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RESEARCH ARTICLE

First Evidence of Increased *Fusarium* Head Blight Symptoms in Durum Wheat Subjected to Post-Flowering Moisture

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ABSTRACT

Fusarium head blight (FHB) impairs wheat yield and quality worldwide; and especially to durum wheat production where most durum cultivars are susceptible to FHB. Humidity has proven to largely contribute to the development processes for *Fusarium* pathogens in wheat head tissues. Some studies explored the impacts of post-flowering moisture on head blight development in bread wheat; however, their impacts on durum wheat are unknown. To end this, the influence of humidity on the infection of head tissues for three durum wheat cultivars of varying resistance levels by four fungal pathogens causing head blight was investigated under natural climatic conditions during the growing season 2022/2023. A pot experiment was designed as split-split-plot with five replicates. Main plots were durations of spray-irrigation of 0, 7, 14, 21, and 28 days; sub-plots were durum wheat cultivars; and sub-sub-plots were 16 fungal isolates of varying pathogenicity of four *Fusarium* species. The quantification of the disease responses to the changeable watered conditions was through the determination of the incidence of FHB, severity of FHB 21 days after inoculation as well as *Fusarium*-damaged kernel (FDK) percentages on harvested grain. No significant differences were observed between the 0 and 7-day spray-irrigation treatments for DI, DS and FDK, showing that extended moisture promotes *Fusarium* development and enhances grain fungus colonization in head tissues. 21 or 28 days of spray had the same impact and were linked with an increase in mean DI, DS and FDK compared with 0 or 7 days of spray, and 14 days of spray was also linked with an increase in mean of these three disease responses. To our best knowledge, this is the first report showing an increase in FHB symptoms in durum wheat infected with *F. culmorum*, *F. solani*, *F. verticillioides*, and *F. equiseti* when subjected to post-flowering moisture. These findings suggest that improved moisture management and cultivar selection are critical strategies for minimizing FHB-related yield losses in durum wheat. Meteorological humidity is a crucial factor determining the disease damage of *Fusarium*-infected durum wheat.

Keywords: A pot bio-experiment, *Fusarium* pathogens, post-anthesis moisture, *Triticum durum*.

INTRODUCTION

Durum wheat (*Triticum durum*) is one of the most important Poaceae species and is grown around the world over almost 17 million ha (5% of the total wheat planted globally), with a worldwide production of 38.1 million tonnes in 2019 (FAO, 2022). The largest producer is the EU, followed by Canada, Turkey, USA, Algeria, Mexico, Kazakhstan, Syria, and India (FAO, 2022). *T. durum*

production and cultivation areas are concentrated in the Mediterranean. This type of wheat is preferred for preparing high quality flour, semolina, and pasta products due to the high gluten strength and protein content of the grain. Durum wheat, as other Poaceae crops, suffers from susceptibility to *Fusarium* head blight (FHB), a destructive disease that affects wheat in several growing

areas of the world (Parry *et al.*, 1995; Buerstmayr *et al.*, 2020) including Mediterranean countries (Dahl and Wilson, 2018; Sakr, 2023). It is well reported that when moisture and warm temperature are favorable (Ma *et al.*, 2019), *Fusarium* invasion and colonization can occur any time after commencement of flowering in wheat (Mesterhazy, 2020, 2024), but anthesis is the growth stage most susceptible to infection (Miedaner *et al.*, 2021). FHB outbreaks are a serious threat for *Triticum* production as its damage is multifold: decreased yields, shriveled and discolored grains, kernels influenced with FHB will also produce less vigorous and healthy seedling when used as seed, and contamination with mycotoxins associated to a number of diseases that leads to health concern (Fernando *et al.*, 2021). This is especially alarming in *T. durum* since it is mainly intended for direct human consumption (Moonjely *et al.*, 2023).

Head blight disease is caused by a board range of fungi from the *Fusarium* genera changing in their adaptation to diverse environments and their worldwide presence (Parry *et al.*, 1995; Miedaner *et al.*, 2021); but the most common species are *Fusarium graminearum* and *F. culmorum*. However, less frequent species have also been isolated globally. *Fusarium* complex has vast differences in disease damage and mycotoxin production potential across and within species accounting on the meteorological conditions (Dahl and Wilson, 2018; Toth *et al.*, 2020; Usman *et al.*, 2024). Till now, the recovery of head blight pathogens has not been achieved from Syria barley plants. Nevertheless, *Fusarium* species are frequently recovered form naturally infected wheat fields and known to strongly infect barley spikes (Sakr, 2023). Namely FHB species were isolates from Syrian wheat production areas: *F. culmorum* was the most frequent (43.8%), followed by *F. equiseti* (23.3%), *F. moniliforme* (14.6%), *F. proliferatum* (7.1%), *F. sambucinum* (2.9%), *F. compactum* (2.1%), *F. solani* (1.7%), *F. crookwellense* (0.8%), *F. avenaceum* (0.8%), and *F. semitectum* (0.4%) were recovered during spring of three seasons (2008-2010) from wheat seeds showing FHB across 20 locations/fields of Ghab Plain, one of the principal Syrian wheat production areas (Al-Chaabbi *et al.*, 2018). Most frequent FHB species were *F. tricinatum* (30% of all *Fusarium* isolates), *F. culmorum* (18%), *F. equiseti* (14%) and *F. graminearum* (13%) from wheat spikes with FHB symptoms across five different Syrian provinces, except for Ghab Plain (Alkadri *et al.*, 2013). Isolate diversity for

aggressiveness (i.e., the ability of a pathogen isolates to cause disease on a susceptible host) and toxin production has been well observed in FHB species (Toth *et al.*, 2020; Sakr, 2022).

Growing *Triticum* cultivars carrying *Fusarium* resistance genes is the most efficient and environmentally sound way of managing FHB (Sakr, 2022). The resistance types of head blight compose a complex syndrome (Fernando *et al.*, 2021) in which five resistance types were observed (Parry *et al.*, 1995; Buerstmayr *et al.*, 2020; Tahir *et al.*, 2023); however, Type I, Type II and Type III are the principal types contributing to “field resistance” and have been more widely assessed in all wheat nursery and breeding programs (Moonjely *et al.*, 2023). Type I, the component for initial infection and reaction to spray inoculation, Type II, describes the spread of *Fusarium* from the ovary to the other parts of the spike and response to spikelete infection as well as Type III, resistance to kernel infection. Till now, strategies to control head blight are restricted since commercial durum wheat cultivars with high levels of resistance are not available to growers (Buerstmayr *et al.*, 2020). Development of cultivars with a high level of quantitative resistance has been slow due to that (1) FHB resistance to *Fusarium* is polygenic and (2) its expression is highly influenced by environmental conditions including moisture and temperature (Fernando *et al.*, 2021).

