Effects of Bicarbonates and Film-Forming Polymers on Cucurbit Foliar Diseases

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ABSTRACT

Ziv, O., and Zitter, T. A. 1992. Effects of bicarbonates and film-forming polymers on cucurbit foliar diseases. Plant Dis. 76:513-517.

The inhibitory effects of sodium, potassium, and ammonium bicarbonates ($NaHCO_3$, $KHCO_3$ and NH_4HCO_3, respectively) alone and in combination with SunSpray Ultra-Fine Spray Oil (SS) on powdery mildew, caused by *Sphaerotheca fuliginea*; gummy stem blight, caused by *Didymella bryoniae*; Alternaria leaf blight, caused by *Alternaria cucumerina*; and Ulocladium leaf spot, caused by *Ulocladium cucurbitae*, were studied. SS oil performed consistently better than ForEverGreen, Masbrane, Crop Life, Vapor Gard, Nu-Film 17, and Bio-Film for powdery mildew control in cucumber and pumpkin. $NaHCO_3$ or $KHCO_3$ combined with SS oil, both at 0.5%, were more effective treatments for powdery mildew on pumpkin than either of the materials used alone, whereas NH_4HCO_3 was ineffective. All three bicarbonates (1% w/v) plus SS oil (1% v/v), and especially NH_4HCO_3 + SS, provided good control of gummy stem blight and Alternaria leaf blight of muskmelon and Ulocladium leaf spot of cucumber in greenhouse trials. The bicarbonate-plus-oil treatments were more effective when applied prior to inoculation. $KHCO_3$ was phytotoxic to mildew-infected pumpkin leaves at concentrations greater than 0.5%; $NaHCO_3$ caused minimal injury, and NH_4HCO_3 caused no injury. Similar results were obtained when bicarbonate solutions were applied to punctured cucumber cotyledons. In vitro studies showed that bicarbonate salts inhibited growth of these organisms and *Colletotrichum orbiculare*, causal fungus of cucurbit anthracnose. NH_4HCO_3 was most inhibitory. Na, K, and NH_4 chloride salts were least inhibitory.

Additional keywords: antitranspirants, disease control, mineral oil

Powdery mildew of cucurbits, caused primarily by *Sphaerotheca fuliginea* (Schlechtend.:Fr.) Pollacci, is a serious problem in cucurbit fields and greenhouses worldwide (20). Resistant cultivars or fungicide sprays are required for control (17). Currently only cucumber cultivars have resistance or, as in the case of cantaloupe, race-specific resistance to *Sphaerotheca*. Benomyl-resistant isolates were reported as early as 1969 in New York (16), and more recently insensitivity to triadimefon has occurred (12).

In addition to powdery mildew, other diseases of importance affecting cucumber, cantaloupe, watermelon, and many *Cucurbita* spp. under greenhouse and field conditions are gummy stem blight, caused by *Didymella bryoniae* (Auersw.) Rehm (1); anthracnose, caused by *Colletotrichum orbiculare* (Berk. & Mont.) Arx; and Alternaria leaf blight, caused by *Alternaria cucumerina* (Ellis & Everh.) J. A. Elliott (17). Recently, Ulocladium leaf spot caused by *Ulocladium cucurbitae* (Letendre & Roumeguere) Simmons has been described as a disease of cucumber in New York (22). Gummy stem blight is particularly important, because plants already infected by powdery mildew are predisposed to more severe gummy stem blight (2). Presently, only cultural practices and weekly fungicide sprays are available for control of these diseases.

Accepted for publication 9 December 1991 (submitted for electronic processing).

Coating polymers, such as antitranspirants, mineral oils, surfactants, and other products, have been used as artificial barriers on leaf surfaces to inhibit foliar pathogen development on various host plants (4,5,10,21,23,24). Most of these coating polymers are nonphytotoxic, permeable to gases, resistant to weathering for at least 1 wk, and biodegradable (5,24).

There is limited information on the use and effects of various bicarbonates on either soilborne or foliar plant pathogens. The fungicidal effects of ammonium bicarbonate (NH_4HCO_3) have been reported mainly on soilborne pathogens, including *Sclerotium rolfsii* Sacc. (11,14,15). McKee (13) reported the control of rose powdery mildew caused by *Sphaerotheca pannosa* (Wallr.:Fr.) Lév. var. *rosae* Woronichin by spraying sodium bicarbonate ($NaHCO_3$) mixed with an unspecified summer petroleum oil on infected leaves. The mixture was twice as effective as either material alone. More recently, Homma et al (7) reported on the use of $NaHCO_3$ and emulsifiers and surfactants to control citrus green mold and cucumber powdery mildew and described the inhibitory effect of $NaHCO_3$ on the life cycle of *S. fuliginea* (8). The use of $NaHCO_3$ and oils for controlling rose powdery mildew and black spot has recently been studied (9). The objective of this study was to determine if control of cucurbit foliar diseases, including powdery mildew, Alternaria leaf blight, gummy stem blight, and Ulocladium leaf spot, could be achieved under greenhouse conditions with a combination of bicarbonates and coating products.

