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Agronomic evaluation of Fusarium Head Blight (FHB) resistance in Italian durum wheat cultivars and screening of advanced lines MAS selected for FHB resistance

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To evaluate the resistance to FHB, in 2009 41 varieties of durum and bread wheat, mainly from Italy, were tested at the CIMMYT (International Maize and Wheat Improvement Center). In addition, to assess the effect of the *Qfhs.ndsu-3BS* QTL (one of the major QTL for FHB resistance, first identified in Chinese bread wheat cultivar 'Sumai 3', on the chromosome 3B), 125 advanced lines of durum wheat BC_4F_6 derived from crosses with initial bread wheat (68 with the 'Sumai 3' QTL and 57 without) were screened in the same artificial inoculation conditions. For both groups, plots were inoculated at flowering with a suspension of monosporic cultures of *F. graminearum*, keeping the humidity close to 100%, to favour disease development, by means of a misting system. Thirty days after inoculation, counts of spikelets infected by *F. graminearum* was carried out in 10 ears for each plot; the damage was expressed as the FHB index (incidence × severity/100, where severity = infected spikelets/total spikelets; incidence × 100 and infected ears/ears total × 100). In both cases, late flowering showed to be a key factor, able to limit the seriousness of the disease. Preliminary data concerning the effect of the *Qfhs.ndsu-3BS* QTL, didn't highlight differences between the two groups of advanced lines.

Keywords: *wheat, scab, Fusarium Head Blight (FHB), QTL, disease resistance, Fusarium graminearum, monosporous cultures, incidence, severity, FHB index.*

Introduction

Fusarium Head Blight (FHB), or scab, is one of the most devastating diseases affecting cereals, including durum wheat (*Triticum durum* Desf.). It is caused by several fungal species of the genus *Fusarium*, whose attacks result in quite similar symptoms (Snijders, 1994; Parry *et al.*, 1995; Miedamer, 1997; Leonard & Bushnell, 2003). Such disease produce severe losses of grain yield, as kernels are the most interested part in the infection process. In addition, reduction of grain quality is also observed, due to the production and the accumulation in kernels of mycotoxins, mainly Deoxynivalenol (DON). Wheat can be attacked by several *Fusarium* species like, for instance, *F. culmorum*, *F. graminearum* (teleomorph: *G. zeae*), *F. poe*, *F. crookwellense*, *F. sporotrichioides* and *F. sambucinum* (Desjardin & Hohn, 1997). However, the most diffused species resulted to be *F. graminearum* (Dubin *et al.*, 1996) and *F. culmorum* (Schmolke, 2008). Molecular analyses revealed how the organism previously referred to as *F. graminearum* strain 1, represents a distinct species, named *F. pseudograminearum* sp. Nov. (Aoky & O'Donnel, 1999), which is not a causal agent of FHB. The optimum temperature for the growth of *F. graminearum* in the field is 25 °C, with prolonged moisture conditions (air moisture content near 100%). Other species exhibit different optimum growing conditions. Inoculum can be diffused by animal vectors, raindrops (mainly for conidia) and wind (mainly important for asco-spores, Champeil *et al.*, 2004). Wheat is highly susceptible in the flowering phase (Pugh *et al.*, 1933). Two substances, Betaine and Choline, are commonly detected in anthers and seem able to stimulate *F. graminearum* growth (Strange & Smith, 1978). FHB can be countered using different strategies like, for instance, application to crops of Ergosterol Biosynthesis Inhibitors (EBI) fungicides, rotation with non-host crops and adequate tillage practices (burial of crop debris). A cheap and cost-effective method to combat the disease is the selection of resistant and/or low-susceptibility genotypes through conventional and innovative plant breeding strategies. Breeding programs are hindered by the fact that resistance towards FHB is under polygenic inheritance; furthermore, climatic conditions have a great influence on the severity of disease, which results in a large genotype × environment interaction (Parry *et al.*, 1995, Miedaner *et al.*, 2001). Sources of resistance were identified in bread wheat (*Triticum aestivum*) genotypes, like the Chinese cultivar 'Sumai 3', the Brazilian genotype 'Frontana' and the Eastern Europe line 'Prag 8' (Mentewab *et al.*, 2000). Other sources of resistance were found in species of the *Triticeae* tribe, like *Elymus giganteus* L. (syn. *Leymu racemosus* Lam., 2n = 4x = 28 JJNN) (Mujeeb-Kazi *et al.*, 1983, Wang *et al.*, 1986, 1991), *Roegneria kamoji* C.Koch (syn. *Agropyron tsukushiense* Honda, 2n = 6x = $42S^{ts}S^{ts}H^{ts}Y^{ts}$) and *Rciliaris* (Trin) Nevski (syn. *A. ciliare* (Trin) Franchet, 2n = 4x = 28, $S^cS^cY^cY^c$,Weng & Liu, 1989, 1991). The last 2 species originated in the Southern China, a region characterized by a wet and warm climate (Cai *et al.*, 2005). Hybrids were also created, between durum wheat and *Thinopyrum junceiforme*, to introduce resistance genes from the latter (Prem & Peterson, 2001). To date, very few sources of resistance were identified in durum wheat (Cai *et al.*, 2005). Up to six types of resistance have been described (Schroeder & Christensen, 1963; Langevin *et al.*, 2004):

- Resistance to initial infection (Type I);
- Resistance to the spread of the infection within a spike (Type II);
- Ability of the host to degrade (Type III) and tolerate (Type IV) deoxynivalenol;
- Resistance to kernel infection (Type V);
- Tolerance to FHB (Type VI).

