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***Abstract*. To lower seed yield loss from directly harvested common bean or dry bean, height of the lower pod-bearing nodes needs to be raised. The objective of this greenhouse study was to stimulate lower stem elongation by gibberellic acid (GA_3) of dry bean cultivars. Seeds of cv. Matterhorn, erect indeterminate Type II, and cv. Poncho, prostate indeterminate Type III, were dipped in GA_3 at 62.5 to 16,000 ppm and planted. After 14 d, the height of the unifoliate and first trifoliate nodes showed maximum stimulation of stem elongation by 1000 ppm GA_3 for 'Poncho' and by 2000 ppm for 'Matterhorn'. Application of 1 mL of GA_3 at 0.031 to 2048 ppm to newly expanded unifoliate leaves showed cultivar differences. Whereas 'Matterhorn' was promoted at 64 ppm and reached a maximum height by 512 ppm GA_3, 'Poncho' was promoted at 0.25 ppm and reached a maximum height by 8 ppm GA_3. Flowering of 'Matterhorn' was unaffected by GA_3; flowering of 'Poncho' was completely inhibited by 128 ppm. The sensitivity difference of cultivars was verified with other cultivars. Type I cultivars, which are all determinate, showed a full range of GA_3 sensitivity. Dry bean cultivars may be regrouped based on the GA_3 dose to which they respond. Individual response to GA_3 rates of dry bean cultivars needs to be predetermined using a short-term, 2–3 weeks, greenhouse bioassay before field use of GA_3.**

In dry bean (*Phaseolus vulgaris* L.), growth form, i.e., determinate vs. indeterminate, and growth habit, i.e., upright/erect/bushy vs. viny/prostate, are among the most important characteristics for classifying cultivars from an agronomic viewpoint (Kelly, 2001; Laing et al., 1984; Singh, 1982). Dry bean is morphologically classified as determinate or indeterminate growth forms depending on whether the terminal meristem is reproductive (determinate) or vegetative (indeterminate) (Miklas and Singh, 2007). This characteristic is genetically controlled by the gene *Finfin* and unaffected by the environment (Koinange et al., 1996). Having a determinate terminal meristem was the result of *FinFin* or *Finfin* that is dominant over an indeterminate type (*finfin*) and this probably evolved through natural mutation of the wild-type *Fin* gene (Gepts, 1998). Indeterminate agronomic cultivars were classified into Type II and Type III based on vine growth extension and climbing ability. Determinate cultivars were classified as Type I and subdivided by their climbing ability. North American-grown commercial dry bean cultivars are described by Singh (1982) as:

Type I = determinate, erect (bushy). Further classified into Ia (no climbing ability) and Ib (some climbing ability);
Type II = indeterminate, erect (bushy). Further classified into IIa (no climbing ability) and IIb (some climbing ability = semiclimbing); and
Type III = indeterminate, prostrate (viny). Further classified into IIIa (some climbing ability = semiclimbing) and IIIb (strong climbing ability = climbing).

Vine length is highly affected by environment conditions, especially light (Kelly, 2001; Singh, 2001). The climbing phenotype of dry bean may be the result of a dominant gene, *C1*, whereas the nonclimbing types may be the result of a recessive gene, *c1,* that has evolved through natural mutation of *C1* (Gepts, 1998; Kretchmer and Wallace, 1978).

Type II and III dry bean cultivars are the most common ones grown in the U.S. High Plains. The lower pods of common dry bean grown in the field are very close to the ground. Because of this, the conventional practice in dry bean production in the U.S. High Plains is to harvest by first undercutting plants, conventional harvest, to minimize yield loss (Smith, 2004). The alternate method of harvest is direct harvesting but the yield loss in the Nebraska Panhandle may be greater than 10% even with the addition of lifters (Smith, 2004). In the Red River Valley, the mean of nine cultivars grown in four North Dakota locations over 2 years, seed yield was reduced from 2240 for conventional harvest to 1410 $kg \cdot ha^{-1}$ for direct harvest or 27% (Eckert et al., 2011). Most of the yield reduction was the result of seed loss during harvest, 4.5% by conventional harvest vs. 23.2% by direct harvest (Eckert et al., 2011).

One possible method of reducing yield loss is to stimulate growth of lower internodes, those below the node with the first flower and pod, to raise lower pods higher off the ground and allow the cutting blades on a direct harvester to cut the stem below those pods. This may be accomplished by application of a growth-stimulating compound such as GA_3.

