

Dispersal of *Fusarium* spp. by rainwater and pathogenicity on four plant species

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Abstract Research focused on the occurrence of *Fusarium* spp. in atmospheric dust or rainwater is not common. Preliminary studies with four sampling dates in 2007 revealed that several species of *Fusarium* may also be conveyed by rainwater. In order to determine the regular presence of *Fusarium* spp. in rainfall water, samples were systematically collected for a year (from October 2009 to October 2010) in three points on the Mediterranean coast of the province of Granada (Spain) 10-km distance between them. Throughout the year of sampling, a total of 179 rainwater samples were collected during every significant rainfall event. Eight different *Fusarium* species were isolated from the rainwater samples: *F. oxysporum* (32 %), *F. proliferatum* (26 %) and *F. equiseti* (20 %) coincide with previous studies, while *F. dimerum* (3 %), *F. semitectum* (4.7 %), *F. solani* (8 %), *F. avenaceum* (0.5 %) and *F. chlamydosporum* (3.7 %) were isolated for the first time from rainwater. Results were consistent with previous surveys conducted 100 km away from the sampling sites. Inoculation of 39 different isolates from five different *Fusarium* species

showed pathogenicity on plants. Disease severity differed depending on the inoculated plant species, which means that rain water can be an effective vector to transport new pathogens into new cultivated areas. This work reveals some epidemiological aspects of *Fusarium* genus in natural environments. Some of the isolated *Fusarium* spp. are potential mycotoxin producers, such as zearalenone, fumonisin, moniliformin or nivalenol.

Keywords Epidemiology · Spore transport · Airborne spores · Plant pathogenicity

1 Introduction

Many high-risk plant pathogens are transported over long distances (hundreds of meters to thousands of kilometers) in the atmosphere (Schmale and Ross 2015; Rieux et al. 2014). Research focused on the occurrence of *Fusarium* spp. in aerobiology or aquatic habitats is not common. Although the genus *Fusarium* has regularly been isolated in these works, no specific studies have been performed, and frequently, only the genus is indicated without species assignation (Griffin 2007; Ho et al. 2005; Wu et al. 2004). Aerobiology of *Fusarium* is mainly focused on the processes of spore discharge specially in those species with an important role as pathogens on cereal crops worldwide such as *F. graminearum*, causal agent of *Fusarium* head blight

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(FHB) of wheat and barley. Recently, Prussin et al. (2015) developed a Gaussian spore transport model to predict the spore transport of *F. graminearum* over kilometer distances. On the other hand, species of *Fusarium* have been previously reported in marshy waters, and some species has been isolated from beach sands, river water and sea water of southeastern Spain (Palmero et al. 2008, 2009). Preliminary studies (Palmero et al. 2011a) revealed that several species of *Fusarium* may be also conveyed by the rainwater.

These aspects of the ecology of *Fusarium* have been little studied so far in the literature. In contrast, this information could be very important to understand the epidemiology of plant diseases caused by fungal pathogens that might act as an entry point to cultivated crops through rainwater. Also, considering the genetic diversity of fungal spores introduced to local agricultural fields following atmospheric transport, crop breeders should select resistant varieties based on screening against a set of fungal isolates that represent the range of virulence observed in fungal populations across a broader geographic region (Keller et al. 2014).

On the other hand, a number of fungal species isolated are mycotoxin-producing species (Leslie and Summerell 2006; Mirocha et al. 2003). The knowledge of its presence in the rainwater is important from a standpoint of human health. Different studies relate these species with respiratory diseases or allergies.

The aim of this paper is therefore an evaluation of the content of propagules of *Fusarium* in the rainwater over a year. Firstly to know the species involved and subsequently to address the role of these species in plant diseases by inoculations on the four most cultivated horticultural plant species in the sampling area with the five different isolates of *Fusarium* species most frequently isolated rainwater.

2 Materials and methods

2.1 Sampling sites

In order to determine the regular presence of *Fusarium* spp. in rainfall water, samples were systematically collected for a year (from October 2009 to November 2010) in three points on the Mediterranean coast of the province of Granada (Spain).

