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Research Article

Stability of quantitative resistance in wheat and barley to Fusarium head blight

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Abstract: Wheat and barley can be infected with Fusarium head blight (FHB), reducing grain weight and quality. A number of studies have recognized the stability of quantitative resistance (QR) within wheat and barley cultivars; however, the behaviour of QR may not be stable over different environments. We have therefore evaluated QR stability in diverse bread and durum wheat and barley cultivars under artificial infection with a set of 16 fungal isolates of four *Fusarium* species with diverse pathogenicity. Nine QR components were obtained under in vitro, growth camber, and field conditions, and they were used to describe the nature of QR stability at the earliest and latest growth stages. Analysis of the variance of bio-experiments revealed significant cultivar-isolate interactions. The seedling and adult plant results showed that Arabi Aswad (barley) and Bohoth10 (bread wheat) were ranked among the most FHB resistant, whereas Acsad65 (durum) was the most affected cultivar. The reliability of the cultivar ranking was validated by the significant correlation among the resistance measured by the nine resistance components on host cultivars. QR stability in cultivars to FHB infection was fulfilled over years as well as several experimental conditions, suggesting that QR of wheat and barley to *Fusarium* is mainly explained by major quantitative trait loci that confer resistance to all FHB isolates. The constancy of QR resistance ratings of cultivars is consistent with a hypothesis that wheat- and barley-*Fusarium* interactions for QR were of small value. The cultivars AS and Bohoth10 showed remarkable and stable resistance in almost all tests and gave the lowest sensitivity rates; they could be very promising sources of genetic resistance to FHB in breeding programs and an alternative for farmers to *Fusarium*-sensitive cultivars.

Keywords: *Fusarium* pathogens, isolate-nonspecific resistance, stable resistance

Introduction

Wheat, including bread *Triticum aestivum*, durum *T. durum*, and barley *Hordeum vulgare*, are among the most important cultivated food and feed crops across the globe. Wheat alone contributes ~19% of global human protein and calories diurnal intake. Barley is widely used as animal feed (70%) and for malt production (27%), and it has been successfully grown in a wide range of environments. Annually, they have grown over 270 million ha and yielded over 905 million

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metric tons (FAOSTAT, 2022). While wheat and barley are susceptible to a wide array of harmful fungal diseases, cereal losses due to fungal damage continue to pose a huge threat to agricultural food and impact economic decisions and practical developments. In many parts of the world, Fusarium head blight (FHB) not only causes severe losses in both yield and quality but, more seriously, the toxins produced during FHB infection pose a serious health threat to humans and animals (Fernando *et al.*, 2021). Disease symptoms include necrosis, head bleaching and shrivelled kernels (Dahl and Wilson, 2018). The disease is caused by a pathogen complex of several *Fusarium* species, of which *F. graminearum* and *F. culmorum* are of greatest relevance and considered the strongest aggressive pathogens (Sakr, 2022b). Changes in weather conditions, i.e., temperature, air humidity and rainfalls, around the time of flowering strongly interfere with the pathogenicity of the fungi and then play an essential role in FHB epidemics (Miedaner *et al.,* 2021).

The lack of fully effective fungicides to control FHB forces us to seek other mitigation measures, such as the use of resistant cultivars (Janssen *et al.*, 2018). Therefore, breeding and planting wheat and barley cultivars with stable resistance to FHB is considered the most cost-effective and environmentally friendly strategy to reduce the risk of yield and quality losses (Xue *et al.*, 2019). FHB resistance of wheat and barley (Fernando *et al.*, 2021) is a quantitative trait expressed from various quantitative trait loci (QTLs). Different resistance mechanisms to FHB have been described in wheat and barley (Sakr, 2022b). The first two resistance mechanisms are related to severity and include Type I: resistance to initial pathogen infection and Type II: resistance to spread of infection within infected spikes (Dahl and Wilson, 2018). The stability of quantitative resistance (QR) can be evaluated in terms of time and space (Cowger and Brown, 2019). Planting a common set of cereal cultivars at different times in the same location or at different locations makes it possible to test for stability of resistance (Parlevliet, 2002). If instability is detected, however, it may not be clear whether this is due to the environment, pathogen population or a combination of these (Mundt, 2014). The major resistance QTL (*fhb1*) discovered in the Chinese germplasm, Sumai 3, is the most stable and has a major effect on the FHB resistance in wheat (Fernando *et al.*, 2021). Failure of resistance in Sumai 3 source has not been reported, and it is still the best source worldwide for resistance to the spread of symptoms in the spike (Sakr, 2022b).

