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Gibberellic Acid (GA_3) Influence on Vegetative Growth, Nodulation and Yield of Cowpea (*Vigna unguiculata* (L.) Walp.

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Abstract: Two field experiments were carried out to evaluate the effects of GA_3 on the growth and development of cowpea cultivars Blackeye and Tswana. Exogenous application of GA_3, 7 days after emergence at 30, 60 or 90 mg L^{-1} significantly increased cowpea plant height, first node height, leaf area and leaf number/plant, nodulation, plant dry matter accumulation, pod length, pod number/plant, seed number/pod, 100 seed weight, harvest index and seed yield ha^{-1}. Gibberellic acid had no significant effect on cowpea plant senescence. The results of this study suggests that exogenous application of GA_3 can be used to modify growth and development of some cowpea varieties.

Key words: Cowpea, gibberellic acid, vegetative growth, nodulation, yield and yield components

INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.) is cultivated under diverse soil and climatic conditions in Africa. Traditionally cowpea is intercropped with crops such as millet, sorghum, maize, cotton, yam and cassava. However, cowpea is also planted as a pure stand in some countries such as Botswana, Kenya and Republic of South Africa. Cowpea is adapted to warm weather and requires less rainfall than most crops; therefore, it is cultivated in the semi-arid and arid regions of lowland tropics and subtropics, where soils are poor and rainfall is limited (Mortimore *et al*., 1997).

Cowpea is a very important legume crop in Eastern, Southern, Central and Western Africa. It is utilized as grain, vegetable (leaves and green immature pods) and fodder for livestock. It is a major cheap source of protein in human diets with the grains containing about 23-25% protein (Bressani, 1985). In Botswana, more than 30,000 ha of land is planted annually with cowpea, yielding over 600 tons of grain (Mo, 1996). The leaves are harvested and used either fresh or preserved by blanching and kneading to a pulp, followed by squeezing to form small balls (size of tennis ball), which are then dried in the sun (deMooy, 1987). The end product is known as morogo wa dinawa (setswana), which is utilized during winter when many leafy vegetables are scarce. Cowpea is also an important fodder crop especially during the drought years.

The average grain yield in Botswana is less than 100 kg ha^{-1} (Mo, 2001). In Botswana, the constraints to cowpea are drought (rainfall failure), pest attack, diseases, parasitic weeds and soils of low intrinsic fertility, lack of good quality seed and distribution system and inappropriate technologies and management. The poor growth of cowpea observed in the dry season has been reported to be due to lack of elongation of internodes (Ishiyaku and Singh, 2001; Mukhtar and Singh, 2004). For large economic yields, leaf area indices of 1 and 2 are required for as long as possible after flowering but need to be coupled with efficient partitioning of dry matter into fruits (Summerfield *et al*., 1985). Leaf Area Duration (LAD), which is the integral of Leaf Area Index (LAI) from emergence to physiological maturity significantly determines seed yield of cowpea (Laing *et al*., 1983). Any technology that can delay leaf senescence, therefore, increasing LAD would increase seed yield of cowpea. Pate and Minchin (1980) reported that cowpea yields seem to be limited by poor ability of genotypes to assimilate carbon and nitrogen during the reproductive period and to partition large amounts of their daily gains of these two elements into fruits. The challenge is to find ways of improving cowpea productivity. Variety improvement, modified cropping systems and use of Plant Growth Regulators (PGRs) may improve cowpea yields.

Plant growth regulators play an important role in high value horticultural crops to increase yield, enhance crop quality and management (Emongor, 1997). Exogenous applications of gibberellins to Arabidopsis induced early flowering and affected flower morphology (Richards *et al*., 2001). Gianfagna and Merrit (1998) reported that GA_{4+7} increased flowering in a genotype of *Aquilegia* species. Yang *et al*. (1992) reported that GA_{4+7} increased fruit set and fresh weight in cucumber. Emongor (2002) reported that gibberellins (GA_{4+7} and GA_3) and a combination of cytokinins and gibberellins (benzyladine (BA) plus GA_{4+7}) increased vegetative growth of common beans (*Phaseolus vulgaris*) but had no significant effect on seed yield. Gibberellins (GA_{4+7}) significantly reduced 100 seed weight and seed yield of common beans. However, a combination of 25 mg L^{-1} of BA and 2.5 mg L^{-1} GA_{4+7} significantly increased the number of pods per plant, seeds per pod, 100 seed weight and seed yield ha^{-1}. Williams and de Mallorca (1984) reported that foliar application of GA_3 at 2.89×10^{-6} M to soybean plants delayed the formation of nodule initials and reduced the numbers mass $nodule^{-1}$ and specific activity of nodules by 43, 31 and 47%, respectively, without affecting growth. Similar effects on nodulation were produced by foliar application of GA_4 (3.01×10^{-5} M) or GA_7 (3.03×10^{-5} M), or by the addition of GA_3 (2.89×10^{-6} M) to the rooting medium.

