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WATERLOGGING AFFECT THE DEVELOPMENT, YIELD AND COMPONENTS, CHLOROPHYLL CONTENT AND CHLOROPHYLL FLUORESCENCE OF SIX BREAD WHEAT GENOTYPES (*TRITICUM AESTIVUM* L.)

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Abstract

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During rainy crop seasons waterlogging is a serious environmental stress influencing wheat development and production in the North West zones of Tunisia. A field trial was conducted during the two cropping seasons 2005/06 and 2006/07at Oued-Béja Agricultural Experimental Unit (36°44'N; 9°13'E) under rainfed and waterlogging conditions in order to evaluate flooding effects on development, chlorophyll fluorescence, chlorophyll content, yield and components for six bread wheat genotypes (*Triticum aestivum* L.). The floodwater state was applied during 28 days at the tillage stage. The results indicated that waterlogging has significantly affected ($P<0.01$) the vegetative development, physiological traits and yield and components for all studied genotypes. Waterlogging delayed the heading by 9.6 days and reduced the plant height and the tiller number per plant (TN/P) by 25.4% and 44.2% respectively. This vegetative growth limitation resulted in an average decrease of 55.9% in grain yield. The genotype Salammbô presented the lowest levels of yield reduction (≈ 39% and 39.6%) against a reduction of 71.8% and 76.5% recorded for cv. Vaga. In addition, clear variation in chlorophyll fluorescence (Maximum quantum efficiency: Fv/Fm) and chlorophyll content were observed between controls and waterlogged plants. For chlorophyll content index, minima decreases of 41.3% and 44.5% were recorded after 28 days of waterlogging respectively for cv. Salammbô and cv. Utique against maxima of 58.5%, 58.9% and 60.7% recorded for cv. Vaga, FxA and cv. Ariana, respectively. Under water excess conditions F_v/F_m of Vaga and Ariana genotypes were more affected than cvs. Salammbô and Utique.

Key words: Waterlogging, *Triticum aestivum*, Grain yield, Chlorophyll fluorescence

Abbreviations: CCI, chlorophyll content index; MAT, monthly average temperature; PRC, precipitation; NRD, number of rainy days; PH, plant height; TN/P, tillers number per plant; NDH, number of days to heading; NDHD: , number of days to heading delay; EN.m^{-2}, ears number per m^2; GN/E, grains number per ear; BY, biological yield; GY, grains yield; CCI, chlorophyll content index; Fv/Fm, maximum quantum efficiency; FxA, Florance-Aurore; PR, percentage reduction; ETR, maximal relative electron transport rate

Introduction

Waterlogging occurs in many cereals growing areas around the world, mainly under irrigated and high rainfall environments (Samad et al., 2002). In Tunisia, especially in the humid and sub-humid zones of the North West regions, transient waterlogging is a serious environmental constraint affecting

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wheat development and production. Waterlogging decrease the vegetative development, tiller number and the grain yield (Kozlowski, 1984a; Davies and Hillman, 1988; Huang et al., 1994a, b ; Dickin and Wright, 2008) for several cereal crops with an average decreases of 39 to 44% observed for *Triticum aestivum* (Musgrave and Ding, 1998; Collaku and Harrison, 2002) and 30 - 50% for barley (Setter et al., 1999). Linkemer et al., (1998) signaled for Soybean an average decrease of 90% in grain yield after seven days of waterlogging. According to many authors, this decrease was specially related to nutrients uptake limitation such as that of nitrogen (Bennett and Albrecht, 1984; Kozlowski, 1984b and Bacanamwo and Purcell, 1999).

