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The Effects of Application of Exogenous IAA and GA_3 on the Physiological Activities and Quality of *Abelmoschus esculentus* (Okra) var. Singa 979

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ABSTRACT

An experiment was conducted to investigate the effects of growth regulators on growth, yield and the quality of okra. Indole Acetic Acid (IAA) and Gibberellin (GA_3) were applied as foliar spray and stem and flower injection at concentrations of 0, 30, 60, 90, and 120 mg/L on okra plants. The results showed that foliar spray of 90 mg/L IAA, increased the number of leaves, number of branches, number of flowers and number of pods. On the other hand, spraying of 90 mg/L GA_3 increased stomatal conductance and pod weight of okra, while the highest chlorophyll content was recorded with 60 mg/L GA_3. Stem injection of 120 mg/L IAA produced the highest number of leaves, number of branches, number of flowers, number of pods and plant height. Similarly, 120 mg/L GA_3 as stem injection increased the number of branches, number of leaves, number of flowers and number of pods and total soluble solids (TSS). Flower injection of IAA at 30 and 90 mg/L increased pod size, pod weight, pod number and TSS content, while seed production was inhibited by 120 mg/L IAA. GA_3 used in a 90 mg/L treatment as flower injection increased pod size and TSS content. It is concluded that the application of 120 mg/L IAA and 90 mg/L GA_3 increased the growth, development and quality of the okra fruit and stem and that flower injection worked better than foliar spray.

Keywords: GA_3, growth regulators, IAA, injection, okra, spray

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INTRODUCTION

Okra (*Abelmoschus esculentus*) is an annual pod vegetable that grows quickly, bearing many branches. It is able to reach up to a height of 1.82 m. The common name of

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the okra plant is lady's finger, and the plant belongs to the family Malvaceae (Brouk, 1975). Balock (1994) reported that okra is an annual, herbacious and warm season vegetable. Lady's finger is a self-pollinated crop, but about 20% of pollination is cross pollination through the activity of insects and other pollinators (Grubben, 1977). The charateristics of this vegetable are indeterminate growth habit and continuous flowering, with flowering depending on nutrient supply and environmental factors. The plant starts to flower one to two months after the sowing of seeds, which can be manipulated by cultural practices (Adetuyi et al., 2008). The okra pod is a capsule that grows quickly after flowering and pollination. Fruit growth is the highest during the 4th to 6th day after pollination. Adeboye and Oputa (1996) reported that okra is the ultimate source of carbohydrate, fibre, proteins and vitamins. It has been reported that 100 g of fresh okra pod contains 89.6% moisture, 103 mg of potassium, 90 mg of calcium, 43 mg of magnesium, 56 mg of phosphorus, 18 mg of vitamin C and metals such as iron and aluminium (Markose & Peter, 1990). Recently, okra has been grown commercially in India, Turkey, Iran, Western Africa, Bangladesh, Afghanistan, Yugoslavia, Burma, Pakistan, Malaysia, Japan, Brazil, Cyprus Ethiopia, Ghana and the United States of America. India produces 70% of the total world production of okra (3.5 million tons) and ranks first in the world as a producer of the plant (FAOSTAT, 2012).

Kusvuran (2012) reported that the quality of the seed, nutrition application, environmental conditions and cultural practices are the key factors that affect the growth and quality of okra. Plant growth regulators (PGRs) and growth promoting chemicals may change the phenotype of many plants when applied at the early growth stage. PGRs stimulate or retard the natural growth regulatory systems from germination to senescence of plants (Das & Das, 1995). Plant growth regulators affect the physiological efficiency of plants including growth, photosynthesis and accumulation of assimilates. Solaimalai et al. (2001) reported that the productivity of crops is increased by stimulating the translocation of photo-assimilates. In this study, IAA and gibberellin were used to improve the physiological activities and the quality of the okra plant under field conditions. IAA and GA were applied separately to study the specific effects of the two growth regulators on the okra plant. May be the phytohormones auxin (IAA) and gibberellin (GA), which partly control overlapping processes during plant development. It has been proven that isolated or combined plant growth regulators show different responses in biometrical and productive parameters in *Solanum lycopersicum* (Choudhury et al., 2013). Growth regulators might act as a key factor for plant growth and development through various reactions to the environment in different doses, and this was of concern in the current study.

The number of seeds in the okra pod can be a deterrent for some consumers from consuming okra. Correct concentrations and suitable application methods of plant

hormones can reduce the number of seeds in okra pods. This research presents results on the effect of IAA and GA_3 on the growth, physiology and quality of okra, as this information is highly relevant to growers and researchers. This study found that the flower and stem injection technique brought better results than the spraying method.