In several wheat-growing areas, the occurrence of noxious FHB epidemic is often sporadic (Moonjely *et al.*, 2023) and head blight epidemics changes greatly in different years and locations (Parry *et al.*, 1995), being *Fusarium* colonization and development in head tissues strictly dependent on the epidemiological conditions (Sakr, 2022). The form (relative humidity, rainfall, or surface wetness), pattern, period, amount, and timing of humidity events over the infection cycle that coincide with the duration of wheat susceptibility, which extends from anthesis to the soft dough stage of grain development, may all play a role in detecting *Fusarium* intensity. Main outbreaks of FHB were principally linked to humid, wet weather conditions during flowering and early kernel fill (Fernando *et al.*, 2021). Under these conditions, *Fusarium* conidia germinate and the germ tubes grow into spike tissues (Parry *et al.*, 1995; Mesterhazy, 2024). Numerous studies and surveys have established that moisture (rainfall and humidity) is the primary determinants of FHB development (Bai *et al.*,

2022; Matengu *et al.*, 2024; Anda *et al.*, 2024). In fact, the dependence of *F. graminearum* on moisture was reported in bread wheat (Lemmens *et al.*, 2004; Nita *et al.*, 2005; Culler *et al.*, 2007; Cowger *et al.*, 2009; Gautam and Dill-Macky 2012; Andersen *et al.*, 2015), but no information is available for other important fungal species causing FHB on durum wheat (Atiq *et al.*, 2022). Experimental researches and designed trails are needed to assess the relative importance of post-anthesis weather *Fusarium* on damage.

In this investigation, we hypothesized that increased post-flowering moisture promotes FHB development in durum wheat, particularly under natural climatic conditions. Three durum cultivars of varying resistance levels were inoculated at mid-anthesis and plants were subjected to durations of post-anthesis mist from 0 to 28 days in order to acquire a broader range of wet-day durations. The findings we acquired on FHB, disease incidence, disease severity and *Fusarium* damaged kernels, allowed us to elucidate the relationship of variable watering conditions to potential increasing in FHB symptoms in durum wheat. In this present work, our objective was to better analyze the impact of different numbers of post-anthesis wet days on the infection of durum wheat cultivars by 16 fungal isolates of varying pathogenicity of four fungal species causing FHB, i.e., *F. culmorum*, *F. solani*, *F. verticillioides*, and *F. equiseti* which are the prevailing species infecting wheat in Syria (Sakr, 2023).

MATERIALS AND METHODS

Durum wheat materials and growth conditions: The three durum wheat cultivars with favorable agronomic and quality traits (high harvest index, earliness, shorter plants and improved biomass partitioning to the grain) and resistance to fungal diseases widely grown in diverse Syrian locations including Ghab Plain, one of the principal wheat production areas. Acsad65, Cham7 and Cham9 released in 1984, 2004 and 2010, respectively, were used to set up under open field experimental trials. The three cultivars are adopted for rainfed agriculture. Differential resistance reactions to FHB infection on Acsad65, Cham7 and Cham9 were detected under several experimental conditions (Sakr 2023); Cham7 and Cham9 (susceptible to moderately susceptible) showed lower levels of FHB damage than Acsad65 (susceptible).

Durum wheat seeds were surface-sterilized with 5% sodium hypochlorite solution for 8 min and then washed

six times in sterile distilled water. Eight surface-sterilized seeds were sown into plastic 15-cm pots containing clay soil. The potting soil consisted of 2% sand, 39% loam and 57% clay collected from the Sojji Agricultural Experiment Station, located west of Damascus, Syria (33°30' N, 36°07' E) at 700 m above sea level with pH 7.8, organic matter 1.25%, was air dried, sieved to pass a 3 mm screen, and pasteurized at 5 kGy of Gamma Ray (GR) with 60Co source using a gamma irradiator (ROBO, Russia). One week following emergence, plants were thinned to five plants per pot, and nitrogen, in the form of urea, was applied at 0.173 g/pot at two dates: emergence and tillering. Each pot was used as one treatment. The pots were placed outdoor under natural climatic conditions. To reduce year effects on results, it appeared to be crucial in these arid conditions to aid the growth development by irrigation of durum wheat pots at roughly weekly intervals afterward.

Fungal isolates and inoculum preparation: Survey data conducted over the 2015 growing season on wheat spikes displayed typical disease symptoms across nine villages in Ghab Plain with a FHB history indicated that 16 fungal isolates of four FHB species were recovered (Sakr, 2023). In this study, these 16 fungal isolates [*F. culmorum* (5 isolates), *F. verticillioides* (synonym *F. moniliforme*) (4 isolates), *F. solani* (6 isolates), and *F. equiseti* (one isolate)] representing of the range in aggressiveness capacity (Sakr, 2023) were used for the artificial inoculation. FHB isolates were obtained from several field-grown susceptible wheat cultivars to ensure adequate pathogenicity on the three wheat cultivars. Isolates were identified morphologically on the basis of macroscopic observation of cultural features such as pigmentations and growth rates over the surface of PDA as well as their microscopic characteristics involving size of macro conidia, presence of micro conidia and chlamydospores according to Leslie and Summerell (2006). By using random amplified polymorphic DNA markers, the 16 *Fusarium* species causing head blight isolates were recently analyzed (Sakr, 2023). For long term preservation, fungal cultures were maintained in sterile distilled water at 4°C or by freezing at -16°C (Sakr, 2020). FHB inoculum used for artificial inoculation was normally performed as following: fungal suspension or four to six agar plugs out of each stored single-spore culture were put over the surface of Petri dishes PDA and incubated under continuous darkness at 22°C for 10

days to allow sporulation and fungal development. Following incubation, isolates were covered with 10 ml of sterile distilled water and conidia were dislodged. Through 2 layers of sterile cheesecloth, *Fusarium* suspensions were filtered to remove the pieces of mycelia and agar and directly quantified with a Neubauer chamber under an optical microscope and diluted to a desirable concentration as inoculum sources.

Experimental design and treatments: A split-split-plot experiment with five replications was conducted at the research field of Deir AL-Hajar Station located south east

of Damascus, Syria (36° 280E, 33° 210 N; altitude 617m) in the growing season of 2022/2023. The number of five replicates was based on prior experiments (Cowger *et al.*, 2009). The site is located within a dry Mediterranean semiarid area with hot-dry summer and cold winter. The total annual rainfall is about 120 mm, and most precipitations occur between November and early April. For the last ten years, the average minimum temperature in winter was 1.3°C in January, while it increases to the average maximum temperature of 38.3 °C in July. Some climatic data of the experimental site during the growing period is shown in Table 1.

Table 1: Some climatic data collected over the growing seasons 2022/23 at the experimental station

Growing season	Variable	November	December	January	February	March	April	May
2022/23	T _{min} (°C)	8.4	4.7	3.8	3.9	7.2	9.9	13.2
	T _{max} (°C)	21.0	16.1	14.2	16.5	20.3	30.2	31.3
	RH (%)	72.0	74.0	83.5	75.5	73.5	54.5	53.5
	Rainfall (mm)	47.5	42.0	26.9	18.1	23.7	6.4	4.0

Abbreviations: T_{min} – minimum temperature; T_{max} – maximum temperature; RH – relative air humidity.

