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Field validation of TOMCAST modified to manage Septoria leaf spot on tomato in the central-west region of Brazil

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ABSTRACT

Septoria leaf spot, caused by *Septoria lycopersici*, is a devastating disease on tomato in Brazil. In order to rationalize the chemical control, we validated the TOMCAST system to manage Septoria leaf spot on fresh market tomato in the State of Goiás, Brazil. Three field experiments were performed in a randomized complete block with five treatments and four replications. The first experiment was carried out from October 2017 to February 2018, the second from October 2018 to February 2019, and the third from November 2018 to March 2019. The treatments evaluated were: 1. Weekly calendar application of fungicides (WCA); 2 to 4. Disease severity values (DSV) 15, 20, and 25; 5. Control: plants not treated with fungicides. The values of the average air temperature and leaf wetness were used to calculate the DSV. The environmental conditions were favorable to the disease in experiments. The lowest values of the area under the disease progress curve (AUDPC) were recorded in WCA (809), DSV 20 (837), and DSV 15 (842) in the first experiment. Disease rates (r) of 0.010 were estimated in these treatments. Highest AUDPC (1325) and r (0.013) were detected in the control. In the second and third experiments, the highest AUDPC values were 638 and 59 in the control, respectively. The lowest AUDPC values were recorded in DSV 15 and WCA which were 325 and 28, 349 and 26, in the second and third experiments, respectively. No differences of r were detected in the second and third experiments. The highest number of fruits by plant (15) was estimated in DSV 15 in the second experiment. There were no differences on tomato yield in other experiments. As the number of fungicides applications was the highest in DSV 15, the TOMCAST system is not a useful tool for controlling Septoria leaf spot on tomato in the State of Goiás and other Brazilian regions with similar climatic characteristics.

1. Introduction

Septoria leaf spot, caused by *Septoria lycopersici* Speg., is the most important fungal disease on tomato crops in Brazil (Cabral et al., 2013; Becker, 2019a). The combination of optimum temperatures and high precipitation, especially in the summer season, can significantly increase the disease incidence on tomato plants. During periods when the temperatures are above 25 °C and leaf wetness up to 6 h, tomato yields can be reduced by more than 50% (Elmer and Ferrandino, 1995; Sanoubar and Barbanti, 2017). The disease symptoms occur in all stages of the tomato plant development and they are initially observed on the older and lower leaves with circular spots surrounded by dark brown margins and tan to gray centers with black pycnidia. Severe attacks can also cause lesions on the stems, peduncle, and chalice, where the lesions are generally smaller and darker (Stevenson, 2014).

As there is no resistant tomato cultivar to *S. lycopersici*, the methods for the disease management include chemical control and cultural practices such as crop rotation, destruction of crop debris, weed control, and drip irrigation (Cabral et al., 2013; Stevenson, 2014; Becker, 2019a). When the environmental conditions are favorable to the occurrence of Septoria leaf spot, the use of fungicides is the most effective method to reduce the disease severity on tomato plants grown

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mainly during the rainy season. All Brazilian tomato growers adopt a fixed spray program to manage the disease and the fungicides are generally sprayed twice or more times a week before fructification under highly favorable environmental conditions (Inoue-Nagata et al., 2016; Becker, 2019a). This is unsustainable and questioned by the public and governmental sectors due to the risk to the environment and human health (Reis Filho et al., 2009). Also, there is the risk of the selection of resistant isolates of *S. lycopersici* to fungicides.

Therefore, rational management of Septoria leaf spot on tomato is an urgent need. Reducing the crop losses with a decision support system (DSS) can rationalize the use of fungicides. The use of a DSS can reduce the number of fungicide sprays while achieving better control of the disease. If it is not possible to reduce the number of sprays, a better control could also be achieved because the sprays will be carried out at the appropriate times. DSSs have been evaluated mainly for early and late blight on tomato as a useful tool to the integrated management of both diseases in Brazil (Paul et al., 2004; Batista et al., 2006; Duarte et al., 2007; Becker et al., 2011; Becker, 2019b).

TOMCAST is a DSS for early blight, anthracnose, and Septoria leaf spot that was developed based on the disease chart cross referencing temperature and leaf wetness from the FAST program (Pitblado, 1992). The hours of leaf wetness and mean air temperature are combined to estimate the daily severity values (DSV) which increases in the warm and wet weather. FAST was developed to tomato early blight which also includes the period of relative humidity above 90% and total rainfall (Madden et al., 1978). As the weather conditions favorable to early blight, anthracnose, and Septoria leaf spot are similar, TOMCAST was implemented to manage the diseases in Canada (Pitblado, 1992) and USA (Gleason et al., 1995). In this DSS evaluation, the fungicide application was initiated when the DSV reached 35 or 45 according to the tomato planting. Subsequent fungicide sprays occurred when the DSV reached 20. The system contributed to reduce around three applications from 1988 to 1991 (Pitblado, 1992).

In Brazil, the TOMCAST and Lacy models were compared to weekly calendar application of fungicides in field experiments conducted in 2011, 2012, and 2014 in Santa Catarina state (Becker, 2019a). Although there were no differences in AUDPC, disease rate progress and tomato yield, the number of fungicide applications was reduced around 50% in the treatment when the DSV reached 20 (Becker, 2019a). Thus, both models have been used as a DSS to assist tomato growers in the South region of Brazil based on an internet-based platform named Agroconnect from the EPAGRI/CIRAM (http://www.ciram.sc.gov.br/agroconnect/).