Although resistant cereal cultivars show consistent resistance to almost all isolates of *Fusarium* worldwide (Miedaner *et al.*, 2021) in agreement with Van der Plank’s (1968) concept about QR, instability has detected in some cases, showing that expression of QR may be not stable over different environments. Groth *et al.* (2011) compared 40 wheat cultivars for FHB index in Canada and Germany. Canadian and European wheat lines were shown to perform stable across both countries. In contrast, Lu *et al.* (2002) evaluated FHB resistance of two wheat genetic populations (305 lines) in 1999 and 2000, which showed a poor correlation of individual FHB resistance scores. In addition, the consistency of results between greenhouse and field trials has varied in experiments studying FHB resistance in transgenic wheat (Mackintosh *et al.*, 2007).

The presence of an aggressive, variable population of *Fusarium* (Fernando *et al.*, 2021) may affect the stability of QR due to accelerated adaptation of aggressive forms of the pathogen with higher levels of parasitic fitness as observed under *in vitro* conditions in wheat and barley infected with four pathogen species (Sakr, 2022a,c). A change for more aggressive FHB populations may result in an overall reduction in the resistance of wheat and barley cultivars (Dahl and Wilson, 2018). In addition, distinctive modifications in the ranking of quantitative resistant cultivars flowing exposure to diverse pathotypes of the pathogen may occur as observed in the pathosystem of *Phytophthora infestans* and potato (Flier *et al.*, 2003).

The global cereals agricultural nurseries are making many efforts towards developing *Fusarium*-resistant wheat and barley cultivars

(Dahl and Wilson, 2018), but few focus on QR stability to head blight disease (Cowger and Brown, 2019). Syrian wheat and barley cultivars already exist, are widely commercialized, and can be an important source of resistant genes to FHB. The present study aimed to evaluate the stability of QR for wheat and barley cultivars under artificial infection with four *Fusarium* species. To describe the stable nature of QR at the earliest and latest growth stages, nine resistance components generated under *in vitro*, climatic growth chamber and field conditions were used (Sakr, 2023)

Materials and Methods

Plant materials, fungal isolates, and inoculum preparation

A set of eight cereal cultivars with Syrian origin including six *T. aestivum* (Bohoth10, Cham4 and Douma4) and *T. durum* (Cham7, Cham9 and Acsad65) cultivars and two *H. vulgare* cultivars: Arabi Abiad (AB) and Arabi Aswad (AS) was selected based on their known resistance to FHB and representing the maximum genetic variation within wheat and barley in Syria (Sakr, 2023). These cultivars with favourable agronomic and quality characteristics and similar anthesis and maturity date have been the most cultivated genotypes across cereal fields (Sakr, 2023). The stability tests of quantitative resistance in host materials were performed using *Fusarium* isolates. Six *F. solani*, five *F. culmorum*, four *F. verticillioides* (synonym *F. moniliforme*) isolates and one *F. equiseti* isolate were sampled from naturally infected wheat grains. The 16 monosporic-derived cultures of the field background were chosen for their diverse aggressiveness established on earlier various experimental observations (Sakr, 2023). On Petri dishes with potato dextrose agar (PDA) containing 13 mg/l kanamycin sulphate, the isolates were morphologically identified with the aid of the Leslie and Summerell (2006) manual based on microscopic observations of the size and shape of micro- and macro-conidia. Then, FHB isolates were molecularly distinguished by Random amplification of polymorphic DNA markers (Sakr, 2023).

