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Fungicide management of late leaf spot and peanut smut

Uso de fungicidas para el manejo de la viruela tardía y del carbón del maní

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Abstract

Late leaf spot (LLS), caused by *Nothopassalora personata*, is the most devastating peanut disease in the world. In Argentina, peanut smut (*Thecaphora frezii*) has increased significantly in recent decades. LLS is mainly managed through chemical fungicides, however, peanut smut is not effectively controlled, except for some resistant peanut genotypes. This study evaluated the effects of widely used fungicides for LLS control on both diseases and crop yield. Field trials were conducted over three consecutive years in two locations, with different fungicide doses and number of applications. Disease intensities were significantly higher in General Cabrera (GC) than in Vicuña Mackenna (VM) resulting in higher yields in VM. This could be due to the longer history of peanut cultivation in GC, where fungicide applications reduced LLS intensity. Among fungicides, chlorothalonil showed the best performance. However, these treatments were ineffective against peanut smut, likely due to difficulties reaching the infection site. Considering fungicides are one major management tool, further study of different active ingredients against both diseases should also consider sustainable integrated management.

Keywords
Arachis hypogaea • chemical control • fungal diseases • *Nothopassalora personata* • *Thecaphora frezii*

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RESUMEN

La viruela tardía (VT) ocasionada por *Nothopassalora personata* es la enfermedad del maní más devastadora a nivel mundial, mientras que el carbón (*Thecaphora frezii*), es la enfermedad con mayor incremento en Argentina en las últimas décadas. VT es principalmente manejada a través de fungicidas químicos, mientras que, para el carbón del maní, no existen herramientas efectivas, salvo algunos genotipos resistentes. En este trabajo, se evaluó el efecto de fungicidas ampliamente utilizados para el control de VT, sobre ambas enfermedades y sobre el rendimiento del cultivo. Los ensayos de campo fueron realizados en dos localidades por tres años consecutivos, donde se probaron fungicidas en diferentes dosis y número de aplicaciones. La intensidad de ambas enfermedades fue más alta en General Cabrera (GC) que en Vicuña Mackenna (VM), resultando en mayores rendimientos en VM. Esto se debió posiblemente al mayor historial de producción de maní en GC, donde la aplicación de fungicidas redujo la intensidad de VT. Entre los fungicidas, clorotalonil demostró la mejor performance. Sin embargo, estos tratamientos no fueron efectivos frente al carbón del maní, posiblemente debido a no alcanzar el sitio de infección. Teniendo en cuenta que los fungicidas son una de las principales herramientas de manejo, se necesitan más estudios de diferentes ingredientes activos sobre ambas enfermedades, considerando un manejo integrado sustentable.

Palabras clave
Arachis hypogaea • control químico • enfermedades fúngicas • *Nothopassalora personata* • *Thecaphora frezii*

INTRODUCTION

Peanut (*Arachis hypogaea* L.) world production exceeds 49 million metric tons in pods. This oilseed is cultivated in over 100 countries, but approximately 80% of the production is concentrated in 10 countries, with China leading 18 million metric tons annually. Argentina is the tenth peanut producer with more than 950.000 metric tons, and the second exporter, with 16% of worldwide production. The province of Córdoba is the largest producer, accounting for 80% of the national output (32).

Several diseases affect peanut production in Argentina and other countries. Early leaf spot (ELS) caused by *Passalora arachidicola* (Hori) and late leaf spot (LLS) caused by *Nothopassalora personata* (Berk. & Curtis) are the most important foliar diseases worldwide, being LLS the most frequent in some main producing regions (14, 24). These diseases can generate important yield losses, and consequent economic imbalance (2). On the other hand, peanut smut by *Thecaphora frezii* (Carranza & Lindquist) has become the most important soil-borne disease in Argentina due to recent increasing prevalence and intensity (30), causing significant yield losses (25). LLS benefits from rainfall (16), while smut typically thrives under drought conditions, particularly during grain filling (28).

Even though different tools aim to control LLS, its management relies mainly on chemical fungicides (17) like systemic single-site mode carboxamides, strobilurins and triazoles. Many studies have shown beneficial effects of using fungicide mixtures from different chemical groups, mainly with carboxamides (10, 23). Among contact fungicides with multiple modes of action, the majorly used chlorothalonil presents consistent results (9). However, other options must be considered given that some active ingredients (a.i.) may soon be prohibited or useless against resistant strains.

Different management strategies have been tested against peanut smut, without successful effects on intensity. On the other hand, genetics have contributed resistant varieties (5): EC - 191 RC (AO), EC - 394 RC (AO) and EC - 420 RC (AO) (2), still grown only on a reduced area of the country. Meanwhile, biological control agents have proven useful regarding disease severity and grain weight at field scale (15), although still mostly preliminary. Regarding chemical control, many fungicide groups have shown variable results (8, 22). Such variability in disease control may be due to low fungicide efficacy or the impossibility of accessing gynophores, the infection site for *T. frezii* (20). Considering this, Paredes *et al.* (2021) tested 12 different a.i. *in vitro,* pots and field trials, using 1.5 times the recommended dose for the LLS control. Fungicides were applied at night directly to the plant base and pegs in pot trials and targeting the soil in field trials. These authors observed high disease control with azoxystrobin (strobilurin) in pots and a 2016 field trial, and with cyproconazole (triazole) in a 2015 field trial, while chlorothalonil did not control peanut smut, probably given its limited mobility in the plant compared to the other a.i. (6). The one product registered against peanut smut, composed of two triazole fungicides (triadimenol and myclobutanil), is ineffective against LLS (19).

