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Greenhouse Screening of Commercial Products Marketed as Systemic Resistance and Plant Growth Promotion Inducers

Charles S. Vavrina and Pamela D. Roberts
University of Florida, Southwest Florida Research and Education Center, 2686 State Road 29 N, Immokalee, FL 34142

Nancy Kokalis-Burelle
U.S. Dept. of Agriculture, Agricultural Research Service, U.S. Horticultural Research Laboratory, 2001 South Rock Road, Ft. Pierce, FL 34945

Esa O. Ontermaa
Agricultural Resource Associates, Inc., P.O. Box 278, Alva, FL 33920

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Abstract. **Six greenhouse trials of five commercial products marketed as systemic resistance (SR) and plant growth promotion (PGP) inducers were evaluated on tomato (*Lycopersicon esculentum* Mill.) over a 21-month period. The effect of the inducers on treated plants was measured by monitoring plant growth and disease suppression after inoculation with either plant pathogenic bacteria or nematodes. The commercially available SR/PGP inducers included a bacterial suspension [Companion (*Bacillus subtilis* GB03)], two plant defense elicitors with nutrients (Keyplex 350DP plus Nutri-Phite, and Rezist with Cab'y), natural plant extracts (Liquid Seaweed Concentrate and Stimplex), and a synthetic growth regulator (Actigard 50W). Growth enhancement was noted in some trials, but the parameter of growth affected often varied with trial. Response to Actigard treatment included significant suppression of bacterial spot [*Xanthomonas campestris* pv. *vesicatoria* (Xcv)] in three of the six trials. Companion, Keyplex 350DP plus Nutri-Phite, Rezist and Cab'y, and seaweed products induced only partial disease suppression of bacterial spot in inoculated tomato plants. The alpha-keto acids plus nutrients (Keyplex 350DP plus Nutri-Phite) increased plant growth by 14.3% and improved root condition compared to the untreated control following exposure to nematodes. Results are encouraging, if not consistent, and with a greater understanding of the SR system and the conditions related to product efficacy, such materials may become effective tools for production agriculture.**

Florida ranks third in the United States for total vegetable production (National Agricultural Statistics Service, 2003) and first in the production of snap beans, eggplant, sweet corn, and tomatoes (Olson and Simonne, 2003). To stay competitive, growers must be efficient, increase yields, and reduce pesticide use in keeping with consumer desires and environmentally driven legislation, such as the phase-out of the soil fumigant methyl bromide. Vegetable growers are currently dependent on use of methyl bromide with the greatest impact of its phase-out projected to be on U.S. fresh-market tomatoes (≈$115 million) and a total economic loss for vegetable production estimated to exceed $479 million (Carpenter et al., 2000). Much of this loss would occur in Florida. The Food Quality Protection Act (FQPA) has also accelerated the removal of other chemicals used in vegetable production from the market. These policies have accelerated research on agricultural production practices that reduce chemical inputs.

While cultural aspects such as transplant use and handling can aid efficiency and increase yield (Vavrina et al., 1996, 1998), fully 30% to 40% of production costs can be attributed to pesticide applications (Olson and Simonne, 2003). Furthermore, some bacterial and fungal pathogens have developed resistance to older broad-spectrum chemical pesticides, and new chemistries are generally more costly and provide a narrower spectrum of control. Some pest management programs may still not be fully effective in controlling disease. For example, bacterial spot on tomato can be partially controlled by a variety of methods, including host resistance and the use of copper or streptomycin sprays (Jones et al., 1991). Host resistance alone is not completely effective because several races of the bacteria exist. Chemical controls are not adequate when environmental conditions are conducive to disease development, and resistant copper or antibiotic bacterial populations have developed over time.