MATERIALS AND METHODS

Culture of pathogens and hosts. A greenhouse isolate of powdery mildew (*S. fuliginea*) was used throughout these experiments and was maintained on pumpkin (*Cucurbita pepo* L. 'Spirit') and cucumber (*Cucumis sativus* L. 'Marketmore 76'). Five- to 7-wk-old (six- to eight-leaf stage) pumpkin and cucumber plants were grown in 10-cm plastic pots in a greenhouse at 24 C under daylight supplemented with fluorescent light. Three hours after treatment, five test plants were placed in a mist chamber at 25 C with 12 hr of fluorescent light. For each treatment, five pumpkin and/or cucumber plants heavily infected with *S. fuliginea* were placed between each treatment row of plants as an inoculum source in a randomized complete block design. Individual pots served as replicates for each treatment. The treated plants were moved back to the greenhouse after 48 hr. This experiment was repeated three times.

An isolate of *U. cucurbitae* (U313) was maintained on potato-dextrose agar at 21 C with 14 hr of light, as previously described (22). Conidial concentrations were adjusted to 45,000 spores per milliliter and atomized onto test plants at 69 kPa until runoff. Six-wk-old Dasher II cucumber plants in the six- to seven-leaf stage were used for inoculation. The inoculated plants (five pots for each treatment in a randomized complete design) were held in a mist chamber for 48 hr at 25 C and then moved back to the greenhouse. Leaves were inspected for lesions 2–3 days after inoculation. The experiment was repeated once.

An isolate of *D. bryoniae* was isolated from muskmelon leaves showing typical symptoms of gummy stem blight in Onondaga County, New York, in 1990. This isolate was maintained on V8 juice agar plates at 21 C with 14 hr of light. Under these conditions, pycnidia were produced and were used as inoculum (*Phoma cucurbitacearum* (Fr.:Fr.) Sacc., anamorph) (1). Conidial suspensions were prepared by growing the cultures at 21 C for 5–6 days, flooding the cultures with a solution of 0.1% sucrose and 0.05% hydrolyzed casein, gently scraping the cultures, and straining them through two layers of cheesecloth. Subsequently, the concentration of conidia was adjusted to 6×10^4/ml by diluting with the nutrient solution (2). The suspensions were atomized onto the upper leaf surface of muskmelon (*Cucumis melo* L. var. *reticulatus* Naudin 'Saticoy') in the four- to five-leaf stage. After inoculation, the plants (five pots for each treatment in a randomized complete design) were held in a mist chamber for 72 hr at 25 C before being moved back to a greenhouse for observation. The percent leaf area affected was recorded after 3 days. The experiment was repeated once.

An isolate of *A. cucumerina* was collected in 1990 from infected muskmelon plants in Freeville, New York. A single-spore culture was grown on V8 juice agar at 22 C in a 12-hr light regime. Inocula were prepared by flooding the surface of 2-wk-old cultures with sterile distilled water and gently scraping to detach the conidia. The suspension was further diluted with sterile water and adjusted to 3×10^4 conidia ml^{-1}. Saticoy muskmelon plants were grown in a growth chamber at 22 C in a 12-hr light regime. Eighteen-day-old plants in the three-leaf stage were inoculated as above and placed in a mist chamber at 25 C for 48 hr before being returned to the growth chamber. Five pots were used for each treatment, arranged in a randomized complete block design, and the experiment was repeated. Infected leaves were observed after 4–6 days for lesion size and number.

Selection of coating products. The upper leaf surface of pumpkin and cucumber was sprayed to runoff at 69 kPa with 0.6% (v/v) polymer emulsions of the following products: SunSpray Ultra-Fine Spray Oil (SS), a refined petroleum distillate (Safer Inc., Newton, MA, now marketed by Mycogen Corp., San Diego, CA); Vapor Gard (VG) di-1-*p*-menthene (high viscosity, pinolene, Miller Chemical & Fertilizer Corp., Hanover, PA); Nu-Film 17 (NF) di-1-*p*-menthene (low viscosity, pinolene, Miller Chemical); ForEverGreen (FEG), an acrylic copolymer (Safer Inc., Newton, MA, now marketed by Mycogen Corp, San Diego, CA); Crop Life (CL), a protein-enriched acrylate copolymer (Polymer Technologies Inc., Nocatee, FL); Masbrane (GZM) dodecyl alcohol (Aefachemi Ltd., Sheung Wan, Hong Kong); and Bio-Film (BF), an ionic-nonionic blend of five components (Kalo, Inc., Overland Park, KS). Controls consisted of plants sprayed with water or with the fungicide chlorothalonil (Bravo 720) at 800 μg a.i./ml. Each treatment was applied to four plants each of pumpkin and cucumber in separate tests, and both tests were repeated. Plants were rated for disease 8 days after inoculation by recording the number of powdery mildew spots per leaf (adaxial surface). Visual estimates also were made on the length of time (min) required for the polymers to dry, the percent of leaf surface area covered, and the time (min) that free moisture was available.