As Septoria leaf spot is the main fungal foliar disease in other tomato production regions, the DSS should be validated under field experiments in areas with distinct climate conditions. The State of Goiás, located in the Central-West of Brazil, is the major tomato production area in the country, but there is no DSS available to tomato growers in this region. The climate characteristics in the States of Goiás and Santa Catarina are completely different (Alvares et al., 2013). Santa Catarina is one of the coldest state with an annual average temperature of 20 °C and rainfall distributed uniformly along the year; whereas for Goiás, the climate is altitude tropical with average monthly temperatures vary from 26 °C in the warmest month to 22 °C in the coolest. The year is divided into a rainy and a dry season from October to March and April to September, respectively (Alvares et al., 2013).

The objective of this study was to validate the TOMCAST system to manage Septoria leaf spot on tomato in the State of Goiás which is an important representative region of tomato production in the Central-West of Brazil and produces around 50.000 ton of tomatoes in an area of 672 ha (IMB, 2017). We tested whether the modified TOMCAST model initiating the fungicide application according to the DSV established for each treatment would control the disease similarly with the treatment of weekly fungicide application.

2. Material and methods

2.1. Location, field preparation, and cultural procedures

Three field experiments to validate the TOMCAST system in the chemical control of Septoria leaf spot were established in the Horticulture Research Station of the College of Agronomy at Universidade Federal de Goiás, Goiânia, Brazil (16°35′48.56″S, 49°16′53.50″ W, altitude 730 m). The experiments were conducted from October of 2017 to February of 2018, October of 2018 to February of 2019, and November of 2018 to March of 2019 on a clay loam texture soil with 39% of sand, 11% of silt, and 50% of clay. The soil analysis showed the following results: pH ($CaCl^2$) 5.9; 1.7 mg/dm^3 H + Al^{3+}; 3.4 mg/dm^3 Ca^{2+}; 1.1 mg/dm^3 Mg^{2+}; 0.13 mg/dm^3 K^+; 100 mg/dm^3 P; and 100 mg/dm^3 of organic matter.

The soil correction was carried out with a dolomite lime (RTNP 100%) to raise base saturation up to 80%. Raised beds were fertilized with N, P_20_5, and K at 100, 300, and 80 kg/ha, respectively. After 30 days of planting, the fertilizer Hortimax® (Araguaia, Brazil) with 13-3-25 (N–P–K) was applied weekly in the soil surface at 30 g/plant. For the first experiment, it was used the saladette-type tomato cultivar Totalle® (Nunhems, Campinas, Brazil) with a cycle of 120 days and average fruit weight of 200 g. In the second and third experiments, the seedlings were grafted on the tomato cultivar Green Power® (Takii Seeds, Barueri, Brazil) with resistance to *Ralstonia solanacearum*. Tomato seedlings were transplanted to the field 35 days after the sown in the first experiment; while for the second and third experiments, seedlings were transplanted after 50 days after the sown.

Double-stemmed plants sustained by nylon strings were grown in mulched raised beds with double rows spaced at 1.5 m apart and 0.7 × 0.8 m between plants and single rows, respectively. Plants were drip-irrigated and cultural practices such as pruning, sprouting, and apex removal were conducted according to plant development. The insecticides thiamethoxam (10.5 g a. i./ha), lambda-cyhalothrin (7.95 g a. i./ha), chlorantraniliprole (40 g a. i./ha), chlorfenapyr (120 g a. i./ha), spinetoram (37.5 g a. i./ha), triflumuron (144 g a. i./ha), fenpropathrin (45 g a. i./ha), methomyl (215 g a. i./ha), and abamectin (18 g a. i./ha) were applied as needed. Weeds were controlled using a hoe until the end of harvest.

2.2. Design of field experiments and treatments

The experimental design was performed in a randomized complete block with five treatments and four replications. The following treatments were evaluated: 1. Weekly calendar application of fungicides; 2 to 4. DSV 15, 20, and 25; 5. Control: plants not treated with fungicides.

The following protectant and systemic fungicides were applied alternately in the first experiment: metiram (660 g a. i/ha), pyraclostrobin (60 g a. i/ha), difenoconazole (75 g a. i/ha), azoxystrobin (40 g a. i/ha), metconazole (43.2 g a. i/ha), and propineb (2.1 kg a. i/ha). In the second and third experiments, the fungicides metconazole and propineb were changed to pyraclostrobin (30.06 g a. i/ha), fluxapyroxad (99.1 g a. i/ha), and tebuconazole (200 g a. i/ha). To prevent the selection of resistant isolates of *S. lycopersici* to fungicides, all the systemic fungicides were applied in combination with propineb (2.1 kg a. i/ha) or mancozeb (2.25 kg a. i/ha) in the second and third experiments. Fungicides were applied using a battery powered backpack sprayer with 20 L of capacity and hollow-cone nozzles adjusted to spraying volume of 600 L/ha (Jacto PJBA, Pompéia, São Paulo, Brazil).