Systemic acquired resistance (SAR) and its associated plant growth promoting (PGP) effect have been shown to positively impact plant horticultural characteristics and suppress disease. The SAR response can be induced in the host plant by inoculation with a microorganism or by application of chemical or physical inducers (Hammerschmidt and Becker, 1997; Kessmann et al., 1994; Sticher et al., 1997). The SAR response is known to be effective in suppressing diseases caused by some fungi and bacteria on tomato, cucurbits, and other hosts (Enkerli et al., 1993; Kokalis-Burelle et al., 2002; Louws et al., 2001; Spletzer and Enydei, 1999; Wei et al., 1996; Zhang et al., 1996). Although the SAR reaction is usually nonspecific and can be elicited by a broad spectrum of inducing agents or environmental conditions, the level of protection can be specific to a host and/or the type of inducer (Zehnder et al. 1999); it can vary with cultivar (Quintanilla and Brishammar, 1998), and different pathways in the plant can be activated (Hoffland et al., 1996).

Plant growth promoting rhizobacteria (PGPR) used as biocontrol agents can induce resistance in leaves or stems. To differentiate this form of acquired resistance from SAR, the term induced systemic resistance (ISR) has been used (Pieterse et al., 1996). Ton et al., (2002) demonstrated that activation of the ISR or SAR response results from different pathways when challenged by fungal, bacterial, or viral pathogens. Therefore, the plant's response may depend upon the type of stimulus. For the purposes of this study, systemic activation of resistance is referred to as systemic resistance (SR) and includes activation by either mechanism.

Our objectives were to evaluate the effect of commercially available products claiming SR properties on tomato transplants and to define the range of capabilities of these SR products. This information should facilitate strategies for the integration of this technology into production systems and assist vegetable growers in making informed decisions about the efficacy of these products. In addition, we hoped to determine if materials with varied mechanisms of SR activation, including biologically based products (fungi and bacteria), pathogenesis-related proteins, organic amendments, chemical elicitors, nutritional supplements, and plant growth regulators, elicited the same plant growth and disease suppression responses under similar circumstances.

Materials and Methods

A series of six greenhouse trials were conducted over a 21-month period from Fall 2000 through Spring 2002. Each trial included a transplant growth assessment, screening for bacterial spot disease severity, and a root-knot nematode (*Meloidogyne incognita)*

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Table 1. Treatment schedules and material sources for experiments involving tomato plants.

Product, source	Trial[z] 1	2	3	4	5	6	Greenhouse applications[z]
Actigard, Novartis Crop Protection[1, y]	x	x	x	x	x	x	Foliar 22.2 mL per 378.5 L
Companion, Growth Products[2]	x	x	x				Drench at seeding (473 mL per 378.5 L)
				x	x	x	Drench at 4 and 6 weeks (473 mL per 378.5 L)
KeyPlex 350DP, Morse Enterprises, Ltd.[3]	x	x	x				Foliar at 3 and 5 weeks (½% KeyPlex 350DP with ¼% Nutri-Phite)
Plus Nutri-Phite, Biagro Western Sales, Inc.[4]				x	x	x	Foliar at 4 and 6 weeks (½% KeyPlex 350 DP with ¼% Nutri-Phite)
ReZist and Cab'y Stoller Enterprises[5]	x	x	x				Foliar at 3 and 5 weeks (½% each of ReZist and Cab'y)
				x	x	x	Foliar at 5 weeks (½% each of ReZist and Cab'y, max at 2.3 L·ha^{-1})
Seaweed extract	x	x	x				Drench at seeding (8 mL/10 L)
Liquid Seaweed Conc., Stimplex				x			Drench at 4 weeks (8 mL/10 L) with Liquid Seaweed concn and 6 weeks (8 mL/10 L) with Stimplex
Stimplex, Acadian Seaplants, Ltd.[6]					x	x	Drench at 4 and 6 weeks (12 mL/L)
Control	x	x	x	x	x	x	NA

[z]Group I = Trials 1 and 2, Fall 2000; Trial 3, Spring 2001. Group II = Trial 4, Fall 2001; Trials 5 and 6, Spring 2002.
[y]Actigard was applied for the pathology and nematology assessments only following transplant production.
[1]Syngenta Crop Protection, P.O. Box 18300 Greensboro, NC 27419.
[2]Growth Products, P.O. Box 1252, White Plains, NY 10602.
[3]Morse Enterprises Limited, Brickell East, Floor 10, 151 S.E. 15th Rd., Miami, FL 33129.
[4]Biagro Western Sales, 35803 Rd. 123, Visalia, CA 93292.
[5]Stoller Enterprises, 4001 West Sam Houston Pkwy. N., Suite 100, Houston, TX 77043.
[6]Acadian Seaplants Ltd., 30 Brown Ave., Dartmouth, N.S., Canada, B3B 1X8.

