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Presowing Bioregulator Seed Treatments Increase the Seedling Growth and Yield of Tomato (*Solanum lycopersicon*)

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Abstract The bioregulators indole acetic acid (IAA), indole butyric acid (IBA), and naphthalene acetic acid (NAA) were investigated for their effects on seedling growth and yield of tomato (*Solanum lycopersicon*). Seeds of tomato genotypes NHLy11, NHLy12, NHLy13, NHLy15 and NHLy16 were subjected to presowing treatments in 25-, 50-, 75-, 100-, 125-, and 150-mg/l concentrations of each of the bioregulators and control replicated three times in a completely randomized design. Results revealed that IAA and IBA significantly retard ($P < 0.05$) the growth of radicles and hypocotyls of all test genotypes relative to controls, especially at the high concentrations of 125- and 150-mg/l solutions of the bioregulators. NAA treatments enhanced seedling growth moderately at concentrations up to 100 mg/l. At 125- and 150-mg/l concentrations, the seedlings showed reduced radicle and hypocotyl lengths compared with those of controls. All treated genotypes had higher average fruit weight and mean fruit yield than controls at the 100-mg/l concentration of the bioregulators. IAA had the highest yield of 25,900 kg fw ha^{-1} in the NHLy12 genotype, whereas the lowest yield of 3,760 kg fw ha^{-1} was obtained in the IBA-treated NHLy16 genotype. This study showed that presowing seed treatments with IAA, IBA, and NAA were effective in enhancing seedling growth and yield in tomato, especially at the 100-mg/l concentration.

Keywords Bioregulator · Seed treatment · *Solanum lycopersicon* · Seedling growth · Yield

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Introduction

Tomato (*Solanum lycopersicon*) is a vegetable crop that enjoys wide consumption among the populace in developing countries, especially in the raw fresh state (COA 2001). Fresh tomatoes and canned products such as concentrates, puree, and paste are increasing in demand in West Africa where fresh or processed tomatoes form an essential part of the diet of the inhabitants of this region. It is the most important commercial vegetable grown in Nigeria (Ibrahim and others 2000). The recognition of the nutritional value of the tomato coupled with its use as raw material for local canning and small cottage industries has led to increased production of the crop in recent years (Odegbaro 1996; Olowu and Onyemelukwe 2001). The economic production of tomato is determined and dictated by its yield and quality. The annual production figures of tomatoes are given in Table 1. Some treatments such as fertilizer application for increased fruit yield of crops have been reported to have adverse effects on the fruit quality and also on the environment (Olienyk and others 1997; Ruiz and Romero 1998). Nitrate leaching, eutrophication, and greenhouse gas emissions are the major environmental concerns associated with fertilizer applications (PPI/PPIC/FAR 1991; Su and others 2003). Pollution may thus arise from excessive fertilization with inorganic chemicals. In addition, breeding programs are becoming more complex and costly (Olmos and Hellin 1998; Badejo and Okoh 2001), and therefore research into other methods or treatments is being intensified to meet the demands of growers, processors, and consumers (Song and Fujiyama 1996; Pacini and others 2003).

The discovery of indole-3-acetic acid (IAA) in the mid-1930s has resulted in the development of synthetic plant bioregulators for the purpose of manipulating plant growth and development for possible crop improvements in yield and

Table 1 Annual production figures of tomatoes

Countries	Area ($\times 10^3$ ha)	Yield (t/ha)	Production ($\times 10^3$ t)
Nigeria	25	9.0	225
Ghana	21	4.7	98
Egypt	130	15.2	1,976
Cameroon	8	1.8	14
Algeria	12	10.6	124
Libya	16	11.6	186
Morocco	14	28.3	396
Sudan	12	11.6	138
Tunisia	16	15.6	249
Total (Africa)	254	12.04	3,406
Italy	110	30.4	3,346
USA	187	39.4	7,402
World	2,062	20.6	42,446

