HortScience 33(2):318–320. 1998.

Response of Leading Bell Pepper Varieties to Bentazon Herbicide

Howard F. Harrison[1] and Richard L. Fery[2]
U.S. Vegetable Laboratory, Agricultural Research Service, U.S. Department of Agriculture, 2875 Savannah Highway, Charleston, SC 29414-5334

Additional index words. Capsicum annuum, herbicide resistance, weed control

Abstract. **Greenhouse and field studies were conducted to assess the relative tolerance of leading bell pepper (*Capsicum annuum* L.) varieties to the herbicide bentazon. In the greenhouse, nine bell pepper varieties varied in bentazon tolerance. One of the most tolerant varieties, 'King Arthur', was not severely injured, and its shoot mass was not reduced by 2.0 kg·ha^{-1} bentazon. The shoot mass of one of the least tolerant bell varieties, 'Summer Sweet 860', was reduced by 1.0 kg·ha^{-1} bentazon. The bentazon rates resulting in 50 percent reduction in shoot mass (MR_{50}) or injury (I_{50}) estimated by logit–probit analysis were 7.9 and 3.1 kg·ha^{-1} for 'King Arthur' and 3.8 and 1.5 kg·ha^{-1} for 'Whopper Improved', respectively. In a field study, F_1 'King Arthur', the tolerant control 'Santaka', and the F_2 progeny of 'King Arthur' were similar in bentazon tolerance, and there was no genetic segregation for tolerance in the F_2 population. Some modern bell pepper varieties appear to be sufficiently tolerant to allow bentazon use. Chemical name used: 3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3 *H*)-one 2,2 dioxide (bentazon).**

Bell peppers for the fresh market in the southeastern United States are typically grown in beds mulched with black polyethylene and fumigated with methyl bromide to control yellow nutsedge (*Cyperus esculentus* L.), root knot nematodes (*Meloidogyne* sp.), and other soil pests. Even with methyl bromide fumigation, yellow nutsedge is common in pepper fields, probably due to encroachment from row middles or emergence from below the fumigated soil layer (personal observations and communication with growers). There is concern that with the ban of methyl bromide for soil fumigation scheduled for 2001 (Crop Protection Coalition, 1995), yellow nutsedge will become unmanageable in peppers and other fumigated vegetable crops. Schroeder et al. (1994) reported that yellow nutsedge is an alternate host for root-knot nematode, an important pepper pest. Schroeder et al. (1993) concluded that crop rotation and other cultural practices to manage nematodes in peppers will not be effective if yellow nutsedge is not controlled.

Bentazon effectively controls yellow nutsedge, although repeated applications may be required (Basagran herbicide label; BASF Corp., P.O. Box 13528, Research Triangle Park, N.C.). Pepper varieties vary in bentazon tolerance, and the most susceptible varieties are severely injured by the normal use rate of 1.1 kg·ha^{-1} (Baltazar et al., 1984; Harrison and Fery, 1989; Wolff et al., 1989). The most tolerant varieties are not severely injured and exhibit no yield reduction at up to 4.5 kg·ha^{-1} bentazon. Due to the inadequate tolerance of many varieties, bentazon has never been registered for general use in peppers, but a special local registration (Section 18 approval) was granted for processing chili peppers in North Carolina (personal communication with David M. Peele). Fery and Harrison (1990) reported that tolerance was controlled by a single dominant gene in the highly tolerant chili variety Santaka. Wolff et al. (1992) concluded that genetic control of tolerance in the highly tolerant variety Bohemian Chili was more complex, involving a single major dominant gene and several modifying genes. They indicated that expression of bentazon tolerance was affected by environment and even varied within populations of plants expected to be homogeneously tolerant or susceptible.

The pending loss of methyl bromide for soil fumigation in bell peppers has necessitated the development of alternative methods for controlling yellow nutsedge and other weeds. Thus, an investigation was initiated to assess bentazon tolerance in several modern bell pepper varieties. The objectives of this study were to determine the relative bentazon tolerance of nine currently grown bell pepper varieties that were not evaluated in previous studies (Baltazar et al., 1984; Harrison and Fery, 1989; Wolff et al. 1989) in a greenhouse experiment, and to confirm high tolerance under field conditions.

