# Humic Acid and Boron to Minimize the Incidence of Alternate Bearing and Improve the Productivity and Fruit Quality of Mango Trees

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***Abstract*. Mango production faces several challenges, such as nutrient deficiency, physiological stress, and alternate bearing, which eventually affect tree productivity. This study was carried out during the 2017 and 2018 seasons to evaluate the effect of single and combined applications of humic acid (as potassium humate; 0.15%, 0.30%, 0.45%) and boron (as boric acid; 300, 600 mg·L$^{-1}$) on 'Zebda' mango trees grown at Dir AlMalak region, Sharkeya Governorate, Egypt. Foliar spray was applied twice before flowering (first week of January and first week of February), and a third spray was applied by the beginning of flowering (first week of March) in both seasons. Humic acid and boron effectively enhanced tree growth, flowering, yield, and fruit quality. Humic acid was more effective than boron in this respect. Combined application of both materials surpassed the single application of each material on overall tree physiology and annual productivity. The observed results may be a consequence of the increase in tree photosynthetic pigments, nutrients, organic solutes, and phytohormones such as auxins, gibberellins, and cytokinins. The reduction in abscisic acid content may be related to the role of humic acid and boron protecting the plant against destructive oxidative reactions; improving the ability of the trees to withstand environmental stresses; thereby reduce floral malformation percentage, minimize the incidence of alternate bearing, and improve annual tree productivity and fruit quality. The most pronounced effect in this regard was noted with the application of 0.30% humic acid + 600 mg·L$^{-1}$ boric acid.**

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Mango [*Mangifera indica* (L.)], a member of family Anacardiaceae, is considered one of the most important fruit tree grown in tropical and subtropical regions (Masroor et al., 2016). It is also considered the second cultivated tropical fruit, and the sixth major fruit crop worldwide (UNCTAD, 2016). It can be successfully cultivated in all irrigated semi-arid regions, such as Egypt, which considered the most important mango producer in the Middle East that successfully grown a wide variety of mango cultivars (Elkhishen, 2015). Total cultivated area in Egypt is ≈78,847.6 ha, and total annual production is 850,114.85 t (Food and Agriculture Organization of the United Nation, 2018). Mango is mainly being cultivated in the Sharkeya, Ismailia, Fayoum, Qena, and Beheira Governorates. The most important varieties are Hindi, Taymour, Ewais, Zebda, Langara, Alphonse, and Keitt (Riad, 1997).

Mango production faces several challenges, such as micronutrients deficiency, biotic and abiotic stresses, and problems related to fruit yield and quality (Kumar and Kumar, 2016). Alternate bearing; high fruiting in a year ("on-year") and unsatisfactory fruiting in the next year ("off-year"), as well as low fruit set and fruit retention are the main reasons of low yield in mango (Saker and Rahim, 2013). Most of the Egyptian mango cultivars, particularly Zebda, suffer from alternate bearing (Shaban, 2009a). The variation in temperature or humidity during flowering, pollination, fruit set or maturation, in addition to the depletion in tree reserves during the period of heavy crop load, and vigorous vegetative growth with high levels of gibberellins during flower bud differentiation period, as well as the imbalance in carbon:nitrogen (C/N) ratio have been considered some of the major causes for alternate bearing in mango (Chadha, 1993). Some field practices, such as foliar spray of organic biostimulants (e.g., humic acid, fulvic acid, and amino acids) and micronutrients (e.g., Fe, Zn, Mn, Cu, and B), were used to improve 'Keitt' and 'Ewais' mango fruit quantity and quality (El-Kosary et al., 2011). Humic acid directly absorbed by leaves, resulting in low energy consumption, metabolism improvement, and stress mitigation, which in turn promote plant growth and productivity (Yakhin et al., 2017). A combined foliar application of N and B has alleviated the incidence of alternate bearing in 'Zebda' mango by 41% and improved yield by 5.9-fold compared with the untreated trees during the off-year (El-Motaium et al., 2019). Under salinity stress conditions, the application of ZnO and Si nanoparticles has improved plant resistance to salinity, reduced floral malformation percentage, minimized the incidence of alternate bearing, and improved annual productivity and fruit quality of 'Ewais' mango trees (Elsheery et al., 2020).

Humic acid (HA) is the active constituent of organic humus. It is not considered a fertilizer; instead, it is used as a soil conditioner or as a plant biostimulant (Ngullie et al., 2014). Humic acid directly and indirectly affects plant growth and development (Chen et al., 2004). It stimulates enzymes in many biological processes, enhances plant resistance to biotic stress, improves chlorophyll synthesis and photosynthesis rate, promotes sugars and amino acids metabolism, and increases cell wall thickness prolonging fruit storage period (Abd El-Razek et al., 2012; Hagagg et al., 2013). Humic acid application on mango trees induced nutrient uptake and enhanced vegetative growth, flowering and fruiting characteristics (Pablo Morales and William, 2003). However, the action of humic acid is dose dependent; for instance, high concentrations are inhibitory for nutrient accumulation (Chen and Avaid, 1990). Application of HA increased P content in leaves of 'Florida Prince' peach trees (Abd El-Razek et al., 2012). Humic acid improved shoot length and diameter, leaf area, fruit weight, dimensions, firmness, anthocyanin content, total soluble solids (TSS), TSS/acid ratio, and decreased the percentage of fruit drop and acidity in 'Anna' apple (Mosa et al., 2015). A positive correlation between fruit yield and leaf nutrients content was noticed with the application of HA on 'Red Delicious' apple trees (Hidayatullah et al., 2018). Humic acid increased fruit TSS and total sugars but reduced acidity of 'Ewais' mango fruit (El-Kosary et al., 2011).

Boron (B) is a critical nonmetal immobile micronutrient, important for plant growth and development, pollen germination, and pollen tube elongation (Saini et al., 2019). It has a role in cell wall synthesis, structure and lignification, and plasma membrane integrity (Srivastava and Gupta, 1996). Careful application of B is important because of the narrow threshold between B deficiency and toxicity (Yua and Ryan, 2008). Boron improves enzymes activity, promotes phytohormones and nucleic acids, activates nutrient uptake and mitigates plant tolerance to salinity, increases carbohydrates and sugars allocation, and stimulates phenols metabolism (Khayyat et al., 2007; Marschner, 2012). Boron foliar spray on 'Dashehari' mango trees during the off-years has increased C/N ratio and ultimately improved flowering, fruit set, number of fruit per tree, and total yield (Negi et al., 2009). Foliar spray of B and putrescine significantly decreased fruit drop percentage and improved fruit yield and quality of 'Zebda' mango (Ali et al., 2017). A mixture of Fe, B, and Zn increased nutrient uptake and improved fruit quality of 'Dusehri' mango (Anees et al., 2011) and 'Bhaskara' cashew (Lakshmipathi et al., 2018).

Most of the previous reports have focused on plant response to soil application of humic acid. Limited reports have shed light on foliar application of humic acid on fruit tree, and mango in particular. The aim of this study was to evaluate the effect of foliar spray with humic acid and boron on minimizing the incidence of alternate bearing and improving the yield and fruit quality of 'Zebda' mango trees grown under the Egyptian conditions.

## Materials and Methods

*Experiment.* This research was carried out on 15-year-old mango trees [*Mangifera indica* (L.) 'Zebda'] in a private orchard located at Dir AlMalak Valley, Sharkeya Governorate (lat. 30°73′27″N, long. 31°71′95″E), Egypt, during two consecutive seasons; 2017 off-year and 2018 on-year. Thirty-six 'Zebda' mango trees from polyembryonic-seeds, planted at 7 × 7 m spacing, similar in vigor and size, lacking any symptoms of nutrients deficiency nor diseases, were chosen for this experiment. Trees were grown in sandy soil and subjected to drip irrigation at approximate daily rate of 8 to 10 $L \cdot h^{-1}$ based on weather conditions (e.g., temperature, humidity, etc.) and the growth stage of the trees (i.e., shoot growth, flowering, and fruiting). Soil analysis was carried out according to Klute and Dirksen (1986), and data are displayed in Table 1.

