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Effects of sowing date on severity of blight caused by *Ascochyta rabiei* and yield components of five chickpea cultivars grown under two climatic conditions in Tunisia

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Abstract Five chickpea cultivars, Chitoui, Neyer, Kasseb, Beja 1 and Bouchra, were planted on three sowing dates at two Experimental Stations in Tunisia: Bou Salem in the north and the more southerly Mornag, where the climate is drier. Severity of blight, caused by *Ascochyta rabiei*, was measured on a 1–9 scale (defined) on vegetative parts and on pods as percent infected and percent infected that were empty. At both locations, disease was essentially absent on plants sown on the third dates but present on plants sown on the two earlier dates. At Bou Salem, disease severity was highest for the second sowing date whereas at Mornag it was highest for the first sowing date; but for each sowing date, disease severity was lower at Mornag than at Bou Salem. Yield components were measured as number of pods per plant, number of seeds per plant, number of seeds per 100 pods, 100 seed weight and weight of seeds per plant. Both disease severity and yield differed significantly among sowing dates (differently at each location) and also among cultivars for each sowing date, these differences depending both on sowing date and location. A lower yield was always associated with a higher disease severity, although the quantitative relationship differed between cultivars and locations. Cultivar Beja 1 had the lowest vegetative disease scores at both locations and both sowing dates 1 and 2. Beja 1 also scored well for all yield components. Plants sown on the third (latest) date gave the highest yields for all cultivars at both locations (except for an unusually high yield of Neyer at Mornag on sowing date 2), in some instances being more than double those from the earlier sowing dates.

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Thus, in contrast to other studies, late sowing did not result in yield loss.

Keywords Field trial · *Cicer arietinum* · Infected pods · Seeds per plant · 100 seed weight

Introduction

The fungus, *Ascochyta rabiei*, is the causal agent of chickpea blight and is the major biotic constraint limiting chickpea production in the Mediterranean region and most other parts of the world where chickpea is grown, such as west and central Asia, North Africa, Australia and North America (Nene 1982). Severe attacks may result in total loss of the crop (Reddy and Singh 1990; Singh et al. 1981; Singh and Reddy 1990; Solh et al. 1994) and, in some years, the disease has even affected international trade (Dusunceli et al. 2007b). Pande et al. (2005) recently reviewed the biology and management options of Ascochyta blight of chickpea.

Spread of the disease is favoured by cool and wet weather such as occurs in winter in the Mediterranean region. Here, in order to avoid the disease, some farmers sow chickpea as late as early March or even April but yields may then be limited by the onset of hot and dry weather before maturity (Dusunceli et al. 2007a). In contrast, providing that blight is controlled, yields of winter sowings may be double those of spring sowings (Singh and Reddy 1990).

In Tunisia, chickpea is the second most important grain legume crop after beans, occupying about 33,400 ha. Annual production during the last decade has been nearly 17,800 tonnes, the yield fluctuating generally between 500 and 800 kg ha^{-1}. This variation has been attributed to variation in the severity of attacks by *A. rabiei*. Djerbi et al. (1979) estimated that, under conditions of moderate disease severity, yield losses were about 40%. Although in the semi-arid regions of Tunisia, yields of autumn or winter sown chickpeas were greater than chickpeas sown in the spring (Bouslama et al. 1988), optimal sowing dates which would allow stable yields and minimal Ascochyta blight remain to be established, particularly in northern areas where the wetter and cooler climate favours the disease. One aim of the current work was therefore to determine the effect of using earlier sowing dates on the severity of Ascochyta blight and yield components of five chickpea cultivars grown under wet and semi-arid conditions in Tunisia.

Materials and methods

Experimental stations

Two field trials were conducted, one at Bou Salem Experimental Station (latitude 36°36′N, longitude 88°8′E, altitude 143 m) which is located in the wetter northern part of Tunisia 128 km north west of Tunis in the valley of the Medjerda river and about 80 km from the Mediterranean Sea, and the other at Mornag Experimental Station (latitude 32°7′N, longitude 10°14′E, altitude 33 m) which is located 16 km South East of Tunis and about 16 km from the Mediterranean Sea, and has a semi-arid climate. Five chickpea cultivars were sown manually according to a split-split plot design with three replications. Each of three blocks of land was divided into three main plots with one sowing date allocated to each, and each main plot was divided into five sub-plots with one cultivar allocated to each, giving three replicates of the 15 sowing date×cultivar combinations at each location.

The cultivars (Chitoui, Kasseb, Bouchra, Beja 1 and Neyer) were kindly provided by Dr Mohamed Kharrat of the Grain Legume Laboratory, Institut National de la Recherche Agronomique de Tunisie (INRAT). They were all thought to be resistant to disease, although not equally so: Kharrat and Halila (2006) classified Chitoui and Kasseb to be less resistant than Bouchra, and Beja 1 and Neyer to be more resistant.

