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## Pathogenicity of nine *Fusarium* species causing head blight and crown rot in Iraqi wheat cropping system, Basra province

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### ABSTRACT

This experiment was conducted to determine pathogenicity of 32 isolates of nine *Fusarium* spp. (*F. chlamydosporum*, *F. equiseti*, *F. graminearum*, *F. pseudograminearum*, *F. solani*, *F. avenaceum*, *F. culmorum*, *F. cerealis* and *F. nygamai*) on the heads, stems and seeds of soft winter wheat cultivar, Abu Ghraib 3 (AG 3). For pathogenicity test on head bleaching, the effects of disease severity and percent *Fusarium* head blight (FHB) were significant ( $P \leq 0.05$ ) for each of *Fusarium* species and isolates as well as time were analyzed individually. Analysis by *Fusarium* species displayed that *F. culmorum*, *F. cerealis* and *F. graminearum* caused the highest percent FHB at 21 days after inoculation, while *F. chlamydosporum* and *F. nygamai* were the least pathogenic. *F. Pseudograminearum* had the greatest effect on seed germination (40-48%), followed by *F. culmorum* (53-60%). The effects of most examined *Fusarium* species and isolates were significant ( $P \leq 0.05$ ) for discoloration rating of basal stem as indications of *Fusarium* crown rot (FCR). *F. pseudograminearum* had the highest average percent disease severity of FCR (60.58%), followed by *F. cerealis* (51.13%), *F. culmorum* (49.58%), *F. avenaceum* (48.61%) and *F. graminearum* (43.92%). Infected heads and seeds might be resulted in basal stem infections, consequently serving *Fusarium* inoculum to be survived over time. Infected ground and underground plant parts could then become an inoculum sources for head infection in the next seasons.

**Keywords:** FCR, FHB, *Fusarium*, Pathogenicity, Wheat.

### INTRODUCTION

According to (Leslie and Summerell, 2008), the genus *Fusarium* encompasses more than 70 worldwide species, arising in natural conditions in various areas of the world. They are saprophytically widespread in soil. Similarly, they can develop on plant debris and other organic material. Under favorable conditions, a number of them are facultative parasites. In such conditions, *Fusarium* spp. might give rise to plant diseases of both upper and under organs of plants. Thereupon, species for the genus *Fusarium* are believed to be a number of the most risky pathogens of cereals and other varieties of plants, producing noteworthy economic losses.

The majority of *Fusarium* spp. are polyphagous, contaminating diverse plant species. In either case, any growth stages of plants can be subjected by *Fusarium* spp., leading to *Fusarium* head blight (FHB), *Fusarium* crown rot (FCR), *Fusarium* root rot (FRR), seedling blight, and leaf necrosis in cereals (Champeil *et al.*, 2004; Łukanowski and Sadowski, 2002). Specifically, in



wheat agricultural fields, the highest substantial problems are FCR and FHB diseases. Reduction of the occurrence of those diseases is tremendously difficult, because of the massive share of cereals cultivation globally. Correspondingly, weather conditions are another factors effecting the presence of those diseases that influence both growth of plants and the infection occurrence (Doohan *et al.*, 2003; Narkiewicz-Jodko *et al.*, 2005). A number of *Fusarium* species that give rise to FHB, can likewise be pathogens to FCR (Mitter *et al.*, 2006). The best example of these species are *F. graminearum*, *F. culmorum*, *F. avenaceum* and *F. acuminatum*. Furthermore, many researches have reported that the biology and epidemiology of FCR and FHB pathogens are related.

As stated by (Dill-Macky, 2003), *F. graminearum* has a great prominence in its ability for variation. This ability is due to the differences in the destructive infections of diverse isolates to small grain cereals as wheat, barley and maize. Differentiations in pathogenicity among these small grain cereals are renowned, however explanation of the relationships between pathogen species or isolates and type of crops is still unclear. The presence of diverse pathogenic isolates seasonally may be highly related to the fluctuations in environmental conditions. In view of that, observation of such different isolates on crowns and stem bases of wheat crops may result in extreme head blight, on the other hand crown rot is generated only by isolates from diseased stem bases or crowns.

