Effect of Plant Growth Regulators on Growth, Yield, and Quality of Sweet Pepper Plants Grown Hydroponically

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Abstract. A 2-year study (2012–13 and 2013–14) was conducted to evaluate the effect of plant growth regulator's (PGRs) on plant growth, yield, and quality of hydroponically grown sweet peppers. In 2012–13, sweet pepper plants were subjected to two levels of gibberellic acid (GA₃) (10 and 15 mg·L⁻¹), two levels of naphthalene acetic acid (NAA) (15 and 30 mg·L⁻¹), and four combinations of NAA and GA₃ (10 mg·L⁻¹ GA₃ + 15 mg·L⁻¹ NAA, 10 mg·L⁻¹ GA₃ + 30 mg·L⁻¹ NAA, 15 mg·L⁻¹ GA₃ + 15 mg·L⁻¹ NAA, and 15 mg·L⁻¹ GA₃ + 30 mg·L⁻¹ NAA) applied to plants at flower initiation in a non-temperature-controlled tunnel. This PGR application was repeated 60 days after transplanting (DAT). In 2013–14, in addition to previously mentioned treatments, two levels of 4-chlorophenoxyacetic acid (4-CPA), at 30 and 45 mg·L⁻¹, were applied at flower initiation followed by three additional applications of the latter treatments at 20-day intervals in a temperature-controlled tunnel. Marketable and total yield were markedly reduced by application of 4-CPA at 30 and 45 mg·L⁻¹. Plant height was increased by application of GA₃, and GA₃ in combination with NAA, compared with application of 4-CPA, 30 mg·L⁻¹ NAA, and the control. Results also showed that application of GA₃ at 10 and 15 mg·L⁻¹ or in combination with NAA increased plant fresh and dry mass as well; however, this had no beneficial effect on the yield of sweet pepper fruit. The application methods and concentrations of various PGRs needs further investigation under different growing conditions on sweet pepper cultivars.

Growing peppers in plastic tunnels has gained interest among hydroponic growers in South Africa, although high temperatures during the summer season limit crop yield. Seed suppliers are continuously improving sweet pepper varieties and recommend varieties to overcome the low productivity and low quality of sweet peppers in South Africa. Lack of adaptive cultivars and poor fruit setting of existing varieties during the hot/dry season, when the demand for peppers is high, is a major challenge for farmers in South Africa (Maboko et al., 2012a). For good fruit set and better yield, pollination, germination of pollen grains, pollen tube growth, fertilization, and fruit initiation must take place successfully (Kinet and Peet, 1997). Pepper plants are more sensitive to temperature extremes than tomatoes. Temperatures in the range of 16 to 28 °C for 4 to 6 months meet the heat requirements for most peppers. Temperatures lower than 15 °C result in poor plant growth, whereas temperatures higher

than 32 °C result in flower drop and poor fruit set (Niederwieser, 2001).

PGRs modify plant physiological processes. PGRs are used by growers to promote fruiting and fruit development when temperature inhibits fruit set. PGRs can affect rooting, flowering, fruiting and fruit growth, leaf or fruit abscission, senescence, regulation of some metabolic processes, and plant resistance to temperature or water stress (Gelmese et al., 2010) and are normally active at very low concentrations in plants. Induction of artificial parthenocarpy through application of PGRs enables fertilization-independent fruit development that can reduce yield fluctuation in crops such as tomato and peppers (Heuvelink and Korer, 2001). Gemici et al. (2006) reported increased fruit size and fruit setting in tomato resulting from the application of PGRs such as 4-CPA and β-naphthoxyacetic acid (β-NAA). Tomato fruit setting was promoted by GA₃ at low concentration (Sasaki et al., 2005). Alam and Khan (2002) reported reduced preharvest fruit drop with increased number of fruits per plant and increased yield as a result of the application of NAA or β-NAA spray. Repeated application of 27 mg·L⁻¹ NAA at the beginning of flower initiation significantly increased marketable and total yield of greenhouse-grown peppers and reduced the number of unmarketable fruits (physiological damage, unsuitable color, or small size) (Belakbir et al., 1998). Gibberellin was reported to contribute

in preventing flower and fruit abscission, which is a major determinant of production loss in peppers (Tiwari et al., 2012). Silveira and Taborada (1986) reported increased early pepper yield when gibberellic acid was applied at 10 mg·L⁻¹.