The ability of gibberellins to promote stem growth was known since the 1930s when a rice disease was identified to be the result of a pathogenic fungus *Gibberella fujikuroi* (Takahashi et al., 1991). Since then, there have been more than 130 gibberellins identified. Gibberellic acid, a key gibberellin, is highly active and well known to stimulate stem elongation (Davies, 2010; Marth et al., 1956). A greenhouse bioassay for GA_3 applied to fully opened unifoliate leaves of snap bean cultivars (*P. vulgaris*) was developed showing a dose–response for stimulating stem elongation and exposure between 2 and 10 µg GA_3/plant for maximum effect (Knoche et al., 1998, 2000).

The objective of this study was to compare the GA_3 dose–response of indeterminate dry bean cultivars with an erect, upright (Type II) growth or a prostate (Type III) growth habit and determinate cultivars (Type I).

Materials and Methods

Greenhouse conditions. Experiments were conducted in March and April of 2005, 2006, and 2007 in a greenhouse at the Panhandle Research & Extension Center of the University of Nebraska in Scottsbluff (lat. 41.9° N, long. 103.7° W, elevation 1208 m). The maximum daytime temperature was ≈35 °C, and minimum nighttime temperature was ≈23 °C. Metal halide lamps were used to supplement sunlight to maintain a 14-h photoperiod. Lamps were kept 1.5 m above plants. Pots were watered at planting and checked three times weekly and watered as needed to maintain a full water profile throughout the experiments.

Plant material. Dry bean cultivars, i.e., common bean and dry edible bean, listed in Table 1, were obtained from various seed programs such as the University of Idaho, University of Saskatchewan, and Michigan State University and purchased through Kelley Bean Co., Scottsbluff, NE. Type II, indeterminate and upright, and Type III, indeterminate and prostate, cultivars are commonly grown in western Nebraska. The cv. Matterhorn and cv. Poncho were chosen as to initially represent Type II and Type III cultivars, respectively, because they are major cultivars grown in this area. Type I, determinate, cultivars are not commonly grown in this area, but as a result of the range of responses to GA_3 application of Type II and III cultivars, Type I cultivars

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Table 1. Dry bean cultivars, their market class and type, used in greenhouse studies, and a summary of the GA_3 concentration applied to the unifoliate leaves that resulted in the maximum stimulation of internode elongation (combination of 3 years' data).

Cultivar	Market class	Type	GA_3 concn for maximum response (ppm)	Relative GA_3 foliar sensitivity level[z]
Poncho[y]	Pinto	III[x]	2	High
Marquis	Great Northern	III	8	High
Frigate	Navy	II	0.5	High
Vision	Pinto	II	32	Medium
Matterhorn[y]	Great Northern	II	512	Medium
Ensign	Navy	II	512	Medium
Agate	Pinto	I	0.125	High
Amber	Pinto	I	8	High
CDC Pintium	Pinto	I	8	High
Doray	Pinto	I	0.125	High
Early Ray	Pinto	I	8	High
G2883	Great Northern	I	0.125	High
Nordic	Great Northern	I	512	Medium
Newport	Navy	I	512	Medium
Seafarer	Navy	I	512	Medium
Foxfire	Light Red Kidney	I	512	Medium
Pink Panther	Light Red Kidney	I	512	Medium
Rog 776	Light Red Kidney	I	512	Medium
Moldova-104	Large White Kidney	I	2048	Low

[z]Relative sensitivity was based on the concentration of foliar-applied GA_3 that resulted in the maximum stimulation of internode elongation: high = 8 ppm or less, medium = 32–512 ppm, low = 2048 ppm or greater.

[y]'Matterhorn' and 'Poncho' were the standards for Type II and Type III cultivars and for medium and high GA_3 sensitivity, respectively.

[x]Type III cultivars are prostate (viny) and indeterminate. Type II cultivars are bushy (erect) and indeterminate. Type I cultivars are determinate and bushy.

GA_3 = gibberellic acid.

were also tested for their foliar response. Seeds were treated with streptomycin for pathogen suppression by Kelley Bean Co. using standard commercial practices.

