Journal of Applied Horticulture, 11(2): 99-102, July-December, 2009

Influence of fungicides and *Phytophthora capsici*-resistant/ tolerant cultivars on bell pepper yield and farm-gate revenues

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Abstract

Phytophthora blight, caused by *Phytophthora capsici* Leonian, is a widespread and destructive disease of bell pepper (*Capsicum annuum* L.). Bell pepper yield, farm-gate revenues and Phytophthora blight incidence were determined during 2005 and 2006 in a *P. capsici*-infested field near Shawneetown, Illinois. The study evaluated 12 bell pepper cultivars (one resistant, three tolerant, and eight susceptible to *P. capsici*) with or without a recommended fungicide treatment (mefenoxam at transplant and dimethomorph + copper alternated with manganese ethylenebisdithiocarbamate + copper at 10 day intervals). Bell pepper plants receiving fungicide applications showed less Phytophthora blight incidence throughout the growing season and produced greater yield and farm-gate revenues compared to untreated plants. Additionally, *P. capsici*-resistant 'Paladin' and *P. capsici*-tolerant 'Alliance', 'Aristotle X3R', and 'Revolution' produced greater yields (≥ 17,800 and 33,800 kg ha^{-1} for 2005 and 2006, respectively) and farm-gate revenues [≥ $12,700 and $27,000 (USA) ha^{-1} for 2005 and 2006, respectively] compared to the susceptible cultivars. Therefore, in fields with a high incidence history of Phytophthora blight, 'Paladin' could be a reliable choice for commercial bell pepper production. However, 'Alliance', 'Aristotle X3R', and 'Revolution' may be preferred by growers due to the added benefits of bacterial spot [*Xanthomonas campestris* pv. *vesicatoria* (Doidge) Dye] resistance and better fruit quality compared to 'Paladin'. Furthermore, this research indicates that plant resistance and/or tolerance should not be relied upon as the only method of *P. capsici* control and growers should also incorporate fungicides into their management program to provide additional protection.

Key words: *Capsicum annuum*, chemical control, economics, *Phytophthora capsici*, Phytophthora blight, disease management, disease resistance/tolerance

Introduction

Phytophthora capsici causes Phytophthora blight, which is a devastating disease affecting many vegetable crops including bell peppers. Recently, the incidence of this rapidly spreading disease has dramatically increased in Illinois and has caused yield losses of up to 100% in pepper fields (Babadoost, 2001; Islam and Babadoost, 2002).

P. capsici is a soil-borne oomycete that thrives under warm (25 to 30°C) and excessively wet conditions; furthermore, Phytophthora blight is often observed on plants in low-lying or poorly drained areas of the field (Hausbeck and Lamour, 2004). Crown rot is usually the first symptom of Phytophthora blight observed on bell pepper plants in the field and generally results in rapid collapse and death of plants (Babadoost, 2001). During the aerial phase of the disease, sporangia are produced on the surface of the lesion, spread to healthy plants by splashing rain, and release zoospores causing the development of stem lesions in branch axils (Babadoost, 2001; Kline and Johnston, 2005). These girdling lesions lead to plant death above the affected area. Other disease symptoms on bell pepper include root rot, fruit rot, seedling damping-off, and to a lesser extent, leaf spot (Babadoost, 2001).

Although there is no single method to provide adequate control of *P. capsici* in bell pepper production, practices such as planting on raised beds, removal of symptomatic plants, managing field moisture levels, mulching plants, planting resistant or tolerant cultivars, and timely fungicide applications may reduce the incidence of this disease (Islam and Babadoost, 2002). Plant resistance and/or tolerance are often the basis of disease management programs and can be used as part of disease management program to provide *P. capsici* control in bell pepper production (Hausbeck and Lamour, 2004). Bell pepper cultivars tolerant to *P. capsici* include Alliance, Aristotle X3R, and Revolution, while Paladin is considered resistant (Anonymous, 2006b).

