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Article

# Effect of Foliar Application of Boron, Auxin, and Methionine and Their Interactions on Some Quality Attributes of 'Shada Al-Aswad' Grape *(Vitis Vinifera L.)* Fruits

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**Abstract:** This experiment was carried out in a private vineyard in Al-Dujail District, Salah al-Din Governorate, Iraq for the growing season of 2024 to study the influence of foliar application boron, auxin and methionine on some qualitive properties of 'Shada Al-Aswad' grapevine (Vitis vinifera L.) fruits. The experiment was conducted in a randomized complete block design (RCBD) with 3 replications and included two boron levels (0 and 10 g $L^{-1}$), three auxin concentrations [0, 0.015 and 0.030 mg L-1] and three methionine concentrations [0, 0.010 or 0.030 g L-1]. Results indicated that foliar boron significantly improved some fruit quality attributes by elevated the concentration of sugar, anthocyanin and carbohydrate contents of 7.04%0-1 (793.15 mg 100 $g^{-1}$), 283.68 mg 100 $g^{-1}$; 13.71%, at mean levels with early spring among two treatments with decreasing in acidity and nitrate content recorded to be %0-1;and mmg/ mi01$g^{-1}$,.respectively. This emphasizes the importance of boron in controlling physiological processes associated with fruit quality. Moreover, the elicited metabolite content by auxin at 0.030 mg $L^{-1}$were significantly higher in TSS (14.47%), sugars (6.77%) anthocyanins(TSAC) (271.48 mg/100 g),CHO(13.48%) and much lower in acidity than nitratesabout or equal to 6 h (0.60% and 0,87mg/100g). This is indicative of its regulatory role on fruit ripening and synthesis of quality-related compounds. Additionally, foliar methionine application (0.030 g $L^{-1}$) was able to enhance fruit quality by increasing anthocyanin pigment and carbohydrate contents and decreasing acidity percentages at 271.42 mg 100 $g^{-1}$, 13.48%, and 0.60% respectively. This is a proof of its contribution to biochemical pathways leading to better quality of crop. In general, the results indicate that the application of these compounds especially at the highest applied concentrations can successfully improve quality characteristics of 'Shada Al-Asward' grapes. It is advisable to include them in the current nutrition programs of vineyards placed under similar environmental conditions.

**Keywords:** Grape, Boron, Auxin, Methionine, Fruit Quality

**Introduction**

Grapevine (*Vitis vinifera* L.) is considered one of the most important fruit crops with high economic and food value worldwide. FAOSTAT cited annual world production higher than 77 million tons. Grape berries possess high amounts of sugars, vitamins, minerals, and phenolic compounds, which are highly beneficial for human health and the prevention of chronic disease [1]. Fruit quality attributes, including berry size, color, flavor, and other chemical components (sugar content, acidity) and texture, are the main criteria determining market price and competition both in domestic and international markets.

Thus, in the context of increasing limitations arising from climate changes and urgent demand for agricultural sustainability, improvement of qualitative traits in horticultural crops become a systematic scientific research concern. Recent research showed that GOOD agricultural practices, nutrient application with the right ratio rates to crop demands, as well as correct micronutrients, PGRs, and biostimulant compounds can be successful tools to enhance fruit yield and quality.

Boron (B) is an essential micronutrient and performs crucial biological roles in plants, e.g., cell wall synthesis and its structure the transport of sugars and phenolics, cellular proliferation/differentiation, flowering process, fertilization/fruit set. A recent study conducted by Lateef et al. in 'Halawany' grapevines showed that the foliar application of boron significantly increased TSS and total sugars while vitamin C content was enhanced, and titratable acidity decreased [2].

In another study reported in Food Research International, Bredun et al. found that the infiltration with boron in clusters of 'Merlot' grapevine cultivar led to a higher content of anthocyanins and flavanols [3]. From histological examinations of the berry skin, it also emerged that there was a significantly higher accumulation of polyphenols in the cell tissue compared with the control not treated with alginate.

Similarly, a study by \(Agronomy of\) Álvarez-Herrera et al. was necessary for fruit set stage, growth, and final quality [4]. Reductions in weight loss and retention of firmness were positive effects of boron application; colour development was enhanced, total soluble solids increased, and titratable acidity and pH were maintained since slower degradation of the vitamin led to accumulation of higher levels of ascorbic acid.