reduction screen. Eight products from five manufacturers representing five treatment programs were tested. The products were Companion™ (Growth Products, White Plains, N.Y.), Keyplex™ 350 DP (Morse Enterprises, Miami), Nutri-Phite™ (Biagro Western Sales, Visalia, Calif.), ReZist™ and Cab'y™ (Stoller Enterprises, Houston), Stimplex™ and Liquid Seaweed Concentrate (Acadian Seaplants Ltd., Dartmouth, Nova Scotia), and Actigard 50W™ (Syngenta Crop Protection, Greensboro, N.C.). Complete information regarding treatment application schedules for the six trials is listed in Table 1.

Companion is a microbial suspension of *Bacillus subtilis* GB03, *B. subtilis, B. licheniformis,* and *B. megaterium*. Keyplex 350 DP, the product of a collaborative effort between the USDA and Morse Enterprises, contains Mg, S, B, Fe, Mn, Mo, Zn, humates, and alpha-keto acids, which are pathogenesis-related (PR) proteins. Nutri-Phite is a potassium salt of a phosphorous acid. The Rezist and Cab'y combination includes Cu, Mn and Zn (Rezist), and Ca and B (CaB'y). The seaweed extracts are known to contain numerous plant growth-promoting substances, including cytokinins (Senn, 1987). Stimplex and Liquid Seaweed Concentrate are varying concentrations of *Ascophyllum nodosum* and addressed as seaweed products, denoting a single treatment group (Table 1). Actigard 50W™ (acibenzolar-*S*-methyl) is described as a plant activator. Actigard is not labeled for use in greenhouses, and was applied just prior to the disease and nematological challenges that occurred 6 weeks after seeding. Actigard, therefore, does not appear in the horticultural evaluations.

Vegetable horticulture. Transplants used in these trials were grown commercially and transferred to UF/SWFREC greenhouses in Immokalee, Fla., as either 3- or 4-week-old plants. Commercial transplant production scheduling often resulted in seedlings of slightly different chronological age in these trials. Plants in Trials 1, 2, and 3 were treated when 3 weeks old, whereas treatments in Trials 4, 5, and 6 were applied to 4-week-old transplants. The cultivar Florida 47 (Seminis, Oxnard, Calif.) was used in every trial except Trial 4, where 'Agriset' (Seminis) was used. Treatments were arranged in a randomized complete-block design with four replications within the greenhouse. Generally, plants in each treatment were in four 242-seedling polystyrene trays, with each tray representing a replication. In Trials 2 and 3, plants in 20-cell trays were used (Table 2). Plants were fertilized weekly with N at 100 mg·L^{-1} with soluble 20N–8.6P–16.6K with 0.1% Mg; 0.02% B, Cu, Fe, Mn, and Zn; and 0.0005% Mo (Peters Professional Soluble Plant Food, Scotts-Sierra Horticultural Products Co., Marysville, Ohio). In Trial 2, fertilizer applications were reduced to N at 80 mg·L^{-1} and applied as needed. Five finished plants per replication were sampled (Table 2) to assess plant growth response to treatments. Roots were washed, oven-dried, and weighed. Shoots were measured for plant height, stem diameter, leaf area, number of true leaves, and dry shoot weight. The leaf area was measured with a LI-COR leaf area meter (LI-COR, Lincoln, Nebr.).

Due to variation in treatment programs, data were analyzed two ways: as a whole across all trials (Group 1); and based on age (3 vs. 4 weeks) of the transplants when treated (Group 2). Data collected were analyzed by analysis of variance (ANOVA) (SAS) with mean separation via Fisher's protected least significant difference(LSD) at $P \leq 0.05$ and 0.1.

