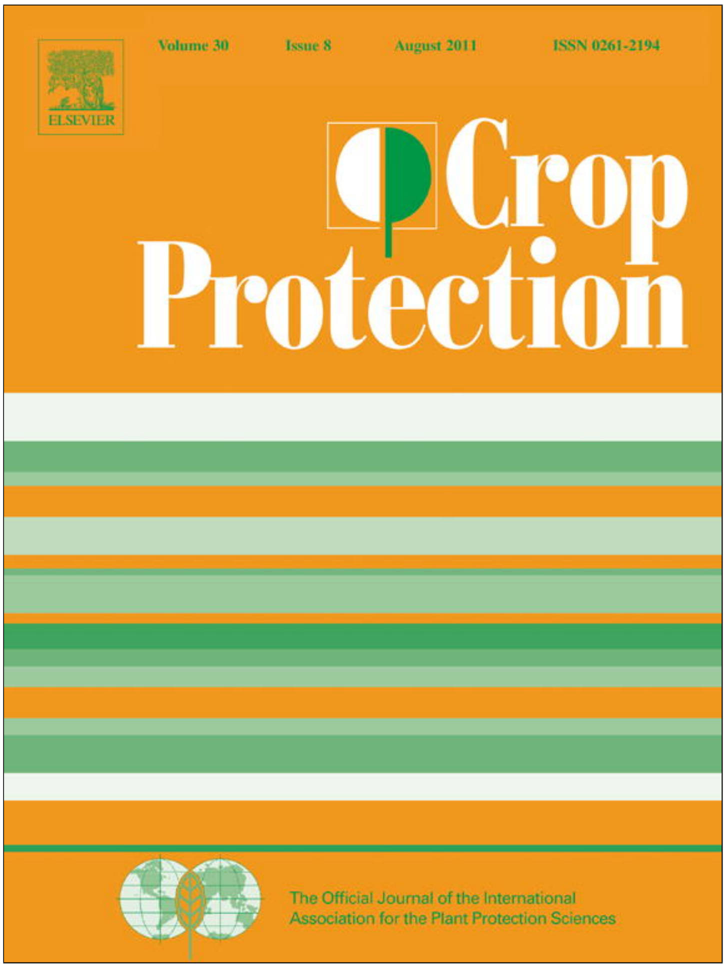
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Effects of crop mixtures on chocolate spot development on faba bean grown in mediterranean climates

M. Fernández-Aparicio [a,b], M.J.Y. Shtaya [c], A.A. Emeran [d], M.B. Allagui [e], M. Kharrat [e], D. Rubiales [a,*]

[a] Institute for Sustainable Agriculture, CSIC, Apdo. 4084, 14080 Córdoba, Spain
[b] Virginia Tech, Dep. Plant Pathology, Physiology and Weed Science, Blacksburg, VA 24061, USA
[c] Faculty of Agriculture, An-Najah National University, P.O.Box 7, Nablus, Occupied Palestinian Territory
[d] Faculty of Agriculture, Kafr El-Sheikh University, 33516 Kafr El-Sheikh, Egypt
[e] INRAT, Rue Hédi Karray, 2049 Ariana, Tunisia

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ABSTRACT

Chocolate spot incited by *Botrytis fabae* is a serious faba bean disease of worldwide distribution. The increasing interest in sustainable tools for disease control, together with the lack of sufficient levels of genetic resistance triggered our interest in the use of intercropping as a tool for the management of this disease. The effect of intercropping on chocolate spot severity was studied in field experiments performed in Egypt, the Palestinian Territories, Spain and Tunisia, in which a susceptible faba bean cultivar was grown as a monocrop or with two mixed species intercrops of either barley, oat, triticale, wheat, pea or common vetch, or with three mixed species intercrops of wheat and berseem clover. Chocolate spot was significantly reduced when faba bean was intercropped with cereals, but not when intercropped with legumes. Suppressive effects can be ascribed to a combination of host biomass reduction, altered microclimate and physical barriers to spore dispersal.

1. Introduction

Chocolate spot disease, incited by *Botrytis fabae* Sard. is one of the most important causes of instability for faba bean (*Vicia faba* L.) crop yields across the world. Severe outbreaks are most common in the Nile delta, near rivers in China, rainy coastal areas of the Mediterranean and the more oceanic climate of western France and western UK (Stoddard et al., 2010). It is characterized by spot lesions on leaves that start as rust coloured to dark-brown spots which become surrounded by an orange–brown ring. Lesions can expand to a diameter of 5–10 mm and have a tobacco-coloured centre. Light and dark concentric ridges often develop during lesion expansion (Harrison, 1988). Chemical control is possible, but it is costly and harmful to the environment, reducing the crop's profitability (Stoddard et al., 2010). Breeding of resistant cultivars is a priority to control the disease, but no completely resistant cultivars have been developed so far (Sillero et al., 2010; Villegas-Fernández et al., 2010).

Intercropping is an agronomic system where two or more species are cultivated simultaneously in the same field, establishing interspecific interactions in both time and space (Trenbath, 1976). When the associated crops are correctly chosen, intercrop results in an improved efficiency of resources use due to the complementarities in growth patterns. This improved efficiency is remarkable in cereal–legume intercrops (Jensen et al., 2010). Faba bean intercrops were very common in the past but intensification of agriculture through synthetic inputs favoured monocropped faba beans in recent decades. However, there is a renewed demand for alternative production techniques with reduced synthetic inputs in the farming system such as intercropping (Jensen et al., 2010).

Intercropping legumes with cereals are known to improve disease control (Boudreau and Mundt, 1992; Fernández-Aparicio et al., 2007, 2010; Schoeny et al., 2010). Chocolate spot reduction has been reported in faba bean intercropped with cereals, but there are conflicting reports on the effect in intercrops with other legumes (Dillon Weston, 1944; Sahile et al., 2008). The aim of this study was to discern the effects of species mixtures in the development of *B. fabae* in faba bean in different environments across the Mediterranean area, identifying optimal species mixtures with the highest suppressive potentials and to investigate some candidate mechanisms of suppression.