Single spore isolates were stored short-term on PDA at 4 °C and long-term by freezing at -16 °C or in sterile distilled water at 4 °C (Sakr, 2020), and fresh cultures were produced on PDA medium. After 14 days, conidia were collected in sterile distilled water (SDW). Then, the suspensions were filtered through two layers of sterile cheesecloth to remove agar and adhere mycelia. The spore concentration was adjusted under an optical microscope before use using a Neubauer chamber and diluted to appropriate concentrations as inoculum sources.

Stability of quantitative resistance under several experimental conditions

The stability of QR of three bread cultivars, three durum cultivars and two barley cultivars with varying resistance levels to head blight was evaluated at the seedling and adult plant stages under *in vitro*, climatic growth chamber and field conditions for their nine pathogenic responses to sixteen *Fusarium* isolates with diverse pathogenicity. The nine resistance components of all cultivars infected with *Fusarium* fungi were previously evaluated (Sakr, 2023) and include the resistance measured by a latent period of detached leaf inoculation, the area under disease progress curve of Petri-dish inoculation and coleoptile length reduction of a coleoptile infection detected *in vitro*, disease incidence (DI) and disease severity (DS) detected using a detached head test under controlled conditions, DI and DS detected using a head and floret artificial inoculation, respectively under controlled conditions, and DI and DS detected using a head artificial inoculation under field conditions over three consecutive growing seasons. Since no significant interaction year × fungus/cultivar was observed (climatic data for the station were somewhat similar during the three growing seasons (Sakr, 2023)), field data were shown as the averages of the three growing seasons. To test the stability of resistance, we correlated disease values of the resistances measured by the nine tested components on eight wheat and barley cultivars infected with a set of 16 fungal isolates of four FHB species. For a given resistance component, the experiment layout was arranged in a completely randomized design with three replicates for each isolate and cultivar and the experiment was repeated twice.

Statistical analyses

The experimental data were subjected to analysis of variances (ANOVA) using DSAASTAT add-in version 2011. Before statistical analysis, the percentages were transformed using the angular transformation to stabilize variances. ANOVA incorporating the Fisher's LSD test at P = 0.05 was used to determine the host cultivar × isolate interactions. The sample correlation (Pearson r) at P = 0.05 was used to test for correlations among the resistances measured by the nine disease components. A set of eight cultivars was evaluated under several experimental conditions of the study. It was analyzed to determine the stability of cultivars for FHB resistance at the seedling and adult plant stages.

Results and Discussion

A major and continuing challenge for breeders in wheat and barley-producing countries is providing cultivars with high and stable levels of resistance to FHB, significantly reducing yield and quality losses (Fernando *et al.*, 2021). Because the severity of FHB generally varies from year to year and from region to region, leading to variation in disease epidemics (Sakr, 2022b), studies to explore the stability of QR are of great importance (Cowger and Brown, 2019). Environmental and climatic conditions could influence the stability of QR to FHB of wheat and barley. Weather conditions during wheat flowering are the key factor for *Fusarium* infection and disease spread. Generally, the air humidity and precipitation during flowering enhance the risk of FHB epidemics (Miedaner *et al.*, 2021). For the first time, this research indicates that QR to head blight is stable across the earliest and latest growth stages, representing a wide range of experimental conditions, i.e., in vitro, climatically controlled, and field conditions. In agreement with susceptibility ranking to *Fusarium* development in the heads of small-grain cereals (Sakr, 2022b), our results showed that barley and bread wheat consistently exhibited very low mean levels of FHB disease compared to durum wheat among the three tested crop species.