Although plant resistance is an important part of managing *P. capsici*, it is often combined with fungicide applications to achieve effective control of this pathogen. Recommended fungicide treatments for *P. capsici* control include soil applications of mefenoxam (Ridomil Gold EC, Syngenta Crop Protection, Inc., Greensboro, N.C.) at 1.17 L ha^{-1} during transplanting. This is followed by the application of dimethomorph (Acrobat 50WP, BASF, Research Triangle Park, N.C.) at 0.45 kg ha^{-1} or famoxadone plus cymoanil (Tanos 50WP, DuPont, Wilmington, Del.) at 0.56 to 0.70 kg ha^{-1} alternated with manganese ethylenebisdithiocarbamate (Maneb 80, Cerexagri, Inc., King of Prussia, Penn. or Manex, DuPont, Wilmington, Del.) at 1.68 to 3.36 kg ha^{-1} or 1.14 to 2.27 L ha^{-1}, respectively, during production (Egel *et al.,* 2005). Therefore, the objectives of this study were to determine the efficacy of plant resistance and recommended fungicide applications on bell pepper yield, farm-gate revenues, and Phytophthora blight disease incidence in a *P. capsici*-infested field.

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Materials and methods

The experiment was conducted during 2005 and 2006 near Shawneetown, Illinois in a field infested with *P. capsici*. The field soil type was an Alvin-Roby-Ruark association (with Alvin a coarse-loamy, mixed, mesic, Typic Hapludalf; Roby a coarse-loamy, mixed, mesic, Aquic Hapludalf; and the Ruark a fine-loamy, mixed, mesic, Typic Ochraqualf) (Wallace and Fehrenbacher, 1969). A split-plot design was used with three replications. The main plots were: 1) fungicide treatment, and 2) no fungicide treatment. The fungicide treatment consisted of: 1) mefenoxam (Ridomil Gold EC) applied at 1.17 L ha^{-1} during transplanting, and 2) a spray application at 10 day intervals of dimethomorph (Acrobat 50 WP) at 0.45 kg ha^{-1} + copper (Tenn-Cop, Griffin LLC, Valdosta, GA) at 3.6 L ha^{-1} alternated with manganese ethylenebisdithiocarbamate (Maneb 80) at 2.8 kg ha^{-1} + copper (Tenn-Cop) at 3.6 L ha^{-1}. The subplots were twelve bell pepper cultivars: Aladdin X3R, Alliance, Aristotle X3R, Brigadier, California Wonder, Camelot X3R, Commandment, King Arthur, Legionnaire, Paladin, Red Knight X3R, and Revolution. All seeds were obtained from Seedway, Inc., Elizabethtown, PA.

Bell pepper seeds were planted into 72-cell plastic trays (TLC Polyform Inc., Plymouth, MN) containing Pro-Mix (Premiere Horticulture Inc., Quakertown, PA), a soilless medium, which consists of 2:1:1 peat moss, vermiculite, and perlite, respectively, in a greenhouse. Seedlings remained in the greenhouse for approximately six weeks and were then hardened-off in an outdoor cold frame for five days prior to transplanting.

Raised beds were formed on 1.8 m centers and covered with 0.03175 mm black plastic mulch with drip irrigation. Bell pepper seedlings were transplanted on double rows spaced 0.5 m apart, with 0.5 m in-row spacings. Plots were 2.5 m in length with 10 plants in each plot. Trickle fertigation was used to supply the water and nutrients necessary for bell pepper plant growth and development (Sanders *et al.,* 1995), with approximately 135 kg ha^{-1} N applied over the growing season. No insecticides or additional fungicides were applied to plants. Weeds between plastic were controlled by paraquat dichloride (Gramoxone Max, Syngenta Crop Protection, Inc., Greensboro, N.C.) at 2.3 L ha^{-1}.