Pathology. Tomato plants taken from the horticultural study were transplanted at 6 weeks into 15-cm pots of MetroMix 330 (Scotts-Sierra) containing 5 g of 15–15–15 Sierra (Scotts-Sierra) slow-release fertilizer. Plants were maintained in the Plant Pathology greenhouse located at UF/SWFREC, Immokalee, Fla. Seven days after transplanting, plants were inoculated with a suspension of *Xanthomonas campestris* pv. *vesicatoria* (Doidge) Dye (Xcv), tomato race 1 and 3, mixed equally at 10^4 colony forming units (CFU) per mL. The bacterial suspension was sprayed on the plants until runoff with a handheld aerosol sprayer. Seven days after inoculation, a visual assessment of the percentage of symptomatic leaf tissue (disease severity) was made and assigned a rating using a modified Horsfall-Barratt scale of 0 to 5, where 0 = no foliar symptoms; 1 = 1% to 2%; 2 = 3% to 5%; 3 = 6% to 10%; 4 = 11% to 25% and 5 ≥ 26% disease severity (Horsfall and Barratt, 1945). The data were analyzed using ANOVA with means separation by Duncan's multiple range test, $\alpha = 0.05$.

Data were further analyzed to assess the percent disease reduction on plants receiving treatments compared to the disease severity

Table 2. Seeding and transplanting times, cultivars, growing media, and nutrient protocol sources for tomato plants treated with commercial plant systemic resistance and plant growth promoters.

Trial	Seeding date	Replication	No. of treatments	Sampling day (DAS[z])	Variety	Seed source	Tray	Media
1	08/11/2002	4	11	34	Florida 47	Asgrow	242-cell polystyrene	Pro-Mix 'VFT[y]
2	09/02/2000	4	11	36	Florida 47	Asgrow	20-cell tray	Pro-Mix 'VFT
3	01/09/2001	4	11	43	Florida 47	Asgrow	20-cell tray	Pro-Mix 'VFT
4	08/14/2001	4	8	43	Agriset	Agrisales Inc.	242-cell polystyrene	Pro-Mix 'VFT
5	01/08/2002	4	9	50	Florida 47	Asgrow	242-cell polystyrene	Pro-Mix 'VFT
6	03/02/2002	4	9	54	Florida 47	Asgrow	242-cell polystyrene	Pro-Mix 'VFT

[z]Days after seeding.
[y]Premier Horticulture Inc., Canada.

on the untreated control (UTC) in each trial. Disease reduction on plants for each treatment was calculated as percentage of the untreated control. The mean disease reduction on plants for each treatment in all six trials compared to the UTC was calculated and correlation analysis was applied.

Nematology. Tomato plants from the horticultural phase were transported to the USDA, ARS Horticultural Research Laboratory in Ft. Pierce, Fla., for nematode challenge experiments. Plants for all studies were transplanted into 10-cm pots containing a mixture of 1 sand : 1 field soil that was naturally infested with root-knot nematode. Experiments were set up in randomized complete blocks with 15 replications and were evaluated for growth and disease after 4 to 5 weeks. The plants were maintained in the greenhouse, fertilized once a week with Peters 20–20–20 solution (Peters Professional Soluble Plant Food, Scotts-Sierra), weeded by hand, and treated with insecticide as necessary. Treatment applications were performed according to the manufacturer's field application protocol.

Four to five weeks after transplanting, the plants were evaluated for terminal shoot length taken from the last mature leaf to the base of the stem, fresh root weight, fresh shoot weight, stem diameter taken at the base of the stem, overall root condition using a scale of 1–5, with 1 = healthy roots with good color, and 5 = 100% necrotic roots, and a nematode gall rating performed on a 0–10 scale with 0 = no galling, and 10 = complete galling (Zeck, 1971). Data were analyzed using ANOVA with mean separation by LSD analysis at $\alpha = 0.05$.

Results

Vegetable horticulture. Combined data from all trials showed plants treated with Keyplex 350DP plus Nutri-Phite produced a larger stem diameter ($P \leq 0.1$) and a greater number of true leaves ($P \leq 0.05$) compared to other treatments (Table 3). A significant treatment × trial interaction occurred with number of true leaves, however, when evaluated by trial; transplants treated with Keyplex 350DP plus Nutri-Phite consistently showed an increase (average 5%) in leaf number compared to the UTC (Table 3). This increase in leaf number implies advanced maturity, though the response was minimal. Other SR treatments did not affect leaf number when compared to the UTC.