Samples were taken in the municipality of Motril, an agricultural town in the central part of the Costa Tropical (Autonomous Community of Andalusia) close to the Mediterranean Sea. In this area, different intensive greenhouse vegetable species are grown (85 % of the tomatoes consumed in Europe are produced in the Andalusian countryside). Three sampling sites (coded as AM, AP and AC) were sampled, and their UTM coordinates are as follows: AM sampling point: 36.751064, −3.511469 (Santa Elena St., Motril); AP sampling point: 36.725559, −3.532079 (Trasmallo St., Motril); AC sampling point: 36.703055, −3.443729 (Montezuma St., Carchuna). Throughout the year of sampling, a total of 179 rainwater samples were collected.

Rain water samples were collected at 6 m above the ground. Rain water samples were collected during every significant rainfall event. Water samples were analyzed within 24–48 h after collecting. Analysis of the *Fusarium* microbiota in water samples involved gently shaking each jar, transferring 1 ml of the rain water sample to a 9-cm Petri dish containing 10 ml *Fusarium* selective medium Tello et al. (1991), cooled to 35 °C, and then gently agitating the mixture. Ten plates (replicates) were analyzed per sample. Plates were incubated for 10 days at laboratory temperature under continuous fluorescent light. The mean number of CFU per Petri dish was calculated for all *Fusarium* colonies and used as the basis for comparisons.

2.2 Maintenance and identification of *Fusarium* species

The whole collection was maintained on PDA and Komada's media and stored at 4 °C in the fungus collection of the Agronomy Department of the University of Almeria and in the Plant Protection laboratory at the Technical University of Madrid. The identification procedures, and the taxonomic criteria of Nelson et al. (1983) and Leslie and Summerell (2006) were followed to assign isolates to the *Fusarium* species level.

2.3 Pathogenicity tests

A total of forty isolates of five species of *Fusarium* obtained during rainwater sampling were inoculated onto melon (*Cucumis melo* L. cv. Piñonet), tomato (*Lycopersicon esculentum* Mill. cv. Marmande),

watermelon (*Citrullus lanatus* (Thunb.) Matsum. and Nakai cv. Sugar Baby) and cucumber (*Cucumis sativus* L. cv. Marketmore). These species were chosen because they are the main herbaceous crops in Almeria and Granada provinces. Seeds were first disinfected with sodium hypochlorite (40–50 mg/l of active Cl^-) for 15 min, washed with sterilized water and then germinated in paper toweling over 3–7 days at room temperature (20–25 °C).

Inoculation tests followed a modification of the technique proposed by Messiaen and Casini (1968). Inoculum for each isolate was prepared by growing the culture for 2 week in complete darkness on potato dextrose agar plates kept at 25 °C until the colony reached the edge of the dish. Plastic 350-ml greenhouse pots were filled to two-thirds capacity with disinfected (30 min at 120 °C) vermiculite substrate [Agroalse S.L. Poligono Virgen de los Dolores, 220, n°15, 46113-Moncada (Valencia)]. A fungal colony was then scraped off a PDA plate and added to the surface of a pot; three pots were used per *Fusarium* isolate. Ten pre-germinated seeds (with a root length of 1–2 cm at the time of sowing) were placed into each pot and covered with a surface layer of 1 cm of disinfected vermiculite. Once the pot was full, it was watered with sterilized water until saturation and then weekly watered with 250 ml. Care was taken to keep pot leachates from contaminating other pots by keeping inoculated pots with different isolates in different trays and removing excess of water from the trays daily. Sterile agar control was included in the inoculation test for each species of *Fusarium* tested. Inoculated and control plants were kept in a growth chamber set at 25–28 °C under a photoperiod of 16 h at 12,000 lux.