2. Materials and methods

2.1. Identification of suitable crop mixtures for disease reduction

A first series of experiments were carried out during the 2005–2006 and 2006–2007 growing seasons at Córdoba (37°51′N;

* Corresponding author. Tel.: +34 957499215; fax: +34 957499252.
E-mail address: diego.rubiales@ias.csic.es (D. Rubiales).

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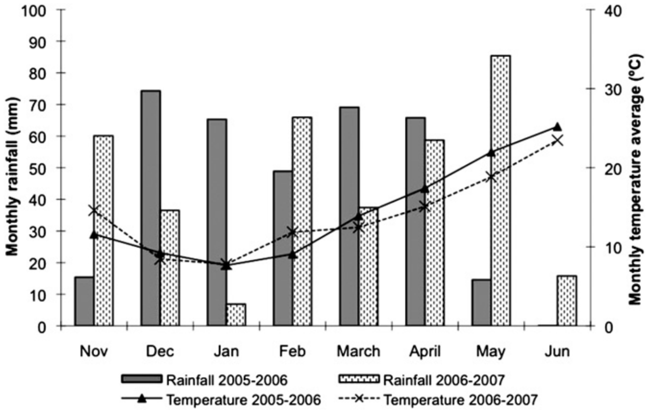

Fig. 1. Average air temperature and rainfall during the seasons 2005–2006 and 2006–2007 at Córdoba, Spain.

04°48′W; 117 m altitude), southern Spain. Faba bean (*V. faba* var. *minor*, cv. Prothabon) was grown as a monocrop (100%) as a positive control and in two or three species mixture intercrops with cereals or legumes.

In the two species intercrop faba bean was intercropped with cereals: barley (*Hordeum vulgare* L., cv. Cory), durum wheat (*Triticum durum* L., cv. Meridiano), oat (*Avena sativa* L., cv. Aspen) or triticale (*XTriticosecale* Wittm., cv. Peñarroya) or with legumes: common vetch (*Vicia sativa* L., cv. Mezquita) or field pea (*Pisum sativum* L., cv. Messire). The two species intercrops were based on the replacement principle where the species were mixed in the same row in 50%:50% ratios. Plant density was 100 faba bean plants m^{-2} in monocrop, 50 faba bean plants m^{-2} plus 50 companying legume plants m^{-2} in the various faba bean–legume intercrops, and 50 faba bean plants m^{-2} plus 75 cereal plants m^{-2} faba bean–cereal intercrops. Plant density in the three species mixed intercrop was 50 faba bean plants m^{-2} plus 50 durum wheat plants m^{-2} plus 200 berseem clover (*Trifolium alexandrinum* L. cv. Tigri) plants m^{-2}.