Disease incidence (number of plants per plot with visible Phytophthora blight symptoms) was rated at four week intervals [4, 8, 12, and 16 weeks after transplanting (WAT)] during the growing season. Visible symptoms included plant wilting, crown rot, stem lesions, and fruit rot. Farm-gate revenues were calculated using a $10 (USA)/12.6 kg box conversion factor which was based upon the average St. Louis, Mo. produce terminal market prices for 2005 and 2006. Pepper fruit were harvested every 10 to 14 days with a total of 6 harvests. Fruit harvests began on 14 or 21 July and ended on 21 or 14 September for 2005 and 2006, respectively. Fruit were weighed and graded into marketable (Fancy, No. 1 and No. 2) and cull (misshapen or decaying fruit) based on USDA standards (Anonymous, 2005).

Bell pepper plants with Phytophthora blight symptoms were collected from the experimental site each year. *P. capsici* was isolated using the method described by Islam *et al.* (2004). 'California Wonder' seedlings were inoculated in a greenhouse with the isolated *P. capsici*; and, in all instances, Phytophthora blight disease symptoms developed. *P. capsici* was then successfully re-isolated from the infected seedlings.

Data were subject to analysis of variance procedures appropriate for a split plot design using the PROC GLM procedure of SAS (SAS Inst., Cary, N.C.). Fisher's least significant difference (LSD) tests were used to separate differences among fungicide treatment and bell pepper cultivar means at $P \leq 0.05$.

Results

The data were combined over the 2005 and 2006 growing seasons and analyzed. Interactions of year with cultivar and fungicide treatment ($P \leq 0.05$) were observed for Phytophthora blight incidence, yields, and farm-gate revenues indicating that cultivar and fungicide treatment performance for these variables depended on year. Therefore, results for these variables are presented by year. However, cultivar by fungicide treatment interactions ($P > 0.05$) were not observed during either year, indicating that cultivar performance was consistent across fungicide treatments.

Phytophthora blight incidence: The fungicide treatment used reduced Phytophthora blight incidence on bell peppers compared to those not receiving fungicide applications ($P \leq 0.0001$) for both 2005 and 2006 growing seasons (Tables 1 and 2). Although Phytophthora blight incidence increased as the season progressed, the fungicide treatment significantly reduced the number of plants with visible symptoms.

Table 1. Effect of fungicide treatment and cultivar on Phytophthora blight incidence in bell peppers during 2005 in a *P. capsici*-infested field near Shawneetown, Illinois

Treatment	Phytophthora blight incidence(%), weeks after transplanting			
	4	8	12	16
Fungicide[z]				
Non-treated	27	39	80	97
Treated	2	7	26	76
Significance	***	***	***	***
Cultivar[y]				
Paladin[x]	3a	5a	15a	42a
Revolution[w]	8a	20ab	43a	73b
Alliance[w]	13a	15ab	42ab	82bc
Aristotle X3R[w]	10a	10ab	42ab	85bc
King Arthur[v]	23a	32ab	68b	90bc
Brigadier[v]	22a	32ab	62b	92bc
Camelot X3R[v]	18a	30ab	53b	92bc
Commandment[v]	15a	27ab	53b	92bc
Legionnaire[v]	12a	23ab	67b	93bc
Cal. Wonder[v]	12a	22ab	65b	98bc
Aladdin X3R[v]	17a	20ab	53b	100c
Red Knight X3R[v]	18a	40ab	72b	100c

[z]Fungicide treatment: non-treated = no fungicide treatment and treated = fungicide treatment of: 1) mefenoxam (Ridomil Gold EC, 1.17 L ha^{-1}) at transplant and 2) a spray application of dimethomorph (Acrobat 50WP, 0.45 kg ha^{-1}) + copper (Tenn-Cop, 3.6 L ha^{-1}) alternated with manganese ethylenebisdithiocarbamate (Maneb, 2.8 kg ha^{-1}) + copper (Tenn-Cop, 3.6 L ha^{-1}) at 10 day intervals.

[y]Cultivars are ranked according to least amount of Phytophthora blight incidence at 16 WAT. Visible symptoms included wilting of plants, crown rot and stem lesions, and fruit rot. Means followed by the same letter in each column are not significantly different at $P \leq 0.05$.