Experiments were split-split-plots with five replications. Main plots were spray-irrigation treatments with four levels [spray irrigation from inoculation until 7, 14, 21, or 28 days after inoculation (DAI) which corresponds to the wheat growth stages of 67, 75, 83 and 85, respectively]. Sub-plots were the durum wheat cultivars [Acsad65, Cham7 and Cham9] and the sub-sub-plots were the isolates of four *Fusarium* pathogens with contrasting aggressiveness. Non-inoculated plants were arranged in five replicates and were treated with SDW. Replications within each spray-irrigation main plot, cultivars within replications and isolates within the cultivar sub-plots were assigned randomly. Five replicate pots of each cultivar were subjected to each duration of post-anthesis spraying, and the experiment was repeated twice.

Inoculation and spraying: For inoculation of pots placed under natural climatic conditions, durum wheat cultivars were separately inoculated with the 16 *Fusarium* cultures to evaluate head blight incidence (DI, Type I resistance), head blight severity (DS, Type II) and *Fusarium*-damaged kernels (FDK, Type III) as indicators of the cultivar's resistance. At full anthesis (GS=65) in the early morning, infection of wheat plants was conducted by head spraying of *Fusarium* suspension or SDW for non-inoculated wheat plants. The rainfall amounts during key growth phases (flowering and heading) were 23.7 mm for March, 6.4 mm for April, and 4.0 mm for May. The average of rainfall

Uniform inoculum spraying onto wheat heads was conducted on one date. The infected wheat heads were kept inside plastic bags the inner surfaces of which had been sprayed with SDW. Acsad65, Cham7 and Cham9 plants were kept under these conditions for 48 h in order to supply humid conditions suitable for the premiere stage of pathogenesis.

Spraying was provided using sprinkler heads. The different durations of post-anthesis spray were provided by opening or closing individual lateral irrigation lines. By means of a programmable timer, spraying was provided for 2 min of each 20-min period for 3 h each in the morning and afternoon, or a total of 36 min per day in order to avoid drying of inoculum. All periods of post-anthesis spraying (0, 7, 14, 21 or 28 DAI) started on in April, 2023. Spraying treatments were initiated at the first inoculation date.

Disease assessment: Under natural climatic conditions, disease evaluations were carried out on each cultivar approximately 21 days after it has been inoculated. DI, DS and FDK were determined to detect the level of head blight progress and colonization in light of visual symptoms in head tissues under changeable watered conditions. DI was determined as the proportion of heads with diseased spikelets and DS as the average proportion of diseased spikelets in the infected heads. After harvesting, mature inoculated spikes from each

replication were taken for additional evaluations; the spikes were threshed to save shrivelled and infected kernels. The percentage of scabby (tombstone) kernels was assessed visually on 100 grains for each replication to estimate FDK for Type III (Mesterhazy *et al.*, 1999).

Statistical analysis: The experimental data were subjected to analysis of variances (ANOVA) using DSASTAT add-in version 2011. Before statistical analysis, the percentages of disease incidence, disease severity and *Fusarium* damaged kernels were transformed using the angular transformation to achieve homogeneity of variances. Disease incidence, disease severity and *Fusarium* damaged kernels data from 7, 14, 21, and 28 DAI treatments were combined, as all three treatments received equal spraying until the time when FHB symptoms were scored. ANOVA incorporating the Fisher’s LSD test at $P>0.05$ was used to compare the means of treatments receiving changeable watered conditions.

RESULTS

During the durum wheat cycle in the growing season of 2022/2023, climatic conditions including temperature and rainfall (Table 1) were favorable to FHB disease. ANOVA showed that moisture, isolate, cultivar, isolate × cultivar, isolate × moisture interaction, and cultivar × moisture interaction had highly significant effects ($p<0.05$) on DI and DS (data not shown). However,

significant interactions ($p<0.05$) were observed for isolate × moisture interaction and cultivar × moisture interaction regarding FDK (data not shown). These interactions were significant in aligning with our hypothesis that moisture had an effect of aggressiveness of fungi and resistance of plants. None of the three tested durum wheat cultivars: Acsad65, Cham7 and Cham9 was immune from FHB disease under changeable watered conditions (Tables 2, 3 and 4). On Acsad65, Cham7 and Cham9, duration of post-anthesis spraying irrigation resulted in higher disease intensity based on the percentage of diseased florets and smaller necrotic patches, and more bleaching of the florets and discolored kernels as compared to treatments receiving no moisture excess (Tables 2, 3 and 4). Average disease intensities, when combined across spray-irrigation, wheat cultivar and *Fusarium* isolate treatments, were $16.5\pm4.2\%$, $16.9\pm2.3\%$ and $16.7\pm2.8\%$, respectively, for DI, DS, and FDK, respectively. Overall, the disease DI and DS for susceptible cultivar Acsad65 were significantly higher (15.2% and 12.4%, respectively) than Cham7 and Cham9 cultivars showed susceptible to moderate susceptibility. However, the disease FDK for Acsad65, Cham7 and Cham9 was not statistically different because FDK criterion did not differentiate FHB isolates and the three tested durum wheat cultivars following artificial infection.

Table 2. *Fusarium* head blight symptoms measured by disease incidence (%) for 16 fungal isolates of four *Fusarium* species on three durum wheat cultivars subjected to varying durations of post-anthesis spray under natural climatic conditions

Fungal isolates (identification)	Days of post-anthesis spraying														
	0			7			14			21			28		
	Ac65	Ch7	Ch9	Ac65	Ch7	Ch9	Ac65	Ch7	Ch9	Ac65	Ch7	Ch9	Ac65	Ch7	Ch9
F1 (<i>F. culmorum</i>)	65	55	33	66	54	34	75	62	37	82	65	40	83	67	42
F2 (<i>F. culmorum</i>)	43	40	53	44	39	54	49	44	60	54	47	65	55	48	67
F3 (<i>F. culmorum</i>)	58	56	56	59	55	57	67	63	63	73	66	68	74	67	70
F28 (<i>F. culmorum</i>)	72	35	63	73	34	64	82	39	71	90	41	76	91	42	79
F30 (<i>F. culmorum</i>)	70	37	40	71	37	41	80	42	45	88	44	49	89	45	50
F7 (<i>F. solani</i>)	53	46	48	53	45	49	60	52	54	66	54	58	67	55	61
F20 (<i>F. solani</i>)	69	53	63	70	52	64	79	60	71	86	63	76	88	64	79
F26 (<i>F. solani</i>)	49	42	56	49	41	57	56	47	63	61	50	68	62	50	71
F29 (<i>F. solani</i>)	70	63	52	71	61	53	80	70	59	88	74	63	89	75	66
F31 (<i>F. solani</i>)	33	59	33	34	58	34	38	67	37	42	70	40	42	72	42
F35 (<i>F. solani</i>)	41	64	42	42	62	43	47	71	47	52	75	51	52	77	53
F15 (<i>F. verticillioides</i>)	40	55	43	40	54	44	45	62	49	50	65	52	50	66	54
F16 (<i>F. verticillioides</i>)	53	36	39	54	36	40	61	41	44	67	43	47	68	44	49
F21 (<i>F. verticillioides</i>)	56	65	48	57	64	49	64	73	54	70	77	58	71	78	60
F27 (<i>F. verticillioides</i>)	49	32	37	50	31	38	56	36	42	62	38	45	63	38	47
F43 (<i>F. equiseti</i>)	48	54	40	48	53	40	55	60	45	60	64	48	61	65	50
($P>0.001$)***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***