In addition, waterlogging generally induces a relatively rapid decrease in the rate of photosynthesis in many plant species (Kozlowski, 1997). Several studies showed that, in flooded plants, photosynthesis is significantly decreased within few hours (Beckman et al., 1992; Yordanova and Popova, 2007; Liu and Huang, 2008 and Zheng et al., 2009; Balakhnina et al., 2010; Souza et al., 2011). For example photosynthesis rate significantly decreased within 5 h for *Pseudotsuga menziesii* seedlings (Zaerr, 1983) and within 24 h for citrus rootstocks (Phung and Knipling, 1976). The chlorophyll fluorescence is subtle reflection of primary reactions of photosynthesis (Sayed, 2003). So, the photochemical processes alterations appeared in the chlorophyll fluorescence kinetics induce changes in the established parameters of fluorescence and the damages in PSII are usually the first sign of stress in the leaf that could be used to estimate photosynthetic performance under stress conditions (Maxwell and Johnson, 2000). Recently, the use of different fluorescence assess to supervise responses to abiotic stresses has been reviewed (Sayed, 2003). Several works described relationships between Chlorophyll fluorescence and photosynthesis (Govindjee, 1995; Schreiber, 1998; Schreiber and Bilger, 1998; Lazar, 1999; Maxwell and Johnson, 2000 and Schreiber et al., 2000) and others describe its use in stress physiology (Rohacek and Bartak, 1999; Schreiber et al., 2000; Rohacek, 2002; Zakhidov et al., 2002). In fact, chlorophyll fluorescence represents a promising tool for detection of plant tolerance to various environmental stresses (Zivcak et al., 2008).

The aim of the present work was to study the behavior of six *Triticum aestivum* genotypes under rainfed and waterlogging conditions in order to evaluate and to identify amount the studied genotypes possible sources of tolerance/resistance to this serious production constraint.

Materiel and Methods

Plant material

Six bread wheat (*Triticum aestivum*) genotypes were used in this study (Table 1).

Experimental conditions

The trial was conducted during 2005-06 and 2006-07 seasons at the Agricultural Experimental Unit Oued-Beja in the Beja region (36°44'N; 9°13'E) situated in North West of Tunisia characterized by sub-humid climate with moderate winter (average annual rain of 600 mm) and a vertisol soil with silty-clay texture (clay 49%, silt 35% and sand 16%). The trial was installed according a split-plot design with three replications and two treatments were applied rainfed and waterlogging conditions (main plots). Each experimental unit consists of four rows of 2 m (2 m²). During the two cropping seasons sowing was made the first week of December with seeding rates of 300 seeds per m2.Waterlogging treatment was applied at tillage stages (Z21) (Zadoks et al., 1974) with continuous submersion irrigation during 28 days. Nitrogen fertilization was applied after seedling at the three leaves stage with 40 Unit/ha rate.

Meteorological data

The meteorological data have been collected from the METHOS meteorological station installed at the Agricultural Experimental Unit of Oued Beja (Table 2).

Measurements

Plant development parameters

Plant height (PH): This parameter was measured at physiological maturity by measuring for each plot the main repre-

Table 1
The six studied *T. aestivum* genotypes

Genotypes	Cross and Pedigree
"Ariana"	Kenya 338 et Etoile de Choisy cross realized in France. Introduced in Tunisia in 1962 in F5 stage
Florence Aurore "FxA"	Cross performed in France. Introduced in Tunisia in 1922 in F2 stage
"Haïdra"	Bow « S » /Dougga 74 cross performed at INRAT Tunisia.
"Salammbô"	«Poto//correcawinnos/–INIA 66» cross performed at CIMMYT– Mexico. Introduced in Tunisia in F2 stage
"Utique"	Attila"S"cross performed at CIMMYT– Mexico. Introduced in Tunisia in F2 stage
"Vaga"	CM66684 cross realized at CIMMYT– Mexico. Introduced in Tunisia in F7 stage

sentative plant height from ground to the top ears top without awns.

Tillers number per plant (TN/P): for each genotype the total tiller number per plant was counted at the stem elongation stage on five plants per plot.

Number of days to heading (NDH): Heading date for each genotype was recorded when approximately 50% of plants in the plot had a fully emerged head. The NDH was calculated as the number of days from emergence to heading.

Yield and components

Number of ears per m² ($EN.m^{-2}$): recorded at the maturity stage for each plot in an area of one meter square.

Number of grains per ear (GN/E): recorded at maturity stage on five randomly chosen ears of five different plants.