Previously, the authors of this study have isolated and identified morphologically and molecularly nine *Fusarium* species (*F. pseudograminearum*, *F. graminearum*, *F. culmorum*, *F. chlamydosporum*, *F. equiseti*, *F. solani*, *F. avenaceum*, *F. cerealis*, and *F. nygamai*) from Iraqi wheat crops as causal agents of FHB and FCR (Minati and Mohammed-Ameen, 2019d). Also, they have studied the interaction between FHB and FCR disease incidences and cultural practices on wheat in the south of Iraq (Minati and Mohammed-Ameen, 2019b). Furthermore, they have studied the interaction between FHB and FCR disease incidences and environmental factors and soil physiochemical analysis on wheat in Basra Province (Minati and Mohammed-Ameen, 2019c). Moreover, they investigated the co-occurrence of FHB and FCR on several wheat cultivars in the south of Iraq (Minati and Mohammed-Ameen, 2020). Additionally, they have conducted an important study to detect and quantify three mycotoxins Dioxynivalenol, Nivalenol and Fumonisin B2 in seeds of seven wheat cultivars contaminated with those nine *Fusarium* species in 17 wheat fields distributed in the south of Iraq (Minati and Mohammed-Ameen, 2019a). For comprehensive and complementary study, the objective of our study was conducted to determine the pathogenicity of 32 isolates of those nine *Fusarium* species on heads, stems and seeds of a susceptible winter wheat cultivar.

## MATERIAL AND METHODS

### Isolate sources of *Fusarium* species

Isolates of the *F. chlamydosporum*, *F. equiseti*, *F. pseudograminearum*, *F. solani*, *F. avenaceum* and *F. culmorum* were isolated from wheat roots, stems and heads. *F. graminearum* isolates were isolated from wheat roots, stems and rhizosphere. While, isolates of *F. cerealis* and *F. nygamai* were isolated only from wheat stems and roots respectively. Based on field assessments of the disease incidence experiment (Minati and Mohammed-Ameen, 2020), Abu Ghraib 3 (AG 3) was the most FCR and FHB-susceptible cultivar.

## Planting

Seeds of the AG 3 cultivar were planted in 10-cm diameter pots. The soil mixture contained of 50% clay loam soil and 50% Turkish sphagnum peat moss. The peat moss was sterilized by autoclaving at 15 lbs.' pressure (121°C) for 20 minutes.

## Inoculum preparation

For pathogenicity evaluation of seed germination and seedling survival as well as occurrence of stem lesions (FCR symptoms), one square centimetre of mycelial plug of PDA agar from energetically growing edges of the each *Fusarium* isolate was placed in a depth of 5 cm in the soil mixture for each pot. Pots then watered lightly and covered with a transparent plastic bag for 48 hours following inoculation. Seeds of the AG 3 cultivar, surface-sterilized by moistening with 70% ethanol for two minutes, soaking in 2% sodium hypochlorite for one minute, rinsing in sterile distilled water several times and then air dried on a filter paper. Sterilized seeds were planted on the 30<sup>th</sup> November 2018 at rate of 10 seed / pot after 60 days of vernalisation at 4°C. Pots with no fungal agar plug on them were used for the control treatment. Pots were kept under semi-controlled conditions (25°C day/18°C night ±3). The pots were located on a greenhouse worktop and fertilized weekly. European fertilizer contained of 20:20:20 NPK added weekly at a rate of tow tablespoon per 10 litres throughout regular watering.

For pathogenicity evaluation of head bleaching, seeds were planted on the 15<sup>th</sup> of November 2018 at rate of three seed / pot (10-cm diameter pots) after 60 days of vernalisation at 4°C. The soil mixture was not inoculated with mycelial plugs. The pots were also located on a greenhouse worktop and fertilized weekly. European fertilizer contained of 20:20:20 NPK added weekly at a rate of tow tablespoon per 10 litres throughout regular watering. Plants were kept until ripening stage under the same conditions used prior to inoculation. At ripening stage, three spikes / pot were sprayed (using hand-held sprayer) to overflow with a spore suspension ( $1 \times 10^{-6}$  conidia / ml) of each isolate and concealed with a transparent plastic bag for 72 h. Spore suspension was facilitated by adding one drop of Tween 20 (polyoxyethylene sorbitan monolaurate) to each 250 ml. *Fusarium* isolates were grown on PDA for 7-10 days in 9-cm-diameter Petri dishes in a low temperature incubator set at 25°C ±2. Control plants were sprayed in the same way with sterile distilled water.

Each spike was rated in a visual manner for percent surface area with FHB symptoms at one, two, and three weeks after inoculation. A design of these experiments was chosen to be a split plot randomized complete block with three replications for each isolates (each replicate containing of a pot with three plants).