During both seasons, foliar spray of humic acid (HA) [as potassium humate ($C_9H_8K_2O_4$), 12% $K_2O$, imported from China by Humy Nasser Inc., Cairo, Egypt] at 0.15%, 0.30%, and 0.45%; B [as boric acid (BA; $H_3BO_3$), Sigma Aldrich, St. Louis, MO] at 300 and 600 $mg \cdot L^{-1}$, and their combinations was applied twice before flowering (first week of January and first week of February), and a third spray was applied after a month (first week of March) during flowering period (early March–early April). Control trees were also sprayed at the same three times using distilled water. Trees selected for this experiment were receiving other regular agricultural practices as the entire orchard. The experimental design was in a randomized complete block system of 12 treatments with three replicates each. Each replicate was represented by one tree.

*Leaf area.* At full bloom (first week of April), leaf area ($cm^2$) of the fourth leaf from 10 branches at the top of the tree was estimated according to the formula of Ahmed and Morsy (1999): LA = [0.70 (L × W) – 1.06]; where LA = leaf area ($cm^2$), L = maximum leaf length (cm), W = maximum leaf width (cm), and then average leaf area was calculated.

*Leaf analysis.* The same 10 leaves were used to determine the concentration of photosynthetic pigments; chlorophyll (a) and (b), and carotenoids (%) according to Fadeel (1962), and the content of total flavonoids [μg/100 g dry weight (DW)] according to Jordan et al. (1994) using a spectrophotometer (Model ultraviolet 9100; LabTech Inc., Hopkinton, MA). Percentage of nitrogen (N), phosphorus (P), and potassium (K) was also determined (Wilde et al., 1979). Total carbohydrates ($\mu g \cdot g^{-1}$ DW) and sugars ($mg \cdot g^{-1}$ DW) were estimated according to Dubois et al. (1956) and Ackerson and Krieg (1977), respectively. Estimation of total free amino acids (Rosed, 1957), proline (Bates et al., 1973), and total phenols (Gao et al., 2006) [$\mu g \cdot g^{-1}$ fresh weight (FW)] was also carried out. Phytohormones ($\mu g \cdot g^{-1}$ FW); auxins [mainly indole-3-acetic acid (IAA)], gibberellins (mainly $GA_3$), and abscisic acid (ABA) were determined according to Koshioka et al. (1983) using high performance liquid chromatography (M5 Micro flow HPLC system; SCIEX, Framingham, MA), whereas cytokinins (CKs) were determined using the methodology of Nicander et al. (1993).

*Floral malformation assessment.* At full bloom, trees were inspected for malformed floral panicles, which characterized by compacted, stunted, thickened, and branched panicles with larger flower number and size. Symptoms also included green and dwarfed panicles with distorted leaves growing instead of flowers (Helaly et al., 2018). The total number of panicles per tree was counted, and floral malformation percentage was calculated using the following equation:

$$\text{Malformation \%} = (\text{Number of malformed panicles per tree} \div \text{Total number of panicles per tree}) \times 100.$$

*Yield and fruit physiochemical characteristics.* At commercial harvest time by late August–early September, yield was recorded as total fruit weight (kilograms) per tree. A sample of 10 ripe fruit per tree was randomly selected from the four directions (north, east, south, and west) and three levels (top, medium, and bottom) of the tree to calculate average fruit and pulp weight, in addition to fruit length and width. Fruit and pulp weight (grams) were measured using a bench-top digital scale Model PC-500 (Doran scales, Inc., Batavia, IL). Fruit length and width (millimeters) were measured using a digital caliper (Grizzly Industrial,

Table 1. Soil analysis of the experimental site (values are means of two seasons).

| | Characteristics | Soil depth (cm) 0–30 | 30–60 |
|---|---|---|---|
| Physical | Texture | Sandy | |
| | Fine sand (%) | 29.44 | 34.12 |
| | Coarse sand (%) | 67.2 | 62.23 |
| | Silt (%) | 2.10 | 2.27 |
| | Clay (%) | 1.26 | 1.38 |
| | Field capacity (%) | 11 | 12 |
| Chemical | Electrical conductivity ($dS \cdot m^{-1}$) (1:5 extract) | 0.46 | 0.42 |
| | pH (1:5 extract) | 8.11 | 8.23 |
| | Organic matter (%) | 2.07 | 1.67 |
| | $CaCO_3$ (%) | 1.6 | 1.6 |
| | N (%) | 0.074 | 0.086 |
| | P (ppm) | 5.50 | 0.20 |
| | K (ppm) | 4.59 | 0.19 |
| | $K^+$ ($mEq \cdot L^{-1}$) | 0.32 | 0.36 |
| | $Na^+$ ($mEq \cdot L^{-1}$) | 4.46 | 4.69 |
| | $Mg^{+2}$ ($mEq \cdot L^{-1}$) | 1.27 | 1.36 |
| | $Ca^{+2}$ ($mEq \cdot L^{-1}$) | 4.31 | 4.17 |
| | $Cl^-$ ($mEq \cdot L^{-1}$) | 4.27 | 3.96 |
| | $SO_4^-$ ($mEq \cdot L^{-1}$) | 4.86 | 6.14 |
| | $CO_3^-$ ($mEq \cdot L^{-1}$) | 0 | 0 |
| | $HCO_3^-$ ($mEq \cdot L^{-1}$) | 1.23 | 1.02 |

Bellingham, WA). At room temperature (≈22 to 23 °C), TSS percentage was estimated using a handheld refractometer Model RA-130 (KEM Kyoto Electronics Manufacturing Co. Ltd., Tokyo, Japan). Total acidity, as grams citric acid per 100 mL juice, equivalent to % citric acid (using phenolphthalein indicator), as well as total sugars, as grams per 100 g pulp, expressed as % sugars were estimated according to Association of Official Analytical Chemists (1990).

*Statistical analysis.* The SPSS statistical analysis package (version 16; SPSS Inc., Chicago, IL) was used for data analysis. Data were statistically analyzed by analysis of variance, and means were compared using the least significant difference test at $P \leq 0.05$ (Snedecor and Cochran, 1980).

## Results and discussion

*Leaf area and photosynthetic pigments.* Results displayed in Table 2 indicated that untreated 'Zebda' mango trees recorded the lowest values of leaf area and photosynthetic pigments in both seasons. The single application of either HA or BA at any concentration was only effective in improving leaf area and chlorophyll (a) content compared with the control, whereas the effect on chlorophyll (b) was only noticeable with the highest concentration of either HA or BA application during both seasons. The main effect of HA or BA was not significant compared with the control in regard to carotenoids content in both season. On the other hand, the combined application of HA and BA at any concentration significantly improved leaf area and photosynthetic pigments during both seasons. The most pronounced effect in this regard was referred to the combined application of 0.30% HA + 600 mg·L$^{-1}$ BA, followed by 0.15% HA + 600 mg·L$^{-1}$ BA. The difference between both treatments was insignificant in regard to the carotenoids content only. Increasing the concentration of HA and BA (i.e., 0.45% HA + 600 mg·L$^{-1}$ BA) led to a significant reduction in leaf area and chlorophyll (a), whereas no effect was noticed on chlorophyll (b) and carotenoids compared with 0.15% HA + 600 mg·L$^{-1}$ BA. The difference was also significant compared with 0.30% HA + 600 mg·L$^{-1}$ BA in regard to leaf area, and chlorophyll (a) and (b). The reduction in leaf area and chlorophyll content with the application of 0.45% HA + 600 mg·L$^{-1}$ BA could be due to the inhibitory effect of the high concentrations of both HA (Chen and Avaid, 1990) and BA (Yua and Ryan, 2008).

