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Influence of planting date, intercropping and plant growth promoting rhizobacteria on cumin (*Cuminum cyminum* L.) with particular respect to disease infestation in Iran

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ABSTRACT

This study was performed to evaluate the effect of different planting dates, planting pattern and plant growth promoting rhizobacteria (PGPR) on yield, growth and also disease development in cumin (*Cuminum cyminum* L.) when intercropped with fenugreek (*Trigonella foenum-graecum* L.). For this purpose, a field experiment was conducted in a split-plot factorial arrangement based on randomized complete block design with three replications in Ferdowsi University of Mashhad, Iran in 2012 and repeated in 2013. The experimental treatments were planting dates (5 November, 5 December and 5 March) assigned to main plots, planting patterns (sole cropping and intercropping of cumin and fenugreek) and PGPR (control, *Pseudomonas putida* and *Azotobacter chroococcum*) that were randomized in subplot. Results showed that fall planting dates and intercropping system had positive effects on cumin disease control, whereas application of PGPR had no significant effect in both years. Fall planting dates produced more seed yield in both crops than spring planting. The benefit of *Pseudomonas* was demonstrated on seed yield of cumin and fenugreek. The values of land equivalent ratio (LER) for all treatments of planting dates and PGPR were more than one. This issue indicated that the intercropping system had positive effect on diseases control because of the physical barrier established by the fenugreek and subsequently on seed yield for 2012 and 2013 growing seasons. In essence, modifying planting date and using intercropping systems contribute to the reduction of disease infestation of cumin without using chemicals.

1. Introduction

Medicinal plants play major roles in human health services worldwide. Many people in both developing and developed countries are turning to herbal medicine (Wondimu et al., 2007). Iran has a long medical tradition and traditional learning of plant remedies (Ghorbani, 2005). Besides serving medical and cultural functions, medicinal plants have also an important economic role across the country. The planting area of medicinal plants is about 166,527 ha which contains nearly 1% of total planting area in Iran (Koocheki et al., 2004).

Fenugreek (*Trigonella foenum-graecum* L.) is widely cultivated in the warm temperate and tropical areas of the Mediterranean in Europe and Northern Africa, Indian subcontinent, in West and South Asia, in North and South America, and in Australia (Acharya et al., 2006; Montgomery, 2009) for edible and medicinal values of

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its seeds (Yoshikawa et al., 1997) and also animal feed. The medicinal uses of fenugreek are various and include wound-healing, bust enhancement, aphrodisiac (Acharya et al., 2008; Tiran, 2003), galactogogue (Tiran, 2003), and expectorant. The crop is commonly cultivated as a spring crop for seed and forage consumption in Iran. Nutrient enrichment of soils by nitrogen fixing symbiotic bacteria present in fenugreek has been known (Singh et al., 2008).

Cumin (*Cuminum cyminum* L.) is an annual plant which commonly cultivated in arid and semiarid regions of Iran, especially in Great Khorasan province (Kafi et al., 2006; Kamkar et al., 2011; Rezvani Moghaddam et al., 2007). India (70%), Syria (7%), Turkey (6%) and Iran (6%) are the main producers of cumin. The crop has a wide range of uses including medicinal, cosmetic and food industry (Kafi et al., 2006). Cumin occupies about 26% of total area devoted to medicinal plants in Iran (Koocheki et al., 2004).

However, cumin is seriously affected by the Fusarium wilt and blight diseases incited by the soil borne pathogen *Fusarium oxysporum* f. sp. *cumini* and *Alternaria burnsii*, respectively (Azza et al., 2004; Kafi et al., 2006; Lodha, 1995). Kafi et al. (2006) reported that in wet years with high spring rainfall, damage due to Fusarium wilt is more than 27%. The diseases usually increase under warm and wet conditions and has been reported as a principle factor limiting the production potential (Lodha, 1995). Infested field may not be replanted with cumin for at least 10 years (Azza et al., 2004). Control of diseases incidence is a crucial factor for cumin production. Limited control the diseases is provided by seed pre-sowing with certain fungicides such as benlate (Azza et al., 2004; Champawat and Pathak, 1991). Soil fumigation with methyle bromide (Larkin and Fravel, 1998) can provide a control measure against the disease but may be limited application value for large scale production systems in the open field. In addition, methyle bromide is considered an ozone-depleting compound and has potential risk on the living environment and human health. Considering the environmental limitations of chemical fungicides, it seems necessary to search for a supplemental control strategy (Wang et al., 1999).

The Fusarium wilt is generally spread by irrigation water (Kafi et al., 2006; Kamkar et al., 2011). Cultivating another crop between the cumin rows can effectively reduce the disease incidence. Therefore, intercropping systems can be considered as an appropriate method for disease management (Gomez-Rodrıguez et al., 2003). Numerous theoretical and experimental studies demonstrated the effectiveness of intercropping in disease management (Bouws and Finckh, 2008). For example, the density of Fusarium wilt (*F. oxysporum* f. sp. *niveum*) was decreased about 91% where that watermelon (*Citrullus lanatus* (Trunb.) was planted with rice (*Oryza sativa*) as intercropping system in comparison with the mono-crop (Ren et al., 2008).