Auxins are one of the most important classes of plant growth regulators that regulate a wide range of developmental processes, including cell division, elongation, differentiation and fruit development. Indole-3-acetic acid (IAA) and IAA-synthetic analogs, including 1-naphthaleneacetic acid (NAA), have been shown to influence berry size, shape, and pitch rate.

In a paper published in Frontiers in Plant Science, Böttcher et al. showed that external application of auxin to grape berries delayed ripening by reprogramming gene expression and cell wall metabolism, thus alleviating some detrimental climate change impacts [5]. Furthermore, Davies et al. evidenced a strong effect of NAA application timing on berry growth, ripening time and synchronism of sugar accumulation [6]. When applications were performed at veraison, harvest delay was prolonged, berry shrinkage decreased, and synchronization of total soluble solids accumulation between clusters was better.

Fasoli et al. showed that NAA treatment 1 week prior to veraison brought about striking changes in the transcription rate of ~1,500 genes, thus suggesting that auxin retards grape berry ripening at the transcriptional level [7]. The study also revealed strong antagonistic interaction between auxin and ethylene, and strong synergistic interaction between auxins and abscisic acid (ABA).

Amino acids, such as methionine, are the most biostimulant compounds that increase metabolic processes, synthesis of proteins and enzymes, efficiency of photosynthesis, and tolerance to biotic and abiotic stresses. Methionine is an essential sulfur amino acid and a biological precursor of ethylene, polyamines, and glutathione.

In a systematic review, Henderson et al. pointed out that AAs as biostimulants are a natural and stable solution for increasing yield, growth and abiotic stress resistance by mitigating the impact of abiotic stresses and triggering defense mechanisms in plants [8]. Additionally, Li et al. reported that foliar application of fertilizer-type biostimulants increased endogenous hormone contents in leaves and vinegrape berry quality [9].

Rashid and Al-Atrushy indicated that the phytochemical properties of berries, particularly for 'Red Globe' grapevines, could be significantly enhanced through foliar application of phenylalanine and proline at different concentrations, and this occurred at 1000 ppm phenylalanine [10]. Al-Saif et al., in a research on Peach Trees [11]. Application of methionine and amino acids (500 ppm) as foliar sprays increased the total, reducing sugars, and vitamin C in fruits.

Although grape production is often of high economic significance, many growers are under considerable pressure to achieve modern quality standards in some regions. These include low sugar content, uneven berry size, poor coloration, unequally high sugar-to-acid ratio, and low level of phenolic compounds and anthocyanins that directly affect market value and competitiveness.

Some of these problems are due to unbalanced nutrition, mainly from a lack of essential trace elements (i.e., boron) and/or insufficient regulation of growth and development during sensitive periods for fruit set and ripening. Furthermore, rapid climatic variation such as higher temperatures and water stress affects grape berry quality significantly.

However, while a number of recent studies have considered the effects of boron [2], [3]. Auxins (Davies et al.; Böttcher et al.) or amino acids (Rashid & Al-Atrushy) individually on fruit quality there is an unequivocal absence of information on their combined interactions and synergistic effect [6], [5], [10]. In addition, details of the desirable concentrations, suitable application times and effective integration methods are extremely limited; consequently, extensive experiments should be carried out to bridge this knowledge gap.

Accordingly, in this study, we make a thorough investigation into the potential effects of foliar application of B, auxin, and met on physical and chemical characteristics of grape berries. Objectives of the study are as follows

1. **Assessment of chemical quality attributes:** Precise determination of total soluble solids (TSS), total titratable acidity (TA), total sugar content, and percentage of carbohydrates, in addition to estimation of anthocyanin pigment and nitrate content.
2. **Identification of optimal treatments and concentrations:** Utilization of appropriate experimental design and advanced statistical analyses to determine the most effective concentrations and optimal application timings.
3. **Evaluation of interactive and synergistic effects:** Analysis of potential interactions among treatments to identify synergistic or antagonistic relationships.

**Materials and Methods**

This experiment was conducted in a season 2024 at a private vineyard in Al-Dujail District, Salah al-Din Governorate, Iraq to study the impact foliar-applied boron, auxin and methionine on some qualitative characters of 'Shada Al-Aswad' grape (Vitis vinifera L.) berries. The vineyard was planted with 8-year old vines spaced at 4 × 2.5 m using an overhead trellis system. Record Keeping A total of 54 vines were chosen for the trial.

