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Effect of Benzyladenine Plus Gibberellins and Gibberellic Acid on Yield and Yield Components of Cucumber (*Cucumis sativus* L. cv. 'tempo')

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Abstract: Two greenhouse trials were carried out to evaluate the effect of benzyladenine plus gibberellins (GA_{4+7}) and gibberellic acid (GA_3) on yield and yield components of cucumber. Gibberellic acid significantly increased leaf number per plant compared to control plants. Benzyladenine plus GA_{4+7} at 25, 50, or 75 mg L^{-1} significantly increased cucumber leaf size, flower number, fruit number, fruit yield and mean fruit weight compared to fruit from control cucumber plants. Gibberellic acid and benzyladenine (BA) plus GA_{4+7} at 25, 50, or 75 mg L^{-1} significantly increased fresh fruit yield of cucumber plants. The increase in yield was linear with increasing GA_3 concentration and quadratic with increasing BA plus GA_{4+7} concentration. The results of this study suggest that GA_3 and BA plus GA_{4+7} have the potential to be used to in the culture of cucumber under greenhouse conditions.

Key words: Cucumber, fruit size, fruit yield, benzyladenine plus GA_{4+7}, GA_3

INTRODUCTION

Plant Growth Regulators (PGRs) are natural and synthetic compounds applied to plants or plant organs to regulate growth and development. Exogenous application of the PGRs may in addition to a response by a plant tissue, be accompanied by a change in hormonal concentration, frequency and availability of a receptor protein, which amplify the hormonal signal. This could bring about changes in plant developmental processes.

Plant growth regulators play an important role in high value horticultural crops to increase yield, enhance crop quality and management (Davies, 1995; Latimer, 1992). In plants such as citrus, yield increases are obtained through improved fruit set and/or fruit size and flower number per plant when PGRs are applied (El-Otmani *et al.*, 2000). Exogenous applications of gibberellins to Arabidopsis induced early flowering and affected flower morphology (Richards *et al.*, 2001). In similar studies GA_{4+7} increased flowering in a genotype of Aquilegia species (Gianfagna and Merritt, 1998) and increased fruit set and fresh weight in cucumber (Yang *et al.*, 1992). Thidiazuron, which has cytokinin-like activity, has been reported to induce precocious *in vitro* flower initiation in *Cymbidium ensifolium* (Chang and Chang, 2003).

A combination of BA+ GA_{4+7} increased fruit size and quality of grapes (Carlson and Crovetti, 1988). Benzyladenine (BA) has been reported to increase fruit size of McIntosh (Greene and Autio, 1989) and Empire (Emonogor and Murr, 1994) apples, respectively, without inducing thinning, suggesting BA-induced increase in cell numbers. Benzyladenine increased the rate of cell layer formation and cell division in the cortex of Empire apple fruits, but no effect on cell size (Emomogor, 1995; Wismer, 1994). It was concluded that BA increased fruit size by increasing number of cell layers and not cell expansion (Emomogor, 1995; Wismer, 1994). Natural cytokinins in fruit play an important role in determining the eventual cell number of the fruit (Williams and Letham, 1969). Fruit size increase due to BA+GA_{4+7} application to apples, cucumber and grapes may be due to increased cell division and elongation and cell wall extensibility (Carlson and Crovetti, 1988; Emomogor, 1995; Emongor and Murr, 2001). Exogenous application of gibberellins has been reported to promote cell enlargement by increasing plant cell wall extensibility (Brock and Cleland, 1990; Keyes *et al.*, 1990). Plant organs, such as fruits, with increased sink strength may have increased growth due to plant hormones in fruit seed. Cytokinins have the ability to promote carbohydrate metabolism and create new source-sink relationships (Monthes and Engelbrecht, 1961; Dyer *et al.*, 1990), thus leading to increased sink strength (fruit), fruit size and fruit dry matter at harvest (Emongor and Murr, 2001; Dyer *et al.*, 1990).