In the 2005 rate tests, seeds were planted in durable molded fiber pots that were 20 cm in diameter and 20 cm deep. In the tests conducted in 2006 and 2007, seeds were planted in plastic pots, 15 cm in diameter by 15 cm deep, because of acceptability, availability, and bench space limitation. Seeds were planted 2 cm deep in Fafard Superfine Germination Mix (American Clay Works, Denver, CO). In the seed application tests in 2005, emergence of all planted seeds and plant height of all emerged seedlings were determined. In all tests in which GA_3 was applied to the foliage, four seeds were planted per pot and thinned after a few days to three plants before treatment for uniformity. On a per-cultivar basis, four pots were used for each GA_3 treatment. Pots were arranged in an randomized complete block design based on GA_3 treatment separated by cultivar on a greenhouse bench. The heights of nodes and apices were measured, and emergence and flowering were observed. Experiments were analyzed using SAS Proc analysis of variance and means were separated using least significant difference (SAS Institute, 2003) for each cultivar separately.

Chemical preparation. Gibberellic acid was applied as Release LC, a 4% a.i. weight by weight, i.e., 1 g GA_3/30 mL, formulation (Valent BioScience Corp., Long Grove, IL). Release LC was diluted serially with water from 16,000 to 0.031 ppm GA_3. A sticker-spreader-type surfactant, X77, at 0.125% was added to solutions applied to foliage until determined not to be needed in a greenhouse test in 2007 (unpublished data).

Seed application experiments. Emergence tests were conducted in 2005 when 32 seeds of 'Matterhorn' and 'Poncho' were soaked in 15 mL GA_3 solutions for 5 min. Seeds were removed and air-dried for 2 to 3 h at 20 °C and then planted in pots placed in the greenhouse in 2005. Three seeds of each seed treatment of the two cultivars were planted together into each of four pots and were used as replicates. Therefore, the treatments were paired per pot while the pots were placed randomly by replication on a greenhouse bench. Emergence was determined at 7 d after planting (DAP) and height of unifoliate and trifoliate nodes were measured at 9 and 14 DAP.

Foliar application method. Foliar applications were made to the unifoliate leaves at Stage V2 (Schwartz et al., 1993), which was reached between 10 and 14 DAP. Cosmetic squirt bottles (59 mL) were used to apply ≈1 mL (seven squirts) to the two unifoliate leaves (0.5 mL/leaf). The rates of GA_3 in the initial dose test in 2005 ranged from 0.03125 to 2048 ppm increased by increments of 2×, i.e., 0.03125, 0.0625, 0.125, 0.25, etc.

Cultivar sensitivity tests. In 2006, the doses were individualized to the cultivar types as a result of differential sensitivity between 'Matterhorn' (Type II) and 'Poncho' (Type III) observed in 2005 in the foliar application experiments. Nine cultivars were tested to determine whether they would show a wide range of GA_3 sensitivity and could be grouped based on their sensitivity to GA_3 in 2006. Cultivars CDC Pintium, Nordic, and Seafarer were classified as Type I; cultivars Ensign, Frigate, Matterhorn, and Vision were as Type II; and cultivars Marquis and Poncho were classified as Type III. The market class represented were Pinto (cvs. CDC Pintium, Poncho, and Vision), Great Northern (cvs. Marquis, Matterhorn, and Nordic), and Navy (cvs. Ensign, Frigate, and Seafarer) (Table 1). Cultivars Poncho, Marquis, and Frigate were treated with GA_3 at 0, 0.125, 0.5, 2, 8, and 32 ppm applied to the unifoliate leaves 10 DAP (V2); and cultivars Matterhorn, Vision, Ensign, CDC Pintium, Nordic, and Seafarer were treated with GA_3 at 0, 8, 32, 128, 512, and 2048 ppm. Height to the unifoliate node, i.e., plant height at time of treatment, was measured at treatment and measured again along with heights to the first and second trifoliate nodes and the plant apex at 7 DAT. New growth at 7 DAT was defined as the height of the plant apex at 7 DAT minus the plant height at the time of GA_3 application (10 DAP), i.e., the height of the unifoliate node. As a result of the responsiveness of the Type I cultivars in 2006, 13 Type I cultivars were tested in 2007. These cultivars represented five market classes, 'Pinto', 'Great Northern', 'Navy', 'Light Red Kidney', and 'Large White Kidney' (Table 1). Unifoliate leaves were treated at 12 DAP with GA_3 at 0, 0.125, 8, 512, and 2048 ppm. These rates were chosen based on the 2006 results. Apical height was measured at 7 DAT.