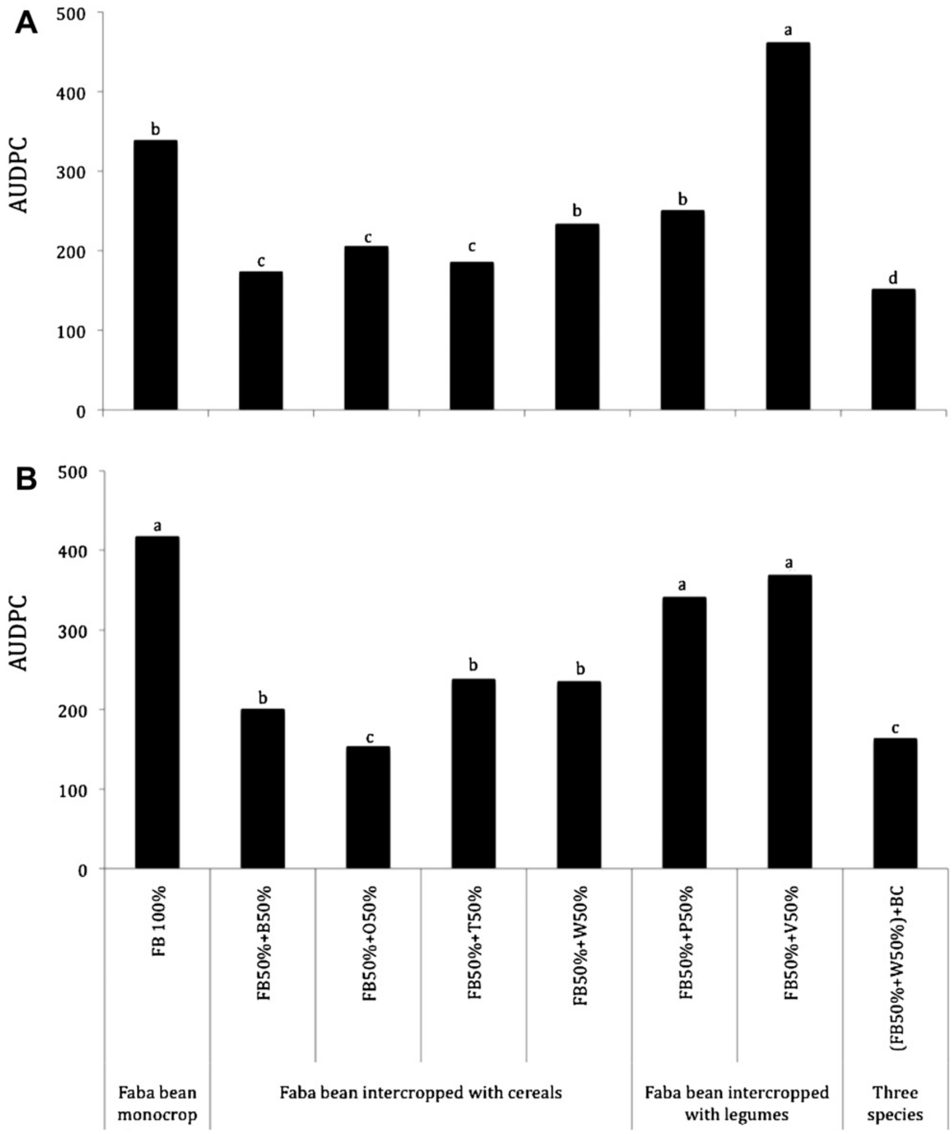

Fig. 2. Area under the disease progress curve (AUDPC) of chocolate spot on faba bean observed in Spain during (A) 2005–2006 and (B) 2006–2007 seasons when monocropped at full plant densities (FB100%) and when intercropped in replacement with cereals: barley (FB + B), oat (FB + O), triticale (FB + T) and wheat (FB + W); with legumes: pea (FB + P) and vetch (FB + V); and in a three species mixed intercrop with wheat + berseem clover (FB + W) + BC. Means of each year with no letters in common are significantly different. Tukey's test ($\alpha = 0.050$).

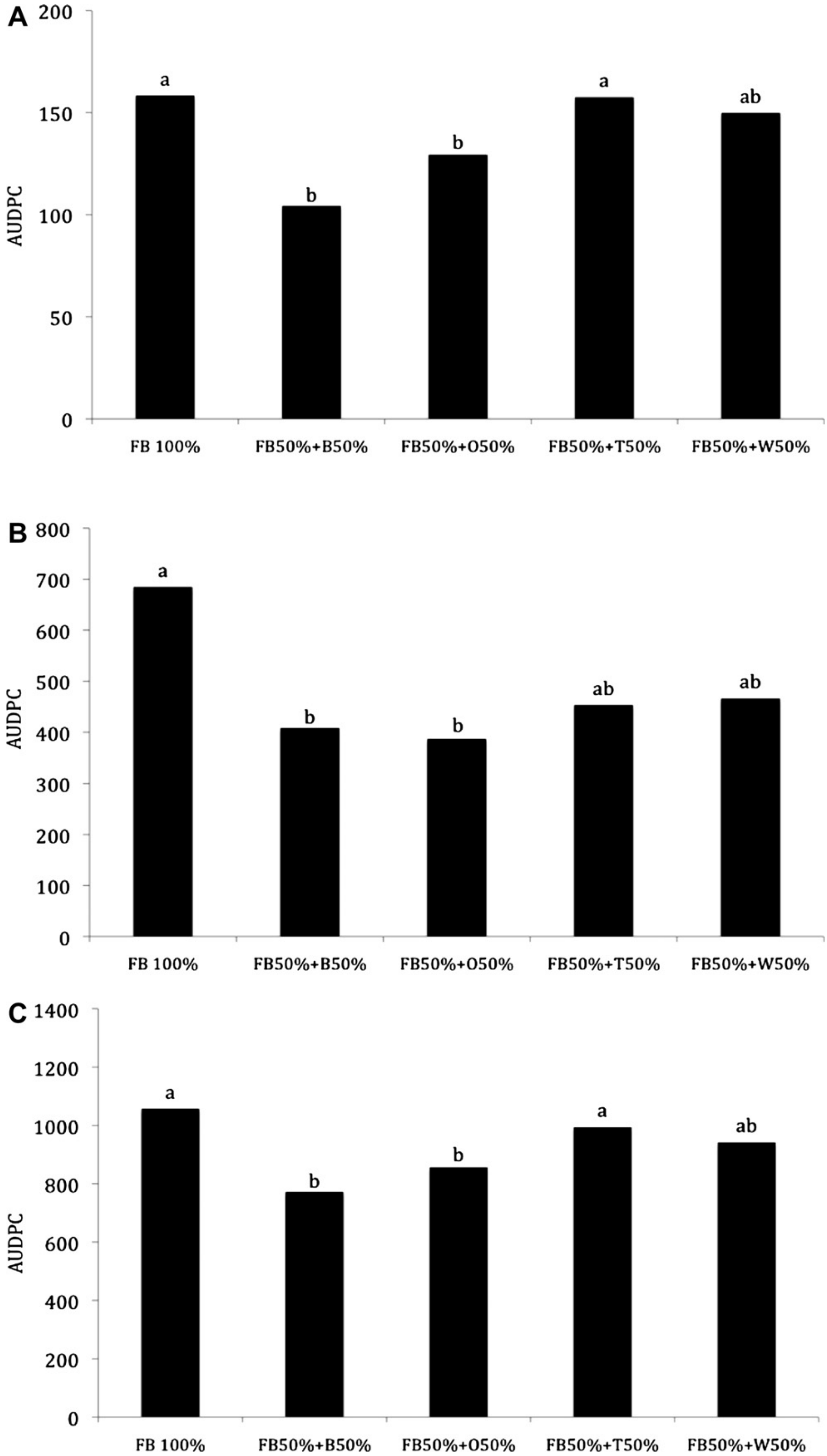

Fig. 3. Area under disease progress curve (AUDPC) of chocolate spot on faba bean observed in (A) Palestinian Territories and (B) Tunisia during 2006–2007 and in (C) Egypt during 2007–2008 when monocropped at full plant densities (FB100%) and when intercropped with cereals in replacement: barley (FB + B), oat (FB + O), triticale (FB + T) and wheat (FB + W). Means of each country with no letters in common are significantly different. Tukey's test ($\alpha = 0.050$).

All species were mechanically sown at the same time in November. The experimental plots (1.7 × 10 m^2) were laid out in a randomised complete block design with 4 replicates. The crops were grown organically, without any fertiliser or pesticide application. Hand weeding was performed when needed. No artificial inoculation was performed relying on the natural onset of the disease.