MATERIALS AND METHOD

The present study was carried out from September 2014 to June 2015 at the field farm of the Faculty of Bioresources and Food Industry Farm, Besut Campus, Universiti Sultan Zainal Abidin. One hundred fifty okra plants were used for the treatment application. Okra seeds were sown in germination trays at the nursery and seven days after sowing (DAS) at 3-5 leaf stage, all the seedlings were transplanted to polybags containing garden soil and coco peat. Experimental plants were arranged under a completely randomised design (CRD) with five replicates. GA_3 and IAA at 0, 30, 60, 90, and 120 mg/L concentrations were applied to the experimental plant. Foliar spray, stem injection and flower injection techniques were used to apply the plant growth regulators. In using foliar spray, different concentrations of IAA and GA_3 were applied to the leaves and stems of the okra plants. A volume of 1.5 mL IAA and GA_3 was applied to the stem by injecting the okra plant stems using a surgical needle at the height of 3 cm from the ground level. Distilled water mixed with 2 mL of 1% ethanol was used in the control treatment. For flower injection, IAA and GA_3 were applied to the female okra flower before anthesis through injection using a surgical needle (Mekhled, 2011).

Plant Growth and Yield Measurements

Plant height (cm), number of leaves, number of branches, number of flowers, number of pods, pod size and weight (g) were recorded once a week after the treatment application. Plant height was measured from above the ground level up to the uppermost tip of the leaves. Numbers of leaves, branches, flowers, pods and pod weight were counted and measured on each treated and control plant. For seed production, the percentage of healthy seeds and aborted seeds were recorded and calculated using the formula (Mekhled, 2011) below:

$$\text{Healthy seed (\%)} = \frac{\text{Total number of healthy seeds}}{\text{Total number of seeds}} \times 100$$

$$\text{Aborted seed (\%)} = \frac{\text{Total number of aborted seeds}}{\text{Total number of seeds}} \times 100$$

Leaf chlorophyll content of treated and control plants was measured by SPAD meter (Minolta Japan). Stomatal conductance ($mmol/m^{-2}s^{-1}$) was measured using leaf porometer from 12 nn to 1 pm in full sunshine conditions and readings were taken a week after the treatment for three consecutive weeks. Green fruit or okra pod weight (g) was measured. A small fraction

of a homogenous mixture of okra pod was centrifuged at 4000 × g for 10 min, and the clear supernantant was evaluated for total soluble solids (TSS). The total soluble solid content of pod wax was evaluated using a hand refractometer (Atago 8469) and expressed as percentage (%) of Brix.

Statistical Analysis

All the data obtained were analysed using the IBM Statistical Package for the Social Sciences (SPSS) version 22. Significant difference of mean values were determined and analysed using one-way ANOVA and the mean differences were compared using Duncan's Multiple Range Test (DMRT) at 5% level of significance.

RESULTS

Effect of Foliar Spray of IAA on the Growth and Physiological Activities of Okra

The results showed that the 90 mg/L IAA treatment produced the highest number of leaves (35) compared to the control (26.00). The number of okra branches was significantly affected by 120 mg/L IAA applied using the spray technique, and this treatment produced 1.2 times more branches compared to control. Foliar spray of 90 mg/L IAA significantly increased the number of leaves, number of flowers, number of fruit, fruit weight and TSS content of fruit. The highest number of flowers (8), number of fruit (7), fruit weight (26 g) and TSS content (2.47% Brix) were recorded for the 90 mg/L IAA treatment (Table 1).

Table 1
Effects of spray technique on Okra growth, development and fruit quality using different concentrations of Indole Acetic Acid (IAA)

Concentration of IAA	No. of branches	No. of leaves	No. of flowers	No. of fruit	Fruit weight (g)	TSS (% Brix)
0	4.00± 0.58^{c}	26.0± 1.15^{b}	5.00±0.33^{b}	4.00±0.33^{c}	24.0±0.31^{a}	2.26±0.02^{b}
30	5.00±0.00^{bc}	28.0± 1.45^{b}	7.00±0.88^{a}	6.00±1.00^{ab}	25.0±0.31^{ab}	2.37±0.02^{ab}
60	5.00± 0.00^{bc}	30.0± 0.88^{b}	7.00±0.33^{a}	7.00±0.33^{a}	25.0±0.43^{ab}	2.43±0.02^{a}
90	6.00± 0.58^{ab}	35.0± 1.20^{a}	8.00±0.33^{a}	7.00±0.33^{a}	26.0±0.23^{a}	2.47±0.03^{a}
120	7.00 ± 0.33^{a}	28.0± 0.88^{b}	6.00±0.33^{ab}	6.00±0.33^{bc}	25.0±0.52^{ab}	2.46±0.08^{a}