Results

Seed application (2005). Emergence from pots in the greenhouse of 'Matterhorn' seed treated with 16,000 ppm GA_3 was 25%, significantly less than for both water-treated checks (75%) and seed treated with 63 to 4000 ppm GA_3 (67% to 83%). In contrast, 'Poncho' did not show a significant effect of GA_3 seed treatment on emergence at any treatment level (67% to 75%). At 14 DAP, the height of the unifoliate and first trifoliate nodes was measured. Stem elongation promotion by GA_3 was highly significant (Fig. 1). 'Poncho' grew more than 'Matterhorn' and its nodes were higher. Significant height promotion was obtained between 250 and 1000 ppm GA_3. Maximum stimulation by GA_3 was reached at 1000 ppm for 'Poncho' and 2000 ppm for 'Matterhorn', indicating a possible difference in sensitivity.

Foliar application (2005). The rate response of 'Matterhorn' and 'Poncho' to GA_3 applied to unifoliate leaves at V2 was tested also in 2005. Initially, GA_3 was applied at 2 to 2048 ppm in 2× increments (Fig. 2). 'Matterhorn' showed significant height promotion of the first trifoliate node after 1 week exposure to 64 ppm GA_3 or greater and the response reached a plateau at 256 ppm GA_3. 'Poncho' was much more sensitive to GA_3 than 'Matterhorn' (Fig. 2). Within 7 DAT, it was clear that 'Poncho' was affected by 2 ppm. The rate response was repeated with lower doses, 0.031 to 4 ppm GA_3. Significant height promotion of the first and second trifoliate nodes at 7 DAT was observed with 0.25 ppm