It is widely accepted that QR of the host plant to fungal infections does not confer absolute protection (Parlevliet, 2002; Mundt, 2014), but is considered to be effective against all known races/isolates of the pathogen (Van der Plank, 1968). In the present research, no wheat and barley cultivars were completely resistant to FHB in harmony with Van der Plank's (1968) concept about QR. Compared to the water control, cereal plants growing in the presence of 16 *Fusarium* isolates causing FHB under several experimental conditions showed typical disease symptoms, suggesting a strong effect of the fungi on the growth of wheat and barley plants across the earliest and latest development stages (Sakr, 2023). In wheat-and barley-FHB associations, resistant cereal cultivars consistently resist almost all FHB isolates worldwide, indicating no significant fungus × cultivar interactions (Fernando *et al.*, 2021). In our investigation, a combined analysis of bio-experiments demonstrated that isolate × cultivar interactions were significant (Table 1). Our results are in harmony with previous studies that showed a significant interaction between wheat and barley and isolates of *Fusarium* pathogens (Xue *et al.*, 2019). In other pathogen-host interactions such as *Phoma*-sunflower (Darvishzadeh *et al.*, 2007), leaf blast-rice (Zenbayashi-Sawata *et al.*, 2005) and *Septoria tritici* blotch-wheat (Chartrain *et al.*, 2004) pathosystems, identical impacts have been observed. The results above indicate these hosts may possess diverse genes to resist the respective pathogen species. However, Miedaner *et al.* (2021) found in their study about the resistance of four cereal crops (triticale, bread wheat, rye and durum wheat) challenged with FHB fungi that isolate × cereal and isolate × cultivar interactions were not significant.

Table 1 Analyses of variance for latent period (LP) of detached leaf inoculation, area under disease progress curve (AUDPC) of Petri-dish inoculation and coleoptile length reduction (CL) of a coleoptile infection detected *in vitro*, disease incidence (DI, Type I) and disease severity (DS, Type II) detected using a detached head test (DHT) under controlled conditions, and disease incidence (DI^{CC}, Type I) detected using a head artificial inoculation and disease severity (DS^{CC}, Type II) detected using a floret artificial inoculation under controlled conditions in a growth chamber, disease incidence (DI, Type I) and disease severity (DS, Type II) detected using a head artificial inoculation under field conditions (FC) over the three growing seasons (F-test values).

Source of variation	df	LP, AUDPC, CL, DI^{DHT}, Type I, DS^{DHT}, Type II, DI^{CC}, Type I, DS^{CC}, Type II, DI^{FC}, Type I, DS^{FC}, Type II
Cultivar (C)	7	$^{++}$
Isolate (I)	15	$^{++}$
C × I	105	$^{++}$
Error	256	

$^{++}$ – significant at 1% level; df – degree of freedom.

Resistance of the eight wheat and barley cultivars infected with *Fusarium* fungi was earlier analyzed and presented by Sakr (2023).

Efficient use of appropriate QTL alleles in QR breeding requires QTL to be stably expressed over different environments over the years (Cowger and Brown, 2019). It is assumed that QR is generally controlled by broad-spectrum resistance factors that are effective against a large number of isolates for one pathogen, and the ranking of the cultivars according to disease severity is independent of the isolates used for testing QR (Mundt, 2014). Several reports in different crop plants characterize disease resistance QTLs that are stable across multiple environments, involving researchers exploring resistance to oilseed rape/blackleg (Pilet *et al.*, 2001), barley/leaf rust (Marcel *et al.*, 2007), bean/white mold (Ender *et al.*, 2008), pea/Aphanomyces root rot (Hamon *et al.*, 2011), potato/late blight (Johnson *et al.*, 2012) interactions. Under the tested experimental conditions, the different wheat and barley cultivars were shown to have highly differing responses depending on the resistance types measured (Figure 1), which may be a sign of different genes and gene interaction impacting the resistance. Generally, susceptibility to FHB infection decreases from durum wheat to bread wheat to barley (Miedaner *et al.*, 2021). Overall, AS, AB and bread wheat cultivars Bohoth10, Cham4, Douma4, showed lower infection FHB levels than did durum cultivars Acsad65, Cham7 and Cham9, indicating that barley and bread wheat provided broad, though incomplete, resistance to the four *Fusarium* species causing FHB examined compared to durum wheat. In the present study, QR stability in eight wheat and barley cultivars to FHB infection was fulfilled across years and over several experimental conditions, i.e., seedling and adult plant stages (Figure 1). In any case, the ranking of the cultivars was similar, regardless of the isolates inoculated (Figure 1). In all bio-experiments, our data showed that `Acsad65` was susceptible and `AS and Bohoth10` were moderately resistant, indicating that the order of Acsad65, AS and Bohoth10 was stable. Moreover, the ranking of the five remaining cultivars of diverse QR levels was stable under several experimental conditions (Fig. 1).

