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Interaction between *Fusarium* head blight and crown rot disease incidence and cultural practices on wheat in the south of Iraq, Basra province

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Abstract

Background: This study was conducted to estimate *Fusarium* head blight (FHB) and crown rot (FCR) disease incidence on wheat and their interaction with cultural methods (cultivar types, planting time, seed rate, crop rotation, and fertilizer practices) that are used in wheat cropping system in the south of Iraq, Basra province.

Results: The results showed that the mean average of FHB and FCR was 27.2% and 31%, respectively. This displays that very nearly one-third of wheat crop planted in those 14 fields were infected by both diseases but not very severely, except in two fields (D and HM), which were devastating, 54% and 71% and 41% and 52% for FHB and FCR, respectively. The highest level of incidence for both diseases was associated with the earlier and latest planting dates 28 Oct. and 10 Dec., while the lowest was with 1, 10, and 23 Nov. A 200 and 120 kg/ha were the highest and lowest seed rates used in this study. The selected wheat fields differed in their pre-crop rotations (legume, corn, sorghum, okra, and continuous cropping system of wheat) in a previous year. The amount of added fertilizers (urea, DAP, and NPK) to the studied fields was in a high variation. The seven wheat cultivars examined in this study showed different levels of susceptibility to both diseases.

Conclusion: The results verified that most of the agricultural practices examined in this study were associated with positive correlation for FHB and FCR in the occurrence of disease incidence. Except the cultivar type and fertilizer application had unclear relationship with the incidence of both diseases.

Keywords: Crop rotation, Cultivar, Disease incidence, Fertilizers, Planting date, Seed rate

Introduction

Wheat (*Triticum aestivum* L.) plays a substantial role in the world. It is one of the most significant sources of human food and the remarkably grown crop all over the world (Chakraborty et al. 2006; Baenziger et al. 2006). For example, wheat is the first cultivated crop and the highest cereal consumed by humans in a number of third world countries, i.e., Iraq (Food and Agriculture Organization of the United Nations (FAO) Database Results 2018). It has been influenced damagingly by many plant pathogens, such as fungi, bacteria, and viruses, that cause severe problems in growing crops (Chakraborty et al. 2006). Specifically, fungal diseases are considered one of the most important restrictive factors in wheat production around the world causing yield losses, bad quality, and decreasing the cost-effectiveness for producers (De Villiers 2009).

In the case of Iraq, FCR caused by *F. graminearum* was observed for the first time in the last few years on irrigated wheat in the southern areas, but only reported in 1998 from the marsh land in Amarah province, south of Iraq by Dewan et al. (1998). Thereafter, Hameed et al. (2012) have detected FCR caused by *F.pseudograminearum* on wheat crop in Shatt Al-Arab, Basra, extremely south of Iraq. Recently, Khudhair et al. (2015) stated that FCR caused by *F. Pseudograminearum* was

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isolated from wheat in Najaf province, middle of Iraq. Matny et al. (2017) studied crown rot of wheat caused by *F. pseudograminearum* and *F. graminearum* in the middle and western areas of Iraq such as Baghdad, Karbala, Dyala, Anbar, Kirkuk, and Babylon. More recently, Lahuf et al (2018) have reported that FCR disease was caused by *F. equiseti* on wheat crops in Karbala province. While for FHB disease in Iraqi wheat cropping system, it has been reported for the first time in the south of Iraq by Minati and Mohammed-Ameen (2019).

A number of *Fusarium* species, the major fungal pathogens, are responsible for highly destructive and economically important cereal diseases, such as *Fusarium* head blight (FHB) and *Fusarium* crown rot (FCR). These diseases are the most common wheat infections that have occurred in most countries around the world (Smiley and Patterson 1996; Koch et al. 2006; Hogg et al. 2010).

Regarding FHB disease, also known as scab, it is mainly caused by *Fusarium graminearum* Schwabe (teleomorph *Gibberella zeae* (Schwabe) Petch) (Wegulo et al. 2011), while FCR disease is mostly caused by *Fusarium pseudograminearum* teleomorph *Gibberella coronicola* (Aoki and O'Donnell 1999; Li et al. 2008). Moreover, globally, the dominant species associated with these two diseases are *Fusarium graminearum*, *Fusarium culmorum*, and *Fusarium pseudograminearum.* However, *Fusarium equiseti*, *Fusarium avenaceum*, *Fusarium poae*, *Fusarium crookwellense*, *Fusarium sporotrichioides*, *Fusarium acuminatum*, and *Fusarium oxysporium* have been also reported as less frequently isolated species causing FHB and FCR diseases on wheat (Braithwaite et al. 1998; Bottalico and Perrone 2002; Monds et al. 2005).

There are several cultural practices may promote *F. graminearum* and *F. pseuograminearum* to cause the plant diseases, such as FHB and FCR, on wheat cultivars: Firstly, the narrow-row spacing could increase the density of wheat seedling and therefore a high amount of soil water will be used per hectare (Cook 1980). This cultural practice probably reduces moisture from the soil and it would be involved with increasing *Fusarium* crown rot disease (Papendick and Cook 1974; Backhouse et al. 2004; Obanor et al. 2013). Secondly, excessive irrigation without improving irrigation canals may lead to increasing incidence of FHB and FCR diseases by raising the humidity levels of the soil (reviewed by Cook (1980)). Thirdly, extensive application of zero tillage has encouraged revival in FCR disease in many countries (including Australia) that produce cereal crops (Fernandez et al. 2011; Dill-Macky and Jones 2000). Spring wheat that is planted under zero tillage may have a higher prevalence of *Fusarium* species than spring wheat planted under conventional tillage (Windels and Wiersma 1992). Moreover, the occurrence of *Fusarium* spp. from sub-crown internodes of spring wheat residues probably increases with reducing the number of other tillage practices (deep ploughing) (Fernandez et al. 2011). On the word of Fernandez et al. (2005), the main reason for this issue is that infected residues of wheat left on the soil surface may not be destroyed and buried effectively by this cultural practice that promotes the potential inoculum of the fungal pathogens for the next wheat growing season. Fourthly, the extreme use of nitrogen fertilizers under low levels of precipitation could affect vegetative growth negatively, in particular, tiller formation of wheat plants (Papendick and Cook 1974). As a result of this case, wheat plants will probably encounter the severity of FHB and FCR disease during heading as well as grain fill. In addition to all the points mentioned above, there is a risk of FHB and FCR infection, when small wheat seeds are grown in the same field that is infected in the previous growing season. Also, growing corn as a rotational crop is another serious risk of *F. graminearum*, because the pathogen can be able to survive for more than one growing season in residues of corn (Root and Crown Diseases of Wheat and Barley in Northern NSW 2005).

This study was conducted to estimate FHB and FCR disease incidence on wheat by calculating infected plant parts (root, crown, stem, and head) at symptom occurrence, evaluate the cultural methods that promote causal agents to cause these diseases, and also to assess the management practices of fungi that were used during the search time.

Material and methods

Disease incidence estimation

In 2017/2018, the estimation of disease incidence for FHB and FCR was executed in the 14 selected wheat fields as provided in (Table 1). The FHB incidence was calculated based on obvious partially or entirely symptomatic heads, while the FCR incidence was measured based on observable symptomatic stems and crowns. For every field, infected plants with visible symptoms were collected within 15–20 days before harvest. In specific, samples were collected between April 10 and May 1. Disease incidence was estimated by obtaining a number of square meters of whole wheat plants (from head to root) picked up randomly from each field. In order to collect representative samples, the collection method was based on noticeable symptoms of the diseased plants, which took from each field randomly according to Yonghao (2013). The formula that was used in calculating the disease incidence is [%DI = TN. of SP/TN of PI × 100] where %DI is the percentage of disease incidence, TN of SP is the total number of symptomatic plants, and TN of PI is the total number of plants inspected.