2.2. Validation of optimal crop mixtures under contrasting environments

Additional experiments were performed in Beja (36°44′N; 9°13′E; 159 m altitude), Tunisia and Khadoorie, (32°18′N; 35°01′E; 90 m altitude), Palestinian Territories during 2006–2007 season, and in Kafr El-Sheik (30°47′N; 30°59′E; 0 m altitude), Egypt during 2007–2008. Four intercrop combinations were included in this study: faba bean intercropped with barley, durum wheat, oat and triticale. Faba bean monocropping was used as a control. The same cereal varieties were used in all the countries as described above. However faba bean cultivars were different in each country using the local varieties: Giza Blanca, Baladi and Chahbi in Egypt, Palestinian Territories and Tunisia respectively. The intercrop design was based on the replacement principle where the two species were mixed in the same row in 50%:50% ratios. Final plant density in monocrop was 100 faba bean plants m^{-2} in Tunisia and Palestinian Territories and 66 plants m^{-2} in Egypt. Faba bean density was reduced by half in all intercrops being replaced by 75 cereal plants m^{-2}. Sowing was done by hand during November. Again, no artificial inoculation was performed relying on natural onset of the disease.

2.3. Effect of host density on disease

An additional experiment was performed in Egypt (2007–2008) and Palestinian Territories and Tunisia (2006–2007). In this experiment only monocropped faba bean was included being the reduction of plant density the main effect of study. The same faba bean varieties and plant densities indicated in Section 2.2 were used. Eight monocropped plots (1.7 × 10 m^2), four at full (100%) and four at reduced density (50%) were grown following a randomized complete block design. The purpose of this experiment was to study the effect of host density reduction on chocolate spot development, isolated from the effect of insertion of non-host species (host frequency reduction) studied in Sections 2.1 and 2.2.

2.4. Effect of plant height on disease development

The effect that differences in host stature relative to the associated crop have on disease development was established in an additional experiment in Egypt (2007–2008) and Tunisia (2006–2007). Eight intercrop systems were included in this study: two faba bean cultivars differing in plant size were each combined with 4 cereal species: barley, durum wheat, oat and triticale. The tall size cultivars used were Giza Blanca and Chahbi and the short size were Sidiqui and Badï in Egypt and Tunisia, respectively. Two monocrops at full density were used as controls in each country, one per each faba bean cultivar. Same plant densities than in Section 2.2 were used. The plots (1.7 × 10 m^2) were laid out in a complete one-factorial randomised design with four replicates. The intercrop design was based in the replacement principle using the plant densities described in Section 2.2.

2.5. Disease assessment

In all countries, disease severity was assessed during setting and filling of faba bean pods by a visual estimation of the proportion of plant tissue affected by disease. Measurements were made on 10 randomly chosen plants per plot, 4 plots per treatment. First assessment was made when first symptoms were observed. This was followed by two additional assessments at two weeks interval. These data were used to calculate the area under the disease progress curve (AUDPC) using the formula:

$$\text{AUDPC} = \sum_{i=1}^{K} 1/2[(S_i + S_{i+1})(t_{i+1} - t_i)]$$

where S_i is the chocolate spot severity at assessment date i, t_i is the number of days after the first observation on assessment date i and k is the number of successive observations.

2.6. Effects of intercrop on faba bean structure

In Spain, faba bean plants were harvested by cutting the plant parts at 2 cm above the soil surface. Length, total fresh weight, number of leaves, and fresh leaf weight were measured during April 2007 in ten plants randomly selected per plot. This was done on three plots per treatment of experiment Section 2.1. Data observed in each intercrop was compared with the respective data obtained in the faba bean monocrop. In addition, the height reached by faba bean plants above soil surface was measured in

Table 1
Faba bean plant height in faba bean monocrops at in full plant densities (FB100%) and in intercrops with cereals in replacement: barley (FB + B), oat (FB + O), triticale (FB + T) and wheat (FB + W), legumes: pea (FB + P) and vetch (FB + V) and in a three species mixed intercrop with wheat + berseem clover (FB + W) + BC. Data in brackets represent the difference in height between faba bean and its associated crop. Positive numbers indicate the associated crop is higher than faba bean. Data are the mean ($n = 40$) observed at the beginning of disease symptoms appearance in faba bean. Means with no letter in common differ significantly, Tukey's test ($\alpha = 0.050$).

Cropping system		Faba bean crop height (cm)			
		Córdoba, Spain	Kafr El-Sheikh, Egypt	Khadoorie, Palestinian Territ.	Beja, Tunisia
Faba bean monocropped	FB100%	112.2a	86.6a	95.3a	84.3a
Faba bean intercropped with cereals	FB50% + B50%	98.3c (−2)	74.1b (−36)	92.7a (−28)	83.5a (−30)
	FB50% + O50%	93.6d (+5)	77.5b (−46)	96.4a (+22)	81.9a (−13)
	FB50% + T50%	105.6b (+23)	75.7b (−27)	85.1a (−8)	78.9a (−27)
	FB50% + W50%	97.0cd (−10)	63.8c (−33)	93.5a (−33)	80.8a (−34)
Faba bean intercropped with legumes	FB50% + P50%	102.6b (−20)	nd	nd	nd
	FB50% + V50%	103.2b (+2)	nd	nd	nd
Faba bean intercropped with wheat and berseem clover	(FB50% + W50%) + BC	93.8d (−6)	nd	nd	nd

experiment Sections 2.1 and 2.2 and compared with the height of the companion crop. This measurement was done placing a tape measure near to ten random plants in each plot without stretching or cutting the plants.

2.7. Microclimate modification

Data on temperature and relative humidity were collected inside the canopy, at 1-h intervals during disease development of each plot in the Spanish trial (Section 2.1) during April 2007. This was done by placing sensors (Gemini Tinytag Plus Data Logger) fixed to a stick placed in the centre of the plot so that the sensors were located in the canopy at 50% plant height of faba beans of mono-and intercropped plots. Data were collected in 3 replications of all intercrops, except for vetch-faba bean intercrops.

2.8. Statistical analysis

Data were subjected to analysis of variance (ANOVA). For multiple comparisons Tukey's tests ($\alpha = 0.050$) were conducted on the data. Statistical analyses were performed using SPSS 15.0.