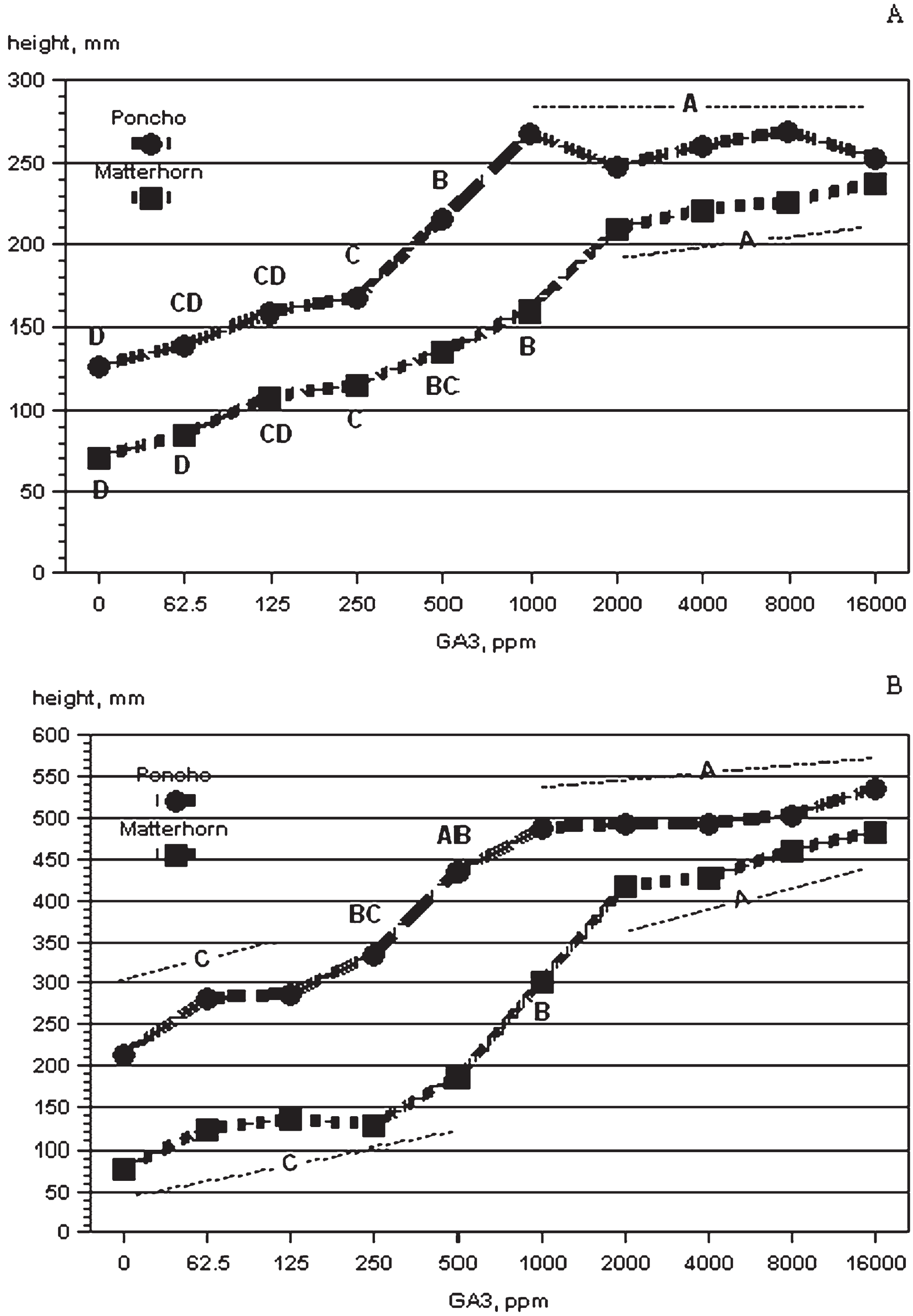

Fig. 1. Height of the unifoliate (**A**) and first trifoliate (**B**) nodes of dry bean cultivars Poncho and Matterhorn 2 weeks after planting seed treated with gibberellic acid (GA_3; 2005). Means separated between GA_3 doses for each cultivar (curve) by least significant difference at $P < 0.05$.

GA_3 applied to unifoliate leaves and the response reached a plateau at 4 ppm GA_3 (Fig. 2). When 'Poncho' plants were held to 21 and 35 DAT to observe floral and subsequent pod development, GA_3 at 32 ppm and greater had a significant inhibiting effect on flowering and pod formation (Fig. 3). No flowers or pods were present on 'Poncho' plants exposed to 128 ppm GA_3 and greater. A similar effect was not observed with 'Matterhorn' (data not shown); floral and pod development showed no significant difference between water-treated checks and plants treated with up to 2048 ppm GA_3.

Cultivar sensitivity (2006, 2007). Because results in 2005 showed that GA_3 applied to the unifoliate leaves at V2 affected the internode length above the unifoliate node (Fig. 2), new growth, i.e., difference between the plant height at treatment and that at 7 DAT, should be indicative of a GA_3 effect. In 2006, nine cultivars were used, some of Type I, Type II, or Type III with three cultivars being in one of three market classes, 'Great White Northern', 'Pinto', or 'Navy' market class (Table 1). Cultivars Marquis and Poncho, both Type III, and Type II cultivar Frigate reached a plateau in the amount of new growth when exposed to GA_3 at less than 8 ppm (Table 2). 'Frigate' is a Type IIB cultivar that can be viny, behaving similar to a Type IIIA cultivar in the environment of western Nebraska. The Type II cultivar Vision attained a plateau in new growth with GA_3 at 32 ppm, whereas the other two Type II cultivars, Ensign and Matterhorn, attained a plateau in new growth response with GA_3 at 512 ppm (Table 2). Cultivar Poncho's higher sensitivity and cv. Matterhorn's lower sensitivity to GA_3 was at the same level as observed in 2005 (Fig. 2). The three Type I cultivars, CDC Pintium, Nordic, and Seafarer