The role of HA on leaf area and chlorophyll synthesis has been reported in tomato (Turkmen et al., 2004) and corn (Khan et al., 2019). Humic acid significantly increased chlorophyll (a) and (b), total chlorophyll, and carotenoids in faba bean (El-Ghamry et al., 2009) and pearl millet plants (Hassanein et al., 2017). The availability of HA was might be responsible of increasing photosynthesis rate, and hence leaf area of salt-stressed bean plants (Aydin et al., 2012). The positive effect of HA on leaf area and photosynthetic pigments of 'Zebda' mango (Table 2) is consistent with the previous reports. Humic acid increased N and $NO_3$ uptake, which enhanced N metabolism and protein production, and thereby increased chlorophyll content (Haghighi et al., 2012). Humic acid also increased cell membrane permeability, oxygen uptake, respiration and photosynthesis rate, phosphorus uptake, and root elongation (Rajpar et al., 2011). It was also reported that HA induces $H^{+}$-ATPase activity in plasma membrane and promotes plant growth (Dobbss et al., 2010) throughout the increase in lateral root emergence and overall root absorbance (Schmidt et al., 2007).

A significant increase in leaf area of 'Feutrell's Early' mandarin with foliar spray of B has been reported (Khan et al., 2012). This may be due to the stimulating role of B in cell division, elongation, and turgor pressure (Camacho-Cristóbal et al., 2015). As with the results of the present study (Table 2), it was previously reported that foliar spray of B at flowering stage significantly improved total chlorophyll, and chlorophyll (a) and (b) in 'Frantoio' olive leaves (Hegazi et al., 2018). The combined application of Zn and B improved the biosynthesis of chlorophyll (a) and (b), total chlorophyll, and carotenoids, as well as leaf area, which in turn increased 'Bhaskara' cashew nut production (Lakshmipathi et al., 2018). A mixture of Si and B significantly increased shoot height and leaf area of wheat plants, as well as the grain yield per plant (Hanafy et al., 2008). A positive correlation was reported between leaf area and B concentration in plant shoots (Eggert and von Wiren, 2017), and this is consistent with the results shown in Table 2. Increasing B concentration enhanced the production of brassinosteroid, which enhanced cell elongation and differentiation, and stabilized pectin fractions in cell wall (Wolf et al., 2014). Both HA and B increased chlorophyll and nutrient content, and thus photosynthesis rate in 'Kesar' mango. This effect could be attributed to the improvement in N and K uptake, which involved in chloroplast formation and chlorophyll biosynthesis (Ngullie et al., 2014).

*Leaf N–P–K content.* Results displayed in Table 3 indicated variations among all three macronutrients in response to foliar application of HA and BA. The single application of BA at high concentration (600 mg·L$^{-1}$) and all levels of combined application of HA and BA increased N uptake compared with the control during both seasons. Although the treatment of 0.30% HA + 600 mg·L$^{-1}$ BA was the most effective in increasing N concentration, the difference was not significant compared with all other combined treatments in both seasons but was significant compared with 600 mg·L$^{-1}$ BA during the second season only. For P concentration, the single application of 0.45% HA, as well as the combined application of 300 mg·L$^{-1}$ BA with any concentration of HA, significantly improved P level compared with the control in both seasons. The most pronounced effect was referred to the application of 0.15% HA + 300 mg·L$^{-1}$ BA; however, the difference was insignificant compared with all other combined treatments, except 0.45% HA + 600 mg·L$^{-1}$ BA that significantly reduced P concentration in both seasons. In regard to K concentration, all treatments significantly improved K content compared with the control during both seasons, except for 0.15% HA that was only effective during the first season. The highest K value was recorded with the application of 0.30% HA + 600 mg·L$^{-1}$ BA, which was significantly different from all other treatments. Control recorded the lowest N–P–K values in both seasons. These results indicate that both N and K were

Table 2. Effect of humic acid (HA) and boron [as boric acid (BA)] on leaf area and photosynthetic pigments of 'Zebda' mango trees during 2017 and 2018 seasons.

| | Leaf area (cm$^2$) | | Chlorophyll (a) (%) | | Chlorophyll (b) (%) | | Carotenoids (%) | |
|---|---|---|---|---|---|---|---|---|
| Treatments | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| Control | 56.6 | 57.4 | 6.2 | 6.4 | 3.1 | 3.3 | 2.0 | 2.2 |
| 0.15% HA | 58.1 | 58.7 | 6.5 | 6.6 | 3.2 | 3.2 | 2.3 | 2.3 |
| 0.30% HA | 60.4 | 60.8 | 6.6 | 6.6 | 3.2 | 3.3 | 2.3 | 2.4 |
| 0.45% HA | 61.8 | 62.3 | 6.7 | 6.8 | 3.4 | 3.5 | 2.5 | 2.5 |
| 300 mg·L$^{-1}$ BA | 59.3 | 60.1 | 6.6 | 6.7 | 3.3 | 3.4 | 2.4 | 2.5 |
| 600 mg·L$^{-1}$ BA | 61.3 | 62.2 | 6.8 | 6.9 | 3.5 | 3.6 | 2.5 | 2.6 |
| 0.15% HA + 300 mg·L$^{-1}$ BA | 61.4 | 62.4 | 7.0 | 7.1 | 3.7 | 3.8 | 2.8 | 2.9 |
| 0.30% HA + 300 mg·L$^{-1}$ BA | 62.2 | 63.3 | 7.1 | 7.3 | 3.9 | 3.9 | 2.9 | 2.9 |
| 0.45% HA + 300 mg·L$^{-1}$ BA | 63.3 | 64.2 | 7.2 | 7.3 | 4.1 | 4.0 | 3.0 | 3.1 |
| 0.15% HA + 600 mg·L$^{-1}$ BA | 65.8 | 65.7 | 7.6 | 7.8 | 4.1 | 4.1 | 3.2 | 3.2 |
| 0.30% HA + 600 mg·L$^{-1}$ BA | 67.3 | 68.7 | 7.9 | 8.1 | 4.3 | 4.4 | 3.5 | 3.6 |
| 0.45% HA + 600 mg·L$^{-1}$ BA | 63.2 | 64.1 | 7.4 | 7.6 | 4.0 | 4.1 | 3.1 | 3.2 |
| Least significant difference ($P \leq 0.05$) | 1.11 | 0.99 | 0.07 | 0.04 | 0.11 | 0.13 | 0.70 | 0.43 |

highly responsive to the application of 0.30% HA + 600 mg·L$^{-1}$ BA, similar to leaf area and photosynthetic pigments, whereas P highest concentration was more related to the lowest concentrations of both HA and BA (i.e., 0.15% HA + 300 mg·L$^{-1}$ BA).

Previous reports confirmed the role of HA increasing N–P–K content in faba bean plants grown in clayey soil (El-Ghamry et al., 2009) and drought-stressed pearl millet plants (Hassanein et al., 2017) due to the increase in root growth and development, thereby improving water and nutrient uptake, and hence plant tolerance to environmental stresses (Canellas et al., 2015). Under salinity stress conditions, HA increased N–P–K uptake in pepper plants (Cimrin et al., 2010). The positive role of HA could be due to the hormone-like activity of some HA components or may be related to IAA-independent mechanism, which might be activated by HA (Trevisan et al., 2011). In addition, HA contains phenolic, acidic, amino and quinine groups, which improve nutrient availability in calcareous alkaline soil that are poor in organic matter (Gaines and Yilmaz, 1983) and N content (Khan et al., 2019). Application of HA improved the permeability of root cells (Vaughan and Ord, 1981), hormonal and reactive oxygen species (ROS) balance (Can et al., 2008), macro- and micronutrient uptake (Arslan and Pehlivan, 2008), and primary and secondary metabolism (Zanin et al., 2019), which eventually reflected on overall plant growth and development (Canellas and Olivares, 2014).

Boron enhanced N–P–K uptake and photosynthesis rate (Hermans et al., 2006). Spraying B, either alone or combined with Zn, increased K content in ‘Feutrell’s Early’ mandarin leaves (Khan et al., 2012). Boron application improved P concentration in wheat grains (Irfan et al., 2019). Foliar application of B caused changes in the concentration of other nutrients, possibly due to the interactions in ion uptake and transport (Bonilla et al., 2004). The increase in P uptake with B application indicated their synergistic relationship (Huang et al., 2012), which ultimately enhanced biomass production in rapeseed (Lei et al., 2009). Boron is also an essential micronutrient in N metabolism and water relations (Marschner, 2012).