## Statistical analysis

Based on the percent symptoms of FCR and FHB, discoloration ratings, seed germination and seedling survival for each plant, average values were considered for each replicate (pot). The effects of *Fusarium* species, and isolates at different three times on percent FHB in the head bleaching test, and the effects of *Fusarium* species, and isolates on seed germination, seedling survival and discoloration ratings of basal stem in the seed and seedling tests, were evaluated using the statistical program (SPSS<sup>®</sup> ver. 21) software (SPSS, 2012). Percentage data of FHB and FCR tests were arcsine-transformed before analysis to stabilize variance. When *F* values were significant ( $P \leq 0.05$ ), least significant differences were calculated. Interaction between species and time, isolates and time, species and isolate source as well as isolates and source were

done to make comparisons among percent FHB in the head test, and among seed germination, seedling survival and discoloration ratings of basal stem in the seed and seedling tests.

## RESULTS

### Pathogenicity test on head bleaching

The interactions of *Fusarium* species  $\times$  time and *Fusarium* isolates  $\times$  time and species  $\times$  source were not significant ( $P > 0.05$ ) for most of the measurements employed. The only one-way interaction that was significant was *Fusarium* isolates  $\times$  isolate sources ( $P \leq 0.01$ ). However, when *Fusarium* species and isolates as well as time were analyzed individually, the effects of disease severity and percent FHB were significant ( $P \leq 0.05$  to  $P \leq 0.01$ ) for each of the measurements taken. The majority of examined nine *Fusarium* species with their 32 isolates were shown significant percent FHB ( $P \leq 0.05$  to  $P \leq 0.01$ ) at 7, 14 and 21 days after inoculation, except *F. nygamai*, *F. chlamydosporum* and some isolates of other *Fusarium* species their effects were less than 15%, which is not significant. There was no significant differences between (7 and 14) days after inoculation, whereas, the difference between (21 and 7) days was highly significant ( $P \leq 0.01$ ), and between (21 and 14) days was significant ( $P \leq 0.05$ ) according to LSD tests.

Analysis by *Fusarium* species displayed that *F. culmorum*, *F. cerealis* and *F. graminearum* caused the highest percent FHB at 21 days after inoculation, while *F. chlamydosporum* and *F. nygamai* were the least pathogenic (**Table 1**).

**Table 1.** Mean percent *Fusarium* head blight (FHB) caused by 9 *Fusarium* species at 7, 14, and 21 days after inoculation.

SPECIES	FHB (%)		
	7 days	14 days	21 days
<i>F. GRAMI.</i>	15,67	19,76	21,24
<i>F.SOLANI</i>	10*	9,87*	10,4*
<i>F.EQUISETI</i>	13,66*	9,92*	18,37
<i>F.CHLAM.</i>	5,53*	4,71*	5,6*
<i>F.CULMORUM</i>	17,35	21,98	24,48
<i>F.NYGAMAI</i>	1,33*	2,02*	3,23*
<i>F.CEREALIS</i>	17,42	22,48	23,82
<i>F.PSEUDO.</i>	7,38*	9,53*	20,77
<i>F.AVENAC.</i>	10,69*	14,54*	20,05
<b>CONTROL</b>	0*	0*	0*

Values followed by (\*) are not significantly different ( $P > 0.05$ ) according to LSD tests.

When evaluations were analyzed by *Fusarium* isolates, pathogenicity of *F. graminearum*, *F. culmorum* and *F. pseudograminearum* was almost similar for isolates within their species, while

for isolates of *F. solani*, *F. equiseti*, *F. cerealis* and *F. avenaceum* the pathogenicity was highly at variance (**Table 2**).

