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# Effects of foliar application of gibberellic acid, boric acid and sucrose on noni (*M. citrifolia L.)* fruit growth and quality

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ABSTRACT

Noni juice processing industry depends explicitly on the quality of noni fruits and its juice together with increased production of fruits. This study evaluated the effects of chemical treatments on noni's fruiting capacity, fruit yield and the fruit antioxidant properties. Noni plants in fruiting stage were foliar fed with boric acid (BA) at a concentration of 100 ppm or 200 ppm, gibberellic acid ($GA_3$) at 20 ppm or 40 ppm and sucrose solution at 5 or 20% and water (control). Changes in fruiting numbers, fruit growth rates, fruit yield, total soluble solids (TSS), fruit antioxidant capacity and total phenolic content of fruits were determined after the foliar treatments. Fruiting, fruit growth rate and yield were significantly increased in BA, $GA_3$ and sucrose treated plants when compared to the control treatment. Fruit TSS, antioxidant capacity and total phenol content were not affected. Sucrose 20% and BA treatments (100 ppm and 200 ppm) produced the highest fruit yields.

## 1. Introduction

Noni (*Morinda citrifolia* L.) is well-known globally as an important health supplementing plant. All parts of the plant are known to contain bioactive compounds with health benefits such as nitric oxide, alkaloids and sterols with antioxidant potential. Noni fruits are mostly used source for bioactive compounds (Nelson and Elevitch, 2006). Noni fruits contain antioxidants such as beta-carotene, ascorbic acid, terpenoids, alkaloids, beta-sitosterol, carotene, polyphenols such as flavonoids, flavone glycosides, rutin etc. (Wang et al., 2002; Yashaswini et al., 2014). The fruit juices or extracts have been shown to scavenge free radicals and inhibit low-density lipoprotein oxidation (Kamiya et al., 2004; Yang et al., 2011; Chen et al., 2018; West et al., 2018). Based on its high antioxidant properties, noni fruit juice products are a cornerstone within its industrial sector. The fruit juice is obtained from compressing the whitish ripe fruits. Most noni juice products use 100% pure fruit juice without any additives such as water or sugar. Fresh noni juice is usually obtained from compressing the fruits immediately after harvesting, whereas fermented juice is prepared by letting the fruits decompose naturally (Nelson and Elevitch, 2006). For both preparations, mature noni fruits picked directly from the tree are used. Fruits are perfect to be picked from the tree when they turn whitish-yellow and are still hard. To ensure the highest quality, the noni fruits of 8 $^{o}$Brix are preferred for juicing (Stemmler, 2020).

Noni fruits are multiple fruits (syncarps) which are formed from capitulum inflorescences ranging from 75 to 90 florets (Nelson and Elevitch, 2006) or 97 to 104 florets (Lin et al., 2014). Noni fruit growth stages include inflorescence initiation, inflorescence development, fruitlet setting, end of floret initiation, the lag phase of fruit growth and the maturity stage. For the fruits to develop from floral initiation stage to the mature fruit stage, it takes an average of 126 days (Lin et al., 2014). Fruiting in noni usually begins 9-12 months after planting (Nelson and Elevitch, 2006). During this time, fruits are generally smaller, and the yield is low. Many farmers choose not to harvest the fruits during its first and second year of fruiting. Under excellent farm management practices, the fruit yield (number of fruits per trees and fruit weight) gradually increases as the tree increases in age (Nelson and Elevitch, 2006; Nelson 2003).

Noni plants flower and fruit throughout the year and the plants, although like any other plant, do have seasonal trends in the amount of flowering and fruiting that may be influenced by weather, fertilizer applications and irrigation. Changes in the pattern, time and amount of flowering and fruiting are possible through foliar fertilization where essential nutrients and plant growth hormones are fed to the plants through the foliage. Foliar fertilization via application of liquid fertilizer or nutrient solutions directly on the leaves, when timed well, encourages and enhances critical points in tree phenology, including flowering, fruiting and seed formation (Lovatt, 2013). Foliar application of

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nutrients and plant growth regulators have become an essential feature in the production of fruits for commercial purposes globally. Advantages of foliar fertilization include the application of nutrients throughout the growing season, spraying of small quantities of nutrients appropriate to specific requirements, faster uptake of nutrients through foliage compared to soil, and quick correction of nutrient-deficient physiological disorders (Haytova, 2013; Singh et al., 2017).