*Carbohydrates and osmostimulants.* Foliar spray of HA, BA, and their combinations was generally effective in carbohydrates and osmostimulants content in ‘Zebda’ mango leaves. Likewise leaf area, photosynthetic pigments, N and K content, the application of 0.30% HA + 600 mg·L$^{-1}$ BA was the most effective treatment in carbohydrate and osmostimulant content compared with the control during both seasons (Tables 4 and 5). Application of 0.15% HA + 600 mg·L$^{-1}$ BA was the second most effective treatment, affecting all parameters except sugar content, where the application of 0.45% HA + 600 mg·L$^{-1}$ BA was the second most effective treatment and significantly differed from 0.30% HA + 600 mg·L$^{-1}$ BA. Treatment 0.15% HA + 600 mg·L$^{-1}$ BA ranked third in regard to sugar content (Table 4). However, the difference between 0.30% HA + 600 mg·L$^{-1}$ BA and 0.15% HA + 600 mg·L$^{-1}$ BA was only significant in terms of sugar and proline content in both seasons (Tables 4 and 5, respectively). The increase in carbohydrates and osmostimulants may be considered a direct result of the high rate of photosynthesis due to large photosynthetic area and pigment content, which were positively affected by 0.30% HA + 600 mg·L$^{-1}$ BA treatment (Table 2).

The complex nature of biostimulant composition and the variety of molecules they contain make it difficult to know which components are the most active. Their effect is not due to a single component; instead, it is the consequence of the interaction of different components (Bulgari et al., 2019). They were able to modify some molecular processes, and enhanced primary and secondary metabolism (Yakhin et al., 2017) that might improve plant water and nutrient use efficiency, stimulate growth and development, and improve plant tolerance to abiotic stress (Van Oosten et al., 2017). Phenols are one of the most important groups of secondary metabolites in plants (Boud, 2007). Their concentration is seasonal and depends on the plant development stage (Ozyigit et al., 2007). Photo inhibition and nutrient deficiency such as N, P, K, S, Mg, Fe, and B triggers the synthesis of phenols (Dixon and Paiva, 1995) and flavonoids, which improve plant tolerance to stress conditions (Balasundram et al., 2006). Free amino acids are derived from protein hydrolysis (Colla et al., 2015). Proline is one of the common amino acids that improve plant tolerance to environmental stresses (Nanjo et al., 1999). Carbohydrates, proteins, amino acids, and lipids may increase stress tolerance throughout different stages of plant growth and development (Van Oosten et al., 2017). Amino

Table 3. Effect of humic acid (HA) and boron [as boric acid (BA)] on the percentage of nitrogen (N), phosphorus (P), and potassium (K) in leaves of ‘Zebda’ mango trees during 2017 and 2018 seasons.

| | N (%) | | P (%) | | K (%) | |
|---|---|---|---|---|---|---|
| Treatments | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| Control | 1.43 | 1.46 | 0.21 | 0.21 | 1.18 | 1.20 |
| 0.15% HA | 1.48 | 1.51 | 0.24 | 0.25 | 1.23 | 1.23 |
| 0.30% HA | 1.54 | 1.57 | 0.27 | 0.27 | 1.25 | 1.26 |
| 0.45% HA | 1.63 | 1.65 | 0.29 | 0.30 | 1.28 | 1.29 |
| 300 mg·L$^{-1}$ BA | 1.58 | 1.61 | 0.26 | 0.27 | 1.26 | 1.27 |
| 600 mg·L$^{-1}$ BA | 1.66 | 1.67 | 0.28 | 0.28 | 1.29 | 1.31 |
| 0.15% HA + 300 mg·L$^{-1}$ BA | 1.68 | 1.68 | 0.35 | 0.36 | 1.34 | 1.35 |
| 0.30% HA + 300 mg·L$^{-1}$ BA | 1.71 | 1.72 | 0.34 | 0.34 | 1.35 | 1.36 |
| 0.45% HA + 300 mg·L$^{-1}$ BA | 1.75 | 1.75 | 0.29 | 0.28 | 1.37 | 1.39 |
| 0.15% HA + 600 mg·L$^{-1}$ BA | 1.77 | 1.78 | 0.28 | 0.29 | 1.41 | 1.41 |
| 0.30% HA + 600 mg·L$^{-1}$ BA | 1.81 | 1.83 | 0.28 | 0.30 | 1.46 | 1.48 |
| 0.45% HA + 600 mg·L$^{-1}$ BA | 1.75 | 1.76 | 0.27 | 0.28 | 1.38 | 1.39 |
| Least significant difference ($P \leq 0.05$) | 0.21 | 0.15 | 0.07 | 0.04 | 0.03 | 0.05 |

Table 4. Effect of humic acid (HA) and boron [as boric acid (BA)] on carbohydrates, sugars, and flavonoids content in leaves of ‘Zebda’ mango trees during 2017 and 2018 seasons.

| | Total carbohydrates (μg·g$^{-1}$ DW) | | Total sugars (mg·g$^{-1}$ DW) | | Total flavonoids (μg/100 g DW) | |
|---|---|---|---|---|---|---|
| Treatments | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| Control | 164.6 | 168.5 | 18.5 | 18.8 | 7.1 | 7.1 |
| 0.15% HA | 176.4 | 179.2 | 19.6 | 19.8 | 7.3 | 7.4 |
| 0.30% HA | 182.4 | 184.3 | 20.2 | 20.6 | 7.6 | 7.7 |
| 0.45% HA | 188.4 | 189.2 | 21.7 | 21.9 | 7.9 | 7.9 |
| 300 mg·L$^{-1}$ BA | 181.7 | 181.9 | 20.4 | 20.8 | 7.5 | 7.6 |
| 600 mg·L$^{-1}$ BA | 183.7 | 184,6 | 21.1 | 21.3 | 7.7 | 7.8 |
| 0.15% HA + 300 mg·L$^{-1}$ BA | 188.7 | 189.3 | 22.6 | 22.8 | 7.9 | 8.0 |
| 0.30% HA + 300 mg·L$^{-1}$ BA | 192.3 | 192.8 | 23.2 | 23.7 | 8.2 | 8.2 |
| 0.45% HA + 300 mg·L$^{-1}$ BA | 195.8 | 196.3 | 24.1 | 24.3 | 8.4 | 8.3 |
| 0.15% HA + 600 mg·L$^{-1}$ BA | 196.5 | 196.8 | 25.4 | 25.6 | 8.6 | 8.6 |
| 0.30% HA + 600 mg·L$^{-1}$ BA | 199.6 | 199.8 | 27.7 | 27.8 | 9.2 | 9.4 |
| 0.45% HA + 600 mg·L$^{-1}$ BA | 191.2 | 192.4 | 25.8 | 26.3 | 8.5 | 8.6 |
| Least significant difference ($P \leq 0.05$) | 2.11 | 3.66 | 1.07 | 1.09 | 1.21 | 0.25 |

acids affect K efflux through cell membrane improving plant tolerance to salinity (Cuin and Shabala, 2007). Amino acids may also play a role in increasing plant cold tolerance (Botta, 2013). Increase in N and photosynthesis rate resulted in the accumulation of amino acids and sugars necessary to regulate plant biological activities and maintain cell integrity (Ratthaphol et al., 2017).

Humic acid enhanced drought tolerance of kentucky bluegrass (Nabati, 1991) and salinity tolerance of tomato seedlings (Turkmen et al., 2004) due to the increase in proline level (Demir et al., 1999) and phenolic compounds (Aslam et al., 2016). A decrease in proline content and increase in nutrient uptake have been reported with exogenous application of HA on salt-stressed tomato plants (Farahat et al., 2012). Humic acid also affects enzyme activity and plant secondary metabolism (Canellas and Olivares, 2014), as well as plant respiration and photosynthesis, which in turn affect carbohydrate level (Nardi et al., 2007), protein synthesis (Carletti et al., 2008), and sugar and amino acid metabolism (Boehme et al., 2005). These reports are consistent with results in Tables 2–5. Similarly, HA improves tolerance to environmental stress through hormonal regulation (Cimrin et al., 2010), which reflected on membrane permeability, protein synthesis, and root elongation (Saruhan et al., 2011). These findings could be related to the regulation of C/N ratio and its role in alternate bearing of mango trees.