Foliar application of cowpea plants with 15 mg L^{-1} naphthaleneacetic acid (NAA) at 15, 30 and 45 days after sowing increased vegetative growth, fruit set and grain yield (Resmi and Gopalakrishnan, 2004). Resmi and Gopalakrishnan (2004) further reported that foliar application of 2-chloroethyl trimethyl ammonium chloride (CCC) at 300, 400 and 500 mg L^{-1} to cowpea plants increased vegetative growth, fruit set and yield and grain yield. However, 2,4-dichlorophenoxyacetic acid (2,4-D) at 2,4 or 6 mg L^{-1} and para-chlorophenoxyacetic acid (PCPA) at 25, 50 or 75 mg L^{-1} depressed vegetative growth and seed yield ha^{-1} of cowpea. Mukhtar and Singh (2006) reported that GA_3 stimulated an increase in growth, flowering, pod maturity and grain yield of cowpea. Okelana and Adedipe (1982) reported that foliar application of GA_3, BA and 2-chloroethylphosphonic acid (CEPA) to cowpea cultivars (Adzuki, Ife Brown and New Era) had no significant effects on vegetative growth, however, CEPA suppressed stem elongation and root dry weight and caused defoliation. As efforts are being made towards maximizing the yield of cowpea in the dry season with irrigation, efforts should be made on improving not only reproductive development but vegetative growth as well. Foliar application of GA_3 appears promising (Mukhtar and Singh, 2006) but the authors concluded that more research be done to determine the optimum concentration of GA_3 as well as explore the possibility of using other hormones or PGRs and/or combination of PGRs. The objective of this study was to evaluate the effects of GA_3 on the growth and development of cowpea. The cowpea cultivars used in the study, Blackeye and Tswana are what the farmers grow commercially or traditionally in Botswana.

MATERIALS AND METHODS

Experimental site: Two field experiments were conducted at Botswana College of Agriculture (BCA) Gaborone Botswana from 18th February 2002 to 21st January 2004. Botswana College of Agriculture is located at Sebele Content farm (latitude 24° 34' S and latitude 25° 57' at altitude of 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 de 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. 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). The cowpea cultivars Blackeye and Tswana were used in the study because of their popularity and availability in Botswana. Before the start of the experiment soil was randomly sampled at 0-30 cm depth within the study field. The soil was analyzed in the laboratory for pH, cation exchange capacity, calcium, sodium, potassium, magnesium and organic carbon. The soil used for the study had the following properties: sodium, potassium, magnesium and calcium contents have 0.09, 0.39, 0.16 and 9.53 meq/100 g, respectively. The organic carbon and CEC contents were 1.04 and 7.53 meq/100 g, respectively and pH of 6.5.

Experimental design: The experiments were laid out in a completely randomized design with three replicates. Each replication was made up of 3 plots of 3×3 m. The cowpea plants were sprayed to run-off with Gibberellic acid (GA_3) at 0, 30, 60 and 90 mg L^{-1} (GA_3, a liquid concentrate containing 4% g ai (w/V), Abbott Laboratories, North Chicago, USA) using a pressurized hand knapsack sprayer. The control plants (0 mg L^{-1} GA_3) were sprayed with distilled water.

Crop husbandry: All trials in the experiment used whole cowpea plants, with GA_3 sprayed to run-off using a pressurized hand knapsack sprayer. The spacing was 30 cm between rows and 15 cm between plants and one seed was planted per hole. The 1st and 2nd trials were planted on 19th January 2007 and 31st January 2007, respectively. In the first trial, the cowpea cultivar Blackeye was used in the study. While in the second trial, the cowpea cultivar Tswana was used. No fertilizer was applied. Gibberellic acid was sprayed seven days after emergence. Weeds were controlled by hand cultivation (hoeing between and within rows) throughout the growing period.

Dependent variables determined: The dependent variables that were determined included: plant dry mass, shoot and root dry mass, shoot-to-root ratio, plant height, number of leaves/plant, leaf area, plants with 50% or more yellowing 66 days after emergence, height of first node, number of nodules/plant, number of pods per plant, pod length, number of seeds per pod, 100 seed weight, harvest index and seed yield. Plant height and 1st node height were determined by measuring the plant and node heights of 10 randomly selected plants per replicate using a 1 m steel ruler. The leaf number was determined by counting the number of leaves on 10 randomly chosen plants per replication. Leaf area was determined from 3 plants per replicate at the onset of flowering. The leaf area was determined using a leaf area meter (C1-202 CID, Scanman Logitech, Inc., USA). The fresh and dry weights of cowpea plants were determined by destructive harvesting of five plants per replication. The plants were watered 24 h earlier before they were carefully dug to ensure at least 99% of the roots were included. The shoots and roots of five plants per replication were separated and put in already weighed brown paper bags. The fresh shoot and root samples were weighed using Mettler PM 400 digital balance. The fresh mass was determined by subtracting the weight of paper bag from the weight of paper bag plus fresh sample. The plant samples (shoots and roots) were oven dried at 66°C to constant weight. The plant water content was determined by subtracting dry weights from their corresponding fresh weights. The total plant dry mass and water content was determined by adding the shoot and root dry mass and water contents, respectively. The shoot-to-root ratio was determined by dividing the corresponding shoot-dry mass with root-dry mass.

Pod length, number and number of seeds per pod were determined from 10-tagged plants per replication. Pod length was determined by measuring the length of 50 pods per replication using a 30 cm ruler. Pod number was determined by counting all the pods of the 10-tagged plants per replication. The number of seeds per pod was determined by counting the number of seeds per pod using 50 pods were replication. Hundred seed weight was determined by weighing 100 representative seeds per treatment per replication. The seed yield ha^{-1} was estimated from the seed yield of an area of 2 m^2. The harvest index was determined by harvesting (uprooting) 10 whole plants at physiological maturity (roots, shoot, pods) per replication. The whole plants were oven dried at 66°C for 72 h. The whole dried plants were weighed to determine the whole plant mass. Then the pods were removed from the dried plants and threshed to separate the seeds. The seed mass of 10 plants was determined. The Harvest Index (HI) was estimated by diving the seed mass with the corresponding whole plant dry mass of 10 plants (seed mass/whole dry plant mass).