Some of rhizosphere microorganisms fix the atmospheric nitrogen and dissolve the phosphorus and potassium of the soil (Moradi et al., 2011; Sturz and Christie, 2003), control plant stress (Lugtenberg and Kamilova, 2009) and also, could provide defense against pathogen attack (Siddiqui, 2004; Weller, 1988). Plant growth promoting rhizobacteria (PGPR) are able to produce plant growth promoting substances and antibiotics (Haas and Défago, 2005). They are capable of providing substantial protection against diseases (Haas and Défago, 2005; Lugtenberg and Kamilova, 2009; Siddiqui and Mahmood, 1999) and stimulate the growth of plants by helping to control pathogenic organism (Vessey, 2003). Siddiqui (2004) reported that the PGPR mainly *Pseudomonas fluorescens* and *Azotobacter chroococcum* could reduce the nematode population. Many literature illustrated the suppressive effect of *Pseudomonas putida* (De Boer et al., 2003; Duijff et al., 1994; Park et al., 1988; Tari and Anderson, 1988) and *A. chroococcum* (Alkhail, 2004; Bishta et al., 2003; Kumar et al., 2011; Maheshwari et al., 2012) against the Fusarium wilt.

This experiment was conducted to assess the effect of row intercropping, various planting dates and PGPR (*P. putida* and *A. chroococcum*) on yield and yield components of cumin and fenugreek, essential oil quantity of cumin and also examine the feasibility of the treatments for management of diseases that has been commonly reduced the cumin production in Iran.

2. Materials and methods

2.1. Study location

The study was carried out at the experimental field of Ferdowsi University of Mashhad in 2012 and repeated in 2013. The Research Station (36°16′ N, 59°36′ E) is located at about 985 m a.s.l., in the northeast of Iran, having a semiarid climate with hot summers and fairly cool winters. Average temperature and precipitation rate of Research Station at 2 years are shown in Fig. 1. Temperature mean and sum of the precipitation during growth period in various sowing dates are placed in Table 1. The soil of the experimental field at 0–30 cm depth was silty loam with pH 7.9, contains total N (0.078%), total P (13 ppm), and total K (386 ppm) with an EC of 3.36 ds m^{-1}.

2.2. Experimental design

The three-factor experiment was set up in a split-plot factorial arranged in a randomized complete block design with three replications. The experimental treatments were planting date at three levels (5 November, 5 December and 5 March) assigned to main plot, planting pattern at three levels (row intercropping of cumin – fenugreek and sole-cropping of them) and PGPR (plant growth promoting rhizobacteria) at three levels (control, *P. putida* and *A. chroococcum*) that were factorially combined as subplot.

2.3. Inoculation procedure

We choose *P. putida* and *A. chroococcum* as bacterial strains against the cumin pathogens based on scientific reports (Alkhail, 2004; Bishta et al., 2003; De Boer et al., 2003; Duijff et al., 1994; Kumar et al., 2011; Maheshwari et al., 2012; Park et al., 1988; Tari and Anderson, 1988). *A. chroococcum* and *P. putida* (at least 10^7 CFU ml^{-1}) were supplied from Mehr Asia Biotechnology Company (MABCO), Semnan, Iran. Before inoculations of cumin and fenugreek seeds with *Azotobacter* and *Pseudomonas*, seeds were

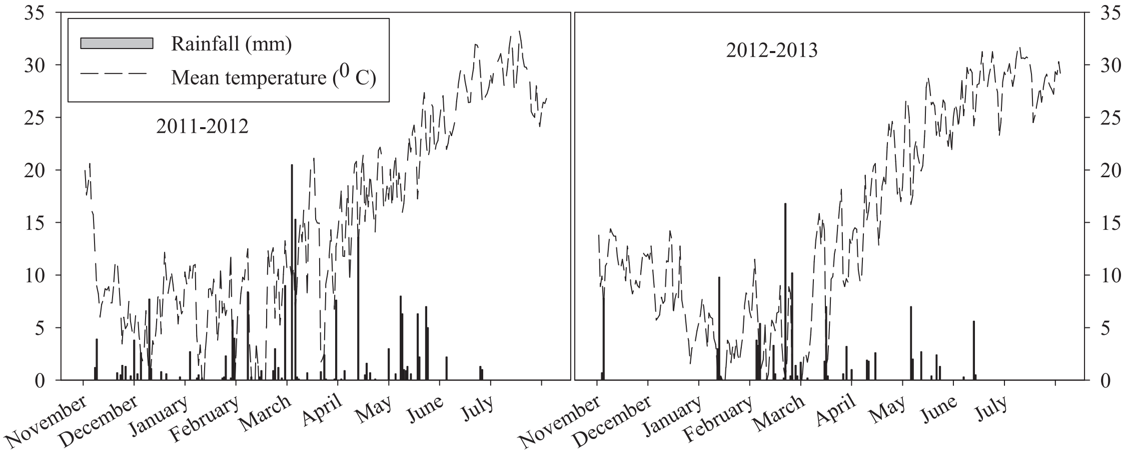

Fig. 1. Trend of precipitation (mm) and average temperature (°C) for two experimental years in Mashhad, Iran.

surface sterilized with acid (H_2SO_4) for 5 min followed by six thorough washings with distilled water (Dadarwal et al., 1987; Sindhu et al., 2002) and afterward were treated with sugar solution. Then *A. chroococcum* and *P. putida* were added to the solution and shaken thoroughly to facilitate uniform coating of seeds with the inocula. The inoculated seeds were kept in shade for about 1 h for drying before sowing so that *Azotobacter* and *Pseudomonas* inocula adhere to the seed properly.