The reliability of this cultivar ranking was confirmed by the significant correlation among the resistance measured by the nine pathogenic criteria on host cultivars of Syrian origin infected with a set of 16 fungal isolates of four *Fusarium* species (Table 2). All tested wheat and barley cultivars showed a qualitative pattern in which FHB isolates expressed either high or low virulence. Our data suggest that QR of wheat and barley to *Fusarium* is probably mainly explained by major QTLs with an incomplete expression that confers resistance to a large number of isolates as observed previously in wheat infected with *Mycosphaerella graminicola* (Krenz *et al*., 2008). It is accepted for QR that the order of the cultivar depending on disease severity is independent of the isolates used for assessing the resistance (Van der Plank 1968). Our results align with those found by Miedaner *et al.* (2021), in which the cultivars showed an identical order as analyzed with FHB isolates with different aggressiveness levels. Another prominent example of the FHB-wheat relationship, the failure of QR in Sumai 3, released 50 years ago, has not been observed, and it is still the best source globally for resistance to the development of symptoms in the head (Fernando *et al.*, 2021). Le Clerc *et al.* (2015) found that the host order was similar upon inoculation, with fungal isolates varying in their aggressiveness under several experimental conditions in the pathosystem of carrot and *Alternaria dauci*. Field studies demonstrated a small cereal–*Fusarium* interaction for epidemic rate (Fernando *et al.*, 2021), but this was inconsistent over the years. Other studies could not measure such interaction (Dahl and Wilson, 2018). Host-pathogen interactions may exist for QR, but are probably of reduced magnitude (Sakr, 2022b). In the present work, the constancy of resistance ratings of cultivars over years and several experimental conditions is consistent with a hypothesis that host-pathogen interactions for QR are of little practical importance, as observed in *P. infestans*/potato interaction (Forbes *et al.*, 2005).