Data from NAS (1996)

quality (Belakbir and others 1998; El-al and Faten 2008). Their use as a unique facet of plant biotechnology has been described as a chemical revolution in agricultural and horticultural practices (Hanisch ten cate and Breteler 1982; Arinaitwe and others 1999). They have a universal effect on photosynthetic plants, algae, bacteria, and other autotrophic organisms, suggesting that they act through a common pathway relative to derepression of the genetic material (Gausman 1991). Bioregulators play essential roles in plant development by influencing various biochemical and physiological responses. They have been implicated in the induction of antioxidant enzymes (El-Khallal and others 2009), enhancement of seedling emergence (Olaiya and Osonubi 2009), and increased seed cotton yield (Lamas 2001). In recent years, some work has been done on the application of bioregulators for increasing the growth and yield of crops (Strong 1991; Maske and others 1997; McCarty and others 1999; King and others 2000; Lamas 2001). However, there is insufficient information in the literature on the effects of these bioregulators on tomato growth and yield, especially in the Black African subcontinent. Understanding this phenomenon is vital for improving tomato production and optimizing resource use efficiency (CGIAR 1996). Therefore, in this work we investigated the effects of three bioregulators, indole acetic acid (IAA), indole butyric acid (IBA), and naphthalene acetic acid (NAA), on seedling growth and yield of tomato (*S. lycopersicon*).

Materials and Methods

Plant Material

Homogenous seeds of five improved tomato (*S. lycopersicon*) genotypes were obtained from the Genetic Resources Unit of the National Horticultural Research Institute (NIHORT), Idi-Ishin, Ibadan. They were the NHLy11, NHLy12, NHLy13, NHLy15, and NHLy16 genotypes. The seeds were surface sterilized with 1% (v/v) Na hypochlorite solution for 2 min and thoroughly rinsed with distilled water several times before use.

Plant Biochemical Regulators

The exogenous plant bioregulators used in this study were indole acetic acid (IAA: 98% pure, Sigma), indole butyric acid (IBA: 98% pure, Sigma), and naphthalene acetic acid (NAA: 96% pure, Sigma). Test solutions of the bioregulators were prepared by the method of Heydecker and Coolbear (1977) with slight modifications, as described below.

A total of 37.5 mg of each of IAA, IBA, and NAA was dissolved in 10 ml 60% ethanol containing 0.5% Tween 20 in different 250-ml volumetric flasks. Distilled water was added to the mark on each flask to obtain concentrations of 150 mg/l. These solutions were serially diluted with distilled water to yield 125-, 100-, 75-, 50-, and 25-mg/l concentrations of each bioregulator. The six concentrations of each compound were used in the tomato seedling growth tests. A control with distilled water was also set up.

The Experimental Site

All the field experiments were conducted in the vegetable experimental plots of NIHORT, Idi-Ishin, Ibadan (longitude 3°50′–52′E and latitude 7°23′–25′N of the equator).

Tomato Seedling Growth Tests

The bioassays were carried out using the method of Rohloff and others (1997). Twenty-five sterilized seeds of the tomato genotypes NHLy11, NHLy12, NHLy13, NHLy15, and NHLy16 were placed respectively on moistened filter papers in petri dishes which were then incubated at 26°C for 2–3 days in the dark to enhance germination and root initiation. Five germinated seeds with 1–2-mm-long roots were transferred into petri dishes containing filter papers supplied with the different concentrations (25, 50, 75, 100, 125, and 150 mg/l) of each bioregulator and a control (distilled water). They were incubated for 3 days. The phytotoxic effect of test compounds was determined by measuring the length of radicles and hypocotyls. The treatments were set up in three replications in a completely randomized design.

Field Studies

Sterilized seeds of each of the five tomato genotypes were subjected to presowing treatments prior to germination.

The seeds were soaked in 100-mg/l solutions of IAA, IBA, and NAA, respectively, and in distilled water (control) for 24 h in the dark at 25°C. The treated and control seedlings of the five tomato genotypes NHLy11, NHLy12, NHLy13, NHLy15, and NHLy16 were raised in the nursery in seed trays (300 × 200 × 60 mm) and were later transplanted into prepared plots at the Vegetable Experimental Site. The plants were grown under prevailing field agricultural conditions; no insecticide or fertilizer was applied. Field plot dimensions were approximately 5 m^2, with each plot containing an average of 20 seedlings. There were four plots within a row corresponding to four treatments per genotype and 20 plots in a block. The rows were separated by 1 m. At flowering (anthesis), IAA, IBA, and NAA at 100-mg/l concentration were applied respectively to separate plots by dipping the whole flower cluster into the solutions once (Thomas 1982). One of the plots in each row served as the check or control plot. The experimental design was a randomized complete block with four treatments, including a control, and replicated three times. The treatments were as follows: water-treated control (T_0), 100 mg/l IAA (T_1), 100 mg/l IBA (T_2), and 100 mg/l NAA (T_3). Tomato fruits in all the treatments were harvested at the orange-red ripe stage. Fruits were harvested from each of the treatments and the control, weighed, and washed in cold tap water, and the total fresh weights were recorded for each batch.