Currently, chemical control of fungal pathogens can be achieved by different target site fungicides, depending on their mode of action. Fungicides with varying modes of action can be used mixed or in alternating regimes on the same crop. Before testing new a.i. against a given disease we should evaluate efficacy of currently registered fungicides. Another key aspect is to evaluate dose and number of applications with the lowest environmental impact. If some a.i. registered for LLS could impact smut, a simultaneous control of both diseases would be highly beneficial. Thus, we evaluated the effect of widely used fungicides against LLS in peanut crops, simultaneously considering LLS and smut intensities, and crop production.

Materials and methods

Field trials were conducted during three consecutive seasons, 2017/18, 2018/19 and 2019/2020, in General Cabrera (GC) and Vicuña Mackenna (VM), Córdoba, Argentina (table 1). GC is representative of the historical peanut-producing area, while in VM, peanut has been recently introduced. They have loam and sandy loam soil texture, respectively.

Table 1. Coordinates, sowing and harvest dates and accumulated rainfalls at both locations for three agricultural seasons.

Tabla 1. Coordenadas, fechas de siembra y cosecha y precipitaciones acumuladas para ambas localidades durante las tres campañas agrícolas.

Location, season	Coordinates	Sowing date	Harvest date	Accumulated rainfalls (mm)
GC 2017/18	32°49’39.49’’S 63°51’55.57’’W	10/31/2017	03/22/2018	263
GC 2018/19	32°49’46.80’’S 63°51’57.73’’W	11/06/2018	04/12/2019	616
GC 2019/20	32°49’42.13’’S 63°51’56.42’’W	11/21/2019	04/13/2020	468
VM 2017/18	33°56’14.39’’S 64°27’51.95’’W	10/24/2017	04/03/2018	298
VM 2018/19	33°56’33.07’’S 64°28’20.68’’W	11/08/2018	04/05/2019	563
VM 2019/20	33°46’11.41’’S 64°25’12.34’’W	11/19/2019	04/04/2020	398

GC: General Cabrera.
VM: Vicuña Mackenna.

All trials followed a randomized complete block design with three replications, and four furrows 5 m long, spaced 0.70 m. Ten treatments were composed of different a.i. or mixtures, doses, and number of applications (table 2, page XXX). All fungicides are registered in Argentina for LLS control (7). Applications were performed with a carbon dioxide pressurized backpack sprayer equipped with six hollow cone spray nozzles spaced 0.35 m apart, calibrated to 180 L/ha. Applications began upon the first symptoms of LLS. Seeds of cv. Granoleico (INASE Reg. N° 7907) were treated with 2.5 g (a.i.) of ipconazole + 2 g of metalaxyl and 30 g of carboxin + 30 g of thiram per 100 kg of seeds, preventing other soil pathogens and those carried by seeds.

Table 2. Treatments at both locations during three agricultural seasons.

Tabla 2. Tratamientos en ambas localidades durante tres campañas agrícolas.

Treat.	Active ingredients	Doses (g a.i./ha)	Number of applications
1	Control	-	-
2	Pyraclostrobin + epoxiconazole	99.75 + 37.5	4
3	Fluxapyroxad + epoxiconazole + pyraclostrobin	60 + 60 + 97.2	4
4	Chlorothalonil	1008	5
5	Pyraclostrobin + epoxiconazole	99.75 + 37.5	2
6	Fluxapyroxad + epoxiconazole + pyraclostrobin	60 + 60 + 97.2	2
7	Chlorothalonil	1008	3
8	Pyraclostrobin + epoxiconazole	59.85 + 22.5	4
9	Fluxapyroxad + epoxiconazole + pyraclostrobin	36 + 36 + 58.32	4
10	Chlorothalonil	604.8	5

g a.i/ha: grams of active ingredient per hectare.

Gramos de ingrediente activo por hectárea.

Treatments 2, 3 and 4 implied using fungicides in the registered doses and number of applications, considering residual periods. Treatments 5, 6 and 7 maintained doses but reduced applications. Finally, treatments 8, 9 and 10, reduced a.i. dose to 60% of the recommended. Treatments 5, 6, 7, 8, 9 and 10 tested whether a different dose and application number was as efficient as the registered, representing a more interesting option for peanut producers. However, risks of generating resistance must be considered at reduced doses that should not be massively adopted (as in treatments 8 to 10) (1). For all cases, the Environmental Impact Quotient (EIQ) was calculated according to Kovach *et al.* (1992), determining the environmental impact for each a.i. based on physicochemical and toxicological information. This widely used indicator evaluates pesticide risks and is useful for selecting less harmful molecules (13).

Before harvest, two cotyledonary branches per plot were collected (one branch per central furrow) and LLS intensity was calculated through incidence and severity. The first represents the percentage of diseased leaflets and the last considers the percentage of affected tissue. Incidence was calculated as the number of leaflets with LLS spots over the total number of leaflets. Severity (S) was calculated through the equation proposed by Plaut and Berger (1980): $S = [(1-D) * Sx] + D$, considering defoliation (D), and average severity (Sx) (calculated by a diagrammatic scale) (31).

At harvest maturity (150 days after planting), all plants in 1 m^2 per plot were collected. Pods were separated and allowed to dry until constant weight, in a dry and ventilated place. Once weighted and shelled, yield was estimated via total and confectionery quality weights, considering confectionary quality as those grains greater than 7,5 mm sieve size. Simultaneously, peanut smut incidence (percentage of affected pods) and severity (degree of symptoms in pods, through the disease severity index (DSI)) (27) were evaluated. The DSI involves a five levels scale: 0 = healthy pod, 1 = normal pod with a small sorus in a single seed, 2 = deformed or normal pod with one seed half affected, 3 = deformed pod and a completely smutted seed, 4 = deformed pod, both seeds completely smutted. The DSI was calculated using the following equation:

$$\mathbf{DSI = [(n \times 0) + (n \times 1) + (n \times 2) + (n \times 3) + (n \times 4)]\, N^{-1}}$$

where:
n = number of pods corresponding to each level (0-4)
N = total number.