Plants in plots were rated every 5 days for percent emergence. After 20 days, plants were evaluated for the percent damping off (Schumann and D'Arcy 2009), non-emerged pre-germinated seeds were uncovered, and symptoms were evaluated for root rot and seed rot (referred to preemergence damping off, hereafter). The fungus was re-isolated from all affected samples, and the identity was confirmed by morphological characters, fulfilling Koch's postulates. The experiment was repeated sequentially.

Data collected in experiments were subjected to two types of ANOVA. In the first experiment, treatments were analyzed separately for each

Fusarium species according to the linear model $Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \tau_k + \varepsilon_{ijk}$ where Y_{ijk} is the ijk th observation, μ is the overall mean of the variable in question (damping off percentage), α_i is the effect of the i th isolate, β_j is the effect of j th plant species (for melon, watermelon, tomato and cucumber), $(\alpha\beta)_{ij}$ is the effect of the interaction isolate $\times$ plant species, τ_k is the effect of the k th block and ε_{ijk} is the experimental error.

The second type of multiway ANOVA was used to assess the effect of the interaction *Fusarium* species $\times$ plant species as source of variability. Therefore, the control treatment was not taken into account. The linear model for this analysis was $Y_{ijkl} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \tau_k + \varepsilon_{ijkl}$ where Y_{ijkl} is the $ijkl$ th observation, μ is the overall mean of the variable in question (damping off), α_i is the effect of the i th plant species, β_j is the effect of the j th fungal specie, $(\alpha\beta)_{ij}$ is the effect of the interaction plant $\times$ fungal specie, τ_k is the effect of the k th block and ε_{ijkl} is the experimental error. ANOVA was carried out using the data from both experiments. Comparison between mean results for each treatment was undertaken using multiple range tests (least significant difference method) (Montgomery 1991). All ANOVA calculations for all the plant species and cultivars inoculated were carried out using StatsGraphics Centurion XV.II (Statistical 195 Graphics Corp., Herndon, VA).

3 Results

3.1 Fungal isolation

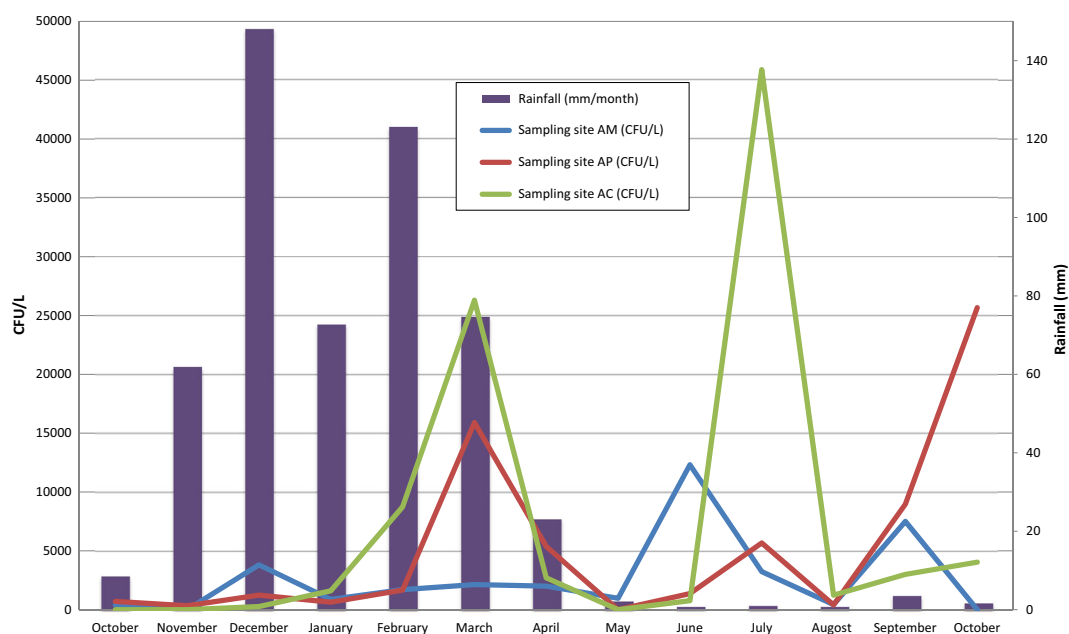
Eight different *Fusarium* species were isolated from the rainwater samples: *F. oxysporum* (31.27 %), *F. proliferatum* (29.05 %), *F. equiseti* (46.94 %), *F. dimerum* (2.78 %), *F. semitectum* (5.58 %), *F. solani* (12.84 %), *F. chlamydosporum* (6.13 %) and *F. avenaceum* (1.7 %). Data in brackets represent the percentage of the total samples analyzed (Table 1).