Selected wheat cultivars and agricultural practices

Seven soft winter wheat cultivars were planted in the surveyed fields, Abu Ghraib 3 (AG3), Ebaa-99 (I.99), Adana

Table 1 Details about cultural practices, cultivars (C), planting time (PT), seeding rate (SR), fertilizer type (FT) and fertilizer level (FL), and crop rotation (CR)

Field location	C	PT	SR Kg./ha	CR	FT and FL kg/ha		
					Urea	Dap*[1]	NPK*[2]
QM	B.	25 Nov.	160	Okra	80	0	0
QRS	Res.22	23 Nov.	120	None	300	200	0
TI1	B.	25 Nov.	170	Wheat	0	0	0
TI2	AG3	22 Nov.	160	Wheat	100	0	0
TI3	AG3	15 Nov.	160	Wheat	100	0	0
TK	R.	1 Nov.	150	Maize	160	120	0
D	AG3	10 Dec.	180	Maize	100	0	0
N	Res.22	15 Nov.	160	Sorghum	160	0	160
MSR	A.99	15 Nov.	160	Wheat	80	0	20
MSP	I.99	10 Nov.	140	Legumes	160	0	80
ML1	AG3	15 Nov.	160	Wheat	160	100	0
ML2	AGRI S.	5 Nov.	160	Okra	0	0	0
HM	A.99	28 Oct.	200	Maize	100	0	60
H	AG3	5 Nov.	160	Wheat	100	0	0

*DAP**[1] diammonium phosphate (most commonly used binary fertilizer), *NPK**[2] nitrogen, phosphorus, and potassium

99 (A.99), Bengal (B.), Research 22 (Res.22), Rasheed (R.), and AGRI-Saaten (AGRI S.). In addition, synchronized with sample collection times, farmers were asked about their cropping systems using a paper questionnaire. The question form was about cultivar type, planting time, seed rate, crop rotation, and fertilizer practices (Table 1).

Statistical analysis

Analysis of variance was executed using the statistical program SPSS® ver. 21.0 software (SPSS 2012) to determine the statistical differences among the selected 14 wheat fields, 7 wheat cultivars, 9 planting times, 7 seed rates, 6 crop rotations, and 3 types and 12 levels of fertilizer applications for the occurrence of disease incidence of FHB and FCR.

Results

According to the formula that was used in calculating the disease incidence of FHB and FCR, Table 2 shows the lowest percentage of FHB disease incidence was 3% which occurred in the TK wheat field, while the highest percentage of FHB disease incidence was 54% found in the D field. In terms of FCR, the lowest percentage of disease incidence was 6% which occurred in the QRS wheat field, while the highest percentage of disease incidence was 71% which was also recorded in the D field. The mean average of FHB and FCR was 27.2% and 31%, respectively. Showing that about one-third of the wheat crop planted in those 14 fields were infected by both diseases but not very severely, except in two fields (D and HM), which were devastating, 54% and 71% and 41% and 52% for FHB and FCR, respectively.

The graphical depiction (Fig. 1) displays the percentages of both FHB and FCR disease incidences on the wheat that occurred in the 14 selected wheat fields. It evidently can be revealed that the highest percent incidence of both diseases was observed in the D and HM wheat fields, while the lowest was verified in the QRS, TK, and MSP wheat fields.

Table 2 The sampling sites and percentages of disease incidence of wheat in the 14 selected fields of the current study

No.	Region and (field name)	Coordinates	D.IN. %	
			FCR	FHB
1	Qurna/Mzeara'a (QM)	34° 38′ 66.5″ N, 73° 27′ 40″ E	38	34
2	Qurna/research station (QRS)	34° 36′ 51.8″ N, 73° 54′ 41″ E	6	11
3	Thagar/Al-Izz1 (TI1)	34° 50′ 40.5″ N, 73° 03′ 68″ E	41	38
4	Thagar/Al-Izz2 (TI2)	34° 54′ 92.1″ N, 72° 84′ 09″ E	36	33
5	Thagar/Al-Izz3 (TI3)	34° 54′ 43.6″ N, 72° 87′ 72″ E	40	32
6	Thagar/Karakor (TK)	34° 51′ 91.1″ N, 73° 28′ 64″ E	7	3
7	Dair (D)	34° 09′ 05.2″ N, 74° 48′ 90″ E	71	54
8	Nashwa (N)	34° 15′ 46.5″ N, 74° 98′ 04″ E	27	32
9	Al-Modienh/Salih River (MSR)	34° 24′ 99.1″ N, 70° 76′ 14″ E	33	28
10	Al-Modienh/Salt Project (MSP)	34° 22′ 68.9″ N, 70° 89′ 05″ E	9	4
11	Talha/Marsh land1 (ML1)	34° 15′ 00.7″ N, 71° 49′ 14″ E	32	29
12	Talha/Marsh land2 (ML2)	34° 16′ 63.8″ N, 71° 55′ 44″ E	17	26
13	Al-Hammar Marsh (HM)	34° 07′ 68.9″ N, 71° 52′ 68″ E	52	41
14	Huwair (H)	34° 36′ 08.9″ N, 71° 58′ 79″ E	25	16
	Mean		31	27.2