All the data are the mean of three replications; ± indicates the standard of error. Different letters in the same column are significantly different at 5% level (Duncan's Multiple Range Test)

Table 2 shows that the percentage of healthy seeds of the okra pod was reduced with the increase in IAA concentrations, while the percentage of aborted seeds in the pods of okra significantly increased in all treated plants compared to in the control plants. IAA treatments produced a significant effect on the leaf chlorophyll content and stomatal conductance of the okra plants (Table 2). The highest chlorophyll content of leaves

(50 SPAD) was recorded in 30 mg/L of the IAA treatment. The highest stomatal conductance (117 mmol/$m^{-2}s^{-1}$) was obtained at the concentration of 120 mg/L IAA and the lowest conductance (82 mmol/$m^{-2}s^{-1}$) was recorded in the control, and the difference was statistically significant (Table 2).

Table 2
Effects of spray technique on the leaf chlorophyll, stomatal conductance and seed quality of Okra using different concentrations of Indole Acetic Acid (IAA) and gibberellin (GA_3)

Treatment (mg/L)	Healthy seed (%)	Aborted seed (%)	Chlorophyll content	Stomatal conductance (mmol/$m^{-2}s^{-1}$)	Fruit weight (g)
IAA					
0	95.0± 0.55^{a}	4.54± 0.55^{b}	41.9± 0.69^{d}	86.2± 0.59^{e}	----
30	94.0± 0.48^{b}	6.30± 0.48^{a}	49.7± 0.29^{a}	88.5± 1.38^{d}	----
60	93.0± 0.08^{b}	6.8± 0.08^{a}	43.7± 0.29^{c}	93.8± 0.69^{c}	----
90	95.00± 0.39^{b}	6.37± 0.39^{a}	46.6± 0.18^{b}	97.1± 1.01^{b}	----
120	93.00± 0.28^{b}	6.72± 0.27^{a}	45.8± 0.72^{b}	117.1± 0.69^{a}	----
GA3					
0	95.0± 0.48^{a}	4.7±0.50^{a}	40.6± 0.17^{d}	34.6±0.74^{e}	23.5±0.15^{e}
30	96.0±0.54^{a}	4.5± 0.48^{a}	46.5± 0.05^{b}b	90.8±0.70^{c}	28.5±0.33^{d}
60	95.0± 0.46^{a}	4.6±0.12^{a}	47.5± 0.24^{a}	88.2±1.22^{d}	32.1±0.43^{b}
90	95.0± 0.47^{a}	4.5±0.22^{a}	41.4± 0.23^{c}	156.6±1.25^{b}	33.5±0.19^{a}
120	96.0±0.55^{a}	4.4±0.18^{a}	40.9± 0.25^{d}	285.2±0.45^{a}	30.4±0.25^{c}

All the data are the mean of three replications. Different letters in the same column are significantly different at 5% level (Duncan's Multiple Range Test)

Effect of Foliar Spray of GA_3 on the Physiological Activities of Okra

Foliar spray of the 90 mg/L GA_3 produced the highest fruit weight (34 g) (Table 2). The medium concentration of GA_3, that is, the 60 mg/L treatment, increased the chlorophyll content (48). The results also showed that stomatal conductance of the okra plant leaf was significantly affected by GA_3 treatment, and the highest value of stomatal conductance (285 mmol/$m^{-2}s^{-1}$) was recorded in the 120 mg/L GA_3 treatment, whereas the control produced the lowest stomatal aperture (35 mmol/$m^{2}s$).

Effect of Stem Injection of IAA on the Growth and Physiological Activities of Okra

The results showed that the number of leaves, branches, flowers and fruit of the okra plants increased significantly when a concentration of 120 mg/L IAA was applied in the stem injection (Table 3). The highest number of leaves (37) recorded was in the 120 mg/L IAA treatment. IAA at the 120 mg/L treatment produced the highest number of branches (6) compared to other treatment. Stem injection of 120 mg/L IAA produced the the highest number of

okra flowers and pods, as seen in Table 3. The highest amount of TSS was recorded in the 30 mg/L IAA treatment (Table 3). IAA at 120 mg/L using rge stem injection treatment produced the highest plant height (48 cm). Chlorophyll content and stomatal conductance of okra plant were significantly affected by the stem injection of IAA (Figure 1). The highest amount of leaf chlorophyll content (45) was measured at 60 mg/L IAA treatment compared to the control (40). The highest stomatal conductance of the okra leaf (152 mmol/m^{2}s) was obtained in the treatment using 30 mg/L IAA (Figure 1).