Sowing dates at Bou Salem were 8th December 2001, 3rd January 2002 and 5th February 2002 and at Mornag 5th December 2001, 24th January 2002 and 9th March 2002. Farmers in Tunisia often sow chickpea as late as March to avoid disease. We used earlier sowing dates, with higher likelihood of disease, partly to study how yield might be affected and partly to compare the cultivars un-

der higher disease pressure and different climatic conditions.

Individual plots were 2 m × 1.5 m and contained four rows spaced 50 cm apart with a sowing density of 10 seeds per linear meter, giving a total of 80 seeds per plot (20 plants per m^2). Farmers normally sow 20–25 plants per m^2. The susceptible cultivar Amdoun1 was sown as a border crop around each plot (width 1.5 m). Inoculum was provided by infected chickpea seeds, prepared in the laboratory according to the method of Alam et al. (1987) and distributed immediately after each sowing (50 g/row). At Bou Salem, plants from sowing dates 1 and 2 were harvested on 14th June and those from sowing date 3 on 1st July. At Mornag plants from sowing dates 1 and 2 were harvested on 16th June and those from sowing date 3 on 5th July.

Weather conditions

Temperature, relative humidity (RH) and rainfall were monitored in November 2001 and throughout the experiment. For Bou Salem, temperature and RH data were provided by the National Institute of Meteorology of Tunis, while the local rainfall was measured at the Jenjouba weather station, about 20 km from the experimental station. At Mornag, the climatic data were measured at the INAT weather station on the same location as the field trial.

Figure 1 shows the climatic data, along with the sowing and harvest dates. RH and maximum and minimum temperatures were similar at Bou Salem and Mornag but rainfall differed markedly. The total rainfall between 1st November and 30th June at Bou Salem of 515.3 mm was more than twice

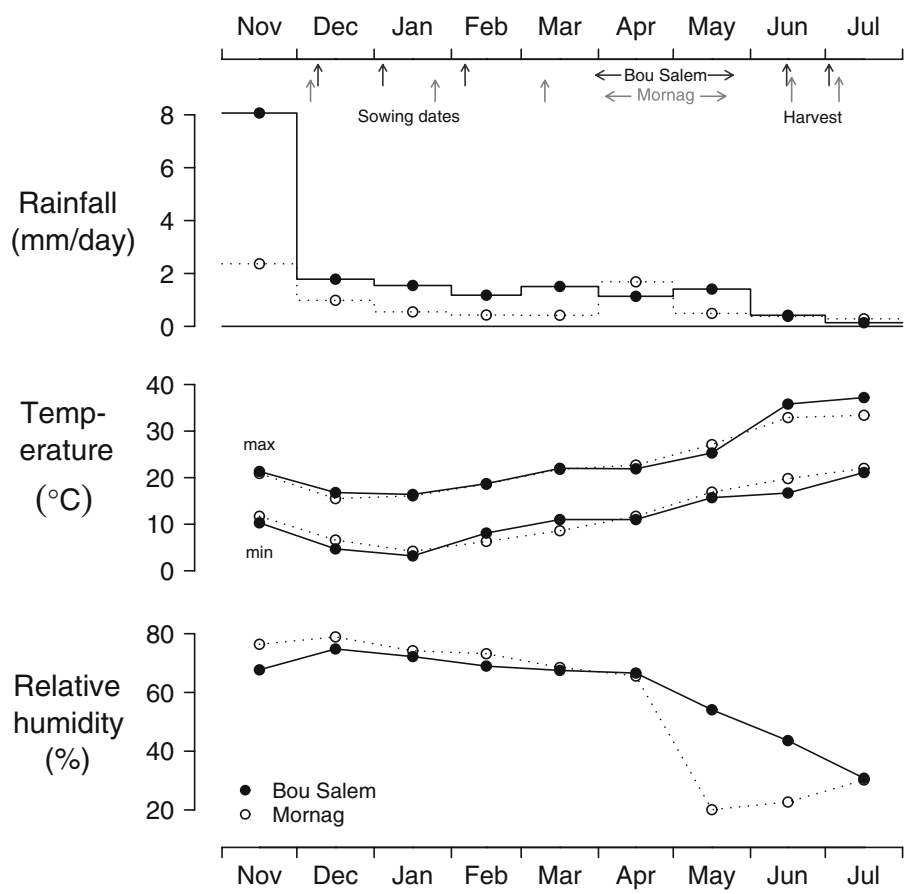

Fig. 1 Meteorological data at Bou Salem and Mornag by month during the 2001–2002 growing season: average daily rainfall, maximum and minimum temperature, and relative humidity. The total rainfall is given by the area under each curve. Arrows denote dates of sowing and harvesting

that at Mornag, 220.6 mm. However, nearly half of the rainfall at Bou Salem fell in November, before the first sowing date, but even if this month is disregarded, the rainfall for the remaining months at Bou Salem, 273.3 mm, was still almost twice that of the same period at Mornag, 149.6 mm.