Abbreviations, Ac65= Acsad65, Ch7 = Cham7, Ch9 = Cham9. Values are means of five replications.

All the 16 analyzed *Fusarium* isolates were pathogenic and induced typical and clear head blight symptoms which are simple to evaluate in the infected heads and florets over periods of spray-irrigation of 0, 7, 14, 21, and 28 days (Tables 2, 3 and 4), showing a strong effect of duration of humidity on FHB growth in head tissues of the three wheat cultivars, while no symptoms were present in

the control with no fungal infection. Isolates did significantly differ for DI and DS in all tested cultivars. However, The FHB DI and DS did not vary in their relative rankings under changeable watered conditions. Regarding *Fusarium* FDK, FHB isolates did not change in Acsad65, Cham7 and Cham9 leading to constancy of aggressiveness ranking among head blight isolates.

Table 3. *Fusarium* head blight symptoms measured by disease severity (%) for 16 fungal isolates of four *Fusarium* species on three durum wheat cultivars subjected to varying durations of post-anthesis spray under natural climatic conditions

Fungal isolates (identification)	Days of post-anthesis spraying														
	0			7			14			21			28		
	Ac65	Ch7	Ch9	Ac65	Ch7	Ch9	Ac65	Ch7	Ch9	Ac65	Ch7	Ch9	Ac65	Ch7	Ch9
F1 (<i>F. culmorum</i>)	47	46	25	46	48	26	55	55	28	58	56	30	59	55	30
F2 (<i>F. culmorum</i>)	31	32	41	30	34	41	36	39	46	39	40	49	40	39	48
F3 (<i>F. culmorum</i>)	41	45	42	40	47	43	48	54	48	51	55	51	52	54	50
F28 (<i>F. culmorum</i>)	52	27	48	50	29	49	60	33	54	64	34	58	65	33	56
F30 (<i>F. culmorum</i>)	51	29	31	50	31	31	60	35	34	64	36	37	65	35	36
F7 (<i>F. solani</i>)	43	36	39	42	38	40	50	43	44	54	44	47	55	43	46
F20 (<i>F. solani</i>)	56	45	51	55	47	51	66	54	57	70	55	61	71	54	60
F26 (<i>F. solani</i>)	40	35	45	39	37	46	46	42	51	49	43	55	50	42	53
F29 (<i>F. solani</i>)	57	49	42	56	51	43	67	59	47	71	60	51	72	59	50
F31 (<i>F. solani</i>)	27	46	27	26	49	27	31	56	30	33	57	32	34	56	31
F35 (<i>F. solani</i>)	34	51	34	33	53	35	39	61	38	42	62	41	43	61	40
F15 (<i>F. verticillioides</i>)	30	45	36	30	47	37	36	54	41	38	55	44	39	54	43
F16 (<i>F. verticillioides</i>)	40	30	33	39	31	33	47	36	37	50	36	40	51	36	39
F21 (<i>F. verticillioides</i>)	42	54	40	41	56	41	49	65	45	52	66	48	53	65	47
F27 (<i>F. verticillioides</i>)	29	25	31	29	27	32	34	31	35	36	31	38	37	31	37
F43 (<i>F. equiseti</i>)	36	43	33	35	46	33	42	52	37	45	53	40	46	52	39
(P>0.001)***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***

Abbreviations, Ac65= Acsad65, Ch7 = Cham7, Ch9 = Cham9. Values are means of five replications.

Table 4. *Fusarium* head blight symptoms measured by damaged kernels (%) for 16 fungal isolates of four *Fusarium* species on three durum wheat cultivars subjected to varying durations of post-anthesis spray under natural climatic conditions

Fungal isolates (identification)	Days of post-anthesis spraying														
	0			7			14			21			28		
	Ac65	Ch7	Ch9	Ac65	Ch7	Ch9	Ac65	Ch7	Ch9	Ac65	Ch7	Ch9	Ac65	Ch7	Ch9
F1 (<i>F. culmorum</i>)	37	37	37	38	36	39	43	43	42	46	44	47	45	45	44
F2 (<i>F. culmorum</i>)	36	35	36	37	34	38	42	41	41	45	42	46	44	43	43
F3 (<i>F. culmorum</i>)	38	37	37	39	36	39	44	44	42	47	45	46	46	46	44
F28 (<i>F. culmorum</i>)	40	40	40	41	39	42	46	47	45	49	48	51	48	49	48
F30 (<i>F. culmorum</i>)	37	35	37	38	34	39	43	42	42	46	43	47	45	43	44
F7 (<i>F. solani</i>)	37	36	37	38	35	39	42	43	42	45	44	47	44	45	44
F20 (<i>F. solani</i>)	39	36	38	40	35	40	45	43	44	49	44	49	47	45	46
F26 (<i>F. solani</i>)	36	41	37	36	40	39	41	49	42	44	50	46	43	51	44
F29 (<i>F. solani</i>)	38	39	37	39	38	39	44	46	42	47	47	47	46	48	44
F31 (<i>F. solani</i>)	38	38	39	39	37	41	43	45	45	46	46	50	45	47	47
F35 (<i>F. solani</i>)	39	40	39	40	39	41	45	47	44	49	48	50	47	49	46
F15 (<i>F. verticillioides</i>)	38	38	40	39	37	42	44	45	45	47	46	51	46	47	47
F16 (<i>F. verticillioides</i>)	40	40	38	41	39	40	46	48	44	49	49	49	48	50	46
F21 (<i>F. verticillioides</i>)	38	38	37	39	37	39	43	45	42	46	46	47	45	47	44
F27 (<i>F. verticillioides</i>)	38	37	37	39	36	39	43	43	42	46	44	46	45	45	44
F43 (<i>F. equiseti</i>)	38	37	39	39	36	41	44	44	44	47	45	49	46	46	46
(P>0.001)***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***

Abbreviations, Ac65= Acsad65, Ch7 = Cham7, Ch9 = Cham9. Values are means of five replications.