Several common promising chemicals that are widely used to improve fruit set, yield and fruit quality include micronutrients (boron, zinc and iron,), plant growth regulators such as gibberellic acid ($GA_3$) and auxins, and carbohydrates such as sucrose (Lovatt, 2013). Boron is the most common foliar nutrient used as an essential micronutrient. It is required for pollen germination and pollen tube growth, which increase fertilization and fruit setting (Yehia and Hassan, 2005). Gibberellins, as phytohormones, have an essential role in promoting the change from vegetative to reproductive development in angiosperms with key functions in flower development, fertilization and fruit development (Plackett and Wilson, 2016). Reproductive development in plants is a highly energy consuming process which requires an adequate supply of carbon, provided through sugar signalling pathways and changing source-sink relationship. Sucrose is the main carbohydrate carried via the source-sink transport and is involved mainly in the sugar signalling pathways controlling metabolism. Changing patterns of assimilate distribution results in hormonal changes that regulate growth, flowering, fruit set and fruit development (Bruton et al., 1998). Sucrose, as a soluble sugar, has a crucial role in maintaining the fruit quality of the fleshy fruits (Li et al., 2018). Application of boric acid (BA), gibberellin and sucrose as foliar nutrients to increase fruiting and fruit yield have been reported for various fruits trees (Perica et al., 2001; Ebeed and El-Migeed, 2005; Aliyu et al., 2011; Krishna et al., 2017; Souza et al., 2017). Use of boron as a foliar nutrient resulting in increased flower buds and fruiting has been stated for coffee plants which belong to the same family Rubiaceae as noni (Rodrigues and Rodrigues, 2016). However, foliar nutrient and plant growth regulator applications have not been reported so far in noni plants.

Since noni industry heavily depends on the fruit juice, increased production of fruits, fruit size and fruit weight becomes a vital marketing parameter for commercial noni farmers. Improving fruit production and fruit yield through chemical treatments would improve the economic benefits for both the farmers and the juice processors. This study aims to investigate if foliar applications of different concentrations of BA, $GA_3$, and sucrose solution influence noni fruit yield (fruit numbers per plant and fruit mass) and fruit quality (total soluble solids and its antioxidant properties).

## 2. Materials and method

### 2.1. Plant establishment and foliar treatments

Four-month old noni plants were transplanted into a 12 m × 12 m ground plot at the University of the South Pacific, Laucala Campus, Suva (18.1489°S, 178.4474°E). Soil type was clay loam soil with a pH of 7.2 and electrical conductivity of 28 mS/cm. A spacing of 1.5 m was used between the plants. To help with establishment, the plants were watered for a month and a half after transplanting after which the plants were left to be rain-fed. A balanced N.P.K fertilizer (15:15:15) was applied in equal amounts (2 g) to the plants during transplanting. After 2 months of growth on the ground, N.P.K fertilizer in a 13:13:21 ratio was applied in equal amounts (2 g). The plants were then left to flower and fruit with N.P.K fertilization at 2-month intervals. For the year of the experiment, the total annual rainfall recorded for the experimental site was 3314 mm, with an average temperature of 26.2°C. Average annual sunshine hours for Suva was 4.3 hours per day.

Plants in the experimental plot were into their flowering and fruiting stage after three months of growth. Once all the plants started flowering and fruiting, they were foliar fed with boric acid (BA), ($GA_3$) and sucrose solutions. Seven respective treatments; BA 100 ppm or 200 ppm, $GA_3$20 ppm or 40 ppm, sucrose 5 or 20% and control (water treatment) were prepared according to the concentrations reported by Yehia and Hassan (2005).

For each foliar treatment, 8 replicate plants were used. The plants were labelled accordingly and sprayed with chemical preparations of BA, $GA_3$ and sucrose solutions individually until the solutions ran off the leaves. The control treatment plants were sprayed with distilled water only. The experiment followed a complete randomized block design based on applied treatments on 56 plants. The spraying was done in the morning from 800 to 900 h on a clear day. Foliar feeding was done two times once all the plants were into their flowering and fruiting stage (after three months of growth in the ground plot). The second foliar feeding was done three weeks after the first one.