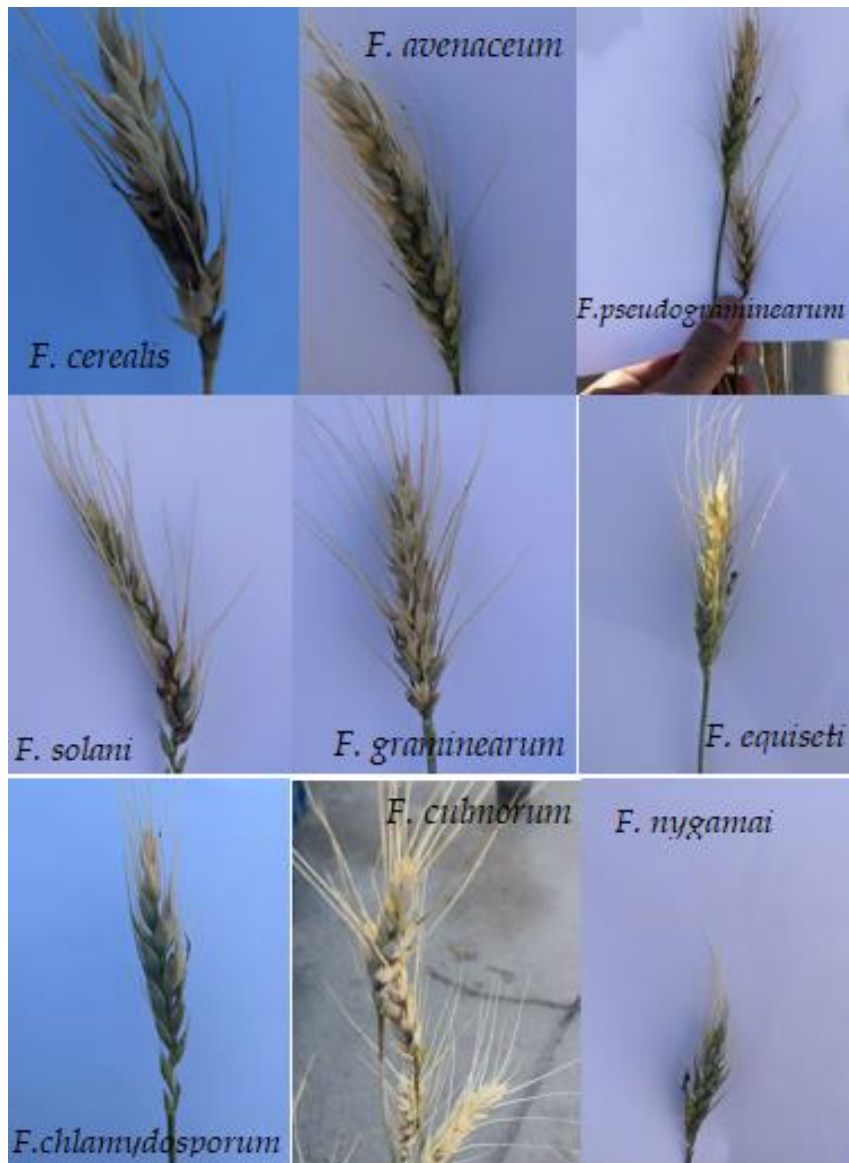
**Table 2.** Mean percent *Fusarium* head blight (FHB) caused by 32 *Fusarium* isolates originated from different sources at 7, 14, and 21 days after inoculation.

SPECIES	Isolate Source	FHB (%)		
		7 days	14 days	21 days
<b>FGR.1</b>	Root	16,67	10,34*	10,34*
<b>FGR.2</b>	Stem	17,67	21,43	25,76
<b>FGR.3</b>	Stem	16,33	20,37	24,33
<b>FGR.4</b>	Head	18	16,07	12,63
<b>FGR.5</b>	Stem	9,67*	30,6	35,16
<b>FSO.1</b>	Head	21,33	22,22	25,91
<b>FSO.2</b>	Root	6*	6*	6*
<b>FSO.3</b>	Root	2,67*	1,39*	2,1*
<b>FEQ.1</b>	Stem	20,33	4,17*	7,47*
<b>FEQ.2</b>	Rhizo.	7*	15,67	29,27
<b>FCHLAM.1</b>	Seed	2,12*	3,6*	4,51*
<b>FCHLAM.2</b>	Soil	8,67*	3,12*	4,29*
<b>FCHLAM.3</b>	Stem	2,33*	3*	4,4*
<b>FCHLAM.4</b>	Head	9,01*	9,12*	9,2*
<b>FCU.1</b>	Head	23,67	10,63*	15,46
<b>FCU.2</b>	Stem	16,35	17,07	21,72
<b>FCU.3</b>	Head	10,77*	10,55*	13,26
<b>FCU.4</b>	Root	19,94	23,99	34,15
<b>FCU.5</b>	Stem	15,73	21,31	23,77
<b>FCU.6</b>	Root	14	19	24,97
<b>FCU.7</b>	Stem	23,67	30,33	36,34
<b>FCU.8</b>	Root	18,67	23	28,43
<b>FCU.9</b>	Stem	13,33	15	22,23
<b>FNYG.1</b>	Root	1,33*	2,02*	3,23*
<b>FCER.1</b>	Stem	11,9	13,72	16,4
<b>FCER.2</b>	Root	22,95	31,25	31,25
<b>FPSEUD.1</b>	Stem	2,38*	3,4*	22,16
<b>FPSEUD.2</b>	Root	8,03*	12,1	16,33
<b>FPSEUD.3</b>	Root	11,73	13,09	23,81
<b>FAVE.1</b>	Root	16	22,67	27,19
<b>FAVE.2</b>	Head	8,68*	12,62	13,54
<b>FAVE.3</b>	Stem	7,41*	8,33*	19,44
<b>CONTROL</b>	S.D.W	0*	0*	0*