Figure 1 shows all pathogenic criteria on Acsad65, Cham7 and Cham9 collected under natural climatic conditions. Generally, no significant differences were observed between the 0 and 7-day spray-irrigation treatments. 21 or 28 days of spray had the same effect and were associated with an increase in mean DI by 20.6% and 21.7%, respectively and DS by 19.6% and 21.2%, respectively compared with 0 or 7 days of spray, and 14

days of spray was also linked with an increase by 12.9% and 14.6%, respectively in mean of these pathogenic criteria (Figure 1). Mean *Fusarium* damaged kernel proportions at 0 and 7 days of spray were similar and significantly lower than *Fusarium* damaged kernel proportions under 21 days by 19.1% or 28 days by 17.4% of spray, and 14 days of spray was also linked with an increase by 13.6% in mean of FDK (Figure 1).

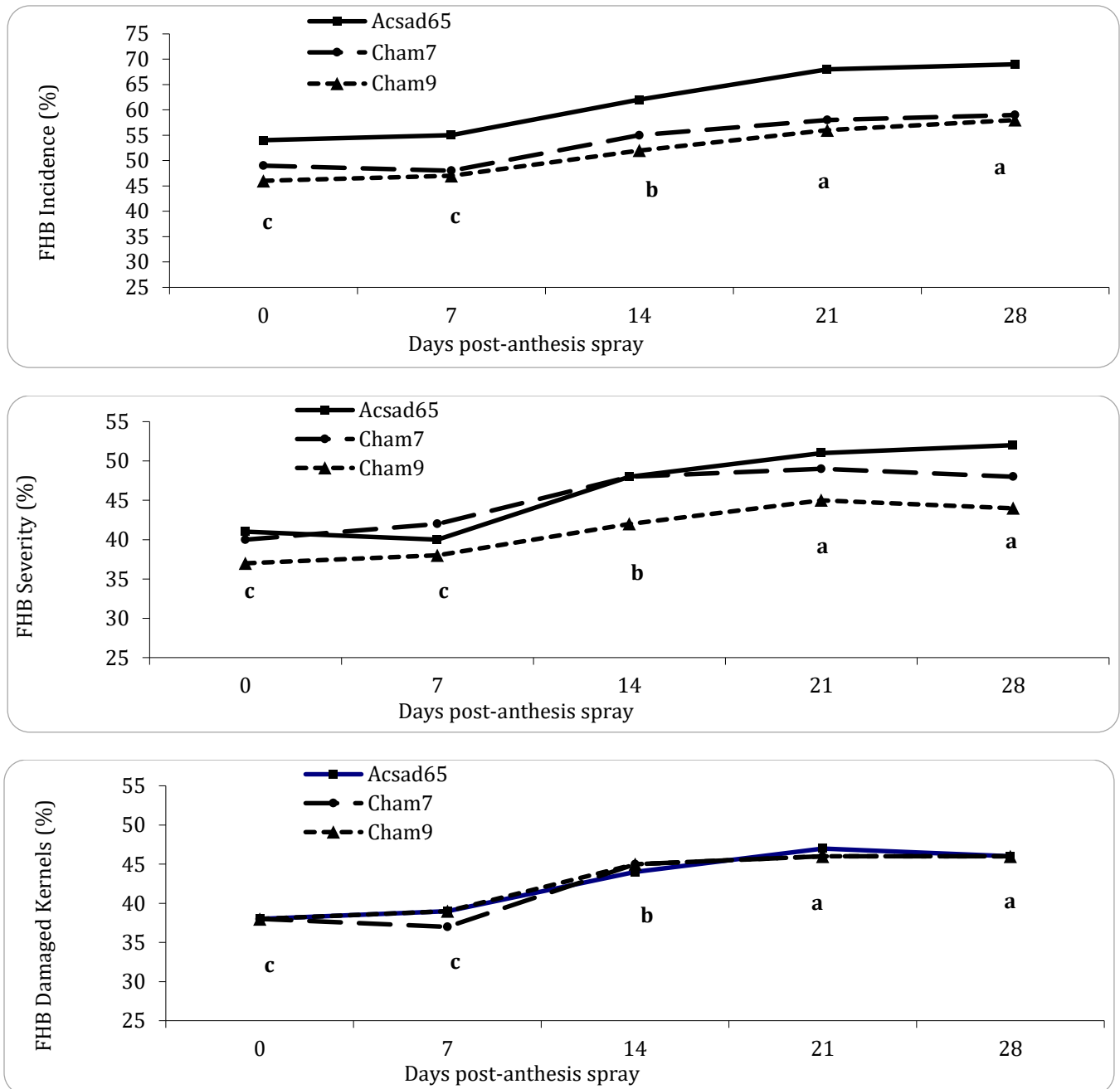


Figure 1. Mean values (%) for Fusarium head blight symptoms of 16 *Fusarium* isolates on three durum wheat cultivars subjected to varying durations of post-anthesis spray. Data points with the same letter are not significantly different at $P > 0.05$.

DISCUSSION

Warm temperatures and extended periods of moisture on plant surfaces around anthesis favor the infection and colonization of wheat tissues by *Fusarium* species (Parry *et al.*, 1995). Since the early 1990s, FHB has become the major disease threatening durum production worldwide has caused major economic losses for producers (Fernando *et al.*, 2021; Moonjely *et al.*, 2023). For instance, a severe FHB epidemic caused 65% of the common wheat and 36% of the durum wheat to be downgraded in Saskatchewan, Canada in 2016, with an estimated economic loss of \$1 billion (FAO, 2022). Canada is the largest producer and exporter of durum wheat supplying more than a half of the world's total exported durum (FAO, 2022). In addition, *Triticum durum* is principally cultivated under rain-fed climates in the Mediterranean basin (FAO, 2022). In fact, an increasing demand for high quality flour, pasta, and semolina products has led to an expansion of *T. durum* production zones from traditional warm and dry cropping areas to more humid regions with climatic conditions conducive to FHB disease (Fernando *et al.*, 2021). This connecting to the economic and food security impact of FHB in major durum wheat-growing regions might emphasize our study's importance.

The abundance of weather conditions, mainly moisture, during and after anthesis determines the severity of FHB disease (Buerstmayr *et al.*, 2020; Ahmad *et al.*, 2024). The effect of moisture on FHB development has noted to be a significant factor on *F. graminearum* (Mesterhazy *et al.*, 1999, 2020) in bread wheat head tissues. However, there are not available observations related to *Fusarium* development in durum wheat heads under changeable watered conditions, with reference to other FHB species. To fill this gap, we reported for the first time the effect of extended periods of moisture at and / or shortly after anthesis that favor the FHB infection and colonization of three durum wheat cultivars with contrast resistance to disease (Sakr, 2023). We found that spray irrigation duration treatments had a significant impact on all pathogenic components evaluated in the current investigation. Longer periods of spray-irrigation resulted in increased disease incidence, disease severity and *Fusarium* damaged kernels values. Our data suggest that cultivar rankings for several indicators commonly used by breeders (DI, DS, and FDK) may change under extended post-anthesis irrigation. The implications of our findings

for breeding programs should be considered. Many breeders now assess cultivars for FHB resistance based on either natural rainfall or misting during the period around anthesis. Our data suggest that cultivar rankings for several indicators commonly used by breeders (DI, DS, and FDK) may change under extended post-anthesis irrigation.