Except *F. dimerum*, which was not detected at AC sampling point, the remaining seven species of *Fusarium* appeared to be isolated in the same sample at different locations. The species most frequently isolated during the months of sampling in the three sampling points were *F. oxysporum*, *F. proliferatum* and *F. equiseti*.

Table 1 Frequency of isolation of *Fusarium* species isolated from rainwater for 12 months in three sampling sites

Sampling site	Analyzed samples	Samples with <i>Fusarium</i> (%)	<i>Fusarium</i> species isolated (%)							
			Fav	Fch	Fd	Fe	Fs	Fo	Fp	Fse
AM	59	72.88	–	5.08	3.39	40.68	13.56	32.20	32.20	6.78
AP	60	70	117.00	8.30	3.30	51.70	13.30	28.30	35.00	8.30
AC	60	60	–	5.00	1.67	48.33	11.67	33.33	20.00	1.67

Fav, *F. avenaceum*; Fch, *F. chlamydosporum*; Fd, *F. dimerum*; Fe, *F. equiseti*; Fs, *F. solani*; Fo, *F. oxysporum*; Fp, *F. proliferatum*; Fse, *F. semitectum*

**Fig. 1** *Fusarium* species isolated from rainwater in three sampling points for 13 months and rainfall in each month (October 2009–October 2010). Expressed in colony forming units per liter of water (UFC l^{-1})

Differences were observed between the amount of inoculum and the month of sampling in the three localities sampled (Fig. 1). Data show a negative relationship between the amount of rainfall and the number of colony forming units (CFU l^{-1}) in the three sampling locations. In the first months of sampling, where the monthly rainfall always exceeded 2 mm of rainfall per month, the ratio CFU l^{-1} through the three locations sampled never exceeded 200 CFU. By contrast, during the driest months (from June to September) where the rainfall recorded never exceeded 2 mm of rain per month, *Fusarium* detection rate was always higher than 600 CFU l^{-1} becoming maximum in the month of July with an average of isolation of the three locations of 15221.94 CFU l^{-1} (Fig. 1).

3.2 Pathogenicity tests

Pathogenicity assays were conducted with a total of 39 selected isolates of *Fusarium* species: 7 *F. proliferatum*, 8 *F. oxysporum*, 8 *F. solani*, 8 *F. equiseti* and 8 *F. semitectum* isolates were tested on tomato, watermelon, cucumber and melon to evaluate their pathogenicity.

Little pathogenicity was observed on tomato caused by *F. solani*, but damping off on tomato was always over than 60 % of seedlings. *F. proliferatum* and *F. semitectum* were always more pathogenic on melon and water melon (Table 2). On cucumber, tested isolates of *F. semitectum* did not cause a significant decrease in seedling emergence.

A multiway ANOVA was performed for eight isolates for each fungal species, using isolate, cultivar