Temperature, relative humidity, and rainfall were measured with the weather station Davis Vantage Pro 2 (Davis, Hayward, USA). To monitor leaf wetness, the probes LWS-L (Decagon, Pullman, USA) were installed near to the lower and upper third of the plants. Values of the average air temperature and leaf wetness were used to calculate the DSV daily after the tomato planting according to the methodology proposed by Madden et al. (1978). When the DSV was reached for each treatment, the

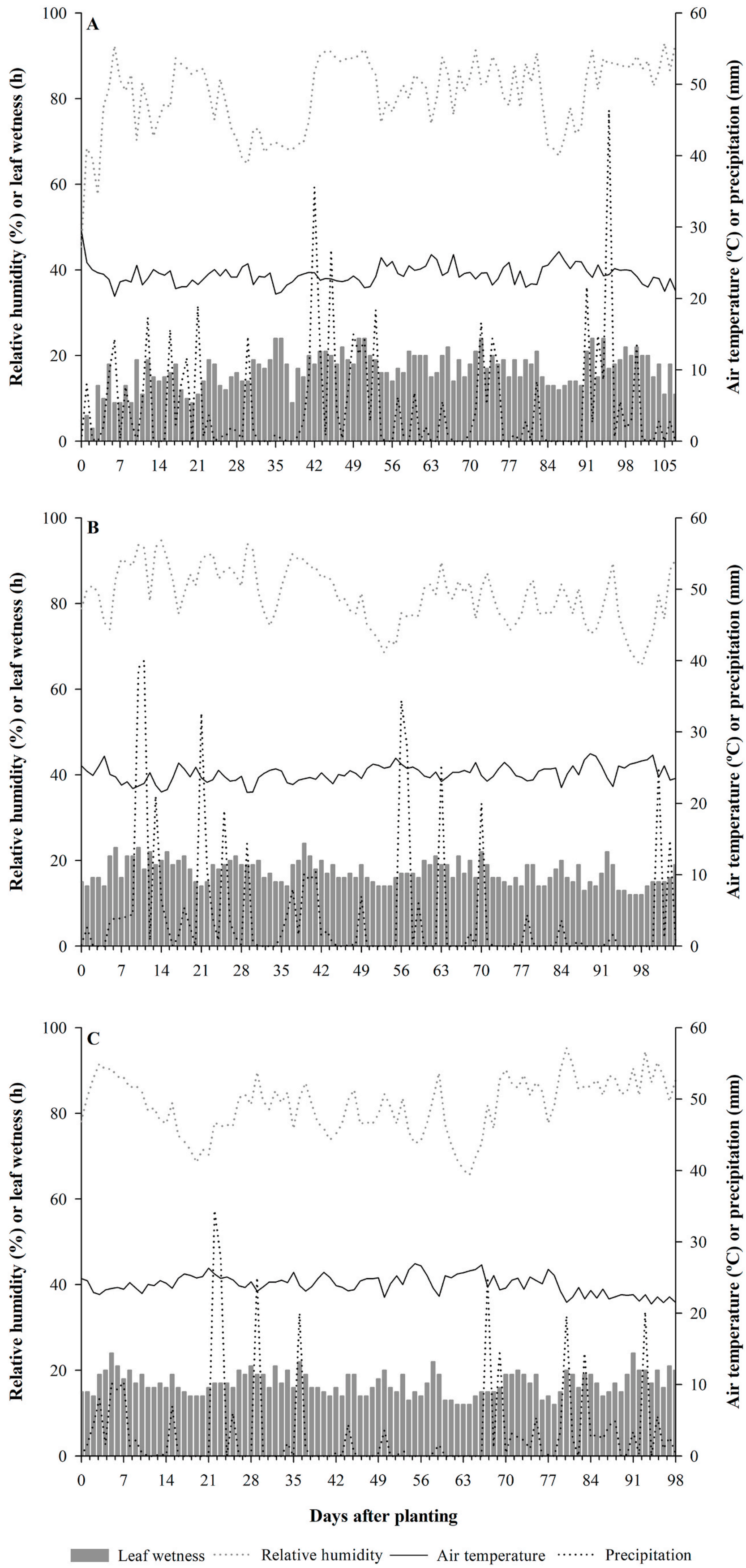

Fig. 1. Leaf wetness, relative humidity, air temperature, and precipitation measured daily by a weather station in the experiments conducted from October of 2017 to February of 2018 (A), October of 2018 to February of 2019 (B), and November of 2018 to March of 2019 (C).