3. Results

3.1. Weather condition influenced disease development across years

High and uniform chocolate spot infection was observed at Córdoba in both seasons, however, infection started earlier and reached higher values in the 2006–2007 than in 2005–2006 season (maximum values of 33.8% *vs* 42.8% of diseased tissue were observed per monocropped faba bean plant during first *vs* second growing season). In addition the disease inhibiting effect of intercrops was stronger ($P = 0.027$) in 2006–2007 (on average 47.2% reduction of disease severity compared to that of the faba bean monocrop) than in 2005–2006 (on average 29.6% less disease (AUDPC) for intercrops compared to the faba bean monocrop) but no year × treatment interaction effect was observed (Fig. 2 for AUDPC values). Differences in disease onset and development with earlier and higher disease spread during 2006–2007 can be explained by differences in weather conditions (Fig. 1). Delayed disease appearance during the 2005–2006 season was likely caused by a cooler winter period (686.8 accumulated degree days during December to February in 2005–2006, compared to 739.4 accumulated degrees in the same period of 2006–2007). Chocolate spot onset under southern Spanish conditions usually starts in February. Average temperature for February was 2.8 °C lower in 2006 than in 2007. During February 2006 only 9 days (6 of them with rain) presented an average temperature above 10 °C whereas during February 2007 there were 22 days with daily average temperature above 10 °C (including 18 days with rain).

Weather conditions (data not shown) were also conducive for chocolate spot in the Palestinian Territories and Tunisia in 2006–2007, and in Egypt in 2007–2008, where maximum values of 9%, 45% and 85% of diseased tissue were observed per faba bean monocropped plant (Fig. 3 for AUDPC values). As only one season was studied in these countries, in which faba bean varieties and inoculum were different, no relation between climatic conditions and epidemic development could be established.

3.2. Species mixtures effect on disease development

Although the same cereal cultivars were used in all countries, plants grew taller in Spain than in the rest of the countries (Table 1). The shorter height reached by these non-host components of the mixture observed in Egypt, Tunisia and Palestine could explain the smaller, although still significant suppressive effect observed in these countries. However when we compared plant height of different species with their ability to suppress disease in each country, there was no correlation indicating that additional factors different from plant height influenced disease suppression.

In the Spanish trials replacing half the population of faba bean with cereals as mixed intercrops significantly reduced chocolate spot ($P < 0.0001$). Chocolate spot AUDPC was reduced by growing faba bean mixed with barley (49 and 52% reduction during 2005–2006 and 2006–2007, respectively), oats (39 and 63%), triticale (45 and 43%), wheat (31 (although not significant) and 44%) and wheat–berseem (55 and 61%) in comparison with the AUDPC

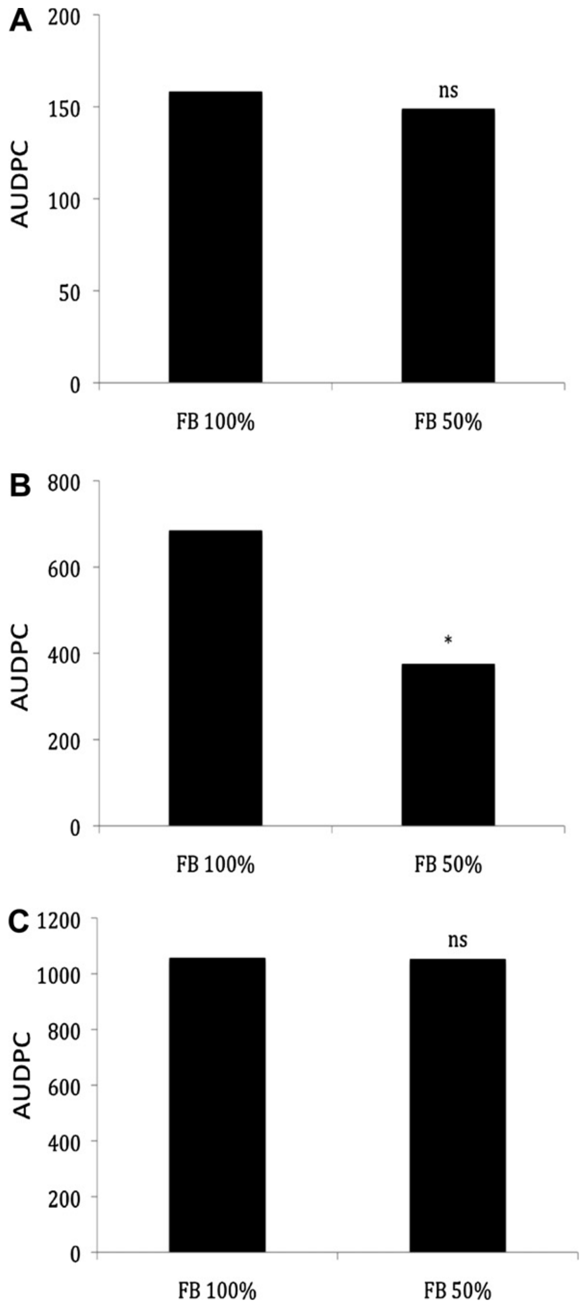

Fig. 4. Chocolate spot area under disease progress curve (AUDPC) observed in (A) Palestinian Territories and (B) Tunisia during 2006–2007, and in (C) Egypt during 2007–2008 on faba bean when sole cropped in full plant densities (FB100%) and in half density (FB50%). *, indicate significant effect of treatment (reduction of faba bean sowing density by half) on chocolate spot AUDPC (ANOVA, $P < 0.01$); ^{ns}, indicate no significant effect.