2.4. Field conditions

The seedbed preparation was made based on common practices at the location. Plots size under the trial was 4 m × 3 m so as to get 50 cm inter row spacing in six rows. Cumin and fenugreek seeds were hand sown in mentioned planting dates. The ideal density of the crops was considered as 120 and 40 plant m^{-2} for cumin and fenugreek, respectively. The intercropping included the replacement series. So, three rows of cumin in each plot were alternately replaced with fenugreek. As soon as the seeds were sown, irrigation continued every 10 days. A furrow system of irrigation was laid out in study plots. The thinning operation was postponed until 15 March to avoid cold stress for the crops when planted at 5 November and 5 December (fall planting dates). Therefore, hand thinning was performed at 15 March for first and second planting dates and 17 April for third planting date in both plants. Based on this, cumin and fenugreek densities were recorded as 120 and 40 plants m^{-2} in both years of study. No herbicides and chemical fertilizers were applied during the course of the trials and weeding was done manually when necessary.

2.5. Data collection

2.5.1. Growth and yield

Height and yield components of cumin (number of umbels and seeds per plant) and fenugreek (number of pods per plant and number of seeds per pod) were determined by randomly choosing 20 plants of each species on each plot. All plants in the central four rows of each plot were hand-harvested to determine biological (sum of the seed and chaff with moisture content of 8–10%) and seed yield and harvest index (HI) of cumin and fenugreek based on Eq. (1).

$$HI = \frac{\text{seed yield}}{\text{biological yield}} \times 100 \quad (1)$$

2.5.2. Disease assessment

Based on previous studies Fusarium wilt disease was recognized as main factor to wilt of cumin plants in the region (Kafi et al., 2006; Kamkar et al., 2011; Rezvani Moghaddam et al., 2007; Saeid Nezhad and Rezvani Moghaddam, 2010). After anthesis period, five cumin plants showing symptoms of wilt were collected from each plot and were transferred in ployethylene bags to the laboratory. The fungal pathogens were isolated from root tissues on potato dextrose agar (PDA medium) based on (Gamliel et al., 1996) requirements at 25 °C for 7 days. After the Fusarium development, species identification was done according to the morphological characteristics of their mycelia and spores as reported by Nelson et al. (1983). Disease severity was assessed by counting the number of infected plants in 3 m^2 in each plot.

Table 1
Climatic conditions in various sowing dates during growth period.

Planting date	5 November		5 December		5 March	
Year	2012	2013	2012	2013	2012	2013
Temperature mean (°C)	16.49	15.10	16.66	15.94	22.42	21.02
Sum of the precipitation (mm)	173	103	156	103	69	43

Table 2
Analysis of variance (mean squares) of measured traits of fenugreek for the 2012 and 2013 growing seasons.

S.O.V.	df	Height	Number of pods per plant	Number of seeds per pod	Biological yield	Seed yield	Harvest index
		2012					
Block	2	0.019 ns	3.50 ns	9.05 ns	21,186 ns	3508 ns	0.129 ns
A	2	2092.5**	414.5**	176.1**	656,065**	40,399**	10.24 ns
Error 1	4	120.9	5.33	8.22	63,586	654	6.04
B	1	294.0**	127.6*	73.50**	16,145,301**	977,250**	5.35 ns
C	2	75.62 ns	143.1**	1.16 ns	25,665 ns	1192 ns	0.074 ns
B × C	2	46.88 ns	20.91 ns	12.50 ns	7144 ns	160 ns	5.58 ns
A × C	4	10.82 ns	13.31 ns	3.66 ns	2973 ns	48.78 ns	3.32 ns
A × B	2	13.39 ns	2.46 ns	46.51**	57,510 ns	3592*	0.685 ns
A × B × C	4	23.19 ns	4.05 ns	3.53 ns	15,768 ns	90.93 ns	0.935 ns
Error 2	30	23.33	18.05	7.10	48,531 ns	844	6.81
		2013					
Block	2	23.75 ns	13.41 ns	0.92 ns	33,680 ns	3990 ns	0.02 ns
A	2	1975**	446**	229**	393,586**	48,894**	1.56 ns
Error 1	4	74.19	8.42	11.35	21,604	2642	0.48
B	1	27.51 ns	95.04*	6.83 ns	6,504,121**	814,199**	3.13 ns
C	2	76.81 ns	237**	0.08 ns	519,421*	55,983*	3.16 ns
B × C	2	36.61 ns	1.71 ns	0.19 ns	1380 ns	861 ns	2.14 ns
A × C	4	22.59 ns	18.32 ns	0.68 ns	16,391 ns	2833 ns	7.96 ns
A × B	2	4.50 ns	1.61 ns	0.81 ns	22,676 ns	3774 ns	1.23 ns
A × B × C	4	15.61 ns	0.62 ns	2.09 ns	5751 ns	224 ns	0.83 ns
Error 2	30	54.95	18.47	8.85	27,418	2549	3.49

df, degree of freedom; A, planting date; B, planting pattern; C, PGPR; ns, non-significant.
* Significant at 5% level.
** Significant at 1% level.

2.6. Extraction of cumin essential oil

From each plot, cumin seed were crushed at 50 g by electric grinder and suspended in 750 ml distilled water. Ground mass was subjected to hydro-distillation using Clevenger's apparatus (Clevenger, 1928). After 4 h, the essential oils were collected and dehydrated with sodium sulphate (Na_2SO_4) using the method of Guenther (1961). Then essential oil percentage (weight/weight^{-1}) and yield (kg ha^{-1}) was determined.