For all parameters, ANOVA was performed, and means were compared using Tukey's test ($p \leq 0.05$) with InfoStat software (12).

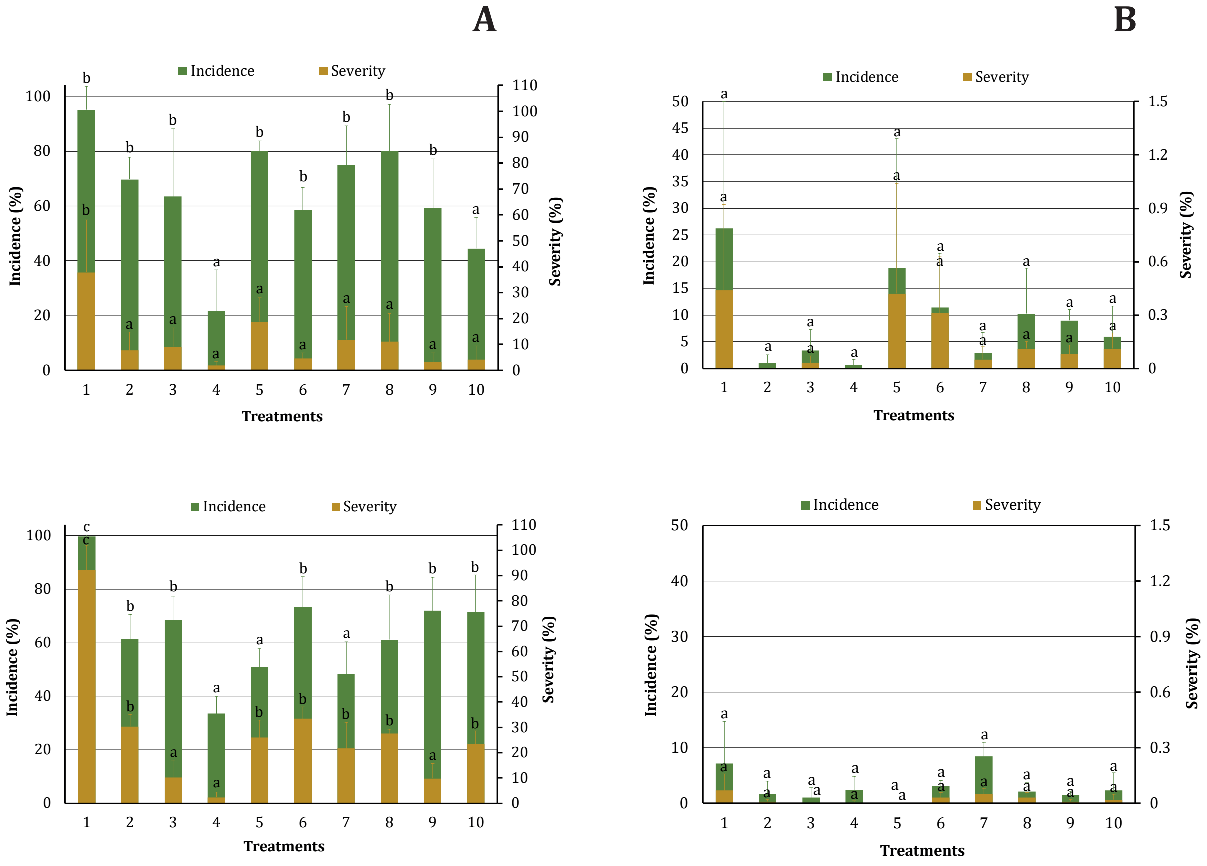
RESULTS AND DISCUSSION

According to a.i., concentration, dose and number of applications, EIQ values per treatment were: 1=0, 2=17.16, 3=21.80, 4=202.5, 5=8.58, 6=10.9, 7=121.23, 8=10.29, 9=13.08, and 10=121.5.

During the first year, LLS was not observed given environmental conditions, mainly precipitation (21). For the other campaigns, the disease appeared in both locations with higher intensity values in GC. In the GC 2018/19 trial (figure 1A, page XXX), the lowest incidence levels were observed with chlorothalonil in five applications (treatments 4 and 10), while severity was higher only in the control (treatment 1). This agrees with Culbreath *et al.* (2018), who found chlorothalonil more efficient than almost all evaluated triazoles. Concerning the 2019/20 trial, treatment 4 had, once more, the best performance. However, other treatments, like treatment 4, achieved lower incidence (5: pyraclostrobin + epoxiconazole in 2 moments, and 7: chlorothalonil in 3 moments), and severity (3 and 9: fluxapyroxad + epoxiconazole + pyraclostrobin in 4 moments) levels. These last results show effective disease management with mixes including carboxamides, and better behavior with shorter periods between applications, as previously found (10, 23). Treatments 8 to 10, with a.i. in reduced doses, achieved effective LLS control. However, it should not constitute a strategy to be applied solely due to the possibility of creating fungal resistance (1). Nevertheless, treatments with fewer applications and thus, lower EIQ, represent a good option considering environmental risk (13). Another interesting fact is that treatments 4 and 10, with chlorothalonil, led to better control than other a.i., but with higher EIQ values. However, this a.i. has significantly low selection pressure (Fungicide Resistance Action Committee, Code M5). On the other hand, no differences were evidenced among VM treatments (figure 1B, page XXX), probably because of the low disease intensity registered in that location. However, the highest LLS incidence and severity were observed without fungicides (treatment 1).