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Yield can also be improved when the mother plants' productivity is enhanced. This can be achieved by increasing leaf light interception, CO_2 fixation, mineral uptake and reduction in competition for photoassimilates and nutrients between the plant organs. Cytokinins and gibberellins have been reported to stimulate the formation of well-developed chloroplasts in *Helleborus niger* (Salopeck-Sondi *et al*., 2002); increase vegetative growth and delay senescence in sugar cane, spinach and apples (Carlson and Crovetti, 1988; Emongor and Murr, 2001). Reduction in flower senescence has been reported when Asiflorum hybrid lilies were sprayed with Promalin ($BA+GA_{4+7}$ a ratio of 1:1) (Funnel and Heins, 1998). Promalin has been reported to increase vegetative and root growth and yield of kale (Emongor *et al*., 2004). An increase in light interception can also be achieved when bigger leaves are produced and this can enhance leaf level photosynthesis. It has been reported that transgenic tobacco plants with enhanced cytokinin content produced more leaf cells and bigger leaves than the controls (Werner *et al*., 2001). Treatment of wheat with GA_3 improved nitrogen metabolism by favouring nitrogen translocation into tillers at the later stages of growth (Guoping, 1997).

Delayed senescence, increased vegetative growth, well developed chloroplast could enhance photosynthetic efficiency and CO_2 assimilation at leaf and plant level, resulting in improved yields. Plant growth regulators can be used to modify plant growth and development in such a manner to increase crop yield (El-Otmani *et al*., 2000; Emongor, 1997). The objectives of this study were to evaluate the effects of benzyladenine plus gibberellins (GA_{4+7}) and gibberellic acid (GA_3) on cucumber yield and yield components under greenhouse conditions.

MATERIALS AND METHODS

Location and site: Greenhouse house experiments were conducted during the periods of August 2003 to December 2003 and January 2004 and May 2004, at the Botswana College of Agriculture, Farm at Sebele (24°33'S, 25°54'E, 994 m above sea level). The climate in Sebele is semi-arid with an average annual rainfall (30 year mean) of 538 mm (Bekker and Wilt, 1991). Most rain falls in summer, which generally starts in late October and continues to March/April. Prolonged dry spells during rainy seasons are common and rainfall tends to be localized (Persaud *et al*., 1992). The soils are shallow, ferruginous tropical soils, mainly consisting of medium to coarse grain sands and sandy loams with a low water holding capacity and subject to crusting after heavy rains. The soils are deficient in phosphorus, have low levels of mineral nitrogen and low organic matter (Persaud *et al*., 1992).

Experimental design: In trial 1, the treatments were Accel [a liquid concentrate containing 20 g a.i L^{-1} (w/w) 6-benzyladenine (BA) and 2 g a.i L^{-1} gibberellins (GA_{4+7})-Abbot Laboratories, North Chicago, USA] at 0, 25, 50, or 75 mg L^{-1} or Progibb [a liquid concentrate containing 4% (w/w) gibberellic acid (GA_3)-Abbot Laboratories, North Chicago, USA] at 0, 25, 50, or 75 mg L^{-1} GA_3. In trial 2, only Accel was used at 0, 25, 50, or 75 mg L^{-1}. All the two trials used whole cucumber plants, the cultivar tempo. Whole plants were sprayed with either Accel, Progibb or distilled water to run-off using a pressurized knapsack sprayer. Cucumber plants were sprayed with either Accel, Progibb or distilled water 6 weeks after seedling emergence. The experimental design was a completely randomized design with 7 replicates.

Crop husbandry: Polyethene bags (eight litre capacity) were filled with 10 kg of freely draining river sand and highly leached with irrigation water before planting. The bags were arranged along a 20 m drip irrigation line spaced at 1.2 m between and 0.75 m within rows. Each line represented a replication. Two seeds of cucumber per bag were directly planted on 15th August 2003 and 18th January 2004, in trials 1 and 2, respectively. After emergence, the seedlings were thinned to one per bag. The plants were irrigated with two hydroponic solutions containing 110 g L^{-1} hydrogrow fertilizer [85 g N kg^{-1}, 45 g P kg^{-1}, 240 g K kg^{-1}, 30 g Mg kg^{-1}, 60 g S kg^{-1}, 1.63 g Fe kg^{-1}, 0.4 g Mn kg^{-1}, 0.5 g B kg^{-1}, 0.2 g Zn kg^{-1}, 0.03 g Cu kg^{-1} and 0.05 g Mo kg^{-1}] and 10 g L^{-1} of $CaNO_3$ (26% N) fertilizer solution. The fertilizer solutions were injected automatically into the drip line at the rate of 0.5 L/bag every two days. This was alternated with irrigation water without fertilizer. The crop was kept weed free by hand cultivation (using a forked trowel) throughout the growing season. When the growing points reached 60 cm, the tips were pinched to encourage the production of laterals where most of the fruit were produced. The cucumber plants were trained vertically on wire trellises until the plants reached a height of about 2-2.5 m.