[x]*Phytophthora capsici*-resistant

[w]*Phytophthora capsici*-tolerant.

[v]*Phytophthora capsici*-susceptible.

Table 2. Influence of fungicide treatment and cultivar on Phytophthora blight incidence in bell peppers during 2006 in a *Phytophthora capsici*-infested field near Shawneetown, Illinois

Treatment	Phytophthora blight incidence (%) weeks after transplanting			
	4	8	12	16
Fungicide[z]				
Non-treated	4	7	14	42
Treated	2	3	7	18
Significance	NS	NS	*	***
Cultivar[y]				
Paladin[x]	2a	2a	3a	3a
Aristotle X3R[w]	0a	0a	2a	7ab
Revolution[w]	0a	0a	0a	8a-c
Alliance[w]	3a	3a	7a	25a-e
Legionnaire[v]	2a	7a	8a	30a-e
Camelot X3R[v]	8a	10a	13a	37a-e
Red Knight X3R[v]	2a	2a	8a	37a-e
Commandment[v]	5a	8a	20a	42b-e
Brigadier[v]	3a	7a	18a	47de
Cal. Wonder[v]	8a	8a	15a	47de
Aladdin X3R[v]	0a	3a	12a	52de
King Arthur[v]	5a	7a	20a	58e

[z]Fungicide treatment: non-treated = no fungicide treatment and treated = fungicide treatment of: 1) mefenoxam (Ridomil Gold EC, 1.17 L ha^{-1}) at transplant and 2) a spray application of dimethomorph (Acrobat 50WP, 0.45 kg ha^{-1}) + copper (Tenn-Cop, 3.6 L ha^{-1}) alternated with manganese ethylenebisdithiocarbamate (Maneb, 2.8 kg ha^{-1}) + copper (Tenn-Cop, 3.6 L ha^{-1}) at 10 day intervals.

[y]Cultivars are ranked according to least amount of Phytophthora blight incidence at 16 WAT. Visible symptoms included wilting of plants, crown rot and stem lesions, and fruit rot. Means followed by the same letter in each column are not significantly different at $P \leq 0.05$.

[x]*Phytophthora capsici*-resistant

[w]*Phytophthora capsici*-tolerant.

[v]*Phytophthora capsici*-susceptible.

[NS], *, ***Non-significant and significant at $P \leq 0.05$ and $P \leq 0.0001$, respectively.

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In 2005, *P. capsici*-resistant 'Paladin' had the lowest disease incidence rating at 42% at 16 WAT which differed ($P \leq 0.05$) from all other bell pepper cultivars (Table 1). The tolerant cultivars, Alliance, Aristotle X3R, and Revolution, tended to express less Phytophthora blight incidence of 82, 85 and 73%, respectively, compared to all susceptible cultivars that had ≥ 90% incidence at 16 WAT. For 2006, *P. capsici*-resistant 'Paladin' had the lowest Phytophthora blight disease rating (3%) at 16 WAT; furthermore, two of the *P. capsici*-tolerant cultivars, Aristotle X3R and Revolution, had disease incidence ratings of 7 and 8%, respectively (Table 2). All susceptible cultivars expressed ≥ 30% Phytophthora blight disease incidence at 16 WAT.

Fungicide treatment: For both 2005 and 2006, bell pepper plants receiving fungicide applications produced greater marketable weights and farm-gate revenues compared to non-treated plants (Table 3). Under high *P. capsici* disease pressures in 2005, fungicide-treated plants generated almost double the marketable yields and farm-gate revenues compared to non-treated plants.

Bell pepper cultivar – 2005: *P. capsici*-resistant 'Paladin' produced the highest yields and farm-gate revenues compared to any other cultivar (Table 3). Farm-gate revenue produced by 'Paladin' ($20,800 ha^{-1}) was more than double of those from most susceptible cultivars. High marketable yields (≥ 19,600 kg ha^{-1}) and farm-gate revenues (≥ $15,600 ha^{-1}) were also produced by 'Alliance' and 'Aristotle X3R'. Although 'Paladin' had the lowest Phytophthora blight incidence of 42% at 16 WAT compared to all other cultivars (Table 1), it did not differ ($P > 0.05$) from *P. capsici*-tolerant Alliance, Aristotle X3R, or Revolution and susceptible King Arthur for marketable weights and farm-gate revenues (Table 3). Conversely, 'California Wonder' produced the lowest marketable yields (7,900 kg ha^{-1}) and farm-gate revenues ($6,300 ha^{-1}), and had 98% Phytophthora blight incidence at 16 WAT.