Biological yield (BY in $kg.m^{-2}$) and Grain Yield (GY in $g.m^{-2}$): Those parameters were recorded at harvesting time from the two central rows.

Biochemical and Physiological parameters

These parameters were recorded only during the second cropping season 2006-07 at the 28th day of flooding treatment for both rainfed and waterlogged plants.

Chlorophyll content index (CCI): Chlorophyll content index was determined after 28 days of treatment on the last leaf with non destructive method using a CL-01 Chlorophyll Content Meter of "Hansatech". Part of the leaf was placed between two clips and the chlorophyll content index was determined in dual wavelength optical absorbance (620 and 940nm).

Chlorophyll fluorescence: Maximum quantum efficiency (Fv/Fm): Maximum quantum efficiency values (Fv/Fm) were recorded on the last leaf after 28 days of treatment using a Plant Efficiency Analyzer (Handy-PEA, Hansatech instruments Ltd, P02.002 version). A part of the leaf delimited by a measure clip was maintained in dark during 12 min by closing the clip shutter. After that, chlorophyll fluorescence transients were induced by a red light of 1500 $\mu mol.m^{-2}.s^{-1}$ intensity applied during 1 s.

Statistical analysis

The analysis of variance (ANOVA) was determined using the SPSS statistical program v.13 and differences among treatments for all measurements were compared at 0.05 significance level.

Results

Effect of waterlogging on plant development

For the six tested genotypes, the ANOVA showed highly significant effect ($p<0.01$) of waterlogging on the tiller number per plant (TN/P), the plant height (PH) and the number of days to heading (NDH) (Table 4). During the two cropping seasons, compared to the control conditions, waterlogging resulted in important decreases of TN/P varying from 33.5% for cv. Salammbô to 51.2% for cv. Vaga. The other genotypes Ariana, Utique, FxA and Haïdra showed a decrease of 36.8%, 46%, 47% and 50.45% respectively, with an average decrease of 44.2% recorded for the six tested genotypes (Table 3). Also, results showed that waterlogging has significantly delayed heading during the two cropping seasons with an average of 9.6 days for the six genotypes. Compared to rainfed conditions, 28 days of waterlogging delayed the heading by a minimum of 7 days for cv. Salammbô to a maximum of 12.3 days for cvs. Vaga and FxA (Table 3).

In addition, water excess has also affected the plant height for the six tested genotypes with variable degree (Figure 1). during the two cropping seasons and compared to rainfed conditions, a minimum reduction of 23% was observed for Salammbô and Utique against a maximum of 29.2% recorded for cv. Vaga. The non significant difference observed for the genotypes*treatment interaction especially for TN/P and the PH shows that the six tested genotypes presented a similar behavior under waterlogging stress.

Effect of waterlogging on yield and components

During the two cropping seasons waterlogging stress has significantly affected ($p<0.01$) the ears number per m²

Table 2
Monthly average temperature (MAT), precipitation (PRC) and number of rainy days (NRD) recorded in the Agricultural Experimental Unit Oued Beja during the two cropping seasons 2005/06 and 2006/07

		Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun
MAT, °C	2005-06	23.9	21.5	15.3	10.3	8.9	7.7	13.1	17.5	18.4	25.5
	2006-07	24.5	21.9	15.8	11.5	11.9	12.4	12.5	16	19.2	25
PRC, mm	2005-06	0.8	21.4	37.4	108.3	172	96.8	49.7	23.9	26.8	0
	2006-07	31.5	23.9	21.9	108.2	21.4	60.1	137.9	64.6	17.8	12.4
NRD*	2005-06	0	4	6	10	12	6	5	5	3	0
	2006-07	3	4	3	7	4	5	10	7	4	2

* Precipitation ≥ 2 mm

(EN.m^{-2}), the grains number per ear (GN/E), the biological yield (BY) and the grains yield (GY) (Table 5).