2.7. Land equivalent ratio

The advantages of cumin–fenugreek intercropping were estimated using the land equivalent ratio (LER) index (Willey and Osiru, 1972). LER indicates the efficiency of intercropping for using the resources of the environment compared with sole-cropping (Mead and Willey, 1980). When LER is higher than one the intercropping favors growth and yield of the species. In contrast, when it is lower than one there is a disadvantage of intercropping. When LER = 1, there is no advantage to intercropping in comparison with sole (Caballero et al., 1995; Dabbagh Mohammadi Nassab et al., 2011). LER was calculated as:

$$LER = (LER_{cumin} + LER_{fenugreek}), \quad (2)$$

$$LER_{cumin} = \left(\frac{Y_{Ci}}{Y_{Cs}}\right), \quad LER_{fenugreek} = \left(\frac{Y_{Fi}}{Y_{Fs}}\right), \quad (3)$$

where Y_{Cs} and Y_{Fs} are the seed yields of cumin and fenugreek, respectively, as sole crops and Y_{Ci} and Y_{Fi} are the seed yields of cumin and fenugreek, respectively, in intercrops.

2.8. Statistical analysis

Data were subjected to two-way analysis of variance (ANOVA) and the difference between treatment means was separated using least significant difference test (LSD) (SAS Institute, 2003). A significance level of 95% was applied according to Little and Hills (1978).

3. Results and discussion

3.1. Fenugreek

The effect of planting date on all plant parameters was significant except for harvest index (HI) in 2 years study (Table 2). The ANOVA results showed difference between 2 years based on planting pattern and PGPR treatments. Planting pattern had no significant effect on HI in 2012. PGPR had significant effect on number of pods per plant in 2012 whereas the effect of PGPR was significant on number of pods per plant, biological and seed yield of fenugreek in 2013. Fenugreek plant height, number of seeds per pod and HI were not significantly affected by planting pattern in 2013 (Table 2). All interaction effects of applied treatments on all plant parameters in both years, except for effect of planting date × planting pattern treatments on number of pods per plant and seed yield in 2012 were not significant (Table 2).

Significant decline in plant height, number of pods and seeds per plants, biological and seed yield of fenugreek were observed in spring planting compared to fall plantings in the 2 years responses (Table 3). These differential rates of response to planting dates suggest that fall planting had better influence on growth of fenugreek. Intercropping of fenugreek with cumin led to significantly higher plant

Table 3
Effect of planting date, planting pattern and plant growth promoting rhizobacteria (PGPR) on measured traits of fenugreek for the 2012 and 2013 growing seasons.

	Treatments	Height (cm)	Number of pods per plant	Number of seeds per pod	Biological yield (kg ha^{-1})	Seed yield (kg ha^{-1})	Harvest index
		2012					
Planting date	5 November	63.27a	32.05a	17.00a	1944a	455.3a	22.50a
	5 December	61.50a	30.88a	17.16a	1865a	449.1a	24.00a
	5 March	43.77b	23.22b	11.67b	1581b	370.3b	23.11a
Planting pattern	Monoculture	53.85b	30.26a	14.11b	2343a	559.4a	23.51a
	Intercropping	58.51a	27.19b	16.44a	1249b	290.4b	22.88a
PGPR	Control	54.44a	25.67b	15.00a	1753.0a	416.1a	23.28a
	Azotobacter	58.43a	29.28ab	15.50a	1818.4a	426.5a	23.17a
	Pseudomonas	51.67a	31.22a	15.33a	1818.7a	432.2a	23.16a
		2013					
Planting date	5 November	86.01a	34.51a	20.11a	4230a	1472a	34.72a
	5 December	84.41a	33.47a	20.60a	4272a	1459a	34.13a
	5 March	67.12b	25.41b	14.18b	3442b	1181b	34.47a
Planting pattern	Monoculture	78.47a	32.46a	17.94a	5079a	1758a	34.68a
	Intercropping	79.89a	29.80b	18.66a	2884b	982b	34.20a
PGPR	Control	77.61a	27.88b	18.27a	38.93b	1351b	34.93a
	Azotobacter	81.52a	30.45b	18.25a	38.74b	1327b	34.21a
	Pseudomonas	78.40a	35.05a	18.38a	41.77a	1433a	34.19a

Column means with the same letter are not significantly different by LSD test ($p < 0.05$).

height and number of seeds per pod but lower number of pods per plant than sole cropping of fenugreek in 2012, while only number of pods per plant of fenugreek was significantly decreased under intercropping in 2013 (Table 3). In regard to lower density of fenugreek in cumin-fenugreek intercropping than sole cropping of fenugreek, lower biological and seed yield of fenugreek were observed for intercropping system than sole cropping (Table 3). Significant increase in number of pods per plant was obtained by applying *Pseudomonas* compared with *Azotobacter* and control (Table 3). Whereas, phosphate solublizing bacterium such as *Pseudomonas* sp. improved plant growth through production of growth-promoting substance such as indole acetic and cytokinins (Banchio et al., 2008), subsequently, it may be led to increase in number of pods per plant. Although no significant difference among PGPR treatments were observed for plant height, the fenugreek height as affected by *Azotobacter* was higher than *Pseudomonas* and control treatments (Table 3). Moradi et al. (2011) reported that free-living nitrogen-fixing bacteria, e.g. *A. chroococcum* have not only the ability to fix nitrogen but also release phytohormones similar to gibberellic acid and indole acetic acid, which could stimulate plant growth, absorption of nutrients, and photosynthesis. These parameters may be caused to improvement of fenugreek height.

Spring planting significantly reduced seed yield of fenugreek compared with fall plantings and there was no significant difference between fall plantings in both years (Table 3). Fenugreek planting in fall season caused to progressing of fenugreek growth in early of spring season which it clearly resulted in production of more strong and productive plants. Maletić and Jevdjović (2007) noted that earlier planting of fenugreek produced higher seed yield than late planting. Seed yield of fenugreek under all treatments in 2013 was higher than obtained in 2012. Statistical analysis indicated significant differences among PGPR treatments in terms of biological and seed yield in 2013 (Table 3). The significantly higher seed yield was achieved by application of *Pseudomonas* than *Azotobacter* and control treatments in 2013 but that is insignificant in 2012, although a negligible increase in seed yield was also observed using *Pseudomonas* in this year (Table 3). This issue can be due to better establishment of *Pseudomonas* in second year.