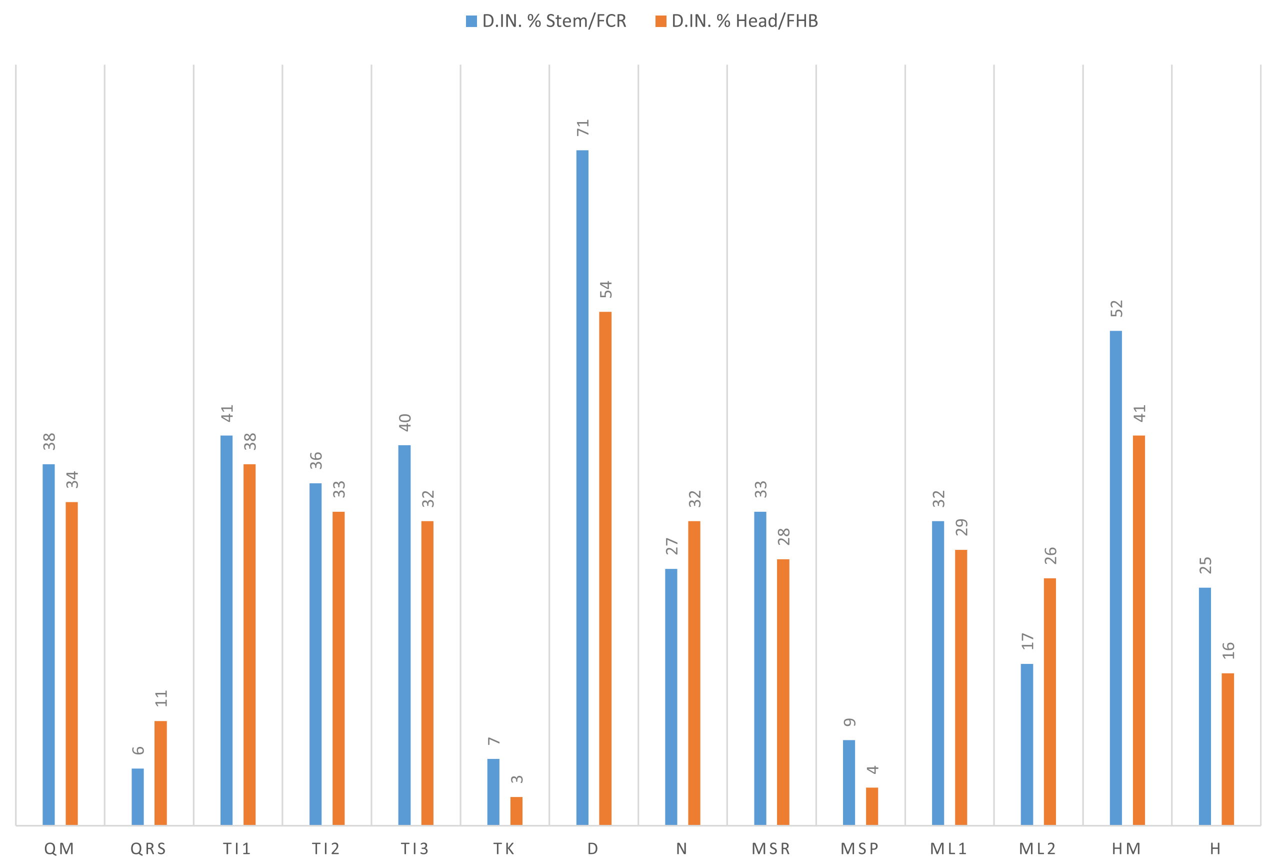

Fig. 1 The percentage of FHB and FCR disease incidence of wheat in the 14 selected fields in the south of Basra province during 2017/2018

Based on the obtained results of the recent study, it obviously can be indicated that there were evident differences in the percent disease incidence among the 14 selected wheat fields. Therefore, interaction between the occurrence of disease incidence and agricultural practices (cultivar types, planting time, seeding rate, fertilizer applications, and crop rotation) should be investigated.

All the six agricultural practices were subjected to the initial major component analysis, but only planting time, seed rate, and crop rotation had significant differences among the selected wheat fields for the occurrence of disease incidence of both FHB and FCR during this study, whereas the cultivar type and fertilizer application had unclear relationship with incidence of both diseases.

Planting time

According to the questionnaire data, the seven wheat cultivars planted in the 14 examined fields were seeded in different times of planting in 2017/2018. Only one field (HM) was planted at the end of October (28 Oct.). Twelve out of the 14 wheat fields were planted in November but with various dates, such as the TK field (1 Nov.); Ml2 and H fields (5 Nov.); MSP field (10 Nov.); TI3, N, MSR and ML1 fields (15 Nov.); TI2 field (22 Nov.); QRS field (23 Nov.); and QM and TI1 (25 Nov.), whereas the D field was the only one that was planted on 10 Dec. The data analysis results of planting dates showed significant ($p < 0.05$) differences of both FCR and FHB among the studied fields.

The highest percentages of disease incidence for FCR and FHB were observed in the HM and D wheat fields, which were planted in earlier and latest planting dates 28 Oct. and 10 Dec., respectively. The lowest disease incidence was detected in the TK, MSP, and QRS wheat fields, which were planted on 1, 10, and 23 Nov., respectively. The moderately infected wheat fields ML2 and H; TI3, N, MSR, and ML1; TI2; and QM were planted on 5, 15, 22' and 25 Nov., respectively (Fig. 2).

Seed rate

In terms of local cultivars such as I.99 and AG3, according to Al-Maeini and Mohsin (2016), the best seed rate of wheat per hectare is 120–140 kg/ha (400 seeds/m^2 when the weight of thousand grains is 30–35 g. The 14 surveyed fields in the recent study were seeded in various rates of seed during the growing season in 2017. The two fields HM and D were cultivated with the highest seed rate (200 and 180 kg/ha, respectively), followed

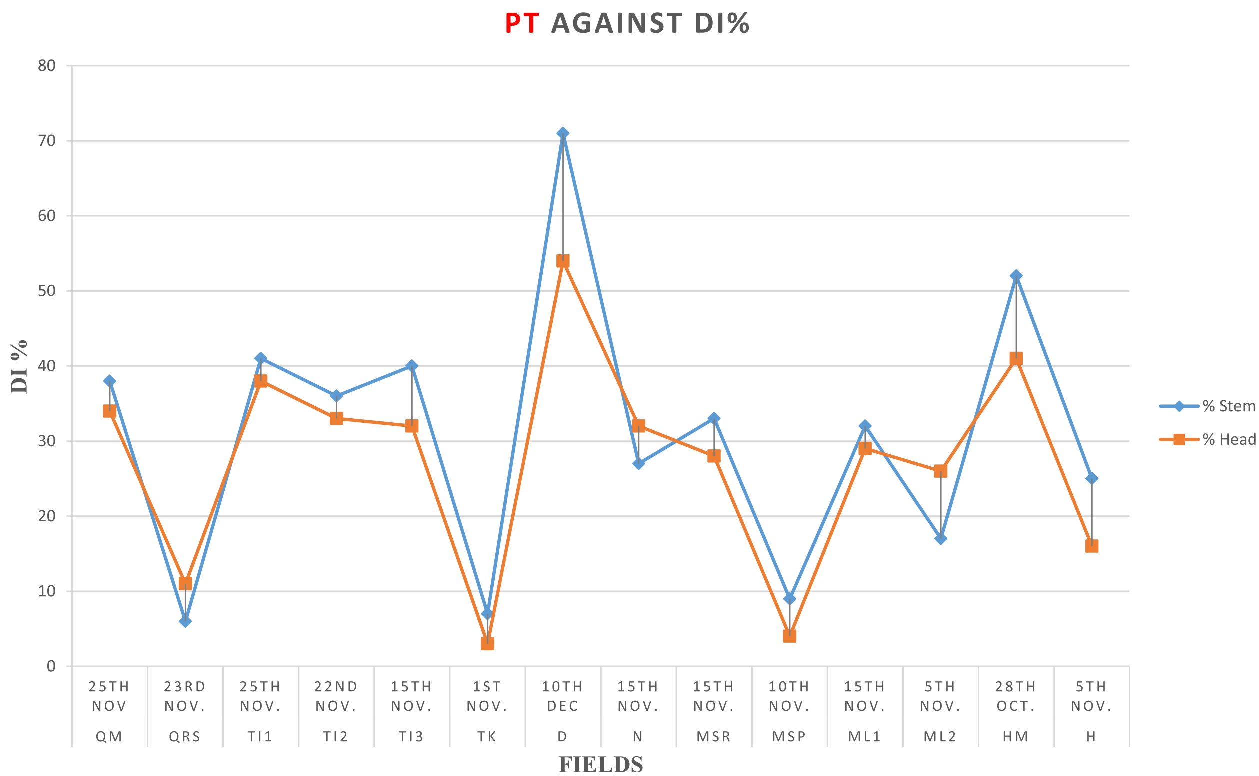

Fig. 2 The effect of planting time on disease incidence in plant head and stem in the 14 selected wheat fields in the south of Iraq/Basra province

by the TI1 field that was cultivated with a seed rate of 170 kg/ha. The lowest seed rates (120, 140, and 150 kg/ha) were seeded in the fields QRS, MSP, and TK, respectively. The remainder of fields (QM, TI2, TI3, N, MSR, ML1, ML2, and H) were all seeded with 160 kg/ha.