Values followed by (\*) are not significantly different ( $P > 0.05$ ) according to LSD tests.

Isolates of *F. graminearum*, *F. culmorum* (originated from stem) and *F. cerealis* (originated from root) seemed to be more pathogenic to heads compared to other isolates of the same species.

Whereas, only one isolate of *F. solani* (originated from head) had significant effect on examined wheat heads as shown in (Figure 1).



**Figure 1.** *Fusarium* head blight (FHB) symptoms caused by 9 *Fusarium* spp. on wheat heads.

### Pathogenicity test on seeds

Analysis of the seed test of AG 3 cultivar indicated that the interaction of *Fusarium* species × seed germination and *Fusarium* species × seedling survival was not significant ( $P > 0.05$ ). However, when isolate sources were analyzed, the source effects of *Fusarium* species and isolates were significant ( $P \leq 0.05$  to  $P \leq 0.01$ ) for most measurements taken, except *F. chlamydosporum* had the least effect on seed germination and development of surviving plants, which were not significantly different ( $P > 0.05$ ) from the control. *F. solani* and *F. nygamai* were intermediate in their effects. *F. Pseudograminearum* had the greatest effect on seed

germination (40-48%), followed by *F. culmorum* (53-60%), (Table 4). Few seedlings emerged from seeds inoculated with isolates of these pathogens, or were still healthy at the end of experiment. Development of the surviving plants was stunted most by *F. pseudograminearum* (from 0 -7%), followed by *culmorum* (7-28%) and *F. cerealis* (14-21%), (Table 4).

### Pathogenicity test on seedlings

The interaction of *Fusarium* species × isolate sources and *Fusarium* isolates × isolate sources was not significant ( $P > 0.05$ ) for all of the percent disease severity. However, when both measurements were analyzed together, the effects of most examined *Fusarium* species and isolates were significant ( $P \leq 0.05$  to  $P \leq 0.01$ ) for discoloration rating of basal stem. *F. pseudograminearum* had the highest average percent disease severity of FCR (60.58%), followed by *F. cerealis* (51.13%), *F. culmorum* (49.58%), *F. avenaceum* (48.61%) and *F. graminearum* (43.92%). Only inoculation with *F. nygamai* and *F. chlamydosporum* caused a lower average percent disease severity (11.36 and 19) % respectively compared to the other species. In turn, *F. equiseti* caused almost similar discoloration of basal stem as *F. solani* (Table 3).