Identification of molecular markers associated to QTLs for FHB resistance allows Marked Assisted Selection (MAS), which could be a useful tool for breeders. So far, several studies concerning QTL maps were performed, mainly using sources of resistance collected in Asia, like the cultivars 'Sumai 3', 'Wangshuibai' e 'Wuhan-1' (Bai *et al.*, 1999; Waldron *et al.*, 1999; Buerstmayr *et al.*, 2002, 2003; Li *et al.*, 2004; Mardi *et al.*, 2005; Somer *et al.*, 2005). One of the main QTL is *Qfhs.ndsu-3BS*, located on the short arm of the chromosome 3B (Bai *et al.*, 1999; Waldron *et al.*, 1999; Buerstmayr *et al.*, 2002, 2003; Liu & Anderson, 2003; Lin *et al.*, 2004; Mardi *et al.*, 2005; Somer *et al.*, 2005). Aim of this work was to evaluate the resistance towards FHB of a huge group of Italian commercial genotypes, comparing in the same time with that of some resistant and susceptible bread wheat varieties ('Sumai 3' and 'Gamenya'). In the same time, a field trial was carried out using 125 advanced lines (F6), part of which containing the *Qfhs.ndsu-3BS* QTL, to assess the effect of the above mentioned QTL on the field resistance in plants inoculated with *F. gramineaarum*.

Materials and methods

Genotypes

A group of 41 Italian durum wheat (*Triticum durum* Desf.) cultivars and bread wheat (*Triticum aestivum*) were tested in 2009 at the CIMMYT (International Maize and Wheat Improvement Center) at El Batán research station, México. Another group of 125 durum wheat advanced lines (F6), derived from an initial cross between durum wheat and bread wheat materials derived from 'Sumai 3'. The initial population (sterile) was backcrossed 4 times (BC4); following, F1 plants derived from BC4 were selected using the molecular marker in order to obtain family plants. F2 plants were selected according with the same procedure; in addition, plants were artificially inoculated in field with *F. gramineaurum*. Even these activities were carried out at El Batán research station. F3 plants were selected without molecular markers and without artificial inoculation at the Obregon CIMMYT research station, México. F4 plants were selected without the molecular marker and with natural inoculation at the CIMMYT Toluca research station, México. Following F5 generation, 68 lines were selected containing the molecular marker, and 57 lines not having the marker.

Field experiments

Each genotype was sown in June 2009 at the El Batán station on 1 m double rowed plots. For the Italian cultivars, the experimental design was a Randomized Complete Block Design with 2 replication. For the advanced lines, a screening scheme without replication was carried out. Sowing was performed by means of a sowing machine, using 5 g of seed for each plot. Maize was the previous crop for both tested groups. Plots were irrigated soon after the sowing, to favour a fast and homogeneous germination. Nitrogen (150 kg ha-1) and Phosphorous (40 kg ha-1) were applied in two solutions, soon after the sowing and 40 days after the sowing. The entire experimental field was equipped with a fine misting system, in order to maintain high air moisture conditions, which are requested for Fusarium growth and development after the inoculation. Misting was ensured by DAN modular microsprinklers, arranged in a 3×4 m scheme. System is managed by a programmable timer, and it is able to ensure high moisture conditions 24 hrs a day.

Inoculum

Choice of inoculum

Inoculum was prepared from monosporic cultures of *F. graminearum* strains, previously tested in greenhouse experiments on durum wheat plants.

Syringe inoculation was performed, in order to assess type II resistance. The most aggressive strains were successively grown on Rice Medium for the evaluation of their ability to produce DON. For the field infections, the strain was used with both the greater aggressiveness and the greater ability to produce DON.

Inoculum preparation

Five to six fragments of agarized substrate previously inoculated with monosporic cultures of *F. graminearum* were transferred in glass Erlenmayer flasks containing Lima beans (*Phaseolus lunatus* L.) liquid medium. Such substrate was prepared from 20 g l-1 of previously washed and dried Lima beans, covered with water and placed to boil until the colour

Inoculum preparation

solution turned to red. Liquid was filtered, volume was adjusted to 1 l and autoclaved at 120 °C for 20 min. Inoculated Erlenmeyer flasks were placed in a horizontal stirrer at 200 rpm for 7 dd. at room temperature (22–25 °C). After 7 dd., the cultures were filtered and poured in a 250 ml flask and stored at 4 °C to allow the sedimentation. After the sedimentation has completed, the conidia at the bottom of the flask were collected and centrifuged for 10 min at 3000 rpm. Supernatant was discarded, sterilised distilled water was added to resuspend the conidia; 0.5 ml of the suspension was collected and poured in 100 ml of sterilised distilled water. Finally, micropipette is used to transfer an aliquot of the diluted suspension on a Petri dish containing Lima beans agarized medium. Suspension was thoroughly distributed upon the surface; inoculated dishes were incubated for 7 dd. with 12 hrs of daylight and 12 hrs of darkness.

Production of the inoculum for field infections

The content of 40 agarized dishes were poured in 2 l of sterilised distilled water (agarized substrate was discarded). This suspension, containing mainly conidia, was diluted with sterilised water up to a 50000 conidia ml-1 density. Conidial density was assessed by means of a Neubauer-counting chamber.

