Influence of Gibberellic Acid on Carrot Growth and Severity of Alternaria Leaf Blight

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ABSTRACT

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Applications of gibberellic acid (GA) to carrot foliage consistently reduced the percentage of leaf area affected by *Alternaria dauci* compared with nontreated plants. The degree of leaf blight reduction with two applications of GA was similar to that achieved with four applications of the fungicide iprodione. At the rates examined (GA at 2.5 to 250 mg/liter), foliage dry weights were generally increased by GA. Although root weight was significantly reduced by rates of 250 mg/liter, applications of lower rates (40 mg/liter or less) reduced leaf blight severity without affecting root quality. Applications of GA usually resulted in plants with longer leaves, wider petioles, and a more upright growth habit. In one trial, leaf length and petiole diameter increased linearly with increasing rates (20, 30, and 40 mg/liter). When applied twice at 30 mg/liter, GA did not affect cuticle, epidermal, or leaf thickness. In general, the initial timing of two applications of 20 to 40 mg/liter (4, 6, or 8 weeks after plant emergence) did not influence the effects of GA. However, in one trial, there was a greater incidence of core separation from the root cortex when 40 mg/liter was applied initially at 4 weeks. GA at 30 mg/liter slightly but significantly decreased inner root color in one of two trials.

Alternaria leaf blight of carrots (*Daucus carota*), caused by *Alternaria dauci*, and carrot black rot, caused by *A. radicina*, are often difficult to manage when the crop is exposed to prolonged periods of leaf wetness and warm temperatures (15). Fungicides are a primary control strategy, but as the crop matures and the leaf canopy becomes increasingly dense, good coverage is difficult to obtain. The potential use of gibberellic acid to augment fungicide applications in carrots originated in an evaluation of the ability of plant hormones to affect petiole senescence (R. M. Davis, *unpublished*). Because senescing petiole bases often serve as an infection court for *A. radicina* (8), it was hypothesized that foliar applications of these hormones might delay the senescence process, thus reducing the incidence of black rot. While black rot severity was not reduced by any treatment, the incidence of leaf blight was significantly lower in plots treated with gibberellic acid than in nontreated plots. Root size, however, was sometimes reduced in treated plots. The objectives of this study were to evaluate rates and timing of applications of gibberellic acid for the management of leaf blight and to determine the effect of gibberellic acid on root quality.

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MATERIALS AND METHODS

Field trials were conducted in commercial carrot fields in the lower San Joaquin Valley, California. All experimental plots consisted of a single row, 4.6 m long, of the variety Caropak. A single buffer row was included between all plots. Treatments were arranged in a randomized complete block design. In the initial two trials, carrots were treated with two applications of gibberellic acid (GA) (ProGibb Plus 2x, Abbott Laboratories, Abbot Park, IL) at 2.5, 25, or 250 mg/liter, beginning 6 weeks after seedling emergence. In two subsequent experiments, two applications of 0, 20, 30, or 40 mg/liter, beginning 4, 6, or 8 weeks after seedling emergence, were made in order to determine an optimum application schedule. Treatments were replicated five times. In all trials, the interval between applications of GA was 14 days. In the second pair of experiments, the fungicide iprodione (Rovral F-4, Rhone-Poulenc Ag. Co., Research Triangle Park, NC) was included to compare the efficacy of GA with the standard fungicide used by the California carrot industry. The fungicide was applied every 2 weeks for a total of four applications at the recommended rate of 0.112 g a.i./m^2. The fungicide spray schedule began 4 weeks after seedling emergence. All GA and fungicide treatments were applied in a volume of water equivalent to 280 liters/ha.