Incidence of flower drop/abortion has been reported on sweet pepper grown under shadenets (Maboko et al., 2012b), whereas increasing temperatures during the summer season exacerbated the incidence of flower drop/abortion. GA₃ is important for tomato production to boost yield and improve fruit quality under unfavorable climatic conditions of high temperature (Gelmese et al., 2010). There is little or no information available regarding the use of PGRs, i.e., NAA, GA₃, and 4-CPA, in sweet pepper production under conditions where production is negatively affected by high temperatures. Temperatures in South Africa are often higher than the optimal temperature, causing a reduction in quality and/or yield of vegetable crops such as tomatoes and peppers (Maboko et al., 2012b, 2013).

In South Africa, the majority of hydroponic farmers are growing peppers in non-temperature-controlled tunnels, which rely on natural ventilation by opening the doors and flaps. This often results in poor plant growth, low yield, and poor fruit quality during the hot summer season (Maboko et al., 2013). PGRs, especially those that promote fruit set and yield, might assist farmers in maximizing production under such conditions. As a result of the beneficial effects of PGRs on plant growth and yield, particularly under conditions of environmental stress, this study was carried out to identify PGRs and/or combinations thereof to promote fruit set and development of summer season sweet peppers grown in plastic tunnels.

Materials and Methods

The research was conducted in a non-temperature-controlled (2012–13) and a temperature-controlled plastic tunnel (2013–14) at the ARC-Roodeplaat VOPI, South Africa (lat. 25°59' S, long. 28°35' E, altitude 1200 m above sea level). The non-temperature-controlled tunnel relied on natural ventilation by means of a flap and a door that could be opened on each side (Fig. 1A), whereas the temperature-controlled plastic tunnel was equipped with a fan and pad (1.1-kW fans, 1300 mm diameter) cooling system (Fig. 1B). The size of the tunnel was 10 × 30 × 4.2 m (width × length × height) and was covered with a 200-μm light diffusive plastic (Evadek Green Tint; Gundle Plastics Pty. Limited, Germiston, South Africa). The floor was covered with 200 μm white plastic. Maximum, minimum, and average monthly air temperatures inside the tunnels during the experimental period were recorded using data loggers [Tinyview; Gemini data-loggers (UK) Ltd.], which were placed at a height of 1.5 m and covered with a Stevensontype screen ACS-5050 (Gemini data-loggers) (Table 1). Sweet pepper seedlings (cv. King Arthur) were established at a population

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of 2.5 plants/m². A nutrient solution reported by Maboko et al. (2012b) was administered to individual plants by means of a dripper line. Seven-week-old seedlings were transplanted into 10-L plastic bags filled with sawdust as a growing medium. The seeds were sown in 200-cavity polystyrene trays. The growing media used was Hygromix® (Hygrotech Pty. Limited, Pretoria, South Africa) and vermiculite was used to cover the seeds after seeding. Seedlings were fertigated with Multifeed® (Plaaskem Pty. Limited, South Africa) at a rate of 1 g·L⁻¹ of water once daily from the two-leaf stage until transplanting (49 d after seeding).

Expt. 1. Commercial tissue culture grade of GA₃ (C₁₉H₂₂O₆) powder (95% purity) and NAA (C₁₂H₁₀O₃) (98% purity) were used (SMM Instrument, South Africa). Applications were made on the whole plant until runoff with a hand sprayer at two levels of GA₃ (10 and 15 mg·L⁻¹), two levels of NAA (15 and 30 mg·L⁻¹), and four combinations of NAA and GA₃ (10 mg·L⁻¹ GA₃ + 15 mg·L⁻¹ NAA, 10 mg·L⁻¹ GA₃ + 30 mg·L⁻¹ NAA,

15 mg·L⁻¹ GA₃ + 15 mg·L⁻¹ NAA, and 15 mg·L⁻¹ GA₃ + 30 mg·L⁻¹ NAA) and a control (untreated plants). The control treatment plants were sprayed with water only. Stock solutions of the PGRs were prepared by dissolving in 1 mL of 97% ethanol. Each stock solution was diluted in 1 L distilled water to prepare the working solution, just before application. Spraying was performed early in the morning to avoid rapid drying of the spray solution as a result of evaporation. The solution was poured into a handheld sprayer and was directly sprayed onto the plants at first flower initiation, and the treatments were repeated 20 d after the first application (60 DAT). The nine treatments were arranged in a randomized complete block design with four replications.

Expt. 2. Similar treatments applied in Expt. 1 were applied in Expt. 2 with an additional two levels of 4-CPA (C₈H₇ClO₃) at 30 and 45 mg·L⁻¹, supplied by Sigma-Aldrich (South Africa). The solution was poured into a handheld sprayer and was directly sprayed onto the plants at flower

initiation followed by three applications at 20-d intervals. Eleven treatments were arranged in a randomized complete block design with four replications.