Table 2 Pathogenicity test

<i>Fusarium</i> species	Isolate code	Cucumber	Melon	Tomato	Water melon
<i>F. proliferatum</i>	Control	0000 a	23 ,333 a	10,000 a	18,333 a
	MLLFp1	5000 ab	33,333 a	13,333 a	38,333 a
	MLLFp2	8333 ab	46,667 a	23,333 a	46,667 a
	MLLFp3	20,000 abc	21,667 a	21,667 a	41,667 a
	MLLFp4	36,667 c	55,000 a	15,000 a	43,333 a
	MLLFp5	33,333 c	45,000 a	13,333 a	35,000 a
	MLLFp6	23,333 bc	45,000 a	16,667 a	35,000 a
	MLLFp6a	33,333 c	45,000 a	16,667 a	45,000 a
Significance		**	NS	NS	NS
Isolate × plant specie		NS			
<i>F. equiseti</i>	Control	0000 a	25,000 a	11,667 a	8333 a
	Pm3Fr1	6667 ab	90,000 b	21,667 a	76,667 cd
	AP29Fr1	11,667 abc	85,000 b	16,667 a	66,667 bcd
	AP31Frg1	15,000 abc	76,667 b	20,000 a	38,333 b
	AM2Fr1	16,667 bc	90,000 b	13,333 a	65,000 bcd
	AC29Frg5	18,333 bc	80,000 b	15,000 a	56,667 bc
	AC58Fr2	21,667 bc	83,333 b	13,333 a	75,000 cd
	AC29Frg3	25,000 c	85,000 b	23,333 a	83,333 cd
	AP37Fr1	43,333 d	88,333 b	60, b000	86,667 d
Significance		***	***	***	***
Isolate × plant specie		***			
<i>F. oxysporum</i>	Control	1667 a	33,333 a	18,333 ab	33,333 a
	AFo2	20,000 bc	68,333 bc	31,667 bc	60,000 b
	AFo3	8333 ab	76,667 c	20,000 abc	50,000 ab
	AFo4	5000 ab	48,333 ab	18,333 ab	36,667 a
	AFo5	18,333 abc	66,667 bc	26,667 bc	56,667 b
	AFo7	8333 ab	75,000 c	35,000 c	68,333 bc
	AFo10	8333 ab	75,000 c	28,333 bc	68,333 bc
	AF011	10,000 ab	61,667 bc	33,333 bc	60,000 b
	AFo12	35,000 c	51,667 ab	10,000 a	86,667 c
Significance		**	**	*	***
Isolate × plant specie		***			
<i>F. semitectum</i>	Control	0000 a	21,667 a	8333 a	31,667 a
	AC58FR1	0000 a	88,333 d	20,000 ab	66,667 a
	AC58FR4	0000 a	78,333 cd	35,000 c	56,333 a
	AP58FR6	0000 a	63,333 bc	20,000 ab	51,667 a
	AM57FR1	0000 a	71,667 bcd	20,000 ab	61,667 a
	AM57FR2	0000 a	58,333 bc	18,333 ab	41,667 a
	AM59FR4	5000 a	73,333 bcd	20,000 ab	60,000 a
	AM58FR8	21,667 b	55,000 b	28,333 bc	55,000 a
	AM58FR9	1667 a	61,667 bc	23,333 bc	40,000 a
Significance		***	***	*	NS
Isolate × plant specie		NS			

Table 2 continued

<i>Fusarium</i> species	Isolate code	Cucumber	Melon	Tomato	Water melon
<i>F. solani</i>	Control	0,000 a	30,000 a	5,000 a	8,333 a
	PMFs1	5,000 a	76,667 bc	18,333 a	31,667 bc
	PMFs3	0,000 a	61,667 b	16,667 a	21,667 abc
	PMFs4	25,000 c	68,333 bc	20,000 a	38,333 c
	AM49FS1	6,667 a	65,000 bc	10,000 a	18,333 abc
	PcFs1	8,333 ab	63,333 b	13,333 a	15,000 ab
	PpFs1	23,333 bc	70,000 bc	15,000 a	38,333 c
	Pc10Fs2	10,000 abc	85,000 c	18,333 a	18,333 abc
	Pp11Fs8	10,000 abc	70,000 bc	6,667 a	31,667 bc
Significance		**	***	NS	*
Isolate $\times$ plant specie		NS			

Incidence of damping off on four plant species inoculated with isolates of *Fusarium* recovered from rain water

DSI values with the same lower case letter did not differ significantly. ANOVA according to the model $Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \tau_k + \varepsilon_{ijkl}$

NS not significant

*, **, *** $p \leq 0.05$, 0.01, and 0.001, respectively

and isolate $\times$ cultivar as source of variability. There is a clear overall difference in susceptibility between the inoculated plant species with differential varietal response against one or more pathogen isolates (Table 3).