### 2.2. Determination of fruiting changes

The number of fruits were counted three months after the completion of foliar chemical treatments (after the second spraying). All half-developed fruits (with bottom fruitlet development) and fully developed fruits (Fig. 1) were counted.

### 2.3. Determination of fruit growth rate, yield and total soluble solids

Ten inflorescences from each treatment before the start of anthesis (Fig. 1) were randomly marked and labelled using flag tapes. Equatorial diameter of all the marked inflorescences was measured with a Vernier caliper (Analytical Equipment Company) at 14-day intervals till the fruit maturity stage. The fruit growth rate in mm per day was calculated by dividing the change in diameter by the number of days of growth.

For measurement of fruit parameters, mature fruits (once they were hard and whitish-yellow in colour) that were available were harvested. For fruit yield and total soluble solids (TSS), mature fruits from all treated and the control plants were collected and weighed using a top pan balance. The weight of the fruit was recorded as yield in grams (g). The TSS in °Brix was also measured using the optical refractometer for the same fruits. A total of 12 fruits from each treatment were collected randomly and measured.

### 2.4. Determination of antioxidant capacity of fruits

The total antioxidant activity of mature fruits from chemically treated and control plants was estimated by the 2, 2-diphenyl-1-picrylhydrazyl (DPPH) method as described by Yang et al. (2011). Ten mature fruits from each treatment were used to find out the antioxidant capacity. A solution of DPPH was made in methanol using 0.025 g DPPH in 1L of methanol. Noni fruit was ground, and its juice was extracted using a muslin cloth. Diluted noni fruit extracts (2 μL, 5 μL, 10 μL, 20 μL, 30 μL and 40 μL) were added to the 3 mL DPPH solution and incubated at room temperature for about 40 min. After 40 min, the absorbance of the mixture was measured at 515 nm with a spectrophotometer (CE1021 UV-VIS). Inhibitions of DPPH radicals in percentage were calculated as follows:

$$\%Inhibition = [(Acontrol - -Asample)/Acontrol] \times 100$$

Where A control is the absorbance value of the control reaction (containing all reagents except for the tested fruit extracts), and A sample is the absorbance value of fruit extracts.

The 50% radical scavenging activity of fruits was determined by calculating the half-maximal inhibitory concentration ($IC_{50}$). The $IC_{50}$ value was calculated by plotting the percentage inhibition against the concentrations of fruit extracts. The concentration that provided 50% inhibition was noted as the $IC_{50}$ value. The noni fruit extract concentration at $IC_{50}$ was expressed as ascorbic acid equivalent antioxidant capacity (AEAC) in mg/ 100g fresh weight (FW) of fruits. To find out the AEAC, a standard curve was prepared using ascorbic acid at 1 mg/mL