Disease evaluation

Plants selected for disease assessment were the 20 at the centre of the second and third rows (10 from each row) of each of the sub-plots. Disease severity on vegetative parts of the plants was assessed at 9–20 day intervals after detection of the first symptoms, using a 1–9 scale modified from that of Singh et al. (1981) and F. Dusunceli (personal communication), where 1 denotes no disease and 9 denotes a dead plant. The main criterion for determining a disease score was the % of infected leaf area (Table 1) but in ambiguous cases it was sometimes necessary to use the % of broken branches as an additional criterion. Disease severity on reproductive parts of the plant was scored at harvest as pods showing symptoms of infection and expressed as percentages of the total number of pods. The percentages of infected pods that were empty and healthy pods that were empty at harvest were also recorded.

Yield components

Plants selected for yield components were also the 20 at the centre of the second and third rows of each sub-plot (i.e., the same plants as those used for disease evaluation) effectively from an area of 1 m^2. All samples of 20 plants were evaluated for number of pods per plant, number of seeds per plant, number of seeds per 100 pods (i.e., 100 times the total number of seeds divided by the total number of pods) and 100 seed weight (obtained by weighing a random sample of 100 seeds). The average weight of seeds per plant was calculated by multiplying the mean seed weight (100 seed weight/100) by the number of seeds per plant. This last measure is the yield in g per plant; multiplying it by 200 formally gives the yield in kg ha^{-1} for plants sown under these conditions.

Table 1 The 1–9 scale for scoring the severity of Ascochyta blight on vegetative organs

Disease score	% of infected leaf area	% of broken branches
1	0	0
2	>0–5	0
3	>5–10	0
4	>10–25	>0–10
5	>25–40	>10–20
6	>40–60	>20–30
7	>60–75	>30–50
8	>75–90	>50–75
9	>90–100	>75–100

Statistical analysis

The data were checked for consistency and plotted by location, sowing date and cultivar for each outcome variable. By using multiple panels with common scales, the graphs show the different sources of variation and enable many comparisons to be made between factor combinations and variables. Most of these graphs are omitted here for reasons of space (but are available as online supporting material) and the main patterns can be seen in the tables of mean outcomes presented in the results section. A split-plot analysis of variance (ANOVA) was applied using the factors: location, blocks (nested within location), sowing dates (nested within location) and cultivar, where the experimental units were taken to be the sets of 20 plants harvested in each sub-plot. This enabled reliable estimates of the error standard deviation to be obtained (from the variation between main and sub-plots at each factor combination) as well as assessment of the statistical significance of any differences between mean outcomes at different factor levels.

Given the design of the experiment, it is appropriate to use plots as experimental units, rather than individual plants. Furthermore, the plot averages can reasonably be deemed to be normally distributed when factor levels are kept fixed. For the outcome variables that are percentages P (percentages of infected and empty pods) the variance stabilising transformation $y = 100 \arcsin \sqrt{P/100}$ was also used, but this made practically no difference to the ANOVA, so the results for the un-transformed percentages are reported. Formally, the disease score is an ordinal, rather than

quantitative, variable. However, inspection of the frequency distributions of scores for each sub-plot and factor level (i.e., the contingency table) showed that (a) the distributions are homogeneous between the three sub-plots at each factor level and (b) that the mean disease score is both a sensible and useful summary measure (Table ESM–1). We therefore report the ANOVA of the mean disease score also.

Because the actual sowing dates differed at each location, and the climates also differed, the factor sowing date was treated as being nested within locations. Standard diagnostic plots were made to confirm the appropriateness of the analysis.

Results

Disease severity

Disease was practically absent at both Bou Salem and Mornag in plants sown on the third date, but was prevalent to different degrees in plants sown earlier. Figure 2 shows the progress of vegetative disease over time for the first two sowing dates. At Bou Salem it started 50–60 days after sowing for both the first and second sowings, but progressed faster and to a higher level in the latter case. At Mornag, it began about 120 days after the first sowing and progressed to a moderate level, while for the second sowing it started sooner but progressed much more slowly and to a low level.