Table 3 Multiway ANOVA for the evaluation of the different susceptibility of the species to the pathogen and the existence of a differential specific response against one or more isolates

	Damping off	LSD
<i>Fusarium</i> species		
<i>F. proliferatum</i>	30.59	a
<i>F. solani</i>	30.62	a
<i>F. semitectum</i>	37.29	b
<i>F. oxysporum</i>	41.45	b
<i>F. equiseti</i>	49.01	c
Significance	***	
Plant species		
Cucumber	14.05	a
Tomato	20.76	b
Watermelon	50.34	c
Melon	66.75	d
Significance	***	
<i>Fusarium</i> specie $\times$ plant species	***	

DSI values with the same lower case letter did not differ significantly

*, **, *** $p \leq 0.05$, 0.01, and 0.001, respectively

F. proliferatum isolates showed pathogenicity in melon, tomato and watermelon, but four out of seven isolates were pathogenic when inoculated on cucumber. All *F. equiseti* isolates were highly pathogenic, with average rates of infection up to 84.79 and 68.54 % for melon and watermelon, respectively. Four out of eight isolates inoculated produced extensive damping off on pre-germinated cucumber seeds, but no significant differences were observed with uninoculated control on tomato. All isolates of *F. oxysporum* were pathogens when inoculated on all plant species. Although its pathogenicity varied significantly with the inoculated species ($p < 0.001$), *F. semitectum* and *F. solani* were pathogenic in melon but weakly pathogenic in other plant species.

4 Discussion

At least one species of *Fusarium* was isolated from 67.59 % of the rainwater samples (Table 1) suggesting that the *Fusarium* genus has a very regular presence in rainwater. In a previous work, Palmero et al. (2011a) reported five different species of *Fusarium* isolated from rain and atmospheric dust from one single point of the city center of Almeria (*F. oxysporum*, *F. solani*, *F. equiseti*, *F. dimerum* and *F. proliferatum*). In this work, with a more systematic

sampling, and different sampling points at a distance of 10 km, the same five species have been isolated and three new ones were isolated for the first time from rainwater (*F. semitectum*, *F. chlamydosporum* and *F. avenaceum*).

These results indicate a regular presence of three potentially toxigenic species of *Fusarium* in rainwater, and *F. equiseti* is associated with toxicities on chickens, guinea fowl, pigeons, pigs, rabbits and rats. Among the produced toxins butenolide, beauvericin, trichothecenes, nivalenol and zearalenone have been studied (Verma et al. 1998; Leslie and Summerell 2006). *F. solani* has been isolated in human eyes, nails and skin (Mowbray et al. 1988). It has been also associated with endocarditis and lung diseases and isolated from the water tanks in hospitals (Anaissie et al. 2001). It has been isolated from snakes, turtles, insects, leeches, dogs, shrimp and sharks and produces furanoterpenoids, cyclosporine, moniformin and other unidentified toxins (Leslie and Summerell 2006).

F. proliferatum produces fumonisins in large quantities, and it also produces gibberellic acid and other mycotoxins such as fusarininas, moniliforminas or beauvericin (Palmero et al. 2012). The contaminated seeds cause death, bleeding and diarrhea in rats and may affect immunocompromised patients (Leslie and Summerell 2006).

Other species such as *F. semitectum*, *F. dimerum* or *F. avenaceum* have been isolated at a lesser extent, but they are also mycotoxin producers (Austen et al. 2001; Letscher-Bru et al. 2002; Logrieco et al. 2002; Thrane 1988). In the case of *F. semitectum*, which produce trichothecene and zearalenone, it can cause endocarditis and dermatitis in humans. It has been also associated with pulmonary emphysema in animals such as cattle or turtles (Marasas et al. 1984).