Boron has been reported to improve the metabolism of phenolic compounds in 'Manaki' olive trees (Liakopoulos and Karabourniotis, 2005) due to the increase in gene expression responsible of phenolic compound biosynthesis (Manas et al., 2014; Song et al., 2015). Boron has also a positive role in the synthesis of nucleic acids, carbohydrate metabolism and transport from source to sink, and total plant biomass (Oyinlola, 2007) due to the increase in enzyme activity and carbon assimilation (Han et al., 2008), as well as sugar and carbohydrate metabolism (Hansch and Mendel, 2009). Pommerrenig et al. (2019) reported a reduction in sucrose transport from source to sink under B deficiency conditions. Foliar spray of B and Zn increased total sugars in papaya (Singh et al., 2005), 'Khasi' mandarin (Babu and Yadav, 2005) and 'Dusehrifruit' mango (Anees et al., 2011), as well as total phenols in three olive cultivars (Saadati et al., 2013), pungent pepper (Manas et al., 2014), and 'Merlot' grape (Song et al., 2015). Combined deficiency of P and B inhibits protein synthesis leading to inhibition of plant growth (Bould et al., 1983).

*Phytohormones.* All foliar applications of HA, BA, and their combinations have significantly increased the level of IAA, $GA_3$, and CKs but decreased ABA level in 'Zebda' mango trees compared with the control in both 2017 and 2018 seasons (Table 6). In this regard, the most pronounced effect was referred to the combined application of 0.30% HA + 600 mg·L$^{-1}$ BA. Application of 0.15% HA + 600 mg·L$^{-1}$ BA was the second affecting the content of all phytohormones, except for $GA_3$. In addition, the difference between both treatments was only significant in regard to IAA and CKs. Treatment 0.45% HA + 600 mg·L$^{-1}$ BA was the second most significant in regard to increasing $GA_3$ level and was significantly different from 0.30% HA + 600 mg·L$^{-1}$ BA, whereas the difference was insignificant compared with 0.15% HA + 600 mg·L$^{-1}$ BA.

Humic acid improves plant growth due to hormone-like activity, particularly IAA (Quaggiotti et al., 2004), which enhances $H^+$ pumping through the plasma membrane; lowering of cell wall pH; and initiating a cell wall loosening process and cell enlargement (Hager, 2003). Humic acid also acts as a hormonal balance and affects the emergence of lateral roots, improving water absorbance and nutrient uptake under stress conditions (Canellas et al., 2015). Increasing CK level with IAA could result in increased vegetative growth, photosynthetic pigments, yield, and fruit quality of 'Chemlali' olive trees (Dabbaghi et al., 2018) and potato plants (Ekin, 2019). Humic substances improve plant tolerance to environmental stress through the regulation effect on phytohormone levels,

Table 5. Effect of humic acid (HA) and boron [as boric acid (BA)] on free amino acids, proline, and phenols content in leaves of 'Zebda' mango trees during 2017 and 2018 seasons.

| | Total free amino acids (μg·g$^{-1}$ FW) | | Proline (μg·g$^{-1}$ FW) | | Total phenols (μg·g$^{-1}$ FW) | |
|---|---|---|---|---|---|---|
| Treatments | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| Control | 11.1 | 11.2 | 8.28 | 8.36 | 32.34 | 32.37 |
| 0.15% HA | 11.8 | 11.9 | 9.46 | 9.52 | 34.74 | 34.86 |
| 0.30% HA | 12.4 | 12.4 | 9.73 | 9.82 | 37.62 | 38.23 |
| 0.45% HA | 12.8 | 12.9 | 10.30 | 10.50 | 39.27 | 39.38 |
| 300 mg·L$^{-1}$ BA | 12.3 | 12.4 | 8.86 | 8.95 | 36.64 | 36.76 |
| 600 mg·L$^{-1}$ BA | 12.7 | 12.7 | 9.53 | 9.64 | 37.36 | 37.65 |
| 0.15% HA + 300 mg·L$^{-1}$ BA | 13.2 | 13.4 | 9.78 | 9.86 | 39.84 | 39.93 |
| 0.30% HA + 300 mg·L$^{-1}$ BA | 13.5 | 13.5 | 10.27 | 10.29 | 41.27 | 41.54 |
| 0.45% HA + 300 mg·L$^{-1}$ BA | 13.8 | 13.9 | 10.74 | 10.82 | 43.75 | 43.84 |
| 0.15% HA + 600 mg·L$^{-1}$ BA | 14.3 | 14.4 | 11.13 | 11.17 | 45.68 | 45.87 |
| 0.30% HA + 600 mg·L$^{-1}$ BA | 14.9 | 15.1 | 11.68 | 11.77 | 47.63 | 47.92 |
| 0.45% HA + 600 mg·L$^{-1}$ BA | 13.9 | 14.1 | 10.34 | 10.32 | 42.67 | 42.96 |
| Least significant difference ($P \leq 0.05$) | 0.72 | 0.71 | 0.53 | 0.41 | 2.01 | 1.79 |

Table 6. Effect of humic acid (HA) and boron [as boric acid (BA)] on auxin (IAA), gibberellin ($GA_3$), cytokinins (CKs), and abscisic acid (ABA) content in leaves of 'Zebda' mango trees during 2017 and 2018 seasons.

| | IAA (μg·g$^{-1}$ FW) | | $GA_3$ (μg·g$^{-1}$ FW) | | CKs (μg·g$^{-1}$ FW) | | ABA (μg·g$^{-1}$ FW) | |
|---|---|---|---|---|---|---|---|---|
| Treatments | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| Control | 14.17 | 14.19 | 17.67 | 17.89 | 11.34 | 11.38 | 1.36 | 1.32 |
| 0.15% HA | 14.58 | 14.62 | 18.64 | 18.68 | 11.66 | 11.69 | 1.24 | 1.21 |
| 0.30% HA | 14.85 | 14.93 | 19.82 | 19.87 | 11.75 | 11.79 | 1.18 | 1.15 |
| 0.45% HA | 15.32 | 15.47 | 20.26 | 20.38 | 11.92 | 11.93 | 1.13 | 1.12 |
| 300 mg·L$^{-1}$ BA | 14.93 | 15.15 | 19.91 | 19.97 | 11.61 | 11.65 | 1.21 | 1.19 |
| 600 mg·L$^{-1}$ BA | 15.22 | 15.26 | 20.13 | 20.17 | 11.73 | 11.77 | 1.17 | 1.16 |
| 0.15% HA + 300 mg·L$^{-1}$ BA | 15.56 | 15.62 | 22.14 | 22.17 | 12.02 | 12.11 | 1.15 | 1.13 |
| 0.30% HA + 300 mg·L$^{-1}$ BA | 15.76 | 15.79 | 23.46 | 23.49 | 12.17 | 12.18 | 1.11 | 1.10 |
| 0.45% HA + 300 mg·L$^{-1}$ BA | 15.91 | 15.96 | 24.35 | 24.39 | 12.23 | 12.26 | 1.09 | 1.08 |
| 0.15% HA + 600 mg·L$^{-1}$ BA | 16.24 | 16.27 | 24.65 | 24.68 | 12.31 | 12.33 | 1.06 | 1.05 |
| 0.30% HA + 600 mg·L$^{-1}$ BA | 16.74 | 16.72 | 26.37 | 26.45 | 12.63 | 12.67 | 1.03 | 1.03 |
| 0.45% HA + 600 mg·L$^{-1}$ BA | 15.93 | 15.97 | 24.82 | 24.93 | 12.27 | 12.32 | 1.11 | 1.09 |
| Least significant difference ($P \leq 0.05$) | 0.21 | 0.26 | 0.43 | 0.46 | 0.17 | 0.19 | 0.03 | 0.05 |

particularly ABA (Cimrin et al., 2010). Salt-stressed 'Zaghloul' date palm showed a reduction in IAA, $GA_3$, and CK content with increased levels of ABA and ethylene (Helaly et al., 2016). Results in Table 6 show that 'Zebda' mango trees were not environmentally stressed.