Bell pepper cultivar – 2006: Lower Phytophthora blight incidence during the 2006 growing season directly resulted in higher total yields and farm-gate revenues for all bell pepper cultivars compared to 2005 (Table 3). *P. capsici*-tolerant

Table 3. Impact of fungicide application and cultivar resistance/tolerance on bell pepper marketable weights and farm-gate revenues in a *Phytophthora capsici*-infested field near Shawneetown, Illinois during 2005 and 2006

Treatment	2005 (x 1,000)[z]		2006 (x 1,000)[z]	
	MW (kg ha^{-1})	FGR ($ ha^{-1})	MW (kg ha^{-1})	FGR ($ ha^{-1})
Fungicide[y]				
Non-treated	10.3	8.2	29.1	23.2
Treated	19.3	15.4	34.6	27.6
Significance	**	**	**	**
Cultivar[x]				
Paladin[w]	26.0a	20.8a	33.8b-f	27.0b-f
Aristotle X3R[v]	19.9ab	15.9ab	34.8b-d	37.7b-d
Alliance[v]	19.6a-c	15.6a-c	40.1ab	32.0ab
Revolution[v]	17.8a-d	12.7a-d	42.6a	34.0a
King Arthur[u]	16.6a-d	13.2a-d	33.9b-e	27.0b-e
Commandment[u]	13.3b-d	10.6b-d	25.2h-j	20.1h-j
Red Knight X3R[u]	12.9b-d	10.3b-d	38.6a-c	29.2a-c
Legionnaire[u]	12.1b-d	9.6b-d	33.5b-g	26.7b-g
Aladdin X3R[u]	11.3b-d	9.0b-d	24.7h-j	19.7h-j
Brigadier[u]	10.9b-d	8.7b-d	31.0c-h	24.7c-h
Camelot X3R[u]	9.3b-d	7.4b-d	27.3e-i	21.7e-i
Cal. Wonder[u]	7.9d	6.3d	18.7j	14.9j

[z]MW = marketable weights and FGR = farm-gate revenues. FGR was calculated using a $10 (USA)/12.6 kg box conversion factor which was based upon the average St. Louis, Mo. produce terminal market prices for 2005 and 2006. Means followed by the same letter in each column are not significantly different at $P \leq 0.05$.

[y]Fungicide treatment: non-treated = no fungicide treatment and treated = fungicide treatment of:

1) mefenoxam (Ridomil Gold EC, 1.17 L ha^{-1}) at transplant and 2) a spray application of dimethomorph (Acrobat 50WP, 0.45 kg ha^{-1}) + copper (Tenn-Cop, 3.6 L ha^{-1}) alternated with manganese ethylenebisdithiocarbamate (Maneb, 2.8 kg ha^{-1}) + copper (Tenn-Cop, 3.6 L ha^{-1}) at 10 day intervals.

**Significant at $P \leq 0.01$.

[x]Cultivars are ranked according to total marketable yields for 2005. Visible symptoms included wilting of plants, crown rot and stem lesions, and fruit rot.

[w]*Phytophthora capsici*-resistant

[v]*Phytophthora capsici*-tolerant.

[u]*Phytophthora capsici*-susceptible.