Field infections

In every plot, infection was performed when at least 50% of the plants were at full flowering. For each genotype, ten plants were chosen for the evaluation. Each plot were identified by a label, whose colour corresponded to a specific flowering date. Inoculation was performed by means of a CO_2 sprayer (3 seconds per plot) with the 50000 conidia ml-1 solution.

Disease evaluation

Visual evaluation of the symptoms was carried out for each plot on every selected spike, 30 dd. after the inoculation. Damage caused by the disease was expressed as FHB Index, which was calculated as follows:

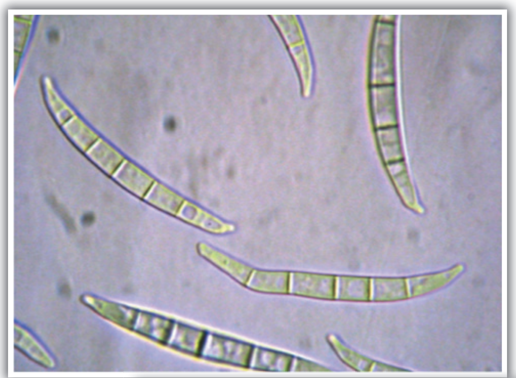
$$\text{FHB Index} = \text{Severity} \times \text{Incidence}/100$$

Where: $\text{Severity} = (\text{Diseased spikelets}/\text{total spikelets}) \times 100$

$\text{Incidence} = (\text{Diseased spikes}/\text{total spikes}) \times 100$

Field infections and misting system

Diseased spikelets
(Photo Dr. Bentivenga)



Macroconidia of *F. graminearum* (Photo Dr. Bentivenga)

Morphophysiological evaluation

Flowering dates, physiological ripening (both expressed as days after August, the 1st) and plant heights (cm) were determined for each plots following field surveys. After harvesting, Thousand Kernels Weight (TKW, g.), number of seeds spike-1 and number of damaged seeds were assessed.

Statistical analysis

For the Italian genotypes data were evaluated using analysis of variance (ANOVA) and correlation by means of MSTAT 2.1 software. Means were separated according with the Student-Neuman-Keul's (SNK) Multiple range Test for the varieties group. For the second group of advanced line (F6), data were evaluated using analyses of correlation by Excel.

Results

Italian genotypes

Analysis of variance (tab ANOVA) showed a strong influence of genotype on the most of the observed variables. Values of FHB Index (Tab. 1) revealed a large variability. The lower value was 0.05 for bread wheat cultivar 'Sumai 3'; on the contrary, the highest one was 66.05 for the highly susceptible genotype 'Gamenya'. Regarding the group of Italian durum wheat cultivars, only 3 ones ('Dupri', 'Tiziana' and 'Dylan') revealed to be enough FHB resistant, seen as their FHB Index were respectively, 1.85, 2.45, 3.85. A significant ($r = 0.6166$, $P = 0{,}001$) positive correlation emerged between FHB Index and % of damaged seeds trasf. (Tab. 2); indeed, low FHB Index values were associated with a reduced number of damaged seeds. In particular, the 3 above mentioned durum wheat cultivars were characterized by a % of damaged seeds not exceeding 4%. Flowering dates (expressed as dd after 1st August) ranged from 11 to 31 (average value 19.2). 'Overall', 'Dupri', 'Tiziana' and 'Dylan' in the Mexican growing environment showed flowering dates of, respectively, 26, 22 and 22 days. Thus, compared to the rest of the genotypes, they resulted medium-late maturing cultivars. Significant correlations emerged between other observed traits; in particular, FHB Index was negatively correlated with flowering date, accordingly with the findings reported in other works. Moreover, another negative correlation emerged between FHB Index and plant height. As expected, a significant negative correlation was also found between FHB Index and Thousand Kernel Weight.

Advanced lines

A group of 125 advanced lines were tested for their susceptibility towards FHB; 68 lines showed to contain the molecular marker for the *Qfhs.ndsu-3BS* QTL, whereas the remai-