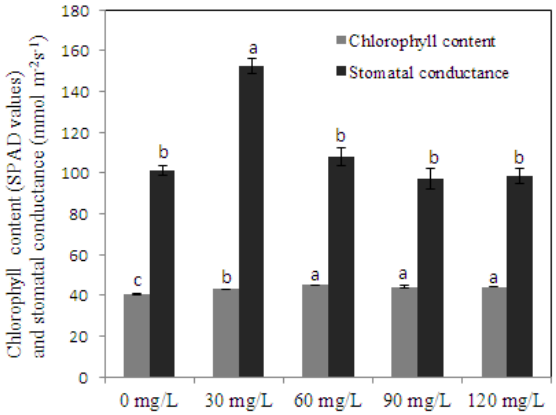

Figure 1. Effects of different treatments of IAA as stem injection on chlorophyll content and stomatal conductance of okra. Bars indicate mean ± S.E. Mean values with the same letters (a or b) are not significantly different at p=<0.05

Effect of Stem Injection of GA_3 on the Growth and Physiological Activities of Okra

Table 3 shows that all the okra plants treated with GA_3 produced the highest number of branches. At 120 and 90 mg/L, GA_3 produced the highest number of branches (6). The number of okra plant leaves was also significantly increased with the GA_3 application, and it was the highest in 120 mg/L treatment with a value of 80. Different treatments of GA_3 produced a significant effect on the number of flowers, pods, pod size, pod weight and pod TSS content of okra. The highest number of flowers (8) and pods (8) was obtained with the treatment of 120 mg/L GA_3. The results showed that fruit size of the okra plant increased with concentration up to 90 mg/L but thereafter decreased (Table 3). Pod weight of okra was the highest (44 g) in the 90 mg/l GA_3 treatment. In addition, TSS content of the okra pods also increased significantly with the stem injection of higher concentrations of GA_3. The highest TSS (2% Brix) content was recorded at a concentration of 120 mg/L GA_3 compared to the control (2% Brix) (Table 3).

Table 3
Effects of stem injection on the plant growth, flowering and fruit quality of Okra using different concentrations of Indole Acetic Acid (IAA) and Gibberellin (GA_3)

Treatment (mg/L)	No. of leaf/ plant	No. of branches	No. of flowers	No. of fruit/ plant	TSS (% Brix)	Plant height (cm)
IAA						
0	23.0± 1.45^{d}	3.0± 0.58^{b}	7.00± 0.33^{b}	6.00± 0.33^{b}	2.24± 0.03^{cd}	44.0± 2.00^{b}
30	26.0± 0.88^{cd}	4.0± 0.58^{b}	8.00± 0.58^{b}	7.00± 0.88^{ab}	2.85± 0.01^{a}	46.0± 2.00^{ab}
60	28.0± 1.15^{bc}	4.0± 0.58^{b}	8.00± 0.58^{b}	7.00± 0.88^{ab}	2.43± 0.01^{b}	45.6± 1.53^{ab}
90	31.0± 1.15^{b}	4.00± 0.33^{ab}	8.00± 0.58^{b}	8.00± 0.88^{ab}	2.21± 0.01^{d}	47.1± 1.04^{ab}
120	37.0± 2.40^{a}	6.0± 0.58^{a}	11.0± 0.33^{a}	9.00± 0.33^{a}	2.28± 0.02^{c}	48.8± 2.57^{a}
GA_3						
0	25.0± 2.40^{e}	3.00± 0.58^{b}	5.00±0.33^{b}	4.00±0.58^{b}	2.11±0.01^{c}	40.8± 2.01^{b}
30	46.0± 1.15^{d}	4.00± 0.58^{b}	7.00±0.33^{b}	7.00±0.58^{a}	2.32±0.02^{b}	45.9± 2.57^{a}
60	55.0± 2.03^{c}	4.00± 0.58^{b}	7.00±0.33^{b}	7.00±0.58^{a}	2.36±0.02^{b}	46.5± 2.40^{a}
90	66.0± 0.88^{b}	6.00± 0.58^{a}	8.00±0.33^{ab}	8.00±0.88^{a}	2.36±0.01^{b}	45.4± 1.15^{a}
120	80.0± 0.33^{a}	6.00± 0.33^{a}	9.00±0.33^{a}	8.00±0.67^{a}	2.43±0.03^{a}	45.2± 1.04^{a}

All the data are the mean of three replications. Different letters in the same column are significantly different at 5% level (Duncan's Multiple Range Test)

GA_3 increased the height of the okra plant under field conditions (Table 3). The results showed that the stem injection of the GA_3 treatment did not produce any significant effect on healthy seed percentage of the okra plant (Table 4). On the other hand, it was observed that the stem injection of 30 and 60 mg/L GA_3 increased the percentage of aborted seeds compared to the control. Leaf chlorophyll content and stomatal conductance of the treated okra plant were significantly higher in the treated plant compared to in the untreated plant, and the highest chlorophyll and stomatal conductance were recorded in the 120 mg/L GA_3 treated okra plant (Table 4).