The statistical analysis results of the seed rate displayed significant ($p < 0.01$) differences of both FHB and FCR among the studied fields (Fig. 3).

Crop rotation

Based on the questionnaire conducted during sample collection times in this study, the 14 selected wheat fields differed in their pre-crop rotations in the previous year. Six fields (TI1, TI2, TI3, MSR, ML1, and H) used a continuous cropping system of wheat. Two fields (TK and MSP) were planted in legumes in a preceding year. The QM and ML2 fields used okra and the D and HM fields used corn as a pre-crop, whereas only the N field was planted in sorghum and the QRS was left unplanted for many previous years (Fig. 4).

The statistical analysis results of crop rotation showed significant ($p < 0.05$) differences of FCR and FHB among the studied fields. The lowest disease incidence for both diseases FHB and FCR in the recent study was recorded in the TK and MSP fields (used legumes as a pre-crop), as well as the QRS field (as maiden land), while the highest incidence of both diseases was observed in the D and HM fields that were planted with corn in a previous year.

The usual control method, such as crop rotation, is used rarely by wheat growers in Basra province. This is because the majority of wheat fields found in the dried marsh lands, which are located far away from water sources. Therefore, these wheat fields mostly cultivate once a year, only in winter wheat crops. However, some wheat fields are very close to the main rivers (Tigris, Euphrates, and Shatt Al-Arab) and thus cultivate routinely twice a year, in winter wheat crop and different summer crops. In addition to, fungal pathogens are not economically important for wheat crops in previous years due to inappropriate weather conditions.

Fertilizer application (level and type)

Based on the questionnaire data, no one of wheat farmers has made soil analysis to determine the nutrient balance of soil. As a result, the amount of added fertilizers (urea, DAP, and NPK) to the 14 selected wheat fields was in a high variation as shown in Table 1. In general, the application of nitrogen ranged from 0 to 300 kg/ha, DAP fertilization ranged from 0 to 200 kg/ha, and the rate of NPK application was from 0 to 160 kg/ha. The statistical analysis results of fertilizer application were not significant for the occurrence of both FCR and FHB diseases among the studied fields.

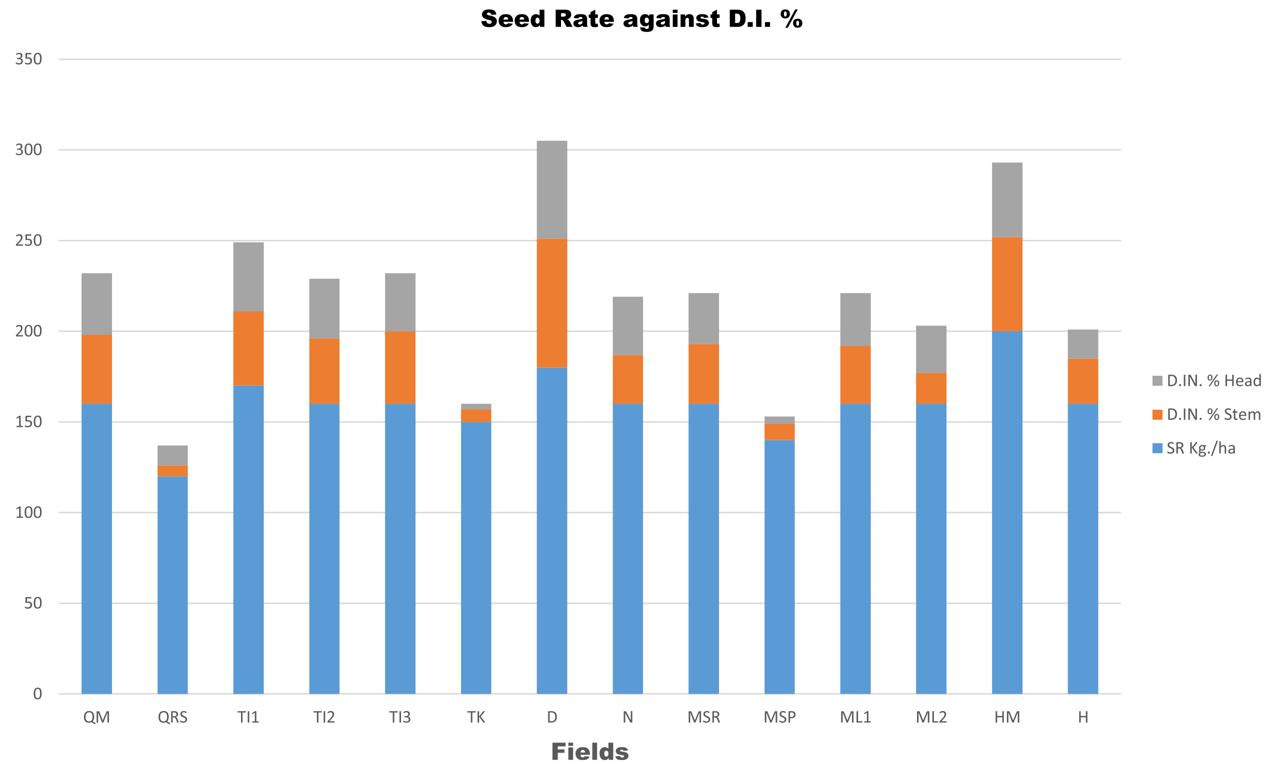

Fig. 3 The effect of seed rate with kilogram per hectare on disease incidence on the plant head and stem in the 14 selected wheat fields in the south of Iraq/Basra province