The age of the transplant governed treatment effect response, as indicated by a significant main effect of age. Treatment application on plants at 4 and 6 weeks after sowing (Group II) resulted in generally larger transplants in every respect compared to Group I plants. Only when plants were treated at 3 and 5 weeks after sowing (Group I) were treatment effects manifested (Table 3). When plants in Group I were treated with Keyplex 350DP plus Nutri-Phite, stem diameter, leaf area, shoot dry weight, and leaf number increased compared to most other treatments at $P \leq 0.05$, and root dry weight increased ($P \leq 0.1$). Plants in Group II (treated at 4 and 6 weeks) exhibited no such plant growth effects when treated with Keyplex 350DP plus Nutri-Phite. No age × treatment or treatment × trial interactions were evident.

Table 3. Tomato plant growth and dry weights at the time of transplanting to field. Trial Groups I and II and combined data.

Treatment	Stem length (cm)	Stem diam (mm)	Leaf area (cm^2)	Dry shoot (mg)	Dry root (mg)	True leaf no.
			All six trials combined			
Companion	9.7	2.47 b[z]	17.6	177.2	46.4	3.5 b
KeyPlex, Nutri-Phite	9.9	2.55 a	19.0	184.6	47.4	3.7 a
ReZist and Cab'Y	9.2	2.47 b	17.8	173.8	45.8	3.5 b
Seaweed products	9.5	2.47 b	18.0	181.1	45.9	3.5 b
Untreated control	9.6	2.48 b	17.9	179.9	46.9	3.5 b
$LSD_{0.05}$	NS	NS	NS	NS	NS	0.1
$LSD_{0.10}$	NS	0.05	NS	NS	NS	---
			Group I[y] Trials 1, 2, and 3			
Companion	9.1	2.2 b	13.2 b	114.4 b	31.4	3.0 b
KeyPlex, Nutri-Phite	9.7	2.4 a	15.4 a	133.1 a	34.5	3.2 a
ReZist and Cab'Y	8.4	2.2 b	13.0 b	110.6 b	30.2	2.9 b
Seaweed products	8.7	2.2 b	13.2 b	115.2 b	31.0	2.9 b
Untreated control	9.1	2.2 b	13.6 b	121.6 ab	31.5	3.0 b
$LSD_{0.05}$	NS	0.1	1.7	14.4	NS	0.2
$LSD_{0.10}$	NS	---	---	---	2.5	---
			Group II Trials 4, 5 and 6			
Companion	10.2	2.7	22.1	239.9	61.5	4.0
KeyPlex, Nutri-Phite	10.1	2.7	22.5	236.1	60.4	4.0
ReZist and Cab'Y	9.9	2.7	22.5	237.0	61.3	4.0
Seaweed products	10.4	2.7	22.8	247.0	60.9	4.0
Untreated control	10.0	2.7	22.2	238.2	62.3	4.0
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS
$LSD_{0.10}$	NS	NS	NS	NS	NS	NS

[z]Mean values in each column followed by the same letter are not significantly different according to Fisher's Protected LSD.

[y]The transplants were treated at 3 and 5 weeks in Group I, and 4 and 6 weeks in Group II when the first applications were made. Application frequency and rates of some of the treatments were changed from Group I to Group II as well.

The possibility that physiological age may play a role in plant response to SR induction raises some interesting questions. Whether the increase in plant growth seen in Group I plants was the result of the SR effect or of the additional nutrients supplied by Keyplex 350DP (K, Mg, S, B, Fe, Mn, Mo, and Zn) and Nutri-Phite (P, K) was not confirmed. It is known that phosphorus contributes to growth in tomato seedlings (Garton and Widders, 1990; Melton and Dufault, 1991a, 1991b; Vavrina, 1997) but the Keyplex 350DP plus Nutri-Phite P contribution was minimal (<0.093 mg/plant) and prone to leaching (Brown et al., 2002), making this addition unlikely to impact growth. Potassium, while an important factor in plant health, does not result in a visible manifestation of growth (Melton and Dufault, 1991a) and little is documented on the contribution of the remaining elements on tomato seedling growth (Vavrina, 1997).