Ears number per m² (EN.m^{-2})

The flooding has significantly affected the number of ears per m² during the two cropping seasons. A highly significant difference between genotypes was observed. Figure 2 shows that compared to the rainfed conditions cv. Salammbô and cv. Haïdra expressed the minima decreases with averages of 35.3% and 35.9% respectively. The genotype Ariana was most affected by waterlogging with 45.1% of decrease of the EN.m^{-2}. The other genotypes FxA, Utique and Vaga showed decreases of 39.6%, 39.4% and 41.7% respectively with an average reduction of 39.5% recorded for the tested genotypes during the two cropping seasons.

Number of grain per ear (NG/E)

Grown under waterlogging during 28 days, the six evaluated genotypes showed significant decreases of the grain number per ear during the two cropping seasons with a highly significant difference between them (Table 5). An average decrease of 27.9% was observed for the all tested genotypes with maxima of 55.1% and 53.9% recorded respectively for cv. Vaga and cv. Ariana. Minima of 1.1% and 6.2% were recorded for cv. Utique and cv. Salammbô. For this parameter the two cultivars FxA and Haïdra showed intermediate behavior with respectively 18.5% and 32.5% of reduction (Table 6).

Biological yield (BY)

Results showed that during the two cropping seasons flooding stress has highly and significantly affected the bio-

Table 3
Effect of waterlogging on the tiller number per plant (TN/P) and the number of days to heading (NDH) for the six evaluated genotypes. (FxA: Florance-Aurore)

			Genotypes					
			Ariana	FxA	Haïdra	Salammbô	Utique	Vaga
TN/P	2005/06	Rainfed	5.4±1.4^{a}	6.1±1^{a}	6±1.20^{a}	5.95±0.34^{a}	6.11±0.4^{a}	6±0.3^{a}
		Waterlogged	3.5±0.4^{a}	3.1±0.2^{a}	3.11±0.84^{a}	3.88±0.39^{a}	3.33±0.3^{a}	2.89±1.2^{a}
		PR (%)	35.6±6.3^{a}	48.7±3.17^{a}	48.15±13.98^{a}	34.77±6.53^{a}	45.45±5.5^{a}	51.83±19.5^{a}
	2006/07	Rainfed	5.1±0.8^{a}	5.9±0.77^{a}	6.11±1.02^{a}	5.22±0.84^{a}	6.44±0.2^{a}	6.29±0.6^{a}
		Waterlogged	3.2±0.3^{a}	3.2±0.19^{a}	2.89±0.51^{a}	3.54±0.18^{a}	3.44±0.2^{a}	3.11±0.5^{a}
		PR (%)	38.1±5^{ab}	45.3±3.25^{bc}	52.75±8.31^{b}	32.28±3.45^{a}	46.57±3^{bc}	50.50±8.1^{b}
NDH	2005/06	Rainfed	115.7±0.6^{d}	105±0^{a}	110±1^{c}	106±1^{a}	105.3±0.6^{a}	108.7±0.6^{b}
		Waterlogged	127.3±0.6^{e}	117.3±0.6^{bc}	118.7±0.6^{c}	113.7±0.6^{a}	116.3±0.6^{b}	121±2^{d}
		NDHD	11.7±0.6^{b}	12.3±0.6^{b}	8.7±0.6^{a}	7.7±0.6^{a}	11±0.6^{b}	12.3±2^{b}
	2006/07	Rainfed	117.7±0.6^{a}	111±0^{a}	119±1^{a}	114.7±15.9^{a}	110.7±1.2^{a}	112.3±0.6^{a}
		Waterlogged	124.7±0.6^{c}	119.7±0.6^{a}	126.7±0.6^{d}	122.7±0.6^{b}	119±1^{a}	124.3±0.6^{c}
		NDHD	7±0.6^{a}	8.7±0.6^{b}	7.7±0.6^{ab}	8±0.6^{ab}	8.3±1^{b}	12±0.6^{c}

Data are three replication means ± SD
Data with the same letter per line are non-significantly different at P=0.05 (Duncan test).