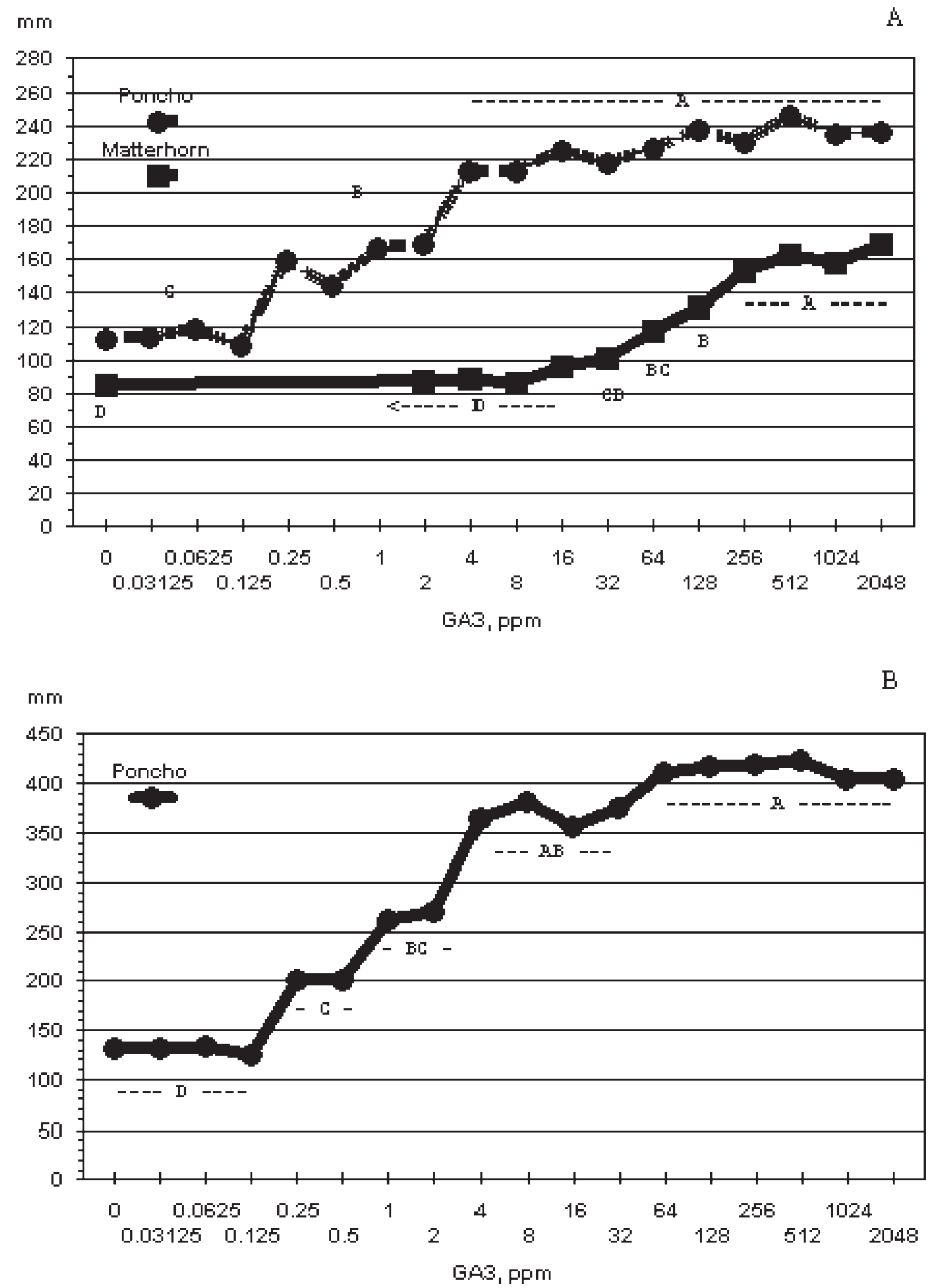

Fig. 2. Height of the first trifoliate nose of dry bean cultivars Poncho and Matterhorn (**A**) and the second trifoliate node of the cultivar Poncho (**B**) 1 week after treating unifoliate leaves with gibberellic acid (GA_3; 2005). 'Matterhorn' had not developed the second trifoliate node at this time. Means separated between GA_3 doses for each cultivar (curve) by least significant difference at $P < 0.05$.

showed a sensitivity plateau between 8 and 32 ppm (Table 2). Although a statistical comparison was not possible, market class, which is based on seed characteristics, did not show a pattern to GA_3 sensitivity. In 2007, 13 Type I cultivars (Table 1) were tested. Type I cultivars reacted to GA_3 doses in three groupings classified by the degree of cultivar sensitivity to GA_3 (Table 3). Cultivars Agate, Amber, CDC Pintium, Doray, Early Ray, and G2883 reached a sensitivity plateau at or below 8 ppm GA_3 similar to Type III cultivars and the Type II cultivar Frigate. Cultivars Nordic, Newport, Seafarer, Foxfire, Pink Panther, and Rog 776 reached a plateau between 8 and 512 ppm GA_3 similar to 'Matterhorn', 'Vision', and 'Ensign' (Table 3). The cultivar Moldova 104 did not reach a maximum elongation stimulation until exposed to 2048 ppm GA_3 or greater indicating a lower level of sensitivity than the other cultivars (Table 3).