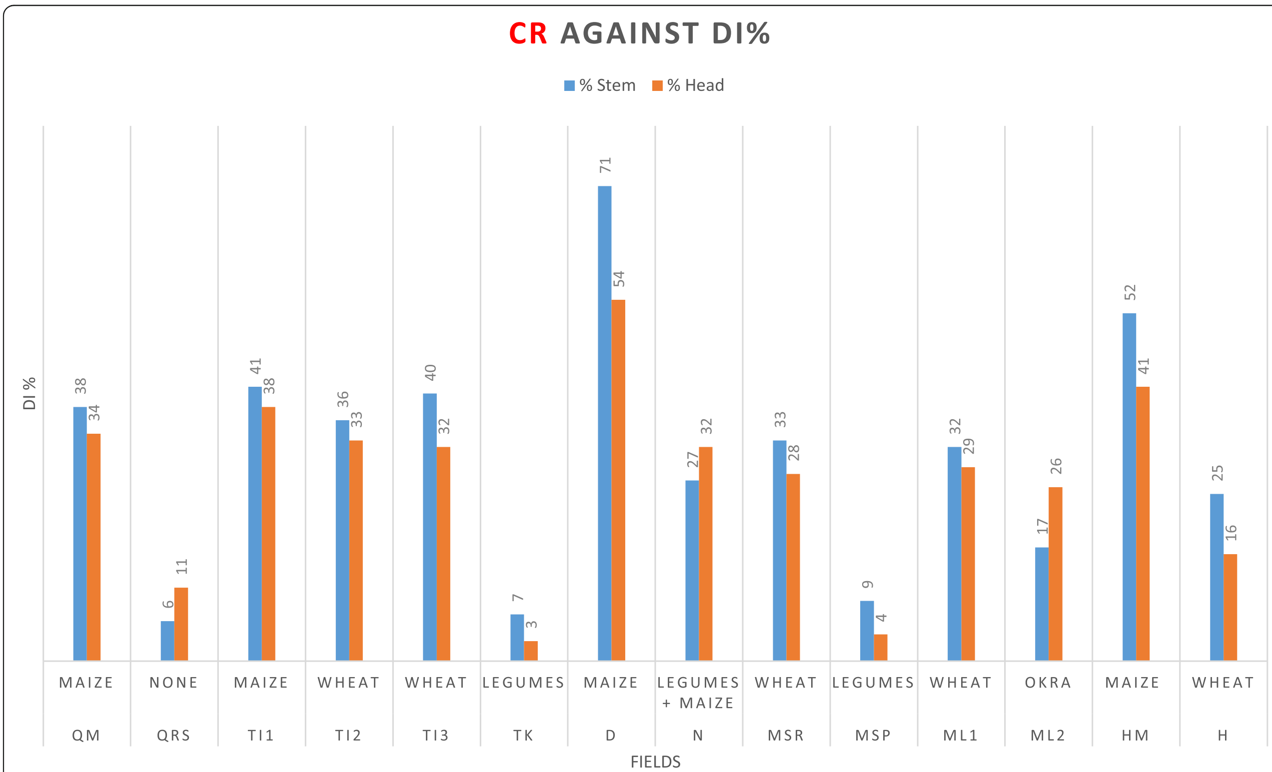

Fig. 4 The effect of crop rotation on disease incidence in plant head and stem in the 14 selected wheat fields in the south of Iraq/Basra province

Cultivar type

The seven winter wheat cultivars were distributed unequally among the 14 studied fields. AG3 is a local cultivar that was planted in five fields (TI2, TI3, D, ML1, and H) as a dominant cultivar in the south of Basra. Res.22 is also a local cultivar that was planted in two fields (QRS and N) only. R. and I.99 are also local cultivars that were planted each in one field TK and MSP, respectively. A.99 is a Turkish cultivar that was planted in two fields (MSR and HM). Bengal (B.) is a Spanish cultivar originated from Barcelona that was planted in two fields (QM and TI1). Finally, AGRI S. is a German cultivar that was planted for the first time in the south of Iraq, exactly in the ML2 field.

The seven cultivars examined in this study showed different levels of susceptibility to both diseases observed during the growing season. As the percentage of disease incidence for FHB and FCR varied among the seven cultivars (Fig. 5a, b). The three cultivars (B., AG3, and A.99) showed the highest mean of disease incidence ranged from 33 to 36% and 40 to 43% for FHB and FCR, respectively. The moderate mean of disease incidence occurred in the Res.22 and AGRI S. cultivars with 17% and 22–26% for FHB and FCR, respectively, whereas the remainder two cultivars (I.99 and R.) showed the lowest disease incidence percentages 4 and 9% and 3 and 7% for FHB and FCR, respectively (Fig. 5a, b). Nonetheless, no steady or substantial tolerance was noticed in the seven different wheat cultivars against both diseases. The statistical analysis results showed no significant differences in the occurrence of both FHB and FCR diseases among the examined cultivar types.

Discussion

In terms of the earlier planting date (28 Oct. in the HM field), it had the highest disease incidence during this study. This result is completely in accordance with the findings of Cook (2010) who pointed out as a general statement that planting winter wheat in an early date encourages diseases. Similarly, Purss (1971) indicated that a high percentage of disease incidence occurred in early planted wheat in a selected field that was FCR-infected in the previous year. He also found that disease symptoms were severely expressed on wheat plants.

Likewise, the D field that was planted in a very late time of planting (10 Dec.) also had a significant infection of both diseases. Interestingly, this result also totally agree with the findings of Gorczyca et al. (2018) who observed an increase of disease incidence on wheat crop that sowed in delayed date. Moreover, the occurrence of disease symptoms observed in both earlier and delayed planting date may be related to the changed weather conditions associated with the growing season in this study (Minati and Mohammed-Ameen 2019) and may also be interconnected to other agricultural practices used in each wheat field.

In general, a number of wheat farmers schedule their planting dates in different time periods or sow plant cultivars that differ in maturity time to attain diverse flowering dates through their field areas. Thereby, they could minimize the risk that their whole harvest would come across climate conditions at flowering stage and premature grain fill encouraging for *Fusarium* contamination (McMullen et al. 2012). This strategy is most substantial where high productive cultivars with FHB adequate resistance are not yet obtainable.

Although the crop rotation is covered later, we mention it here for convenient explanation. Stimulatingly, the D and HM fields were planted in maize in the last season as a crop rotation. Consistent with Matny (2015), the *Fusarium* species that cause FHB and FCR in wheat and barley fields can also infect many crops such as maize, consequently planting wheat crop close to or following maize rotation in a certain field will enhance colonization of *Fusarium* pathogens that resulted in extreme disease incidence. Furthermore, along with Khudhair et al. (2014), an occurrence of both diseases (FHB and FCR) in an unaccustomed way in Iraqi wheat

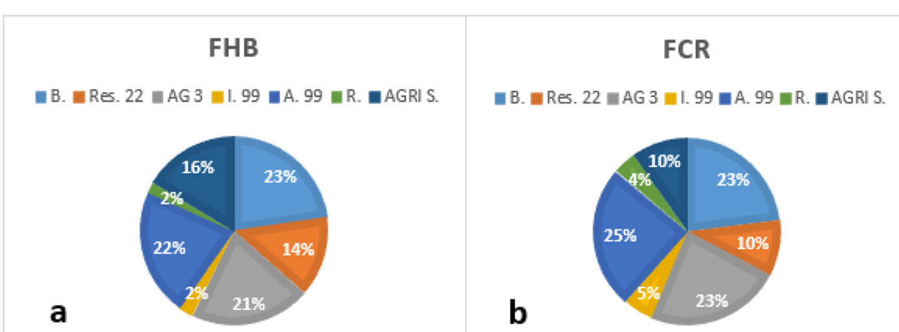

Fig. 5 The disease incidence percentage of FHB (**a**) and FCR (**b**) on the seven cultivars planted in the 14 selected wheat fields in the south of Iraq/Basra province

and barley fields during the last a few years might be attributed to attracting attention alteration of weather conditions, such as increasing the intensity and distribution of rainfall amount. They also imputed that to the different agricultural practices performed by certain growers, for example tending to the surface tillage, do not eliminate the straw from wheat fields and do not use effective crop rotation.

Incidence of both diseases on winter wheat can be reduced in several simple actions, such as following the selective planting date for each a geographic area. In spite of the success of planting date in reducing disease incidence of both pathogens, the management of it depends on the planted areas managed by certain growers and more importantly environmental factors associated with each region (Cook 2010).

The influence of agricultural practices on FHB and FCR diseases are frequently unpredictable (Bailey et al. 2000) and count on the causative agents (pathogens) as well as the climatic conditions (Parry et al. 1995; Champeil et al. 2004). Based on the obtained results of the recent study, evidently, it can be stated that the too early and too late time of planting could lead to devastating consequences of disease incidence and severity for both FHB and FCR diseases in wheat fields in the south of Basra. Particularly, continuing of planting wheat crop in previous infected fields or after a host crop, such as maize, may increase the opportunity of disease incidence and severity of both diseases.