Table 4
Mean squares of the tiller number per plant (TN/P), the plant height (PH) and the number of days to heading (NDH) for the six evaluated genotypes

Source	df	Tiller number plant (TN/P)		Plant Height (PH)		Number of days to heading (NDH)	
		2005/06	2006/07	2005/06	2006/07	2005/06	2006/07
Genotypes	5	0.19ns	0.45ns	1050.98**	1101.78**	110.52**	59.29*
Treatment	1	61.93**	61.62**	7084.03**	6696.69**	1013.36**	667.36**
Genotypes*Treatment	5	0.37ns	0.64ns	44.23ns	42.09ns	5.89**	4.63ns
Error	24	0.59	0.34	20.11	27.69	0.72	21.5
		R^2 = 0.821	R^2 = 0.893	R^2 = 0.963	R^2 = 0.949	R^2 = 0.989	R^2 = 0.657

**: significant at the 0.01 level; *: significant at the 0.05 level; ns: non significant logical yield for the six evaluated genotypes with an average decrease of 48.3%. During the two cropping seasons the cv. Salammbô showed a minimum reduction of 39.1% against a maximum of 57.3% recorded for cv. Vaga. The cultivars Ariana, FxA, Haïdra and Utique showed decreases of 54.2%, 51.1%, 45.3% and 42.9% respectively (Table 6).

Grain yield (GY)

During the two cropping seasons 2005-06 and 2006-07 flooding applied for 28 days has significantly affected grain yield for the six evaluated genotypes (Table 5). Compared to rainfed conditions (control) waterlogging induced an average decrease of 55.9% with a maximum of 74% recorded for cv. Ariana and cv. Vaga against a lowest decrease of 39.4% recorded for the cultivars Salammbô and Utique. The two cultivars FxA and Haïdra showed an intermediate behavior with respective decreases of 59.85% and 48% (Table 6).

Effect of waterlogging on chlorophyll content and Chlorophyll fluorescence

The chlorophyll content index (CCI)

After 28 days of floodwater stress the chlorophyll content for all studied genotypes was highly and significantly affected by waterlogging ($p<0.01$) for all studied genotypes (Table 7). Compared to control plants the waterlogged plants showed important decreases in chlorophyll content with an average decrease of 52.3% recorded for the six tested genotypes (Table 8). Minima decreases of 41.3% and 44.5% were recorded respectively for cv. Salammbô and Utique. The most pronounced decreases were observed for the genotypes Vaga, FxA and Ariana with 58.5%, 58.9% and 60.7% respectively.

Chlorophyll fluorescence

Maximum quantum efficiency (Fv/Fm)

Results showed F_v/F_m ratio was significantly affected by waterlogging stress for the six evaluated genotypes. Com-

Table 5
Mean squares of the ears number per m² (EN.m^{-2}), the grains number per ear (GN/E), the biological yield (BY) and the grains yield (GY) for the six evaluated genotypes

Source	df	Ears number per m² (EN.m^{-2})		Grains number per ear (GN/E)		Biological yield (BY)		Grains yield (GY)	
		2005/06	2006/07	2005/06	2006/07	2005/06	2006/07	2005/06	2006/07
Genotypes	5	20095.2**	19852.6**	100.7**	76.7**	0.07*	0.05ns	29851.3**	25303.9**
Treatment	1	309506.8**	273529**	432.3**	590**	9.05**	8.1**	710030.9**	662940.6**
Genotypes*Treatment	5	1290ns	1070.9*	38.3*	77**	0.03ns	0.03*	5918.8*	8349.5**
Error	24	609.3	334.4	6.6	7.4	0.02	0.03	1625	1030
		R^2=0.966	R^2=0.979	R^2=0.878	R^2=0.884	R^2=0.952	R^2=0.918	R^2=0.958	R^2=0.971