Discussion

Gibberellic acid dose–response. A cultivar-specific stem elongation response to GA_3 was first observed with seed treatments. 'Poncho', a Type III cultivar, showed elongation of the stem below the first trifoliate internode with one-fourth to half the concentration needed by 'Matterhorn', a Type II cultivar, to reach maximum effect. Foliar GA_3 application resulted in a similar effect but with lower GA_3 doses and showing a greater difference in dose–response between the two cultivars. Much lower GA_3 rates applied to foliage significantly stimulated stem elongation for 'Poncho' compared with 'Matterhorn' (Fig. 2). On snap bean (*P. vulgaris*), the GA_3 exposures of unifoliate leaves at V2 that resulted in maximum elongation of the internode above the unifoliate within 1 week after exposure were between 2 and 10 μg/leaf or 1 mL of a 10 ppm solution (Bukovac et al., 1958; Knoche and Bukovac, 1999; Knoche et al., 1998, 2000;

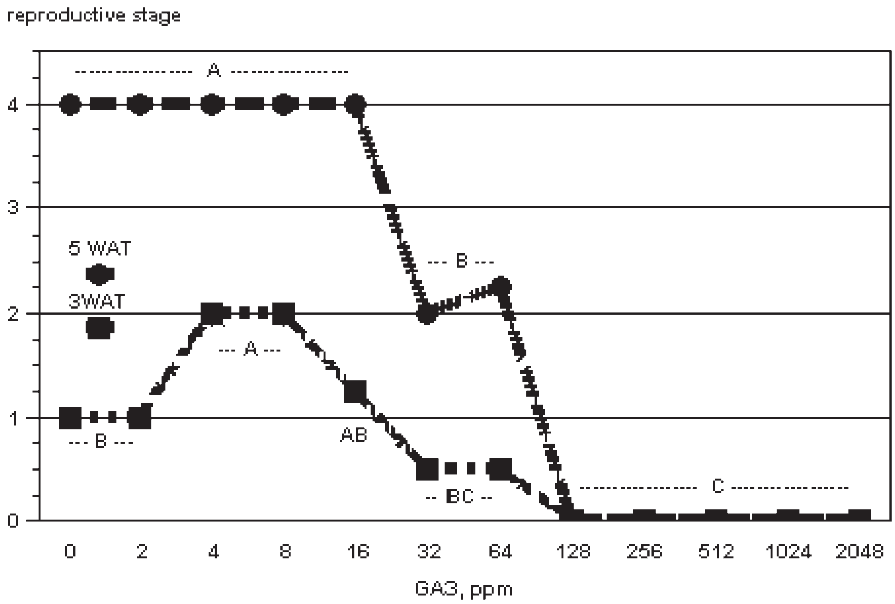

Fig. 3. Floral stage of dry bean cultivar Poncho 3 and 5 weeks after treating (WAT) unifoliate leaves with gibberellic acid (GA_3; 2005). Reproductive scale indicates presence of no flowers (0), closed flowers (1), open flowers (2), small pods, less than 2.5 cm (3), and large pods, greater than 2.5 (4). Means separated between GA_3 doses for each WAT (curve) by least significant difference at $P < 0.05$.

Table 2. New growth of Type I, II and III cultivars 1 week after exposure of unifoliate leaves to gibberellic acid (2006).

		GA_3 exposure (ppm)					
		0	0.125	0.5	2	8	32
Cultivar	Type	New growth (mm)[z]					
Poncho[y,x]	III[w]	504 D[v]	557 CD	642 BC	719 AB	695 AB	762 A
Marquis	III	109 C	212 B	222 B	294 B	447 A	464 A
Frigate	II	380 BC	326 C	496 AB	518 A	625 A	531 A
		GA_3 exposure (ppm)					
		0	8	32	128	512	2048
Cultivar	Type	New growth (mm)					
Vision	II	121 C	234 B	514 A	573 A	600 A	563 A
Matterhorn	II	147 C	162 C	407 B	473 B	590 A	604 A
Ensign	II	66 D	109 D	269 C	381 B	484 A	468 A
CDC Pintium	I	465 B	530 B	582 AB	571 AB	570 AB	671 A
Nordic	I	326 B	554 AB	622 A	615 A	647 A	637 A
Seafarer	I	226 C	427 B	486 AB	508 AB	577 A	563 A

[z]New growth was calculated as the plant height 7 d after treatment minus the plant height at time of treatment.
[y]'Poncho', 'Vision', and 'CDC Pintium' are in the market class Pinto; 'Marquis', 'Matterhorn', and 'Nordic' are in the market class Great White Northern; and 'Frigate', 'Ensign', and 'Seafarer' are in the market class Navy.
[x]'Matterhorn' and 'Poncho' were the standards for Type II and Type III cultivars and for low and high GA_3 sensitivity, respectively.
[w]Type III cultivars are prostate (viny) and indeterminate. Type II cultivars are bushy (erect) and indeterminate. Type I cultivars are generally reported bushy (erect) and determinate.
[v]Mean separation for each cultivar (rows) by least significant difference at $P < 0.05$.
GA_3 = gibberellic acid.