Table 1

Analysis of variance (ANOVA) of the 41 Italian varieties

Variety	Flowering day from 1/8		Physiological maturity days from 1/8	Plant height, cm		Weight 1000 seeds		Severity	Severity tras ang		FHB Index	FHB Index tras ang		Seeds spikes		% damaged seeds	% damaged tras ang	
ARCANGELO	14	fh	71,5	54,5	g	28,35	ab	40,1	39,3	ae	37,95	38,05	ae	25,25	be	5,95	14,1	b
BRAVO	31	a	69,5	73,5	ce	30,45	ab	19,25	25,9	cg	15,8	23,15	cg	20,2	de	8,2	16,45	b
CAMPODORO	25	ad	72,5	73	ce	33,1	ab	14,5	22,35	dh	13,05	21,15	dh	25,8	be	7,75	16,2	b
CRESO	17	eh	62	55	fi	33,85	a	36,1	36,95	be	36,1	36,95	be	23,1	be	5,65	13,7	b
CRISPIERO	21	cg	69,5	69	ch	38,3	a	22,05	27,9	cg	21,15	27,2	cf	19,45	de	7,55	15,9	b
DAUNIA	11	h	68,5	60	ei	26	ab	41,55	40,1	ad	41,55	40,1	ad	23,6	be	12,35	20,5	b
DUILIO	17	eh	65	68	ch	34,55	a	34,55	35,95	be	33,05	35	be	30,7	be	10,9	18,9	b
DUPRI	26	ad	74	65	dh	32,65	a	3,35	9,35	hi	1,85	6,2	hi	31,75	be	4,45	11,95	b
DURANGO	31	a	74	80	cd	31,05	ab	26,55	31,05	bg	22,5	28,35	bf	25,05	be	8,85	17,3	b
DYLAN	22	bf	65	62,5	ei	36	a	8	15,55	fi	3,85	10,55	fi	35,55	be	3,4	10,5	b
FALCIN	11	h	60,5	70,5	cg	37,35	a	18,1	24,7	cg	17	23,7	cg	43,65	ac	10,25	18,5	b
FORTONE	19	dh	65	67,5	ch	27,15	ab	30,25	33,1	bf	29,15	32,35	be	25,9	be	10,1	18,5	b
GABBIANO	24	ae	69,5	72,5	cf	31,5	a	19,55	26,25	cg	18,6	25,5	cg	18,95	be	9,9	17,1	b
GAMENYA	17	eh	56	82,5	c	16,45	b	66,05	54,5	a	66,05	54,5	a	19,85	be	14,4	22,3	b
GONGO/CBRD	26	ad	72,5	91,5	b	37,25	a	0,8	3,6	i	0,25	1,95	i	54,35	a	1,45	4,9	b
GRECALE	14	fh	65,5	66,5	dh	26,75	ab	22,9	28,55	bg	21,7	27,7	bf	30,9	be	12,7	20,85	b
HEILO	13	gh	65	62,5	ei	28,05	b	22,3	27,9	cg	21,55	27,25	cf	38,4	bd	0,75	5	b
IRIDE	19	dh	65	62,5	ei	32,55	a	33,4	34,5	be	33,4	34,5	be	36,6	be	6,15	14,3	b
ITALO	17	eh	56	52,5	hi	25,25	ab	43,05	40,95	ad	43,05	40,95	ad	32,6	be	9,55	17,95	b
LEVANTE	21	cg	74	65,5	dh	32,65	a	20,1	26,25	cg	16,9	23,6	cg	21,75	de	5,05	12,8	b
MERIDIANO	17	eh	68	70,5	cg	37,55	a	42,8	40,8	ad	42,8	40,8	ad	29,2	be	6,2	14,1	b
NERONE	25	ad	74	80	cd	27,65	ab	15,55	23,1	ch	11,8	19,95	eh	26,55	be	8,2	16,65	b
NIBBIO	17	eh	56	64	dh	25,9	ab	43,45	41,2	ad	43,45	41,2	ad	27,35	be	6,85	13,45	b
OCORONI F 86	11	h	59	62	ei	27,95	ab	27,25	31,4	bg	27,25	31,4	be	39,95	ad	5	12,6	b
PELEO	16	fh	60,5	63	di	33,35	a	30,4	33,4	bf	30,4	33,4	be	34,85	be	11,55	19,7	b
PERSEO	14	fh	60,5	63,5	di	35,45	a	31,4	33,9	bf	31,4	33,9	be	32,2	be	10,5	18,15	b
PICENO	21	cg	63,5	66	dh	33,65	a	21,95	27,4	cg	19,45	25	cg	21,05	de	9,35	17,75	b
PLINIO	17	eh	69,5	61,5	ei	30,6	ab	53,25	46,9	ab	53,25	46,9	ab	25,3	be	13,65	20,6	b
POGGIO	16	fh	65	61	ei	37,25	a	26,1	30,15	bg	24,65	28,9	bf	30,95	be	12,35	20,4	b
RAMSETE	11	h	56	58,5	ei	34,9	a	34,55	36	be	32,75	34,85	be	30,7	be	7,75	14,95	b
ROMANO	28	ac	74	69	ch	33,6	a	12,3	20,5	eh	11,2	19,4	eh	25,45	be	11,05	19,3	b
SAADI	17	eh	69,5	63,5	di	33,15	a	45,5	42,45	ac	45,5	42,45	ac	25,7	be	13,2	20,85	b
SARAGOLLA	24	ae	74	75,5	ce	35,45	a	15,8	23,05	ch	14,25	21,5	dh	25,25	be	5,9	14	b
SIMETO	29	ab	74	62,5	ei	29,05	ab	21,9	27,8	cg	21,9	27,8	bf	15,75	e	12	20,25	b
SUMAI#3	26	ad	74	105	a	33,05	a	0,25	2,05	i	0,05	0,65	i	44	ab	0,45	3,9	b
SUMMA	11	h	60,5	65	dh	28,95	ab	53,1	46,8	ab	53,1	46,8	ab	16,4	e	28,4	32,2	a
TIZIANA	22	df	65	64,5	dh	38,35	a	5,45	13,5	gi	2,45	9	gi	40,4	ad	4,3	11,95	b
TRESOR	19	dh	56	47,5	i	27,05	ab	26,6	29,8	bg	26,1	29,3	be	22,4	ce	8,55	16,7	b
ULISSE	17	eh	65	65,5	dh	28,45	ab	44,65	41,95	ad	44,65	41,95	ac	24,45	be	6,5	14,7	b
VETTORE	16	fh	56	61,5	ei	25,85	ab	41,35	39,95	ad	41,35	39,95	ad	31,25	be	9,6	17,6	b
VIRGILIO:DR	25	ad	69,5	68	ch	27,2	ab	17,9	25	cg	15,3	22,95	cg	18,55	de	9,1	17,55	b
media	19,22		66,10	67,12		31,31		27,66	30,29		26,53			28,56		8,68	16,22	
min	11,00		56,00	47,50		16,45		0,25	2,05		0,05			15,75		0,45	3,90	
max	31,00		74,00	105,00		38,35		66,05	54,50		66,05			54,35		28,40	32,20	