For both experiments, 4 weeks after transplanting, plants were trained using a “V” trellising system. Each stem was trellised by twisting twine around the main stem and fixing it to a stay wire 2 m above the ground surface to support the plant. Side branches were removed weekly to maintain two stems per plant. Mature green fruits were harvested every second week from eight plants per treatment for data collection. Sweet peppers were graded according to mass: extralarge (XL) greater than 250 g, large (L) = 250 to 200 g, medium (M) = 200 to 150 g, small (S) = 150 to 100 g, and extrasmall (XS) less than 100 g. Extrasmall-sized fruits, number, and mass of fruits exhibiting blossom-end rot, sunscald, and deformed fruits were recorded as unmarketable yield. Four large fruits per treatment per replicate were selected to determine total soluble solids (TSS), pH, and electrical conductivity (EC). Fruits were cut into pieces, chopped with a blender, and the puree filtered through cheesecloth. The TSS was determined using a pocket refractometer PAL-1 (Atago®, Japan), whereas EC and pH were determined by combo meter (HANNA Combo Instrument, South Africa).

Data were subjected to analysis of variance using GenStat®, Version 11.1 (Payne et al., 2008). Means were separated using Fisher’s protected *t* test least significant difference (Snedecor and Cochran, 1980).

Results and Discussions

The application of PGRs (GA₃ and NAA, and the combinations of the two) did not have a significant effect on sweet pepper yield in the non-temperature-controlled tunnel (Table 2) in 2012–13. High temperatures (45 °C) in the non-temperature-controlled tunnel in 2012–13 significantly reduced yields and might have contributed to the lack of effects of PGRs on yield (Table 1). These high temperatures reduce fruit set and fruit production in peppers (Erickson and Markhart, 2002) and also in tomato (Gelmesa et al., 2010; Maboko et al., 2013). In 2013–14, repeated applications (four times) of PGRs

Fig. 1. (A) Non-temperature-controlled tunnel. (B) Temperature-controlled tunnel.

Table 1. Maximum, minimum, and average monthly air temperatures of the tunnels during the experimental period.

Month	Non-temperature-controlled tunnel (°C) in 2012–13			Temperature-controlled tunnel (°C) in 2013–14		
	Maximum	Minimum	Avg	Maximum	Minimum	Avg
October	45.5	16.9	27.9	34.5	16.0	23.6
November	44.2	14.9	28.7	31.4	13.5	23.9
December	46.7	17.4	27.9	28.0	16.3	22.9
January	44.8	18.3	28.8	24.1	18.0	21.5
February	40.8	17.4	24.3	23.7	16.1	20.4
March	37.7	15.4	22.7	24.1	18.1	19.5
April	36.6	14.9	22.0	23.2	18.0	19.1

Table 2. Effect of plant growth regulators on sweet pepper yield in a non-temperature-controlled tunnel (2012–13).^z

Plant growth regulators	Marketable yield (kg/plant)	Total yield (kg/plant)	Number of marketable fruits	Unmarketable yield (kg/plant)	Plant ht (cm)	Plant fresh wt (g/plant)	Plant dry mass (g/plant)
10 GA ₃	0.43	1.38	3.4	0.95	181.4 a	823 a	149.3 a
10 GA ₃ + 15 NAA	0.44	1.52	3.4	1.08	170.3 ab	682 bc	127.6 abcd
10 GA ₃ + 30 NAA	0.46	1.49	4.3	1.03	177.9 a	695 ab	121.2 bcde
15 NAA	0.70	1.72	5.3	1.02	174.5 a	661 bc	113.3 cde
15 GA ₃	0.33	1.26	3.0	0.93	180.1 a	777 ab	139.3 ab
15 GA ₃ + 15 NAA	0.40	1.41	3.4	1.01	168.5 ab	682 bc	129.6 abc
15 GA ₃ + 30 NAA	0.58	1.67	5.0	1.09	177.1 a	646 bcd	119.7 bcde
30 NAA	0.63	1.64	4.9	1.01	154.0 bc	561 cd	102.8 de
Control	0.49	1.43	3.9	0.94	147.1 c	523 d	96.1 de
Least significant difference 0.05	NS	NS	NS	NS	19.69	132.1	25.53

^zValues in a column followed by the same letter are not significantly different (*P* > 0.05) using Fisher’s protected *t* test.