Thecaphora frezii field inoculum was quantified before planting according to Marinelli *et al.* (2008), estimating 10000 and less than 2000 teliospores per gram of soil in GC and VM, respectively. Given this disease is less dependent on weather conditions than LLS, we could evaluate smut intensity during three seasons in both locations (27). Intensity was high in GC and moderate in VM (figure 2A and 2B, page XXX), incidence reached 72.08% and severity 2.34 in GC, while in VM, maximum values were 22.66% and 0.55, respectively. These results may depend on GC long history of peanut cultivation and processing, and thus, high inoculum (27). We did not observe fungicide effect on disease intensity when compared to the untreated control throughout all trials. Some authors (3, 4, 33) cite the action of chlorothalonil, triazoles, strubilurins and carboxamides for controlling soil pathogens. However, for peanut smut, effects are variable probably because of low efficacy or inability to reach gynophores through spraying (8, 20, 25). We evaluated fungicides with different mobility in plants: a non-penetrating a.i. (chlorothalonil) that cannot translocate through tissues and penetrant and mobile a.i. (epoxiconazole, pyraclostrobin and fluxapyroxad) transported through the xylem (6). These mobility differences could help these a.i reach gynophores and stop infections. Paredes *et al.* (2021) observed lower severity with azoxystrobin when compared to other fungicides and control pots. On the other hand, smut intensity in untreated control did not differ from treatments with chlorothalonil and pyraclostrobin. These outcomes align with our findings. Finally, in field trials, cyproconazole and azoxystrobin showed the best control efficiency among all treatments.

Since peanut smut intensity is directly related to crop production losses (25), and no significant effect of fungicides was observed on the former, we expected no differences in yield (table 3, page XXX). In GC, differences in grain and confectionery quality grain yields were observed during the 2017-2018 season, where the untreated control presented higher production than other treatments. These results could be given by decreased yield when fungicides are applied to stressed plants (11). Treatments 1 (untreated control), 2, 3 and 5 had the highest total grain yield (864, 892, 917 and 914 kg/ha, respectively), and confectionery quality grain yield (757, 804, 791 and 792 kg/ha, respectively).