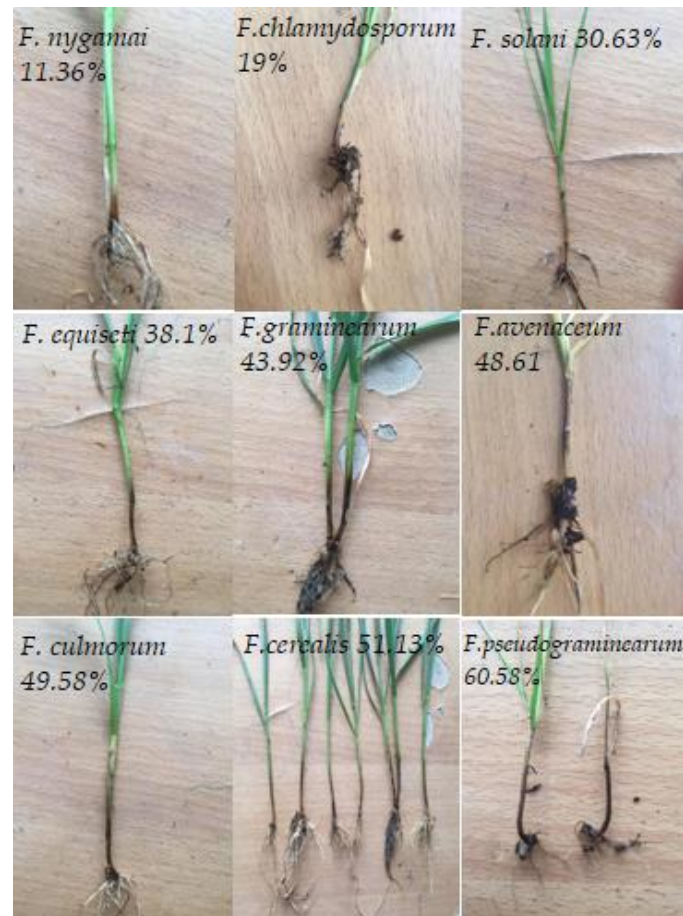
**Table 3.** Mean percent *Fusarium* crown rot (FCR) on wheat cultivar AG 3 inoculated at planting time with 9 *Fusarium* species.

<i>Spp.</i>	<i>Mean of D. sev. %</i>
Control	0*
<i>F. avenaceum</i>	48,61
<i>F. cerealis</i>	51,13
<i>F. chlamydosporum</i>	19
<i>F. culmorum</i>	49,58
<i>F. equiseti</i>	38,1
<i>F. graminearum</i>	43,92
<i>F. nygamai</i>	11,36*
<i>F. pseudograminearum</i>	60,58
<i>F. solani</i>	30,63

Values followed by (\*) are not significantly different ( $P > 0.05$ ) according to LSD tests.

In the seedling test, the discoloration of basal stem detected at harvest time elongated up to the basal stem of plants on an average of (60%, 51% and 49%) of the seedlings inoculated with *F. pseudograminearum*, *F. cerealis* and *F. culmorum* respectively and 48% and 43% of the seedlings inoculated with *F. avenaceum* and *F. graminearum* respectively, and the discoloration frequently touched and sometime passed the first node (Figure 2). The obvious spread of the discoloration for the rest of examined *Fusarium* species on the basal stem ranged between 19-30%, except *F. nygamai*, which caused less discoloration rate (11.36%).





**Figure 2.** *Fusarium* crown rot (FCR) symptoms caused by 9 *Fusarium* spp. on wheat basal stems.

In general, all *Fusarium* isolates caused discoloration of the basal stems. The isolates of *F. pseudograminearum* (ranged between 45 to 70.83%), *F. cerealis* (ranged between 47.72 to 54.54%), *F. culmorum* (ranged between 41 to 57.14%) and *F. graminearum* (ranged between 41.07 to 54.61%) caused the greatest discoloration ratings. Furthermore, even though there were some differences in pathogenicity among isolates within some of the *Fusarium* species, but on the whole, there were not significant differences among isolates of the rest of examined species, except that isolate of *F. nygamai* that caused the least discoloration (11.36%), which was not different ( $P > 0.05$ ) from the control treatments (**Table 4**).

**Table 4.** Percent seed germination at 10 days after planting, *Fusarium* crown rot (FCR) of wheat cultivar AG 3 inoculated at planting time with 32 *Fusarium* isolates originated from different sources and seedling survival at 35 day after inoculation.