Materials and Methods

Greenhouse study. Seeds of nine bell pepper varieties ('Boynton Bell', 'Camelot', 'Capistrano', 'Jupiter', 'King Arthur', 'Orobella', 'PR-9600-8', 'Summer Sweet 860', and 'Whopper Improved') commonly grown commercially in the southeastern United States at the time that the studies were initiated (consultation with extension and seed company representatives) were obtained from commercial sources. 'Capistrano' and 'Jupiter' are open-pollinated varieties, and the others are F_1 hybrid varieties. Seeds of the control varieties, 'Santaka' (a chili variety) and the sweet pepper varieties Keystone Resistant Giant and Sweet Banana, were produced at the U.S. Vegetable Laboratory. 'Santaka', 'Keystone Resistant Giant', and 'Sweet Banana' were known from previous studies (Harrison and Fery, 1989) to be highly tolerant, intermediate, and highly susceptible to bentazon, respectively. Pepper seeds were germinated in flats containing a commercial peat–vermiculite potting medium, and after emergence, seedlings were transferred to 500-mL styrofoam cups containing the potting medium. Pepper plants were grown in the greenhouse without supplemental lighting, and greenhouse temperatures ranged from 20 to 32 °C. Peppers were fertilized weekly with a complete water soluble fertilizer. When peppers reached ≈10 to 12 cm in height, they were treated with bentazon using a conveyor belt sprayer that delivered 286 L·ha^{-1} spray volume at 275 kPa. Bentazon rates were 0, 0.5, 1.0, 2.0, 4.0, and 8.0 kg·ha^{-1} and crop oil concentrate was included at 2.5 L·ha^{-1}. One week after application, pepper plants were rated for bentazon injury on a scale from 0 to 100, where 0 = no injury, 30 = moderate leaf chlorosis and slight necrosis, 70 = severe leaf chlorosis and necrosis with some leaf loss, 100 = dead plant. Immediately after rating, pepper shoots were excised at the soil surface and weighed. The experiment was arranged in a randomized complete-block design with six replications and was repeated four times. Means of injury ratings, shoot mass and shoot mass reduction as percentage of control mass from the four experiments were analyzed in a randomized complete-block design where each experiment mean constituted a block, and protected least significant differences at the 95% level of significance were used to compare means within varieties and bentazon rates. Linear regression analysis was used to determine rate-response to bentazon within cultivars. The bentazon rates that caused 50% reduction in shoot mass (MR_{50}) or injury (I_{50}) were determined for each variety using logit–probit analysis of the averaged data after the method of Finney (1971).

Field study. A field experiment was conducted to confirm the tolerance of the F_1 hybrid variety, 'King Arthur', and to observe the response of F_2 plants of 'King Arthur' in order to obtain preliminary information about the inheritance of tolerance. Seeds were collected from eight self-pollinated 'King Arthur' plants that were grown in the greenhouse. Seedlings of 'King Arthur', 'Santaka', 'Sweet Banana', and the eight F_2 populations were produced in the greenhouse and transplanted at the 4- to 6-leaf stage to the field on 15 May 1996. The

Received for publication 15 May 1997. Accepted for publication 10 Oct. 1997. The authors wish to acknowledge the assistance of Agricultural Research Technicians F.P. Maguire and L.L. Lawrence and the donation of pepper seed for this project by Pepper Research, Bell Glade, Fla. This work was supported in part by the Integrated Pest Management Collaborative Research Support Program (IPM CRSP), U.S. Agency for International Development (USAID), under Grant No. LAG-4196-G-00-3053-00. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

[1]Research Agronomist.
[2]Research Geneticist.

Table 1. Pepper shoot mass reduction in response to postemergence bentazon application and estimated bentazon rates required to cause 50% reduction in shoot mass (MR_{50}) for pepper 12 varieties in a greenhouse experiment.

	Shoot mass reduction (% of untreated control)						
	Bentazon ($kg\cdot ha^{-1}$)						
Variety	0.5	1	2	4	8	Regression[y]	MR_{50} ($kg\cdot ha^{-1}$)
			Bell varieties				
Summer Sweet 860	15 a[z]	21 a	34 a	50 a	71 a	**	3.6
Boynton Bell	1	16	23 a	48 a	69 a	***	4.3
PR 9600-8	8	9	21 a	36 a	57 a	***	6.7
Camelot	8	23 a	34 a	52 a	65 a	**	3.9
King Arthur	1	6	14	30 a	50 a	***	7.9
Whopper Improved	17	21 a	40 a	53 a	75 a	**	3.1
Orobella	–9	1	9	38 a	55 a	**	6.4
Jupiter	1	11	18 a	41 a	69 a	***	4.9
Capistrano	8	12	22 a	41 a	71 a	***	4.7
			Control varieties				
Santaka[x]	22 a	20 a	29 a	31 a	50 a	**	13.3
Sweet Banana[w]	49 a	52 a	65 a	74 a	79 a	*	0.7
Keystone Resistant Giant[v]	20	23	16	47 a	70 a	**	4.0
$LSD_{0.05}$[u]	18	20	23	17	15		

[z]Values significantly less than that of the untreated control at $P \leq 0.05$.
[y]Linear regression significant at $P \leq 0.05$ (*), 0.01 (**), or 0.001 (***).
[x]Tolerant control, chili-type pepper.
[w]Susceptible control.
[v]Intermediate control, bell-type pepper.
[u]Protected least significant differences at $P \leq 0.05$ for comparing cultivar means within bentazon rates.