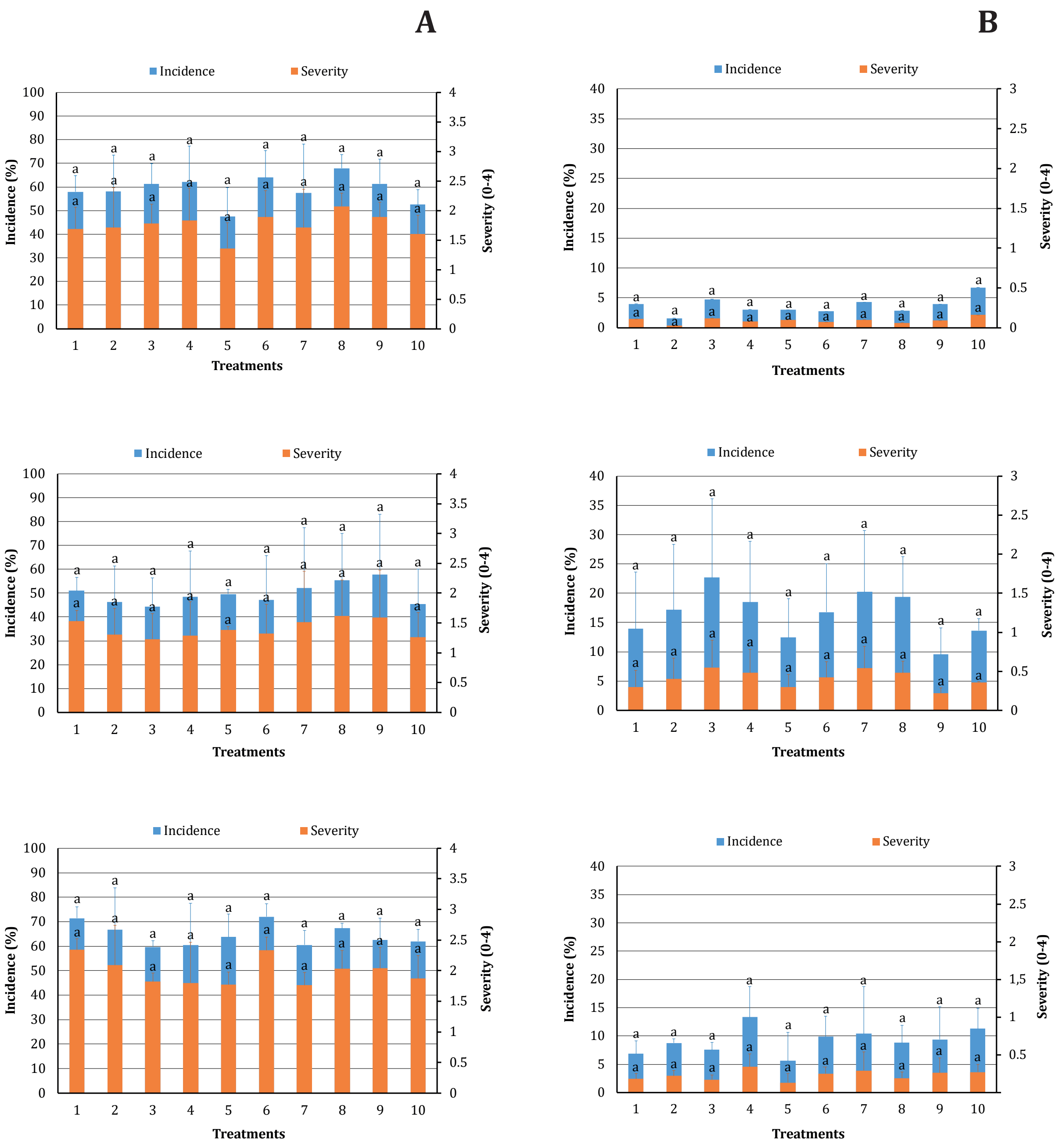


Treatments: 1) untreated control; 2) pyraclostrobin + epoxiconazole four times, 3) fluxapyroxad + epoxiconazole + pyraclostrobin four times; 4) chlorothalonil five times; 5) pyraclostrobin + epoxiconazole twice; 6) fluxapyroxad + epoxiconazole + pyraclostrobin twice; 7) chlorothalonil three times; 8) pyraclostrobin + epoxiconazole four times, reduced dose; 9) fluxapyroxad + epoxiconazole + pyraclostrobin four times, reduced dose; and 10) chlorothalonil five times, reduced dose. Different letters indicate significant differences ($p<0.05$).

Tratamientos: 1) control sin fungicida; 2) pyraclostrobin + epoxiconazole 4 aplicaciones; 3) fluxapyroxad + epoxiconazole + pyraclostrobin 4 aplicaciones; 4) clorotalonil 5 aplicaciones; 5) pyraclostrobin + epoxiconazole 2 aplicaciones; 6) fluxapyroxad + epoxiconazole + pyraclostrobin 2 aplicaciones; 7) clorotalonil 3 aplicaciones; 8) pyraclostrobin + epoxiconazole 4 aplicaciones, dosis reducida; 9) fluxapyroxad + epoxiconazole + pyraclostrobin 4 aplicaciones, dosis reducida; y 10) clorotalonil 5 aplicaciones, dosis reducida. Letras diferentes indican diferencias significativas ($p<0{,}05$).

Figure 1. Incidence and severity of late leaf spot in 2018/19 and 2019/20 on General Cabrera (A) and Vicuña Mackenna (B) field trials.

Figura 1. Incidencia y severidad de viruela tardía en 2018/19 y 2019/20 en los ensayos de campo de General Cabrera (A) y Vicuña Mackenna (B).



Treatments: 1) untreated control; 2) pyraclostrobin + epoxiconazole four times, 3) fluxapyroxad + epoxiconazole + pyraclostrobin four times; 4) chlorothalonil five times; 5) pyraclostrobin + epoxiconazole twice; 6) fluxapyroxad + epoxiconazole + pyraclostrobin twice; 7) chlorothalonil three times; 8) pyraclostrobin + epoxiconazole four times, reduced dose; 9) fluxapyroxad + epoxiconazole + pyraclostrobin four times, reduced dose; and 10) chlorothalonil five times, reduced dose. Different letters indicate significant differences ($p<0.05$).

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Figure 2. Incidence and severity of peanut smut in 2017/18, 2018/19 and 2019/20 in General Cabrera (A) and Vicuña Mackenna (B) field trials.

Figura 2. Incidencia y severidad de carbón del maní en 2017/18, 2018/19 y 2019/20 en los ensayos de campo de General Cabrera (A) y Vicuña Mackenna (B).

Table 3. Peanut yield parameters (kg/ha) recorded in General Cabrera (GC) and Vicuña Mackenna (VM) for the three agricultural seasons.

Tabla 3. Parámetros de rendimiento de maní (kg/ha) medidos en General Cabera (GC) y Vicuña Mackenna (VM) para las tres campañas agrícolas.

Location	Treat.	2017-2018			2018-2019			2019-2020		
		P.	G.	C.Q.	P.	G.	C.Q.	P.	G.	C.Q.
GC	1	1977±550	864±145*	757±109*	4390±588	2451±314	2174±245	2867±1051	1138±481	856±326
	2	1907±245	892±180*	804±155*	4850±331	2832±316	2535±261	4491±946	1981±750	1682±688
	3	1940±207	917±174*	791±128*	5801±402	3354±424*	2860±262*	4179±1059	1978±683	1625±571
	4	1717±368	708±249	631±249	4997±662	2735±734	2405±775	3921±2063	1791±1023	1544±890
	5	1777±453	914±224*	792±148*	5045±1149	2812±624	2430±451	3327±1013	1508±277	1202±132
	6	1407±699	576±243	483±263	4395±637	2348±98	2078±98	4115±1536	1527±578	1231±498
	7	1063±131	471±157	433±152	4417±1478	2378±110	1888±718	3067±958	1401±519	1140±461
	8	1330±140	518±28	457±60	4443±584	2259±470	1995±453	3499±914	1553±733	1318±611
	9	1400±234	623±124	581±120	4711±709	2459±239	2142±313	4160±1269	1825±902	1551±840
	10	1423±193	695±133	606±135	5880±509	3362±461*	2996±632*	4597±1858	2273±1248	1907±1048
VM	1	6807±202	5038±314	4590±477	6009±751	4264±476	3799±427	2761±691*	1973±683*	1316±377*
	2	5200±223	3887±1825	3456±165	5076±293	3206±258	2587±177	3520±268	2645±198	2175±119
	3	6303±200	4655±1621	4262±160	5109±383	3279±401	2729±376	5404*±363	3959*±62	3130±180
	4	5030±215	3715±1679	3216±154	5452±438	3652±331	3140±504	4371±1246	3241±896	2656±933
	5	7610±275	5617±1860	5064±168	5586±413	3854±272	3167±133	3705±671	2808±445	2197±452
	6	5267±173	3946±1404	3496±140	5963±1689	3986±865	3370±747	4065±483	2935±428	2488±756
	7	5727±772	4158±745	3664±691	5134±268	3422±104	2846±109	4589±523	3326±499	2580±1152
	8	4277±190	3140±1485	2850±133	5065±1163	3369±947	2844±1025	4417±852	3297±649	2740±607
	9	5923±879	4405±668	3839±659	4931±1209	3332±106	2664±1141	4136±166	3089±249	2582±490
	10	5323±847	3876±517	3594±498	5922±557	4087±311	3451±230	4335±850	3164±686	2671±694