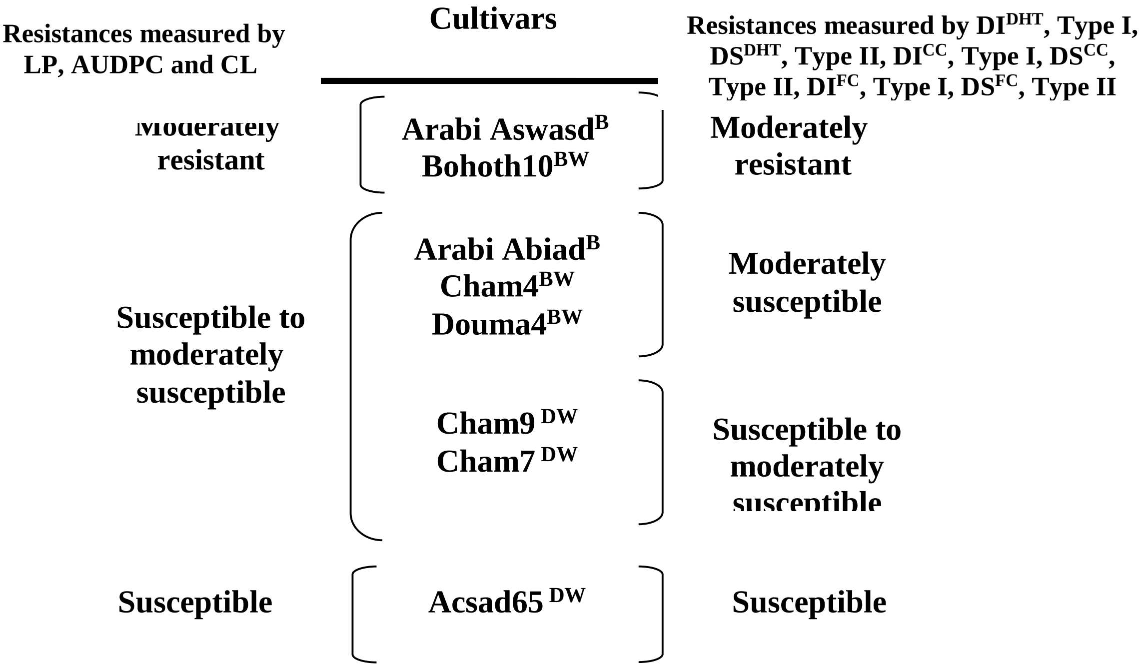

Figure 1 Ranking of eight bread wheat ^{BW}, durum wheat ^{DW} and barley ^{B} cultivars of Syrian origin infected with a set of 16 Fusarium head blight based on the resistance measured by latent period (LP) of detached leaf inoculation, area under disease progress curve (AUDPC) of Petri-dish inoculation and coleoptile length reduction (CL) of a coleoptile infection detected *in vitro,* disease incidence (DI, Type I) and disease severity (DS, Type II) detected using a detached head test (DHT) under controlled conditions, and disease incidence (DI^{CC}, Type I) detected using a head artificial inoculation and disease severity (DS^{CC}, Type II) detected using a floret artificial inoculation under controlled conditions in a growth chamber, disease incidence (DI, Type I) and disease severity (DS, Type II) detected using a head artificial inoculation under field conditions (FC) over the three growing seasons.

Table 2 Correlation coefficients between the resistance measured by latent period (LP) of detached leaf inoculation, area under disease progress curve (AUDPC) of Petri-dish inoculation and coleoptile length reduction (CL) of a coleoptile infection detected *in vitro*, disease incidence (DI, Type I) and disease severity (DS, Type II) detected using a detached head test (DHT) under controlled conditions, and disease incidence (DI^{CC}, Type I) detected using a head artificial inoculation and disease severity (DS^{CC}, Type II) detected using a floret artificial inoculation under controlled conditions in a growth chamber, disease incidence (DI, Type I) and disease severity (DS, Type II) detected using a head artificial inoculation under field conditions (FC) over the three growing seasons on eight wheat and barley cultivars of Syrian origin infected with a set of 16 fungal isolates of four Fusarium head blight species.

Resistance component	AUDPC	LP	CL	DI^{DHT}, Type I	DS^{DHT}, Type II	DI^{CC}, Type I	DS^{CC}, Type II	DI^{FC}, Type I	DS^{FC}, Type II
AUDPC	1.000								
LP	-0.756*	1.000							
CL	-0.970***	0.742*	1.000						
DI^{DHT}, Type I	0.943***	-0.878**	-0.871**	1.000					
DS^{DHT}, Type II	0.991***	-0.731*	-0.950***	0.956***	1.000				
DI^{CC}, Type I	0.956***	-0.887**	-0.902**	0.988***	0.958***	1.000			
DS^{CC}, Type II	0.991***	-0.769*	-0.954***	0.971***	0.989***	0.976***	1.000		
DI^{FC}, Type I	0.826**	0.806*	-0.786*	0.799*	0.876**	0.811**	0.836**	1.000	
DS^{FC}, Type II	0.741*	0.765*	-0.740*	0.769*	0.785*	0.709*	0.730*	0.964***	1.000

(P = 0.05)*, (P = 0.01)**, (P = 0.001)***.

The order of magnitude of cultivar-by-isolate specificity relative to the differences in cultivar resistance and aggressiveness of isolates determines the potential ability of the pathogen population to adapt to partial resistance and, therefore, the stability of such resistance (Flier *et al.*, 2003). In the pathosystem of potato and *P. infestans*, Inglis *et al.* (1996) compared cultivar rankings in response to foliar infection with new isolates of *P. infestans* and rankings obtained with isolates that had been predominant in the USA before 1990. Cultivar rankings were found to be nearly identical to the previously obtained data. These data and our findings support the view that erosion of partial resistance is of little importance. Nevertheless, in our previous *in vitro* studies (Sakr, 2022a,c), we showed that the QR decreased over time by selecting aggressive isolates on both resistant and susceptible wheat and barley cultivars. Specificity and adaptation to head blight resistance are more likely to occur when genetic variation is maintained very high (Parlevliet, 2002; Mundt, 2014). If QR can be bridged by pathogen diversity, it also appears feasible that QR could be overcome (Cowger and Brown, 2019). Differential interaction indicates some adaptation of *Fusarium* to QR and, consequently, adverse effects on the stability and durability of QR to FHB (Sakr, 2022b).