Dependent variables determined: The dependent variables that were determined included: plant height, number of leaves, number of tendrils, number of primary branches, number of flowers and the total yield per plant.

Fruit was harvested every week and only fruit that was ≥ 35.0±2.0 cm long were harvested. Ten fruit per replicate were weighed using AFW-120K electronic balance (Adam equipment Co, UK). The cucumber fruit length was determined by measuring the length of 10 fruit per replicate per harvest using a one-metre ruler. All the data obtained from these harvests were used for the final analysis. Two uniformly sized fruits (25±1 cm long) on the same position of the plants in each treatment were tagged. All the other fruits and flowers on the plants were removed. By use of varier calipers, fruit diameter (center of the fruit) of those fruits were measured daily for ten days. Some fruits were left to grow until physiological maturity (until signs of ripening were visible). These fruits were harvested, weighed had their length and diameter determined.

Statistical analysis: Data collected was subjected to analysis of variance using the general linear models (Proc GLM) procedure of the Statistical Analysis System (SAS, Carey, NC) program package. The treatment means were separated using the Least Significant Difference (LSD) at p = 0.05. Appropriate linear regression model was used to determine the response surface of cucumber plants to increasing concentration of Accel. Proc univariate procedure was carried out on residuals to support the assumptions of normality made by the researchers.

RESULTS

In the first trial, Progibb had no significant effect on plant height, leaf number, primary branch number and flower number per plant (Table 1). However, Progibb tended to increase flower number per plant but non-significantly (Table 1). In trial 1, Progibb significantly increased leaf number per plant compared to control plants (Table 1). However, there were no significant differences among the Progibb concentrations in their ability to increase leaf number (Table 1). Accel at 25, 50 or 75 mg L^{-1} had no effect on plant height, leaf number, tendril number, primary branch number and flower number per plant in trial 1 (Table 1). Progibb and Accel at 25, 50, or 75 mg L^{-1} significantly increased fresh fruit yield per

Table 1: The Effect of Progibb and Accel on vegetative growth, flower number and fmit yield of cucumber, trial 1

Treatment	Leaf plant height (cm)	Tendril No/plant	Primary branch No./plant	flower No/plant	No/plant	Yield/plant (kg)
Control	157.75^{a}	63.50^{b}	37.00^{a}	3.80^{a}	41.50^{a}	13.94^{d}
Progibb (mg L^{-1})						
25	157.75^{a}	72.25^{ab}	37.25^{a}	4.20^{a}	51.00^{a}	17.22^{c}
50	159.40^{a}	72.00^{ab}	39.50^{a}	4.50^{a}	51.00^{a}	17.57^{c}
75	158.65^{a}	72.25^{ab}	40.75^{a}	4.50^{a}	54.75^{a}	21.90^{a}
Accel (mg L^{-1})						
25	157.65^{a}	76.25^{a}	40.75^{a}	4.20^{a}	55.75^{a}	18.91^{bc}
50	158.15^{a}	77.50^{a}	40.75^{a}	4.21^{a}	55.72^{a}	20.76^{ab}
75	162.55^{a}	75.25^{a}	41.00^{a}	4.25^{a}	55.74^{a}	20.77^{a}
LSD (0.05)	7.75	10.85	5.99	1.09	14.89	2.49
Significance	NS	NS	NS	NS	NS	***

***, significant at p = 0.0001, NS, non-significant at p = 0.05. Means within columns followed by the same letter are not significantly different at p = 0.05, LSD (0.05)

Table 2: The effect of Accel on vegetative growth of cucumber, trial 2

Accel (mg L^{-1})	Leaf No.	Leaf diameter (cm)	Leaf length (cm)	Tendril No.	Branch No.	Plant height (cm)
0	30.50^{a}	16.94^{b}	17.76^{b}	12.50^{a}	5.00^{a}	122.75^{a}
25	31.50^{a}	18.24^{a}	21.27^{a}	13.25^{a}	5.25^{a}	128.00^{a}
50	34.00^{a}	19.21^{a}	21.95^{a}	12.50^{a}	4.75^{a}	131.25^{a}
75	33.75^{a}	20.12^{a}	22.49^{a}	13.00^{a}	5.00^{a}	130.00^{a}
LSD (0.05)	27.86	2.17	2.94	3.74	2.16	24.79
Significance	NS	**	**	NS	NS	NS