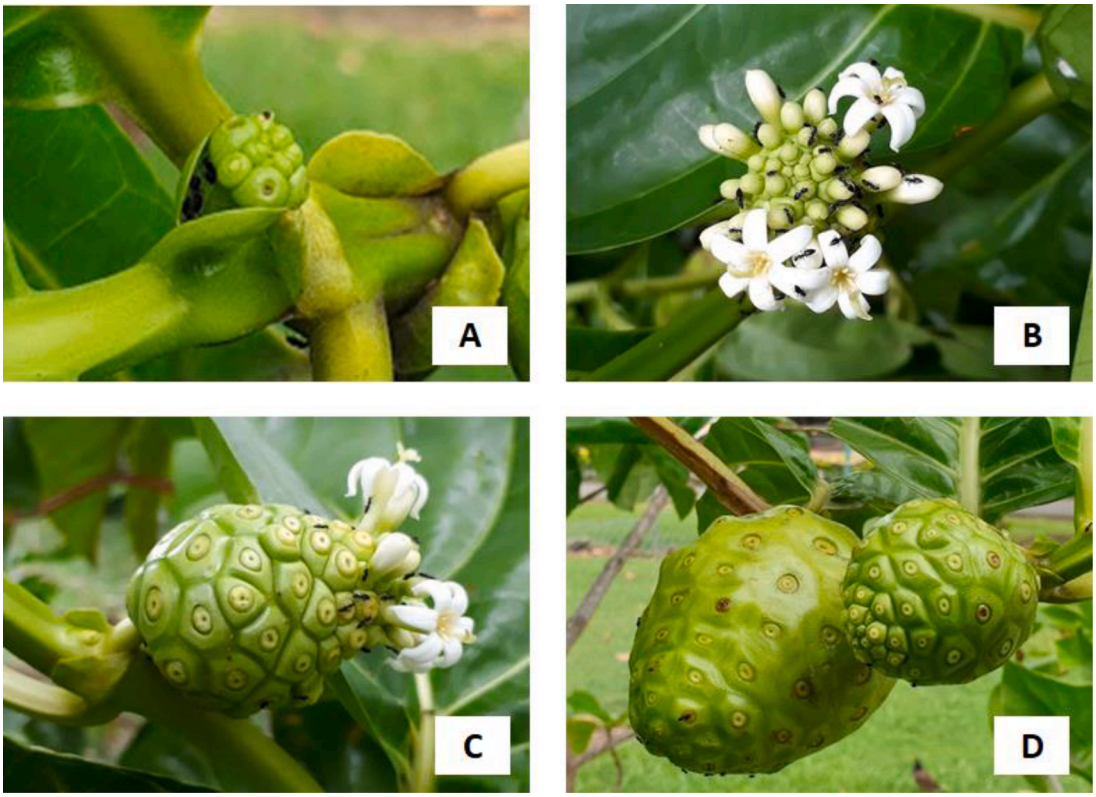


**Fig. 1.** Stages of noni fruit growth; (A) inflorescence development; (B) flowers at anthesis stage; (C) bottom fruitlet setting and development; (D) fully developed young and mature green (under-ripe) fruit.

concentration. From a stock solution of ascorbic acid at 1mg/mL, various concentrations of 2 μg/mL, 3 μg/mL, 5 μg/mL, 10 μg/mL, 20 μg/mL, 30 μg/mL, 40 μg/mL and 50 μg/mL were prepared. Exactly 3 mL DPPH solution was added to each aliquot and incubated at room temperature for about 40 min. After 40 min, the absorbance of the mixture was measured at 515 nm with a spectrophotometer. Similar to the noni fruit samples, % DPPH inhibition and the $IC_{50}$ value of ascorbic acid was determined. The antioxidant capacity of noni fruits was expressed as AEAC per 100 g of fresh weight (AEAC/ 100 g FW):

AEAC = $IC_{50}$ (ascorbic acid)/ $IC_{50}$ (sample) X $10^5$ (Van De Velde et al., 2013)

### 2.5. Determination of total phenol content in fruits

Ten mature fruits were used to determine the total phenol contents (TPC) with Folin-Ciocalteu reagent as described by Yang et al. (2011). Exactly 20 μL of noni fruit extract was mixed with 1.58 mL of distilled water. To this mixture, 100 μL of Folin-Ciocalteu reagent and 300 μL of 20% sodium carbonate ($Na_2CO_3$) was then added. After addition, the mixture was incubated at 40 °C for 30 min. After 30 min, the absorbance was measured at 765 nm with the spectrophotometer (CE1021 UV-VIS). A standard curve of total phenols was prepared using gallic acid at various concentrations of (1 mg/mL, 2 mg/mL, 4 mg/mL, 6 mg/mL, 7 mg/mL, 10 mg/mL and 20 mg/mL). The equation of the standard curve was used to determine the TPC and was expressed as mg of gallic acid equivalent (GAE) per 100 g of fresh weight (mg GAE/100g of FW).

### 2.6. Statistical analysis

Analysis of data collected was performed by using Graph Pad Prism version 7.0 (GraphPad Software Inc, San Diego, California, USA). Shapiro-Wilk test was used to determine the normality of the data. Ordinary One-way ANOVA (analysis of variance) and multiple comparison test (Tukeys test) were used to test the significant differences among the results obtained for the different foliar chemical treatments at 95% confidence level. The differences were considered significant only when the p-value was less than 0.05 ($p < 0.05$).

## 3. Results

### 3.1. Fruiting

Number of fruits per plant increased significantly for all chemical treatments when compared to the plants with no chemical treatment (Table 1). Lowest amount of fruits occurred in the control treatment (Table 1). Fruit numbers in all chemical treatments were statistically comparable.