All plants in 9 m^2 plots were observed for chlorophyll degradation in order to determine the number of plants with $\geq$50% leaf yellowing as a sign of senescence. The change in leaf colour from green to yellow was observed.

Data analysis: Analysis of variance was performed on the data collected using the general linear models (Proc GLM) procedure of Statistical Analysis System (SAS) program package. Where a significant F-test was observed, multiple comparisons among treatments was carried out using the Least Significant Difference (LSD) at $p \leq 0.05$. Linear, quadratic and cubic orthogonal polynomials were tested using appropriate regression models to examine the nature of the response of cowpea plants to increasing GA_3 concentration (Snedecor and Cochran, 1989). Proc univariate procedure was carried out on residuals to support the assumptions of normality made by the researcher.

RESULTS

Vegetative growth: Application of GA_3 to cowpea plants at 7 DAE significantly ($p \leq 0.001$) increased vegetative growth compared to control plants (Fig. 1-4). Cowpea plant height and first node height were significantly ($p \leq 0.001$) increased by GA_3 (Fig. 1a, b). The response to increasing GA_3 concentration was linear and quadratic for plant height and first node height, respectively (Fig. 1a, b). The effect of GA_3 on increasing plant height was evident fours days after application (11DAE) in Tswana cowpea (Table 1). The cultivar Tswana significantly responded to GA_3 application compared to Blackeye with respect to increase in plant height (Fig. 1). Cowpea plants treated with GA_3 had significantly ($p \leq 0.0001$) higher leaf number and leaf area per plant compared to control plants. The increase in leaf number and leaf area per plant was linear with increasing GA_3 concentration (Fig. 2, 3). At 20 mg L^{-1} GA_3, the response of both cowpea cultivars was relatively the same with respect to leaf number/plant, but at higher GA_3 concentration Blackeye significantly increased leaf number/plant than Tswana (Fig. 2).

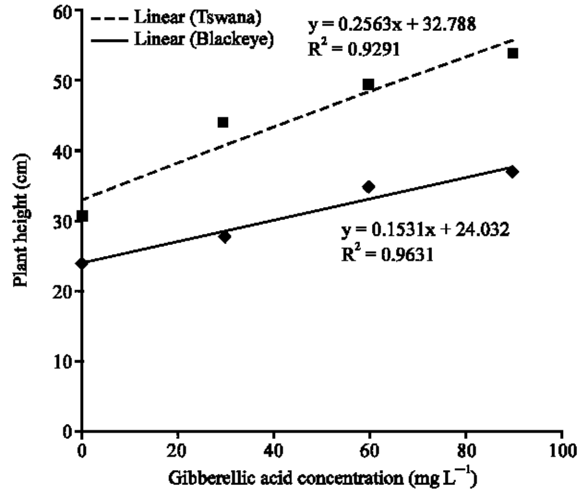

Fig. 1a: Effect of gibberellic acid on cowpea plant height

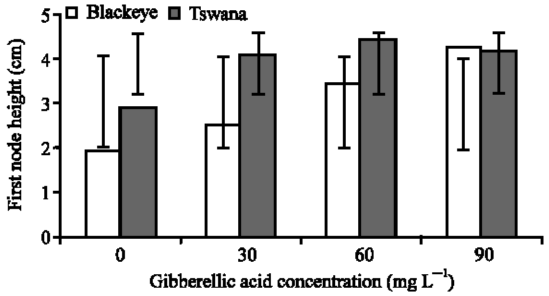

Fig. 1b: Effect of gibberellic acid on first node height of cowpeas

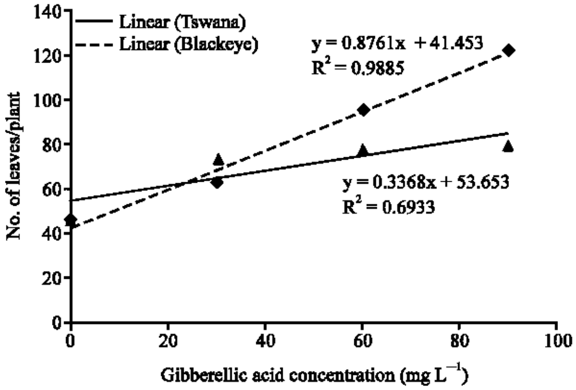

Fig. 2: Effect of gibberellic acid on number of cowpeas

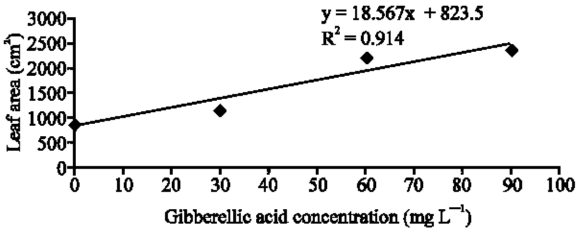

Fig. 3: Effect of gibberellic acid on leaf area of Blackeye cowpea

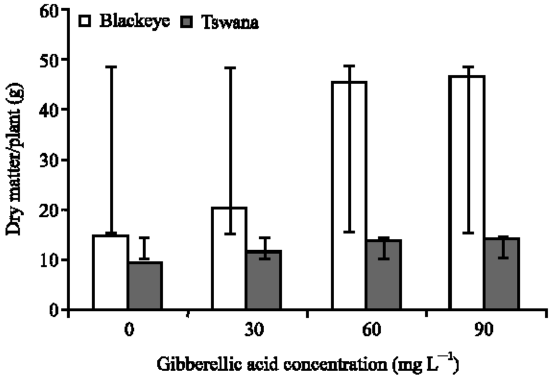

Fig. 4: Effect of gibberellic acid on plant dry matter content of cowpea

Dry matter partitioning and nodulation: Cowpea plants applied with GA_3 had significantly higher dry matter contents in whole plant, shoot and root than control plants. The cultivar Blackeye had significantly higher dry matter than Tswana (Fig. 4, Table 1). The response of Blackeye cowpea to increasing GA_3 concentration was quadratic with respect to dry matter accumulation (Fig. 4). In the cultivar Tswana there were no GA_3 concentration differences in respect to shoot and root dry matter accumulation. However, GA_3 had relatively more dry matter accumulation in the shoots than roots. Gibberellic acid had no significant effect on Tswana cowpea tap root length (Table 1).