Data plots (Fig. ESM–1) of the four disease measures (disease score on the last day of assessment, percentage of pods infected at harvest, and the percentages of infected and healthy pods that were empty) showed consistently small scatter between the three sub-plots for each cultivar, sowing date and location. Table 2 gives summary ANOVAs for these disease measures for the first two sowing dates. For the first three outcomes (disease score, percentage of pods infected, and percentage of infected pods that were empty) there were large and statistically significant differences between sowing dates at each location, and these differences differed significantly be-

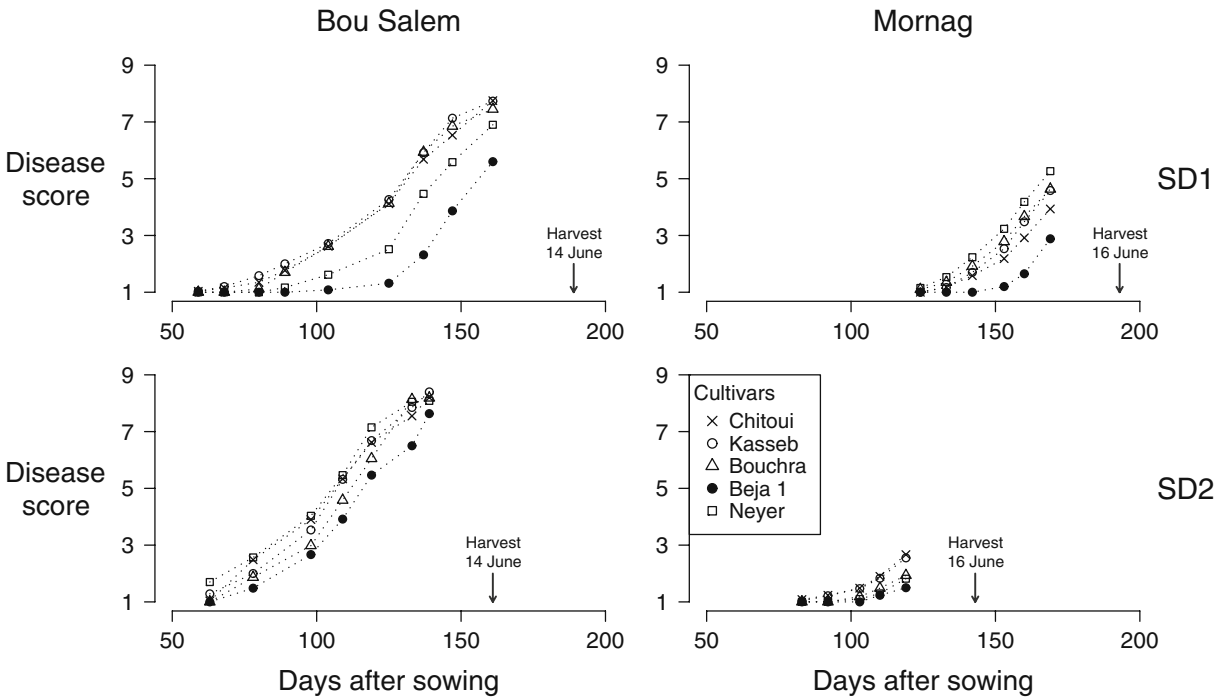

Fig. 2 Progress of Ascochyta blight on five cultivars of chickpea scored on the 1–9 scale (see Table 1) on sowing dates 1 and 2 (SD1 and SD2) at Bou Salem and Mornag. Arrows denote dates of harvesting

Table 2 Summary analyses of variance for infection variables for data from the first two sowing dates: disease score at the last day of assessment, % of pods that were infected at harvest, % of infected pods that were empty, and % of healthy pods that were empty

Source of variation	Degrees of freedom	Square root of mean square[a]			
		Disease score	% pods infected	% pods empty	
				infected	healthy
Locations	1	$17.05^{.00}$	$45.1^{.00}$	4.5	$5.8^{.04}$
Blocks (within locations)	4	0.22	6.5	4.7	2.6
Sowing dates					
Bou Salem	1	$2.75^{.00}$	$46.3^{.00}$	0.2	1.6
Mornag	1	$5.93^{.00}$	$57.3^{.00}$	$21.1^{.02}$	1.5
Main plot error	4	0.30	3.5	4.4	2.0
Cultivars	4	$1.94^{.00}$	$8.6^{.00}$	$11.9^{.00}$	$5.8^{.00}$
Cultivars × locations	4	$0.47^{.00}$	$9.8^{.00}$	$14.4^{.00}$	$4.9^{.00}$
Sowing dates × cultivars					
Bou Salem	4	$0.77^{.00}$	$10.3^{.00}$	$9.9^{.00}$	1.9
Mornag	4	$1.11^{.00}$	2.8	$14.1^{.00}$	$3.7^{.01}$
Sub-plot error	40	0.19	3.8	3.6	1.8