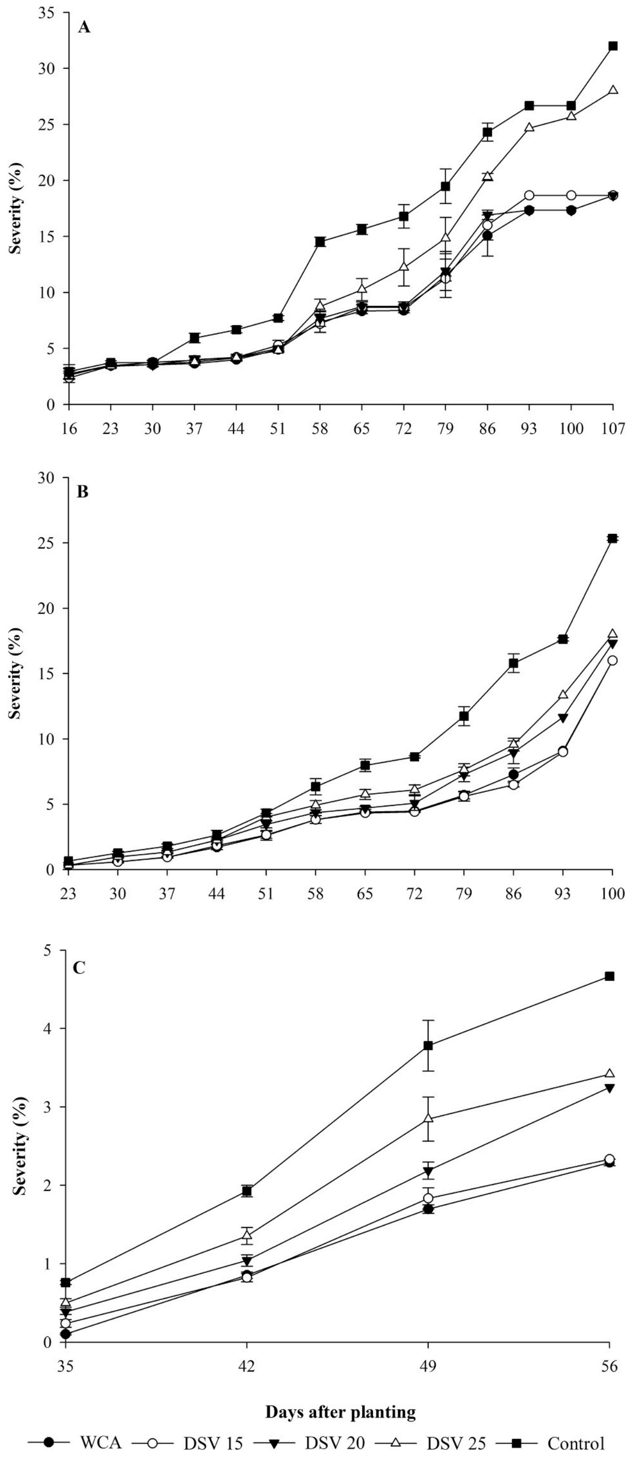

Fig. 2. Disease progress curves for the Septoria leaf spot on tomato plants in the treatments DSV 15, 20, 25, weekly calendar application of fungicides, and control in the experiments conducted from October of 2017 to February of 2018 (A), October of 2018 to February of 2019 (B), and November of 2018 to March of 2019 (C). Each bar represents the standard error of the mean.

fungicides were sprayed on the same day. The DSV scouting was restarted after the fungicide application or after 10 days. For the weekly calendar application of fungicides, the spraying was initiated after 10 DAP and repeated every 7 days until the end of tomato harvest. The time of fungicide applications performed in the treatments is described in Appendix A.

2.3. Disease severity evaluation, yield estimates, and statistical analyses

Disease severity and yield were assessed in eight plants of the double rows (the two plants located at each end of the row were not evaluated). Septoria leaf spot severity was estimated in two leaflets from the upper, middle, and lower third of plants using a diagrammatic scale adapted from the Stemphylium gray leaf spot of tomato (Boff et al., 1991). Disease severity evaluations were conducted at 7 days intervals until the end of harvest.

Values of the area under the disease progress curve of Septoria leaf spot (AUDPC) was calculated (Shaner and Finney, 1977). Nonlinear disease curve progress and disease rate (r) were analyzed (Campbell and Madden, 1990). After fructification and ripening, the harvest was carried out weekly. Fruits were counted, weighed, and classified as the quality (number of marketable fruits without insect damages and physiological disturbances) and type (type 1: 50–60 mm of transverse diameter). Data were subjected to the analysis of variance and Fisher LSD test to determine differences among means. The statistical analyses were conducted using the SAS software (SAS Institute, Cary, NC, version 9.1).

3. Results

The weather conditions were favorable to Septoria leaf spot in all experiments (Fig. 1). Based on the non-linear regression analyses, the Gompertz model was the most appropriate to describe the progress of Septoria leaf spot on tomato plants.

In the first experiment, the average values of relative humidity, leaf wetness, daily temperature, and precipitation were 81%, 16.5 h, 23.4 °C, and 522.1 mm, respectively (Fig. 1A). Disease symptoms appeared 16 days after the planting (DAP) reaching the maximum severity of 32% and 28% in the control and DSV 25 at 107 DAP, respectively (Fig. 2A). The lowest severity was noted in the treatments DSV 15, 20, and weekly calendar application of fungicides (Fig. 2A). There were differences of AUDPC and r among the treatments (Table 1). Highest values of AUDPC and r were recorded in the control (Table 2). DSV 15, 20, and weekly calendar application of fungicides showed the lowest values of AUDPC and r (Table 2). Although the r estimate for DSV 25 was the same compared to DSV 15, 20, and weekly calendar application of fungicides, the AUDPC value was higher in this treatment. Nevertheless, there were no differences in number and weight of fruits (Table 2). The DSV 15 resulted in the highest number of sprays (Table 2).

Weather conditions were also favorable to Septoria leaf spot in the second experiment (Fig. 1B). The average values of relative humidity, leaf wetness, daily temperature, and precipitation were 82%, 15.3 h, 24.2 °C, and 455.6 mm (Fig. 1 B). First symptoms appeared at 23 DAP with a maximum severity of 25% estimated at 100 DAP in the control (Fig. 2B). The lowest disease severity was estimated in DSV 15, 20, 25, and weekly calendar application of fungicides (Fig. 2B). Differences in AUDPC were detected, however, r was not distinct among the treatments (Table 1). The AUDPC was higher in the control (Table 2). The lowest AUDPC was obtained in DSV 15 and weekly calendar application of fungicides (Table 2). The number and weight of fruits were distinct in this experiment (Table 1). The control produced the lowest number and weight of fruits. The highest number of fruits was obtained in DSV 15 (Table 2). No differences of fruits weight were detected between the treatments DSV 15 and weekly calendar application of fungicides. The number of fungicide applications was higher in DSV 15 (Table 2).