The experimental factors were: two B levels (0 and 10 g $L^{-1}$), three IAA [indole-3-acetic acid (IAA)] concentrations (0, 0.015 and 0.030 mg $L^{-1}$) and three metionine levels (0, 0.010 and 0.030 g $L^{-1}$). Vine canopy was sprayed with the foliar spray (50 L mechanical knapsack sprayer, Holder®) to runoff with a water- surfactant (0.1 mL pag Zahi®·$L^{-1}$) mixture in order to release surface tension. Fungicide applications were made during the morning hours. The vines in the control treatment were only distilled water.

Applications were conducted at three development stages: the first application was applied two weeks before full blossoms occurred (April 10), the second a week after fruit set (May 2), and the third four weeks after the second treatment.

The experimental design was a factorial combination (2 × 3 × 3) in an RCBD with three replications and consisted of 18 treatment combinations. Experimental units were individual vines and treatments randomly allocated within blocks. This gave us a total of 54 vines

At harvest maturity, determined based on typical phenotypic indicators for the cultivar such as berry size, color, and flavor, five clusters were randomly sampled from each vine for analysis. The following quality attributes were assessed:

- **Total soluble solids (TSS)** in berry juice were measured with a handheld refractometer and expressed as a percentage (%) [12].
- **Total acidity** was determined by titration with standard sodium hydroxide (NaOH) solution and expressed as a percentage of tartaric acid [13].
- **Total sugars** were quantified using the Fehling's method and expressed as a percentage (%). According to the method of Dubois et al.
- **Anthocyanin content** in the berries was measured spectrophotometrically following the procedure of [14].
- **Nitrate concentration** was determined using steam distillation with a Kjeldahl apparatus. following the procedure of [15].
- **Total carbohydrates** were measured colorimetrically using the anthrone method with a spectrophotometer, following the procedure of [16].

Data were subjected to analysis of variance (ANOVA), and treatment means were compared using the least significant difference (LSD) test at the 5% probability level, as described by [17]. Statistical analyses were performed using Genstat (12th ed).

**Results**

**1. Total Soluble Solids (TSS %)**

Table 1 showed that expressed in the expression of TSS is significantly affected by the study on grape (Shada Al- Aswad). The highest TS contents (14.91%) were noted in $B_{10}$ and also marked significant differences when compared to the one with the lowest value, namely, $B_0$ (13.07%).

With respect to auxin application, the treatment 0.030 mg $L^{-1}$ ($A_{30}$) with spraying resulted in higher TSS levels (14.47%) than control or A0, which presented values of 13.31%. The highest TSS content (14.48%) was observed for $M_2$ treatment with methionine 0.030 $gL^{-1}$ as well (Table 1).

In the two-way interactions, BxA was highly significant for TSS and the highest (15.39%) was recorded by $B_{10}A_{30}$ as compared to $B_6$A24, with a minimum value of 12.48% in ($B_0A_0$). The interaction of boron and methionine was also highly significant, resulting in the highest TSS (15.35%) for ($B_{10}M_2$) and the lowest value (12.13%) for ($B_0M_0$).

The effect of auxin and methionine interaction was also highly significant for TSS, where ($A_{30}M_2$) recorded the highest percentage (15.06%) and ($A_0M_0$) produced the lowest value (13.00%).

For the three-way interaction, the ($B_{10}A_{30}M_2$) combination gave maximum TSS content (15.86%), which was significantly superior to that of the control treatment ( $B_0$ $A_0$ $M^0$), having the minimum value (12.13%).

**Table 1.** Effect of boron, auxin, methionine, and their interactions on the total soluble solids (%) of Shada al-Aswad grape cultivar.