Table 2

Correlation of 41 Italian varieties

		Flowering days from 1/8 Colonna 1		Physiological maturity, days from 1/8 Colonna 2	Plant height, cm Colonna 3		Weight 1000 seeds Colonna 4		Severity Colonna 5		Severity tras ang Colonna 6	FHB Index Colonna 7	FHB Index tras ang Colonna 8		Seeds spikes Colonna 9	% damaged seeds Colonna 10	% damaged tras ang Colonna 11
flowering	gg da 1/8	1,000															
p. maturity	gg da 1/8	0,674		1,000													
plant	height-cm	0,505		0,468	1,000												
weight	1000 seed	0,152		0,311	0,108		1,000										
	Severity	-0,582		-0,526	-0,389		-0,517		1,000								
Severity	tras ang	-0,580	*	-0,521	-0,481	*	-0,496		0,980		1,000						
	FHB Index	-0,597		-0,535	-0,384		-0,512		0,997		0,972	1,000					
FHB Index	tras ang	-0,594	*	-0,526	-0,471	**	-0,496	*	0,980	*	0,997	0,978	1,000				
seeds	spikes	-0,159		-0,102	0,277		0,357		-0,402		-0,480	-0,377	-0,461	**	1,000		
% damaged	seeds	-0,287		-0,242	-0,215		-0,280		0,569		0,586	0,564	0,583		-0,520	1,000	
% damaged	tras ang	-0,249	ns	-0,237	-0,316	***	-0,283		0,574	*	0,625	0,563	0,617	*	-0,604	0,963	1,000

*P = 0.001; **P = 0.01; ***P = 0.05; ns = not significant

ning 57 ones were without such marker. Tab. 3 summarizes the main characteristics of the QTL containing lines; FHB Index values ranged from 0.05 to 61.99, with a mean value of 25.37. Plant heights varied in a range of 50–98 cm, the average value was 71 cm. As regard with flowering dates (expressed as days after 1st August), a minimum value of 10 dd. recorded, while the highest value was 30 dd. (mean value 17.4 dd.). A significant negative correlation was recorded between flowering date and FHB Index (r = -0.65, P = 0,01) (Tab. 4), whereas no significant correlation was found between FHB Index and plant height. The 57 lines without the molecular marker (Tab. 5) showed a FHB Index ranging from 0.00 to 90.45 (mean value 22.15). Mean plant height was 72 cm, with a maximum of 87 cm and a minimum of 61 cm. Average flowering date was 20.6 dd., with the dates ranging from 10 dd. to 30 dd. Even in this case, FHB Index was significantly correlated with flowering date (r = -0.78, P = 0,01); contrary to QTL containing lines, correlation between FHB Index and plant height was positive (r = 0.412, P = 0,01) (Tab. 6).

Discussion

Regarding the Italian genotypes, only 3 ones showed low FHB Index values. Such cultivars revealed to be, in the Mexican environment, medium-late maturing. Overall, FHB Index values were negatively correlated with flowering date. Even both groups of advanced lines showed a similar correlation, but lines without QTL molecular marker evidenced a lower mean FHB Index, together with a tighter correlation between FHB Index and flowering date. As well as for Italian genotypes, also for the advanced lines late flowering date showed to be a factor able to reduce FHB symptoms. Thus, effect of biological cycle was predominant in determining the disease development. Indeed, despite the absence of QTL, the 57 lines showed to be comparable, in terms of FHB Index, with the 68 lines selected for the presence of QTL molecular marker. On the basis of these preliminary data, it seems that disease seriousness is more influenced by the biological cycle, rather than the presence or absence of the *Qfhs.ndsu-3BS* QTL. This could be due to the asynchrony between plant and pathogen biological cycles. The fungus, to infect plants, is obstacled by physiological, morphological and, most of all, environmental barriers. Consequently, many factors play a role in determining disease development and, hence, plant resistance towards the pathogen. It is clear,