**: Significant at the 0.01 level; *: Significant at the 0.05 level; ns: non significant

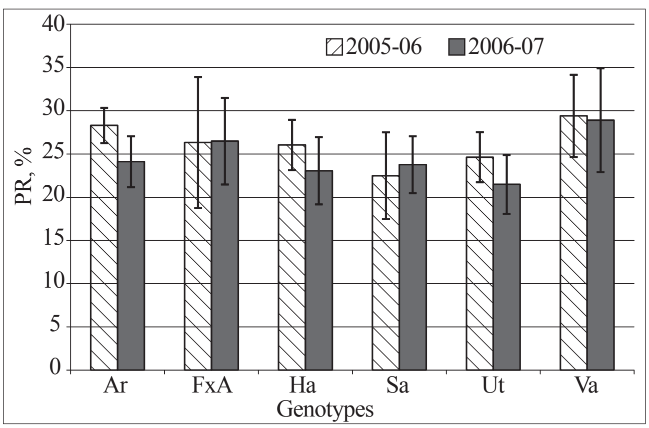

Fig. 1. The plant height percentage reduction (PR) recorded after 28 days of waterlogging for the six bread wheat tested genotypes

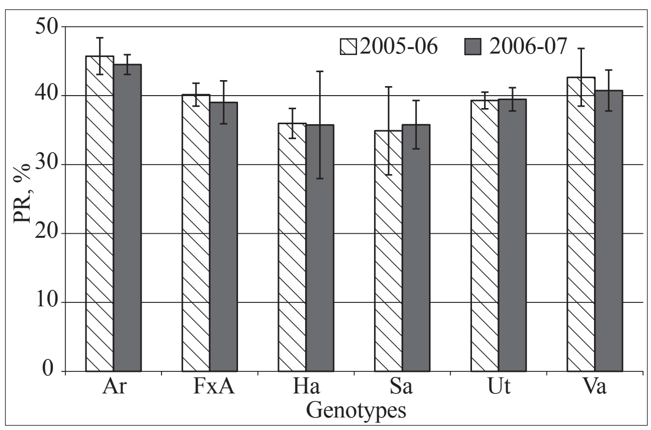

Fig. 2. The percentage reduction of the ears number per m² (EN.m^{-2}) recorded after 28 days of waterlogging for the six bread wheat tested genotypes compared to rainfed conditions

pared to the control plants, the flooded plants showed significant decreases in the maximum quantum efficiency of PSII photochemistry (F_v/F_m) (Table 7). After 28 days of waterlogging the genotypes Salammbô and Utique showed the lowest reduction levels of Fv/Fm ratio which decreased from 0.818 and 0.812 to 0.792 and 0.785, respectively (Table 8). Contrary, important reductions were observed for the genotypes Vaga and Ariana for which water excess effects were more pronounced and F_v/F_m decreased from 0.818 and 0.814 to 0.697 and 0.721 respectively.

Discussion

Effect of waterlogging on plant development

Results showed a highly significant effect of waterlogging on plant development of bread wheat. During the two cropping seasons cv. Salammbô showed the highest tolerance level to waterlogging among the six evaluated genotypes. In fact, cv. Salammbô showed minima decreases of 33.5% and 23% respectively for TN/P and PH with 7 days of heading delay. However, cv. Vaga which was the most sensitive genotype to waterlogging showed the maxima decreases of 51.2% for TN/P, 29.2% for PH, and 12.3 days of heading. The plant height decrease which is strongly related to the stem limitation growth can be explained mainly by a slowdown growth under root anoxia. These results were confirmed by several studies conducted on bread wheat (Belford and Farlane, 2001; Boru 2001; Collaku and Harrison, 2002; Condon and Giunta, 2003; Dickin and Wright, 2008; Robertson et al., 2009), barley (Setter and Waters, 2003; Yordanova, 2004; Pang et al., 2007; Zhou, 2007), oat (Watson et al., 1976), rice (Akihiko

Table 7
Mean squares of the Maximum quantum efficiency: F_v/F_m and Chlorophyll content index (*CCI*) for the six evaluated genotypes

Source	df	Maximum quantum efficiency (Fv/Fm)	Chlorophyll content index (CCI)
Genotypes	5	0.002**	7.616**
Treatment	1	0.04**	473.53**
Genotypes*Treatment	5	0.002**	1.851ns
Error	24	0.00	2.00
		$R^2 = 0.938$	$R^2 = 0.916$