| B | A | M | | | B×A |
|---|---|---|---|---|---|
| | | M0 | M1 | M2 | |
| B0 | A0 | 12.13 | 12.42 | 12.86 | 12.48 |
| | A15 | 12.68 | 13.23 | 13.68 | 13.20 |
| | A30 | 13.02 | 13.38 | 14.26 | 13.55 |
| B10 | A0 | 13.86 | 14.03 | 14.54 | 14.15 |
| | A15 | 14.77 | 15.17 | 15.66 | 15.20 |
| | A30 | 14.96 | 15.35 | 15.86 | 15.39 |
| Mean of B | | | | | |
| B×M | B0 | 12.61 | 13.01 | 13.61 | 13.07 |
| | B10 | 14.53 | 14.85 | 15.35 | 14.91 |
| A Mean of | | | | | |
| A×M | A0 | 13.00 | 13.23 | 13.71 | 13.31 |
| | A15 | 13.73 | 14.20 | 14.67 | 14.20 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | A30 | 13.99 | 14.36 | 15.06 | 14.47 |
| | M Mean of | | 13.57 | 13.93 | 14.48 | |
| L.S.D 5% | | | | | | |
| B×A×M | A×M | B×M | B×A | M | A | B |
| 0.015 | 0.011 | 0.009 | 0.009 | 0.006 | 0.006 | 0.005 |

**2. Total Titratable Acidity (%)**.

The results 2 86.13 (1) Total titratable acidity. The data of the analysis is shown in by Vitis vinifera L. cv. All the studied factors had a highly significant effect on "Shada Al-Aswad". The foliar boron ($B_{10}$) at 10 g·L⁻¹, was superior to the control treatment ($B_0$), with acidity of 0.67% and that of 0.38% respectively. As to auxin, the foliar application of ($A_{30}$) at 0.030 mg·L⁻¹ was significantly higher acidity percentage values (0.60%) than those ones in the treatments with 0.015 and 0.000 mg·L⁻¹ products. For methionine, the treatment ($M_3$) at 0.030 mg·L⁻¹ showed the highest acidity (0.60%) whereas medium concentration($M_2$) at 0.010 mg·L⁻¹ recorded 0.52% as compared to control ($M_0$) with lowest amount of acidity 0.46%.

Significant effect on total acidity percent was observed using the results of two-way interactions. Boron × Auxin interaction ($B_{10}A_{30}$) showed the maximum acidity (0.74%) and the combination $B_0A_0$ lowest (0.27%). Furthermore, the interaction ($B_{10}M_2$) produced the highest acidity content (0.73%) while the lowest value was obtained from ($B_0M_0$) which reached 0.29%, revealing a synergistic impact between the physiological function of boron affecting metabolic plants and methionine inducing natural auxin signaling. The ($A_{30}M_2$) was the highest 0.70%, while ($A_{74}C_1$) combination was lowest with 0.36% value when transferred to methanol as compared with ($A_{15}M_2$) having 0.62%.

With regard to the three-way interaction among the factors, ($B_{10}A_{30}M_2$) was proved most successful having with an acidity percentage of 0.82%, while it significantly differed from ($B_0A_0M_0$) that resulted in the lowest acidity value of 0.21%.

**Table 2.** Effect of boron, auxin, methionine, and their interactions on the total titratable acidity (%) of shada al- aswad grape cultivar.

| B | A | M | | | B×A |
|---|---|---|---|---|---|
| | | **M0** | **M1** | **M2** | |
| | A0 | 0.21 | 0.27 | 0.34 | 0.27 |
| B0 | A15 | 0.31 | 0.41 | 0.46 | 0.39 |
| | A30 | 0.36 | 0.45 | 0.58 | 0.46 |
| | A0 | 0.51 | 0.53 | 0.61 | 0.55 |
| B10 | A15 | 0.67 | 0.71 | 0.77 | 0.72 |
| | A30 | 0.67 | 0.74 | 0.82 | 0.74 |
| **Mean of B** | | | | | |
| B×M | B0 | 0.29 | 0.37 | 0.46 | 0.38 |
| | B10 | 0.62 | 0.66 | 0.73 | 0.67 |
| **A Mean of** | | | | | |
| | A0 | 0.36 | 0.40 | 0.48 | 0.41 |
| A×M | A15 | 0.49 | 0.56 | 0.62 | 0.56 |
| | A30 | 0.52 | 0.59 | 0.70 | 0.60 |
| **M Mean of** | | 0.46 | 0.52 | 0.60 | |

| L.S.D 5% | | | | | | |
|---|---|---|---|---|---|---|
| B×A×M | A×M | B×M | B×A | M | A | B |
| 0.013 | 0.009 | 0.007 | 0.007 | 0.005 | 0.005 | 0.004 |