Aggressiveness, a term used to refer to quantitative traits related to pathogenicity, such as rate of disease progress, lesion size and infection efficiency (Van der Plank, 1968) variability, has been shown to be well known and confirmed in subsequent studies (Mesterhazy, 2024). More aggressive isolates (Sakr, 2022) will cause more damage and therefore greater economic loss (Xue *et al.*, 2019). In this study, although the sixteen isolates tested changed in their ability to stimulate head blight symptoms in inoculated plants under natural climatic conditions, moisture in late stages after anthesis, i.e., 14, 21, and 28 days after infection did not vary the relative rankings of FHB DI and DS for the tested isolates on durum cultivars differed in FHB susceptibilities, showing that extended moisture does not influence aggressiveness order among FHB isolates whatever the level of resistance of materials plants. Gautam and Dill-Macky (2012) reported comparable results for *F. graminearum* strains on bread wheat cultivars showing different resistance levels. Therefore, it is speculated that there must be other factors besides toxins which contribute to isolate aggressiveness (Mesterhazy, 2020, 2024).

Moisture in the form of rainfall or relative humidity, during or shortly after anthesis, has been linked to higher FHB incidences, Type I and FHB severities, Type II (Parry *et al.*, 1995; Rohacik and Hudec, 2005). In this study, no significant differences were observed between the 0 and 7-day spray-irrigation treatments, suggesting that extended moisture promotes disease development and increases grain fungus colonization. FHB severity did significantly change among treatments receiving diverse durations of spray irrigation (0 and 7 days of spray versus 14, 21 and 28 DAI). The scores of FDK, assessed in kernel harvested at maturity, were significantly higher in the treatments which received longer durations of spray irrigation and lowest in the treatment receiving the shortest period of spraying. These results agree with the results obtained by Cowger *et al.*, (2009) in *F. graminearum*-inoculated winter wheat. They observed lower FHB intensities and FDK in treatments receiving 0

and 10 days of misting after flowering, relative to those treatments receiving 20 and 30 days of misting. Higher FHB severities in mist-irrigated plots compared to non-misted plots have also been reported by Lemmens *et al.* (2004), although in their study the *Fusarium* damage to grain was not examined. Culler *et al.* (2007) also reported higher FHB severities and FDK levels in *F. graminearum* inoculated wheat receiving mist-irrigation for 31–32 days after inoculation compared to treatments receiving misting for only 15–16 days. The role of moisture on FHB development has been investigated by Gautam and Dill-Macky (2012), providing valuable information pertaining to the effects of moisture on FHB disease and its associated toxin. In addition, our results have obvious implications for disease prediction models. For practical purposes, increasing numbers of wet days after flowering are likely to be associated with increased disease symptoms. Longer durations of post-anthesis moisture are thus likely to result in yield and test weight losses (Parry *et al.*, 1995).

Substantial gains in our understanding of the biology and epidemiology of FHB have been made in recent years (Moonjely *et al.*, 2023). It is now well reported that meteorological variables, especially those linked to humidity, are significant for several processes in *Fusarium* infection cycle (Fernando *et al.*, 2021). The resistance of wheat to *Fusarium* can affect the progress of head blight pathogens in head tissues. Culler *et al.* (2007) also reported that the resistance in moderately resistant cultivars can be overwhelmed by high inoculum pressure under highly favorable environmental conditions. In the present study, a susceptible cultivar, i.e., Acsad65, had consistently, and significantly, higher FHB severities, compared to the cultivars with susceptible to moderate susceptibility moderate resistance, Cham7 and Cham9. This observation suggests that in Cham7 and Cham9, their quantitative resistance level results in slower development of the FHB pathogens, and might be due to the complex resistance mechanisms expressed by differential reactions conferred by quantitative trait loci mediated during FHB invasion (Fernando *et al.*, 2021; Moonjely *et al.*, 2023), governing more resistance in cultivars showing a susceptible to moderate susceptibility moderate resistance, i.e., Cham7 and Cham9 than a susceptible cultivar, i.e., Acsad65. Gautam and Dill-Macky (2012) achieved very similar results when testing *F. graminearum* and bread wheat cultivars with different

levels of FHB resistance. Our results appeared to apply equally to moderately resistant cultivars with either Type I or Type II resistance, or both, and to susceptible cultivars. Thus, our results are likely applicable to breeding programs worldwide. Our result suggests that the possible leaching of mycotoxins that may act as aggressiveness factors and enhance the pathogenicity of *Fusarium* fungi in durum wheat (Buerstmayr *et al.*, 2020), is also higher in susceptible cultivars than resistant ones. We hypothesize that a higher level of lignin accumulation in the resistant cultivar in reaction to head blight colonization and invasion (Kang and Buchenauer, 2000; Iqbal *et al.*, 2022; Atiq *et al.*, 2023) might in turn have some influence on decreased leaching of mycotoxin from the head tissues. However, further study on this aspect is warranted to derive a definitive conclusion.

Given the dependence of FHB epidemics on a wet and warm growing season, and the relatively short period of susceptibility of heads to infection (Fernando *et al.*, 2021), it would appear that knowledge of influence of extended periods of moisture on durum wheat-FHB pathosystem will be of great importance. In particular, environmental conditions favorable to the infection on durum wheat were not investigated exhaustively (Parry *et al.*, 1995; Moonjely *et al.*, 2023). What mechanisms could underlie the association between increasing durations of post-flowering moisture and increasing FHB severities? One possibility is that the higher relative humidity around heads is conducive to fungal development (Cowger *et al.*, 2009). The additional moisture in treatments conducted under experimental conditions with longer durations of spraying presumably provided an environment conducive for fungal growth and disease development that contributed to the observed increase in FHB symptoms as observed earlier. Another possible factor is reduced water stress in host plants, which could facilitate head colonization, perhaps by delaying the onset of senescence (Cowger *et al.*, 2009). Under suitable climatic conditions (high relative humidity) over wheat flowering, *Fusarium* inoculum is able of dispersing by rain or wind to reach the anther and begin the plant infection (Fernando *et al.*, 2021). First, the spores germinate; then the hyphae grow on the ovary, palea, and lemma; and, after that, they start symptom production (Ma *et al.*, 2019; Shad *et al.*, 2023). Fungal growth by the *Fusarium* pathogens account on complicated interactions between biotic and abiotic factors (Xue *et al.*, 2019; Miedaner *et al.*, 2021;

Mesterhazy, 2020, 2024). Within the latter, water activity represents one of the main factors that has a strong influence on the transcriptional activation of pathogenicity genes (Moonjely *et al.*, 2023; Shad *et al.*, 2024).