All growth parameters measured were greater in spring trials, as evidenced by a significant main effect of season, as expected. Seasonal photoperiod and temperature variations obviously impact physiological age. Thus, finished transplants (i.e., those possessing five leaves) can range in age from 35 to 49 d, depending on time of year. Generally, a fall transplant in south Florida is marketable in 5 weeks, whereas a spring transplant takes 6 weeks. The lack of treatment × season interaction indicated that treatment effect was similar across season.

Of the six trials undertaken, only Trials 2 (Fall 2000), 3 (Fall 2001), and 5 (Spring 2002) produced significant treatment-driven growth differences at transplanting compared to the UTC (data not shown). Most differences occurred between the SR treatments themselves. Of the six trials and 42 measurements taken per trial, the highest measured treatment value was only different from the UTC twice; stem diameter and leaf area produced by Keyplex 350DP plus Nutri-Phite in Trial 2. Values that proved to be lower than those of the UTC included root : shoot ratio with Companion and seaweed products in Trial 5, and root and shoot dry weight of Rezist/Cab'y in Trial 3. None of the treatments produced statistically fewer true leaves, had a lower leaf area, stem diameter, or stem length than the UTC treatment. The most consistent PGP response was elicited with Keyplex 350DP plus Nutri-Phite. In 21% of the parameters measured (nine occasions out of the 42 possible) this treatment was statistically higher than one or more of the accompanying treatments.

Pathology. Untreated control plants had average disease severity ratings ranging from the low of 0.9 to the high of 3.4 in the six trials (Table 4). Disease severity ratings for plants receiving the experimental treatments ranged from 68.5% lower to 83.5% higher than the UTC plants in the various trials. Disease ratings and percent disease reduction for plants receiving a particular treatment varied from trial to trial. Therefore, determining disease suppression based upon a single trial did not adequately describe plant response to a product.

When data from all six trials were averaged, all SR treatments generally reduced disease,

but only Actigard significantly reduced disease compared to UTC (Table 4). Plants treated with Actigard had the greatest percent disease reduction compared to the UTC plants when the six trials were averaged (35.1% disease reduction). Plants treated with Actigard exhibited significantly reduced disease severity in three of the six trials (Trials 2, 3, and 6). In Trial 4, plants treated with Actigard had more bacterial spot than all other treatments including the UTC. Trial 4 was the only trial in which 'Agriset' was used instead of 'Florida 47'. Trial 4 also produced the lowest UTC disease severity rating of all trials. When all six trials were averaged, disease severity of plants treated with Actigard was significantly lower than the UTC, or those treated with seaweed products, and Resist and CaB'y.

In Trials 1 and 5, no treatment was different from the UTC in response to infection. In Trial 2, all treatments significantly reduced disease compared to the UTC. Keyplex 350DP plus Nutri-Phite-treated plants significantly reduced disease compared to the UTC in Trials 2, 4, and 6. In Trials 2 and 6, plants treated with seaweed products had significantly reduced disease severity compared to the UTC but not to Actigard-treated plants. Plants treated with ReZist and Cab'y only reduced disease severity in Trial 2 compared to the UTC, but not to Actigard-treated plants. In the mean of all six trials, only Actigard reduced disease severity compared to the UTC plants.

Nematology. Plant growth and disease evaluations of tomato plants transplanted into root-knot nematode-infested soil after 4 weeks are shown in Table 5. The greatest plant growth increase was obtained with Keyplex 350DP plus Nutri-Phite and seaweed products. The Keyplex 350DP plus Nutri-Phite treatment significantly increased shoot weight, shoot length, stem diameter, and root condition compared to all other treatments, including the UTC. Root weight and gall rate were also increased by Keyplex 350DP plus NutriPhite but were not significantly higher than the UTC. Increased root weights are often correlated with increased root galling, and consequently, gall rate values. It is interesting to note that, although the Keyplex 350DP plus NutriPhite treatment had slightly higher gall rates, there appeared to be an increased tolerance for nematode infestation that is reflected in the increased plant growth for all parameters measured. Seaweed products resulted in the largest root system of all treatments tested. Although they were not significantly larger than the UTC, they were larger than those in the Actigard treatment, with no corresponding increase in galling. Actigard treatment resulted in a general reduction of plant growth parameters measured, while the Rezist/Cab'y treatment did not differ from the UTC.