Statistical Analysis

All data obtained were analyzed using analysis of variance (ANOVA) Statistica software (Statsoft, Inc., Tulsa, OK); means and standard error were determined. Means were compared by Duncan's multiple-range test (DMRT) at 5% significance.

Results and Discussion

The effects of different concentrations of the bioregulators on seedling growth of test tomato genotypes are given in Tables 2, 3 and 4. The radicle length in the IAA-treated seedlings ranged from 8.1 to 28.4 mm and the hypocotyl length was between 10.3 and 32.8 mm (Table 2). For the IBA treatments, radicle length ranged from 10.8 to 28.8 mm and the hypocotyl length ranged from 10.9 to 35 mm (Table 3). The results showed that IAA and IBA

Table 2 Effect of IAA on growth of tomato seedlings

IAA Conc. (mg/l)	Growth profile				
	Average radicle length (mm)[a]				
	NHLy11	NHLy12	NHLy13	NHLy15	NHLy16
Control	28.8 ± 1.2	30.1 ± 2.3	30.7 ± 1.3	27.3 ± 1.6	28.1 ± 2.3
25	21.2 ± 1.8 (26.4) d	28.4 ± 1.9 (5.7) d	23.5 ± 2.8 (23.5) d	20.8 ± 1.1 (23.8) d	22.9 ± 1.2 (18.5) d
50	20.9 ± 0.8 (27.4) cd	24.2 ± 1.1 (19.6) cd	23.4 ± 1.7 (23.8) d	20.1 ± 2.9 (26.4) d	20.7 ± 0.3 (26.3) cd
75	20.7 ± 2.4 (28.1) c	23.7 ± 0.8 (21.3) cd	20.3 ± 1.2 (33.9) cd	17.2 ± 1.8 (37.0) cd	19.6 ± 2.1 (30.3) c
100	20.6 ± 1.5 (28.5) c	22.4 ± 1.8 (25.6) c	20.1 ± 2.4 (34.5) c	15.1 ± 1.3 (44.7) c	19.1 ± 1.9 (32.0) c
125	13.2 ± 2.1 (54.2) b	18.3 ± 2.3 (39.2) b	19.3 ± 1.2 (37.1) b	10.0 ± 2.4 (63.4) b	16.3 ± 1.2 (42.0) b
150	10.1 ± 1.7 (64.9) a	12.7 ± 1.9 (57.8) a	11.2 ± 2.2 (63.5) a	8.1 ± 0.8 (70.3) a	12.4 ± 0.6 (55.9) a
IAA Conc. (mg/l)	Growth profile				
	Average hypocotyl length (mm)[a]				
	NHLy11	NHLy12	NHLy13	NHLy15	NHLy16
Control	41.3 ± 1.8	40.2 ± 1.1	38.3 ± 0.8	39.7 ± 1.9	40.7 ± 1.2
25	33.0 ± 2.8 (20.1) d	30.1 ± 1.3 (25.1) d	31.2 ± 1.3 (18.5) d	32.8 ± 1.2 (17.4) d	32.4 ± 2.7 (20.4) d
50	30.4 ± 1.4 (26.4) d	29.4 ± 1.4 (26.9) d	26.5 ± 1.4 (30.8) cd	29.7 ± 1.3 (25.2) d	29.6 ± 1.4 (27.3) d
75	26.1 ± 2.2 (36.8) c	27.3 ± 1.2 (32.1) bc	24.3 ± 2.6 (36.6) c	25.2 ± 2.8 (36.5) cd	23.4 ± 1.7 (42.5) cd
100	24.3 ± 2.6 (41.2) bc	26.1 ± 2.3 (35.1) c	23.1 ± 2.7 (39.7) c	22.1 ± 2.7 (44.3) c	21.6 ± 1.1 (46.9) c
125	20.8 ± 1.7 (49.6) b	22.4 ± 1.4 (44.3) b	19.2 ± 1.8 (49.9) b	20.2 ± 1.0 (49.1) b	18.7 ± 2.1 (54.1) b
150	13.1 ± 1.2 (68.3) a	16.3 ± 0.9 (59.5) a	13.4 ± 1.0 (65.0) a	12.4 ± 1.8 (68.8) a	10.3 ± 1.4 (74.7) a