Table 1. Incidence of powdery mildew on greenhouse-grown cucumber and pumpkin plants treated with film-forming products

	Powdery mildew (%)[y]	
Treatment	Cucumber	Pumpkin
Water	49.7 a[z]	73.2 a
ForEverGreen	23.1 b	39.7 b
Masbrane	19.8 b	16.7 bc
Crop Life	61.4 a	93.4 a
Vapor Gard	17.2 bc	15.3 c
Nu-Film 17	6.5 c	19.0 bc
SunSpray Oil	5.3 c	6.1 c
Bio-Film	9.7 bc	14.4 c
Chlorothalonil	12.9 bc	32.0 b

[y]The average number of mildew (*Sphaerotheca fuliginea*) colonies per leaf was recorded for Marketmore 76 cucumber in the six-leaf stage and for Spirit pumpkin in the eight-leaf stage.

[z]Numbers in each column followed by the same letter are not significantly different according to Duncan's multiple range test at $P = 0.05$.

Use of bicarbonates and oil for foliar disease control. Four Spirit pumpkin plants (9 wk old) already heavily infected with powdery mildew were used as treatment plants. Plants were sprayed to runoff with $NaHCO_3$, potassium bicarbonate ($KHCO_3$), and NH_4HCO_3 at 0.5, 1.0, and 2.0% in distilled water (w/v); 0.5% $NaHCO_3$, $KHCO_3$, and NH_4HCO_3 plus 0.5% SS oil (v/v); and 0.5% SS oil alone. Treatments were randomized within the mist chamber in a complete block design. The effectiveness of treatments based upon visual appearance of percent leaf area affected was recorded daily for 10 days.

To observe the effects of bicarbonates alone on the control of powdery mildew, infected Spirit pumpkin leaves sprayed with 0.5% bicarbonate solutions were observed by light microscopy every 2 days for a 10-day period. Two leaves were sampled for each treatment by removing five 1-cm^2 tissue pieces from each leaf. The sections were taped onto slides for observation. The experiment was repeated three times.

The three bicarbonates (1%, w/v), the SS oil (1%, v/v), or the mixture of bicarbonates and SS oil (both at 1%) were also tested for the control of three additional foliar pathogens: *U. cucurbitae, P. cucurbitacearum*, and *A. cucumerina*. The treatments were applied to four plants preinoculation and postinoculation. The protective treatments were applied and allowed to air-dry for 2 hr before the plants were inoculated and incubated as described above. In postinoculation treatments, the plants were treated 24 hr after inoculation and incubation. The experiments were repeated.

In vitro studies. The inhibitory effect of the three bicarbonates and the corresponding chloride salts (NaCl, KCl, and NH_4Cl) was studied. The bicarbonate and chloride solutions were prepared in distilled water and added to water agar (WA) at 0.0, 0.5, 1.0, and 2.0% (w/v) prior to autoclaving. No pH adjustments were made to the media. Single-spore cultures of *P. cucurbitacearum, U. cucurbitae, A. cucumerina*, and *C. orbiculare* were begun by placing conidia of each organism in the center of four petri plates for testing each solution. The isolate of *C. orbiculare* was obtained from infected pumpkin fruit in 1990 and subsequently maintained on PDA at 22 C with 12 hr of light. The plates were incubated in a growth chamber (22 C, 65% RH, and 12 hr of fluorescent light) and the colony diameter measured daily for 5 days.

Phytotoxicity studies. Because visible phytotoxicity appeared only on powdery mildew–infected tissue of the bicarbonate-treated pumpkin leaves and not on healthy tissue, we established two experiments, one using greenhouse-grown pumpkin leaves infected with powdery mildew, and a second using punctured cucumber cotyledons. Solutions of Na, K, and NH_4 bicarbonates were prepared in distilled water at 0.0, 0.5, 1.25, 2.5, and 5.0% (w/v). Twelve 40-μl drops of the bicarbonate solutions were placed at random on either powdery mildew–infected or healthy Spirit pumpkin leaves. The necrotic areas were recorded 24 hr after treatment. Dasher II cucumber plants were grown in a growth chamber until the cotyledons were fully expanded (12 days old). One cotyledon on each cucumber seedling was punctured with a sharp needle, and the other cotyledon served as a nonpunctured control. Six 40-μl drops of the three bicarbonate solutions at each concentration were placed on each cotyledon of four seedlings. The seedlings were incubated in the growth chamber, and the phytotoxicity damage was evaluated after 24 hr. This experiment was repeated on both the punctured and nonpunctured cotyledons; but instead of adding the bicarbonates as droplets, the materials of the same concentrations were atomized at 69 kPa until runoff. Necrotic and water-soaked areas were evaluated on a scale of 0–3, with 0 = no damage, 1 = 1- to 2-mm areas, 2 = 5- to 8-mm areas, and 3 = 80–100% of the cotyledon damaged.