Prior to harvesting, a minimum of 12 carrots in each plot was evaluated for leaf blight severity on a scale of 0 to 5, indicating 0, 1, 5, 10, 20, and 40% or more, respectively, of the total leaf area blighted. Each value represented the incremental midpoint on the severity scale (14). Shoot length, petiole diameter, top dry weight, and root dry weight of 12 carrots arbitrarily selected from each plot were measured at the time of harvest (12 to 14 weeks after plant emergence). Shoot length and petiole diameter measurements were made on the two youngest fully expanded leaves. Measurements of petiole diameters were made 10 cm from the base of the leaf.

The effect of GA on carrot root color, core separation, and leaf morphology was determined in the latter two trials. Inner and outer root color were measured using a Minolta tristimulus colorimeter, model CR-200, calibrated with the no. 9 channel (orange tile). The colorimeter defined color by lightness of color and ratios of red–green and blue–yellow (3,18). Triplicate readings were recorded from three locations along the length of 12 roots from each plot. Inner root color was measured on the cortex of three cross sections of each root. Core separation, characterized by an initial fracture in the phloem parenchyma that eventually led to the separation of the core from the rest of the root, also was determined. A total of 50 2-cm-long root sections from five or more carrots from each plot was stored at 5°C in a plastic bag. After 30 days, the percentage of sections with separated cores was recorded.

To determine the effect of applications of GA on the thickness of the leaf cuticle, epidermis, and blade, six carrots from the nontreated plots and plots treated with GA at 30 mg/liter at all application schedules were harvested approximately 90 days after seedling germination. The terminal leaflet of each of two leaves from each carrot was freehand sectioned with the aid of a dissecting microscope. Sections were immediately stained in a saturated solution of Nile Red in pure acetone for 5 min, rinsed in double-deionized water, and mounted in a drop of glycerol. The cuticle was identified as the area above the periclinal cell wall that fluoresced gold when viewed using a FITC 09 filter and epifluorescence (6). Using a calibrated eyepiece at ×1,500 magnification, three measurements were made of the cuticle, epidermal, and

leaf thickness from four different cross sections of each leaflet. In addition, cuticular leaf waxes were extracted as a second means of assessing cuticle thickness. Leaves of 15 carrots treated with GA at either 0 or 30 mg/liter were washed and placed on paper towels. When dry, leaflets were removed from the petioles, and the combined fresh weight of the 15 leaves was recorded. The leaflets were then dipped in chloroform for 2 min. The weight of the cuticular waxes in the extractions was determined after the chloroform evaporated.

Table 1. Influence of gibberellic acid (GA) on carrot growth and severity of Alternaria leaf blight

Treatment[a]	Leaf length (cm)	Petiole diam (mm)	Top dry wt (g)	Root dry wt (g)	Blight rating[b]
None	51.6	4.4	3.2	7.5	3.7
2.5 mg/liter	55.7	4.3	3.4	7.5	3.2
25 mg/liter	57.4	4.4	3.9	7.2	2.7
250 mg/liter	62.2	5.0	5.0	5.3	2.3
Contrast			Sum of squares[c]		
None vs. all GA	176.817*	0.113	3.083*	2.684	2.321*
2.5 vs. 25 + 250 mg/liter	58.241*	0.736*	4.181*	4.872*	1.240*
25 vs. 250 mg/liter	57.600*	1.089*	3.364*	9.428*	0.625
Mean square error	12.439	0.113	0.338	0.625	0.045

[a] GA was applied twice as a foliar spray, with a 2-week interval between applications. The first application was made 6 weeks after plant emergence.
[b] Severity of blight was determined on a scale of 0 to 5, where 0 = 0%, 1 = 1%, 2 = 5%, 3 = 10%, 4 = 20%, and 5 > 40% of the leaf blade affected.
[c] Contrasts noted with an asterisk are significant at $P \leq 0.05$.