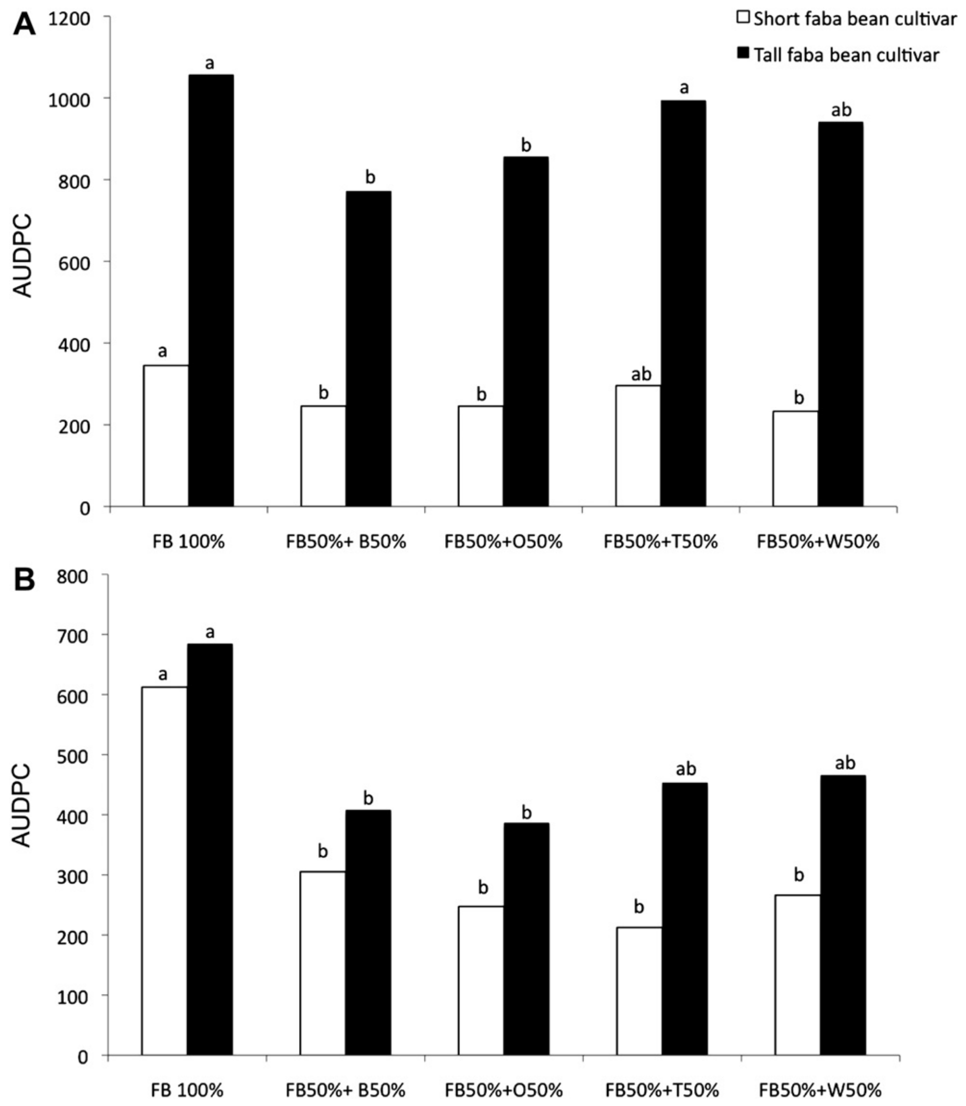

Fig. 5. Effect of plant height of faba beans cultivars on the efficiency of intercrops to reduce chocolate spot severity measured as area under the disease progress curve (AUDPC). (A) Egypt during 2007–2008, (B) Tunisia during 2006–2007. Means of each faba bean cultivar with no letter in common are significantly different. Tukey test ($\alpha = 0.050$).

levels observed in faba bean monocrops. In contrast, pea and vetch had little or no significant effect on chocolate spot reduction in faba bean.

The reduction of chocolate spot in intercrops with cereals observed in Spain was confirmed in Palestinian Territories, Tunisia and Egypt (Fig. 3). The reduction on AUDPC was significant ($P < 0.0001$) when faba bean was intercropped with barley (27.0, 34.1 and 40.4% in Egypt, Palestinian Territories and Tunisia, respectively) and oats (19.0, 18.3 and 43.5% in Egypt, Palestinian Territories and Tunisia, respectively). In all countries, there was

Table 2
Modifications on faba bean plant architecture through competition with barley (FB + B intercrop), rust-susceptible oat variety (FB + O intercrop), triticale (FB + T intercrop) and wheat (FB + W intercrop), pea (FB + P intercrop) and wheat + berseem clover (FB + W) + BC intercrop. Data are the mean ($n = 30$) observed in faba bean in Spain during April 2007. Means with no letter in common letter are significantly different, Tukey's test ($\alpha = 0.050$).

Cropping system		Faba bean final height (cm)	Faba bean plant weight (g)	Total weight of leaves per faba bean plant (g)	Faba bean internode length average (cm)
Faba bean monocrop	FB 100%	116.9a	70.0a	15.6a	8.4a
Faba bean intercropped with cereals	FB50% + B50%	98.6cd	49.5b	14.6a	7.4b
	FB50% + O50%	96.1d	52.2b	12.6a	7.5b
	FB50% + T50%	108.2ab	51.2b	13.3a	7.4b
	FB50% + W50%	99.3bcd	55.4b	13.4a	7.3b
Faba bean intercropped with legumes	FB50% + P50%	106.3bc	58.8ab	16.8a	7.9ab
	FB50% + V50%	106.1bc	52.6b	14.9a	8.5a
Three species mixed intercrop	(FB50% + W50%) + BC	94.8d	46.5b	14.0a	6.7b

a trend for reduction of chocolate spot disease in intercrops with triticale and wheat but it was not significant.

3.3. Host density effect on disease development

Disease was significantly reduced by 45.2% ($P = 0.006$) in Tunisian plots when monocropped faba bean cv. Chahbi was sown at half density compared to full density (Fig. 4). However, no significant effects were observed either in Egypt or Palestinian Territories.