Table 3

Characteristic lines with QTL

	Flowering days from 1/8	Line number	FHB severity, %	FHB incidence, %	FHB index, %	Damaged seeds, %	Plant height, cm	Physiological maturity
	23	515	6,74	90,00	6,06	5,8	64	13-Oct
	30	516	10,22	90,00	9,19	3,9	70	13-Oct
	30	517	8,99	80,00	7,20	1,9	74	13-Oct
	30	518	18,39	100,00	18,39	5,3	65	13-Oct
	23	536	7,14	80,00	5,71	5,1	76	13-Oct
	25	537	6,21	80,00	4,97	23,0	71	13-Oct
	25	538	8,84	50,00	4,42	13,9	72	4-Oct
	23	539	11,24	70,00	7,87	9,5	75	4-Oct
	23	540	11,45	80,00	9,16	10,1	71	13-Oct
	25	541	10,73	90,00	9,66	9,6	65	13-Oct
	30	542	24,55	100,00	24,55	24,9	65	13-Oct
	23	545	22,98	90,00	20,68	10,2	67	13-Oct
	25	546	10,86	70,00	7,60	6,5	75	13-Oct
	26	547	0,54	10,00	0,05	3,8	72	13-Oct
	25	548	15,38	80,00	12,31	18,4	70	13-Oct
	25	549	17,65	100,00	17,65	3,9	65	13-Oct
	25	550	16,85	80,00	13,48	9,0	71	13-Oct
	13	551	33,52	100,00	33,52	18,5	80	10-Oct
	13	552	25,00	100,00	25,00	16,2	80	10-Oct
	13	553	27,55	100,00	27,55	9,4	70	10-Oct
	13	554	22,40	100,00	22,40	20,8	65	10-Oct
	13	555	17,82	100,00	17,82	6,0	70	10-Oct
	19	559	16,77	80,00	13,41	17,9	80	13-Oct
	13	560	36,53	100,00	36,53	6,7	75	13-Oct
	13	561	34,97	100,00	34,97	23,5	72	4-Oct
	13	562	33,52	100,00	33,52	11,7	75	4-Oct
	13	563	28,90	100,00	28,90	12,6	71	4-Oct
	13	564	16,67	88,89	14,81	12,0	75	4-Oct
	13	565	26,14	100,00	26,14	11,7	70	4-Oct
	16	566	30,36	100,00	30,36	8,4	76	4-Oct
	13	575	34,20	100,00	34,20	16,4	65	4-Oct
	13	576	36,81	100,00	36,81	19,1	53	13-Oct
	13	577	18,92	100,00	18,92	13,1	50	4-Oct
	13	578	27,17	90,00	24,46	13,8	53	13-Oct
	10	579	40,13	100,00	40,13	11,3	50	10-Oct
	13	580	25,85	100,00	25,85	28,7	53	4-Oct
	13	581	23,27	100,00	23,27	24,3	50	10-Oct
	30	582	7,69	60,00	4,62	21,5	52	10-Oct
	13	583	33,52	100,00	33,52	43,9	57	13-Oct
	13	584	34,95	100,00	34,95	28,6	56	13-Oct
	10	585	22,94	100,00	22,94	5,7	55	13-Oct
	13	586	35,40	100,00	35,40	8,0	67	10-Oct
	13	587	37,70	100,00	37,70	38,2	70	10-Oct
	13	588	44,59	100,00	44,59	10,5	66	10-Oct
	13	589	28,57	100,00	28,57	17,2	66	10-Oct
	16	590	35,50	100,00	35,50	5,5	71	13-Oct
	16	591	23,75	100,00	23,75	11,1	61	10-Oct
	16	592	31,21	90,00	28,09	2,2	70	10-Oct
	16	593	32,69	100,00	32,69	9,9	70	13-Oct
	16	594	41,08	100,00	41,08	9,3	72	13-Oct
	16	595	44,94	100,00	44,94	5,2	75	13-Oct
	16	596	40,76	100,00	40,76	5,3	77	13-Oct
	16	597	29,63	100,00	29,63	20,9	75	10-Oct
	16	598	28,42	90,00	25,58	10,4	78	10-Oct
	13	599	38,65	100,00	38,65	11,4	77	10-Oct
	16	600	33,71	100,00	33,71	5,6	75	13-Oct
	16	601	18,58	100,00	18,58	5,2	74	13-Oct
	16	606	40,86	100,00	40,86	15,0	79	13-Oct
	16	607	34,09	100,00	34,09	2,1	70	13-Oct
	16	608	33,73	100,00	33,73	10,6	79	13-Oct
	16	609	33,71	100,00	33,71	2,5	79	10-Oct
	16	610	32,97	90,00	29,67	3,5	79	13-Oct
	16	617	61,99	100,00	61,99	6,3	81	13-Oct
	16	621	40,32	100,00	40,32	6,6	90	10-Oct
	16	622	40,70	100,00	40,70	10,0	87	13-Oct
	16	623	10,53	90,00	9,47	13,2	98	13-Oct
	16	624	15,61	100,00	15,61	13,6	96	13-Oct
	16	625	22,54	100,00	22,54	12,8	95	13-Oct
Min	10		0,54	10,00	0,05	1,86	50	
Max	30		61,99	100,00	61,99	43,86	98	
Mean	17,4		26,13	92,92	25,37	12,33	71	

Table 4

Correlation of advanced lines containing the QTL

		Correlation					
		days from 1 Aug	severity	incidence	FHB index	damaged seeds	plant height
Days from 1 Aug	Correlazione di Pearson	1	-,639**	-,583**	-,654**	-,203*	,035
	Sig. (1-coda)		0,000	0,000	0,000	,048	,388
	N	68	68	68	68	68	68
Severity	Correlazione di Pearson	-,639**	1	,630**	,996**	,065	,058
	Sig. (1-coda)	0,000		0,000	0,000	,298	,320
	N	68	68	68	68	68	68
Incidence	Correlazione di Pearson	-,583**	,630**	1	,658**	,121	-,010
	Sig. (1-coda)	0,000	0,000		0,000	,162	,467
	N	68	68	68	68	68	68
FHB index	Correlazione di Pearson	-,654**	,996**	,658**	1	,073	,051
	Sig. (1-coda)	0,000	0,000	0,000		,278	,339
	N	68	68	68	68	68	68
Damaged seeds	Correlazione di Pearson	-,203*	,065	,121	,073	1	-,311**
	Sig. (1-coda)	,048	,298	,162	,278		,005
	N	68	68	68	68	68	68
Plant height	Correlazione di Pearson	,035	,058	-,010	,051	-,311**	1
	Sig. (1-coda)	,388	,320	,467	,339	,005	
	N	68	68	68	68	68	68

* La correlazione è significativa al livello 0,05 (1-coda).
** La correlazione è significativa al livello 0,01 (1-coda).