The average greatest biomass and plant growth in the presence of nematode pressure, 14.30% above UTC, was observed with Keyplex 350DP plus Nutri-Phite with the biomass gain of four times that observed with the horticultural assessment prior to nematode challenge. The lowest biomass and plant growth in the presence of nematode pressure, 11.3% below that of UTC, were with Actigard treatment. The root condition of the plants treated with Actigard was equal to that of UTC.

Table 4. Disease severity rating[z] and percent disease reduction[y] of tomato plants treated with systemic resistance-inducing and plant growth-promoting products evaluated 7 d after inoculation with *Xanthomonas campestris* pv. *vesicatoria*.

	Trial 1		Trial 2		Trial 3		Mean of six trials	
	DS[x]	DR%[y]	DS	DR%	DS	DR%	DS	DR%
Actigard 50WG	1.8[ns]	12.5	1.3 d	61.2	0.5 c	57.6	1.5 b	35.1
Companion	2.0[ns]	0.0	2.6 c	29.9	1.1 b	15.2	2.0 ab	12.4
Keyplex/Nutri-Phite	1.5[ns]	23.5	3.0 b	11.9	1.2 ab	3.2	1.9 ab	15.6
ReZist andCaB'y	1.8[ns]	9.5	2.3 c	31.3	1.0 b	20.0	2.1 a	8.0
Seaweed products	2.3[ns]	–12.5	2.2 c	34.3	1.4 a	–12.0	2.1 a	6.7
Untreated control	2.0[ns]		3.4 a		1.3 ab		2.3 a	

	Trial 4		Trial 5		Trial 6	
	DS	DR%	DS	DR%	DS	DR%
Actigard 50WG	1.7 a	–83.5	2.7 b	19.7	0.9 c	68.5
Companion	0.8 c	8.8	3.0 b	10.6	2.7 a	1.9
Keyplex 350 DP	0.7 d	27.5	3.0 b	10.6	2.1 b	22.2
ReZist and CaB'y	1.0 bc	–9.9	3.8 a	–15.2	2.5 a	7.4
Seaweed products	1.2 b	–27.5	3.8 a	–13.6	1.9 b	31.5
Untreated control	0.9 bc		3.3 ab		2.7 a	

[z]Rating: 0 = No disease; 2 = 3% to 5%; 3 = 6% to 10%; 4 = 11% to 25%; and 5 ≥ 26% disease severity. Data shows means of one or more disease evaluation methods.
[y]DR% = Disease reduction, percentage of control; negative values denote disease levels higher than untreated control.
[x]DS = disease severity.
[ns]Nonsignificant; LSD = 0.05.

Table 5. Growth and root disease of tomato plants treated with systemic resistance-inducing and plant growth-promoting products after 4 weeks in nematode-infested soil. Combined data from Trials 1, 2, 3, 5[z], and 6.

	Root wt (g)	Shoot wt (g)	Shoot length (mm)	Stem diam (mm)	Root condition[y]	Gall rating[x]
Actigard	5.5 b	18.6 d	36.4 b	4.8 c	2.4 a	3.6 b
Companion	6.9 ab	19.5 d	33.9 c	5.0 bc	2.3 a	4.0 ab
Keyplex/Nutri-phite	8.8 a	26.8 a	39.1 a	5.4 a	1.6 b	4.2 a
ReZist/Cab'y	7.5 ab	21.1 bc	35.2 bc	5.1 b	2.1 a	4.2 ab
Seaweed products	9.1 a	22.0 b	35.7 bc	5.1 b	2.2 a	4.0 ab
Control	7.3 ab	22.2 b	35.9 b	5.1 b	2.4 a	3.8 ab
$LSD_{0.05}$	2.7	2.3	1.8	0.2	0.3	0.6

[z]Trial 4 was not taken to completion.
[y]Root condition rating 1–5: 1 = 0% to 20% discolored roots; 2 = 21% to 40%; 3 = 41% to 60%; 4 = 61% to 80%; and 5 = 81% to 100%.
[x] Gall rating 1–10: 1 = no galling; 10 = complete galling.