RESULTS

Coating products. The best control of powdery mildew using coating materials on a numerical basis was achieved with SS on both cucumber and pumpkin (Table 1). BF and NF, followed by VG and GZM, also significantly reduced disease compared to the control. FEG had an intermediate effect, and CL was ineffective. SS, BF, NF, VG, and GZM had several physical properties in common, which may account for their biological performance. The average time required for the materials to dry on the leaf surface was less than 5 min, compared to 16.8 min for FEG and CL. The percent surface area covered with these polymers was greater than 87%, compared to 48% for the water control. Finally, the length of time that free water droplets were visible on the leaf surface was less than 14 min, compared to 249 min for water alone. On the basis of consistent mildew control, SS was selected for further testing.

Use of bicarbonates and oil for foliar disease control. Na and K bicarbonates at 1% reduced powdery mildew 63.1 and 48.1%, respectively, 1 day after treatment (Table 2). NH_4HCO_3 alone had no effect after 1 day. When Na and K bicarbonates were combined with SS at 0.5%, they were the most effective treatments in controlling powdery mildew (6.1 and 5.9%, respectively), with the inhibitory effect lasting for 10 days. SS alone also reduced mildew over the 10-day period but was not as effective as the combinations. Because these readings were based upon visual assessment, with lesion area reflecting previous damage and possible new mildew growth, the experiment was repeated with the same rates and combinations of materials, with lesion appearance assessed visually, with a hand lens, and microscopically. The order of control remained the same, with $KHCO_3$ performing slightly better than $NaHCO_3$ and superiorly to NH_4HCO_3. Microscopic observations of *S. fuliginea* revealed the presence of conidia and conidiophores 2 days after treatment with either water or NH_4HCO_3 (Fig. 1a), a limited number of conidia 6 days after treatment with $NaHCO_3$, and no conidia or conidiophores on tissue 10 days after treatment with $KHCO_3$ (Fig. 1b). With this treatment, the mycelia appeared in compressed mats and were not of uniform thickness.

Control of *U. cucurbitae, P. cucurbitacearum*, and *A. cucumerina* was better when the treatments were applied before inoculation, but the differences were not always statistically significant (Table 3). Control of *A. cucumerina* was significantly better when Na and NH_4 bicarbonates were used either alone or in combination with SS. NH_4HCO_3 + SS also provided significantly better control of *U. cucurbitae* and *P. cucurbitacearum*. Overall, NH_4HCO_3 + SS performed slightly better than the other bicarbonates.

In vitro studies. Bicarbonates inhibited the growth of all four pathogens tested on WA. NH_4HCO_3 was only slightly more inhibitory than $NaHCO_3$ at the three concentrations, but it was significantly more effective than $KHCO_3$ at 0.5% (Table 4). Only a limited amount of sporulation was observed in the cultures of *A. cucumerina* and *U. cucurbitae* when grown in WA with 2% bicarbonates. Of the three chlorides tested, NH_4Cl was most similar to $NaHCO_3$ and $KHCO_3$ in its inhibiting ability. KCl was least inhibitory at all concentrations.

Phytotoxicity. Phytotoxicity in the form of beige necrotic areas was noted on powdery mildew-infected pumpkin leaves treated with 1% and higher concentrations of $KHCO_3$ (Fig. 2a). A few beige necrotic spots appeared on infected leaves treated with the higher concentrations (2.5 and 5.0%) of $NaHCO_3$ and NH_4HCO_3. Tests with cucumber cotyledons also showed that phytotoxic symptoms were related to the concentration of the bicarbonate used; the higher the concentration, the greater the injury. In general, punctured cotyledons were more sensitive to the bicarbonate treatments than nonpunctured cotyledons (Fig. 2b). At the 5% concentration, all of the cotyledons, whether punctured or not, showed maximum injury (rated 3). The 2.5 and 1.25% $KHCO_3$ solutions still caused damage (rated 3 and 2, respectively) with or without punctures, while $NaHCO_3$ and NH_4HCO_3 showed less phytotoxicity (rated 2 and 1, respectively), and only on punctured tissue at these concentrations. At 0.5% no injury appeared with any of the treatments. When bicarbonate solutions were atomized onto cucumber cotyledons instead of being applied as droplets, no phytotoxicity occurred.