Table 4
Effects of stem injection method on the physiology and fruit quality of Okra using different concentrations of Gibberellin (GA_3)

Treatment (mg/L)	Fruit size (cm)	Fruit wt (g)	Healthy seed (%)	Aborted seed (%)	Chlorophyll content	Stomatal conductance ($mmol/m^{-2}s^{-1}$)
0	5.13±0.03^{e}	28.6±0.18^{e}	96.0± 0.24^{b}	4.00± 0.24^{b}	43.4± 0.19^{c}	98.6± 0.85^{e}
30	14.8±0.03^{d}	29.7±0.18^{d}	95.0± 0.18^{c}	5.00± 0.18^{a}	49.6± 0.15^{b}	168.5± 0.52^{d}
60	28.5±0.23^{c}	36.5±0.18^{c}	95.0± 0.03^{c}	5.00± 0.03^{a}	49.4± 0.35^{b}	184.5± 0.29^{c}
90	43.2±0.35^{a}	44.4±0.06^{a}	96.0± 0.03^{a}	4.00± 0.03^{c}	50.5± 0.32^{a}	218.1± 0.53^{b}
120	41.4±0.22^{b}	42.6±0.21^{b}	96.0± 0.04^{b}	4.00± 0.04^{b}	50.6± 0.06^{a}	221.1± 0.47^{a}

All the data are the mean of three replications. Different letters in the same column are significantly different at 5% level (Duncan's Multiple Range Test)

Effect of Flower Injection of IAA on the Growth and Physiological Activities of Okra

Flower injection of IAA significantly affected the number of leaves and branches of the okra plant (Table 8). The number of leaves was the highest (30) in the treatments of IAA at 90 and 120 mg/L.The highest number of branches (6) was also recorded with the 120 mg/L IAA treatment compared with the control (Table 5). The number of flowers and fruit of the okra plant was significantly increased with flower injections of 90 and 120 mg/L IAA (Table 5). The highest number of flowers (10) and fruit (9) was found in the 90 mg/L IAA treatment. It was observed that flowering and fruit formation increased the concentration of IAA. The fruit size was significantly increased with the IAA concentration with the highest value, 60 mg/L IAA. The result also showed that the 30 mg/L IAA applied as a flower injection increased the fruit weight and TSS content of the okra fruit compared to other treatments and the control. The TSS value was the highest (3) in the 30 mg/L of IAA treatment (Table 5). IAA at 60 mg/L doses produced the highest plant height of okra (48 cm) compared with the lowest height, which was recorded for the control plant (42 cm).

Flower injection of IAA produced a significant effect on healthy and aborted seed percentage of the okra fruit (Table 6). In this study, the highest healthy seed percentage per plant (88%) was recorded in the control plants using the flower injection method, while the lowest heathy seed percentage was recorded in the 120 mg/L treatment (Table 6). It was also found that flower injection of higher doses of IAA reduced the production of seeds in the okra fruit. The highest stomatal conductance of the okra plant was recorded in the 60 mg/L treatment, while the highest chlorophyll content was recorded in the 60 mg/L IAA treatment (Table 6).

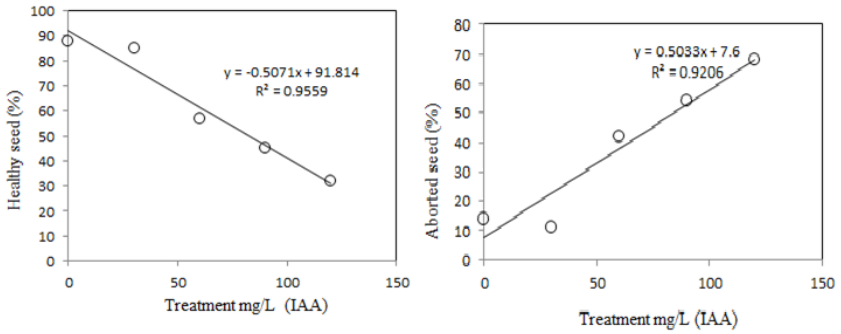

Figure 2. Correlation between concentration of IAA and % healthy seed and % aborted seeds of okra as a result of flower injection

Effect of Flower Injection of GA_3 on the Growth and Physiological Activities of Okra

Flower injection of 90 mg/L GA_3 increased the number of branches and leaves of the okra plant compared with the other treatments and the control and their mean difference was statistically significant (Table 5). The highest number of flowers (8) and fruit (7) was recorded for the 120 mg/L GA_3 treated plants (Table 5).