Table 5

Characteristic lines without QTL

Flowering days from 1/8	Line number	FHB severity, %	FHB incidence, %	FHB index, %	Damaged seed, %	Plant height, cm	Physiological maturity
23	501	11,48	70	8,03	12,2	75	13-Oct
23	502	9,29	60	5,57	15,7	85	13-Oct
23	503	11,41	70	7,99	10,4	87	13-Oct
30	504	10,36	80	8,29	1,2	70	13-Oct
23	505	15,52	90	13,97	2,0	69	13-Oct
30	506	12,82	90	11,54	1,8	65	13-Oct
25	507	8,19	50	4,09	4,2	65	13-Oct
23	508	5,56	60	3,33	6,1	65	13-Oct
25	509	6,04	70	4,23	8,6	65	13-Oct
23	510	14,13	100	14,13	6,6	65	13-Oct
30	511	19,27	80	15,42	19,6	63	13-Oct
23	512	1,70	30	0,51	31,2	65	13-Oct
23	513	10,56	100	10,56	10,0	65	13-Oct
23	514	6,95	70	4,87	8,0	65	13-Oct
25	519	11,11	70	7,78	15,1	63	13-Oct
23	520	10,34	90	9,31	5,8	61	13-Oct
26	521	3,39	40	1,36	4,9	65	13-Oct
30	522	2,75	40	1,10	6,5	70	16-Oct
30	523	11,89	50	5,95	2,3	79	13-Oct
30	524	12,50	80	10,00	2,5	70	13-Oct
30	525	14,05	90	12,65	2,5	69	13-Oct
23	526	6,88	70	4,81	16,8	72	13-Oct
23	527	10,81	90	9,73	18,1	72	13-Oct
25	528	2,72	50	1,36	11,3	75	13-Oct
23	529	11,80	80	9,44	11,5	71	13-Oct
25	530	11,11	70	7,78	7,5	70	13-Oct
23	531	13,41	80	10,73	5,7	69	13-Oct
23	532	6,37	60	3,82	2,2	68	13-Oct
25	533	10,37	80	8,29	11,4	67	13-Oct
23	534	9,94	70	6,96	0,9	71	13-Oct
26	535	0,00	0	0,00	3,7	70	13-Oct
23	543	13,46	90	12,12	3,9	74	13-Oct
23	544	8,33	80	6,67	22,0	69	13-Oct
19	556	15,48	90	13,93	23,9	76	10-Oct
19	557	22,62	80	18,10	24,5	77	13-Oct
13	558	37,08	100	37,08	14,3	80	13-Oct
16	567	36,96	100	36,96	14,5	72	13-Oct
13	568	41,88	100	41,88	25,1	74	13-Oct
13	569	38,95	100	38,95	8,4	71	13-Oct
13	570	47,25	100	47,25	34,6	76	13-Oct

Continuation of Table 5

	Flowering days from 1/8	Line number	FHB severity, %	FHB incidence, %	FHB index, %	Damaged seed, %	Plant height, cm	Physiological maturity
	16	571	72,99	100	72,99	23,3	75	13-Oct
	13	572	50,84	100	50,84	21,7	74	13-Oct
	13	573	52,28	100	52,28	37,6	67	10-Oct
	13	574	52,27	100	52,27	15,8	72	4-Oct
	16	602	12,22	80	9,78	5,5	79	10-Oct
	16	603	10,81	70	7,57	6,1	69	10-Oct
	16	604	21,28	100	21,28	3,1	79	13-Oct
	16	605	36,26	100	36,26	5,7	82	13-Oct
	16	611	51,12	100	51,12	7,1	78	13-Oct
	13	612	43,29	100	43,29	18,6	74	13-Oct
	10	613	90,45	100	90,45	16,5	76	13-Oct
	16	614	45,71	100	45,71	13,3	74	10-Oct
	13	615	30,18	100	30,18	19,9	70	4-Oct
	13	616	43,04	100	43,04	26,4	74	13-Oct
	16	618	65,03	100	65,03	6,1	80	13-Oct
	16	619	68,60	100	68,60	2,4	82	13-Oct
	13	620	45,09	100	45,09	8,8	76	13-Oct
Min	10		0,00	0,00	0,00	0,94	61	
Max	30		90,45	100,00	90,45	37,61	87	
Media	20,6		23,62	81,05	22,15	11,85	72	

Table 6

Correlation of advanced lines without QTL

		Correlation					
		Days from 1 aug	Severity	Incidence	FHB index	Damaged seeds	Plant height
days from 1 aug	Correlazione di Pearson	1	-,773**	-,614**	-,783**	-,466**	-,431**
	Sig. (1-coda)		0,000	0,000	0,000	0,000	0,000
	N	57	57	57	57	57	57
severity	Correlazione di Pearson	-,773**	1	,671**	,999**	,348**	,423**
	Sig. (1-coda)	0,000		0,000	0,000	,004	,001
	N	57	57	57	57	57	57
incidence	Correlazione di Pearson	-,614**	,671**	1	,679**	,228*	,242*
	Sig. (1-coda)	0,000	0,000		0,000	,044	,035
	N	57	57	57	57	57	57
FHB index	Correlazione di Pearson	-,783**	,999**	,679**	1	,350**	,412**
	Sig. (1-coda)	0,000	0,000	0,000		,004	,001
	N	57	57	57	57	57	57
damaged seeds	Correlazione di Pearson	-,466**	,348**	,228*	,350**	1	,054
	Sig. (1-coda)	0,000	,004	,044	,004		,346
	N	57	57	57	57	57	57
plant height	Correlazione di Pearson	-,431**	,423**	,242*	,412**	,054	1
	Sig. (1-coda)	0,000	,001	,035	,001	,346	
	N	57	57	57	57	57	57

* La correlazione è significativa al livello 0,05 (1-coda).