DISCUSSION

Film-forming polymers have been widely reported to provide protection against many foliar pathogens, including both obligate and facultative parasites (4,5,10,21,24). In previous studies Vapor Gard, Bio-Film, and Masbrane have shown activity against powdery mildew when applied prior to inoculation (4,5). In the present study, SunSpray provided the most consistent control of powdery mildew, suppressing mildew on the ad-

Table 2. Effect of bicarbonates alone and in combination with SunSpray Ultra-Fine Spray Oil (SS) on visual appearance of powdery mildew (*Sphaerotheca fuliginea*)-infected Spirit pumpkins in the greenhouse

	Leaf area covered with powdery mildew (%)				
	Days after treatment				
Treatment	1	4	7	10	Phytotoxicity[y]
$NaHCO_3$, 2%	18.4 b[z]	18.6 bc	20.3 b	23.8 b	+
$NaHCO_3$, 1%	63.1 b	70.1 a	81.4 a	91.1 a	−
$NaHCO_3$, 0.5%	90.3 a	89.5 a	84.9 a	90.9 a	−
$NaHCO_3$ + SS, both 0.5%	2.1 d	2.3 c	2.6 c	6.1 c	−
$KHCO_3$, 2%	5.2 c	6.0 c	8.3 b	11.2 b	+
$KHCO_3$, 1%	48.1 b	51.3 ab	72.4 a	83.6 a	−
$KHCO_3$, 0.5%	87.0 a	90.7 a	91.1 a	95.0 a	−
$KHCO_3$ + SS, both 0.5%	2.1 c	2.6 c	3.0 b	5.9 c	−
NH_4HCO_3, 2%	91.1 a	91.8 a	90.3 a	95.1 a	−
NH_4HCO_3, 1%	90.4 a	89.5 a	94.1 a	93.8 a	−
NH_4HCO_3, 0.5%	92.7 a	90.7 a	93.6 a	96.1 a	−
NH_4HCO_3 + SS, both 0.5%	11.8 b	21.1 b	44.7 b	61.6 ab	−
SS, 0.5%	9.1 b	16.8 bc	31.0 b	47.6 ab	−

[y] + = Necrotic spots on diseased leaves only (none on healthy tissue); − = no necrotic spots.
[z] Values in each column followed by the same letter do not differ significantly according to Duncan's multiple range test at $P = 0.05$.

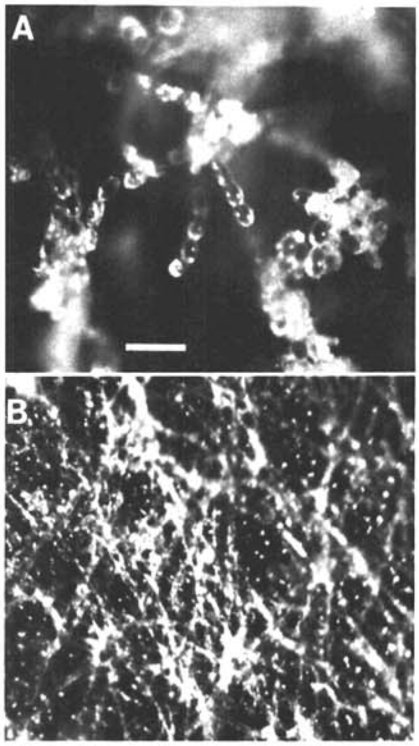

Fig. 1. Light micrograph of *Sphaerotheca fuliginea* on the upper leaf surface of powdery mildew-infected Spirit pumpkin leaves 6 days after bicarbonate treatments: **(A)** Conidia present on 0.5% NH_4HCO_3 and control treatments. **(B)** Compressed mycelia but no sporulation after 0.5% $KHCO_3$ treatment. Scale bar = 100 μm.

Table 3. Effect of bicarbonates with and without SunSpray Ultra-Fine Spray Oil (SS) on the incidence of Ulocladium leaf spot, gummy stem blight, and Alternaria leaf blight in the greenhouse

		Disease incidence[w]	
Disease and pathogen[u]	**Treatment**[v]	**Preinoculation**[x]	**Postinoculation**[y]
Ulocladium leaf spot	Control	69 a[z]	78 a
(*U. cucurbitae*)	SS	42 a	53 a
	$NaHCO_3$	34 ab	67 a
	$NaHCO_3$ + SS	28 ab	43 a
	NH_4HCO_3	35 ab	58 a
	NH_4HCO_3 + SS	11 b	42 a
	$KHCO_3$	41 ab	70 a
	$KHCO_3$ + SS	37 ab	54 a
Gummy stem blight	Control	78 a	81 a
(*Phoma cucurbitacearum*)	SS	26 b	49 ab
	$NaHCO_3$	18 b	51 ab
	$NaHCO_3$ + SS	10 bc	30 ab
	NH_4HCO_3	11 bc	22 b
	NH_4HCO_3 + SS	4 c	16 b
	$KHCO_3$	21 b	58 ab
	$KHCO_3$ + SS	18 b	61 ab
Alternaria leaf blight	Control	139 a	153 a
(*A. cucumerina*)	SS	23 bc	80 b
	$NaHCO_3$	7 c	68 b
	$NaHCO_3$ + SS	5 c	74 b
	NH_4HCO_3	7 c	62 b
	NH_4HCO_3 + SS	5 c	69 b
	$KHCO_3$	11 bc	89 b
	$KHCO_3$ + SS	6 c	82 b