In the third experiment, the average values of relative humidity, leaf wetness, daily temperature, and precipitation were 80%, 14.2 h, 24 °C, and 306.6 mm, respectively (Fig. 1 C). The first symptoms were detected at 35 DAP. As there was high incidence of bacterial spot, the experiment was concluded at 56 DAP with maximum severity of Septoria leaf spot of 4% estimated in the control (Fig. 2C). The lowest disease severity was observed in DSV 15, 20, 25, and weekly calendar application of fungicides (Fig. 2C). Differences of AUDPC were detected among the

Table 1
Analysis of variance for the effect of the treatments DSV 15, 20, 25, weekly calendar application of fungicides, and control in the experiments conducted from October of 2017 to February of 2018 (Experiment 1), October of 2018 to February of 2019 (Experiment 2), and November of 2018 to March of 2019 (Experiment 3) in the area under the disease progress curve of Septoria leaf spot (AUDPC), disease rate (*r*), fruits weight (FW) and number of fruits (NF) by plant.

Experiment	Source	DF	AUDPC			*r*			FW			NF		
			QM	F	P > F	QM	F	P > F	QM	F	P > F	QM	F	P > F
1	Treatments	4	184826.3	104.5	<0.0001	0.000007	8.5	0.0017	1.97	0.39	0.8108	80.70	0.55	0.7029
2	Treatments	4	60614.1	282.5	<0.0001	0.000017	1.3	0.3262	17.48	4.58	0.0178	1412.17	4.81	0.0151
3	Treatments	4	732.1	84.9	<0.0001	0.000009	1.0	0.4381	0.80	0.21	0.9280	193.07	2.22	0.1278

Table 2
Number of fungicide spraying (NFS), area under the disease progress curve of Septoria leaf spot (AUDPC), disease rate (*r*), fruits weight (FW, kg), and number of fruits by plant (NF) in the treatments (T) DSV 15, 20, 25, weekly calendar application of fungicides (WCA), and control in the experiments conducted from October of 2017 to February of 2018 (Experiment 1), October of 2018 to February of 2019 (Experiment 2), and November of 2018 to March of 2019 (Experiment 3).

T	Experiment 1					Experiment 2					Experiment 3				
	NFS	AUDPC	*r*	FW	NF	NFS	AUDPC	*r*	FW	NF	NFS	AUDPC	*r*	FW	NF
WCA	15	809 c[a]	0.010 b	1.4^{ns}	6^{ns}	14	349 d	0.014^{ns}	5.2 a	12 b	14	26 d	0.018^{ns}	3,9^{ns}	8^{ns}
DSV 15	16	842 c	0.010 b	1.2	5	17	325 d	0.014	5.1 a	15 a	16	28 d	0.017	3.9	8
DSV 20	12	837 c	0.010 b	1.4	5	13	395 c	0.011	4.8 ab	10 b	13	35 c	0.021	4.0	9
DSV 25	10	939 b	0.010 b	1.4	5	11	456 b	0.014	4.6 ab	10 b	9	43 b	0.020	3.9	10
Control	0	1325 a	0.013 a	1.3	5	0	638 a	0.017	4.6 b	9 b	0	59 a	0.019	4.0	9
CV (%)	–	4	8	21	27	–	3	25	5	19	–	8	16	6	13

[a] Means followed by the same letter are not significantly different according to Fisher LSD test (P ≤ 0.05); ns: means are not significant at P ≤ 0.05.

treatments (Table 1). The highest AUDPC was estimated in the control (Table 2). Lowest values of AUDPC were recorded in DSV 15 and weekly calendar application of fungicides (Table 2). There were no differences of *r* estimates, number, and weight of fruits (Table 1). The number of fungicide applications was highest in DSV 15 (Table 2).

4. Discussion

Although the TOMCAST system resulted in Septoria leaf spot control on tomato that were comparable to the weekly calendar application of fungicides, the number of sprays was not reduced. These findings provide evidence that the TOMCAST is not a useful tool to manage Septoria leaf spot in the State of Goiás and other regions with weather conditions highly favorable to the disease. Only in the first experiment the DSV 20 reduced the number of fungicides applications, however, the AUDPC values were higher in this treatment than DSV 15 and weekly calendar application of fungicides in the second and third experiments. Differences of tomato yield were not detected in the first and third experiments due to physiological disorders and the occurrence of bacterial spot, respectively. There was phytotoxicity on tomato plants after the planting in the first experiment caused probably by herbicide drift from other trials conducted in the same area. In the last experiment, the high incidence of bacterial spot interfered in the Septoria leaf spot evaluation and tomato yield.

The DSV 15 was efficient in the Septoria leaf spot control and tomato yield in the second experiment, however, the number of fungicide applications was higher in this treatment. In situations with favorable weather for plant diseases and when a susceptible cultivar is used, the DSS can recommend more fungicide applications than weekly schedule but with improved disease control. This was observed with the use of BlightPro decision support system in the potato late blight management which can increase the fungicide application if the grower uses a susceptible cultivar when the environmental conditions are conducive to the disease (Liu et al., 2017).

In our case, all tomato cultivars are susceptible to *S. lycopersici* and most farmers prefer to grow tomato in rainy season due to the higher prices of fresh market tomato in the Brazilian summer (Machado et al., 2008; Inoue-Nagata et al., 2016; Becker, 2019a). Thus, tomato growers can apply fungicides twice to three times a week to control Septoria leaf spot and other plant diseases in the vegetative and flowering stages (Inoue-Nagata et al., 2016; Becker, 2019a). As the number of multisite and site-specific fungicides is limited for Septoria leaf spot management, the intensive chemical control should be avoided to prevent the selection of resistant isolates of *S. lycopersici* to fungicides. In a preliminary study conducted in Brazil, there was evidence of reduction in fungicide sensitivity regarding azoxystrobin, chlorothalonil, thiophanate-methyl, and tebuconazole in the *S. lycopersici* population (Costa, 2019).