[a]The entries are the square roots of the usual mean squares so they are on the original scales of measurement (i.e., they are standard deviations rather than variances). Conventional *P*-values for the F-statistics were calculated using the main plot or sub-plot error as appropriate; those < 0.10 are shown as superscripts, where .00 denotes a *P*-value < 0.005

tween cultivars (shown as sowing date × cultivar interaction). There was no evidence, though, that sowing date affected the percentage of healthy pods that were empty. There were also statistically significant differences between cultivars (for all disease outcomes) and these were different

Table 3 Mean values for vegetative disease scores, % of pods that were infected, % of infected pods that were empty and % of healthy pods that were empty, for each location, sowing date and cultivar

Sow date	Cultivar	Bou Salem				Mornag			
		Disease score	% pods infected	% pods empty		Disease score	% pods infected	% pods empty	
				infected	healthy			infected	healthy
1	Chitoui	7.7	44	41	2	3.9	57	46	3
	Kasseb	7.7	56	37	6	4.6	59	28	8
	Bouchra	7.5	42	38	2	4.6	**52**	45	5
	Beja 1	**5.6**	57	42	1	**2.9**	53	29	2
	Neyer	6.9	**40**	48	3	5.2	54	32	6
2	Chitoui	8.2	**59**	55	2	2.7	37	42	4
	Kasseb	8.4	67	38	8	2.6	34	54	2
	Bouchra	8.1	62	34	3	1.9	34	48	4
	Beja 1	**7.6**	66	36	3	**1.5**	**31**	38	3
	Neyer	8.0	70	44	1	1.8	34	38	9
Standard error[a]		0.12	2.2	2.1	1.0	0.12	2.2	2.1	1.0
3	Chitoui	1.2	1		4	1.0	0		7
	Kasseb	1.3	1		2	1.0	1		4
	Bouchra	1.4	1		2	1.0	0		3
	Beja 1	1.3	3		1	1.0	0		6
	Neyer	1.4	1		3	1.0	1		6

Lowest figures for disease scores and % of pods infected are in bold

[a]Calculated as $s/\sqrt{3}$ where s is the pooled error standard deviation from main and sub-plots, estimated with 44 degrees of freedom (Table 2)

at Bou Salem and Mornag (location × cultivar interaction).

Table 3 presents mean values for the disease measures along with their standard errors for the first two sowings. Each mean in the same column has the same standard error, calculated as $s/\sqrt{3}$ where s was obtained (with 44 degrees of freedom) by pooling the main and sub-plot error standard deviations in Table 2 as these were similar in size. A 95% confidence interval for any mean of interest may be calculated by adding and subtracting 2 standard errors to the estimate. For example, for the cv. Beja 1 at Bou Salem on sowing date 2, the 95% confidence interval for the mean percentage of infected pods is $66 \pm 2 \times 2.2 = (61.6, 70.4)$.

In Table 3, useful comparisons can be made between cultivars at each sowing date and between sowing dates for each cultivar. The local cultivar Beja 1 stands out as having the lowest vegetative disease score under all conditions, but is not generally lower than the others with respect to the percentage of pods that were infected at harvest. Both the disease score and the percentage of infected pods increased at Bou Salem for the second sowing but decreased at Mornag, for all cultivars. The disease also affected the percentage of empty pods, which is much higher for infected pods than for healthy ones; the former varying between 37% and 55% on average, while the latter varied between 1% and 8%.

For comparison, Table 3 also gives means for the third sowing date, except for the percentage of infected pods that were empty, because there were very few infected pods. Here the percentages of healthy pods that were empty are comparable with those for the earlier sowing dates. Note that a disease score of 1 represents no vegetative disease.

Yield components

Data plots of the five yield components (Figs. ESM–1 and ESM–3) also showed consistently small scatter between the three sub-plots for each cultivar, sowing date and location. Table 4 gives summary ANOVAs for the five yield components. In each case, the main plot error standard deviation is only slightly larger, and comparable with the sub-plot error standard deviation. Also the variation between blocks within locations is not significantly larger than these, which attests to the quality of the data and experimental design.

All component measures show similar patterns of variation between locations, sowing dates and cultivars, so we focus mainly on the yield (weight of seed) per plant. Here there is large (and significant) variation between sowing dates at each

Table 4 Summary analyses of variance for yield variables (all data): number of pods per plant, number of seeds per plant, number of seeds per 100 pods, 100 seed weight, and yield (weight of seeds) per plant