[u] Dasher II cucumber plants were inoculated with *U. cucurbitae*; Saticoy muskmelon was inoculated with *P. cucurbitacearum* and *A. cucumerina*.
[v] All concentrations at 1%.
[w] For Ulocladium leaf spot and Alternaria leaf blight, number of lesions per leaf; for gummy stem blight, leaf area affected (%).
[x] Plants were treated 2 hr before inoculation.
[y] Plants were treated 24 hr after inoculation and incubation.
[z] Numbers in each column followed by the same letter do not differ significantly according to Duncan's multiple range test at $P = 0.05$.

Table 4. Effect of sodium, potassium, and ammonium bicarbonates and chlorides on the growth of four cucurbit pathogens on water agar[y]

		Colony diameter (cm)			
		Bicarbonate or chloride concentration (%)			
Pathogen	**Treatment**	**0**	**0.5**	**1.0**	**2.0**
Phoma cucurbitacearum	$NaHCO_3$	5.2 a[z]	0.3 c	0.3 c	0.2 c
	$KHCO_3$	5.2	1.8 b	1.4 bc	1.2 b
	NH_4HCO_3	5.2	0.2 c	0.2 c	0.1 c
	NaCl	5.0 a	4.0 a	3.3 ab	2.8 ab
	KCl	5.0	5.1 a	4.4 a	3.7 a
	NH_4Cl	5.0	3.0 ab	2.1 b	1.2 b
Ulocladium cucurbitae	$NaHCO_3$	4.0 a	2.0 b	1.6 b	1.2 bc
	$KHCO_3$	4.0	2.5 b	1.9 ab	1.5 b
	NH_4HCO_3	4.0	0.3 c	0.2 c	0.2 c
	NaCl	4.1 a	3.4 a	2.6 a	1.8 b
	KCl	4.1	3.9 a	3.7 a	3.4 a
	NH_4Cl	4.1	2.6 ab	2.0 ab	1.5 b
Alternaria cucumerina	$NaHCO_3$	4.6 a	0.5 c	0.4 c	0.3 c
	$KHCO_3$	4.6	1.2 a	0.7 bc	0.4 c
	NH_4HCO_3	4.6	0.2 c	0.2 c	0.1 c
	NaCl	4.3 a	3.1 b	2.0 b	1.4 b
	KCl	4.3	3.9 a	3.1 a	2.5 a
	NH_4Cl	4.3	1.8 bc	1.2 bc	0.6 c
Colletotrichum orbiculare	$NaHCO_3$	3.3 a	0.6 c	0.4 c	0.3 c
	$KHCO_3$	3.3	2.0 ab	1.1 bc	0.6 c
	NH_4HCO_3	3.3	0.8 c	0.6 c	0.4 c
	NaCl	2.9 a	2.5 a	1.7 b	1.1 b
	KCl	2.9	2.7 a	2.5 a	2.4 a
	NH_4Cl	2.9	1.6 b	1.0 bc	0.6 c

[y] Cultures were grown on water agar at 22 C and 65% RH with 12 hr of light. Colony growth was recorded on the 5th day of incubation.
[z] Numbers followed by the same letter for each column and each pathogen are not significantly different according to Duncan's multiple range test at $P = 0.05$.

axial surface for at least 7 days at 0.5%. When used as a preinoculation treatment, SunSpray also significantly reduced the development of gummy stem blight and Alternaria leaf blight, but not Ulocladium leaf spot. None of these pathogens was as effectively controlled with SunSpray as was powdery mildew.

Properties of coating materials that govern deposition and retention on leaves include droplet size, surface tension, viscosity, and velocity of spray application (3), and these properties vary greatly among polymers. The main characteristics of mineral oils, such as SunSpray, are viscosities, unsulfonated residues of 90–96%, API (American Petroleum Institute) gravity of 33–35, and the presence of emulsifiers (0.75–1.25% by volume) (19). These properties provide for safe usage on various horticultural crops. Since oils are protective in nature, their effectiveness depends upon thoroughness of coverage. When properly applied, oils can persist on sprayed leaves for up to 10–14 days (18). In the present study, the method of application of SunSpray under greenhouse conditions was not addressed, but it appears to have been adequate. However, previous studies suggest that application techniques need to be emphasized in future field performance studies (19).