Marth et al., 1956). None of the snap bean cultivars were characterized as upright or erect but as prostate or pole type. This range of sensitivity was the same as observed with the cvs. Poncho and Marquis, Type III cultivars (indeterminate prostate), one Type IIB cultivar, Frigate, and six Type I (determinate) cultivars that showed maximum stimulation to less than 8 μg GA_3/plant (or 8 ppm) (Tables 2 and 3). 'Vision', a Type IIB, semiupright, reached a maximum response with 32 ppm GA_3. The other Type II cultivars, Matterhorn and Ensign (indeterminate upright or erect stature), and seven Type I cultivars may require as much as 512 ppm (512 μg GA_3/plant) to show maximum stimulation of internode elongation above the node of application (Tables 2 and 3). There was as much as a 64-fold difference between the GA_3 sensitivity of 'Matterhorn' vs. 'Poncho' (Fig. 2). One Type I cultivar required 2048 ppm GA_3 for maximum promotion of stem elongation (Table 3).

Cultivar sensitivity. The genetics of gibberellin sensitivity in common bean cultivars seemed to be highly variable and may be grouped into at least two categories based on their sensitivity to GA_3. Type I cultivars showed a mixed response to GA_3, from low to high doses. Unlike indeterminate cultivars, Type I cultivars (determinate) are loosely described as bushy. Based on their GA_3 response, some Type I cultivars may be less sensitive to GA_3, similar to the Type II cultivar Matterhorn; other Type I cultivars may be more sensitive to GA_3, similar to the Type III cultivar Poncho. In the present study, significant differences in response to GA_3 doses were observed among cultivars regardless of their growth habit, e.g., erect/upright vs. prostate/viny, determinate vs. indeterminate. Dry bean cultivars with a similar sensitivity to GA_3 dose may have similar genetics related to gibberellin response.

Conclusion

This study showed that stem elongation of common bean cultivars responds to different doses of GA_3 and that this difference may be categorized in at least two groups, high and medium GA_3 sensitivity. GA_3 sensitivity could not be correlated to determinate vs. indeterminate, growth habit, e.g., erect/upright/bush vs. prostate/viny, or to market class. Individual cultivars would need to be evaluated in a short-term foliar bioassay for their specific GA_3 sensitivity before applying GA_3 in the field to raise lower pods and improve direct harvest.

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Table 3. New growth of Type I cultivars 1 week after exposure of unifoliate leaves to gibberellic acid (2007).

		GA_3 exposure (ppm)				
		0	0.125	8	512	2048
Cultivar	Market class	New growth (mm)[z]				
Agate	Pinto	488 B[y]	593 AB	725 A	743 A	691 A
Amber	Pinto	487 BC	444 C	702 A	648 AB	800 A
CDC Pintium	Pinto	309 C	505 B	642 AB	725 A	639 AB
Doray	Pinto	520 B	669 A	749 A	748 A	616 AB
Early Ray	Pinto	396 B	429 B	515 AB	486 AB	525 A
G2883	Great Northern	424 B	567 AB	612 AB	684 A	697 A
Nordic	Great Northern	210 C	177 C	462 B	607 A	622 A
Newport	Navy	33 C	31 C	100 B	418 A	423 A
Seafarer	Navy	89 C	115 C	321 B	523 A	598 A
Foxfire	Light Red Kidney	131 C	143 C	431 B	658 A	700 A
Pink Panther	Light Red Kidney	279 C	288 C	522 B	675 A	686 A
Rog 776	Light Red Kidney	155 C	211 C	516 B	729 A	660 A
Moldova 104	Large White Kidney	217 D	361 C	618 B	668 B	813 A

[z]New growth was calculated as the plant height 7 d after treatment minus the plant height at time of treatment.

[y]Mean separation for each cultivar (rows) by least significant difference at $P < 0.05$.

GA_3 = gibberellic acid.