Application of GA_3 at 30,60 or 90 mg L^{-1} on Blackeye cowpea plants significantly ($p \leq 0.01$) increased the number of nodules/plant compared to control plants. The response of Blackeye cowpea plants to increasing GA_3 concentration with respect to nodulation was quadratic. However, GA_3 had no significant effect on number of nodules/plant in Tswana cowpea plants (Fig. 5).

Yield components and yield: Gibberellic acid application to cowpea plants significantly ($p \leq 0.01$) increased pod length compared to control plants. The response to increasing GA_3 concentration was quadratic in both Blackeye and Tswana cowpea cultivars (Fig. 6). There were no GA_3 concentration differences with respect to increase in cowpea pod length. Gibberellic acid treated cowpea plants significantly ($p \leq 0.01$) produced more pod numbers/plant than control plants (Fig. 7). The response to increasing GA_3 concentration was linear and quadratic

Table 1: Effect of gibberellic acid on plant height, dry matter partitioning and senescence of cowpeas

	Blackeye			Tswana						
GA_3 concentration (mg L^{-1})	Shoot dry matter/plant (g)	Root dry matter/plant (g)	Shoot-to-root ratio	Plant height 11DAE (cm)	Shoot dry matter/plant (g)	Root dry matter/plant (g)	Shoot-to-root ratio	Tap root length (cm)	Harvest index (HI)	No. of plants yellowing out of 200
0	12.44^{c}	2.04^{c}	6.20^{b}	10.65^{b}	5.58^{b}	1.20^{b}	4.65^{b}	13.41^{a}	0.18^{b}	112^{a}
30	17.55^{b}	2.64^{b}	6.63^{b}	20.77^{a}	12.13^{a}	2.04^{a}	5.94^{a}	13.57^{a}	0.23^{a}	128^{a}
60	41.90^{a}	3.36^{a}	11.97^{a}	22.53^{a}	13.40^{a}	2.14^{a}	6.26^{a}	12.56^{a}	0.27^{a}	111^{a}
90	43.65^{a}	3.08^{a}	14.27^{a}	22.01^{a}	14.31^{a}	2.24^{a}	6.39^{a}	11.96^{a}	0.23^{a}	131^{a}
Significance	***	***	**	***	*	**	**	NS	*	NS
LSD	5.01	0.54	5.32	4.30	3.83	0.53	0.86	3.26	0.04	39.38

*, **, ***, NS significant at p = 0.05, 0.01, 0.001, or non-significant, respectively. Means separated using the Least Significant Difference (LSD) at p = 0.05; Means within column(s) followed by the same letter(s) are not significantly different. DAE: Days After Emergence