### 3.2. Fruit growth rate

It took about 148 days for the fruits to develop up to maturity stage from inflorescences, where the flowering stage was up to 80 to 85 days after which the fully formed fruit developed further. Growth rate of fruits were significantly higher in chemically treated plants (Table 1). Mean growth rate of fruit was highest in the sucrose 20% treatment while the control treatment had the lowest growth rate. Mean growth rates for BA 100 ppm, BA 200 ppm, $GA_3$ 20 ppm, $GA_3$ 40 ppm (0, sucrose 5%, and sucrose 20% were comparable (Table 1). When looking at the growth dynamics (Fig. 2), there was no significant difference in growth rates among the chemical treatments up to 70 days. From 84 days onwards, the growth rate in sucrose 20% treatment increased significantly.

### 3.3. Fruit yield

Fruit weights at the maturity stage of 146 to 148 days (when whitish in colour) were significantly higher in plants treated with chemicals

**Table 1**
Fruit numbers and attributes of fruit growth and yield in plants treated with different chemicals.

| Chemical treatments | Fruit Numbers per plant | Fruit growth rate (mm/day) | Mature fruit weight (g) | Fruit TSS (oBrix) |
|---|---|---|---|---|
| **BA 100 pm** | 11.0 ± 0.8 ac | 0.41 ± 0.04 ab | 265.1 ± 13.5 a | 7.80 ± 0.09 a |
| **BA 200 ppm** | 11.1 ± 0.9 ac | 0.43 ± 0.04 ab | 260.9 ± 7.2 a | 7.70 ± 0.11 a |
| **$GA_3$ 20 ppm** | 8.6 ± 0.4 a | 0.40 ± 0.04 a | 257.7 ± 8.7 ab | 7.43 ± 0.12 a |
| **$GA_3$ 40 ppm** | 9.9 ± 0.5 a | 0.42 ± 0.05 ab | 271.4 ± 13.2 a | 7.40 ± 0.12 a |
| **Sucrose 5%** | 10.6 ± 0.5 ab | 0.44 ± 0.05 ab | 281.4 ± 13.9 a | 7.62 ± 0.11 a |
| **Sucrose 20%** | 12.6 ± 0.6 bc | 0.46 ± 0.05 b | 287.5 ± 6.7 a | 7.70 ± 0.13 a |
| **Control** | 5.3 ± 0.3 d | 0.33 ± 0.04 c | 215.3 ± 8.7 b | 7.43 ± 0.14 a |

Mean ± SE is shown. There was a significant difference in fruit numbers (ANOVA (F df (6, 49) = 15.08, $p < 0.0001$). Mean fruit growth rate (ANOVA (F df (6, 63) = 9.951, p= <0.0001) and mean fruit weight (ANOVA (F df (6,91) = 4.891, p=0.0002) are also significantly different. There is no significant difference between the mean TSS in fruits (ANOVA (F df (6, 77) = 2.012, p=0.0740). Values in the same column not sharing the same letter are significantly different using the Tukey's test at $p < 0.05$.

when compared to the control plants (Table 1). All chemically treated plants had comparable fruit weights. The control treatment had the lowest fruit weight.

### 3.4. Total soluble solids of fruits

TSS in °Brix were statistically comparable in all the treatments. It ranged from 7 to 8 °Brix (Table 1) in all treatments.

### 3.5. Fruit antioxidant capacity

Antioxidant properties were significantly lower in noni fruits from all the chemically treated plants (Table 2). Highest mean AEAC was found in fruits from the control. Mean AEAC were comparable among all chemical treatments.

### 3.6. Total phenol content of fruits

Mean TPC was also highest in control plants which was significantly different from the TPC in the chemically treated plants (Table 2). TPC levels in all chemical treatments were statistically comparable.

## 4. Discussion

### 4.1. Effects of BA, $GA_3$ and sucrose on fruiting

Fruiting in noni plants that were foliar sprayed with BA, $GA_3$ and sucrose doubled when compared to the control plants (Table 1). The highest mean number of fruits were recorded for sucrose 20% treatment

**Table 2**
Antioxidant capacity (AEAC) and total phenol content (TPC) in fruits from noni plants treated with different chemicals.