Evaluating of interaction of planting date × planting pattern demonstrated that the highest number of pods per plant was obtained where fenugreek was planted in 5 November under sole cropping system, although, no significantly different was observed with 5 December in sole cropping and 5 November in intercropping system (Fig. 2). Seed yield as affected by planting date × planting pattern interaction showed that fall planting dates had significant difference with spring planting date in sole cropping of fenugreek whereas, various planting dates showed no difference under intercropping system (Fig. 2).

3.2. Cumin

Statistical analysis demonstrated significant differences between planting date treatments in terms of all studied traits except HI and essential oil percentage in 2012 and HI in 2013 (Table 4). The planting patterns significantly affected number of seeds per plant, seed and essential oil yields and infected plant percentage in both studied years (Table 4). Significant difference between PGPR treatments for most of traits were observed in 2012 but there was insignificant difference for all traits, except essential oil percentage in 2013 (Table 4). This indicated that PGPR was more effective on cumin in 2012 compared with 2013. No difference among the interactions of planting pattern × PGPR, planting date × PGPR and triple interaction (planting date × planting pattern × PGPR) treatments was

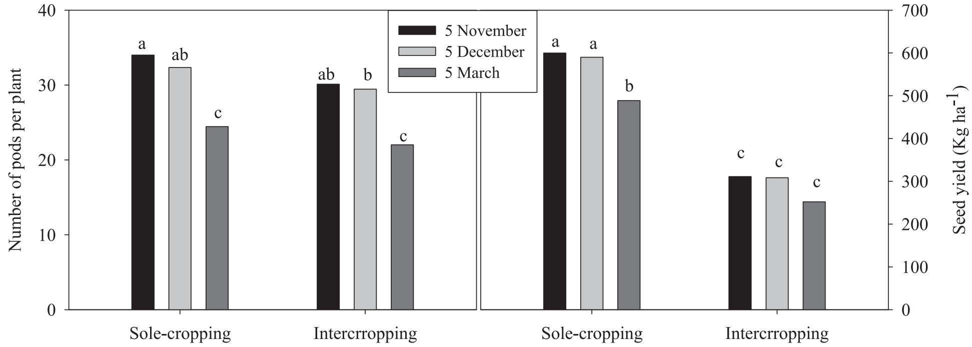

Fig. 2. Effect of planting date and planting pattern interaction on number of pods per plant and seed yield of fenugreek for the 2012 seasons.

detected for traits of cumin. But, there were significant differences between interaction of planting data × planting pattern for number of seeds per plant, seed yield, essential oil yield and infected plant percentage in both years (Table 4).

3.2.1. *Infected plant percentage*

Fall planting dates significantly decreased infected plant percentage compared to spring planting date which indicating that fall plantings were more effective on diseases control (Table 5). The influence of planting date on incidence and severity of diseases has been confirmed in several literatures (Adejumo and Ikotun, 2003; Adipala et al., 1998; Egesi et al., 2007). With respect to the spreading diseases under warm and wet conditions, planting of cumin in spring led to coinciding of tender stage of cumin with warm condition (July–August). Therefore, fall planting can be used to avoid this condition due to harvesting of cumin in early of July, hence it can be concluded that choosing fall planting may be ideal compared to spring planting. Our findings were similar to another report (Kamkar et al., 2011), who demonstrated that the best sowing date of cumin was December. Sowing time management should be planned to avoid coinciding sensitive stage of the plant with warm condition.

Comparison of planting pattern treatments showed that intercropping system could result in acceptable control of diseases in comparison with sole cropping system (Table 5). The results demonstrated that intercropping system caused to lower infected plant percentage than sole cropping of cumin especially in 2013, which almost agreed with efficient control of diseases using intercropping system (Table 5). Fenugreek cultivated between the cumin rows as physical barrier may be led to avoid of transferring and spreading of disease agent from one row of cumin to other rows. Gomez-Rodrıguez et al. (2003) illustrated that the intercropping with marigold (*Tagetes erecta* L.) induced a significant reduction in tomato (*Lycopersicon esculentum*

Table 4
Analysis of variance (mean squares) of measured traits of cumin for the 2012 and 2013 growing seasons.