3.4. Relative height differences between associated crops and its effect on disease development

In a second series of experiments performed in Egypt and Tunisia we compared the effect of intercropping cereals with short- and tall-sized faba bean cultivars (Fig. 5). Tall faba bean cultivars were more infected by chocolate spot than short ones both in monocrops and intercrops (Fig. 5). These differences between faba bean cultivars were more marked in Egypt ($P < 0.0001$). Cereal species were more effective at reducing chocolate spot severity when intercropped with short faba bean cultivars. Cereal intercropping resulted in a reduction of chocolate spot severity of on average 15.5% on the tall faba bean cultivar and 25.9% on the short one ($P = 0.009$). Chocolate spot was reduced on average by 37.9% on the tall faba bean cultivar and by 56.3% on the short cultivar when intercropped with cereals in Tunisia ($P = 0.003$). Barley and oat significantly reduced chocolate spot disease compared to the monocropped bean when they were intercropped with both tall and short faba bean. The trend of chocolate spot reduction observed to be non-significant when wheat and triticale was intercropped with the tall faba bean cultivar, was significant when these cereals were intercropped with short faba bean cultivars. The extend of the reduction increased from 10.7 to 32.2% for tall and short faba bean cultivar wheat intercropped, respectively, and from 5.9 to 14.0% on tall and short faba bean cultivar triticale intercrop, respectively, in Egypt. In Tunisia, the reduction levels increased from 33.5 to 55.0% for wheat and 33.8–65.2% for triticale when intercropped with tall and short faba bean cultivars.

3.5. Changes in faba bean structure induced by intercrop

Faba bean intercropped with cereals were shorter ($P < 0.0001$) than monocropped ones (Tables 1and 2). Despite the fact that the total weight of intercropped faba bean plants was significantly lower ($P = 0.039$), there were not significant differences in the total weight of leaves per plant between intercropped and monocropped faba bean. The average internode length was shorter in faba bean plants intercropped with barley, susceptible oat, wheat, triticale and wheat–clover but no significant differences were observed with resistant oat cultivar and pea. The internodes were longer when faba bean were co-cultivated with vetch (Table 2).

3.6. Testing modification induced by intercrops on microclimate inside the faba bean canopy

Relative humidity inside faba bean monocropped was 100% all night (Fig. 6) during the period chocolate spot development (April), starting to reduce by 9 am, local time, reaching the lowest values (around 55.0%) from 2 to 8 pm.

Similarly, Fig. 7 shows average hourly canopy temperature during April. The lowest temperature (8 °C) inside the faba bean canopy was recorded by 8 am, from which it increased to 20–25 °C from 1 to 7 pm. Canopy temperature reductions of 2–3 °C were achieved in faba bean intercropped with oat or with barley from midday to 6:00 pm.

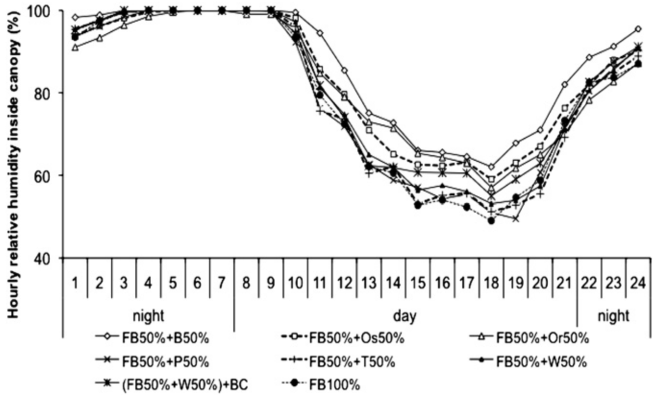

Fig. 6. Average relative humidity measured hourly inside the canopy during April 2007 at Córdoba, Spain.

4. Discussion

Chocolate spot is a damaging disease of faba bean, the incidence and spread are strongly influenced by climatic conditions (Harrison, 1988; Villegas-Fernández et al., 2010). Early infection produces typically dark-brown spots that do not pose a serious threat to the crop. However, when environmental conditions become favourable for the development of the disease (that is, mild temperatures and high humidity) aggressive lesions may appear. In this case, a rapidly expanding necrosis takes place which may eventually lead to defoliation and death of the whole plant (Harrison, 1988). Earlier and more severe epidemic occurred at Córdoba during the second than during the first season of experimentation, explained by the milder winter temperature favouring epidemic development. In addition to a milder winter, this second field season was characterized by cooler spring which also favoured disease spread. As noted by Chorin (1939), too high temperatures limit lesion expansion.

The results of this work confirmed that intercrops with cereals can be an effective strategy for control of chocolate spot in faba bean. This beneficial effect varies with the associated species, being higher for barley and oat. These results were confirmed over two growing seasons (2005–2006 and 2006–2007) in Spain and in different experimental locations (Egypt, Palestinian Territories, Spain and Tunisia). Two species intercrops were designed based on the replacement principle, so that, associated crops were sown to

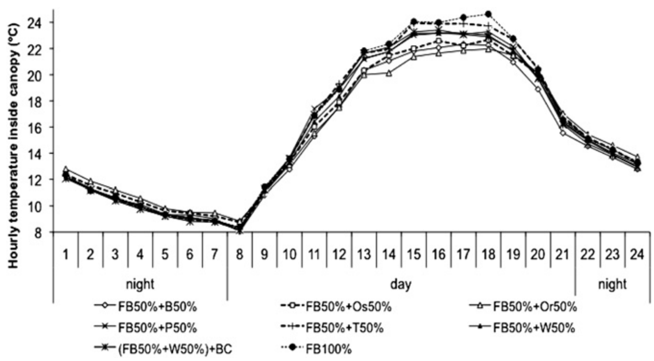

Fig. 7. Average temperature measured hourly inside the canopy during April 2007 at Córdoba, Spain.