Data are means of three replications ± SE. Values followed by similar letters within a column were not measurably different ($P < 0.05$)

[a] Percentage inhibition of radicle and hypocotyl lengths are indicated in parentheses

Table 3 Effects of IBA on growth of tomato seedlings

IBA Conc. (mg/l)	Growth profile				
	Average radicle length (mm)[a]				
	NHLy11	NHLy12	NHLy13	NHLy15	NHLy16
Control	28.8 ± 1.2	30.1 ± 2.3	30.7 ± 1.3	27.3 ± 1.6	28.1 ± 2.3
25	23.9 ± 2.3 (17.0) d	28.8 ± 1.6 (4.3) d	25.3 ± 2.4 (17.6) d	23.7 ± 1.6 (13.2) d	22.8 ± 2.7 (18.9) d
50	22.7 ± 1.8 (21.2) cd	25.3 ± 1.2 (16.0) cd	24.7 ± 1.9 (19.5) d	22.5 ± 1.2 (17.6) cd	21.1 ± 2.4 (24.9) cd
75	21.8 ± 1.2 (24.3) c	24.5 ± 1.1 (18.6) c	21.3 ± 1.3 (30.6) c	18.3 ± 0.9 (33.0) c	20.2 ± 1.7 (28.1) c
100	20.9 ± 1.7 (27.4) c	21.8 ± 1.2 (27.6) bc	20.8 ± 1.5 (32.3) c	15.8 ± 1.5 (42.1) bc	19.4 ± 2.8 (31.0) bc
125	15.5 ± 0.8 (46.2) b	20.7 ± 2.1 (31.2) b	18.3 ± 1.1 (40.4) b	12.3 ± 1.3 (55.0) b	16.2 ± 1.8 (42.4) b
150	12.1 ± 1.1 (58.0) a	14.5 ± 1.7 (51.8) a	13.4 ± 2.1 (56.4) a	10.8 ± 0.5 (60.4) a	11.3 ± 1.9 (59.8) a
IBA Conc. (mg/l)	Growth profile				
	Average hypocotyl length (mm)[a]				
	NHLy11	NHLy12	NHLy13	NHLy15	NHLy16
Control	41.3 ± 1.8	40.2 ± 1.1	38.3 ± 0.8	39.7 ± 1.9	40.7 ± 1.2
25	35.0 ± 0.2 (15.3) d	31.3 ± 1.2 (22.1) d	33.4 ± 2.1 (12.8) d	32.1 ± 2.4 (19.1) d	33.1 ± 2.8 (18.7) d
50	33.2 ± 1.8 (19.6) cd	30.8 ± 0.9 (23.4) d	29.3 ± 1.2 (23.5) cd	30.1 ± 2.2 (24.2) c	25.8 ± 1.5 (36.6) cd
75	30.1 ± 2.9 (27.1) c	29.1 ± 1.9 (27.6) cd	27.8 ± 1.3 (27.4) c	29.2 ± 1.8 (26.5) c	22.6 ± 1.5 (44.5) c
100	27.3 ± 1.2 (33.9) bc	25.1 ± 2.5 (37.6) c	25.1 ± 3.0 (34.5) bc	26.3 ± 1.8 (33.8) bc	20.7 ± 1.7 (49.1) bc
125	20.3 ± 0.8 (50.9) b	21.9 ± 0.6 (45.5) b	20.4 ± 2.1 (46.7) b	20.1 ± 1.1 (49.4) b	17.3 ± 1.4 (57.5) b
150	12.3 ± 1.3 (70.2) a	15.2 ± 1.7 (62.2) a	13.7 ± 1.2 (64.2) a	14.6 ± 1.6 (63.2) a	10.9 ± 2.8 (73.2) a

Data are means of three replications ± SE. Values followed by similar letters within a column were not measurably different ($P < 0.05$)