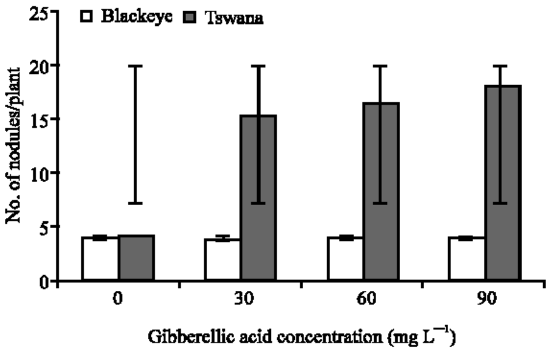

Fig. 5: Effect of gibberellic acid on nodulation of cowpea

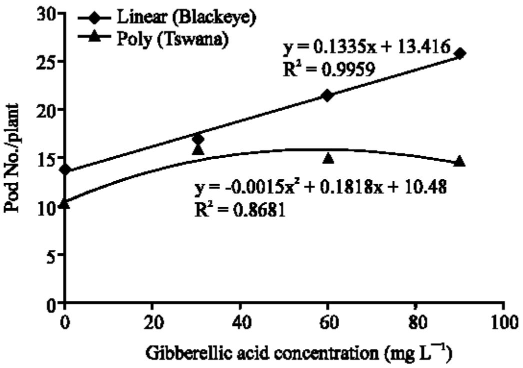

Fig. 7: Effect of gibberellic acid on pod number of cowpea

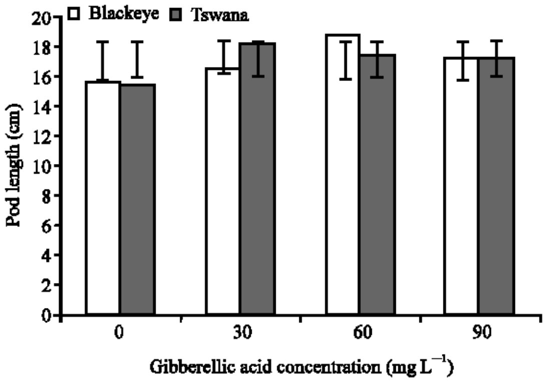

Fig. 6: Effect of gibberellic acid on cowpea pod length

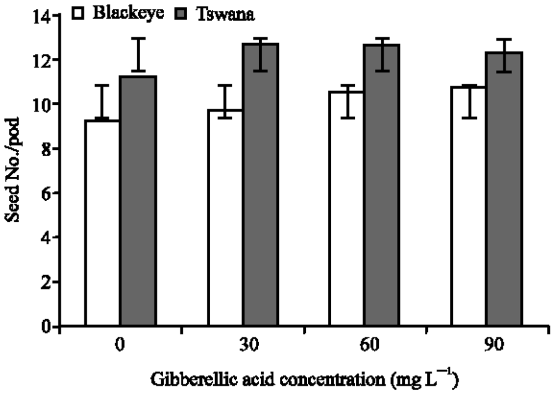

Fig. 8: Effect of gibberellic acid on pod seed number

in Blackeye and Tswana cowpea plants, respectively, in their ability to increase pod number/plant. Cowpea plants applied with GA_3 had significantly ($p \leq 0.05$) higher seed number/pod than control plants. There were no GA_3 concentration differences with respect to increasing seed number/pod (Fig. 8). The lower GA_3 concentrations (30 and 60 mg L^{-1}) had no significant effect on 100 seed weight of Blackeye cowpeas compared to control plants (Fig. 9). However, 90 mg L^{-1} GA_3 significantly increased 100 seed weight of Blackeye cowpea plants compared to control plants (Fig. 10). In Tswana cowpea plants, GA_3 application significantly ($p \leq 0.05$) increased 100 seed weight compared to control plants (Fig. 9). Cowpea plants sprayed with GA_3 at 30, 60, or 90 mg L^{-1} yielded significantly ($p \leq 0.01$) more seed yield ha^{-1} than control plants. The increase in seed yield induced by GA_3 application was linear and quadratic in Blackeye and Tswana cowpeas, respectively, with increasing GA_3 concentration (Fig. 10). Gibberellic acid treated Tswana cowpea plants had a higher harvest index than control plants. Application of GA_3 on cowpea plants had no significant effect on plant senescence (Table 1).

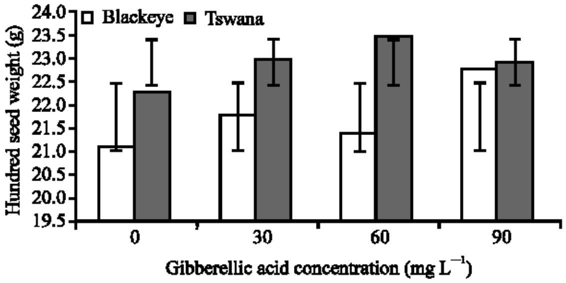

Fig. 9: Effect of gibberellic acid on 100 seed weight of cowpea

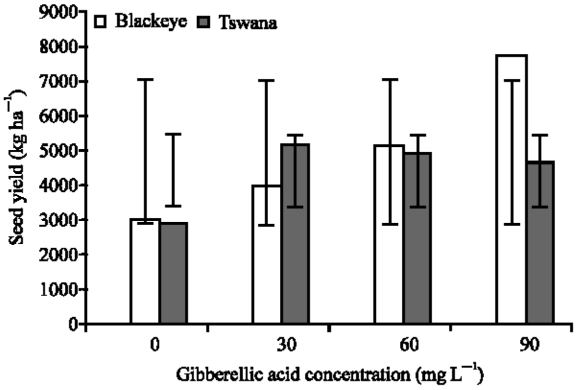

Fig. 10: Effect of gibberellic acid cowpea seed yield

DISCUSSION

The cowpea cultivars used in this study Blackeye and Tswana both have a determinate growth habit. Gibberellic acid application to cowpea plants increased plant and first node height. The GA_3-induced increase in plant and first node (internode) height was attributed to the role of gibberellins in increasing cell elongation and division and internodal elongation (Taiz and Zeiger, 2002). Sachs (1965) and Sauter and Kende (1992) reported that gibberellins increased both cell elongation and division, as evidenced by increase in cell length and number in peas and rice, respectively. It has also been shown that mitosis increases markedly in the subapical region of the meristem of rosette long-day plants after treatment with gibberellins. Gibberellins might have increased cowpea plant height by increasing cell wall extensibility. Behringer *et al.* (1990) reported that in peas, gibberellins decreased the minimum force that will cause cell wall extension. Cowpea plants applied with GA_3 had significantly higher leaf number/plant and leaf area. The increase in leaf number/plant induced by GA_3 could possibly be explained by GA_3 reducing the plastochron. The increase in leaf area of cowpea plants due to GA_3 application could be due to the role of GA_3 in promoting cell division and elongation (Taiz and Zeiger, 2002; Sauter and Kende, 1992). The differences in response to GA_3 application by the two cowpea cultivars Blackeye and Tswana in all variables determined was due to differences in the genotypes.

In general, the rate at which a crop increases in dry weight depends on leaf area index and net assimilation rate. However, changes in leaf area index depend on growth in leaf area and plant senescence. In the current study, GA_3 had no effect on cowpea plant senescence. The increase in plant dry matter in GA_3-treated plants was attributed to the increase in leaf area and leaf number/plant. Large amounts of dry matter are produced when cowpea plants of determinate cultivars maintain relatively large and healthy leaf areas for prolonged periods (Summerfield *et al.*, 1985; Littleton *et al.*, 1979). Emongor (2002) reported that $BA+GA_{4+7}$ increased dry matter accumulation in common beans (*Phaseolus vulgaris*), however, GA_3 and GA_{4+7} had no effect on dry matter accumulation.