The Gompertz model was more suitable to describe the Septoria leaf spot epidemics in our research as also observed in the study conducted in the State of Santa Catarina (Becker, 2019a). This suggests that the fungicide applications can be most effective when applied early in epidemic development. The fungicide application was initiated 10 DAP in the weekly calendar application (Appendix A). As the environmental conditions were favorable to the disease in the experiments, the application of fungicides were performed around 15 DAP in the other treatments. Nevertheless, differences in disease rate were detected only in the first experiment which were not so pronounced between the treatments and control. Thus, further investigations should be done to increase the fungicide efficiency to control Septoria leaf spot. Perhaps, the treatment of tomato seedlings with fungicides or compounds can reduce disease severity after the planting. Other important approaches that should be done is to develop resistant cultivars and biocontrol agents to *S. lycopersici*. Resistant accessions of *Solanum peruvianum* and *S. habrochaites* to *S. lycopersici* were found in a study conducted in Brazil that can be used in a tomato-breeding program (Satelis et al., 2010). In another study, there was reduction of Septoria leaf spot severity on tomato plants grown from seeds microbiolized with *Bacillus cereus* and treated with fungicides under field conditions (Silva et al., 2004).

Our results demonstrated that the TOMCAST is not a useful tool for controlling Septoria leaf spot on tomato in the State of Goiás. Other studies are required to improve the TOMCAST or develop another system that can be used as DSS in the management of Septoria leaf spot. First, it is important to assess the genetic structure of *S. lycopersici* because there is no information of genetic variability and the contribution of evolutionary process as mutation, genetic drift, gene flow, selection, and recombination in the fungus population. Up to date, it is known that the fungus is splash-dispersed only over short distances by conidia produced in pycnidia (Stevenson, 2014). Although sexual reproduction is unknown, the fungus could produce sexual spores that can be dispersed across long distances. Recombination and gene flow are reported in *Septoria* species phylogenetically related which produces ascospores dispersed by wind (Verkley et al., 2013). If *S. lycopersici* produce sexual wind-dispersed spores, the spore monitoring could be included in the DSS system to optimize the fungicide spray timing.

Another important study is to evaluate the efficiency of fungicides in the Septoria leaf spot control. For this plant disease, it is recommended the application of metiram, pyraclostrobin, difenoconazole, azoxystrobin, fluazinam, thiophanate-methyl, metconazole, propineb, fluxapyroxad, tebuconazole, mancozeb, chlorothalonil, and copper fungicides (Inoue-Nagata et al., 2016; Becker, 2019a). Nevertheless, information about the efficiency, persistence on tomato plants, and compatibility of these fungicides with other chemical and biological compounds is very limited. Finally, the monitoring of the sensitivity of *S. lycopersici* isolates to fungicides is fundamental in the Septoria leaf spot management using a DSS system to develop anti-resistance strategies and methods to rapidly detect resistant strains to contain their spread.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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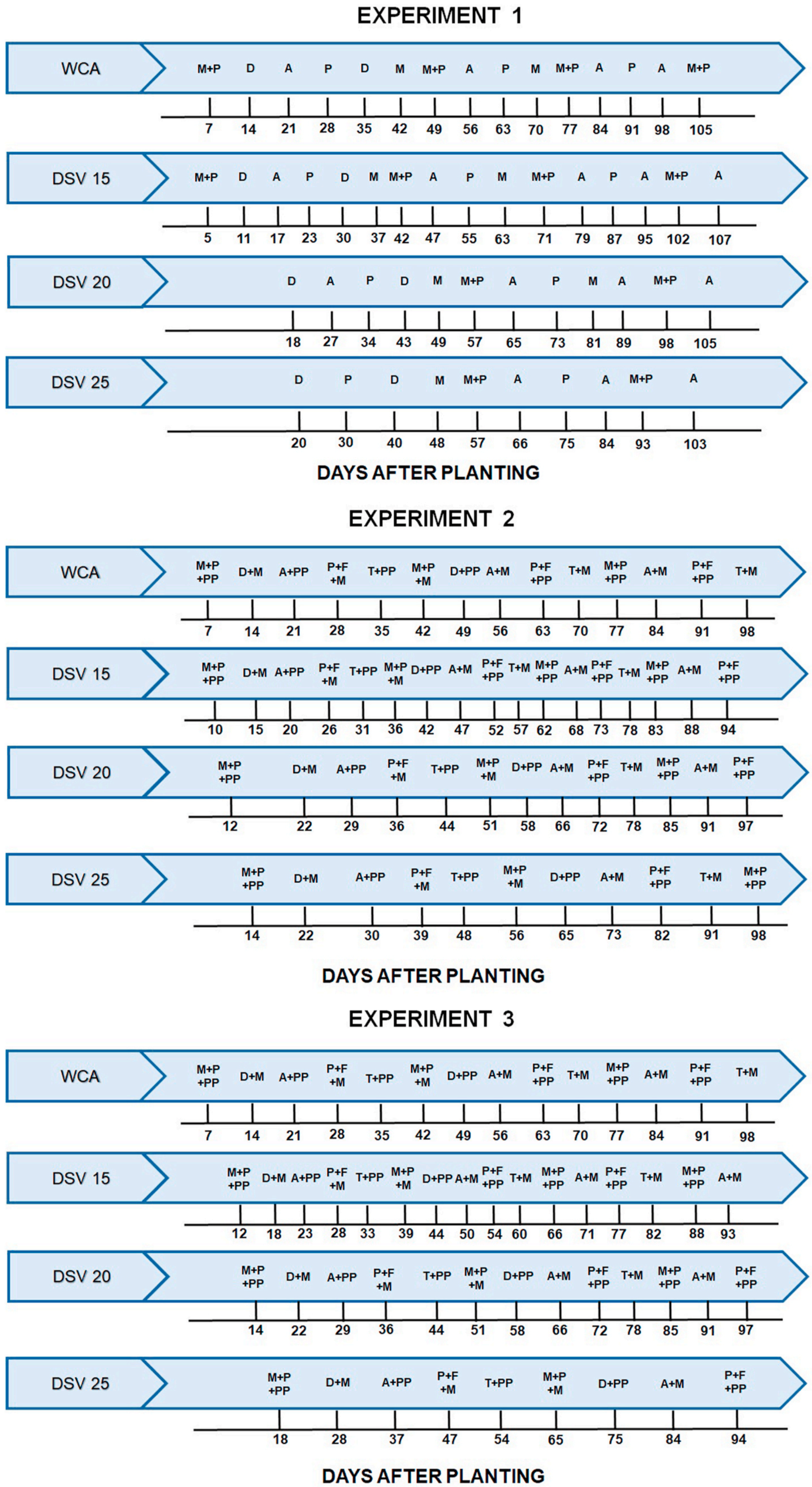
Appendix A. Time of fungicide application (T) in the treatments DSV 15, 20, 25, and weekly calendar application of fungicides (WCA) in the experiments conducted from October of 2017 to February of 2018 (Experiment 1), October of 2018 to February of 2019 (Experiment 2), and November osf 2018 to March of 2019 (Experiment 3). Fungicides were abbreviated as M = Metiram, P = Pyraclostrobin, F = Fluxapyroxad, A = Azoxystrobin, D = Difenoconazole, M = Metconazole, T = Tebuconazole, PP = Propineb, and M = Mancozeb