**3. Total Sugars (%)**

As seen in Table (3) The total sugar percentage was significantly influenced by the individual factors of boron, auxin and methionine as well as their 2-factor and 3-factor combinations at the 0.05 level of probability. The percentage of sugar for the foliar boron spray with 10 g·L⁻¹ ($B_{10}$) significantly exceeded that in control plants, reaching up to 7.04% as opposed to the lowest value of 5.76%, no treatments ($B_0$). For auxin, the highest sugar content (6.77%) was realized from the spray at 0.030 mg·L⁻¹ ($A_{30}$), which were higher as compared to values for 0.015 mg·L⁻¹ and 0.000 mg·L⁻¹. In the case of methionine, when 0.030 mg·L⁻¹ condition was applied ($M_3$), this yield was higher (6.74%) with respect to the control treatment (6.08%), which corresponded to 0.01 mg·L⁻¹ of L-methionine ($M_0$).

Total sugar content was highly impacted by the two-way interactions. The highest percentage of individual tebuconazole and cyflufenamid was registered in the treatment $B_{10}A_{30}$ (7.43%), while value obtained for untreated combination ($B_0A_0$) was the lowest (5.34%). Likewise interaction of boron and methionine ($B_{10}M_2$) showed maximum sugar contents (7.37%) as compared to the minimum in $B_0M_0$ (5.45%). The interaction of auxin × methionine ($A_{30}M_2$) was the highest (7.18%), but the control combination ($A_0M_0$) was the lowest (5.69%).

The three-way interaction between B 10, A 30 and M 20 further proved as the most influential combination, with an average total sugar percentage of7.83% and was significantly different from the lowest (5.13%) of the control (B0A0M0) cocktail.

**Table 3.** Effect of boron, auxin, methionine, and their interactions on the total sugars (%) of Shada al-Aswad grape cultivar.

| B | | A | M | | | B×A |
|---|---|---|---|---|---|---|
| | | | M0 | M1 | M2 | |
| B0 | | A0 | 5.13 | 5.24 | 5.64 | 5.34 |
| | | A15 | 5.45 | 5.88 | 6.14 | 5.82 |
| | | A30 | 5.77 | 6.03 | 6.54 | 6.11 |
| B10 | | A0 | 6.26 | 6.43 | 6.68 | 6.46 |
| | | A15 | 6.87 | 7.24 | 7.61 | 7.24 |
| | | A30 | 7.02 | 7.43 | 7.83 | 7.43 |
| **Mean of B** | | | | | | |
| B×M | | B0 | 5.45 | 5.71 | 6.11 | 5.76 |
| | | B10 | 6.71 | 7.03 | 7.37 | 7.04 |
| **A Mean of** | | | | | | |
| A×M | | A0 | 5.69 | 5.83 | 6.16 | 5.90 |
| | | A15 | 6.16 | 6.56 | 6.88 | 6.53 |
| | | A30 | 6.93 | 6.73 | 7.18 | 6.77 |
| **M Mean of** | | | 6.08 | 6.37 | 6.74 | |
| | | | L.S.D 5% | | | |
| B×A×M | A×M | B×M | B×A | M | A | B |
| 0.016 | 0.011 | 0.009 | 0.009 | 0.006 | 0.006 | 0.005 |

**4. Anthocyanin Content(mg·100g⁻¹)**

As shown in Table (4), the anthocyanin content found in the berries of Vitis vinifera L. cv. 'Shada Al-Aswad' was highly influenced on the factors studied. Foliar spraying at 10 g·L⁻¹ ($B_{10}$) produced the best results compared to the control ($B_0$), with an anthocyanin content of 283.68 mg·100 g⁻¹, whereas in plants that were not sprayed, a value as low as 225.65 mg·100 g⁻¹ was observed. For auxin treatment, spraying with 0.030 mg·L⁻¹ ($A_{30}$) achieved the highest content (271.48 mg·100 g⁻¹), while control ($A_0$) had the lowest value (233.39 mg·100 g⁻¹). In comparison, methionine application at 0.030 mg·L⁻¹ ($M_3$) showed the highest anthocyanin content (271.42 mg·100 g⁻¹), which was higher than those at the other lower levels.