[a] Percentage inhibition of radicle and hypocotyl lengths are indicated in parentheses

significantly inhibited ($P < 0.05$) the growth of radicles and hypocotyls of all test tomato genotypes relative to control, especially at the high concentrations of 125 and 150 mg/l. The retarding effect was more pronounced on the hypocotyl length, with IAA causing the greatest hypocotyl length retardation of 74.7% in the NHLy16 genotype (Table 2). Also, the growth profile of the seedlings in response to NAA treatments showed radicle length ranging from 28.3 to 39.2 mm and hypocotyl length ranging from 39.3 to 51 mm (Table 4). The NAA treatments enhanced seedling growth moderately at concentrations up to 100 mg/l. However, at higher concentrations of NAA (125 and 150 mg/l), the seedlings showed reduced radicle and hypocotyl length compared with controls (Table 4).

The practical implications of the effect of 100 mg/l of the bioregulators on yield of tomato plants were investigated in the field. The average fruit weight and the commercial fruit yield of the test genotypes in response to bioregulator application are given in Tables 5 and 6, respectively. The IAA-treated NHLy12 and NHLy13 genotypes had the highest average fruit weights of 56.25 and 50.20 g fw per plant with corresponding yields ($P < 0.05$) of 25,900 and 23,300 kg fw ha^{-1}, respectively, whereas the IBA-treated NHLy16 genotype had the lowest yield of 3,760 kg fw ha^{-1}.

In the bioassay for phytotoxicity, low concentrations of IAA and IBA (25–100 mg/l) had retarding effects on the growth of radicles and hypocotyls of tomato seedlings relative to controls. At concentrations above 100 mg/l, these parameters were significantly retarded by the bioregulators (Tables 2, 3). Root tissues are sensitive to fluctuating concentrations of auxins (IAA), and the development of the root system can be greatly affected by exogenous sources of this plant bioregulator. At relatively high concentrations, natural auxins such as IAA stimulate root induction while reducing root elongation (Bakrim and others 2007). The reason for the toxic effects of supraoptimal auxin concentrations is unknown (Bensen and others 1990). These observations could mean that the bioregulators disorganize the delicate machinery of growth through inhibition of enzymes involved in metabolic activities in the treated genotypes, with greater effects at very high concentrations. Glick and others (1997, 1998), however, reported that such an effect may be associated with an increase in the level of ethylene in the plant. Auxins and compounds exhibiting auxin-like action are generally

Table 4 Effects of NAA on growth of tomato seedlings

NAA Conc. (mg/l)	Growth profile				
	Average radicle length (mm)[a]				
	NHLy11	NHLy12	NHLy13	NHLy15	NHLy16
Control	28.8 ± 1.2	30.1 ± 2.3	30.7 ± 1.3	27.3 ± 1.6	28.1 ± 2.3
25	28.9 ± 2.2 (0.4)	30.9 ± 2.5 (2.7)	30.8 ± 1.7 (0.3)	28.3 ± 1.5 (3.7)	29.7 ± 1.0 (5.7)
50	29.1 ± 0.8 (1.0)	30.2 ± 1.6 (0.3)	30.8 ± 2.4 (0.3)	29.1 ± 2.9 (6.6)	30.3 ± 1.7 (7.8)
75	29.3 ± 2.0 (1.7)	31.0 ± 2.3 (3.0)	32.0 ± 1.4 (4.2)	30.3 ± 1.8 (11.0)	31.2 ± 1.3 (11.0)
100	33.3 ± 1.2 (15.6)	35.1 ± 1.8 (16.6)	36.4 ± 2.1 (18.6)	35.8 ± 2.3 (31.1)	34.1 ± 2.8 (21.4)
125	30.1 ± 2.1 (4.5)	30.3 ± 2.3 (0.7)	28.1 ± 1.0 (8.5)$^{+}$	26.3 ± 1.3 (3.7)$^{+}$	26.4 ± 0.2 (6.1)$^{+}$
150	26.4 ± 0.3 (8.3)$^{+}$	28.3 ± 0.7 (6.0)$^{+}$	29.2 ± 2.4 (4.9)$^{+}$	27.1 ± 0.6 (0.7)$^{+}$	27.6 ± 2.3 (1.8)$^{+}$
NAA Conc. (mg/l)	Growth profile				
	Average hypocotyl length (mm)[a]				
	NHLy11	NHLy12	NHLy13	NHLy15	NHLy16
Control	41.3 ± 1.8	40.2 ± 1.1	38.3 ± 0.8	39.7 ± 1.9	40.7 ± 1.2
25	42.3 ± 1.2 (2.4)	40.5 ± 2.1 (0.8)	39.3 ± 1.3 (2.6)	39.7 ± 2.8 (0.0)	40.9 ± 2.2 (0.5)
50	43.0 ± 1.5 (4.1)	41.2 ± 1.1 (2.5)	40.2 ± 2.4 (5.0)	41.2 ± 1.5 (3.8)	41.0 ± 1.3 (0.7)
75	43.3 ± 2.1 (4.8)	42.3 ± 2.4 (5.2)	41.8 ± 2.2 (9.1)	42.3 ± 1.8 (6.6)	42.8 ± 1.2 (5.2)
100	47.3 ± 1.2 (14.5)	48.2 ± 1.4 (19.9)	47.1 ± 1.8 (23.0)	48.1 ± 2.0 (21.2)	49.2 ± 1.3 (20.9)
125	40.8 ± 0.4 (1.2)$^{+}$	40.1 ± 2.3 (0.3)$^{+}$	37.3 ± 1.2 (2.6)$^{+}$	40.2 ± 1.9 (1.3)	40.9 ± 2.1 (0.5)
150	8.3 ± 2.3 (79.9)$^{+}$	39.3 ± 0.9 (2.2)$^{+}$	37.2 ± 1.3 (2.9)$^{+}$	38.2 ± 2.1 (3.8)$^{+}$	37.0 ± 1.8 (9.1)$^{+}$