Spp.	Source	D. sev. %	% Seed germ.	% Survival
<i>F. graminearum</i>	Root	50	63	14
<i>F. graminearum</i>	Stem	50,38	67	28
<i>F. graminearum</i>	Stem	44,23	67	14
<i>F. graminearum</i>	Head	41,07	71	14
<i>F. graminearum</i>	Stem	54,61	67	28
<i>F. solani</i>	Head	28,92	78	73
<i>F. solani</i>	Root	35,83	72	74
<i>F. solani</i>	Root	27,14	73	76
<i>F. equiseti</i>	Stem	38,21	90	78
<i>F. equiseti</i>	Rhizo.	38,21	100	100
<i>F. chlamydo.</i>	Seed	38	93	86
<i>F. chlamydo.</i>	Soil	31	100	80
<i>F. chlamydo.</i>	Stem	43,67	93	87
<i>F. chlamydo.</i>	Head	31,67	93	100
<i>F. culmorum</i>	Head	44,64	60	28
<i>F. culmorum</i>	Stem	65,62	60	7
<i>F. culmorum</i>	Head	41,67	60	25
<i>F. culmorum</i>	Root	45	53	20
<i>F. culmorum</i>	Stem	43,18	60	21
<i>F. culmorum</i>	Root	54,16	53	14
<i>F. culmorum</i>	Stem	52,91	60	23
<i>F. culmorum</i>	Root	53,92	53	28
<i>F. culmorum</i>	Stem	57,14	60	21
<i>F. nygamai</i>	Root	11,36*	73	57
<i>F. cerealis</i>	Stem	54,54	67	18
<i>F. cerealis</i>	Root	47,72	73	21
<i>F. pseudogram.</i>	Stem	45	48	2
<i>F. pseudogram.</i>	Root	70,83	40	0
<i>F. pseudogram.</i>	Root	65,9	40	7
<i>F. avenaceum</i>	Root	46,67	67	38
<i>F. avenaceum</i>	Head	41,67	87	41
<i>F. avenaceum</i>	Stem	47,5	67	37
Control	Control	0*	100	100

Values followed by (\*) are not significantly different ( $P > 0.05$ ) according to LSD tests.

In combination of all *Fusarium* isolate treatments, a positive correlation was detected between seed germination and plant survival in the seed test ( $r = 0.93$ ,  $P \leq 0.05$ ). Also, simple correlations was executed among all measurements performed in both tests showed that the survival of inoculated plants in the seed test was correlated with that in the seedling test for *Fusarium*

species ( $r = 0.95$ ,  $P \leq 0.05$ ) and *Fusarium* isolates ( $r = 0.71$ ,  $P \leq 0.01$ ). In contrast, there was a great negative correlation between percent disease severity of FHB at 21 days and seed germination and seedling survival in the seed test ( $r = -0.89$  to  $-0.93$ ,  $P \leq 0.01$  for *Fusarium* species;  $r = -0.87$  to  $-0.95$ ,  $P \leq 0.01$  for *Fusarium* isolates), and between percent disease severity of FHB at 21 days and plant survival ( $r = -0.89$ ,  $P \leq 0.05$  for *Fusarium* species;  $r = 0.71$ ,  $P < 0.05$  for *Fusarium* isolates) in the seedling test.

## DISCUSSION

Neither the difference in pathogenicity of the nine *Fusarium* species nor the pathogenicity of *F. pseudograminearum*, *F. graminearum* and *F. equiseti* on wheat has been previously studied. The high pathogenicity appeared on wheat heads caused by *F. culmorum* and *F. graminearum* compared to the other *Fusarium* species examined in this study agree with a number of studies, even though the use of a spore suspension in which was varied such as injection of the spore suspension into, or dropping it onto a part or an entire spike (Specht and Rush, 1988; Walker *et al.*, 2001; Wilcoxson *et al.*, 1988; Wong *et al.*, 1995). Moreover, we found that the pathogenicity on heads caused by *F. culmorum* was greater than *F. graminearum*, which is also in concurrent with (Balmas *et al.*, 1995; Mihuta-Grimm and Forster, 1989; Wong *et al.*, 1995), however it does not agree with (Fernandez and Chen, 2005), who reported no real differences between the two species in pathogenicity on wheat heads.

The pathogenicity of *F. cerealis* to wheat heads in this study was less than *F. culmorum* and higher than *F. graminearum*. This finding is in accordance with (Xue *et al.*, 2006), who stated that *F. cerealis* is highly pathogenic to heads but not higher than *F. culmorum*. (Sugiura *et al.*, 1994) and (Xue *et al.*, 2004) also confirmed that *Fusarium cerealis* is severe pathogen causing FHB symptoms on wheat heads in Canada.

Furthermore, we also found that *F. avenaceum* and *F. equiseti* were relatively moderate pathogenic species to wheat heads, while (Fernandez and Chen, 2005; Wilcoxson *et al.*, 1988; Wong *et al.*, 1995) found them least pathogenic species. This disagreement can be at least relatively, attributed to the diverse inoculation techniques applied. However, in contrast to our findings, (Golinski *et al.*, 2002) found that *F. avenaceum* had a greater effect on wheat heads than *F. culmorum* when a spore suspension was sprayed onto heads in the field trial.

In general, the pathogenicity results of seed and seedling tests in this study also go along with other researches on *Fusarium* pathogenicity to basal stems of wheat, even though comparative differences among the examined *Fusarium* species have in some circumstances varied.