Source of variation	Degrees of freedom	Square root of mean square[a]				
		Pods/ plant	Seeds/ plant	Seeds/ 100 pods	100 seed weight (g)	Yield/ plant (g)
Locations	1	$8.6^{.00}$	$7.2^{.00}$	4.4	$4.8^{.06}$	0.94
Blocks (within locations)	4	1.6	2.4	4.8	2.0	1.07
Sowing dates						
Bou Salem	2	$3.4^{.02}$	$12.8^{.00}$	$54.5^{.00}$	$16.5^{.00}$	$7.50^{.00}$
Mornag	2	0.4	$11.3^{.00}$	$36.7^{.00}$	$22.8^{.00}$	$9.27^{.00}$
Main plot error	8	1.3	1.5	2.4	2.2	0.82
Cultivars	4	$8.4^{.00}$	$9.2^{.00}$	$9.8^{.00}$	$9.6^{.00}$	$4.87^{.00}$
Cultivars × locations	4	1.4	$4.2^{.00}$	$10.4^{.00}$	$5.7^{.00}$	$2.23^{.00}$
Sowing dates × cultivars						
Bou Salem	8	$2.2^{.00}$	$2.2^{.01}$	$5.7^{.00}$	$3.9^{.00}$	0.62
Mornag	8	$1.5^{.04}$	$2.2^{.01}$	$5.2^{.00}$	$6.9^{.00}$	$2.52^{.00}$
Sub-plot error	48	1.0	1.3	2.3	1.7	0.62

[a] As in Table 2, the entries are the square roots of the usual mean squares, with P-values < 0.10 shown as superscripts, where .00 denotes a P-value < 0.005

location. At Mornag, the sowing date × cultivar interaction is also large, showing that the differences in yield between sowing dates differ between cultivars. This is not the case at Bou Salem, where a similar cultivar pattern was seen for each sowing date. However, for the other yield components, the sowing date × cultivar interaction is significant at both Mornag and Bou Salem. Finally, there are statistically significant differences in yield between cultivars and these differences also differ between locations.

Table 5 presents estimated mean values for the yield measures. Each mean in the same column has the same standard error, estimated (with 56 degrees of freedom) by pooling the main plot and sub-plot error standard deviations, as these are similar in size. A 95% confidence interval for any mean of interest may be calculated by adding and subtracting 2 standard errors to the estimate; and a 95% confidence interval for a difference in two means is obtained by adding and subtracting $2\sqrt{2} = 2.83$ standard errors to the estimated difference. For example, comparing the yield per plant for Beja 1 with that for Chitoui at Mornag for sowing date 3, the 95% confidence interval is $13.0 - 8.7 \pm 2.83 \times 0.37 = (3.25, 5.35)$g. Multiplying by 200, this translates to (650, 1070) kg ha^{-1}. Similarly comparing Beja 1 at Mornag for the first and third sowing dates gives $13.0 - 7.0 \pm 2.83 \times 0.37 = (5.0, 7.0)$ g, corresponding to (1000, 1400) kg ha^{-1}. These represent substantial differences in yield.

In Table 5 cultivars may be compared both within and between sowing dates for each outcome, and sowing dates may be compared for each cultivar. Many detailed comparisons may be seen; we comment on a few key ones here.

At Bou Salem, yields (weights of seed per plant) were moderately high for the first sowing (when substantial disease was present), somewhat lower for the second sowing (when disease was even more severe) and highest for the third sowing (when disease was practically absent). This pattern is repeated for each cultivar. The cultivar Chitoui produced both the lowest number of seeds per plant and the lowest 100 seed weight, and consequently the lowest average yield at each sowing date.

Table 5 Mean values and standard errors of pods per plant, seeds per plant, seeds per 100 pods, 100 seed weight, and yield (weight of seed per plant) for each location, sowing date and cultivar

Sow date	Cultivar	Bou Salem					Mornag				
		Pods/ plant	Seeds/ plant	Seeds/ 100 pods	100 seed wt (g)	Yield/ plant (g)	Pods/ plant	Seeds/ plant	Seeds/ 100 pods	100 seed wt (g)	Yield/ plant (g)
1	Chitoui	25.9	23.4	90	22.8	5.3	27.4	21.0	76	19.9	4.2
	Kasseb	27.9	26.0	**93**	31.5	8.2	29.4	25.3	86	21.6	5.5
	Bouchra	28.9	**26.8**	**93**	30.5	8.2	29.6	23.8	81	19.1	4.6
	Beja 1	**30.4**	24.8	82	**35.5**	**8.8**	**32.6**	**29.1**	**89**	**24.0**	**7.0**
	Neyer	28.6	24.8	86	30.9	7.7	32.4	28.2	87	21.8	6.1
2	Chitoui	25.1	18.9	75	17.8	3.4	27.1	23.6	87	26.6	6.3
	Kasseb	28.9	25.0	**86**	24.8	6.2	29.4	25.4	86	25.6	6.5
	Bouchra	29.7	25.1	84	**27.1**	**6.8**	30.7	26.6	87	26.6	7.1
	Beja 1	**32.6**	**26.5**	81	24.2	6.4	**32.5**	**29.8**	**92**	**30.7**	9.2
	Neyer	31.6	23.4	74	25.3	5.9	32.2	29.0	90	35.2	**10.2**
3	Chitoui	25.6	26.3	103	29.8	7.8	27.2	27.2	100	31.7	8.7
	Kasseb	27.0	30.9	**114**	32.3	9.9	30.8	31.5	102	28.0	8.8
	Bouchra	**30.6**	**33.3**	109	32.2	**10.7**	31.1	32.5	**105**	37.9	12.3
	Beja 1	28.4	30.7	108	31.7	9.7	**33.2**	**33.7**	102	**38.7**	**13.0**
	Neyer	27.6	29.0	105	**33.8**	9.8	30.2	30.6	101	27.7	8.5
Standard error[a]		0.62	0.79	1.3	1.0	0.37	0.62	0.79	1.3	1.0	0.37