** La correlazione è significativa al livello 0,01 (1-coda).

therefore, how it results difficult to find the optimal interaction between genotype and a suitable phenotypic expression in a given growing environment. Consequently, a correct varietal choice, together with suitable agronomic practices (crop rotation, tillage systems) are crucial to keep FHB under control. Crop breeding is an effective tool to create and/or improve cultivars, through the valorisation of the existing variability as well as through the introduction of genetic materials from other sources. An effective in-field wheat improvement program for *Fusarium* resistance, eventually supported by MAS, may lead to the creation of genotypes able to reveal a certain resistance/tolerance when correct agronomic practices are applied.

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Агрономічна оцінка стійкості італійських сортів твердої пшениці до фузаріозу колоса та скринінг удосконалених за допомогою MAS ліній, відібраних за ознакою стійкості до фузаріозу колоса // Сортовивчення та охорона прав на сорти рослин. – 2016. – № 3. – С. 30–41. http://dx.doi.org/10.21498/2518-1017.3(32).2016.75978

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Для оцінки стійкості до фузаріозу колоса в 2009 році 41 сорт твердої та м'якої пшениці, переважно з Італії, пройшов сортовипробування у CIMMYT (Міжнародний центр поліпшення кукурудзи та пшениці). Крім того, виконано оцінку впливу одного з основних QTL стійкості до фузаріозу колоса (*Qfhs.ndsu-3BS* QTL), вперше виявленого у китайського сорту пшениці м'якої 'Sumai 3', на хромосомі 3B, у 125 удосконалених ліній пшениці твердої BC4F6, отриманих шляхом схрещування з вихідним сортом пшениці м'якої 'Sumai 3' (68 ліній з 'Sumai 3' QTL та 57 ліній без цього QTL), були досліджені в однакових умовах штучного зараження. Для обох груп ділянки заражували під час цвітіння суспензією односпорових культур *F. graminearum*, підтримуючи вологість до 100%, щоб сприяти розвитку захворювання за допомогою системи дрібнодисперсного зволоження. Через тридцять днів після зараження підрахували кількість колосків, інфікованих *F. graminearum*, на колосі десяти рослин на кожній ділянці; пошкодження виразили показником зараження фузаріозом (кількість випадків ураження × ступінь ураження / 100, де ступінь ураження = кількість інфікованих колосків / загальна кількість випадків ураження × 100 та кількість інфікованого колосся / загальна кількість колосся × 100). В обох випадках пізнє цвітіння було ключовим чинником, здатним обмежити ураженість хворобою. Попередні дані стосовно впливу *Qfhs.ndsu-3BS* QTL не виявили відмінності між двома групами вдосконалених ліній.

Ключові слова: *пшениця, коренева гниль, фузаріоз колосу (FHB), QTL, стійкість до хвороб, Fusarium graminearum, односпорові культури, кількість випадків ураження, ступінь ураження, показник FHB.*

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Агрономическая оценка устойчивости итальянских сортов твердой пшеницы к фузариозу колоса и скрининг улучшенных с помощью MAS линий, отобранных по признаку устойчивости к фузариозу колоса // Сортовивчення та охорона прав на сорти рослин. – 2016. – № 3. – С. 30–41. http://dx.doi.org/10.21498/2518-1017.3(32).2016.75978

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Для оценки устойчивости к фузариозу колоса в 2009 году 41 сорт твердой и мягкой пшеницы, преимущественно из Италии, прошел сортоиспытания в CIMMYT (Международный центр улучшения кукурузы и пшеницы). Кроме того, проведена оценка влияния одного из основных QTL устойчивости к фузариозу колоса (*Qfhs.ndsu-3BS* QTL), впервые выявленного у китайского сорта пшеницы мягкой 'Sumai 3', на хромосоме 3B) у 125 улучшенных линий пшеницы твердой BC4F6, полученных путем скрещивания с исходным сортом пшеницы мягкой 'Sumai 3' (68 линий с 'Sumai 3' QTL и 57 линий без этого QTL), в одинаковых условиях искусственного заражения. Для обеих групп делянки заражали во время цветения суспензией односпоровых культур *F. graminearum*, поддерживая влажность до 100%, чтобы способствовать развитию заболевания с помощью системы мелкодисперсного увлажнения. Через тридцать дней после заражения подсчитали количество колосков, инфицированных *F. graminearum*, на колосьях десяти растений на каждой делянке; повреждение выразили показателем заражения фузариозом (количество случаев поражения × степень поражения / 100, где степень поражения = количество инфицированных колосков / общее количество случаев поражения × 100 и количество инфицированных колосьев / общее количество колосьев × 100). В обоих случаях позднее цветение было ключевым фактором, ограничивающим поражение болезнью. Предварительные данные относительно влияния *Qfhs.ndsu-3BS* QTL не выявили отличий между двумя группами улучшенных линий.

Ключевые слова: *пшеница, корневая гниль, фузариоз колоса (FHB), QTL, устойчивость к болезням, Fusarium graminearum, односпоровые культуры, количество случаев поражения, степень поражения, показатель FHB.*

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