Two-way interactions were also significant by statistical analysis. The anthocyanin content was highest (302.30 mg·100 $g^{-1}$) in the combination of boron and auxin ($B_{10}A_{30}$) and lowest in the untreated control (209.01 mg·100 $g^{-1}$). The interaction with boron and methionine ($B_{10}M_3$) also caused a marked effect, reaching the maximum value (302.62 mg·100 $g^{-1}$) against the minimum one (212.14 mg·100 $g^{-1}$) in $B_0M_0$. For the interaction of auxin × methionine, the highest content (294.65 mg·100 $g^{-1}$) was obtained from $A_{30}M_2$ while the lowest content (225.53 mg·100 $g^{-1}$) was recorded for $A_0M_0$.

The three-way interaction of the boron, auxin and methionine ($B_{10}A_{30}M_2$) had a greatest influence with 328.80 mg·100 $g^{-1}$ for anthocyanins content and it was statistically different from the lowest value achieved with 201.37 mg·100 $g^{-1}$ obtained by the control treatment ($B_0A_0M_0$).

**Table 4.** Effect of boron, auxin, methionine, and their interactions on the Anthocyanin Content(mg·100$g^{-1}$) of shada al- aswad grape cultivar.

| B | A | M | | | B×A |
|---|---|---|---|---|---|
| | | **M0** | **M1** | **M2** | |
| | A0 | 201.37 | 206.80 | 218.87 | 209.01 |
| B0 | A15 | 210.38 | 230.17 | 241.30 | 227.28 |
| | A30 | 224.70 | 236.80 | 260.50 | 240.67 |
| | A0 | 249.70 | 254.80 | 268.80 | 257.77 |
| B10 | A15 | 274.17 | 288.50 | 310.27 | 290.98 |
| | A30 | 281.50 | 296.60 | 328.80 | 302.30 |
| **Mean of B** | | | | | |
| B×M | B0 | 212.14 | 224.59 | 240.22 | 225.65 |
| | B10 | 268.46 | 279.97 | 302.62 | 283.68 |
| **A Mean of** | | | | | |
| | A0 | 225.53 | 230.80 | 243.83 | 233.39 |
| A×M | A15 | 242.27 | 259.33 | 275.78 | 259.13 |
| | A30 | 253.10 | 266.70 | 294.65 | 271.48 |
| **M Mean of** | | 240.30 | 252.28 | 271.42 | |

| L.S.D 5% | | | | | | |
|---|---|---|---|---|---|---|
| B×A×M | A×M | B×M | B×A | M | A | B |
| 0.1485 | 0.105 | 0.086 | 0.086 | 0.061 | 0.061 | 0.050 |

**5. Total Carbohydrates (%)**

As can be seen from the values in Table 5, there was a remarkable difference in total carbohydrate content between foliar spray of boron, auxin and methionine that were applied individually or together toward Vitis vinifera L. cv. berries of "Shada Al-Aswad" during the season 2024 at a probability level of 0.05. Foliar spray of boron at 10 g·$L^{-1}$ ($B_{10}$) was significantly superior to the control ($B_0$); it resulted in the highest percentage value (13.71%) against a minimum of 12.71%. With respect to auxin, the highest carbohydrate % (13.48%) was observed with foliar application at 0.030 mg·$L^{-1}$ ($A_{30}$), and the lowest (12.84%) was in the control treatment ($A_0$). On the other hand, 0.030 mg·$L^{-1}$ application of methionine ($M_3$) reached the highest value (13.48%), which is greater than those from lower concentrations(use a comma to separate phrases).

Two-way interaction was also important for carbohydrate content. The combination of boron with auxin ($B_{10}A_{30}$) resulted in the highest percentage (13.98%) and the lowest values was obtained from control combination ($B_0A_0$) being 12.40%. As for boron × methionine interaction, the maximim carbohydrate% (13.96) was found in ($B_{10}M_3$), while its minimum, 12.46%, was observed in ($B_0M_0$). The maximum value (13.83%) was recorded in the interaction of aux and met ($A_{30}M_2$), the minimum percentage (12.70%) was noted in the case of $A_0M_0$.

On the other hand, $B_{10}A_{30}M_2$ (the interaction among boron, auxin, and methionine) was the best result for three-way interactions, resulting in the highest carbohydrate percent of 14.27%, which was significantly higher than the lowest value (12.26%) obtained from the control combination, that is, $B_0A_0M_0$.