**, significant at p = 0.01, NS, non-significant at p = 0.05. Means within columns followed by the same letter are not significantly different at p = 0.05, LSD (0.05)

Table 3: The Effect of Accel on yield and yield components of cucumber, trial 2

Accel (mg L^{-1})	Flower No. plant	Yield/plant (kg)	Fruit No. plant	Fruit weight (kg)
0	17.00^{b}	15.63^{b}	6.65^{b}	0.43^{b}
25	19.25^{a}	23.33^{a}	11.25^{a}	0.48^{ab}
50	19.50^{a}	23.45^{a}	11.50^{a}	0.49^{a}
75	19.75^{a}	24.17^{a}	11.97^{a}	0.50^{a}
LSD (0.05)	2.01	5.65	1.40	0.12
Significance	**	**	*	**

*, **, significant at p = 0.05, 0.01 respectively, NS, non-significant at p = 0.05. Means within columns followed by the same letter are not significantly different at p = 0.05, LSD (0.05)

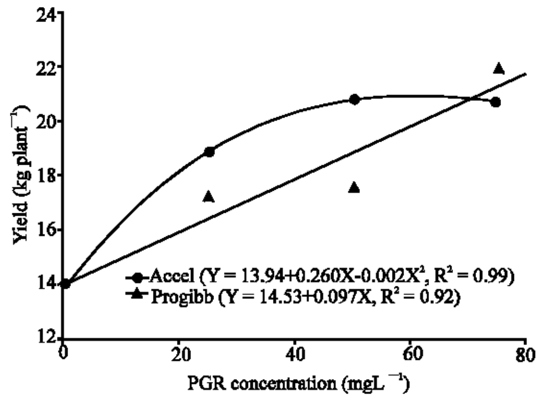

Fig. 1: The relationship between Accel or Progibb concentration on cucumber yield

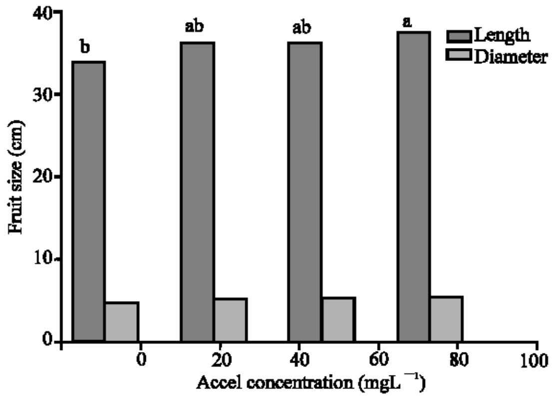

Fig. 2: Effect of Accel concentration on fruit size

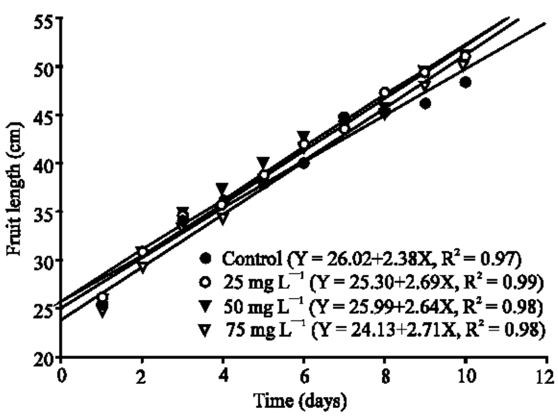

Fig. 3: The relationship between time of growth and fruit length as influenced by Accel concentration

plant (Table 1). The increase in yield was linear ($Y = 14.53 + 0.097X$, $R^2 = 92$) with increasing Progibb concentration and quadratic ($Y = 13.94 + 0.260X - 0.002X^2$, $R^2 = 0.99$) with increasing Accel concentration (Fig. 1). There was also a significant difference between Progibb and Accel at low concentrations. The average treatment increase in yield due to treatment was 4.96 and 6.20 kg for Progibb and Accel, respectively.