Legume plants develop a symbiotic interaction with rhizobia by forming root nodules in which the bacteria fix atmospheric nitrogen. Nodule formation integrates several developmental processes, such as induction of cortical and pericycle cell division and rhizobial invasion, which are coordinated in time and space (Lievens *et al.*, 2005). The onset of symbiosis is marked by a complex exchange of signals, involving plant flavonoids and bacterial nodulation (Nod) factors. Recognition of specific nod factors will switch on the nodulation program in the legume host. Plant hormones control all developmental plant processes, including nodulation that is presumably initiated by a change in the cytokinin-to-auxin ratio within the root. Mathesius *et al.* (1998) reported that nod factor-induced inhibition of auxin transport led to the local accumulation of auxins needed to trigger nodule primordial. Cytokinins have also been reported to be involved in Nod factor induction because non-nodulating bacteria over producing isopentenyl transferase gene (Cooper and Long, 1994) as well as the exogenous application of cytokinin (Libbenga *et al.*, 1973; Reli *et al.*, 1994; Bauer *at al.*, 1996) can provoke nodule-like structures on legume plants. In the current study, application of GA_3 on Blackeye cowpea plants increased the number of nodules/plant compared to control plants. However, GA_3 had no significant effect on number of nodules/plant in Tswana cowpea plants. This conflicting result in nodulation response by the cowpea cultivars to GA_3 application in nodulation response was due to genotype differences between Blackeye and Tswana. This suggests that not all legumes react in the same way regarding to nodulation. Elevated gibberellin levels have been measured in nodules of lima bean (*Phaseolus lunatus*) and cowpea (Dobert *et al.*, 1992). However, analysis of effects of exogenous gibberellins (GAs) on root nodulation yielded conflicting results (Bishnoi and Krishnamoorthy, 1990; Zhang *et al.*, 1997). Exogenous application of GA_3 has been reported to induce the formation of nodule-like structures on the roots of *Lotus japonicus* and the response was nitrogen sensitive (Kawaguchi *et al.*, 1996). Some free-living rhizobia have the capacity to produce GAs (Atzorn *et al.*, 1988; Tully *et al.*, 1998), but they probably do not contribute significantly to the amount of GA within the nodule (Atzorn *et al.*, 1988). Nodulation in some pea (*Pisum sativum*) lines mutated in GA synthesis was hampered, resulting in fewer, nonfunctional nodules, a phenotype that could be completed by exogenous application of GAs (Ferguson *et al.*, 2005). Lievens *et al.* (2005) reported that GAs were involved in infection (*Azorhizobium caulinodans*) pocket and infection thread formation, two Nod factor-dependent events that initiate lateral root base nodulation in *Sesbania rostrata* and that GAs were also needed for nodule primordium development. They further reported that, GAs inhibited the root hair curling process. The results of Ferguson *et al.* (2005) showed that GAs, are Nod factor downstream signals for nodulation in hydroponic growth of *Sesbania rostrata*. The results of Dobert *et al.* (1992) support the hypothesis that the rhizobial strain modifies the endogenous GA status of the symbiotic system. This alteration in GA balance within the plant, presumably, underlies the observed growth response. Fletcher *et al.* (1959) reported that 25 ppm of GA_3 had no effect on nodule numbers of *Trifolium repens* and up to 1000 ppm GA_3 had no effect on the growth of *Rhizobium trifolii*. Williams and de Mallorca (1984) reported that foliar application of GA_3 to soybean plants delayed the formation of nodule initials and reduced the numbers mass per nodule and specific gravity of the nodules, without affecting plant growth.

The increase in seed yield due to GA_3 application observed in the current study was attributed to the enhanced vegetative growth (leaf area and leaf number per plant), dry matter accumulation and increase in yield components (pod length, number of pods/plant, seed number/pod and 100 seed weight). Emongor (2002) reported that GA_3 and GA_{4+7} significantly reduced the seed yield and had no effect on seed number/pod and number of pods/plant of common beans (*Phaseolus vulgaris*). The variability in response by cowpea plants to GA_3 application compared to common beans in respect to yield and yield components suggests that not all legumes respond similarly to plant growth regulators. Resmi and Gopalakrishnan (2004) reported that NAA (15, 30 or 45 ppm), 2,4-D (2 ppm) and CCC (300, 400 or 500 ppm) increased the seed yield, pod length, pod weight, pod number per unit area and pod number per plant of cowpea plants. Kannan *et al.* (2003) reported that application of NAA (30 ppm), mepiquat chloride (120 ppm) and a mixture of NAA (30 ppm) and mepiquat chloride (120 ppm) to blackgram (*Vigna mungo*) increased leaf area index, leaf chlorophyll content, photosynthetic rate and seed yield. The environment in which cowpeas are grown has been reported to be of great importance to cowpea seed yield (Smithson *et al.*, 1980; Summerfield *et al.*, 1983). This implies that breeding and selection may be more usefully directed to overcoming the constraints imposed by adverse environments than aiming for yield improvements in situations conducive to large yields. Since cowpea seed yield is influenced by leaf area index, net assimilation rate and yield components (number of pods/plant, seed number/pod, pod length and 100 seed weight), variables all enhanced by exogenous GA_3 application, breeding and selection should be directed towards varieties probably high in Gas, auxins, cytokinins and abscisic acid (for semi-arid and arid regions).