Table 2. Effect of applications of iprodione and various rates of gibberellic acid (GA) on carrot growth and severity of Alternaria leaf blight, Trial 1

Treatment[a]	Leaf length (cm)	Petiole diam (mm)	Top dry wt (g)	Root dry wt (g)	Blight rating[b]
None	47.6	2.9	2.2	2.7	3.8
Iprodione	48.2	3.1	2.3	2.6	2.5
20 mg/liter	53.5	3.2	2.5	2.9	2.6
30 mg/liter	54.7	3.4	2.7	2.8	2.5
40 mg/liter	56.6	3.5	2.7	3.0	2.1
Contrast			Sum of squares[c]		
None vs. all trtmts	148.062*	0.845*	0.612*	0.177	7.778*
Iprodione vs. all GA	148.790*	0.299*	0.447*	0.400	0.034
GA rate linear	27.929*	0.368*	0.040	0.006	1.500*
Mean square error	4.878	0.038	0.025	0.107	0.230

[a] GA was applied twice as a foliar spray (with a 2-week interval between applications) beginning 4, 6, or 8 weeks after germination. Because timing had no significant effect on any variable ($P > 0.05$), data were combined across timing treatments. Iprodione was applied biweekly for four applications at a rate of 0.112 g a.i./m^2.
[b] Severity of blight was determined on a scale of 0 to 5, where 0 = 0%, 1 = 1%, 2 = 5%, 3 = 10%, 4 = 20%, and 5 > 40% of the leaf blade affected.
[c] Contrasts noted with an asterisk are significant at $P \leq 0.05$.

Table 3. Effect of applications of iprodione and various rates of gibberellic acid (GA) on carrot growth and severity of Alternaria leaf blight, Trial 2

Treatment[a]	Leaf length (cm)	Petiole diam (mm)	Top dry wt (g)	Root dry wt (g)	Blight rating[b]
None	43.6	2.8	2.1	3.5	4.6
Iprodione	44.1	2.9	2.6	4.3	1.6
20 mg/liter	56.0	2.9	2.5	4.5	2.2
30 mg/liter	56.3	3.0	2.9	4.6	2.3
40 mg/liter	59.7	2.9	2.8	4.6	1.6
Contrast			Sum of squares[c]		
None vs. all trtmts	154.731*	0.350	0.946*	1.443*	3.364*
Iprodione vs. all GA	135.807*	0.091	0.370	0.242	0.053
GA rate linear	94.465	0.038	0.043	0.008	1.500
Mean square error	7.931	0.029	0.152	0.717	1.033

[a] GA was applied twice as a foliar spray (with a 2-week interval between applications) beginning 4, 6, or 8 weeks after germination. Because timing had no significant effect on any variable ($P > 0.05$), data were combined across timing treatments. Iprodione was applied biweekly for four applications at a rate of 0.112 g a.i./m^2.
[b] Severity of blight was determined on a scale of 0 to 5, where 0 = 0%, 1 = 1%, 2 = 5%, 3 = 10%, 4 = 20%, and 5 > 40% of the leaf blade affected.
[c] Contrasts noted with an asterisk are significant at $P \leq 0.05$.

Data were subjected to analysis of variance and followed by single-degree-of-freedom orthogonal contrasts using the SAS general linear model procedure (GLM, 6th ed., SAS Institute, Cary, NC). Where rates of GA differed exponentially, linear trends were not explored, since it was desirable to analyze the individual performance of the very high and very low rates of GA on carrot growth and leaf blight development. Linear responses were evaluated where rates of GA increased at regular intervals. Data for shoot and root dry weights were transformed to their log equivalents in order to normalize data sets prior to analysis.

RESULTS

In general, applications of GA increased the growth of carrot foliage while decreasing the relative severity of Alternaria leaf blight. In the initial trial, leaf length and foliage weight increased with increasing rates of GA (Table 1). At 250 mg/liter, petiole diameter was significantly greater than the petiole diameter of leaves treated with 25 mg/liter. In contrast, root dry weight was significantly reduced by GA at 250 mg/liter. Over all rates, GA reduced the relative severity of Alternaria leaf blight. The higher rates of GA, 25 and 250 mg/liter, more effectively reduced symptom expression than the lower rate, 2.5 mg/liter. In the duplicated trial, 250 mg/liter, but not 2.5 or 25 mg/liter, reduced the severity of blight (data not presented); otherwise, trends were similar.