Table 5
effects of flower injection on the plant growth and fruit quality of Okra using different concentrations of Indole Acetic Acid (IAA) and Gibberellin (GA_3)

Treatment (mg/L)	No. of leaf/ plant	No. of branches	No. of flowers	No. of fruit/ plant	Fruit size (cm2)	Fruit weight (g)	TSS (% BRIX)
IAA							
0	23.0± 1.45^{b}	4.00± 0.58^{b}	6.00±0.33^{c}	5.00±0.33^{c}	7.70±0.06^{e}	15.3±0.12^{e}	2.22±0.01^{d}
30	28.0± 1.45^{a}	5.00± 0.58^{ab}	8.00±0.33^{b}	7.00±0.58^{bc}	32.2±0.58^{a}	34.7±0.22^{a}	3.82±0.02^{a}
60	29.0± 1.45^{a}	5.00± 0.58^{ab}	9.00±0.33^{ab}	7.00±0.58^{bc}	26.5±0.09^{b}	32.1±0.58^{b}	2.56±0.02^{b}
90	30.0± 1.45^{a}	5.00± 0.58^{ab}	10.0±0.58^{a}	9.00±0.58^{a}	23.7±0.34^{c}	30.4±0.20^{c}	2.39±0.06^{c}
120	30.0± 1.20^{a}	6.00± 0.58^{a}	10.0±0.58^{a}	8.00±0.67^{ab}	15.0±0.46^{d}	26.43±0.63^{d}	2.53±0.09^{c}
GA_3							
0	22.0± 1.53^{b}	4.00 ± 0.58^{b}	5.00±0.33^{b}	4.00±0.58^{b}	8.08±0.31^{d}	15.1±0.46^{d}	2.24±0.03^{e}
30	25.0± 0.88^{ab}	6.00± 0.58^{a}	6.00±0.58^{b}	5.00±0.88^{ab}	15.0±0.49^{c}	22.1±0.33^{c}	2.90±0.03^{c}
60	25.0± 0.88^{ab}	6.00± 0.58^{a}	6.00±0.58^{b}	5.00±0.58^{ab}	24.5±0.36^{a}	29.8±0.16^{a}	3.24±0.00^{b}
90	28.0± 1.73^{a}	6.00± 0.58^{a}	8.00±0.33^{a}	7.00±0.88^{ab}	24.4±0.25^{a}	29.9±0.41^{a}	3.56±0.17^{a}
120	28.0± 1.73^{a}	7.00± 0.58^{a}	8.00±0.58^{a}	7.00±1.15^{a}	18.3±0.08^{b}	24.6±0.17^{b}	2.60±0.02^{d}

All the data are the mean of three replications. Different letters in the same column are significantly different at 5% level (Duncan's Multiple Range Test)

On the other hand, flower injection of 60 and 90 mg/L GA_3 treatments increased the fruit size and fruit weight significantly compared with the other treatments and the control plants. TSS content of okra fruit was also affected significantly with the flower injection of 90 mg/L GA_3. The highest amount of TSS content (3.5% Brix) was recorded in 90 mg/L GA_3 treatment (Table 5). Flower injection of GA_3 did not produce a significant effect on the plant height of okra. All the treatments had a significant effect on the production of healthy seeds of okra compared with the control. Flower injection of GA_3 at doses of 60, 90 and 120 mg/L had the highest healthy seeds (95%) per fruit and this was statistically higher than in the control (84%) (Table 6). Significant variation was found between the control and the treated group in case of seed abortion intensity, which was highest in the control (6.03%) and lowest in 120 mg/L GA_3 (4%). The chlorophyll content and stomatal conductance of the treated plant were also significantly increased by GA_3 application through the flower injection method (Table 6).