Highest mean values are in bold

[a]Calculated as $s/\sqrt{3}$ where s is the pooled error standard deviation from main and sub-plots, estimated with 56 degrees of freedom (Table 4)

At Mornag, where disease decreased with sowing date, yield per plant increased with sowing date for four of the cultivars. The exception was Neyer, which had an unusually high yield for the second sowing; it produced good numbers of seeds, and heavier ones, compared to the other cultivars (both seeds per plant and 100 seed weight being relatively high). For the third sowing date, Beja 1 and Bouchra produced exceptionally high yields, with both more and heavier seeds compared with the other cultivars. Chitoui had the lowest numbers of seed per plant, though not the lowest 100 seed weight, and was the lowest yielding cultivar for the first two sowings, when disease was present.

No one cultivar stands out as being the highest yielding under all conditions, but Beja 1 produced the highest yields for the first sowing date at both locations and came a close second at Bou Salem for the second sowing, when disease levels were highest. Beja 1 also performed relatively well when disease was low or absent, including having the highest yield at Mornag for the third sowing date.

It is also worth noting that, for the first sowing date, the average yields at Bou Salem were higher than at Mornag, even though disease scores were also higher (although the % pods infected at harvest were lower at Bou Salem). This holds for all cultivars.

Finally, we note that all cultivars averaged more than one seed per pod in the absence of disease (sowing date 3) but rather less than this in the presence of disease (sowing dates 1 and 2), no doubt reflecting the higher proportions of empty pods amongst diseased plants.

Relationship between disease and yield

Figure 3 shows yield per plant plotted against vegetative disease score (at the last day of assessment) and against % pods infected (at harvest) for each location and the first two sowing dates (SD1 and SD2), where disease was present. Looking at the cultivar Beja 1, for example, and comparing SD2 with SD1: at Bou Salem, the % pods infected are higher and yields lower, while at Mornag the % pods infected are lower and yields higher. Furthermore for SD1, the % pods infected are lower and yields higher at Bou Salem compared with Mornag; while for SD2, the % pods infected are higher and yields lower. The same holds for each other cultivar (i.e., a higher yield always being associated with a lower % pods infected) although the quantitative relationship sometimes differs between cultivars. For example, for SD1, Beja 1 has

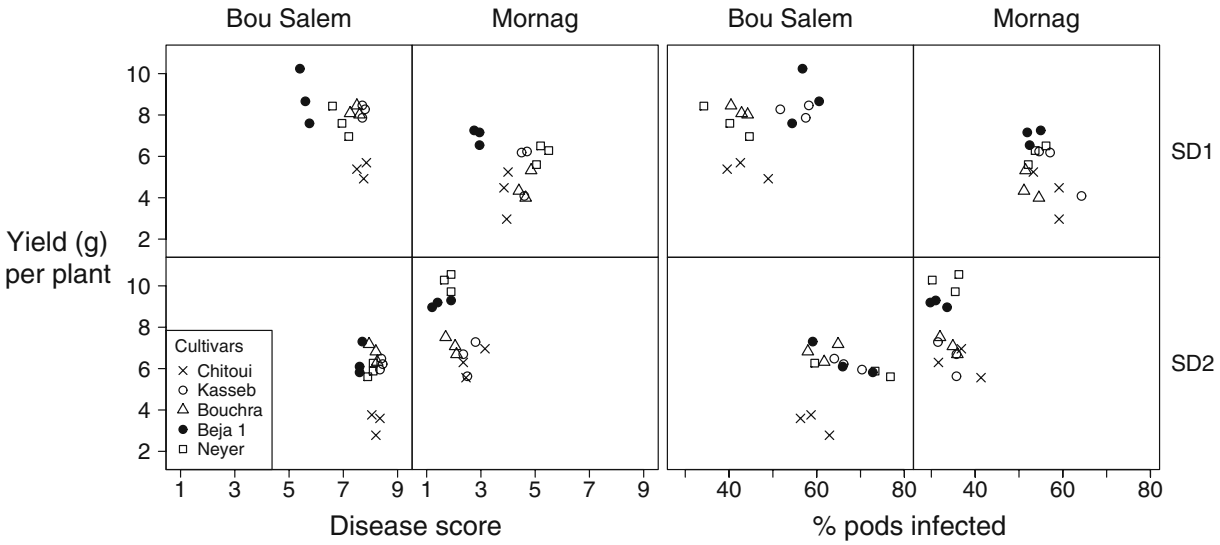

Fig. 3 Yield per plant (g) versus disease severity score at last date of scoring and % pods infected at harvest for each location and cultivar for sowing dates 1 and 2 (SD1 and SD2). Each point is from 20 plants (see "Materials and methods")