'Revolution' produced the highest yields and farm-gate revenues throughout the growing season, which differed from most other cultivars, including Paladin. Similar to 2005, 'California Wonder' produced the lowest marketable yields (18,700 kg ha^{-1}) and farm-gate revenue (\$14,900 ha^{-1}) but did not differ ($P > 0.05$) from 'Aladdin' or 'Commandment'. Furthermore, these cultivars had high Phytophthora blight incidence ratings (≥ 42%) at 16 WAT (Table 2). *P. capsici*-resistant 'Paladin' and *P. capsici*-tolerant 'Alliance', 'Aristotle X3R', and 'Revolution' were in the top half of cultivars with respect to yields and farm-gate revenues, as well as having the lowest Phytophthora blight incidence after 16 weeks at 3, 25, 7 and 8%, respectively (Table 2).

Discussion

Although the two years provided distinctly different growing conditions, Phytophthora blight was prevalent in bell peppers during both years of the study. Overall Phytophthora blight incidence ratings on bell peppers after 16 weeks in 2005 and 2006 were 76 and 18%, respectively, for those receiving fungicide applications and 97 and 42%, respectively, for those without fungicide treatment. Furthermore, marketable yields and farm-gate revenues were lower in 2005 compared to 2006 (Table 3). These results indicate that overall Phytophthora blight incidence in bell peppers was not as high in 2006 compared to 2005 which most likely resulted from: 1) differences in rainfall patterns between the two years, with excessive amounts during July and August 2005 (Anonymous, 2006a) that led to flooding of the field and water often standing between rows of black plastic; and, 2) planting the experiment in a higher, better-drained area of the field in 2006. This further shows that *P. capsici* thrives in wet conditions, particularly in low-lying or poorly-drained areas of the field where water accumulates (Hausbeck and Lamour, 2004).

This research indicated that 'Paladin' generally produces high yield and farm-gate revenues under high Phytophthora blight disease pressures, and this bell pepper cultivar could be a reliable choice for growers in Illinois who have problems with this disease (Table 3). The *P. capsici*-tolerant cultivars, Alliance, Aristotle X3R, and Revolution tended to have a lower incidence of Phytophthora blight and increased yield and farm-gate revenues compared to the susceptible cultivars evaluated.

Although 'Paladin' offers *P. capsici* resistance, other factors such as poor horticultural characteristics and susceptibility to other diseases [*e.g.*, bacterial spot (*X. campestris* pv. *vesicatoria*)] must also be taken into account when choosing bell pepper cultivars for commercial production (Rowell *et al.,* 2006). Kline and Johnston (2005) indicated that 'Aristotle X3R' and 'Revolution' have better fruit quality characteristics than 'Paladin'. In addition, 'Alliance', 'Aristotle X3R', and 'Revolution' have bacterial spot resistance along with *P. capsici*-tolerance (Egel *et al.,* 2005, Rowell *et al.,* 2006, Anonymous, 2006b). Therefore, if growers require bell pepper cultivars having resistance to several diseases or better horticultural characteristics, Alliance, Aristotle X3R, and Revolution may provide a better choice. The multiple disease resistance in these three bell pepper cultivars is important in areas such as the southern United States where bacterial spot disease incidence is high and Phytophthora blight is also a problem (Rowell *et al.,* 2006).

Although plant resistance and/or tolerance are often the basis of disease management programs, these methods should not be relied upon alone to achieve effective control of *P. capsici* (Hausbeck and Lamour, 2004). Furthermore, this research shows that regardless of the level of resistance to *P. capsici,* fungicide applications provided greater bell pepper yields and farm-gate revenues compared to those that were not treated. Although yield and farm-gate revenues were high for the resistant/tolerant cultivars in most cases, fungicide applications provided extra protection by reducing Phytophthora blight incidence compared to non-treated plants. Furthermore, the utilization of *P. capsici*-resistant/tolerant cultivars coupled with fungicides and cultural practices, such as planting into raised beds and managing field moisture levels, may provide growers with further protection from Phytophthora blight-induced bell pepper losses.

Acknowledgements

The authors thank Kate Kammler, Talia Dorton, Robert Britenstine, Nathan Johanning, Alicia Garcia, and Mark Zucco for their technical assistance in this study. The use of trade names in this publication does not imply endorsement of the products named or criticism of similar ones not mentioned.

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