CONCLUSION

The results of this study showed that exogenous application of GA_3 can be used to increase vegetative growth, nodulation, yield components and seed yield of some cowpea varieties. However, more research needs to be undertaken in order to determine the optimum GA_3 concentration on several cowpea varieties, timing of application, economics of using GA_3 as a cowpea production input, as well as breeding and selection of cowpea varieties high in GAs and other phytohormones such as auxins, cytokinins and abscisic acid.

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REFERENCES

Atzorn, R., A. Crozier, C.T. Wheeler and G. Sandberg, 1988. Production of gibberellins and indole-3-acetic acid by *Rhizobium phaseoli* in relation to nodulation of *Phaseolus vulgaris* roots. Planta, 175: 532-538.

Bauer, P., P. Rate, M.D. Crespi, M. Schultze and A. Kondorosi, 1996. Nod factors and cytokinins induce similar cortical cell division, amyloplast deposition and *MsEnod12A* expression pattern in alfalfa roots. Plant J., 10: 91-105.

Behringer, F.J., D.J. Cosgrove, J.B. Reid and P.J. Davies, 1990. Physical basis for altered stem elongation rates in internode length mutants of *Pisum*. Plant Physiol., 94: 166-173.

Bekker, R.T. and P.V. de Wilt, 1991. Contribution to the soil and vegetation classification of Botswana: Soil mapping and advisory services project. Field Document FAO/UNDP Government of Botswana, 34: 66.

Bishnoi, N.R. and H.N. Krishnamoorthy, 1990. Effect of water logging and gibberellic acid on nodulation and nitrogen fixation on peanut. Plant Physiol. Biochem., 28: 663-666.

Bressani, R., 1985. Nutritive Value of Cowpea. In: Cowpea Research, Production and Utilization, Singh, S.R. and K.O. Rachie (Eds.). A Wiley-Interscience Publication: John Wiley and Sons Chichester New York Brisbane Toronto Singapore, pp: 353-359.

Cooper, J.B. and S.R. Long, 1994. Morphogenetic rescue of *Rhizobium meliloti* nodulation mutants by trans-zeatin secretion. Plant Cell, 6: 215-225.

deMooy, B.E., 1987. Botswana Cowpea Germplasm Catalogue. Vol. 3. Republic of Botswana Ministry of Agriculture Publication, Colorado State University in Cooperation with Michigan State University, pp: 55.

Dobert, R.C., S.B. Rood and D.G. Blevins, 1992. Gibberellins and legume-*Rhizobium* symbiosis: Endogenous gibberellins of Lima bean (*Phaseolus lunatus* L.) stems and nodules. Plant Physiol., 98: 221-224.

Emongor, V.E., 1997. The Prospective of Plant Growth Regulators in Kenyan Agriculture. In: Proceedings of the National Horticulture Conference, Agong, S.G., L.S. Wamocho and F.K. Obwara (Eds.). Progress and Prospects in Kenya's Horticulture Development Towards the Year 2000 and Beyond, pp: 227-229.

Emongor, V.E., 2002. Effect of benzyladenine and gibberellins on growth, yield and yield components of common bean (*Phaseolus vulgaris*). UNISWA Res. J. Agric. Sci. Technol., 6: 65-72.

Ferguson, B.J., J.J. Ross and J.B. Reid, 2005. Nodulation phenotypes of gibberellin and brassinosteroids mutants of pea. Plant Physiol., 138: 2396-2405.

Fletcher, W.W., J.W.S. Alcorn and J.C. Raymond, 1959. Gibberellic acid and nodulation of legumes. Nature, 184: 1576.

Gianfagna, T.J. and R.H. Merrit, 1998. GA_{4+7} promotes stem growth and flowering in genetic line of *Aquilegia* x hybrida sims. Plant Growth Reg., 24: 1-5.

Ishiyaku, M.F. and B.B. Singh, 2001. Inheritance of short day induced dwarfing in photosensitive cowpeas. Afr. Crop Sci. J., 9: 369-375.

Kannan, K., M. Prakash, J. Ganesan, M.S. Kumar and J.S. Kumar, 2003. Effect of plant growth regulators on growth, physiology and yield of blackgram. Legume Res., 26: 183-187.

Kawaguchi, M., H. Imaizumi-Anraku, S. Fukai and K. Syono, 1996. Unusual branching in the seedlings of *Lotus japonicus*: Gibberellins reveal the nitrogen-sensitive cell divisions within the pericycle on roots. Plant Cell Physiol., 37: 461-470.

Laing, D.R., P.J. Kretchmer, S. Zuluaga and P.G. Jones, 1983. Field Bean (*Phaseolus vulgaris*). In: Potential Productivity of Field Crops under Different Environments, Smith, W.H. and S. Yashida (Eds.). Los Banos Philippines IRRI., pp: 227-248.

Libbenga, K.R., F. Van Iren, R.J. Bogers and M.F. Schraag-Lamers, 1973. The role of hormones and gradients in the initiation of cortex proliferation and nodule formation in *Pisum sativum* L. Planta, 114: 29-39.

Lievens, S., S. Goormachtig, J.D. Herder, W. Capoen, R. Mathis, P. Hedden and M. Holsters, 2005. Gibberellins are involved in nodulation of *Sesbania rostrata*. Plant Physiol., 139: 1366-1379.

Littleton, E.J., M.D. Dennett, J.L. Monteith and J. Elston, 1979. The growth and development of cowpeas (*Vigna unguiculata*) under tropical field conditions. 2. Accumulation and partitioning of dry weight. J. Agric. Sci. Camb., 93: 309-320.