**Table 5.** Effect of boron, auxin, methionine, and their interactions on the total carbohydrates (%) of Shada al-Aswad grape cultivar.

| B | A | M | | | B×A |
|---|---|---|---|---|---|
| | | M0 | M1 | M2 | |
| B0 | A0 | 12.26 | 12.36 | 12.58 | 12.40 |
| | A15 | 12.45 | 12.77 | 13.01 | 12.74 |
| | A30 | 12.68 | 12.88 | 13.38 | 12.98 |
| B10 | A0 | 13.13 | 13.24 | 13.48 | 13.28 |
| | A15 | 13.57 | 13.84 | 14.14 | 13.85 |
| | A30 | 13.71 | 13.97 | 14.27 | 13.98 |
| **Mean of B** | | | | | |
| B×M | B0 | 12.46 | 12.67 | 12.99 | 12.71 |
| | B10 | 13.47 | 13.68 | 13.96 | 13.71 |
| **A Mean of** | | | | | |
| A×M | A0 | 12.70 | 12.80 | 13.03 | 12.84 |
| | A15 | 13.01 | 13.31 | 13.58 | 13.30 |
| | A30 | 13.20 | 13.43 | 13.83 | 13.48 |
| **M Mean of** | | 12.97 | 13.18 | 13.48 | |

| L.S.D 5% | | | | | | |
|---|---|---|---|---|---|---|
| B×A×M | A×M | B×M | B×A | M | A | B |
| 0.021 | 0.015 | 0.012 | 0.012 | 0.009 | 0.009 | 0.007 |

**6. Nitrate Content in Grapes**

According to the results presented in Table 6, there are significant differences among foliar spray treatments and their interaction effect on the berry accumulated nitrate ($NO_3^-$) content of 'Shadda Al-Aswad' grape cultivar. Nitrate content was much lower (mg·100 $g^{-1}$) in leaves treated with boron spray ($B_1$, at 10 g·L-1), and it was significantly reduced to 0.72 mg·100 $g^{-1}$ with the control treatment ($B_0$; of highest value 1.58 mg·100 $g^{-1}$). With relation to auxin, the level of 0.030 mg·$L^{-1}$of this plant growth regulator ($A_{30}$) induced the lowest nitrate content (0.87 mg·100 $g^{-1}$) compared with the control ($A_0$), which presented the highest value among treatments for all concentrations evaluated (1.59 mg·100 $g^{-1}$). Use of foliar applied methionine ($M_2$) at 0.030 mg·$L^{-1}$ also showed noticeable reduction in nitrate levels (0.90 mg·100 $g^{-1}$) in comparison with the control value ($M_0$;1.46mg·100 $g^{-1}$).

In the binary interactions, boron and auxin interaction had significant effect on nitrate content where the minimum value (0.52 mg·100 $g^{-1}$) was found with treatment $B_{10}A_{30}$ and the maximum (2.15 mg·100 $g^{-1}$) observed under combination ($B_0A_0$). The interaction between boron and methionine was also significant and the lowest nitrate in $B_{10}M_3$ treatment (0.57 mg·100 $g^{-1}$) while the highest content found from $B_0M_0$ treatment (2.07 mg·100 $g^{-1}$). The interaction auxin–methionine had also a marked effect, reaching the lowest content of nitrate with ($A_{30}M_2$) (0.67 mg·100 $g^{-1}$), and the highest one was found with ($A_0M_0$) 2.19 mg·100 $g^{-1}$. With respect to the triple combination, ($B_1A_{30}M_2$) produced nitrate levels of 0.37 mg·100 $g^{-1}$ that were significantly lower than ($B_0A_0M_0$), which showed the highest value (3.22 mg·100 $g^{-1}$).

**Table 6.** Effect of boron, auxin, methionine, and their interactions on the Nitrate Content (mg·100g⁻¹) of Shada al-Aswad grape cultivar.