| Chemical treatment | AEAC (mg/100g FW) | TPC (mg/100g FW) |
|---|---|---|
| **BA 100 pm** | 330.0 ± 10.9 a | 119.2 ± 2.0 a |
| **BA acid 200 ppm** | 319.8 ± 8.8 a | 122.1 ± 2.8 ab |
| **$GA_3$ 20 ppm** | 347.2 ± 11.3 a | 136.4 ± 3.1 c |
| **$GA_3$ 40 ppm** | 346.9 ± 11.3 a | 132.0 ± 3.5 bc |
| **Sucrose 5%** | 359.7 ± 13.8 a | 133.4 ± 3.5 bc |
| **Sucrose 20%** | 313.5 ± 11.2 a | 125.8 ± 1.6 abc |
| **Control** | 506.8 ± 14.1 b | 150.2 ± 1.9 d |

Mean ± SE is shown. There was a significant difference in TPC ANOVA (F df (6, 63) = 13.83, ($p < 0.0001$) and ACEC content ANOVA (F df (6, 63) = 31.86, ($p < 0.0001$). Values in the same column not sharing the same letter are significantly different using the Tukey's test at $p < 0.05$.

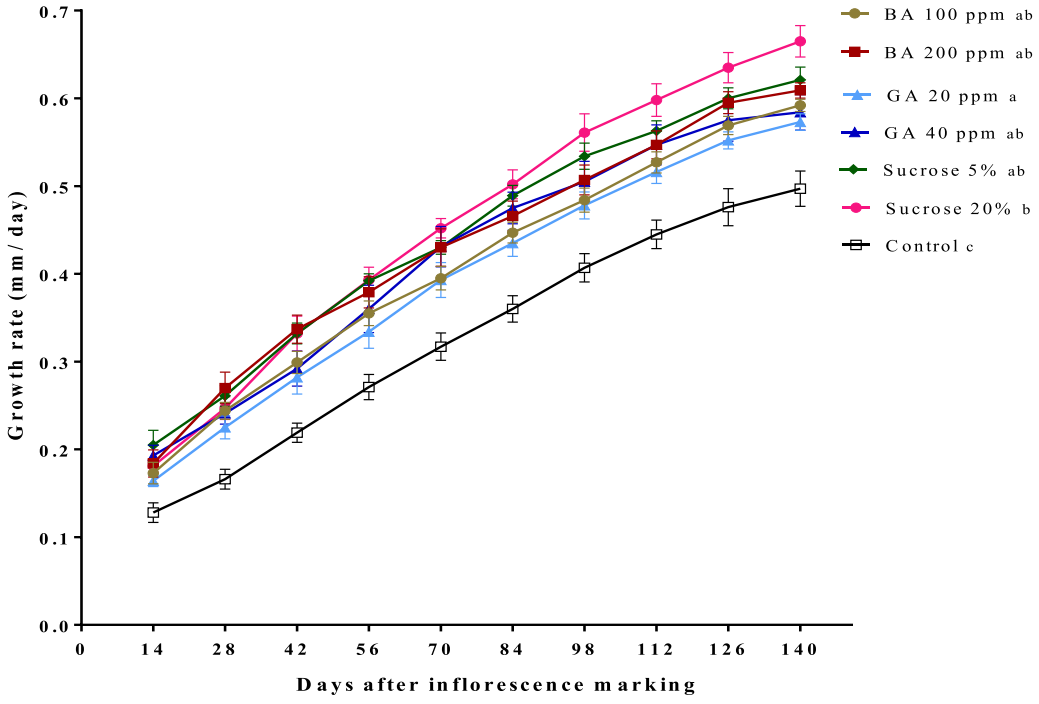


**Fig. 2.** Growth dynamics of fruits from inflorescence stage to the mature fruit stage over 140 days. Mean ± SE of growth rate is shown. There is a significant difference between growth rates among the different chemical treatments, ANOVA (F, df (6, 63) = 9.951, $P < 0.0001$). Treatments followed by the same letter are not significantly different using Tukey's test at $p < 0.05$.