NS = nonsignificant; 10 GA₃ = 10 mg·L⁻¹ of gibberellic acid; 15 GA₃ = 15 mg·L⁻¹ of gibberellic acid; 15 NAA = 15 mg·L⁻¹ of naphthalene acetic acid; 30 NAA = 30 mg·L⁻¹ of naphthalene acetic acid.

on pepper plants showed no beneficial effect on pepper yield (Table 3). However, the temperature-controlled tunnel showed higher yield compared with the non-temperature-controlled tunnel, which could be explained by its reduced temperatures. In 2013–14, marketable and total yield suppression resulted from the application of PGRs. Marketable yield was reduced by foliar spray of 4-CPA followed by the combination of GA₃ and NAA, i.e., 10 mg·L⁻¹ GA₃ and 30 mg·L⁻¹ NAA, 15 mg·L⁻¹ GA₃ and 15 mg·L⁻¹ NAA, and 15 mg·L⁻¹ GA₃ and 30 mg·L⁻¹ NAA. Total yield was also reduced by application of 4-CPA followed by 15 mg·L⁻¹ GA₃ and 15 mg·L⁻¹ NAA (Table 3). Deformed fruits were increased by foliar spray of 4-CPA at 30 mg·L⁻¹. PGRs did not have a significant effect on blossom-end rot and TSS, pH, and EC of tomato juice (Table 4). Application of PGRs showed different response in terms of plant growth and yield. An increase in tomato yield was reported with an application of 4-CPA (Tonder and Combrink, 2003), which was not the case in our sweet pepper trial. Furthermore, previous work by Choudhury et al. (2013), Gelmese et al. (2010), and Tonder and Combrink (2003) found that NAA and GA₃ were used to promote fruit setting and yield in tomatoes; however, it was not effective in improving yield of sweet pepper in our

study. Plant height increased with the application of gibberellic acid. Application of GA₃ showed a positive effect among the different combinations (Table 2). The GA₃-induced increase in plant height was attributed to the role of gibberellins in increasing cell elongation and division (Emongor, 2007). Stimulation of sweet pepper plant height by GA₃ could be ascribed by stimulation of cell division and cellular extensibility (Emongor, 2007; Graham and Ballesteros, 1980). A concentration of GA₃, at 10 mg·L⁻¹, resulted in increased plant height. This is in agreement with Gemici et al. (2000) who indicated that 10 mg·L⁻¹ (10 ppm) GA₃-treated tomato plants showed a 17% increase in stem length. Application of NAA at 15 mg·L⁻¹ concentration increased plant height of sweet pepper significantly, compared with NAA at 30 mg·L⁻¹ (Table 2). This is in agreement with Chhonkar and Ghufra (1968), who reported that plant height decreased in tomato plants treated with an increased concentration of NAA.

Plant fresh and dry mass increased when plants were treated with GA₃ (10 and 15 mg·L⁻¹) (Tables 2 and 3). The increase in plant fresh and dry mass of sweet pepper induced by GA₃ could possibly be explained by the role of GA₃ in the synthesis of proteins, including various enzymes, increased plant

height, and increased photosynthetic capacity (Emongor, 2007). Emongor and Ndambole (2011) reported a GA₃-induced increase in cowpea vegetative growth, nodulation, and yield. In our experiments, sweet pepper plants grown in a non-temperature-controlled tunnel were exposed to temperatures above 40 °C. The high temperatures resulted in a high percentage of unmarketable fruits resulting from fruits being predisposed to blossom-end rot and increased occurrence of deformed fruits. PGRs and their combinations used in this study were not effective in improving sweet pepper yield under non-temperature-controlled tunnel conditions.

The results indicate that foliar application of GA₃ increased plant height and plant fresh and dry mass in hydroponically grown sweet pepper with no significant effect on sweet pepper fruit yield. Foliar application of 4-CPA reduced yield and plant growth significantly. Application rates and their combinations used in this study do not warrant commercial use under similar conditions, although GA₃ and GA₃ in combination with NAA showed increased vegetative growth. Further studies need to be conducted to determine the optimal time of application of PGR and to use a wider range of PGR concentrations to identify the optimal PGR concentration.