Table 2. Pepper injury ratings in response to postemergence application of bentazon, and estimated bentazon rate required to cause 50% injury (I_{50}) for twelve pepper varieties in a greenhouse experiment.

	Injury (%)[z]						
	Bentazon ($kg\cdot ha^{-1}$)						
Variety	0.5	1	2	4	8	Regression[y]	I_{50} ($kg\cdot ha^{-1}$)
			Bell varieties				
Summer Sweet 860	14	25	38	68	89	**	2.3
Boynton Bell	16	32	39	69	88	**	2.1
PR 9600-8	9	15	32	48	73	***	3.8
Camelot	15	27	47	70	85	**	2.1
King Arthur	11	21	32	53	75	***	3.5
Whopper Improved	20	40	58	77	90	**	1.5
Orobella	11	22	32	65	76	**	2.9
Jupiter	16	30	41	67	84	**	2.2
Capistrano	11	22	38	62	92	***	2.4
			Control varieties				
Santaka[x]	15	17	28	31	60	**	7.1
Sweet Banana[w]	58	67	79	90	94	*	0.4
Keystone Resistant Giant[v]	22	31	43	59	85	*	2.2
$LSD_{0.05}$[u]	12	10	11	11	8		

[z]Bentazon injury was rated 5 d after application on a scale where 0 = no injury, 30 = moderate leaf chlorosis and slight necrosis, 70 = severe leaf chorosis and necrosis with some leaf loss, 100 = dead plant.
[y]Linear regression significant at $P \leq 0.05$ (*), 0.01 (**), or 0.001 (***).
[x]Tolerant control, chili type pepper.
[w]Susceptible control.
[v]Intermediate control, bell type pepper
[u]Protected least significant differences at $P \leq 0.05$ for comparing cultivar means within bentazon rates.

plants were managed using standard cultural practices as previously described (Harrison and Fery, 1989). The soil was a Yonges loamy sand (fine-loamy, mixed, thermic Typic Albaqualfs) with a pH of 6.2. Seedlings were transplanted into narrow beds spaced at 1 m, and plants were spaced 0.8 m apart within the row. The experiment was arranged in a randomized complete-block design with 10 replications. Plots consisted of a single row containing 10 plants, and blocks contained one plot of eight F_2 populations and the three varieties. On 5 June, when most plants were in the 6- to 8-leaf stage and were similar in size to plants in the greenhouse study at herbicide application, bentazon was applied as a broadcast application (spray volume 270 $L\cdot ha^{-1}$) to all plants at a rate of 4.0 $kg\cdot ha^{-1}$ with crop oil included at 2.3 $L\cdot ha^{-1}$. Visible injury following this treatment was less than anticipated, thus bentazon was reapplied as described above at 6.0 $kg\cdot ha^{-1}$ on June 15. At this application, most plants were in the 10- to 14-leaf stage. Five d after application, individual plants were rated for visible bentazon injury on a 0 to 10 scale, where 0 = no injury, 3 = moderate leaf chlorosis and slight necrosis, 7 = severe leaf chlorosis and necrosis with some leaf loss, and 10 = dead plant. The frequency distribution of injury ratings was plotted, and mean injury ratings and standard errors of the means were determined for each population.

Results and Discussion

Greenhouse study. The nine commercial bell pepper varieties evaluated in this study exhibited variability in bentazon tolerance; however, there was a significant linear regression for bentazon rate vs. injury rating and shoot mass reduction for all varieties (Tables 1 and 2). 'King Arthur', 'Orobella', and 'PR 9600-8' were the most tolerant bell varieties; their injury ratings and shoot mass reductions