followed by both BA treatments (Table 1). Increase in fruiting with boron and sucrose was reported for date palm (Soliman and Alobeed, 2011) and mangoes (Ebeed and El-Migeed, 2005). Sucrose and BA foliar feeding provide a low-cost method to increase noni fruit production at commercial scale. Boron and sucrose are crucial elements that help in pollen germination, which is a key step in fruit set (Wojcik et al., 2008; Liu et al., 2013; Nogueira et al., 2016). Sucrose acts as an external source of carbohydrates supporting the energy demand in pollen germination (Parrotta et al., 2018). Impairment of pollen growth in absence of sucrose have been shown by Lagera et al. (2017) and Roitsch and Gonzalez (2004). Increased fruiting resulting from BA applications in this study could be due enhanced pollen grain germination and pollen tubes during fertilization. Studies have shown that as an essential element, boron requirement in plants is usually much higher during the reproductive growth phase compared to the vegetative growth phase. Increased fruit set with BA application have been reported for avocados (Robbertse et al., 1990), grapevine (Alva et al., 2015) and peach cultivars (Souza et al., 2017). A study by Fang et al. (2016), showed that BA at a lower concentration (0.01 and 0.02%) stimulated apple pollen germination and that germination and tube growth was inhibited in BA concentrations above 0.02%. Their results also showed that at 0% BA, pollen germination, and growth was significantly lower. BA applied to noni at 100 ppm, and at 200 ppm in this study were equivalent to 0.01% and 0.02%, respectively, which may have influenced pollen tube growth and fruit set. A specific *in vitro* study on noni pollen germination by various BA and sucrose concentrations would provide a more accurate account of optimal concentrations of the two chemicals in increasing fruit set in noni. Some studies had also shown increased fruiting when BA and sucrose were applied to plants in combination (Ebeed and El-Migeed, 2005; Soliman and Al-Obeed, 2011). The influence of this combination on noni's fruiting can be investigated in future studies. Increased fruiting in $GA_3$ treatments in this study could possibly be due to gibberellins taking part in both pollen growth and fruit set. Plants deficient in GA have been reported to have male sterility due to abnormal anther development (Goto and Pharis, 1999; Singh et al., 2002). An increase in fruit set with GA applications in orange and apple respectively, was shown by Baghdady et al. (2014) and El-Seginy et al. (2003).

### 4.2. Effects of foliar chemical treatment on fruit attributes

High growth rate of fruits in BA, $GA_3$ and sucrose treatments accompanied the high fruit yield (Table 1). High growth rates and yield in sucrose treatments may be due to increased mobile sugar content of the plant, which resulted in more sugar available for investing in fruit growth. Silva et al. (2003), showed that foliar sucrose spray increased the endogenous carbohydrates in coffee seedlings that were low on their carbon reserves due to low photosynthesis. Photosynthesis in noni plants at the study site during the experiment was expected to be low due to the considerably low sunshine hours. Enhancement of cell division and cell expansion by sucrose treatments may have resulted in increased fruit growth rate and yield. Sucrose application provides extra energy required for cell division and metabolism. Jia et al. (2013), showed that exogenous sucrose application dramatically increased the endogenous sucrose content leading to increased fruit development of strawberry. High growth rate and yield in BA treatments is attributed to a boost in metabolism via uptake of boron. As stated earlier, boron enhances cell division and cell enlargement, together with increasing the rate of sugar transport to actively growing regions and developing fruits (Shalan, 2013; Sharma, 2016). Significant increase in the fruit sizes with foliar spraying of BA were also reported for guava (Pippal et al., 2019), pineapple (Wei et al., 2018) and mandarin (Ullah et al., 2012). Increased fruit yield and weight with the application of foliar $GA_3$ at 20 ppm and 40 ppm were also reported by Yehia and Hassan (2005) and El-Seginy et al. (2003).

Even though all chemical treatments significantly increased growth rate and fruit weights, TSS in $^{o}$Brix was not affected. Yehia and Hassan (2005), also found no significant difference in the TSS of pear, regardless of increased fruit size with the application of foliar sprays of BA, GA3 and sucrose solutions. Comparable TSS in noni fruits found in this study could be a result of variations and adjustments in the source-sink relationship. Cell expansion, an increase in fruit size and high TSS are associated with the efficiency of the source to sink sugar transport, sugar metabolism and subcellular compartmentalization (Ripoll et al., 2014). All chemically treated plants in this study had a significantly higher number and larger fruits than the control plants. This indicates that the efficiency of the source to sink transport of the noni plants were different among the treated and the control plants. Assuming that photosynthesis was comparable among all plants due to similar environmental conditions, chemically treated plants had a higher number of fruits as important sinks while the control had less number of sinks; hence the final amount of sugar supply into the fruit cells was more or less the same in all treatments. Source-sink transport is highly influenced by the crop or tree load. A high number of fruits per tree leads to a decrease in fruit size and quality (Salvador et al., 2006; Ding et al., 2017). Smaller fruits usually have higher TSS due to lower cell volume and a lower proportion of intercellular spaces. Lower cell volume holding has less water content which prevents dilution of the total soluble solids (Salvador et al., 2006). Due to lower cell volumes and much concentrated cell sap, smaller fruits from the control treatments in this study may have had adequate levels of sugars in their cells which was comparable to the sugar levels in the chemically treated fruit cells. Increase in fruit TSS with an application of BA and $GA_3$ have also been reported by Moradinezhad et al. (2019), Ganai et al. (2018), Ferdosi and Farooq (2017), Shaban et al. (2017), Adbel-Mohsen and Kamel (2015), and Sharma (2011). The important role of BA and GA in translocation of photosynthate in fruit trees have been reported by Han et.al (2008) and Zhang et al. (2007), respectively.