Similar to our results, *F. pseudograminearum* was described as more pathogenic to wheat seedling than other *Fusarium* species (Kazan and Gardiner, 2018), lead to seedling death before or after development, particularly when planted seeds were collected from previously infected fields by different *Fusarium* species (Simpfendorfer, 2013), and it may cause wide browning basal stem directly after infection and during plant growth (Kazan and Gardiner, 2018). We also found that *F. cerealis* was more pathogenic than *F. culmorum* and *F. graminearum* on wheat in causing FCR. This result is completely in agreement with (Liddell, 1985) who stated that *Fusarium cerealis* is severe pathogenic on wheat, causing FCR and FRR higher than *F. culmorum* and *F. graminearum*.

What's more, our result agree with many studies that reported that the pathogenicity of *F. culmorum* to wheat seedling was a greater than *F. avenaceum* (Arseniuk *et al.*, 1993; Colhoun *et al.*, 1968), to wheat seed was a greater than *F. graminearum* and *F. avenaceum* (Uoti, 1976), and cause broad crown rot to wheat seedling compared to *F. graminearum* (Corazza *et al.*, 2001). Besides, according to (Arseniuk *et al.*, 1993), the pathogenicity of *F. culmorum*, *F.*

*graminearum*, and *F. avenaceum* to winter wheat seedling was highly a greater than *F. equiseti*, which is also similar to our result. However, as opposed to our results, the pathogenicity of *F. avenaceum* to winter wheat seedling was a greater than *F. culmorum* and *F. graminearum* (Arseniuk *et al.*, 1993) and (Jenkinson and Parry, 1994), while (Kane and Smiley, 1987) and (Specht and Rush, 1988) have reported that *F. avenaceum* was a weak pathogen to winter wheat. This research has generally revealed parallel proportional susceptibility of wheat heads and basal stems to the most of *Fusarium* species examined, except *F. nygamai* and *F. chlamydosporum* that were less pathogenic species in both tests. However, the rest of *Fusarium* species were unevenly pathogenic to wheat heads and basal stems, except *F. cerealis* and *F. avenaceum* were in the second and fourth level of effects respectively for both tests, but with different percent disease severities. This study also shown that *F. cerealis* is extremely pathogenic and can possibly be a main causative agent of FHB and FCR on wheat in regions where it is present.

*F. Pseudograminearum* was affected basal stems to a greater extent than *F. culmorum*, *F. avenaceum* and *F. graminearum*, whereas *F. culmorum* and *F. graminearum* were affected wheat heads to a greater extent than others. The higher pathogenicity of *F. graminearum* and *F. culmorum* on wheat heads compared to basal stems might be associated with stimulatory compounds existent at ripening stage in anthers. Similar explanation was given by (Stack and McMullen, 1985) when *F. graminearum* was more pathogenic to wheat heads than ground and underground wheat parts. Relative to the other *Fusarium* species examined, *F. solani* and *F. equiseti* were moderate pathogenic to heads and stems in both tests. The observation that the examined *Fusarium* species were differed in pathogenicity to heads than to basal stems or vice versa may be clarified, at least partially, by dissimilarities in the maturity of plant tissue between seed germination and infected plant parts (seedling, basal stems and heads) (Fernandez and Chen, 2005), might be due to the different sources of *Fusarium* species and their isolates resulted in a different adaptation of these isolates to the different infected wheat parts, and also may possibly affected by weather conditions, as they influence both disease incidences and development of plants (Doohan *et al.*, 2003).

## CONCLUSION

Overall, although the number of isolates for each *Fusarium* species was varied in this study, the high number of isolates did not indicate a real adaptation of such isolates to specific plant parts. For example, differences in pathogenicity among the nine isolates of *F. culmorum* did not seem correlated to the source of these isolates for both tests. This explanation, and the results of *Fusarium* species obtained from different sources had various pathogenicity on wheat heads, basal stems, seed germination and seedling survival, suggest that infected heads and seeds might be resulted in basal stem infections, consequently serving *Fusarium* inoculum to be survived over time. Infected ground and underground plant parts could then become an inoculum sources for head infection in the next seasons. Further research is needed to investigate the adaptation of these different isolates of each *Fusarium* species to another wheat cultivars and their developments on these cultivars in other Iraqi provinces, which have various weather conditions.

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