Moving to the seed rate, the highest percentages of disease incidence for both FCR and FHB were detected in the D and HM wheat fields, which had planted in the highest rate of seed 180 and 200 kg/ha, respectively. While, the lowest disease incidence were detected in the QRS, MSP, and TK wheat fields, which had planted in the lowest seed rate 120, 140 and 150 kg/ha, respectively. These findings are in accord with Lyamani (1988) who reported that one of the effects of plant density (seed rate) might be confined to plant competition for sources of water and nutrients existing in the soil, and therefore, may affect the development of endophytic pathogens in plants or those found in soil, such as *Fusariun* spp. (Lyamani 1988). Moreover, although increasing the seed rate in wheat fields may raise the rate of cultivated plant numbers, multiply the number of tillers and ears, and thus increase the amount of production (Baker 1982; Geleta et al. 2002; Lloveras et al. 2004), however, on the same time, in the case of existence of FHB disease, it maximizes the possibility of disease incidence (Schaafsma and Tamburic-Ilincic 2005).

Furthermore, Gorczyca et al. (2018) reported that the differences between 120 and 140 kg/ha were not significant in the statistical analysis. These findings are also in accordance with our results that showed no significant differences between 120 and 140 kg/ha, as the two fields (QRS and MSP) that seeded with 120 and 140 kg/ha had the lowest disease incidence 11 and 4% and 6 and 9% for both FHB and FCR, respectively.

Numerous studies have been conducted to present the benefits of using effective crop rotations in managing FHB and FCR in a number of countries, such as the USA (Broders et al. 2007; Davis et al. 2009; Marburger et al. 2015), India (Teli et al. 2016), New Zealand (Cromey et al. 2002), Slovakia (Bíliková and Hudec 2014), Hungary (Vogelgsang et al. 2007), and South Africa (De Villiers 2009). However, little investigations have paid attention to FHB and FCR diseases on wheat in Iraq, and none has investigated the best strategies of controlling such diseases. Therefore, it is necessary to comprehend and determine the effects of host and non-host previous crops on FHB and FCR enhancement and interactions of these diseases with crop rotations in wheat fields in Iraqi farming systems.

The results of this experiment showed that using crop rotation of legumes in wheat fields had a great role in reducing the effect of both diseases on wheat fields while using maize and continuing wheat system had increased the percent disease incidence for both FHB and FCR. These results are in accordance with Champeil et al. (2004) who stated that crop rotation of non-host plants in wheat fields may minimize the incidence of FHB disease. Similarly, the recommendation of Bíliková and Hudec (2014) was not to cultivate wheat in a certain field where the preceding crop was maize. Furthermore, Lamprecht et al. (2006) pointed out that the lowest incidence and severity of FCR were noticed on wheat crop where the broadleaf crops were used as a pre-crop. They also stated that the continuous cropping system of wheat in particular areas increase the FCR infection.

The three fields (QM, ML2, and N) that used okra and sorghum as a pre-crop also showed disease incidence percentages ranging from 17 to 38% and 22 to 34% for FCR and FHB, respectively (Fig. 4). The percentages of disease incidence in these three fields were almost similar to the percentages of those fields that used wheat as crop rotation. This means that okra and sorghum crops are not recommended as a pre-crop in wheat fields for reducing the incidence of both FHB and FCR diseases.

The results of the present study support the advantages of using effective crop rotations, such as legumes in wheat fields, to minimize the effects of FHB and FCR. In order to successfully reduce the amount of inoculum for both pathogens in soil, the use of effective crop rotation should be combined to other factors, such as the recommended planting date, seeding rate, and fertilizer applications, as well as soil properties that are related to the suppression of soil-borne pathogens. According to Food and Agriculture Organization of the United Nations (FAO) Database Results (2018), the planted areas of legumes in Iraq is approximately 1% compared to the planted areas of wheat crop that is more than 53% of the total planted areas. Therefore, the results of this study greatly encourage Iraqi farmers from using legumes as a pre-crop to encounter the new threat of FHB and FCR diseases in wheat fields.

The result of various fertilizer applications (Table 1) had no effect on the occurrence of FHB and FCR disease incidence. This result agree with the findings of the following authors, Aufhammer et al. (2000), Subedi et al. (2007), Pageau et al. (2008), Yoshida et al. (2008), Krnjaja et al. (2015), and Hofer et al. (2016), who reported that the application of nitrogen fertilization did not increase or even stimulate FHB occurrence. In addition, Parry et al. (1995) stated that the effect of nitrogen application on FHB disease remains uncertain. Broscious and Frank (1986) also declared that nitrogen fertilizer had no impact of *Fusarium* root rot.

Based on the above results, the crucial factors influencing FHB and FCR disease incidence of wheat crop were not the rate of nitrogen and other nutrient applications, but climatic conditions, soil properties (Minati and Mohammed-Ameen, unpublished paper) agricultural practices, and cultivar susceptibility could play an important role in the development or suppression of FHB and FCR diseases. The planting date and continuous cropping system of wheat are also significant factors affecting the FHB incidence in wheat cropping system (Tonev et al. 2008).

In terms of the interaction between FHB and FCR disease incidence and cultivar resistance, all the seven wheat cultivars examined during this study were shown observable symptoms for both diseases, even though the percentage of disease incidence was not identical among those cultivars. This means that the selected cultivars may have different resistance levels to both FHB and FCR. The results of this experiment are in accordance with Dean et al. (2012) who reported that in spite of the resistant cultivar use is the best economically applicable and environment-friendly approach to cope the FHB and FCR diseases, the causative pathogens have the ability to overcome such barriers (resistance) progressively, and resistant cultivars unsurprisingly turn out to be unsuccessful within 2 to 3 winter wheat growing seasons, reviewed by Dean et al. (2012). According to Dweba et al. (2017), thus far there is no particular cultivar of wheat that has been acknowledged and made available to the general growers with full resistance or invulnerability to the FCR and FHB diseases. This means the majority of winter wheat cultivars are vulnerable to *Fusarium* infection, and even the highest resistant cultivars may turn out to be infected. Along with Mesterházy et al. (2011), wheat cultivar resistance cannot be employed as a single management strategy in controlling FHB disease, although investigation efforts have efficiently improved the resistance level to this disease in commercial cultivars. Wheat cultivars with different levels of FHB susceptibility were originally discovered in the USA in the ninetieth century reviewed by Naroei and Salari (2015). Thereafter, a number of resistance levels in wheat cultivars have been proclaimed around the world (Bai and Shaner 2004).

Another explanation of the uncertain correlation between the occurrence of both diseases and the use of cultivar types, because the studied areas in the south of Basra subjected in this study were investigated for the first time in relation to both diseases, the FHB and FCR diseases might be existent in the past but they were not noticeable due to the little rate of infection that can be attributed to the unencouraging weather conditions. Afterward, when the climate becomes optimum to the causative pathogens, they turn out to be effective which can occur observably in the next season.

Conclusion

Using effective crop rotation, such as legumes associated with the recommended planting date, seeding rate, fertilizer applications, and soil properties that are related to the suppression of soil-borne pathogens, could help in reducing the inoculum of *Fusarium* species that cause FHB and FCR on wheat crop in Basra province. The consequence of nitrogen and other nutrient applications may also to some extent affect the establishment of encouraging conditions for both diseases in wheat fields. The seven wheat cultivars examined in this study were shown obvious symptoms for both diseases, but the level of susceptibility varied among these cultivars. There are another seven wheat cultivars (Al-Fatih, Tammuz 2, Latifiah, Baraka, Ebaa 95, and Research 10) grown in the studied areas; therefore, extensive investigates on all growing cultivars should be executed considering the resistance levels against *Fusarium* pathogens, potential yield losses, and identifying mycotoxin levels and their produces.