### 4.3. Antioxidant properties of fruits

Although chemical treatments increased noni fruit numbers, growth rates and fruit yield, the antioxidant properties of fruits were low compared to the control treatment. Decrease in antioxidants properties of fruits, particularly a reduction in phenol with foliar applications of boron and sucrose have also been reported by Ullah et al. (2012), Hegazi et al. (2018) and Eichholz et al. (2011). On the contrary, Saadati et al (2013) and Babalik et al (2018) reported an increase in the antioxidant and phenol contents of olives and grapes, respectively with foliar applications of BA. Boron deficiency and toxicity influence enzymatic and nonezymatic antioxidants (Cakmak and Romeheld, 1997; Marschner, 2012; Landi et al., 2012; Wang, et al., 2015). In this study, noni fruit antioxidant capacity in BA treatments was lower compared to the control treatment which indicated that the level of boron applied to the plants was not sufficient enough to bring about a pronounced effect on the antioxidant metabolism.

Fruits from sucrose treated plants also had lower antioxidant properties compared to the control treatment (Table 2). A decrease in strawberry polyphenol with foliar sucrose application was also reported by Luo et al. (2019). No increase in antioxidant properties in the sucrose treatment can be due to the antioxidant capacity of sucrose itself. The ability of sucrose to act as a protective antioxidant against abiotic stress was reported in *Arabidopsis thaliana* (Qiu et al., 2014) and cucumber (Cao et al., 2015). $GA_3$ treatment also had significantly lower antioxidant properties. A decrease in phenol content with foliar applications of GA was also reported by Maudu et al. (2011) in bush tea leaves and by Tian (2014) in grape berries. According to Maudu et al. (2011), the application of GA inhibited the accumulation of polyphenols due to an increase in amino acid synthesis. Another possible reason for the decrease in antioxidant properties with foliar application of $GA_3$ can be attributed to the antagonistic relationship between ABA and GAs (Shu et al., 2016; Kaur and Zhawar, 2018). In this study the environmental conditions were similar for all treatments. Antioxidant properties are

mainly influenced by environmental conditions and increase significantly in response to abiotic stress which was not the case in this study.

## 5. Conclusion

This is the first report on foliar fertilization of noni which showed positive effects of BA, $GA_3$ and sucrose treatments on noni's fruiting, fruit growth rate and fruit yield. Noni's fruit attributes could be increased using foliar nutrient/chemical feeding which can result in greater economic benefits for commercial farmers and juice processors. Findings show that sucrose 20% and BA treatments (100 ppm and 200 ppm) were most effective in increasing the number of fruits per plant. Enhancement of fruiting in noni as in any other fruit is influenced by source-sink relationship, which can be enhanced by foliar application of these chemicals. Findings also show that foliar chemical treatments do not enhance noni's antioxidant properties. Further investigations into foliar chemical application with a combination of environmental factors is required to explore responses of antioxidant activity.

## Authorship statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the Scientia Horticulturae.

## CRediT authorship contribution statement

**Reema Prakash:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization, Project administration. **Anjeela Devi Jokhan:** Investigation, Writing – review & editing, Supervision. **Ranjila Singh:** Methodology, Formal analysis, Data curation, Writing – review & editing.

## Declaration of Competing Interest

We, Reema Prakash, Anjeela Devi Jokhan and Ranjila Singh, would like to confirm that the work described has not been published previously except in the form of an academic thesis. We also confirm that the manuscript is not under consideration for publication elsewhere. We further confirm that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright holder.

We also declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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