In bread wheat, it is obvious from designed experiments and empirical observations that extended periods of high humidity, particularly around anthesis, are critical for *graminearum* development in head tissues (Lemmens *et al.*, 2004; Nita *et al.*, 2005; Culler *et al.*, 2007; Cowger *et al.*, 2009; Gautam and Dill-Macky 2012; Andersen *et al.*, 2015). This study involved infections occurring due to artificial inoculation in durum wheat on a single day at mid-anthesis. Why, then, did disease incidence, disease severity and *Fusarium* damaged kernels vary with post-anthesis mist duration? The answer is not likely to be secondary infections because, for the most part, there would not have been time for originally infected heads to form sporodochia for polycyclic infections (Dahl and Wilson, 2018). Perhaps some *Fusarium* conidia remained in crevices or on the surface of glume tissues, rather than infecting anthers, and their ability to eventually penetrate the glumes was affected by the duration of moist conditions. However, there are limitations of our study, such as environmental variability or differences in isolate aggressiveness, and they might impact generalizing the results.

CONCLUSION

A better understanding of the role of moisture on this disease invasion in wheat head tissues is important for developing and refining prediction models to help guide FHB management and grain marketing decisions. This is the first report to show that increasing durations of post-flowering humidity can have a crucial enhancing impact on FHB disease incidence, disease severity and *Fusarium* damaged kernels of Syrian durum wheat cultivars upon

REFERENCES

- Ahmad, H., N.A. Rajput, M. Atiq, G.A. Kachelo, M. Usman, H. Tariq and M. Wahab. 2024. Detection of *Phytophthora nicotiana* induced citrus gummosis by the loop mediated isothermal amplification. Pakistan Journal of Botany, 56(5): 1-11.
- Al-Chaabi, S., S. Al-Masri, A. Nehlawi, L. Al-Matroud and T. Abu-Fadel. 2018. Monitoring of *Fusarium* wheat head blight distribution, its causal agents, and pathogenicity variation in Al-Ghab plain, Syria. Arab Journal of Plant Protection, 36: 98-113.
- Alkadri, D., P. Nipoti, K., Doll, P., Karlovsky, A., Prodi and A. Pisi. 2013. Study of fungal colonization of wheat

artificial infection with 16 fungal isolates showing different aggressiveness abilities of four *Fusarium* species. It appears that variable moisture conditions applied on wheat materials of diverse resistance levels do not influence aggressiveness of the analyzed FHB isolates whatever their genetic origin (i.e., *F. culmorum*, *F. solani*, *F. verticillioides*, and *F. equiseti*) and pathogenic backgrounds (high, medium and low pathogenicity), suggesting that post-anthesis flowering non-specifically impact progress of *Fusarium* isolates. These findings suggest that improved moisture management and cultivar selection are critical strategies for minimizing FHB-related yield losses in durum wheat. From a grower's perspective, prolonged rainy periods following wheat flowering should be a signal to scout wheat crops for FHB symptoms, even if pre-flowering conditions were not conducive to FHB. Knowledge of the effect of humidity should be of value to wheat breeders and pathologists, principally by enhancing our comprehension of the conditions that lead to discrepancies between visual assessments of head blight, post-harvest visual evaluation of *Fusarium* damage to grain that are frequently observed in both dry-land and spray-irrigated germplasm screening nurseries. In addition, exploring more diverse *Fusarium* species or testing additional wheat cultivars, could provide a roadmap for other researchers to build upon our work.

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kernels in Syria with a Focus on *Fusarium* species. International Journal of Molecular Sciences, 14(3): 5938-5951.

- Anda, A., B. Simon-Gaspar, S. Simon, G., Soos and L. Menyhart. 2024. Modeling Risk in *Fusarium* Head Blight and Yield Analysis in Five Winter Wheat Production Regions of Hungary. Agriculture, 14(7): 1093.
- Andersen, K. F., L. V. Madden and P. A. Paul. 2015. *Fusarium* head blight development and deoxynivalenol accumulation in wheat as influenced by post-anthesis moisture patterns.