Abbreviations

A.99: Adana 99; AG3: Abu Ghraib 3; AGRI S.: AGRI-Saaten; B.: Bengal; C: Cultivars; CR: Crop rotation; D: Dair district; DAP: Diammonium phosphate; Dec.: December; D.IN.: Disease incidence; FCR: *Fusarium* crown rot; FHB: *Fusarium* head blight; FL: Fertilizer level; FT: Fertilizer type; H: Huwair district; HM: Al-Hammar Marsh; I.99: Ebaa-99; ML1: Talha district/Marsh land1; ML2: Talha district/Marsh land2; MSP: Al-Modienh district/Salt Project; MSR: Al-Modienh district/Salih River; N: Nashwa district; Nov.: November; NPK: Nitrogen, phosphorus, and potassium; Oct.: October; PI: Plants inspected; PT: Planting time; QM: Qurna district/Mzeara'a; QRS: Qurna district/research station; R.: Rasheed; Res.22: Research 22; SP: Symptomatic plants; SR: Seeding rate; TI1: Thagar district/Al-Izz1; TI2: Thagar district/Al-Izz2; TI3: Thagar district/Al-Izz3; TK: Thagar district/Karakor; TN: Total number

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References

Al-Maeini AH, Mohsin RH (2016) Effect of seed quantities and water stress in growth and yield of wheat (Triticum aestivum L.). Euphrates J Agric Sci. 8(2): 180–189

Aoki T, O'Donnell K (1999) Morphological and molecular characterization of Fusarium pseudograminearum sp. nov., formerly recognized as the Group 1 population of F. graminearum. Mycologia, pp 597–609

Aufhammer W, Kübler E, Kaul H, Hermann W, Höhn D, Yi C (2000) Infection with head blight (F. graminearum, F. culmorum) and deoxynivalenol concentration in winter wheat as influenced by N fertilization. Pflanzenbauwissenschaften. 4(2):72–78

Backhouse D, Abubakar A, Burgess L, Dennisc J, Hollaway G, Wildermuth G et al (2004) Survey of Fusarium species associated with crown rot of wheat and barley in eastern Australia. Australasian Plant Pathol. 33(2):255–261

Baenziger PS, Beecher A, Graybosch RA, Baltensperger DD, Nelson LA, Krall JM et al (2006) Registration of 'Infinity CL' wheat. Panhandle Res Extension Center. 7

Bai G, Shaner G (2004) Management and resistance in wheat and barley to Fusarium head blight. Annu Rev Phytopathol. 42:135–161

Bailey K, Gossen B, Derksen D, Watson P (2000) Impact of agronomic practices and environment on diseases of wheat and lentil in southeastern Saskatchewan. Can J Plant Sci. 80(4):917–927

Baker R (1982) Effect of seeding rate on grain yield, straw yield and harvest index of eight spring wheat cultivars. Can J Plant Sci. 62(2):285–291

Bíliková J, Hudec K. Occurrence of Fusarium head blight of barley in Slovakia. . Journal of Central European Agriculture. 2014;15(1).

Bottalico A, Perrone G (2002) Toxigenic Fusarium species and mycotoxins associated with head blight in small-grain cereals in Europe. In: Mycotoxins in Plant Disease. Springer, Dordrecht, pp 611–624

Braithwaite M, Alexander B, Adams R. Nationwide survey of pests and diseases of cereal and grass seed crops in New Zealand. 2. Fungi and bacteria. Nationwide survey of pests and diseases of cereal and grass seed crops in New Zealand 2 Fungi and bacteria. 1998:51-9.

Broders K, Lipps P, Paul P, Dorrance A (2007) Evaluation of Fusarium graminearum associated with corn and soybean seed and seedling disease in Ohio. Plant Dis. 91(9):1155–1160

Broscious S, Frank J (1986) Effects of crop management practices on common root rot of winter wheat. Plant Dis. 70(9):857–859

Chakraborty S, Liu C, Mitter V, Scott J, Akinsanmi O, Ali S et al (2006) Pathogen population structure and epidemiology are keys to wheat crown rot and Fusarium head blight management. Australasian Plant Pathol. 35(6):643–655

Champeil A, Fourbet JF, Doré T, Rossignol L (2004) Influence of cropping system on Fusarium head blight and mycotoxin levels in winter wheat. Crop Prot. 23(6):531–537

Cook RJ (1980) Fusarium foot rot of wheat and its control in the Pacific Northwest. Plant Dis. 64(12):1061–1066

Cook RJ, editor. Fusarium root, crown, and foot rots and associated seedling diseases. University Park: The Pennsylvania State University Press; 2010.

Cromey MG, Shorter SC, Lauren DR, Sinclair KI (2002) Cultivar and crop management influences on Fusarium head blight and mycotoxins in spring wheat (Triticum aestivum) in New Zealand. New Zealand J Crop Horticultural Sci. 30(4):235–247

Davis RA, Huggins DR, Cook JR, Paulitz TC (2009) Nitrogen and crop rotation effects on fusarium crown rot in no-till spring wheat. Can J Plant Pathol. 31(4):456–467

De Villiers CIP (2009) A comparison of screening techniques for Fusarium head blight of wheat in South Africa Faculty of Natural and Agricultural Sciences: University of the Free State Bloemfontein

Dean R, Van Kan JA, Pretorius ZA, Hammond-Kosack KE, Di Pietro A, Spanu PD et al (2012) The Top 10 fungal pathogens in molecular plant pathology. Mol Plant Pathol. 13(4):414–430

Dewan MM, Khalaf JM, Alwan SL (1998) Effect of Fusarium graminearum Schwabe exudates on seed germination and seedling development in wheat. Basra J Agric Sci. 11(1):59–65

Dill-Macky R, Jones RK (2000) The effect of previous crop residues and tillage on Fusarium head blight of wheat. Plant Dis. 84(1):71–76

Dweba C, Figlan S, Shimelis H, Motaung T, Sydenham S, Mwadzingeni L et al (2017) Fusarium head blight of wheat: pathogenesis and control strategies. Crop Prot. 91:114–122

Fernandez M, Selles F, Gehl D, DePauw R, Zentner R (2005) Crop production factors associated with Fusarium head blight in spring wheat in eastern Saskatchewan. Crop Sci. 45(5):1908–1916

Fernandez M, Ulrich D, Brandt S, Zentner R, Wang H, Thomas A et al (2011) Crop management effects on root and crown rot of wheat in west-central Saskatchewan, Canada. Agronomy J 103(3):756–765

Food and Agriculture Organization of the United Nations (FAO) Database Results, Geneva [Internet]. 2018.