Table 3. Effect of plant growth regulators on sweet pepper yield in a temperature-controlled tunnel (2013–14).^a

Treatments	Marketable yield (kg/plant)	Total yield (kg/plant)	Unmarketable yield (kg/plant)	Plant ht (cm)	Plant fresh wt (g/plant)	Plant dry mass (g/plant)
10 GA ₃	1.90 abcd	2.15 ab	0.26	177.5 ab	675.4 a	135.3 a
10 GA ₃ + 15 NAA	1.91 abcd	2.10 ab	0.19	167.3 abc	544.7 bc	105.8 bcd
10 GA ₃ + 30 NAA	1.72 de	2.10 ab	0.38	179.7 a	644.7 ab	127.9 ab
15 NAA	2.04 abc	2.41 a	0.31	161.0 bcd	513.3 c	97.2 d
15 GA ₃	1.90 abcd	2.14 ab	0.29	185.4 a	661.3 a	129.6 a
15 GA ₃ + 15 NAA	1.68 de	1.97 bc	0.30	183.7 a	670.8 a	128.1 a
15 GA ₃ + 30 NAA	1.75 cde	2.15 ab	0.40	180.2 a	633.6 ab	125.3 abc
30 CPA	1.21 f	1.59 d	0.39	144.8 d	493.8 c	85.2 d
30 NAA	2.18 a	2.37 a	0.18	154.4 cd	491.2 c	94.6 d
45 CPA	1.47 ef	1.72 cd	0.25	150.5 cd	536.1 bc	97.1 d
Control	2.12 ab	2.38 a	0.26	157.5 cd	447.6 c	103.1 cd
Least significant difference 0.05	0.30	0.359	NS	18.3	110.10	22.2

^aValues in a column followed by the same letter are not significantly different ($P > 0.05$) using Fisher's protected t test.

NS = nonsignificant; 10 GA₃ = 10 mg·L⁻¹ of gibberellic acid; 15 GA₃ = 15 mg·L⁻¹ of gibberellic acid; 15 NAA = 15 mg·L⁻¹ of naphthalene acetic acid; 30 NAA = 30 mg·L⁻¹ of naphthalene acetic acid; 30 CPA = 30 mg·L⁻¹ of 4-chlorophenoxyacetic acid; 45 CPA = 45 mg·L⁻¹ of 4-chlorophenoxyacetic acid.

Table 4. Effect of plant growth regulators on total soluble solids (TSS), pH, and EC of tomato juice and physiological disorders in a temperature-controlled tunnel (2013–14).^a

Treatments	TSS	pH	EC (mS·cm ⁻¹)	Blossom-end rot		Sunscald		Deformed fruits	
				Number	Mass (g)	Number	Mass (g)	Number	Mass (g)
10 GA ₃	3.8	4.8	3.3	0.21	21.5	0.88	115	0.33 c	45.4 c
10 GA ₃ + 15 NAA	3.8	4.8	3.4	0.04	5.0	0.38	45	0.50 c	55.0 c
10 GA ₃ + 30 NAA	4.0	4.8	3.3	0.04	4.7	1.04	132	1.25 b	155.3 ab
15 NAA	3.8	4.7	3.1	0.25	30.8	1.29	162	0.54 c	68.3 c
15 GA ₃	3.8	4.8	3.2	0.08	11.8	1.17	139	0.50 c	61.7 c
15 GA ₃ + 15 NAA	3.8	4.8	3.1	0.08	11.4	1.08	123	0.75 bc	83.3 bc
15 GA ₃ + 30 NAA	3.7	4.8	3.6	0.13	14.5	1.79	204	0.79 bc	82.8 bc
30 CPA	3.8	4.8	1.9	0.17	25.9	1.00	153	2.21 a	181.5 a
30 NAA	3.6	4.8	3.6	0.08	18.2	0.25	33	0.63 bc	71.3 c
45 CPA	3.6	4.8	2.0	0.13	26.9	0.92	89	0.63 bc	63.0 c
Control	3.9	4.8	2.5	0.13	14.5	0.83	114	0.30 c	33.4 c
Least significant difference 0.05	NS	NS	NS	NS	NS	NS	NS	0.67	75.8

^aValues in a column followed by the same letter are not significantly different ($P > 0.05$) using Fisher's protected t test.

NS = nonsignificant; EC = electrical conductivity; 10 GA₃ = 10 mg·L⁻¹ of gibberellic acid; 15 GA₃ = 15 mg·L⁻¹ of gibberellic acid; 15 NAA = 15 mg·L⁻¹ of naphthalene acetic acid; 30 NAA = 30 mg·L⁻¹ of naphthalene acetic acid; 30 CPA = 30 mg·L⁻¹ of 4-chlorophenoxyacetic acid; 45 CPA = 45 mg·L⁻¹ of 4-chlorophenoxyacetic acid.

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