Table 6
Effects of flower injection on the okra plant physiology and seed quality of Okra using different concentrations of Indole Acetic Acid (IAA) and Gibberellin (GA_3)

Treatment (mg/L)	Plant height (cm)	Healthy seed (%)	Aborted seed (%)	Chlorophyll content	Stomatal conductance ($mmol/m^{-2}s^{-1}$)
0	42.7± 1.31[b]	88.0± 0.74[b]	15.0± 0.74[d]	46.4± 0.32[c]	139.6± 2.75[c]
30	44.3± 1.58[a]	85.0± 0.15[a]	12.0± 0.16[e]	48.9± 0.50[b]	143.9± 2.11[c]
60	48.5± 1.23[a]	58.0± 0.23[c]	42.0± 0.16[e]	48.0± 0.5[b]	266.1± 0.18[a]
90	44.4± 1.12[b]	45.0± 0.46[d]	55.0± 0.46[b]	45.1± 0.95[d]	171.1± 1.19[b]
120	48.1± 1.26[a]	32.00± 0.29[e]	68.0± 0.29[a]	52.8± 0.64[a]	139.2± 7.77[c]
GA3					
0	42.1±0.32[a]	85.0± 0.34[c]	7.00±0.34[b]	43.2± 0.57[d]	95.2± 1.25[e]
30	42.4±0.12[a]	93.0± 0.06[b]	5.00±0.06[a]	44.8± 0.07[c]	138.4± 0.23[d]
60	44.5±0.23[a]	95.0± 0.11[a]	5.00± 0.11[c]	46.8± 0.05[b]	169.7± 6.44[b]
90	44.8±0.12[a]	96.0± 0.07[a]	4.00±0.07[c]	47.5± 0.02[a]	164.4± 0.34[c]
120	44.6±0.08[a]	96.0± 0.04[a]	4.00±0.04[c]	44.6± 0.38[c]	263.5± 0.25[a]

All the data are the mean of three replications. Different letters in the same column are significantly different at 5% level (Duncan's Multiple Range Test)

DISCUSSION

Two different growth regulators were used in this study for improvement of physiological activities and quality of okra. From the results, it was observed that IAA performed better than GA_3 when applied using three different techniques. The results of this study showed that IAA produced more consistent stimulation throughout spraying and stem and flower injection at different concentrations. On the other hand, flower and stem injection of GA_3 showed higher stimulatory effects than foliar spray on growth, development and quality of okra. The results showed that IAA and GA_3 application increased the branch number and plant height of the okra plant. Chhipa and Lal (1998) also reported that IAA application increased the number of branches in wheat plant. These results might be due to increase in cell division and cell elongation, which are effects of GA_3 and auxins (Ranjan et al., 2003). GAs also regulate flower initiation and induce mitotic division in the leaves. Daviere and Achard (2013) stated that GA stimulates growth by activating the degradation of DELLAs protein, a family of nuclear proteins that act as intracellular as well as growth repressors throughout the lifecycle of higher plants. It was recently found that derepression is mediated through the gibberellic acid (GA)-dependent degradation of DELLAs and the key components of the GA-DELLA signalling pathway.

From this study, it is clear that application of growth regulators increased the leaf area and chlorophyll content of the okra plant. Vamil et al. (2010) stated the similar positive effects of IAA and GA_3 on

leaf area and chlorophyll content. It has been reported that IAA application increased leaf number in onion (Hye et al., 2002). GA- has stimulatory effects on cell division and elongation, leaf area and chlorophyll content (Harrington et al., 1996). Mukhtar (2008) reported that GA_3 treatment at 100 mg/L increased the leaf number, leaf area and chlorophyll content in *Hibiscus sabdariffa* L. The results showed that both the IAA and GA_3 increased the plant height of okra. These finding are supported by the findings of Mukhtar (2008), who found that 100 mg/L GA_3 and IAA increased plant height of soybean and red sorrel applied during early seedling growth. Kaur et al. (2000) stated that enhanced plant growth by IAA and GA_3 may be mediated through changes in the activities of carbohydrate metabolism enzymes.

In general, it was found that application of IAA and GA_3 significantly increased okra growth, number of flowers, fruit size and fruit weight, and higher concentrations of 120 and 90 mg/L IAA and GA_3 were comparatively better than lower concentration. These results were parallel to those of Sarkar et al. (2002), who observed that GA_3 and NAA stimulate the fruit set of soybean when applied at 100 mg/L twice. IAA and GA_3 at 90 and 120 mg/L concentrations increased the flowering of okra at different application methods. Moneruzzaman et al. (2011) also reported that exogenous GA_3 increased the number of fruit, fruit weight and fruit quality of wax apple. On the other hand, Mekhled (2011) reported the IAA application at medium concentration (50 mg/L) promotes flowering and at higher concentration, inhibits the flowering process of okra. Awan and Alizai (1989), observed that GA_3 at 100 ppm increased seed yield in okra. Adel et al. (2011) reported that fruit quality also differred with cultural practices, growing conditions and cultivars.

