efficiency. On grapevines revealed that foliar application of boron significantly increased leaf concentrations of iron, zinc, and manganese while improving chlorophyll content and photosynthetic activity (**Nijjar, 1985**).

3.3. Effect of spraying potassium citrate and boric acid on yield and its component

Effect on the number of cluster per vine

The results pertaining to the effect of Potassium citrate and boric acid at different concentrations on the number of clusters per vine are presented in Table (5). The obtained data reveals that non-significant differences in the number of clusters per vine between the control and other treatments were observed during the first season. This seems be logical, as the fruiting buds initiation and differentiation during the preceding summer of the growing season. Contrary, in the second season spraying Potassium citrate and Boric acid remarkably enhanced the number of clusters per vine. It is clear from this table that, all Potassium and Boron treatments were capable to significantly improving the number of clusters per vine. Increasing the concentration of Potassium citrate and boric acid was positively related to increasing the number of clusters/vine. However, the vines received the highest Potassium citrate or Boric acid, each one individually, produced higher and significant cluster numbers/vine rather than those received the lower concentrations.

All combined application of Potassium and Boron failed to improve the number of clusters per vines during the first season. While, the combined application of Potassium citrate and Boric acid significantly increase the number of clusters/vine during the second season. However, all combined treatments were more effective in enhancing the clusters number per vine in compared to the individual application. This increment was parallel to increasing the concentration. Then, the vines received the highest potassium citrate (1.5%) + Boric acid (150 ppm) produced the highest number of clusters per vine, during the second season. Contrary, untreated vines presented the lowest number of clusters / vine (20), during the second season.

Effect on cluster weight (g)

It is clear from Table (5) that all individual or combined Potassium and Boron treatments were capable to improve the weight of Crimson cluster in both experimental seasons. Regarding the individual treatments, it is clear that increasing the concentration of Potassium citrate from 0.5% to 1.5% and Boric acid from 50 ppm to 150 ppm was parallel to gradual and significant increment of cluster weight (g). Whatever the concentration used, spraying Potassium citrate was superior to spraying Boric acid, these findings were true in both experimental seasons.

Concerning the response of ‘Crimson’ cluster weight to combined application of Potassium citrate and Boric acid, it is clear from the obtained results that all combined treatments significantly promoted the cluster weight (g) of Crimson cultivar. In addition, increasing the concentration of the two compounds was parallel to significant increase of cluster weight. However, the vines received the highest concentrations from both compounds in combination produced the highest cluster weight. Contrary, untreated Crimson vines produced the lowest cluster weight. These findings were true in both experimental seasons respectively.

Table (5). Effect of spraying potassium citrate and boron at different concentration on yield and its component of Crimson grapevines, during 2023 and 2024 seasons

Treatments	Number of cluster / vine		Cluster weight (g)		Yield (Kg/Vine)	
	2023	2024	2023	2024	2023	2024
Control	22	20	351.5	355.3	7.73	7.11
K Citrate 0.5 %	21	25	412.3	419.7	8.66	10.49
K Citrate 1.0 %	23	27	422.6	431.5	9.72	11.65
K Citrate 1.5 %	22	29	425.3	431.7	9.76	12.52
B 50 ppm	21	25	401.6	409.3	8.43	10.23
B 100 ppm	21	26	411.5	418.9	8.64	10.89
B 150 ppm	23	28	421.3	422.4	9.59	11.83
K Citrate 0.5% + B 50 ppm	23	29	444.5	448.6	10.22	13.01
K Citrate 1.0% + B 100 ppm	23	31	450.5	456.7	10.51	14.22
K Citrate 1.5% + B 150 ppm	23	32	461.4	470.6	10.61	15.06
Mean	**22**	**27**	**420.3**	**426.7**	**10.17**	**11.70**
New LSD at 5%	**NS**	**2.0**	**21.1**	**27.5**	**0.90**	**1.12**

Effect on yield (kg/vine)

The results pertaining to the effect of Potassium citrate and boric acid concentrations on the yield (kg) / vine of ‘Crimson’ grapevine reveals that, all Potassium citrate and Boric acid concentrations, either individually or in combination, was capable to significantly enhancing the yield (kg/vine) in both experimental seasons.

Regarding the individual treatments, it is clear from Table (5) that increasing the concentrations of Potassium citrate (from 0.5% to 1.5%) and Boric acid (from 50 ppm to 150 ppm) caused a gradual and significant increment in yield (kg/vine), during the two experimental seasons. However, the vines received the highest concentration of Potassium citrate produced higher and significant (9.76 and 12.52 kg/vine). These findings were true during the two experimental seasons.