S.O.V	df	Height	Umbels per plant	Number of seeds per plant	Seed yield	Essential oil yield	Essential oil percentage	Infected plants percentage
		2012						
Block	2	5.55 ns	15.13*	167 ns	432 ns	4.52 ns	0.04 ns	1.85 ns
A	2	587.2**	1675**	2487**	302,249**	349.8**	18.7 ns	4528**
Error 1	4	3.72	0.54	186	31.14	0.19	1.34	1.94
B	1	32.66 ns	29.63 ns	1149*	539,221**	369.4**	1.55 ns	586**
C	2	4.66 ns	71.79**	19.93 ns	5686**	5.91 ns	2.60*	4.07 ns
B × C	2	2.54 ns	0.13 ns	26.56 ns	598 ns	0.78 ns	0.03 ns	3.14 ns
A × C	4	3.16 ns	2.54 ns	17.78 ns	934 ns	0.79 ns	0.18 ns	0.49 ns
A × B	2	6.24 ns	2.78 ns	1109*	27,258*	27.31*	0.07 ns	32.02*
A × B × C	4	6.12 ns	3.29 ns	26.54 ns	132 ns	0.49 ns	0.12 ns	0.27 ns
Error 2	30	11.80	8.67	154	650	2.30	0.55	6.15
		2013						
Block	2	8.00 ns	3.52 ns	61.35 ns	176.2 ns	0.08 ns	0.007 ns	0.72 ns
A	2	845**	569.1**	25,906**	472,644**	537.8**	1.85**	7141**
Error 1	4	5.36	0.77	68.96	26.64	4.54	0.13	2.61
B	1	47.04 ns	374.1**	4446**	761,170**	487.6**	0.17 ns	2948**
C	2	6.72 ns	3.32 ns	51.46 ns	255.9 ns	433 ns	0.25*	9.05 ns
B × C	2	3.84 ns	0.28 ns	0.24 ns	109.56 ns	0.18 ns	0.007 ns	5.72 ns
A × C	4	4.56 ns	2.65 ns	36.57 ns	306.7 ns	0.50 ns	0.016 ns	9.94 ns
A × B	2	8.88 ns	4.29 ns	698**	48,950**	42.00**	0.008 ns	1320**
A × B × C	4	8.88 ns	0.48 ns	6.90 ns	80.91 ns	0.10 ns	0.005 ns	5.38 ns
Error 2	30	16.99	3.41	97.14	110.3	1.78	0.058	24.05

df, degree of freedom; A, planting date; B, planting pattern; C, PGPR; ns, non-significant.
* Significant at 5% level.
** Significant at 1% level

Table 5
Effect of planting date, planting pattern and plant growth promoting rhizobacteria (PGPR) on measured traits of cumin for the 2012 and 2013 growing seasons.

Treatments		Infected plants (%)	Height (cm)	Umbel per plant	Number of seeds per plant	Seed yield (kg ha^{-1})	Essential oil yield (kg ha^{-1})	Essential oil (%)
		2012						
Planting date	5 November	7.72b	35.12a	31.01a	192a	457a	12.88a	2.87a
	5 December	7.67b	31.50a	28.68a	194a	452a	12.80a	2.85a
	5 March	35.16a	23.83b	13.05b	128b	230b	5.20b	2.30a
Planting pattern	Monoculture	20.15a	29.33a	24.81a	167b	480a	12.87a	2.72a
	Intercropping	14.55b	30.89a	23.33a	175a	280b	7.71b	2.62a
PGPR	Control	16.88a	29.67a	21.83a	170a	367b	9.49a	2.64b
	Azotobacter	16.85a	30.66a	23.66a	171a	380b	10.36a	2.57b
	Pseudomonas	16.77a	30.00a	25.72a	173a	398a	10.83a	2.80a
		2013						
Planting date	5 November	7.14b	42.00a	31.38a	218a	553a	15.74a	2.76a
	5 December	9.83b	39.07a	31.52a	216a	555a	15.71a	2.81a
	5 March	42.27a	28.61b	21.71b	151b	274b	6.26b	2.25b
Planting pattern	Monoculture	26.66a	35.20a	25.57b	186b	579a	15.58a	2.61a
	Intercropping	11.88b	37.07a	30.83a	204a	342b	9.57b	2.69a
PGPR	Control	18.50a	35.60a	27.93a	194a	457b	12.38a	2.61b
	Azotobacter	19.44a	36.01a	27.99a	194a	456b	12.21a	2.59b
	Pseudomonas	19.89a	36.80a	28.70a	197a	469a	13.13a	2.78a

Column means with the same letter are not significantly different by LSD test ($p < 0.05$) for each year.