Pod (P.), grain (G.) and confectionery quality grain (C.Q.) yields (kg/ha). Means ± standard deviation. Treatments: 1) untreated control; 2) pyraclostrobin + epoxiconazole four times; 3) fluxapyroxad + epoxiconazole + pyraclostrobin four times; 4) chlorothalonil five times; 5) pyraclostrobin + epoxiconazole twice; 6) fluxapyroxad + epoxiconazole + pyraclostrobin twice; 7) chlorothalonil three times; 8) pyraclostrobin + epoxiconazole four times, reduced dose; 9) fluxapyroxad + epoxiconazole + pyraclostrobin four times, reduced dose; and 10) chlorothalonil five times, reduced dose. Significant differences ($p<0.05$) per column are represented by *.

Rendimientos (kg/ha) de vainas, granos y granos calidad confitería. Medias ± error estándar. Tratamientos: 1) control sin fungicida; 2) pyraclostrobin + epoxiconazole 4 aplicaciones; 3) fluxapyroxad + epoxiconazole + pyraclostrobin 4 aplicaciones; 4) clorotalonil 5 aplicaciones; 5) pyraclostrobin + epoxiconazole 2 aplicaciones; 6) fluxapyroxad + epoxiconazole + pyraclostrobin 2 aplicaciones; 7) clorotalonil 3 aplicaciones; 8) pyraclostrobin + epoxiconazole 4 aplicaciones, dosis reducida; 9) fluxapyroxad + epoxiconazole + pyraclostrobin 4 aplicaciones, dosis reducida; y 10) clorotalonil 5 aplicaciones, dosis reducida. Las diferencias significativas ($p<0,05$) dentro de la misma columna, están representados con *.

On the other hand, during the 2018-2019 season, treatments 3 and 10 showed the highest grain yield (3354 and 3362 kg/ha, respectively) and confectionery quality yield (2860 and 2996 kg/ha, respectively). Both treatments achieved lower LLS intensity than control, as previously found (9, 23). Finally, during the 2019-2020 season, no statistical differences were found for productivity parameters in GC. For VM trials, statistical differences for crop yield were only found in the 2019-2020 season. Treatment 1 had 22-49%, 25-50% and 40-58% lower values than the rest of the treatments for pod, grain and confectionery quality grain yields, respectively. In contrast, treatment 3 had 18-53% and 19-50% higher pod and grain yields than the other treatments. Finally, the difference between treatments 1 and 3 was approximately 100%, as found by Culbreath *et al.* (2018).

Considering each season, results were statistically different between locations. Table 4 shows markedly higher LLS and peanut smut incidence and severity in GC than in VM. Although Paredes *et al*. (2024) report that peanut smut benefits from drought, we did not observe any correlation between the highest intensities and lowest rainfall, except for GC when comparing the first and second seasons. However, this behavior is not linear and depends on whether soil moisture falls below 30% of soil water-holding capacity and on which growth stage (28). Regarding yield, all values were superior in VM for all years. Disease intensity and crop yield are possibly explained by cultivation history in each area.

Table 4. LLS intensity, peanut smut intensity and crop yield, across trials.
Tabla 4. Intensidad de VT, carbón del maní y rendimiento del cultivo a lo largo de los años.

	2017-2018		2018-2019		2019-2020	
	GC	**VM**	**GC**	**VM**	**GC**	**VM**
LLS[a] Incidence (%)	-	-	64.73 b	8.95 a	64.01 b	2.97 a
LLS Severity (%)	-	-	10.99 b	0.16 a	27.66 c	0.02 a
Smut Incidence (%)	58.98 b	3.70 a	49.76 b	16.41 a	64.63 b	9.19 a
Smut Severity	1.76 b	0.09 a	1.40 b	0.40 a	1.99 b	0.23 a
P[b] (kg/ha)	1594 b	5746 a	4892 b	5424 a	3822 a	4130 a
G[c] (kg/ha)	717 b	4243 a	2699 b	3645 a	1697 b	3043 a
CQ[d] (kg/ha)	633 b	383 a	2350 b	3059 a	1405 b	2453 a

[a] Late leaf spot. [b] Pod yield. [c] Grain yield. [d] Confectionery quality grains yield. Comparison between locations partitioned by year. Different letters represent significant differences ($p<0.05$).

[a] Viruela tardía. [b] Rendimiento en vainas. [c] Rendimiento en granos. [d] Rendimiento en granos calidad confitería. Comparación entre localidades, particionadas por año. Letras diferentes representan diferencias significativas ($p<0,05$).