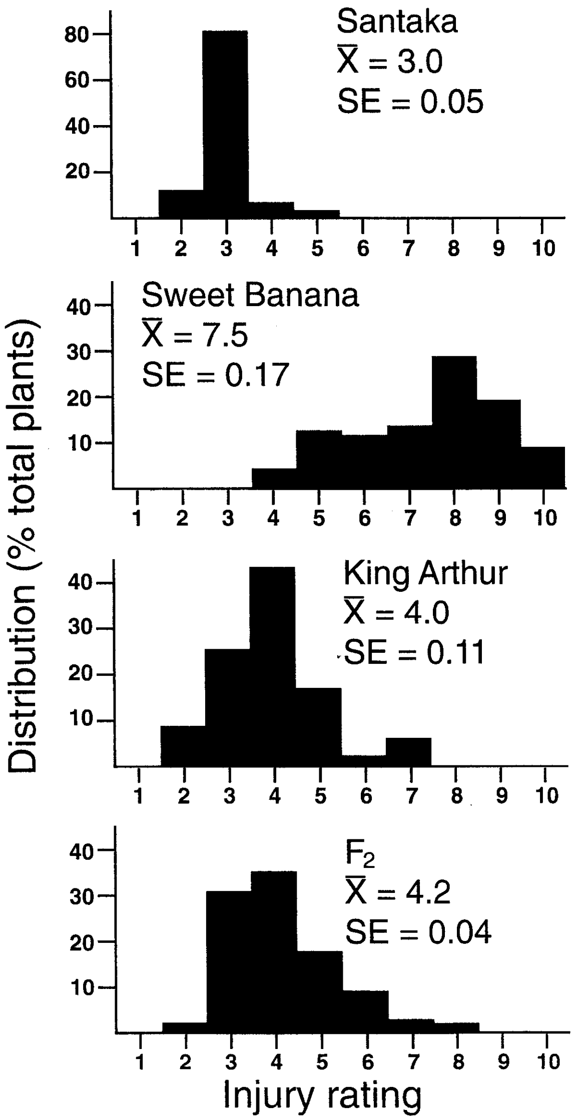

Fig. 1. Comparative frequency distribution of injury ratings of field-grown pepper plants following application of 6.0 kg·ha^{-1} bentazon to 'Santaka', 'Sweet Banana', 'King Arthur' and a pooled F_2 population derived from 'King Arthur'. Injury for individual plants was rated on a 0 to 10 scale, where 0 = no injury, 3 = moderate leaf chlorosis and slight necrosis, 7 = severe leaf chlorosis and necrosis with some leaf loss, and 10 = dead plant.

were not different at any bentazon rate, and their MR_{50} and I_{50} estimates were similar. 'King Arthur', 'Orobella', and 'Keystone Resistant Giant' were the only varieties not exhibiting shoot mass reduction at 2.0 kg·ha^{-1} bentazon. Injury ratings for the most tolerant bell varieties did not differ from 'Santaka' ratings at the lower rates, but at 4 and 8 kg·ha^{-1}, they exhibited greater injury. Shoot masses of the least tolerant bell pepper varieties, 'Whopper Improved', 'Camelot', and 'Summer Sweet 860', were reduced by 1.0 kg·ha^{-1} bentazon. These varieties may not be sufficiently tolerant to allow safe bentazon use. 'Santaka' shoot masses at all bentazon rates were lower than control values, but masses were not different for bentazon application rates between 0.5 and 4.0 kg·ha^{-1}. Shoot mass reduction not accompanied by severe injury symptoms has been observed with this variety in previous studies (Harrison and Fery, 1989). Low rates reduced shoot masses in the greenhouse but did not affect 'Santaka' yield in field studies.

Field study. The average injury ratings at 5 d after application of 6.0 kg·ha^{-1} bentazon were 3.0, 4.0, 4.2, and 7.5 for 'Santaka', 'King Arthur', the F_2 progeny of 'King Arthur', and 'Sweet Banana', respectively (Fig. 1). The moderate injury exhibited by 'King Arthur' at about five times the normal application rate confirms that the tolerance of this variety observed in the greenhouse is also expressed under field conditions. The similarity in average rating and the frequency distribution of injury ratings for 'King Arthur' and its progeny indicate that there was no genetic segregation for tolerance in the F_2 progeny of the hybrid variety.

Conclusions. In previous studies, the response of peppers to bentazon in the greenhouse proved to be similar to their response in the field (Harrison and Fery, 1989; Wolff et al., 1989). Bentazon rates that did not reduce shoot mass in the greenhouse did not affect fruit yields in the field. The results of this greenhouse study indicate that bentazon application at the recommended rates of 0.6 to 1.1 kg·ha^{-1} will not cause severe injury to or reduce yields of the most tolerant commercial bell pepper varieties. One of the most tolerant leading commercial varieties included in this study, 'King Arthur', proved to be tolerant under field conditions. Bentazon may be a viable alternative to methyl bromide for controlling yellow nutsedge and other weeds in bell peppers, but selection of tolerant varieties is necessary to avoid unacceptable levels of crop injury.

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