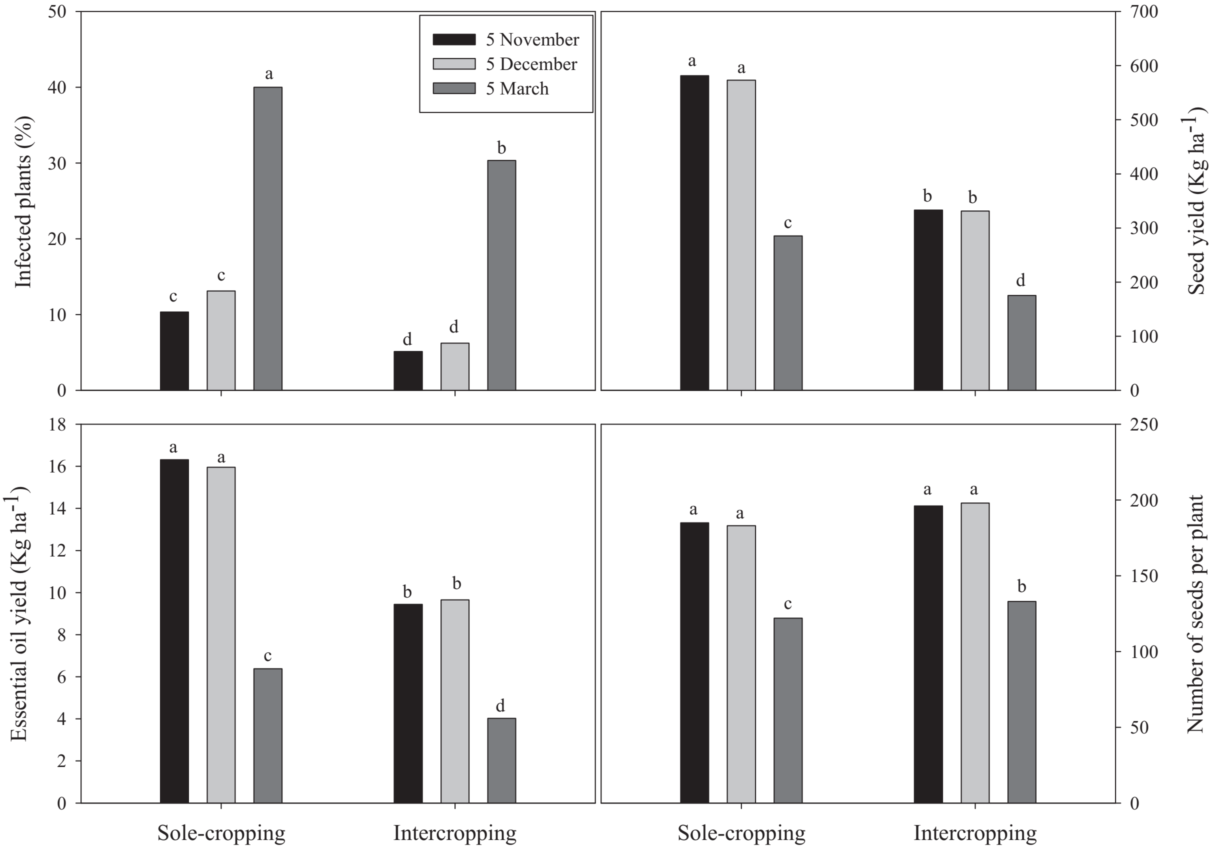

Fig. 3. Effect of planting date and planting pattern interaction on some measured traits of cumin for the 2012 seasons.

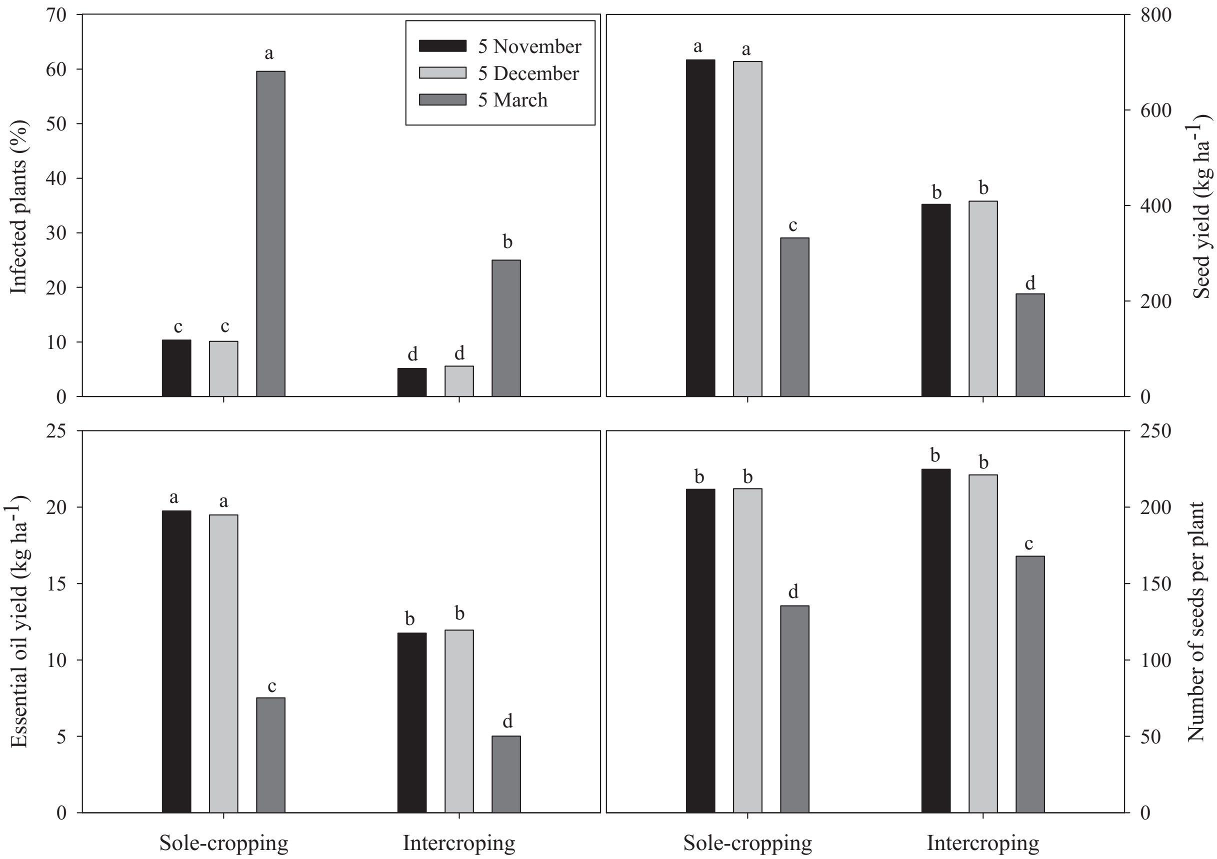

Fig. 4. Effect of planting date and planting pattern interaction on some measured traits of cumin for the 2013 seasons.

Mill) early blight caused by *Alternaria solani*. Michell et al. (1997) intercropped the tomato with cowpea (*Vigna unguiculata* (L.) Walp.) within the same row and observed a significant reduction in bacterial wilt (*Pseudomonas solanacearum* E.F. Smith) compared to tomato cropped alone, because of the physical barrier established by the cowpea roots. Intercropping can improved the pest/disease impacts on crops by means of different mechanisms such as allelopathic effects, altering the microclimatic conditions around the crop canopy, providing a physical barrier against pests spreading (Gomez-Rodrıguez et al., 2003) and increasing population of natural enemies (Michell et al., 1997).