Controlling powdery mildew of cucumber with $NaHCO_3$ has previously been demonstrated (7). Sodium bicarbonate was found to inhibit *S. fuliginea* on cucumber at various stages of pathogen development (8). More recently, $KHCO_3$ solutions at 800–1000 ppm were shown to reduce powdery

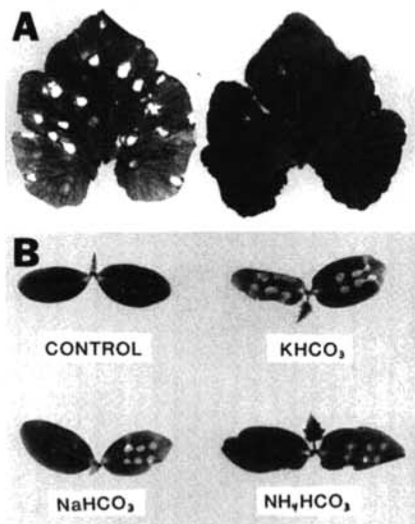

Fig. 2. Phytotoxicity of bicarbonates on cucurbits: **(A)** Twelve 40-μl drops of 2% (w/v) $KHCO_3$ were placed on powdery mildew-infected (left) or healthy (right) leaves of Spirit pumpkin. **(B)** Six 40-μl drops of three bicarbonates at 2.5% (w/v) were placed on nonpunctured (left) or punctured (right) Dasher II cucumber cotyledons.

mildew by 95–100% on cucumber 3–4 days after treatment (6). Our studies have shown that Na and K bicarbonates, but not NH_4HCO_3, are effective for mildew control. Although the bicarbonates are not effective as preventative treatments, they do exhibit curative properties by direct contact with the organism. Collapse of hyphal walls and shrinkage of conidia and conidiophores has been observed (6). Although cucurbit powdery mildew control was not achieved with NH_4HCO_3, this material, especially when combined with SunSpray, was slightly more effective, although not significantly, in most cases in controlling Ulocladium leaf spot, gummy stem blight, and Alternaria leaf blight. NH_4HCO_3 plus oil was significantly better than $KHCO_3$ plus oil for the control of gummy stem blight. The fact that the bicarbonates were more effective when applied with SunSpray than when sprayed alone may be related to the more uniform coverage of leaves obtained when the mixtures were applied. Another possible explanation for achieving better control with mixtures is the possible additive effect of both materials.

Phytotoxicity of the bicarbonates (especially $KHCO_3$) was related to solution concentration and, in part, to the damaging effect of the curative action of bicarbonates on powdery mildew. The same reaction of cucumber cotyledons to bicarbonates was shown on punctured cotyledons. This suggests that some means of entry is required for damage to occur. Phytotoxicity only occurred when high concentrations (1.25–5%) were applied as coarse droplets. Since no injury was noted when materials were applied as atomized solutions at 0.5% and control was still provided, the problem of phytotoxicity can be avoided by using low concentrations for either field or greenhouse applications. Concentrations of $NaHCO_3$ as low as 0.063 M have been shown to control powdery mildew on roses (9).

A comparison of the in vitro inhibitory effect of Na, K, and NH_4 bicarbonates to those of the chloride salts showed that bicarbonates were much more effective, with the NH_4^+ cation being the most effective (Table 4). The anion HCO_3^- was more inhibitory than Cl^-. Since in vivo studies showed that Na and K bicarbonates were more effective than NH_4, the mode of action may differ for in vivo and in vitro tests.

The possible mechanisms of the fungicidal effects of bicarbonates and inhibitory effect of coating polymers need to be further studied. This is particularly important, since the combination of bicarbonates with SunSpray provided excellent control of several pathogens under greenhouse conditions. In 1991 field tests we evaluated the effectiveness of bicarbonates plus SunSpray for powdery mildew control in pumpkins (T. A. Zitter, *unpublished*). One obvious limitation encountered was the lack of control of cucurbit powdery mildew on the abaxial surface with either SunSpray or bicarbonates plus SunSpray. Also, since both materials exhibit protective activity, the treatments had to be applied soon after disease appeared to provide acceptable control. Improved application technology to maximize deposition of materials to both leaf surfaces and field scouting to detect early disease occurrence would help eliminate these shortcomings. Applying the fungicides benomyl, thiophanate-methyl, or triadimefon on an alternating schedule with bicarbonates and oil would provide the necessary systemic activity for good mildew control. Most pumpkin and squash grown in the Northeast tend to be in small fields, and growers are reluctant to make major inputs for disease control. A combined program of bicarbonates and oil plus timely application of conventional fungicides should be more cost-effective and may lessen the development of fungicide resistance during the season.

ACKNOWLEDGMENTS

We thank Church and Dwight Co., Inc., Princeton, New Jersey, and Sun Refining and Marketing Co., Marcus Hook, Pennsylvania, for financial support and supplying materials. This work was also supported by funds allocated by the New York State Department of Agriculture and Markets for integrated pest management research and by Hatch Project NYC 153-417. Special thanks go to H. Israel for microscopic assistance.