Data are means of three replications ± SE

[a] Percentage increases in growth profile of tomato seedlings are indicated in parentheses. Percentage inhibition of radicle and hypocotyl lengths are shown in parentheses with the + sign superscript

Table 5 Effects of bioregulators on average fruit weight of tomato genotypes

Treatments	Average fruit weight (g fw/plant)				
	NHLy11	NHLy12	NHLy13	NHLy15	NHLy16
Control	22.06 ± 1.13c	27.50 ± 1.82c	29.41 ± 0.98c	14.29 ± 1.24c	13.25 ± 1.53c
100 mg/l IAA	27.78 ± 1.10a	56.25 ± 1.68a	50.20 ± 1.21a	20.93 ± 1.46a	27.78 ± 1.18a
100 mg/l IBA	27.30 ± 1.72a	32.14 ± 1.53b	33.20 ± 2.10b	18.00 ± 1.93b	25.00 ± 2.08b
100 mg/l NAA	26.92 ± 0.97b	37.67 ± 1.49b	34.10 ± 1.76b	22.79 ± 0.95a	28.00 ± 1.57a

Data are means of three replications ± SE. Values followed by similar letters within a column were not measurably different ($P < 0.05$)

Table 6 Effects of bioregulators on fruit yield of tomato genotypes

Treatments	Yield (kg fw ha^{-1})				
	NHLy11	NHLy12	NHLy13	NHLy15	NHLy16
Control	7200 ± 380c	8540 ± 460c	8660 ± 490d	4570 ± 320c	2470 ± 200c
100 mg/l IAA	16,600 ± 520a	25,900 ± 740a	23,300 ± 710a	10,600 ± 480a	4860 ± 380a
100 mg/l IBA	7650 ± 390bc	9100 ± 480bc	10,460 ± 460c	9460 ± 450b	3760 ± 250b
100 mg/l NAA	8670 ± 410b	12,360 ± 560b	15,700 ± 510b	10,900 ± 460a	4260 ± 360a
Mean	10,030 ± 425	13,975 ± 560	14,530 ± 543	8883 ± 428	3838 ± 298

Data are means of three replications ± SE. Values followed by similar letters within a column were not measurably different ($P < 0.05$)

known to exhibit this characteristic of inhibiting rather than stimulating growth above a certain concentration.