In the two trials evaluating timing of applications of GA, there were no significant differences in plant growth variables or leaf blight incidence whether GA applications were initiated 4, 6, or 8 weeks after plant emergence; therefore, data of the different timing treatments within trials were combined. In the first trial, leaf length and petiole diameter increased linearly as the concentration of GA increased from 20 to 40 mg/liter (Table 2). Top dry weights were increased by GA compared with the nontreated plants. Root dry weights were not affected by GA or iprodione. Severity of Alternaria leaf blight decreased linearly as the concentration of GA increased. Applications of iprodione similarly decreased the severity of blight. In the duplicated trial, GA application increased leaf length irrespective of rate (Table 3). Petiole diameter was not affected by any treatment. Top and root weights were significantly and similarly increased by iprodione and the GA treatments. Both GA and iprodione decreased the relative severity of leaf blight. In all experiments, applications of GA resulted in plants with a more upright growth habit compared with nontreated plants.

In the first trial that evaluated timing of the initial GA application, GA caused a significant decrease in orange color of the inner root due to a lower red-to-yellow

ratio (Table 4). Outer root color was not affected. In the second trial, root color was not affected by any treatment. Core separation was independent of most GA treatments in the trials (Table 5). However, when applied early (4 and 6 weeks after plant emergence), GA applied at 40 mg/liter significantly increased the incidence of core separation in one trial. In the other trial, the incidence of core separation was negligible, and there were no significant differences between treatments.

There were no significant differences in cuticle, epidermal, or leaf thickness between nontreated plants and plants treated with two applications of GA at 30 mg/liter (data not presented). Additionally, the amount of cuticular leaf waxes in chloroform extractions from treated and nontreated carrot leaves were not significantly different.

DISCUSSION

Applications of GA to carrot foliage consistently reduced the relative severity of Alternaria leaf blight. The reduction of visual symptoms of blight with GA was similar to that achieved with regular applications of iprodione. In one trial, GA increased root yields, presumably due to the relative reduction in leaf damage caused by the pathogen. Greater top growth may have compensated for loss of functional leaf tissue to the disease. However, GA may have affected several other processes. Because GA consistently increased the length of leaves and frequently increased the overall top weight of the plants without affecting cuticle, epidermal, or leaf thickness, the reduction in blight may be a result of a change in plant architecture. The increase in leaf length may explain the strikingly more upright habit of the treated plants compared with the nontreated plants. Such a growth pattern may help improve air movement through the canopy and thus reduce leaf wetness, which is necessary for disease development (14).

The majority of carrots destined for the fresh market are harvested with self-propelled, multirow harvesters that undercut and lift the roots by their tops using a system of belts. Thus, an increase in shoot length and petiole diameter resulting from GA applications may provide the additional benefit of improving the harvestability of the crop. Since the older leaves are most susceptible to Alternaria leaf blight (8,14), a delay in senescence from exogenous GA also may reduce infection. However, in our preliminary trials, GA did not visibly affect leaf senescence (R. M. Davis, *unpublished*).

Gibberellic acid is involved in many plant processes, including cell division and elongation, flowering, seed germination, dormancy, sex expression, parthenocarpy, fruit set, and delaying senescence (7). Since its discovery, synthetic GA has been widely used to manipulate certain functions and characters of agronomic and horticultural crops. For example, GA is used to reduce fruit set in peaches (16) and to delay postharvest senescence in various crops, including roses (5) and citrus (9). GA has also been used in the management of several diseases. Black spot of persimmon, caused by *Alternaria alternata*, was reduced by GA, which reduced the relative humidity around the infection court due to increased calyx erectness (10). GA applications also delayed postharvest decay of celery and rose flowers caused by *Botrytis cinerea*. In celery, reduction of postharvest decay was attributed to the ability of GA to retard senescence and thus degradation of certain phytoalexins (1). A reduction in cell membrane permeability in rose petals due to delayed senescence was implicated in *Botrytis* suppression of cut roses (11–13). By delaying tissue senescence, a single preharvest application of GA at 25 mg/liter also caused a significant decrease in decay of Romaine lettuce caused by *Stemphylium* spp. and *Bremia lactucae* (2).