In the rainiest months, the amount of *Fusarium* species isolated is clearly lower than in the months of lower rainfall, which could be related to the amount of atmospheric dust dragged from distant areas like the Sahara desert. Rieux et al. (2014) when studying wind dispersal of sexually- and asexually-produced spores of *Mycosphaerella fijiensis* indicated that although as cospores distributed evenly in all directions, average dispersal distance was greater in two different directions without obvious correlation with wind patterns.

Almeria province is located on the Spanish Mediterranean coast at a mid-altitude position that is

influenced by high-latitude and subtropical wind systems. Some authors consider the Sahara as the main source of sediments transported by dust to far away areas such as Caribbean islands (Prospero and Lamb 2003; Prospero et al. 2005).

These results suggest that rainwater could be carriers of *Fusarium* propagules from higher layers of the atmosphere. The rain could somehow drag *Fusarium* spores. With heavy rains or high frequency of rainfall events (Fig. 1), the number of spores could decrease by washing.

The *Fusarium* species most frequently isolated in this study have been previously cited as causing disease in different plant genus (*F. oxysporum*, *F. solani* and *F. proliferatum*). *F. oxysporum* is a very particular fungal species since it developed specialized pathogenic forms on a specific plant species (Leslie and Summerell 2006), but it is also capable of expressing a certain polyphagia (Palmero et al. 2011b). *F. solani* and *F. proliferatum* do not exhibit host specificity, but both species can cause disease on plants depending on environmental conditions and the growth stage of the plant (Govindaswamy 1963; Joffe and Palti 1972, 1974; Martínez-Francis et al. 2009; Oelke and Bosland 2001).

In the case of *F. equiseti*, it has not been attributed a role as a pathogen of plants, except Joffe and Palti (1974) who cited high pathogenicity after inoculations on pepper seedlings. It has been commonly associated with diseased plants as a secondary invader, but the diagnosis has not included the completion of Koch's postulates (Leslie and Summerell 2006). *F. semitectum* has neither been considered as an important pathogen of plants, although it has been associated with reduced germination of bean and sorghum, or with mushroom rots during storage.

Results show differences in the pathogenicity of the isolates tested. Damping off evaluated in pathogenicity test increased significantly ($p > 0.05$) after inoculation with the isolates of *F. proliferatum*, *F. semitectum*, *F. solani*, *F. oxysporum* and *F. equiseti*, although individual isolates showed different levels of virulence to the various plant species (Table 3).

The presence of *Fusarium* species in rainwater could indicate long distance dispersal in natural environments, together with their proved pathogenicity; it must be taken into account in epidemiological studies. Low concentrations of propagules should not downplay the finding; we have to keep in mind that the

simple introduction of a propagule of a new species or race in a cultivated area free of the disease can cause significant economic losses to farmers and spread very quickly to the entire production area. *Fusarium* spp. are considered as important soilborne plant pathogens that cause negative economic impacts on crop yield; species of *Fusarium* cause a range of diseases to a very diverse groups of plants. Many species play a role as saprobes, particularly in the degradation of plant debris and other organic matter in soil. An increased understanding of the aerobiology of *Fusarium* spp. contributes to the overall knowledge of plant pathogen transport in the atmosphere. Rainwater not only spreads the inocula of soilborne pathogens to new areas on a scale of hundreds of kilometers but also provides the necessary humidity for germination of the fungal spores. This study of pathogenicity showed that some of these isolates caused preemergence damping off on tomato seedlings. In the case of melon and watermelon, most isolates of *F. oxysporum*, *F. semitectum*, *F. proliferatum* and *F. solani* caused important damping off in seedlings. However, *F. oxysporum*, *F. semitectum* and *F. solani* did not show pathogenicity on cucumber.

This work reveals some epidemiological aspects of *Fusarium* genus in natural environments. Some of the isolated *Fusarium* spp. are potential mycotoxin producers such as zearalenone, fumonisin, moniliformin or nivalenol. The ecotoxicological significance of their presence within rainwater remains to be elucidated.

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