Discussion

Data supporting some of the SR effects of the products evaluated in this study have been demonstrated in the literature. For instance, Companion™ significantly reduced Fusarium patch (*Microdochium nivale*) in Creeping Bentgrass (*Acrostis palustis* 'Penncross') (DiMarco et. al., 2000). Also, defensive proteins (DP), such as alpha-keto acids in Keyplex 350DP™, influence protein, carbohydrate, and fatty acid metabolism in plants (Bryan and Reed, 1971). Keyplex 350DP has been reported to reduce bacterial spot *Xanthomonas campestris* pv. *vesicatoria* (Doidge) and early blight *Alternaria solani* on tomato (Inbar et. al., 1998; Louws et al., 2001). The nutritional supplement Nutri-Phite™ has been reported to increase fruit size, yield, and sugar : acid ratio in fruit and cause fruit to produce higher amounts of suspended solids, e.g., sugars (Biagro Western). Natural seaweed extracts contain numerous plant growth-promoting substances, most notably cytokinins, which have been shown to accelerate uptake of plant nutrients into roots, increase plant growth, and slow the advance of disease (Senn, 1987).

These studies were undertaken to better define the consistency and levels of growth promotion and disease control that can be achieved using these products. Our results indicate that the PGP and SR effects on tomato transplants and young seedlings are material specific and may also be dependent on other factors, such as physiological age of the plant at treatment application. The observed interaction between PGP and SR effects implies a significant response relationship between the acquired disease resistance and plant growth, which was illustrated by a reduction of plant growth with strong SR activation.

The most selective of the treatments was the synthetic SAR inducer Actigard, which produced positive results in disease suppression only. Plants treated with Actigard did not differ from UTC in root condition after nematode exposure, but had a marked reduction in shoot growth. This suggests resource reallocation rather than classical stunting, but would require further study for determination. The alpha-keto acids plus nutrients (Keyplex 350DP plus Nutri-Phite) increased growth over the UTC following exposure to nematodes, as manifested by continued root growth and im-

proved root condition. Additionally, Keyplex 350DP plus Nutri-Phite elicited a moderate disease suppression in tomato seedlings compared to UTC. Consequently, plant response to Keyplex 350DP plus Nutri-Phite showed PGP activation to be, possibly, a part of the SR mechanism, unlike the selective SR-only response observed with Actigard. Inclusion of an appropriate nutrient component with a PGP/SR substance, such as with the Keyplex 350DP plus/Nutri-Phite treatment, may increase PGP/SR substance uptake and thus reinforce the signal. These two treatments represented the two extremes within the selected materials. Plant growth data from the nematode challenge and the disease suppression response indicate that there may be a growth trade-off between selective, highly effective, SR response and generic PGP/SR activation.

Timing of the applications appeared to cause major growth differences between the two trial groups, resulting in significant PGP responses in one but not the other. The level of disease suppression also differed significantly for several of the treatments, suggesting that application timing may influence plant response to biotic pressure. Cultivar response to Actigard treatment may also have occurred. In a series of trials such as these, one expects to see inconsistencies, due to many variables inherent with transplant production. The impact of age and season on the results showed that some of the variability in the PGP/SR effect in fact was attributable to application timing, plant physiological status, season, and material used.

These data imply that the achieved SR effect is not merely a function of product application. A number of undetermined factors may underlie SR activation, including the activation signal strength, the sensitivity of the pathways activated, resources available to complete pathway activation and response, and the interaction between PGP and SR pathways, among others. From a practical point of view, application timing and plant sensitivity to the SR stimulus shown in this study are perhaps most important to the end user. Better understanding of these factors has the potential to markedly improve the consistency of treatment responses with these materials.

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