LITERATURE CITED

1. Arny, C. J., and Rowe, R. C. 1991. Effects of temperature and duration of surface wetness on spore production and infection of cucumbers by *Didymella bryoniae*. Phytopathology 81:206-209.
2. Bergstrom, G. C., Knavel, D. E., and Kuc, J. 1982. Role of insect injury and powdery mildew in the epidemiology of the gummy stem blight disease of cucurbits. Plant Dis. 66:683-686.
3. Boize, L., Gudin, C., and Purdue, G. 1976. The influence of leaf surface roughness on the spreading of oil spray drops. Ann. Appl. Biol. 84:205-211.
4. Elad, Y., Ziv, O., Ayish, N., and Katan, J. 1989. The effect of film-forming polymers on powdery mildew of cucumber. Phytoparasitica 17:279-288.
5. Han, J.-S. 1990. Use of antitranspirant epidermal coatings for plant protection in China. Plant Dis. 74:263-266.
6. Homma, Y., and Arimoto, Y. 1990. Mechanisms of plant disease control by potassium bicarbonate. (Abstr.) Int. Cong. Pestic. Chem., 17th. 2:94.
7. Homma, Y., Arimoto, Y., and Misato, T. 1981. Studies on the control of plant diseases by sodium bicarbonate formulation (Part 1). Effect of emulsifiers and surfactants on the protective values of sodium bicarbonate. J. Pestic. Sci. 6:145-153.
8. Homma, Y., Arimoto, Y., and Misato, T. 1981. Studies on the control of plant diseases by sodium bicarbonate formulation 2. Effect of sodium bicarbonate on each growth stage of cucumber powdery mildew fungus (*Sphaerotheca fuliginea*) in its life cycle. J. Pestic. Sci. 6:201-209.
9. Horst, R. K., Kawamoto, S. O., and Porter, L. L. 1992. Effect of sodium bicarbonate and oils on the control of powdery mildew and black spot of roses. Plant Dis. 76:247-251.
10. Kamp, M. 1985. Control of *Erysiphe cichoracearum* on *Zinnia elegans* with a polymer-based antitranspirant. HortScience 20:879-881.
11. Macauley, B. J., and Griffin, D. M. 1969. Effect of carbon dioxide and the bicarbonate ion on the growth of some soil fungi. Trans. Br. Mycol. Soc. 53:223-228.
12. McGrath, M. T. 1991. Reduced effectiveness of triadimefon for controlling cucurbit powdery mildew associated with fungicide resistance in *Sphaerotheca fuliginea*. (Abstr.) Phytopathology 81:1191.
13. McKee, R. K. 1968. Plant Pathology Research Division. Annu. Rep. Res. Tech. Work Minist. Agric. North. Irel. 1967:83-93.
14. Punja, Z. K., and Grogan, R. G. 1982. Effects of inorganic salts, carbonate-bicarbonate anions, ammonia, and the modifying influence of pH on sclerotial germination of *Sclerotium rolfsii*. Phytopathology 72:635-639.
15. Punja, Z. K., Grogan, R. G., and Unruh, T. 1982. Chemical control of *Sclerotium rolfsii* on golf greens in northern California. Plant Dis. 66:108-111.
16. Schroeder, W. T., and Provvidenti, R. 1969. Resistance to benomyl in powdery mildew of cucurbits. Plant Dis. Rep. 53:271-275.
17. Sherf, A. F., and MacNab, A. A. 1986. Vegetable Diseases and Their Control. 2nd ed. John Wiley & Sons, New York. 728 pp.
18. Simons, J. N., McLean, D. L., and Kinsey, M. G. 1977. Effects of mineral oil on probing behavior and transmission of stylet-borne viruses by *Myzus persicae*. J. Econ. Entomol. 70:309-315.
19. Simons, J. N., and Zitter, T. A. 1980. Use of oils to control aphid-borne viruses. Plant Dis. 64:542-546.
20. Sitterly, W. R. 1978. Powdery mildew of cucurbits. Pages 359-379 in: The Powdery Mildews. M. D. Spencer, ed. Academic Press, London.
21. Zekaria-Oren, J., Eyal, Z., and Ziv, O. 1991. Effect of film-forming compounds on the development of leaf rust on wheat seedlings. Plant Dis. 75:231-234.
22. Zitter, T. A., and Hsu, L. W. 1990. A leaf spot of cucumber caused by *Ulocladium cucurbitae* in New York. Plant Dis. 74:824-827.
23. Ziv, O. 1983. Control of Septoria leaf blotch of wheat and powdery mildew of barley with antitranspirant epidermal coating materials. Phytoparasitica 11:33-38.
24. Ziv, O., and Frederiksen, R. A. 1987. The effect of film-forming antitranspirants on leaf rust and powdery mildew incidence on wheat. Plant Pathol. 36:242-245.