EXPERIMENT 1
WCA
M+P D A P D M M+P A P M M+P A P A M+P
7 14 21 28 35 42 49 56 63 70 77 84 91 98 105
DSV 15
M+P D A P D M M+P A P M M+P A P A M+P A
5 11 17 23 30 37 42 47 55 63 71 79 87 95 102 107
DSV 20
D A P D M M+P A P M A M+P A
18 27 34 43 49 57 65 73 81 89 98 105
DSV 25
D P D M M+P A P A M+P A
20 30 40 48 57 66 75 84 93 103
DAYS AFTER PLANTING
EXPERIMENT 2
WCA
M+P +PP D+M A+PP P+F +M T+PP M+P +M D+PP A+M P+F +PP T+M M+P +PP A+M P+F +PP T+M
7 14 21 28 35 42 49 56 63 70 77 84 91 98
DSV 15
M+P +PP D+M A+PP P+F +M T+PP M+P +M D+PP A+M P+F +PP T+M M+P +PP A+M P+F +PP T+M M+P +PP A+M P+F +PP
10 15 20 26 31 36 42 47 52 57 62 68 73 78 83 88 94
DSV 20
M+P +PP D+M A+PP P+F +M T+PP M+P +M D+PP A+M P+F +PP T+M M+P +PP A+M P+F +PP
12 22 29 36 44 51 58 66 72 78 85 91 97
DSV 25
M+P +PP D+M A+PP P+F +M T+PP M+P +M D+PP A+M P+F +PP T+M M+P +PP
14 22 30 39 48 56 65 73 82 91 98
DAYS AFTER PLANTING
EXPERIMENT 3
WCA
M+P +PP D+M A+PP P+F +M T+PP M+P +M D+PP A+M P+F +PP T+M M+P +PP A+M P+F +PP T+M
7 14 21 28 35 42 49 56 63 70 77 84 91 98
DSV 15
M+P +PP D+M A+PP P+F +M T+PP M+P +M D+PP A+M P+F +PP T+M M+P +PP A+M P+F +PP T+M M+P +PP A+M
12 18 23 28 33 39 44 50 54 60 66 71 77 82 88 93
DSV 20
M+P +PP D+M A+PP P+F +M T+PP M+P +M D+PP A+M P+F +PP T+M M+P +PP A+M P+F +PP
14 22 29 36 44 51 58 66 72 78 85 91 97
DSV 25
M+P +PP D+M A+PP P+F +M T+PP M+P +M D+PP A+M P+F +PP
18 28 37 47 54 65 75 84 94
DAYS AFTER PLANTING

References

Alvares, C.A., Stape, J.L., Sentelhas, P.C., Gonçalves, J.L. de M., Sparovek, G., 2013. Köppen's climate classification map for Brazil. Meteorol. Z. 22, 711–728. https://doi:10.1127/0941-2948/2013/0507.

Batista, D.C., Lima, M.A., Haddad, F., Maffia, L.A., Mizubuti, E.S.G., 2006. Validation of decision support systems for tomato early blight and potato late blight, under Brazilian conditions. Crop Protect. 25, 664–670. https://doi.org/10.1016/j.cropro.2005.09.009.

Becker, W.F., Mueller, S., dos Santos, J.P., Wamser, A.F., Suzuki, A., Marcuzzo, L.L., 2011. Viability of a prediction system for tomato late blight in the integrated production of tomato in Caçador, Brazil. Hortic. Bras. 29, 520–525. https://doi:10.1590/s0102-05362011000400013.

Becker, W.F., 2019a. Avaliação de sistemas de previsão para a septoriose do tomateiro tutorado em Caçador, SC, Brasil. Agropecuária Catarinense 32, 62–67. https://doi:10.22491/RAC.2019.v32n3.8.