| B | A | M | | | B×A |
|---|---|---|---|---|---|
| | | M0 | M1 | M2 | |
| | A0 | 3.22 | 1.72 | 1.52 | 2.15 |
| B0 | A15 | 1.57 | 1.34 | 1.21 | 1.37 |
| | A30 | 1.41 | 1.29 | 0.97 | 1.22 |
| | A0 | 1.12 | 1.04 | 0.91 | 1.02 |
| B10 | A15 | 0.77 | 0.62 | 0.44 | 0.61 |
| | A30 | 0.68 | 0.52 | 0.37 | 0.52 |
| **Mean of B** | | | | | |
| B×M | B0 | 2.07 | 1.45 | 1.24 | 1.58 |
| | B10 | 0.86 | 0.73 | 0.57 | 0.72 |
| **A Mean of** | | | | | |
| | A0 | 2.19 | 1.38 | 1.21 | 1.59 |
| A×M | A15 | 1.17 | 0.98 | 0.83 | 0.99 |
| | A30 | 1.05 | 0.99 | 0.67 | 0.87 |
| **M Mean of** | | 1.46 | 1.09 | 0.90 | |

| L.S.D 5% | | | | | | |
|---|---|---|---|---|---|---|
| B×A×M | A×M | B×M | B×A | M | A | B |
| 0.014 | 0.010 | 0.008 | 0.008 | 0.006 | 0.006 | 0.005 |

## Discussion

The findings also showed that application of B as a foliar spray at 10 g·L⁻¹ significantly improved most qualitative traits studied including TSS (Table 1), titratable acidity (Table 2), total sugars (Table 3), anthocyanin pigment content (Table 4) and total carbohydrates (Table 5) but remarkably reduced nitrate concentration(Table, 6). These effects might be ascribed to the fact that boron is an essential element in sugar transport across cell membranes and improves photosynthetic efficiency by increasing the stability of cell walls due to pectin deposition. Boron also con- tributes to the formation of covalent cross-links among carbo- hydrates in cell wall, thus providing better fruit structure and larger amounts of soluble compounds [18]. Moreover, it is also an important factor in controlling enzymatic activities associated with the nitrate uptake and reduction process, resulting in reduced nitrate accumulation by optimizing nitrogen utilization efficiency within plant tissues [19].

Additionally, the results indicated that the foliar application of auxin passed into effect in improving qualitative traits of grape berries such as TSS (Table 1), titratable acidity (Table 2), total sugars (Table 3), anthocyanin pigment (Table 4) and carbohydrates percentage (Table 5), and decreasing nitrate content, particularly at rate of about(0.030 mg·L⁻¹) level ( Table6). This might be accounted for by the regulating function of auxin on fruit growth and ripening, including increasing sugar and starch (carbohydrate) content in fruits through its regulation to enzyme activities related to starch degradation and nutrient transferring from leaves to fruits. In addition, auxin is known to induce the an-thocyanin pigments associated with fruit color formation through the induction of relevant secondary metabolic pathways [20], [21]. Moreover, the reduction in nitrate content in plant tissues could be possible by an increase of NR activity resulting from the action of auxin [22].

Likewise, application of methionine at 0.030 mg·L⁻¹ resulted in marked increase in TSS (Table 1), TA (Table 2), total sugars (Table 3), anthocyanin content Table-4 and TCH (Table 5) as well as significant decrease in nitrate concentration Table-6. This could be due to methionine being a sulphur-rich amino acid that participates in auxin (IAA) biosynthesis and subsequently improves the development of fruit or ripening [23]. In addition to engage in polyamine metabolism, for example, facilitating lignification of promenacedes and normal growth development in Se male flowers, methionine can be used as a precursor of other physiological processes, including ethylene biosynthesis, which promotes ripening and colouration [21]. In addition, methionine promotes the absorption of nutrients in plants as well as nitrogen fixation, which decreases the accumulation of free nitrates in tissues by attaching them to protein molecules [24].

**Conclusion**

1. Auxin at 0.030 mg·$L^{-1}$ significantly improved most of the studied qualitative traits, particularly by increasing TSS, sugars, anthocyanins, and carbohydrates, while reducing nitrate accumulation in the berries.
2. Boron at 10 g·$L^{-1}$ effectively enhanced fruit quality by increasing sugar and anthocyanin accumulation, improving physiological efficiency, and reducing nitrate buildup.
3. Methionine at 0.030 mg·$L^{-1}$ significantly improved most qualitative traits through its role as a source of auxin and essential amino acids involved in metabolism and physiological processes related to ripening.
4. The results indicate a cumulative effect of the three factors, with the highest qualitative values achieved using the combined treatment: auxin 0.030 mg·$L^{-1}$ + methionine 0.030 mg·$L^{-1}$ + boron 10 g·$L^{-1}$.

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