GA must be applied at appropriate rates to avoid adverse effects on carrot root quality. At the high rate (250 mg/liter) used in this study, larger tops were produced at the expense of root development. A shift in the source–sink relationship after GA applications, resulting in increased shoot growth and an underdeveloped and unmarketable carrot, has been explored (4,17). In one study, GA at 100 mg/liter always increased the shoot-to-root ratio and reduced root yield by 35% (4). In another study, the maximum effect of GA on repartitioning dry matter in carrots occurred at concentrations of 100 to 500 mg/liter (17). At the relatively low rates (20 to 40 mg/liter) used in part of this study, increased top growth did not compromise root yield.

GA also may adversely affect carrot root color. In one trial in this study, GA significantly reduced inner root color, although it was difficult to detect with the naked eye. No effect on outer root color was observed. In addition, a greater number of carrot root disks separated from their core in plants treated with GA at 40 mg/liter at 4 and 6 weeks after plant emergence, relative to the nontreated control, which may be a concern for the cut and peel industry. For reasons unknown, iprodione had a similar effect in one trial. The timing of initial applications of GA used in this study (4 to 8 weeks after planting) did not otherwise influence carrot growth or the relative reduction of leaf blight symptoms. Although these results may differ if leaf blight develops on young plants, leaf blight on carrots in California usually develops on plants older than 8 weeks.

Table 4. Effect of applications of iprodione and various rates of gibberellic acid (GA) on carrot root color

Treatment[a]	Outer root[b]	Inner root[b]
None	0.57	0.54
Iprodione	0.58	0.54
GA 20 mg/liter	0.56	0.51
GA 30 mg/liter	0.56	0.49
GA 40 mg/liter	0.55	0.50
Contrast	Sum of squares[c]	
None vs. all trtmts	0.0006	0.0060*
Iprodione vs. all GA	0.0014	0.0073*
GA rate linear	0.0003	0.0004
Mean square error	9.7598	0.0012

[a] GA was applied twice as a foliar spray (with a 2-week interval between applications) beginning 4, 6, or 8 weeks after germination. Because timing had no significant effect on root color ($P > 0.05$), data were combined within each rate. Iprodione was applied biweekly for four applications at a rate of 0.112 g a.i./m^2.

[b] Root color was measured with a Minolta colorimeter, model CR-200. The ratio of red to yellow quantified the color orange.

[c] Contrasts noted with an asterisk are significant at $P \leq 0.05$.

Table 5. Influence of foliar sprays of gibberellic acid (GA) on carrot core separation

Treatment, application date[a]	Separated disks[b] (%)
None	6
GA 20 mg/liter, 4 and 6 weeks	10
GA 20 mg/liter, 6 and 8 weeks	2
GA 20 mg/liter, 8 and 10 weeks	12
GA 30 mg/liter, 4 and 6 weeks	0
GA 30 mg/liter, 6 and 8 weeks	2
GA 30 mg/liter, 8 and 10 weeks	0
GA 40 mg/liter, 4 and 6 weeks	32*
GA 40 mg/liter, 6 and 8 weeks	4
GA 40 mg/liter, 8 and 10 weeks	12
Iprodione	40*

[a] Timing of applications of GA after plant emergence. Iprodione was applied biweekly for four applications at a rate of 0.112 g a.i./m^2.

[b] A total of 50 carrot disks from each treatment in each of four replications was scored for separation of core from root. Values with an asterisk are significantly different from the nontreated control according to a *t* test ($P = 0.05$).

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