Fungicide application leads peanut LLS management. Additionally, considering peanut smut is hard to control, having a fungicide against both diseases simultaneously would be significantly useful. Considering two different sites and three cropping seasons, this study showed how some majorly used fungicides for peanut crops in Argentina could control LLS even at lower doses and application frames than usual. However, these treatments proved no effects against peanut smut. Further testing should consider different a.i., their combinations, doses and application frames against LLS and peanut smut. Additionally, considering genetic resistance and biocontrol strategies with microorganisms is key for integrated management strategies.

CONCLUSIONS

Disease intensities of late leaf spot (LLS) and peanut smut are closely linked to the agricultural history of locations and weather conditions in a certain season. Chemical control of LLS has been effective, and certain options exhibit a lower environmental impact, particularly important for integrated management strategies. Conversely, fungicides demonstrated inefficacy against peanut smut in these field trials. We also demonstrated the importance of quantifying inoculum density given its direct relationship with disease levels to avoid certain locations or choose resistant varieties. Further studies on the biology of *T. frezii* and management of peanut smut should contribute to genetic resistance development.

References

1. Amaradasa, B. S.; Everhart, S. E. 2016. Effects of sublethal fungicides on mutation rates and genomic variation in fungal plant pathogen, *Sclerotinia sclerotiorum*. PLoS One. 11(12): e0168079. https://doi.org/10.1371/journal.pone.0168079
2. Anco, D. J.; Thomas, J. S.; Jordan, D. L.; Shew, B. B.; Monfort, W. S.; Mehl, H. L.; Small, I. M.; Wright, D. L.; Tillman, B. L.; Dufault, N. S.; Hagan, A. K.; Campbell, H. L. 2020. Peanut yield loss in the presence of defoliation caused by late or early leaf spot. Plant Disease. 104: 1390-1399. https://doi.org/10.1094/PDIS-11-19-2286-RE
3. Augusto, J.; Brenneman, T. B. 2011. Implications of fungicide application timing and post-spray irrigation on disease control and peanut yield. Peanut Science. 38(1): 48-56. https://doi.org/10.3146/PS10-11.1
4. Augusto, J.; Brenneman, T. B.; Culbreath, A. K.; Sumner, P. 2010. Night spraying peanut fungicides. I. Extended fungicide residual and integrated disease management. Plant Disease. 94(6): 676-682. https://doi.org/10.1094/PDIS-94-6-0676
5. Bressano, M.; Massa, A.; Arias, R.; De Blas, F.; Oddino, C.; Faustinelli, P.; Soave, J.; Soave, S.; Perez, A.; Sololev, V.; Marshall, C.; Balzarini, M.; Buteler, M.; Seijo, G. 2019. Introgression of peanut smut resistance from landraces to elite peanut cultivars (*Arachis hypogaea* L.). PLoS ONE. 14(2): e0211920. https://doi.org/10.1371/journal.pone.0211920
6. Carmona, M.; Sautua, F.; Pérez-Hérnandez, O.; Reis, E. M. 2020. Role of fungicide applications on the integrated management of wheat stripe rust. Frontiers in Plant Science. 11: 733. https://doi.org/10.3389/fpls.2020.00733
7. CASAFE. 2023. Cámara de Sanidad Agropecuaria y Fertilizantes. Guía online de productos fitosanitarios. https://guiaonline.casafe.org/ (Accessed on: Sep. 6 2023).
8. Cazón, I.; Bisonard, E. M.; Conforto, C.; March, G.; Rago, A. 2013. Estrategias para el manejo del carbón del maní. Actas de resúmenes XXVIII Jornada Nacional del Maní. General Cabrera, Córdoba. Argentina. p: 28-30.
9. Culbreath, A. K.; Gevens, A. J.; Stevenson, K. L. 2018. Relative effects of demethylation-inhibiting fungicides on late leaf spot of peanut. Plant Health Progress. 19(1): 23-26. https://doi.org/10.1094/PHP-09-17-0053-RS
10. Culbreath, A. K.; Brenneman, T. B.; Kemerait, R. C.; Stevenson, K. L.; Henn, A. 2020. Effect of DMI and QoI fungicides mixed with the SDHI fungicide penthiopyrad on late leaf spot of peanut. Crop Protection. 137: 105298. https://doi.org/10.1016/j.cropro.2020.105298
11. Dias, M. A. 2012. Phytotoxicity: An overview of the physiological responses of plants exposed to fungicides. Journal of Botany. Article ID 135479. https://doi.org/10.1155/2012/135479
12. Di Rienzo, J. A.; Casanoves, F.; Balzarini, M. G.; Gonzales, L.; Tablada, M.; Robledo, C. W. InfoStat versión 2020. Centro de Transferencia InfoStat, FCA, Universidad Nacional de Córdoba, Argentina. http://www.infostat.com.ar
13. Dugan, S. T.; Muhammetoglu, A.; Uslu, A. 2023. A combined approach for the estimation of groundwater leaching potential and environmental impacts of pesticides for agricultural lands. Science of The Total Environment. 901: 165892. https://doi.org/10.1016/j.scitotenv.2023.165892
14. Fulmer, A. M. 2017. Differentiation, prediction and management of early and late leaf spot of peanut in the southeastern United States and Haiti. Ph.D. thesis. University of Georgia, Athens, GA.
15. Ganuza, M.; Pastor, N.; Erazo, J.; Andrés, J.; Reynoso, M.; Rovera, M.; Torres, A. 2018. Efficacy of the biocontrol agent *Trichoderma harzianum* ITEM 3636 against peanut smut, an emergent disease caused by *Thecaphora frezii*. European Journal of Plant Pathology. 151(1): 257-262. https://doi.org/10.1007/s10658-017-1360-0
16. Giordano, D.F.; Pastor, N.; Palacios, S.; Oddino, C.; Torres, A. 2021. Peanut leaf spot caused by *Nothopassalora personata*. Tropical plant pathology. 46: 139-151. https://doi.org/10.1007/s40858-020-00411-3
17. Jordan, B. S.; Culbreath, A. K.; Brenneman, T. B.; Kemerait, R. C.; Branch, W. D. 2017. Late leaf spot severity and yield of new peanut breeding lines and cultivars grown without fungicides. Plant Disease. 101(11): 1843-1850. https://doi.org/10.1094/PDIS-02-17-0165-RE
18. Kovach, J.; Petzoldt, C.; Degni, J.; Tette, J. 1992. A method to measure the environmental impact of pesticides. New York's Food and Life Sciences Bulletin. 139: 1-8.
19. Laboratorios NOVA. 2023. IRIDIUM. https://laboratorios-nova.com/fungicidas-fungicidas-insecticidas/iridium/ (Accessed on Sep. 12 2024).
20. Marinelli, A.; March, G.; Oddino, C. 2008. Aspectos biológicos y epidemiológicos del carbón del maní (*Arachis hypogaea* L.) causado por *Thecaphora frezii* Carranza & Lindquist. AgriScientia. 25(1): 1-5.
21. Marinelli, A.; Oddino, C.; March, G. 2017. 2ª ed. Enfermedades fúngicas del maní. En: Fernández, E.; Giayetto, O. (Ed.). El cultivo de maní en Argentina. Río Cuarto, Córdoba. Ediciones UNRC. p: 285-311.
22. Oddino, C.; Mortigliengo, S.; Moresi, A.; Soave, J.; Giuggia, J.; Ferrari, S.; Cassano, C.; Martinez, F.; Molineri, A.; Moran, F.; Soave, S.; Torre, D.; Butteler, M.; Bianco, C.; Bressano, M.; De Blas, F. 2017. Efecto de fungicidas foliares sobre la intensidad de viruela y carbón en diferentes cultivares de maní. Ciencia y tecnología de Cultivos Industriales. 6(9): 99-105.