In conclusion, QR is the basis of breeding for FHB disease resistance in small-grain crops, i.e., wheat and barley, mainly to obtain durable and stable resistance. Taken into account that effective utilization of favourable resistance in breeding programs requires QR to be stably expressed across environments and years, the cultivars AS and Bohoth10 show very remarkable and stable resistance in almost all tests and give the lowest sensitivity rates, thus could be very promising sources of genetic resistance to FHB in breeding programs, and an alternative for farmers to *Fusarium* sensitive cultivars, revealing the new policy led to cultivars with higher and stable resistance level. The evaluation of the behaviour of given cultivars under specific and changeable conditions of the environment provides valuable information on several aspects: how the cultivar responds to changeable conditions, how adaptable it is under a comprehensive set of environments and what is the area of its eventual distribution. The stability analysis can also help the breeder monitor the resistance level to the tested plant materials and the disease pressure in different environments. Further research to understand the interaction between the host and the pathogen will be valuable for determining additional factors contributing to *Fusarium* resistance in wheat and barley.

Authors' Contributions

The author's contribution is 100%.

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پایداری مقاومت کمّی در گندم و جو نسبت به بیماری فوزاریوم سنبله گندم

نشرات ساکر

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چکیده: گندم و جو می‌توانند به بیماری فوزاریوم سنبله گندم (FHB) مبتلا شوند که منجر به کاهش وزن و کیفیت دانه می‌شود. تعدادی از مطالعات به پایداری مقاومت کمّی (QR) در درون ارقام گندم و جو اشاره کرده‌اند؛ با این حال، رفتار QR ممکن است در محیط‌های مختلف پایدار نباشد. بنابراین، پایداری QR را در ارقام مختلف گندم نان و گندم دوروم و جو تحت آلودگی مصنوعی با مجموعه‌ای از ۱۶ جدایه قارچی از چهار گونه فوزاریوم با حساسیت متفاوت ارزیابی شدند. نه مؤلفه QR تحت شرایط درون‌کشت، اتاق رشد و مزرعه به‌دست آمد و برای توصیف ویژگی پایداری QR در مراحل اولیه و نهایی رشد استفاده شد. تحلیل واریانس آزمایشات بیولوژیکی نشان‌دهنده تعاملات معنادار بین ارقام و جدایه‌ها بود. نتایج گیاهچه و گیاه بالغ نشان داد که "عربی اسود" (جو) و "بوهوت۱۰" (گندم نان) در بین مقاوم‌ترین ارقام نسبت به FHB رتبه‌بندی شدند، درحالی‌که "اکساد۶۵" (دوروم) بیشترین آسیب را دید. اعتبار رتبه‌بندی ارقام توسط همبستگی معنادار میان مقاومت اندازه‌گیری شده توسط نه مؤلفه مقاومت در ارقام میزبان تأیید شد. پایداری QR در ارقام نسبت به بیماری FHB در طول سال‌ها و همچنین در شرایط آزمایشی مختلف محقق شد، که نشان می‌دهد QR گندم و جو نسبت به فوزاریوم عمدتاً توسط مکان‌های صفات کمّی اصلی توضیح داده می‌شود که مقاومت را به تمام جدایه‌های FHB می‌دهد. ثبات رتبه‌بندی مقاومت QR ارقام با فرضیه‌ای که تعاملات گندم و جو با فوزاریوم برای QR ارزش کمّی داشتند، سازگار است. ارقام "AS" و "بوهوت۱۰" در تقریباً تمام آزمایش‌ها مقاومت قابل توجه و پایداری نشان دادند و کم‌ترین نرخ حساسیت را داشتند؛ این ارقام می‌توانند منابع بسیار امیدوارکننده‌ای از مقاومت ژنتیکی به بیماری فوزاریوم سنبله گندم در برنامه‌های اصلاح نژادی و جایگزینی برای کشاورزان نسبت به ارقام حساس باشند.

واژگان کلیدی: بیماری فوزاریوم سنبله گندم، مقاومت غیرخاص به جدایه، مقاومت پایدار