Bioregulators have also been reported to affect the balance between photosynthesis and photorespiration in plants (Fernandez-Garcia and others 2002). In particular, NAA is known to improve the plant–water relationship and the rate of photosynthesis (Maske and others 1997). The observed enhancement of seedling growth by NAA between the concentrations of 25 and 100 mg/l (Table 3) may therefore be attributed to improvement of water absorption by the seedlings and a positive influence on cell division, cell elongation, expansion, synthesis of amino acids (Miko and others 1998), and improved photosynthesis (Maske and others 1997). It has been suggested that bioregulators could be used to manipulate gene expression in transgenic plants (James 2000), a possibility that allows grower flexibility under conditions of environmental fluctuation. This is of importance in the envisioned genetic engineering techniques of manipulating crop growth.

The yield characteristics of test tomato genotypes were determined in the field. Yield is defined as the edible or economically useful portion of the plant at crop harvest (NAS 1993) and is an outcome of genotype interaction with the environment (Abro and others 2004). It has been reported that factors responsible for variation in the yield of field crops are very complex (Watson 1952; Yang and Thseng 1991). The economic yield of tomato results from the number of harvested fruits per unit area and their individual size and weight (Bertin 1995). The IAA-treated NHLy12 and NHLy13 genotypes had significantly higher average fruit weights and fruit yields relative to controls ($P < 0.05$) (Tables 5 and 6). The general trend of higher yield produced in the bioregulator-treated plants in this study might be a consequence of larger fruit sizes and fruit weights. This supports the work of previous workers (Howlett 1986; Akl and others 1995) who reported that increase in yield was due to increase in fruit weight rather than in fruit number. The highest fruit yield of 25,900 kg fw ha^{-1} was obtained by the IAA-treated NHLy12 genotype; this might be connected with the highest rate of seedling growth recorded for this genotype under the same treatment (Table 2). This increase in seedling growth and consequently in the vegetative growth means an increase in the number of leaves per plant, thereby making available more photosynthetic surfaces. There is therefore increased assimilate production and translocation toward the sinks. This could have direct positive effects on the rate and the amount of dry matter produced, thereby positively affecting the final fruit size and weight (Azarmi and others 2008). Significantly higher yields ($P < 0.05$) were obtained for IAA- and NAA-treated plants compared with controls. These results are partly similar to the findings of Ruiz and Romero (1999) who stated that increases in cucumber yield occurred following nitrogen supply. These increases in yield have been attributed to enhanced amino acid translocation toward the fruit (Hedin and McCarty 1994; Rutherford and others 2005) following stimulation of parthenocarpic fruit growth (Spena and Rotino 2001). Therefore, the observed yield increases in the IAA- and NAA-treated plants might be linked to this phenomenon because auxins are key elements in parthenocarpic fruit development (Gorguet and others 2005). The dipping of the inflorescence in the auxin solutions may stimulate parthenocarpic fruit development to compensate for low fruit set due to unfavorable field conditions such as high wind and temperature extremes (George and others 1984). The molecular basis of fruit setting in general and parthenocarpic fruit setting in particular is not fully known (Varga and Bruinsman 1986). Differences in the mode of appearance of denatured protein profiles of developing seeded and seedless tomato fruits might indicate differential gene regulation of these two alternative routes of fruit development (Barg and others 1990). Parthenocarpic fruit development is mainly dependent on the level of auxins and gibberellins in the ovary during anthesis and fruit development (Hong and others 2007). The yield increases in this work therefore suggest that the synthetic auxins enhanced the level of hormones in the fruit, thereby inducing parthenocarpy, in agreement with the report of Gorguet and others (2005) on parthenocarpic mutants and parthenocarpic fruit development after exogenous application of auxins or gibberellins.

The present results demonstrate the potential of bioregulators, especially IAA, for increasing tomato fruit yield and suggest that they could serve as tools for increasing profits for agricultural producers. In comparison with natural auxins, synthetic auxins are cheaper to produce and are much more physiologically active, probably because of the absence of naturally occurring enzymes to break them down (Gilbertz and Lewis 1986; Badejo and Okoh 2001). However, despite their immense usefulness, plant bioregulator application as a commercial practice in food crop production is not yet widely accepted (Looney 2000). The numerous efforts to expand the scope of their use have been hindered by the long developmental process and lack of understanding of the molecular basis for hormone action (Cowan 2009) in whole-plant systems. Successful use of bioregulators is possible only when expert knowledge is integrated into the total production system (Schott and Walter 1991). More investigations are therefore needed for a better understanding of the mode of action, degradation, and specificity of bioregulators in mediating key biochemical steps of cellular processes involved in the growth and development of plants.

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