Mathesius, U., H.R.M. Schlaman, H.P. Spaink, C. Sautter, B.G. Rolfe and M.A. Djordjevic, 1998. Auxin transport inhibition precedes root nodule formation in white clover roots and is regulated by flavonoids and derivatives of chitin oligosaccharides. Plant J., 14: 23-34.

Mo, A., 1996. Annual Report for the Crop Research Division. Department of Agricultural, Research, Ministry of Agriculture Republic of Botswana, pp: 279.

Mo, A., 2001. Ministry of Agriculture Republic of Botswana. Stat. Bull., 26: 140-160.

Mortimore, M.J., B.B. Singh, F. Harris and S.F. Blade, 1997. Cowpea in Traditional Cropping Systems. In: Advances in Cowpea Research, Singh, B.B., D.R. Mohan Raj, K.E. Dashiell and L.E.N. Jackai (Eds.). Copublication of International Institute of Tropical Agriculture (IITA) and Japan International Research Centre for Agricultural Sciences (JIRCAS): IITA, Ibadan, Nigeria, pp: 99-113.

Mukhtar, F.B. and B.B. Singh, 2004. Growth response of photoperiod sensitive and photoperiod insensitive cowpea varieties to plant growth regulator treatments. Soil Environ. Sci. J. Trops (BEST), 1: 79-86.

Mukhtar, F.B. and B.B. Singh, 2006. Influence of photoperiod and gibberelic acid (GA_3) on the growth and flowering of cowpea (*Vigna unguiculata* (L.) Walp). J. Food Agric. Environ., 4: 201-203.

Okelana, M.A.O. and N.O. Adedipe, 1982. Effects of gibberellic acid, benzyladenine and 2-chloroethylphosphonic acid (CEPA) on growth and fruit abscission in cowpea (*Vigna unguiculata* L.). Ann. Bot., 49: 485-491.

Pate, J.S. and F.R. Minchin, 1980. Comparative Studies of Carbon and Nitrogen Nutrition of Selected Grain Legumes. In: Advances in Legume Science, Summerfield, R.J. and A.H. Bunting (Eds.). London UK Her Majesty's Stationery Office, pp: 105-114.

Persaud, N., W.D. Joshua, N. Mokete, F. Pule and S. Maroke, 1992. Report on the soils of the tillage and fertilizer trial sites. Dept. Agric. Res. Botswana. Botswana Government Printer, pp: 28.

Reli, B., X. Perret, M.T. Estrada-GarcRa, J. Kopcinska, W. Golinowski, H.B. Krishnan, S.G. Pueppke and W.J. Broughton, 1994. Nod factors of Rhizobium are a key to the legume door. Mol. Microbiol., 13: 171-178.

Resmi, R. and T.R. Gopalakrishnan, 2004. Effect of plant growth regulators on the performance of yard long bean (*Vigna unguiculata* var. sesquipedalis (L.) Vercourt). J. Trop. Agric., 42: 55-57.

Richards, D.E., K.E.T. Ait-Ali and N.P. Harberd, 2001. How gibberellin regulates growth and development: A molecular genetic analysis of gibberellin signaling. Ann. Rev. Plant Physiol. Plant Mol. Biol., 52: 67-88.

Sachs, R.M., 1965. Stem elongation. Annu. Rev. Plant Physiol., 16: 73-96.

Sauter, M. and H. Kende, 1992. Gibberellin-induced growth and regulation of cell division cycle in deep water rice. Planta, 188: 362-368.

Smithson, J.B., R. Redden and K.M. Rawal, 1980. Methods of Crop Improvement and Genetic Resources in *Vigna unguiculata*. In: Advances in Legume Science, Summerfield, R.J. and A.H. Bunting (Eds.). London UK Her Majesty's Stationery Office, pp: 445-457.

Snedecor, G.W. and W.G. Cochran, 1989. Statistical methods. 8th Edn. Iowa State University Press/Ames, pp: 503.

Summerfield, R.J., F.R. Minchin, E.H. Roberts and P. Hadley, 1983. Cowpea. In: Potential Productivity of Field Crops Under Different Environments, Smith, W.H. and S. Yoshida (Eds.). Los BaZos Philippines IRRI., pp: 249-280.

Summerfield, R.J., J.S. Pate, E.H. Roberts and H.C. Wien, 1985. The Physiology of Cowpeas. In: Cowpea Research, Production and Utilization, Singh, S.R. and K.O. Rachie (Eds.). A Wiley-Interscience Publication: John Wiley and Sons Chichester New York Brisbane Toronto Singapore, pp: 65-101.

Taiz, L. and E. Zeiger, 2002. Plant Physiology. 3rd Edn. Sinauer Associates, Inc., Publishers Sunderland Masschusetts, pp: 690.

Tully, R.E., P. van Berkum, K.W. Lovins and D.L. Keister, 1998. Identification and sequencing of a cytochrome P450 gene cluster from *Bradyrhizobium japonicum*. Biochem. Biophys. Acta, 1398: 243-255.

Williams, P.M. and M.S. de Mallorca, 1984. Effect of gibberellins and the growth retardant CCC on the nodulation of soya. Plant Soil, 77: 53-60.

Yang, Y., D. Lin and Z. Gua, 1992. Promotion of fruit development in cucumber (*Cucumis sativus*) by thidiazuron. Sci. Hortic., 50: 47-51.

Zhang, F., B. Pan and D.L. Smith, 1997. Application of gibberellic acid to the surface of soybean seed (*Glycine Max* (L.) Merr.) and symbiotic nodulation, plant development, final grain and protein yield under short season conditions. Plant Soil, 188: 329-335.