replace half of the faba bean plants. Under these conditions, there are two direct additive factors that alter faba bean disease. First, the reduction of host plant density decreases the amount of susceptible tissue per field area unit. This affects spore production per field unit area and dispersion rates and decreases the likelihood of spore deposition on host tissue by increasing the distance between two neighbouring host plants. Second, the creation of a physical barrier in the form of non-host plants prevents some of the dispersed spores from being deposited on the host tissue by interception. We tried to separate these effects by studying the effect of host density by reducing by half the seeding rate of faba bean without including any intercrop. We observed a reduction in chocolate spot disease severity in faba bean monocrops sown at low density in Tunisia but not in Egypt or in the Palestinian Territories. Chocolate spot had been reported to increase at higher monocropped faba bean densities (Harrison, 1988), although Bulson et al. (1997) observed this reduction as no consistent across scoring dates. Garret and Mundt (2000) observed contradictory tendency during two consecutive years in the relation between severity of stripe rust and plant densities in monocropped wheat. Lower seeding density at Egypt as well as possible different levels of nutrition and water stress, known to influence infection (Garret and Mundt, 2000) could explain the conflicting results observed in the different countries.

When the monocrop density is reduced by half by replacing the host with a non-host plant species, both host density and frequency are simultaneously reduced (Finckh et al., 2000). In our studies this fact led to a disease reduction that was confirmed across years and locations. According to the classic model of Leonard (1969) disease severity is reduced logarithmically as resistant plants are added to a mixture. The cereals could act as a physical barrier; intercepting spores carried by wind from neighbouring infected faba bean plants thereby reducing the amount of effective inoculum available to infect new tissue. Similar effects have been reported in pea–cereal intercrops intercepting *Mycosphaerella pinodes* spores (Schoeny et al., 2010). However, when pea and vetch were intercropped with faba bean reductions in chocolate spot were either not significant or a significant increase was observed. A possible explanation might be the fact that both pea and vetch are themselves hosts of chocolate spot (Ellis and Waller, 1974; You et al., 2009) allowing spore multiplication. An alternative explanation might be the fact that pea and vetch with their less erect growth habit and their tendency to lodge might create a denser canopy particularly at the base of the crop, thus increasing relative humidity which favours disease development. The amount of early lesions at the base of the crop is a major determinant of the initiation of chocolate spot epidemics (Creighton et al., 1985). Sahile et al. (2008) found chocolate spot reduction in faba bean–maize and faba bean–barley intercrops, but not in a faba bean–pea intercrop. However, Dillon Weston (1944) reported that faba bean intercropped with pea, barley and oats were almost chocolate spot-free. Schoeny et al. (2010) considered that reduction in host density was responsible to a large extent for reductions of *M. pinodes* dispersal in pea–barley intercrops, with a significant contribution of non-host plant providing a physical barrier.

When we changed the faba bean cultivars from tall to short plant stature while maintaining the cereal varieties, the suppressive effect of wheat and triticale observed on chocolate spot was amplified, indicating that the height of the living physical barriers wheat and triticale relative to the height of the host faba bean was positively correlated with the reduction on chocolate spot development.

Competition for light, water and nutrient resources between intercropped species leads to an alteration of the host plant architecture, modifying the capability of the host tissue to trap spores (Boudreau and Mundt, 1992). Intercropped faba bean with cereals were reduced in size due to shorter internodes. Although less total biomass was measured in intercropped faba beans there was no differences in the total weight of leaves per faba bean plant and the ratio of leaves/total biomass was higher in intercropped faba beans. This suggests a more compact faba bean structure with reduced air circulation that could decrease spore dispersal. Reduced wind speed has been documented in phaseolus beans–maize intercrop (Boudreau, 1993). Reduced wind might contribute to reduction of chocolate spot spread as the majority of *B. fabae* conidia are dispersed by wind even during rain (Fitt et al., 1985).

Besides wind speed, the microclimate inside canopy is modified when an associated species is mixed in intercrops. Changes in temperature, humidity and light have been described inside canopies of intercropped species in comparison with the monocropped species at equivalent density (Leonard, 1969; Stoetzer and Omunying, 1984; Boudreau, 1993). These changes might alter disease progress by altering infection, sporulation rate, lesion growth and spread of secondary disease cycles (Schoeny et al., 2010). In accordance we observed a reduction in average day temperature and an increase in relative humidity in oat- and barley-faba bean intercrops in comparison with the monocrop. Botrytis spores are released from conidiophores through a hygroscopic mechanism that is favoured by rapidly changing humidity (Jarvis, 1962; Fitt et al., 1985). The stronger decline in relative humidity observed in the morning inside the canopy of faba bean monocrop could favour spore release thereby increasing disease.

In this study, intercropping of faba bean with cereals affected chocolate spot development on faba bean. These results confirm that, under some conditions, faba bean–cereal intercropping could usefully contribute to the management of chocolate spot. In this study, intercropping was only evaluated from the crop protection point of view. The effect of intercropping on yield and disease-yield loss relationship was not investigated. First, the experimental design was not adapted to carry out such agronomic investigation. Indeed, field experiments involved winter faba bean crops in four countries in order to achieve a wide range of epidemics. The differences in potential yield make the comparisons between experiments inappropriate. Agronomic benefits of faba bean intercrops with cereals have been extensively studied by others, demonstrating that the land equivalent ratio (LER) of faba bean intercrops with barley (Agegnehu et al., 2006), bread wheat (Bulson et al., 1997), durum wheat (Tosti and Guiducci, 2010), oat (Helenius and Jokinen, 1994) or triticale (Sobkowicz, 2006) exceed those of the sole components giving better overall yield and income than sole culture of each crop species. Intercropping is more suitable for organic farmers interested in a gross crop product (some feed industry channels) than for more conventional farming where separation of the crop products is required. It is possible to harvest the crop with a combine harvester and the cereal and beans can be planted separately mechanically, therefore this system is suited to mechanized agricultural systems.

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