Regarding the combined application of Potassium citrate and Boric acid, it is clear that all combined treatments successes to improve the yield (kg) / vine significantly in both experimental seasons. This increment was parallel to increasing the concentration used. However, the best yield / vine was obtained from the vines received the highest Potassium citrate concentration (1.5%) + Boric acid (at 150 ppm). On the opposite side, untreated vines produced the lowest yield (7.73 and 7.11 kg/vine). These results were true during the two experimental seasons respectively.

Foliar application of potassium and boron plays a major role in improving the physical characteristics of grape clusters through enhancing berry growth, cluster compactness, berry firmness, cluster weight (**Wang *et al.*, 2024**), and overall market quality (**Al-Wasfy, 2014** and **Hu *et al.*, 2023**). Potassium is considered one of the most important macronutrients required for grapevine growth because it regulates carbohydrate translocation, water balance (**Marschner 2012**), enzyme activation (**Wang *et al.*, 2024**), and sugar accumulation in berries (**Marschner 2012** and **Wang *et al.*, 2024**). However, Boron is an essential micro-nutrient involved in cell wall formation (**Marschner, 2012**), pollen germination, fruit set, and (**Villette *et al.*, 2020**) berry development. Then, spraying grapevines with potassium and boron during critical growth stages positively influences the physical quality attributes of grape clusters (**Hu *et al.*, 2023**).

3.4. Effect of spraying potassium citrate and boric acid on berry setting %

Data presented in Table (6) showed the response of ‘Crimson’ grapevine berry setting % to spraying Potassium citrate (at 0.5, 1.0, and 1.5%) or/and Boric acid at (50, 100, and 150 ppm) and its combination, during 2023 and 2024 seasons. Regarding individual spraying of Potassium citrate and Boric acid, it is clear from this table that, all individual treatments were capable to improve the percentage of berry setting in the two experimental seasons, except the case of lower boric acid only in the first season, failed to vary the berry setting percentage. In addition, whatever the concentration used, spraying with Potassium citrate individually present superiority rather than spraying Boric acid individually.

Regarding the combined application of Potassium citrate and Boric acid, the data presented in Table (6) clearly showed that all combined treatments were succeeded to improve significantly the berry setting %. In addition, increasing the concentration used was parallel to gradual and significant increment of berry setting %. These findings were true in both experimental seasons. Overcome, the vines received the highest concentration of Potassium citrate (1.5%) and Boric acid (1500 ppm) presented the highest percentage of berry setting. On the opposite side, untreated vines produced the lowest percentage of berry settings. These results were true during the two experimental seasons respectively.

Potassium is considered one of the most important macronutrients required for grapevine growth and productivity because it regulates carbohydrate translocation, water balance, enzyme activation, and sugar accumulation in berries (**Mengel and Kirkby, 2001**). Boron is an essential micronutrient involved in cell wall formation, pollen germination, fruit set, and berry development. Therefore, spraying grapevines with potassium and boron during critical growth stages positively influences the physical quality attributes of grape clusters (**Marschner, 2012**). Boron deficiency often results in poor fruit set, shot berries, and loose clusters. Therefore, foliar boron spraying improves cluster compactness and berry uniformity. Studies on grapevines revealed that boron application enhanced fruit set percentage and increased cluster weight due to improved pollen viability and fertilization processes. Moreover, boron stimulates carbohydrate transport toward developing berries, resulting in better berry growth and cluster filling (**Hussain, 2022**).

Table (6). Effect of spraying potassium citrate and Boron at different concentrations on fruit setting % of Crimson grapevines, during 2023 and 2024 seasons

Treatments	Berries setting %	
	2023	**2024**
Control	13.4	13.7
K Citrate 0.5 %	18.5	19.8
K Citrate 1.0 %	21.9	22.1
K Citrate 1.5 %	22.3	24.5
B 50 ppm	15.5	16.8
B 100 ppm	18.1	19.9
B 150 ppm	19.2	20.2
K Citrate 0.5% + B 50 ppm	19.9	21.3
K Citrate 1.0% + B 100 ppm	22.6	23.9
K Citrate 1.5% + B 150 ppm	23.7	24.2
Mean	**19.5**	**20.6**
New LSD at 5%	**3.1**	**2.1**

4. Conclusion

The obtained results indicated that foliar spraying of Potassium and Boron played a vital role in improving nutritional status and productivity of Crimson grapevines. The individual treatments with Potassium showed noticeable superiority over Boron treatments. Moreover, the combined application with Potassium and Boron surpassed the individual application of each one. in order to improve the nutritional status and vine productivity, it is recommended to spray Potassium in form of potassium citrate at 1.5% and Boron in form of boric acid at 150 ppm three times yearly.

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