23. Oddino, C.; Giordano, F.; Paredes, J.; Cazón, L.; Giuggia, J.; Rago, A. 2018. Efecto de nuevos fungicidas en el control de viruela del maní y el rendimiento del cultivo. Ab Intus. 1(1): 9-17.

24. Oddino, C.; Rosso, M.; Soave, J.; Soave, S.; Mendoza, M.; Giordano, D. F.; Bressano, M.; De Blas, F.; Mortigliengo, S.; Butteler, M. 2023. Comportamiento de variedades de maní resistentes a carbón a través de los años. Actas de resúmenes XXXVIII Jornada Nacional del Maní. General Cabrera, Córdoba. Argentina.

25. Paredes, J. 2017. Importancia regional del carbón del maní (*Thecaphora frezii*) y efecto de ingredientes activos de fungicidas sobre la intensidad de la enfermedad. Master thesis. Universidad Nacional de Río Cuarto, Córdoba.

26. Paredes, J. A.; Cazón, L. I.; Oddino, C.; Monguillot, J. H.; Rago, A. M.; Edwards Molina, J. P. 2021. Efficacy of fungicidal management of peanut smut. Crop Protection. 140: 105403. https://doi.org/10.1016/j.cropro.2020.105403

27. Paredes, J. A.; Edwards Molina, J. P.; Cazón, L. I.; Asinari, F.; Monguillot, J. H.; Morichetti, S. A.; Rago, A. M.; Torres, A. M. 2022. Relationship between incidence and severity of peanut smut and its regional distribution in the main growing region of Argentina. Tropical Plant Pathology. 47: 233-244. https://doi.org/10.1007/s40858-021-00473-x

28. Paredes, J. A.; Guzzo, M. C.; Monguillot, J. H.; Asinari, F.; Posada, G. A.; Oddino, C. M.; Giordano, D. F.; Morichetti, S. A.; Torres, A. M.; Rago, A. M.; Monteoliva, M. I. 2024. Low water availability increases susceptibility to peanut smut (*Thecaphora frezzii*) in peanut crop. Plant Pathology. 73(2): 316-325. https://doi.org/10.1111/ppa.13810

29. Plaut, J. L.; Berger, R. D. 1980. Development of *Cercosporidium personatum* in three peanut canopy layers. Peanut Science. 7(1): 46-49. https://doi.org/10.3146/i0095-3679-7-1-11

30. Rago, A.; Cazón, I.; Paredes, J.; Edwards Molina, J.; Bisonard, M.; Oddino, C. 2017. Peanut Smut: From an emerging disease to an actual threat to Argentine peanut production. Plant Disease. 101(3): 400-408. http://dx.doi.org/10.1094/PDIS-09-16-1248-FE

31. Shokes, F. M.; Berger, R. D.; Smith, D. H.; Rasp, J. M. 1987. Reliabity of disease assessment procedures. A case study with late leafspot of peanut. Oléagineux. 42: 245-251.

32. USDA. 2023. United States Department of Agriculture. Peanut explorer. https:// ipad.fas.usda.gov/cropexplorer/cropview/commodityView.aspx?cropid=2221000&sel_year=2022&rankby=Production (Accessed on Sep. 12 2023).

33. Woodward, J. E.; Brenneman, T. B.; Kemerait, R. C.; Smith, N. B.; Culbreath, A. K.; Stevenson, K. L. 2008. Use of resistant cultivars and reduced fungicide programs to manage peanut diseases in irrigated and non-irrigated field. Plant Disease. 92(6): 896-902. http://dx.doi.org/10.1094/PDIS-92-6-0896