Boron plays an important role in promoting phytohormones and nucleic acids (Khayyat et al., 2007). Among all phytohormones, IAA is the most involved with B nutrition in plants. Many B-deficiency symptoms are similar to the symptoms of low IAA levels in plant; these symptoms include the inhibition of root elongation and lateral root initiation (Pilbeam and Kirkby, 1983). Results in Table 6 show that the higher the BA concentration, either alone or combined with HA, the higher the IAA level in 'Zebda' mango leaves, except for the highest concentrations of HA and BA (0.45% HA + 600 $mg \cdot L^{-1}$ BA), which might be related to the inhibition effect of high concentrations of both HA (Chen and Avaid, 1990) and B (Yua and Ryan, 2008). Boron improves the activity of IAA, which enhances carbohydrate transport in plants, especially under stressful conditions (Patrick and Wareing, 1973). Lee et al. (2006) noticed an increase in ABA concentration under B deficiency. Boron deficiency reduced IAA and increased ABA levels in shoots and roots of rapeseed plants (Zhou et al., 2016). These findings are consistent with results of IAA and ABA shown in Table 6. However, some newer reports indicate that B deficiency induces the biosynthesis of both IAA and ABA, but decreased $GA_3$ and CKs biosynthesis in shoots of rapeseed seedlings (Eggert and von Wiren, 2017) and olive leaves and buds (Hegazi et al., 2018). These findings have also been confirmed by the results of $GA_3$, CKs, and ABA displayed in Table 6. It has also been reported that N nutrition is important for CKs metabolism (Kiba et al., 2011). As shown in Tables 3 and 6, treatment with 0.30% HA + 600 $mg \cdot L^{-1}$ BA improved both N and CKs. Reports have also shown an up-regulation of ABA-related genes under conditions of P (Woo et al., 2012), N, or K deficiency (Oka et al., 2012). Control showed the lowest N–P–K concentrations (Table 3), meanwhile it has the highest ABA content (Table 6). Eggert and von Wiren (2017) reported that reduced water uptake under B deficiency conditions may promote water stress and increase ABA concentration. Under such conditions, the increase in ABA level may adjust shoot growth via the regulation of transpiration and photosynthesis. A balance in IAA, $GA_3$, and ABA levels resulted in the highest fruit set and total yield in 'Frantoio' olive trees (Hegazi et al., 2018).

*Floral assessment and total yield.* Regardless of the application of 300 $mg \cdot L^{-1}$ BA during the second season, all single and combined applications of HA and BA were so effective in improving floral development and significantly increased the number of panicles per tree compared with the untreated trees during both seasons (Table 7). Humic acid was also more effective than BA in this regard. Moreover, the percentage of floral malformation was significantly reduced with all treatments, and thus total fruit yield was also increased significantly in both seasons. The best results were achieved with the application of 0.30% HA + 600 $mg \cdot L^{-1}$ BA. Results of both seasons indicated that untreated trees showed ≈25% floral malformation, whereas this percentage was reduced with all treatments to reach a minimum of 14% in trees received 0.30% HA + 600 $mg \cdot L^{-1}$ BA. This was reflected on total fruit yield, which increased and became almost the same (i.e., 43.4 and 43.8 kg/tree) in both 2017 off-year and 2018 on-year, respectively. Total yield increased by 3.3- and 1.5-fold in comparison with the control during the off-year and on-year, respectively.

Mango malformation is a major constraint in mango production areas (Crane and Campbell, 1994) and has been early reported in Egypt (Attiah, 1955). It could be ascribed to physiological disorders that are related to biotic stress (e.g., acarological, viral or fungal disease *Fusarium moniliforme*) or abiotic stress (e.g., salinity, drought, oxidative, low temperature, metal toxicity) (Ansari et al., 2015). Several reports related malformation to the increase in endogenous ethylene (Bains and Pant, 2003), which is usually associated with an increase in ABA, and a reduction in IAA, $GA_3$, and CKs (Helaly et al., 2017). Ansari et al. (2019) noted a higher level of cyanide, as a by-product of ethylene biosynthesis in malformed mango inflorescences. Auxin is important for the production of healthy panicles (Kumar et al., 2011). Results in Table 6 are compatible with previous reports in which the application of 0.30% HA + 600 $mg \cdot L^{-1}$ BA increased the level of IAA, $GA_3$, and CKs but decreased ABA level. Meanwhile, the same treatment reduced the malformation percentage and increased the number of healthy panicles per tree, and thus improved total yield (Table 7). In general, cultivars 'Zebda' and 'Hindi' are less susceptible to floral malformation, but 'Ewais' is moderately susceptible (Azzous et al., 1978). Resistance to malformation in 'Zebda' mango has previously confirmed with using the extract of leaves and shoots to inhibit the growth of *Fusarium subglutinans* fungus in vitro (El-Ghandour et al., 1979). 'Ewais' mango showed the higher values of leaf area, photosynthetic pigments, leaf mineral content, panicle length, sex ratio, fruit retention, and total yield per tree, whereas 'Zebda' mango showed higher attributes of leaf carotene content and resistance to malformation (Zagzog and Gad, 2017). In this respect, it could be mentioned that the growth vigor and susceptibility to malformation of mango cultivars is a genetic-related effect (Bally, 2006), which is also greatly affected with environmental factors that affect growth and development (Zuo et al., 2007). Application of HA and BA has improved overall tree physiology (Tables 2–6) and led to reduced malformation percentage (Table 7).

Results displayed in Tables 3 and 7 confirm previous reports that have described the role of HA in improving nutrient availability, number of flowers per tree, fruit set and retention, and total yield of 'Superior Seedless' grape (Omar and Abdelall, 2005), 'Kinnow' mandarin (Abbas et al., 2013), 'Manfalouty' pomegranate (Khattab et al., 2012), and 'Red Delicious' apple (Hidayatullah et al., 2018). Application of 500 $mg \cdot L^{-1}$ HA increased the number of harvested flowers in gerbera plants by 52% and extended the vase life by 2 to 3.6 d. This effect was mostly due to the auxin component of HA (Arslan and Pehlivan, 2008).

Table 7. Effect of humic acid (HA) and boron [as boric acid (BA)] on the number of panicles, floral malformation, and total yield of 'Zebda' mango trees during 2017 and 2018 seasons.

| | Number of panicles per tree | | Floral malformation (%) | | Total yield (kg/tree) | |
|---|---|---|---|---|---|---|
| Treatments | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| Control | 157 | 272 | 25.2 | 25.5 | 13.2 | 29.3 |
| 0.15% HA | 277 | 283 | 21.5 | 22.1 | 35.7 | 36.4 |
| 0.30% HA | 279 | 291 | 21.0 | 20.2 | 37.5 | 38.2 |
| 0.45% HA | 281 | 296 | 20.3 | 19.6 | 38.6 | 38.9 |
| 300 $mg \cdot L^{-1}$ BA | 267 | 278 | 21.8 | 21.1 | 36.8 | 37.5 |
| 600 $mg \cdot L^{-1}$ BA | 275 | 292 | 20.7 | 20.0 | 37.6 | 38.3 |
| 0.15% HA + 300 $mg \cdot L^{-1}$ BA | 293 | 307 | 19.3 | 19.0 | 39.4 | 39.8 |
| 0.30% HA + 300 $mg \cdot L^{-1}$ BA | 298 | 314 | 17.6 | 17.2 | 40.2 | 40.7 |
| 0.45% HA + 300 $mg \cdot L^{-1}$ BA | 307 | 318 | 17.2 | 16.7 | 40.5 | 41.4 |
| 0.15% HA + 600 $mg \cdot L^{-1}$ BA | 314 | 329 | 16.8 | 16.5 | 41.5 | 42.2 |
| 0.30% HA + 600 $mg \cdot L^{-1}$ BA | 326 | 338 | 14.7 | 14.2 | 43.4 | 43.8 |
| 0.45% HA + 600 $mg \cdot L^{-1}$ BA | 311 | 321 | 16.7 | 16.3 | 41.2 | 41.7 |
| Least significant difference ($P \leq 0.05$) | 11.41 | 10.76 | 0.31 | 0.28 | 1.12 | 1.01 |

Previous findings indicated that annual spray of 'Tommy Atkins' mango trees with micronutrients (e.g., Zn, Fe, B, Cu, and Mn) in combination with HA resulted in healthy mango trees with a lower percentage of malformation, increased fruit retention and tree productivity, and improved fruit physiochemical characteristics (Mouco at al., 2009).