higher yields and % pods infected compared with Neyer, but for SD2 these two cultivars have similar yields and % pods infected. Other differences in the relation (and some similarities) can also be seen in Fig. 3.

The plots of yield against disease score also show a negative association for each cultivar and location. However, comparing Bou Salem and Mornag for SD1 shows an exception, where both the disease scores and yields were higher at Bou Salem. This may be partly because the disease scores were last assessed several days before the plants were harvested (Fig. 2) so that comparatively more vegetative disease may subsequently have appeared at Mornag. Note that the relation between yield and % pods infected at harvest does show the negative association here. Nevertheless, Fig. 3 suggests that the relationship between yield and disease is not straightforward and may depend on factors that differ between locations as well as on the cultivar used.

It has been suggested that linear regression parameters could be used to describe the relationship between yield and disease score. However, this would not be sensible, partly because they would be mainly reflecting differences between cultivars rather than an intrinsic association between disease and yield, and partly because disease scores are not measured on a linear scale—which is especially relevant when they are close to 1 or 9, as they are for SD2.

Discussion

Dusunceli et al. (2007a) found that sowing date profoundly affected the severity of Ascochyta blight in Turkey and, as demonstrated in this paper, this is also true in Tunisia. Here disease at both Bou Salem and Mornag was present in plants from the first two sowing dates but essentially absent for the third sowing. Moisture may have been an important factor as the disease was more severe at Bou Salem than at Mornag where the climate was drier.

The lower yields when Ascochyta blight was severe suggests that the disease may be at least partly responsible. Disease severity of vegetative organs was greatest at Bou Salem SD2 with an average score over the five cultivars of 8.1 and 64.8% pod infection. The overall average yield of these plants was 5.74 g/plant. However, the figure for yield/plant was little different from that of Mornag SD1, 5.48, where average disease severity was only 4.28 and pod infection 55%. If the low yield was really caused principally by Ascochyta blight, then it may be that timing of infection is important, the plants perhaps being at a particularly vulnerable stage at Mornag SD1 when comparatively low disease severity had an apparently disproportionate effect on yield. The lower severity level of disease of Bou Salem plants at SD1 compared with SD2 is less easy to explain.

In this study, the individual cultivars have been compared under five different levels of disease, effectively covering the whole range from 1 to 9. Beja 1 was the most successful overall in terms of having the lowest disease scores for vegetative parts of the plant when conditions conducive to Ascochyta blight were prevalent and was one of the highest yielders under these conditions. It also out-yielded the other cultivars at Mornag SD3, when the disease was essentially absent, with 13.0 g seed/plant but did not do so well at Bou Salem with only 9.7 g seed/plant whereas Bouchra had 10.7 g seed/plant at this location (Table 5). Cultivar Chitoui would seem to be best avoided as its yields were the lowest whether or not the disease was present.

In order to determine if *A. rabiei* was responsible for lower yields, a crucial test would be to set up further plots in which the disease was controlled by a fungicide, allowing for any iatrogenic effects (such as an adverse effect of fungicide on yield). Also it would be important to repeat the experiment in successive years in order to determine if there is a causal relationship between weather conditions and disease severity. Coakley (1988) has suggested that a minimum of 8–12 years is required to define climatic factors important in determining disease occurrence.

On the basis of the results reported in this paper it would seem that the latest planting dates at both locations were the most appropriate ones for obtaining the highest yields. These results contrast with those of Dusunceli et al. (2007a) where yields were severely depressed at the later planting dates. Perhaps this difference may be

attributable to drought stress in Turkey and a more benign climate in Tunisia. Dusunceli et al. (2007a) reported yields that varied from 570 to >2,000 kg ha^{-1} which are similar to those of the present report which, when scaled up from g/plant, varied from 840 to 2,600 kg ha^{-1}.

On a more general level, the normal agronomic practices of only using seed that is not infected by the fungus, avoiding areas in which infected chickpea debris from a previous year is present on the soil surface and interspersing chickpea fields with other crops in order to limit inoculum would help to reduce the risk of severe outbreaks of Ascochyta blight on chickpea.

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