Becker, W.F., 2019b. Validação de um sistema de previsão para a pinta preta na produção integrada do tomateiro. Agropecuária Catarinense 32, 62–67. http://doi:10.22491/RAC.2019.v32n2.9.

Boff, P., Zambolim, L., Ribeiro do Vale, F.X., 1991. Escalas para avaliação de severidade da mancha de estenfílio (Stemphylium solani) e da pinta preta (Alternaria solani) em tomateiro. Fitopatol. Bras. 16, 280–283.

Cabral, R.N., Marouelli, W.A., Lage, D.A.C., Café-Filho, A.C., 2013. Septoria leaf spot in organic tomatoes under diverse irrigation systems and water management strategies. Hortic. Bras. 31, 392–400. https://doi:10.1590/S0102-05362013000300009.

Campbell, C.L., Madden, L.V., 1990. Introduction to Plant Disease Epidemiology. John Wiley & Sons, New York, p. 532p.

Costa, C.A., Caracterização de isolados de Septoria do tomate, 2019. 104 F. Tese (Doutorado Em Fitopatologia). Universidade Federal Rural de Pernambuco, Recife.

Duarte, H. da S.S., Zambolim, L., Jesus Júnior, W.C., 2007. Manejo da requeima do tomateiro industrial empregando sistema de previsão. Summa Phytopathol. 33, 328–334. https://doi:/10.1590/S0100-54052007000400002.

Elmer, W.H., Ferrandino, F.J., 1995. Influence of spore density, leaf age, temperature, and dew periods on Septoria leaf spot of tomato. Plant Dis. 79, 287–290. https://DOI: 10.1094/PD-79-0287.

Gleason, M.L., MacNab, A.A., Pitblado, R.E., Ricker, M.D., East, D.A., Latin, R.X., 1995. Disease-warning systems for processing tomatoes in eastern North America: are we there yet? Plant Dis. 79, 113–121.

IMB, 2017. Instituto mauro borges. Estatísticas municipais. Disponível em. http://www.imb.go.gov.br/index.php?option=com_content&view=article&id=91&Itemid=219.

Inoue-Nagata, A.K., Lopes, C.A., Reis, A., Pereira, R.B., Quezado-Duval, A.M., Pinheiro, J.B., Lima, M.F., 2016. Doenças do tomateiro (Lycopersicon esculentum). In: Amorim, L., Rezende, J.A.M., Bergamim Filho, A., Camargo, L.E.A. (Eds.), Manual de fitopatologia: Doenças das plantas cultivadas. Agronômica Ceres, São Paulo, pp. 697–732.

Liu, Y., Langemeier, M.R., Small, I.M., Joseph, L., Fry, W.E., 2017. Risk management strategies using precision agriculture technology to manage potato late blight. Agron. J. 109, 562–575. https://doi:10.2134/agronj2016.07.0418.

Machado, A.G., Figueiredo, R.S., Silva Junior, R.P., 2008. Variação estacional dos preços de tomate salada comercializados no Ceasa – GO no período de 1999 a 2006. Informações Econômicas 38, 20–27.

Madden, L., Pennypacker, S., MacNab, A., 1978. FAST, a forecast system for Alternaria solani on tomato. Phytopathology 68, 1354–1358. https://doi:10.1094/phyto-68-1354.

Paul, P.A., Vale, F.X.R., Coelho, R.R., Zambolim, L., Fontes, P.C.R., Macabeu, A.J., 2004. Epidemiologia comparativa da pinta preta do tomateiro sob quatro regimes de pulverização. Fitopatol. Bras. 29, 475–479. https://doi:10.1590/S0100-41582004000500001.

Pitblado, R.E., 1992. The Development and Implementation of TOMCAST- a Weather Timed Fungicide Spray Program for Field Tomatoes. Ministry of Agriculture and food, Ridgetown college of Agricultural technology, Ridgetown, p. 22p.

Reis Filho, J.S., Marin, J.O.B., Fernandes, P.M., 2009. Os agrotóxicos na produção de tomate de mesa na região de Goianápolis, Goiás. Pesqui. Agropecuária Trop. 39, 307–316.

Satelis, J.F., Boiteux, L.S., Reis, A., 2010. Resistance to Septoria lycopersici in Solanum (section Lycopersicon) species and in progenies of S. lycopersicum × S. peruvianum. Sci. Agric. 67, 334–341. https://doi:10.1590/S0103-90162010000300012.

Sanoubar, R., Barbanti, L., 2017. Fungal diseases on tomato plant under greenhouse condition. European Journal of Biological Research 7, 299–308. https://doi:10.5281/zenodo.101116.

Shaner, G., Finney, R.E., 1977. The effect of nitrogen fertilization on the expression of slow-mildewing resistance in Knox wheat. Phytopathology 67, 1051–1056.

Silva, H.S.A., Romeiro, R.S., Carrer Filho, R., Pereira, J.L.A., Mizubuti, E.S.G., Mounteer, A., 2004. Induction of systemic resistance by Bacillus cereus against tomato foliar diseases under field conditions. J. Phytopathol. 152, 371–375. https://doi: 10.1111/j.1439-0434.2004.00853.x.

Stevenson, W.R., 2014. Septoria leaf spot. In: Jones, J.B., Zitter, T.A., Momol, T.M., Miller, S.A. (Eds.), Compendium of Tomato Diseases and Pests. APS PRESS, St. Paul, pp. 42–43.

Verkley, G.J.M., Quaedvlieg, W., Shin, H.D., Crous, P.W., 2013. A new approach to species delimitation in Septoria. Stud. Mycol. 75, 213–305. https://doi.org/10.3114/sim0018.