As results, PGPR treatments had no significant effect on diseases control (Table 5). Therefore, modifying planting date and using intercropping systems could be considered as effective management ways to control of diseases without chemical control.

Percentage of infected plants as affected by interaction of planting date × planting pattern ranged 5.11–40% in 2012 and 5.55–59.56% in 2013 (Figs. 3 and 4). As observed, fall planting dates in intercropping system had the lowest infected plants which indicating that these management approaches effectively controlled the disease. The highest infected plants percentage was achieved by spring planting date in sole cropping system (Fig. 3). The results of 2013 illustrated that planting date × planting pattern interaction on infected plants percentage had similar trend with previous year (Fig. 4).

3.2.2. Yield and yield components

Fall planting dates significantly increased yield and yield components of cumin compared to spring planting in 2012 and 2013(Table 5). Intercropping system caused an increase in seed yield components of cumin compared with sole cropping, especially in 2013 (Table 5), Whereas a decrease in cumin seed yield was recorded under intercropping system compared to sole cropping because the cumin density in intercropping was half of sole cropping. As mentioned above, increasing of yield and yield components of cumin in fall planting was related to reducing of diseases severity. Application of *Azotobacter* and *Pseudomonas* showed statistically insignificant effects on yield components, however a negligible increase was observed by the PGPR (Table 5). From experimental results it is observed that, higher cumin seed yield was achieved by application of *Pseudomonas* (Table 5). In regard to insignificant influence of *Pseudomonas* on infected plant percentage, it can be concluded that reason of increase in seed yield may be via enhancement of dissolution of phosphor in the soil and improvement of nutrient status (Rodríguez and Fraga, 1999) in cumin plant.

The results showed that in both planting pattern systems, fall planting dates had higher values than spring

Table 6
Land equivalent ratio of cumin and fenugreek intercropping as affected by planting date and plant growth promoting rhizobacteria (PGPR) for the 2012 and 2013 growing seasons.

2012	5 December			5 November			5 March		
LER	Control	Azotobacter	Pseudomonas	Control	Azotobacter	Pseudomonas	Control	Azotobacter	Pseudomonas
Cumin	0.58	0.57	0.57	0.58	0.58	0.58	0.61	0.62	0.62
Fenugreek	0.51	0.51	0.53	0.51	0.53	0.53	0.50	0.50	0.54
Total	1.09	1.08	1.10	1.09	1.11	1.11	1.11	1.12	1.16
2013									
Cumin	0.58	0.56	0.57	0.57	0.58	0.59	0.67	0.64	0.63
Fenugreek	0.56	0.55	0.57	0.54	0.55	0.59	0.54	0.57	0.56
Total	1.14	1.11	1.14	1.11	1.13	1.18	1.21	1.21	1.19

planting date in terms of number of seeds per plant and seed yield (Figs. 3 and 4). Number of seeds per plant where cumin was intercropped with fenugreek at fall season had no significant difference with sole cropped, although, a numerical increase was observed under intercropping system in both years (Figs. 3 and 4). The highest seed yield was produced in fall planting dates with sole cropping system which statistically showed difference with other treatments for 2 years (Figs. 3 and 4). Generally, the mean of seed yield in 2013 was higher than previous year, because hailstone occurred in 2012 resulted in reduction of seed yield.

3.2.3. Essential oil

The higher essential oil percentage and yield were obtained where cumin was planted at fall season in 2012 (Table 5). The results in 2013 were consistent with findings of 2012. Generally, results indicated that fall planting of cumin could significantly increase essential oil yield, therefore, the essential oil yield as planting at fall season was two times more than spring planting (Table 5). According to mentioned results for seed yield as affected by planting pattern, the essential oil yield was lower in intercropping system than sole cropping system in both years (Table 5). The present observation showed that application of *Pseudomonas* led to increase in essential oil percentage compared with control, whereas *Azotobacter* application had statistically no effect.

As considering, the essential oil yield has been resulted from multiplying of seed yield and essential oil percentage, thus comparison of planting date × planting pattern interaction on essential oil yield showed similar results with seed yield in both years (Figs. 3 and 4). Therefore, the highest and lowest essential oil yield were gained in fall planting dates under sole cropping and spring planting date in intercropping system, respectively (Figs. 3 and 4).

3.3. Land equivalent ratio (LER)

LER was more than 1 in all treatments (Table 6) which indicates the benefit of intercropping system compared to sole cropping. In other word, more land area is required by sole cropping systems to produce the equal amount of seed yield recorded under intercropping systems. Cumin had always greater partial LER than the fenugreek. In 2013, the values of LER were higher than 2012 and also among the various planting dates, the highest LER was recorded when cumin was planted in 5 March. It seems the reason of this was higher incidence of diseases and more effective disease control by intercropping system in 2013 trial.

4. Conclusion

Planting of cumin in fall season produced the greater seed and essential oil yield compared with spring. The superiority of fall planting to enhance cumin seed yield production over all other treatments was attributed to more control of disease. Even though seed yield of cumin was reduced by intercropping system due to lower density of cumin in intercropping system, the advantages of intercropping system for seed yield formation were verified by greater values of LER. Additionally, decreasing of infected plants percentage under this system demonstrated a potential of intercropping to control of disease. PGPR application showed no effect on disease control, although application of *Pseudomonas* caused to higher seed yield of cumin. Higher seed yield of cumin might be associated with increasing of phosphor dissolve in the soil which resulted in improvement of nutrient status in plant. Generally, it could be concluded that using ecological management such as intercropping system and selection of best planting time could be an effective approach to reducing of cumin injury caused by diseases.

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