- Phytopathology, 105(2): 210-219.
- Atiq, M., M.Z. Talib, N.A. Rajput, S.T. Sahi, M.A. Khan, M. Usman, A. Jabar, M.J. Arif, M.D. Gogi, M.A. Khan and A. Akram. 2023. New-fangled tactics towards cotton leaf curl virus disease A review. *Journal of Natural Fibers*, 20 (2): 2217364.
- Atiq, M., N.A. Rajput, S.T. Sahi, A. Akram, M. Usman, G.A. Kachelo, H. Ahmad, A.Q. Khan, H. Tariq, S. Ramzan, Z.B. Tahir and M.J. Matloob. 2022. A way forward towards the management of chilli anthracnose -a review. *Agricultural Science Journal*, 4(1): 1-10.
- Bai, H. Z. D. P. Xiao., B. Wang., D. L. Liu and J. Z. Tang. 2022. Simulation of wheat response to future climate change based on coupled model inter-comparison project phase 6 multi-model Ensemble projections in the North China plain. *Frontiers in Plant Science*, 13: 829580.
- Buerstmayr, M., B. Steiner and H. Buerstmayr. 2020. Breeding for Fusarium head blight resistance in wheat—progress and challenges. *Plant Breeding*, 139(3): 429-454.
- Cowger, C., J. Patton-Özkurt, G. Brown-Guedira and L. Perugini. 2009. Post-anthesis moisture increased Fusarium head blight and deoxynivalenol levels in North Carolina winter wheat. *Phytopathology*, 99: 320-327.
- Culler, M. D., J. E. Miller-Garvin and R. Dill-Macky. 2007. Effect of extended irrigation and host resistance on deoxynivalenol accumulation in *Fusarium*-infected wheat. *Plant Disease*, 91(11): 1464-1472.
- Dahl, B. and W. W. Wilson. 2018. Risk premiums due to Fusarium head blight (FHB) in wheat and barley. *Agricultural Systems*, 162: 145-153.
- FAOSTAT. 2022. Production quantities worldwide. [cited 2022 November 16] Available from: <http://faostat.fao.org/> Accessed 16 Nov 2022.
- Fernando, W. G. D., A. O. Oghenekaro., J. R. Tucker and A. Badea. 2021. Building on a foundation: advances in epidemiology, resistance breeding, and forecasting research for reducing the impact of Fusarium head blight in wheat and barley, *Canadian Journal of Plant Pathology*, 43: 495-526.
- Gautam, P. and R. Dill-Macky. 2012. Impact of moisture, host genetics and *Fusarium graminearum* isolates on Fusarium head blight development and trichothecene accumulation in spring wheat. *Mycotoxin Research*, 28: 45-58.
- Iqbal, S., M.A. Khan, M. Atiq, N.A. Rajput, M. Usman, A. Nawaz, G.A. Kacheo, A. Akram and H. Ahmad. 2022. Mango anthracnose: Global status and the way forward for disease management. *Journal of Innovative Sciences*, 8(2): 222-235.
- Kang, Z. and H. Buchenauer. 2000. Ultrastructural and immunocytochemical investigation of pathogen development and host responses in resistance and susceptible wheat spikes infected by *Fusarium culmorum*. *Physiological and Molecular Plant Pathology*, 57(6): 255-268.
- Lemmens, M., H. Buerstmayr., R. Krska., R. Schuhmacher., H. Grausgruber and P. Ruckebauer. 2004. The effect of inoculation treatment and long-term application of moisture on Fusarium head blight symptoms and deoxynivalenol contamination in wheat grains. *European Journal of Plant Pathology*, 110: 299-308
- Leslie, J. F and A. B. Summerell. 2006. *The Fusarium laboratory manual*. Blackwell Publishing Professional, Ames, USA.
- Ma, H. X., X. Zhang., J. B. Yao and S. Cheng. 2019. Breeding for the resistance to Fusarium head blight of wheat in China. *Frontiers of Agricultural Science and Engineering*, 6: 251-264.
- Matengu, T. T., P. R. Bullock., M. S. Mkhabela., F. Zvomuya., M. A. Henriquez., R.E. Ojo and D. W. G. Fernando. 2024. Weather-based models for forecasting Fusarium head blight risks in wheat and barley: A review. *Plant Pathology*, 73(3): 492-505.
- Mesterhazy, A. 2020. Updating the breeding philosophy of wheat to Fusarium head blight (FHB): resistance components, QTL identification, and phenotyping—A review. *Plants*, 9(12): 1702.
- Mesterhazy, A. 2024. What Is Fusarium Head Blight (FHB) Resistance and What Are Its Food Safety Risks in Wheat? Problems and Solutions—A Review. *Toxins*, 16(1): 31.
- Mesterhazy, A., A. Gyorgy., M. Varga and B. Toth. 2020. Methodical considerations and resistance evaluation against *F. graminearum* and *F. culmorum* head blight in wheat. The influence of mixture of isolates on aggressiveness and resistance expression. *Microorganisms*, 8(7), 1036.
- Mesterhazy, A., T. Bartok., C. G. Mirocha and R. Komoroczy. 1999. Nature of wheat resistance to *Fusarium* head blight and the role of deoxynivalenol for breeding. *Plant Breeding*, 118(2): 97-110.
- Miedaner, T., B. Lieberherr and D. S. Gaikpa. 2021. Aggressiveness of *Fusarium culmorum* isolates for head blight symptoms is highly stable across four cereal crops. *Journal of Phytopathology*, 169(6): 387-392.
- Moonjely, S., M. Ebert., D. Paton-Glassbrook., Z. A. Noel., L. Roze., R. Shay., T. Watkins and F. Trail. 2023 Update on the state of research to manage Fusarium head blight. *Fungal Genetics and Biology*, 169: 103829.
- Nita, M., K. Tilley., E. De Wolf and G. Kuldau. 2005. Effects of Moisture during and after anthesis on the development of Fusarium head blight of wheat and mycotoxins production. *Fusarium Head Blight Forum*, Hilton Milwaukee City Center, Milwaukee, USA, 125-128.

- Parry, D. W., P. Jekinson and L. MCleod. 1995. Fusarium ear blight (scab) in small grain cereals-a review. *Plant Pathology*, 44(2): 207-238.
- Rohacik, T. and K. Hudec. 2005. Influence of agro-environmental factors on *Fusarium* infestation and population structure in wheat kernels. *Annals of Agriculture and Environmental Medicine*, 12(1): 39-45.
- Sakr, N. 2020. Conservation of cereal fungi following different methods of preservation for long terms. *Pakistan Journal of Phytopathology*, 32: 159-168.
- Sakr, N. 2022. Erosion of quantitative resistance in wheat and barley to Fusarium head blight: gene pyramiding achieves and durability study. *The Open Agriculture Journal*, 17(1): e187433152211150.
- Sakr, N. 2023. Resistance to Fusarium head blight in some Syrian wheat and barley cultivars. *Sarhad Journal of Agriculture*, 39: 80-94.
- Savary, S., L. Willocquet., S. J. Pethybridge., P. Esker., N. McRoberts and Nelson. A. 2019. The global burden of pathogens and pests on major food crops. *Nature Ecology and Evolution*, 3, 430-439.
- Shad, M., A. Nazir, M. Usman, M.W. Akhtar and M. Sajjad. 2024. Investigating the effect of SUMO fusion on solubility and stability of amylase-catalytic domain from *Pyrococcus abyssi*. *International Journal of Biological Macromolecules*, 266: 131310.
- Shad, M., N. Hussain, M. Usman, M.W. Akhtar and M. Sajjad. 2023. Exploration of computational approaches to predict the structural features and recent trends in α -amylase production for industrial production. *Biotechnology and Bioengineering*, 120: 2092-2116.
- Tahir, Z.B. M. Atiq, N.A. Rajput, A. Akram, A.M. Arif, S. Iqbal, S. Ali, A. Nawaz, M. Usman and A. Husnain. 2023. Determination of Biochemical base line of resistance against bacterial leaf spot of chilli after application of plant defense activators. *Journal of Global Innovations in Agricultural Sciences*, 11(1): 61-67.
- Toth, B., A. Gyorgy., M. Varga and A. Mesterhazy. 2020. The influence of the dilution rate on the aggressiveness of inocula and the expression of resistance against Fusarium head blight in wheat. *Plants*, 9(8): 943.
- Usman, M., M. Atiq, N.A. Rajput, S.T Sahi, M. Shad, N. Lili, S. Iqbal, A.M Arif, U. Ahmad, K.S. Khan, M. Asif and F.U. Haider. 2024. Efficacy of green synthesized silver-based nanomaterials against early blight of tomato caused by *Alternaria solani*. *Gesunde Pflanzen*, 76(1): 105-115.
- Van der Plank J.E. 1968. *Disease Resistance in Plants*. Academic Press, New York and London, USA and UK.
- Walker, S. L., S. Leath., Jr. W. M. Hagler. and J. P. Murphy. 2001. Variation among isolates of *Fusarium graminearum* associated with Fusarium head blight in North Carolina. *Plant Disease* 85: 404-410.
- Xue, A. G., Chen, Y., Seifert, K., Guo, W., Blackwell, B.A., Harris, L.J. and Overy, D. P. 2019. Prevalence of *Fusarium* species causing head blight of spring wheat, barley and oat in Ontario during 2001-2017. *Canadian Journal of Plant Pathology*, 41(3): 392-402.

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Jalal Attar	: Collecting data
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