Foliar B application improved panicle growth, fruit retention and physicochemical characteristics of 'Himsagar' mango (Dutta, 2004). The key role of B includes floral organ development, male flower fertility, and pollen tube growth (Gupta and Solanki, 2013; Saini et al., 2019). Boron deficiency during flowering period may cause severe yield loss through sterility (Uraguchi and Fujiwara, 2011), low pollen viability, poor pollen germination, or reduced pollen tube growth (Baldi et al., 2004); therefore, B has a vital role in fruit set (Acar et al., 2010). Boron is rapidly absorbed by flowers (Sarrwy et al., 2012) and improves carbohydrate transport affecting fruit set and development (Mengel and Kirkby, 2001). The beneficial effect of B on decreasing malformation percentage may be due to its role in inducing the formation of a Si-cuticle double layer on leaf epidermal tissues, which is responsible for preventing the penetration of fungal hyphae (Baiea et al., 2015). Increases in fruit yield with B application have been reported in 'Conference' pear (Wojcik and Wojcik, 2003), stone fruits (Baldi et al., 2004), and 'Shahany' date palm (Khayyat et al., 2007). Increases in fruit yield with the application of B and Zn was reported in 'Chausa' mango (Singh and Rajput, 1976) and three cultivars of sweet cherry (Usenik and Stampar, 2002). The application of Zn, either alone or in combination with B increased the number of fruit in 'Feutrell's Early' mandarin trees by 17% and 21%, respectively, proving the role of B vitalizing Zn effect (Khan et al., 2012). The highest yield of 'Taimour', 'Mabrouka', and 'Alphonso' mango trees was observed with the annual single or combined application of B, Cu, and naphthalene acetic acid (NAA) (Shinde et al., 2006). Application of B and Zn improves the biochemistry of flowers and enhanced N–P–K uptake, fruit set and retention, total yield, and fruit quality; in terms of fruit weight, TSS, acidity, pulp recovery, and sugar concentration (Alloway, 2009). The effect was more pronounced with B rather than Zn (Davarpanah et al., 2016). It is also suggested to be season-specific effect and does not extend to the next season.

*Fruit physiochemical characteristics.* Like all other studied parameters, foliar spray of 'Zebda' mango trees with 0.30% HA + 600 mg·L$^{-1}$ BA has also reflected on fruit physical and chemical characteristics (Tables 8 and 9) due to the improvement in leaf area, photosynthetic pigments (Table 2), nutrient uptake (Table 3), carbon assimilation (Tables 4 and 5), and phytohormones, particularly IAA, $GA_3$, and CKs (Table 6). These results are in consistence with the previous findings on 'Anna' apple (Khalifa et al., 2009), 'Kesar' mango (Ngullie et al., 2014), and 'Frantoio' olive (Hegazi et al., 2018). Application of HA and B significantly increased total sugars of 'Alphonso' mango fruit (Merwad et al., 2016). The increase in sugar content could be due to the role of B on sugar translocation from leaves (source) to developing fruit (sink). This could also be referred to HA hormone-like effect on plant growth, yield, and fruit quality (Calvo et al., 2014).

Humic acid hormone-like effect, particularly IAA, has been documented on total yield, fruit weight, dimensions, TSS, acidity, and sugar content in 'Italia' table grape (Giuseppe et al., 2005); 'Keitt', 'Ewais', and 'Kesar' mango (El-Kosary et al., 2011; Ngullie et al., 2014); 'Florida Prince' peach (Abd El-Razek et al., 2012); and 'Kalamata' olive (Hagagg et al., 2013). Humic acid at 1% recorded maximum custard apple fruit yield per plant, fruit weight and diameter, TSS, total sugars, reducing and nonreducing sugars, ascorbic acid, and extended shelf life, whereas no effect on acidity has been noticed (Sindha et al., 2018). The increase in 'Askari' grape shelf life may be related to the role of HA in stimulating enzyme activity and firmness of cell walls (Mohamadineia et al., 2015). The increase in fruit weight and TSS may be due to the stimulation of photosynthetic pigment accumulation, photosynthesis rate (Abdel-Mawgoud et al., 2007), N uptake,

Table 8. Effect of humic acid (HA) and boron [as boric acid (BA)] on some fruit physical characteristics of 'Zebda' mango during 2017 and 2018 seasons.

| | Fruit wt (g) | | Fruit length (mm) | | Fruit width (mm) | | Pulp wt (g) | |
|---|---|---|---|---|---|---|---|---|
| Treatments | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| Control | 457 | 442 | 112.4 | 112.7 | 62.3 | 63.4 | 268.6 | 274.3 |
| 0.15% HA | 468 | 471 | 123.6 | 124.3 | 65.4 | 66.5 | 284.5 | 287.2 |
| 0.30% HA | 482 | 488 | 127.2 | 127.8 | 68.8 | 68.8 | 292.4 | 297.5 |
| 0.45% HA | 502 | 495 | 129.2 | 129.8 | 69.6 | 70.4 | 296.8 | 299.4 |
| 300 mg·L$^{-1}$ BA | 482 | 481 | 126.2 | 128.7 | 67.6 | 68.2 | 285.8 | 291.6 |
| 600 mg·L$^{-1}$ BA | 498 | 484 | 127.3 | 129.4 | 68.5 | 69.2 | 287.9 | 297.4 |
| 0.15% HA + 300 mg·L$^{-1}$ BA | 482 | 497 | 132.1 | 133.2 | 70.2 | 70.7 | 298.4 | 301.5 |
| 0.30% HA + 300 mg·L$^{-1}$ BA | 497 | 501 | 135.3 | 135.7 | 71.3 | 72.0 | 302.6 | 304.3 |
| 0.45% HA + 300 mg·L$^{-1}$ BA | 501 | 503 | 136.2 | 137.2 | 71.8 | 72.5 | 304.2 | 235.4 |
| 0.15% HA + 600 mg·L$^{-1}$ BA | 504 | 508 | 137.7 | 137.2 | 72.4 | 73.2 | 308.3 | 309.7 |
| 0.30% HA + 600 mg·L$^{-1}$ BA | 511 | 514 | 138.2 | 138.7 | 75.7 | 76.4 | 316.4 | 318.3 |
| 0.45% HA + 600 mg·L$^{-1}$ BA | 498 | 502 | 134.2 | 135.6 | 71.6 | 72.3 | 305.7 | 306.4 |
| Least significant difference ($P \leq 0.05$) | 11.66 | 10.33 | 4.11 | 4.33 | 1.21 | 1.30 | 2.99 | 6.33 |

Table 9. Effect of humic acid (HA) and boron [as boric acid (BA)] on the percentage of total soluble solids (TSS), total acidity, and total sugars of 'Zebda' mango fruit during 2017 and 2018 seasons.