Geleta B, Atak M, Baenziger P, Nelson L, Baltenesperger D, Eskridge K et al (2002) Seeding rate and genotype effect on agronomic performance and end-use quality of winter wheat. Crop Sci. 42(3):827–832

Gorczyca A, Oleksy A, Gala-Czekaj D, Urbaniak M, Laskowska M, Waśkiewicz A et al (2018) Fusarium head blight incidence and mycotoxin accumulation in three durum wheat cultivars in relation to sowing date and density. Sci Nat. 105(1-2):2

Hameed M, Rana R, Ali Z (2012) Identification and characterization of a novel Iraqi isolate of Fusarium pseudograminearum causing crown rot in wheat. Genet Mol Res. 11(2):1341–1348

Hofer K, Barmeier G, Schmidhalter U, Habler K, Rychlik M, Hückelhoven R et al (2016) Effect of nitrogen fertilization on Fusarium head blight in spring barley. Crop Prot. 88:18–27

Hogg AC, Johnston RH, Johnston JA, Klouser L, Kephart KD, Dyer AT (2010) Monitoring Fusarium crown rot populations in spring wheat residues using quantitative real-time polymerase chain reaction. Phytopathology. 100(1):49–57

Khudhair M, Melloy P, Lorenz DJ, Obanor F, Aitken E, Datta S et al (2014) Fusarium crown rot under continuous cropping of susceptible and partially resistant wheat in microcosms at elevated CO 2. Plant Pathol 63(5):1033–1043

Khudhair MW, Aboud HM, Mustafa DJ, Shbar AK, Khalaf HS (2015) Spatial distribution of Fusarium crown rot (FCR) and Fusarium head blight (FHB) in wheat and barley in the south and middle of Iraq In press

Koch H, Pringas C, Maerlaender B (2006) Evaluation of environmental and management effects on Fusarium head blight infection and deoxynivalenol concentration in the grain of winter wheat. Eur J Agronomy. 24(4):357–366

Krnjaja V, Mandić V, Lević J, Stanković S, Petrović T, Vasić T et al (2015) Influence of N-fertilization on Fusarium head blight and mycotoxin levels in winter wheat. Crop Prot. 67:251–256

Lamprecht SC, Marasas WFO, Hardy MB, Calitz FJ (2006) Effect of crop rotation on crown rot and the incidence of Fusarium pseudograminearum in wheat in the Western Cape. South Africa Australasian Plant Pathology. 35(4):419–426

Li X, Liu C, Chakraborty S, Manners JM, Kazan K (2008) A simple method for the assessment of crown rot disease severity in wheat seedlings inoculated with Fusarium pseudograminearum. J Phytopathol. 156(11-12):751–754

Lloveras J, Manent J, Viudas J, López A, Santiveri P (2004) Seeding rate influence on yield and yield components of irrigated winter wheat in a Mediterranean climate. Agronomy J. 96(5):1258–1265

Lyamani A. Wheat root rot in west central morocco and effects of Fusarium culmorum and Helminthosporium sativum seed and soil-borne inoculum on root rot development, plant emergence and crop yield. Retrospective Theses and Dissertations 8866 https://www.libdriastateedu/rtd/8866. 1988.

Marburger D, Conley S, Esker P, Lauer J, Ané J-M (2015) Yield response to crop/genotype rotations and fungicide use to manage Fusarium-related diseases. Crop Sci. 55(2):889–898
Matny O, Bates S, Song Z (2017) Geographic distribution of Fusarium culmorum chemotypes associated with wheat crown rot in Iraq
Matny ON (2015) Fusarium head blight and crown rot on wheat & barley: losses and health risks. Adv Plants Agric Res. 2(1):38–43
McMullen M, Bergstrom G, De Wolf E, Dill-Macky R, Hershman D, Shaner G et al (2012) A unified effort to fight an enemy of wheat and barley: Fusarium head blight. Plant Dis. 96(12):1712–1728
Mesterházy Á, Tóth B, Varga M, Bartók T, Szabó-Hevér Á, Farády L et al (2011) Role of fungicides, application of nozzle types, and the resistance level of wheat varieties in the control of Fusarium head blight and deoxynivalenol. Toxins. 3(11):1453–1483
Minati MH, Mohammed-Ameen MK (2019) Novel report on six Fusarium species associated with head blight and crown rot of wheat in Basra province, Iraq. Bulle National Res Centre. 43(1):139
Monds RD, Cromey MG, Lauren DR, Di Menna M, Marshall J (2005) Fusarium graminearum, F. cortaderiae and F. pseudograminearum in New Zealand: molecular phylogenetic analysis, mycotoxin chemotypes and co-existence of species. Mycological Res. 109(4):410–420
Naroei K, Salari M (2015) Impacts of Fusarium head blight (FHB). J Novel Appl Sci. 4(11):1109–1122
Obanor F, Neate S, Simpfendorfer S, Sabburg R, Wilson P, Chakraborty S (2013) Fusarium graminearum and Fusarium pseudograminearum caused the 2010 head blight epidemics in Australia. Plant Pathol. 62(1):79–91
Pageau D, Lafond J, Lajeunesse J, Savard M (2008) Impact du précédent cultural et de la fertilisation azotée sur la teneur en désoxynivalénol chez l'orge. Can J Plant Pathol. 30(3):397–403
Papendick RI, Cook RJ. Plant water stress and development of Fusarium foot rot in wheat subjected to different cultural practices. Phytopathology. 1974
Parry D, Jenkinson P, McLeod L (1995) Fusarium ear blight (scab) in small grain cereals—a review. Plant Pathol. 44(2):207–238
Purss G (1971) Effect of planting time on the incidence of crown rot (Gibberella zeae) in wheat. Australian J Exp Agric. 11(48):85–89
Root and Crown Diseases of Wheat and Barley in Northern NSW. [Internet]. NSW Department of Primary Industries. 2005 [cited Feb. 02/2019].
Schaafsma A, Tamburic-Ilincic L (2005) Effect of seeding rate and seed treatment fungicides on agronomic performance, Fusarium head blight symptoms, and DON accumulation in two winter wheats. Plant Dis. 89(10):1109–1113
Smiley RW, Patterson LM (1996) Pathogenic fungi associated with Fusarium foot rot of winter wheat in semiarid Pacific Northwest USA. Plant Dis. 80:944–949
SPSS. Statistical Pachages of Social Sciences. 21 ed. USA. 2012.
Subedi K, Ma B, Xue A (2007) Planting date and nitrogen effects on Fusarium head blight and leaf spotting diseases in spring wheat. Agronomy J. 99(1):113–121
Teli B, Chattopadhyay A, Meena S, Gangwar G, Pandey S. Present status of Fusarium head blight of wheat and barley in India. Diseases of wheat and their management. 2016:79-92.
Tonev T, Kiryakova V, Milev G (2008) Influence of some agronomy factors on spike components after a rare incidence of fusarium head blight epiphytoty of winter wheat I. Effect of long-term crop rotation, mineral fertilization and sowing term. Bulgarian J Agric Sci. 14(3):321–328
Vogelgsang S, Jalli M, Kovács G, Vida G (2007) Proceedings of the COST SUSVAR Fusarium workshop: Fusarium diseases in cereals-potential impact from sustainable cropping systems, 01-02 June 2007, Velence, Hungary, vol 53
Wegulo SN, Bockus WW, Nopsa JH, De Wolf ED, Eskridge KM, Peiris KH et al (2011) Effects of integrating cultivar resistance and fungicide application on Fusarium head blight and deoxynivalenol in winter wheat. Plant Dis. 95(5):554–560
Windels CE, Wiersma JV (1992) Incidence of Bipolaris and Fusarium on subcrown internodes of spring barley and wheat grown in continuous conservation tillage. Phytopathology. 82(6):699–705
Yonghao L. Department of plant pathology and Ecology. The Connecticut Agricultural Experment station wwwctgov/caes (2013). 2013.
Yoshida M, Nakajima T, Tonooka T. Effect of nitrogen application at anthesis on Fusarium head blight and mycotoxin accumulation in breadmaking wheat in the western part of Japan Journal of general plant pathology. 2008;74(5):355.

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