In the second trial, the results showed that Accel did not significantly increase plant height, leaf number, tendril number and number of primary branches per plant (Table 2). Accel at 25, 50, or 75 mg L^{-1} significantly increased leaf diameter and length of cucumber plants compared to control plants in trial 2 (Table 2). However, there were no Accel concentration differences with respect to leaf diameter and length response (Table 2). In trial 2, Accel at 25, 50, or 75 mg L^{-1} increased cucumber flower number, fruit number, fruit yield per plant and mean fruit weight compared to fruit from control cucumber plants (Table 3 and Fig. 3). However, there were no differences among Accel concentrations with respect to increasing flower number, fruit number, fruit weight and fruit yield per plant (Table 3).

Accel increased yield per plant, fruit number and size (length and diameter) (Fig. 2). Fruit size increased with increase in Accel concentration. The linear phase of fruit growth as estimated by regression analysis, suggests that, the treated fruits grow faster than controls, reaching harvestable maturity earlier that the control fruit (Fig. 3). When the fruit are allowed to grow beyond the harvestable maturity to reach their maximum potential size, it was observed that Accel at 50 or 75 mg L^{-1} significantly increased maximum fruit length and diameter (Table 4). However, 25 mg L^{-1} Accel had a non-significant increase in maximum fruit length and diameter (Table 4). Accel at 25, 50, or 75 mg L^{-1} significantly increased the maximum fruit weight of cucumber plants (Table 4).

Table 4: The effect of Accel on fruit growth and morphology, trial 2

Accel (mg L^{-1})	Maximum fruit length	Maximum (cm) fruit diameter	Maximum (cm) fruit weight (kg)
Control	47.25^{b}	6.85^{c}	1.65^{b}
25	47.75^{b}	6.92^{bc}	2.07^{a}
50	50.25^{a}	7.24^{ab}	2.09^{a}
75	50.59^{a}	7.32^{a}	2.20^{a}
LSD (0.05)	2.14	0.36	0.11
Significance	**	**	**

**, significant at p = 0.01 respectively, NA, not applicable. Means within columns followed by the same letter are not significantly different at p = 0.05, LSD(0.05)

DISCUSSIONS

Progibb is a liquid concentrate containing gibberellic acid (GA_3). While Accel is a liquid concentrate containing benzyladenine (cytokinin) and GA_{4+7} at a ratio of 10:1, respectively. Plant hormones are known to influence fruit growth and development (Emongor, 1995). Natural cytokinins play an important role in determining the fruit cell number (Letham, 1969). Fruit growth is characterized by cell division followed by cell elongation, which are all influenced by cytokinins, gibberellins and auxins (Emongor, 1995,2002; Emongor and Murr, 2001). In trial 1, Progibb had no effect on vegetative growth of cucumber plants. While Accel at 25, 50, or 75 mg L^{-1} significantly increased leaf size (diameter and length) of cucumber plants. The increase in leaf size can be attributed to both cytokinins and gibberellins in their role in cell division and elongation, respectively. Cytokinins and gibberellins are known to promote cell division and elongation, respectively (Wismer, 1994; Salisbury and Ross, 1996).

Both Accel and Progibb increased fruit yield of cucumber plants. The increase in fruit yield can be explained by the effect of benzyladenine and gibberellic acid in increasing cucumber fruit size probably by increasing cell division and elongation. Benzyladenine at 100 or 200 mg L^{-1} increased Empire apple fruit weight, diameter and length (Emongor and Murr, 2001). In trial 2, the increase in fruit yield was attributed to the Accel-induced increase in flower number and fruit number per plant (fruit set), plus increased mean fruit weight. The increase in fruit weight was attributed to the effect of benzyladenine and gibberellins (GA_{4+7}) and GA_3 acting synergistically, increasing fruit length and diameter. Spraying GA_3 to cucumber flowers increased fruit set (Yang *et al.*, 1992; Yukiyoshi and Shohei, 1997). Localized applications of BA or GA_{4+7} to tomatoes is known to increase sink strength, enabling them to attract photoassimilates and nutrients from the foliage and to develop fully formed flowers (Luckwill, 1981). In conclusion, BA+GA_{4+7} and GA_3 have the potential to be used to modify the growth and development of cucumber plants, with the objective of increasing fruit size and yield.

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