| | TSS (%) | | Total acidity (%) | | Total sugars (%) | |
|---|---|---|---|---|---|---|
| Treatments | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| Control | 20.2 | 20.3 | 0.25 | 0.24 | 16.2 | 16.5 |
| 0.15% HA | 21.3 | 21.4 | 0.21 | 0.22 | 17.4 | 17.8 |
| 0.30% HA | 21.8 | 21.9 | 0.21 | 0.21 | 17.9 | 18.2 |
| 0.45% HA | 22.1 | 22.5 | 0.19 | 0.19 | 18.1 | 18.5 |
| 300 mg·L$^{-1}$ BA | 21.3 | 21.5 | 0.21 | 0.21 | 17.6 | 18.1 |
| 600 mg·L$^{-1}$ BA | 21.6 | 21.7 | 0.21 | 0.20 | 17.9 | 18.3 |
| 0.15% HA + 300 mg·L$^{-1}$ BA | 22.4 | 22.7 | 0.19 | 0.18 | 18.4 | 18.7 |
| 0.30% HA + 300 mg·L$^{-1}$ BA | 22.7 | 22.9 | 0.18 | 0.18 | 18.8 | 19.2 |
| 0.45% HA + 300 mg·L$^{-1}$ BA | 22.9 | 23.1 | 0.17 | 0.16 | 19.2 | 19.4 |
| 0.15% HA + 600 mg·L$^{-1}$ BA | 23.1 | 23.2 | 0.17 | 0.16 | 19.5 | 19.8 |
| 0.30% HA + 600 mg·L$^{-1}$ BA | 23.6 | 24.7 | 0.15 | 0.15 | 20.3 | 20.5 |
| 0.45% HA + 600 mg·L$^{-1}$ BA | 22.5 | 23.1 | 0.17 | 0.16 | 19.7 | 19.8 |
| Least significant difference ($P \leq 0.05$) | 0.62 | 0.59 | 0.03 | 0.05 | 0.01 | 0.97 |

assimilation ratio, and phytohormone activity (Patrick and Wareing, 1973). The increase in total sugars with HA application might be due to the increase in carbohydrate accumulation in leaf and fruit tissues, which ultimately converted to glucose and sucrose, as well as the breakdown of starch into sugars during ripening (Hermans et al., 2006).

Application of B increases fruit set, yield, and fruit quality of ‘Butte’ almond (Nyomora and Brown, 1999) and ‘Manzanillo’ olive (Perica et al., 2001). It was reported that application of Zn and B increased stomatal number per leaf, and enhanced $CO_2$ inflow into the mesophyll tissue resulting in more photosynthates, which increased fruit yield and quality of Brazilian cashew (Aliyu et al., 2011). Combined application of Zn and B led to increase in ‘Ardestani’ pomegranate fruit maturity index (TSS:acid ratio), whereas physical fruit characteristics were unaffected (Davarpanah et al., 2016). Foliar B application improved fruit physicochemical characteristics of ‘Himsagr’ (Dutta, 2004) and ‘Chaunsa’ mango (Ahmad et al., 2018). Boron (1%) improved TSS of ‘Amrapali’ mango fruit (Umesh et al., 2010). Single or combined foliar application of Zn, Fe, Mn, B, or Cu increased total sugar content in ‘Dashehari’, ‘Hindi’, ‘Taimour’, ‘Mabrouka’, ‘Himsagar’, ‘Langra’, and ‘Amrapali’ mango fruit (Hammam et al., 2001; Rashmi et al., 2007; Vejendla et al., 2008). Boron plays a major role in stabilizing pectin fraction in cell walls, thereby improving fruit firmness and maintaining fruit quality (Goldbach and Wimmer, 2007).

In summary, flowering in mango is a complex physiological process that determines annual fruit production (Davenport, 2007). Mango has high fruiting potential with a tendency of alternate bearing (Saker and Rahim, 2013). Most of the Egyptian mango cultivars, particularly Zebda, suffer from alternate bearing (Shaban, 2009a). As shown in Table 7, the number of panicles and total yield per tree during the off-year were ≈57.7% and 45%, respectively compared with the on-year. Complex interactions between shoot development and environmental conditions resulted in floral bud initiation in mango. This process occurs before the onset of the coolest months of the year, which is the period from December to January in Egypt, and is generally influenced by previous crop load (Shaban, 2009b), bearing habit, genetic characteristics (Smith-Ramirez et al., 1998), age and size of reproductive shoots, and other plant factors (Ramirez and Davenport, 2012). Climatic factors and environmental stresses are also associated with alternate bearing of mango trees in two ways: either by damaging the crop directly through destroying buds, flowers, and fruits or by creating conditions that indirectly affect the production of flower or fruit. The optimal temperature for plant growth and flowering is ≈24 to 30 °C; however, mango trees can tolerate temperatures up to 48 °C for short periods and are sensitive to temperature below 10 °C (Whily et al., 1989). Early spring frost, photoperiod, cloudy weather, and rains during flowering period reduce the crop and could convert an on-year into an off-year (Davenport, 2009). However, mango is highly heterozygous tree; mean genotype × environment interaction is high, and hence, it is stable enough to perform under different climatic conditions of tropical, subtropical, or temperate zones (Eiadthong et al., 2000). In addition, the increase in carbohydrate availability is required for high C/N ratio, which is an important attribute for floral initiation in mango (Upreti et al., 2013). This ratio also differs with the environmental conditions and prevailing metabolic balance. The increase in carbohydrates is concomitant with changes in phytohormones, especially with the decline in gibberellin level (Sandip et al., 2015). Humic acid and B play an important role in hormonal balance (Canellas et al., 2015; Zhou et al., 2016). It should be noted that even in the regular-bearing tree fruit types, if they produce high yield in one year, they show a tendency toward reduced yield the following year. Hence, the basic tendency of alternate bearing exists even in the “regular-bearing” varieties of mango. In other words, the potential of shoot to form flower buds will depend on the nutritional condition of the tree, which in turn will be determined by the amount of fruit load carried by the tree in the previous year. Generally, moderate flowering is one of the major conditions of annual fruit bearing in fruit trees. Therefore, the fruit development depends on the current year assimilates, and to a great extent on the tree reserve. The use of reserve metabolites from vegetative organs during the on-year could contribute to alternate bearing (Singh, 1971). In the present study, we suggest that alternate bearing of ‘Zebda’ mango trees was mainly dependent on annual tree reserve and metabolite availability, and to a lesser extent on weather conditions, which were almost the same in both seasons and hence have minimal effect on the incidence of alternate bearing under the Egyptian conditions. This is also confirmed with the 5-years yield and weather data (World Weather Online, 2020) (Table 10). However, the tendency to alternate bearing has been improved in 2017 off-year with the application of HA and BA (Table 7). Therefore, results of this study confirmed the significance role of HA and BA improving plant nutritional status, growth, and annual productivity.

Table 10. Total yield of untreated ‘Zebda’ mango trees during 5 years, associated with average weather data per year calculated from September to August of each growth season. Yield least significant difference = 8.6 ($P \leq 0.05$).

| Season | 2014–15 | 2015–16 | 2016–17 | 2017–18 | 2018–19 |
|---|---|---|---|---|---|
| Yield (kg/tree) | 9.9 | 25.5 | 13.2 | 29.3 | 11.0 |
| Alternate bearing | Off | On | Off | On | Off |
| Temperature (°C) | 21.8 | 22.5 | 21.5 | 23.0 | 26.8 |
| Humidity (%) | 54.0 | 54.9 | 55.7 | 52.2 | 52.7 |
| Cloud (%) | 12.8 | 15.3 | 14.4 | 14.3 | 15.3 |
| Rainfall (millimeters/month) | 0.4 | 0.8 | 0.6 | 0.4 | 5.2 |
| Rainfall (days/month) | 1.2 | 1.6 | 0.8 | 0.8 | 4.3 |
| Wind speed (kilometers/hour) | 8.2 | 7.9 | 8.2 | 11.9 | 13.1 |
| Gust speed (kilometers/hour) | 11.0 | 10.7 | 11.0 | 16.0 | 18.0 |
| Sun (hours/month) | 299.6 | 296.8 | 300.0 | 293.8 | 291.8 |
| Sun (days/month) | 29.5 | 28.8 | 29.1 | 29.3 | 26.0 |

## Conclusion

Humic acid and B exert direct and indirect effects on plant morphological, physiological, biochemical, and genetic processes, which ultimately affect plant growth, yield, and fruit quality. The tremendous effect of 0.30% HA + 600 $mg \cdot L^{-1}$ BA on nutrient uptake, carbon assimilation and metabolism, and phytohormone activity may indicate a possibility of tree tolerance to adverse conditions that cause floral malformation and reduce productivity. Moreover, the stability and increased consistency of tree productivity from one season to another in response to HA and B are a promising tool to minimize the incidence of alternate bearing and improve mango tree growth, annual productivity, and fruit quality.

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