Foliar spray of IAA significantly increased plant height and the number of branches, leaves, flowers and fruit weight and TSS content in the fruits. It was also observed that higher concentrations of IAA increased the chlorophyll content, stomatal conductance and aborted seed percentage and reduced healthy seed percentage. Similar effects was reported by Prajapati et al. (2015), who found that foliar application of auxin improved the growth and quality of various vegetable crops. It has been reported that IAA promotes GA biosynthesis and inhibits GA deactivation. Damian et al. (2002) stated that due to this double-barrelled effect, even moderate changes in IAA supply can lead to physiologically significant changes in GA content. They also found that IAA application induced the up-regulated expression of gibberellin biosynthesis gene and produced new wall polysaccharides so that growth may continue for longer periods. Auxin stimulates the activities of certain enzymes that are involved in biosynthesis of cell wall polysaccharides and cell wall loosening. Auxin initiates a signal transduction pathway resulting in production of secondary messengers that directly activate pre-existing H+-ATPases and stimulates the expression of several genes related to growth and development.

It has also been reported that foliar application of kinetin enhances flowering of and increases the leaf area and bract colour of the bougainvillea plant (Moneruzzaman et al., 2010). The results also showed that foliar application of GA_3increased the chlorophyll content, stomatal conductance and fruit weight of okra. Ilias et al. (2007) also reported similar results in that plant height, leaf area and biomass were significantly enhanced by the foliar application of GA_3. Ayyub et al. (2013) found that growth regulators through foliar application boosted stem elongation, number of leaves, chlorophyll content, number of pods, number of seeds, seed weight and seed yield. Spraying of GA_3 was observed to have a significant effect on the plant height of okra compared with the seed-soaking application technique (Unamba et al., 2009).

It was found that stem injection of a higher concentration of IAA and GA_3 improved the physiological characteristics of the okra plant and increased the yield parameters such as number of flowers, fruit size, fruit weight and TSS content of fruit. This improved yield and quality, probably due to the fact that GA_3 and IAA treatment might be linked to the efficiency of the photosynthetic apparatus, which leads to increase in plant productivity and quality (Azooz et al., 2004). Stem injection of IAA also increased the chorophyll content and stomatal conductance. This is contrary to what was reporte by Mekhled (2011), who found the effect of IAA on stem growth and other physiological activities of okra via stem injection of IAA and NAA to be insignificant. GA_3 stem injection significantly increased plant growth, number of flowers, fruit size and weight. It was also recorded that the GA_3 stem injection method increased healthy seed and reduced aborted seed percentage in okra pods. TSS content in the fruit and the chlorophyll content and stomatal conductance of the okra leaf were significantly increased using the stem injection method. Average plant height was observed via GA_3 stem injection. Khandaker et al. (2013) reported that localised application of GA_3 increased fruit development, fruit pigmentation and fruit quality of wax apple.

Flower injection of IAA significantly increased all physiological and reproductive parameters studied in this work. IAA at higher concentration (>90 mg/L) increased the physiological activities of the okra plant and increased the flowering and number of fruit. IAA flower injection also reduced the number of healthy seeds and increased the number of aborted seeds; this is probably the most important finding of this current study. In another study, it was reported that the application of 200 mg/L IAA decreased viable seed production (Sarkar et al., 2002). It was also observed that a lower concentration of IAA increased the chlorophyll content, fruit size, fruit weight and TSS content of okra fruit. It has been reported that application of IAA prevented the loss of chlorophyll throughout the ageing of chloroplasts. Shah (2011) reported that IAA application increased the net photosynthetic rate, leaf protein content and dry mass of black cumin.

Improved photosynthesis might increase the assimilates as well as the total soluble solid content in the fruit. For flower injection of GA_3, the same pattern of stimulatory effects was observed but plant height was not significantly affected. Mekhled (2011) stated that 200 mg/L IAA at flower injection and 100 mg/L NAA at ovary injection inhibited seed production and produced 100% aborted seeds in okra; this is known as stenospermocarpy. Comparing the three techniques of plant growth regulator applications, it can be summarised that flower injection is better than stem injection and spraying for improvement of okra production as suggested by Mekhled (2011), who stated that flower injection and ovary injection were better than stem injection.

CONCLUSION

It can be concluded that 120 mg/L IAA and 90 mg/L GA_3 were the best treatments for growth, development and quality of okra. Finally, it can be summarised that flower injection improved the pod quality of okra by reducing the healthy seeds and increasing the abortive seed percentage. Higher concentration of IAA (>90 mg/L) caused stenospermocarpy or reduced viable seed production. Flower and stem injection of IAA and GA_3 improved the physiological activities and quality of the okra plant. These two techniques can be used commercially in vegetable cultivation for improvement of quality. The flower and stem injection techniques also can reduce the use and cost of growth regulators and protect the environment from pollution due to foliar application.

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