Table 6
Effect of waterlogging on the ears number per m² (EN.m^{-2}), the grains number per ear (GN/E), the biological yield (BY) and the grains yield (GY) for the six evaluated genotypes. (FxA: Florance-Aurore)

			Genotypes					
			Ariana	FxA	Haïdra	Salammbô	Utique	Vaga
GN/E	2005/06	Rainfed	25.7±2.8[ab]	28.4±2.9[ab]	30.9±5.2[b]	24.7±1.2[a]	28.2±1.6[ab]	24±0.7[a]
		Waterlogged	12.8±1.3[a]	20.2±1.3[b]	24.5±3.4[c]	23.3±3.4[bc]	27.3±0.9[c]	12.2±2.2[a]
		PR (%)	50.2±4.9[d]	29.1±4.4[c]	20.7±11.1[bc]	5.6±13.7[ab]	3.3±3[a]	49±9.1[d]
	2006/07	Rainfed	28 ±3.9[ab]	29.7±1.7[b]	28.1±4.4[ab]	23.7±3.1[a]	27.3±1.5[ab]	25.9±2.1[ab]
		Waterlogged	11.9±1.4[a]	19±2.1[b]	23.5±4.2[bc]	22.1±3.1[b]	27.6±1.1[c]	10±0.6[a]
		PR (%)	57.7±4.9[d]	35.9±7.2[c]	16.4±14.9[b]	6.9±13.2[ab]	-1.1±4.1[a]	61.3±2.3[d]
BY	2005/06	Rainfed	2.2±0.2[a]	2±0.1[a]	2.2±0.3[a]	2±0.1[a]	2.1±0.2[a]	2±0.2[a]
		Waterlogged	1.1±0.1[abc]	1±0.1[ab]	1.2±0.2[cd]	1.3±0.1[d]	1.2±0.1[bcd]	0.9±0.1[a]
		PR (%)	53.2±4.9[bc]	51.7±3.7[bc]	44.5±7.6[ab]	38±5.5[a]	43.8±4[ab]	56±4.5[c]
	2006/07	Rainfed	2. ±0.2[a]	1.9±0.1[a]	2±0.4[a]	2±0.2[a]	1.9±0.2[a]	1.9±0.2[a]
		Waterlogged	0.9±0.1[ab]	0.9±0.1[abc]	1.1±0.1[bcd]	1.2±0.1[d]	1.1±0[cd]	0.8±0.1[a]
		PR (%)	55.2±3.3[c]	50.5±3.1[bc]	46.1±6.6[ab]	40.2±2.8[a]	42.1±1.7[a]	58.7±6.7[c]
GY	2005/06	Rainfed	475.7±17.1a[b]	440.2±33.4[a]	562.3±117.3[bc]	529.4±28.7[abc]	580.7±11.4[c]	507.4±21.6[abc]
		Waterlogged	128.4±11.5[a]	182±4.5[b]	286.8±40.7[c]	323.1±25.9[cd]	347.2±14.3[d]	143±15. 5[ab]
		PR (%)	73±2.4[d]	58.7±1[c]	49±7.2[b]	39±4.9[a]	40.2±2.5[a]	71.8±3[d]
	2006/07	Rainfed	451±34.6[ab]	425.8±25.4[a]	508.9±70.9[bc]	498.1±47.9[abc]	540±28.3[c]	497.8±22[abc]
		Waterlogged	107.8±12.2[a]	166±7.4[b]	270±28.4[c]	300.9±25.5[cd]	331.5±12.1[d]	116.8±10.5[a]
		PR (%)	76.1±2.7[d]	61±1.7[c]	46.9±5.6[b]	39.6±5.1[a]	38.6±2.2[a]	76.5±2.1[d]

Data are three replication means ± SD
Data with the same letter per line are non-significantly different at P=0.05 (Duncan test).

Table 8
Effect of waterlogging on the maximum quantum efficiency: F_v/F_m and chlorophyll content index (*CCI*) after 28 for the six evaluated genotypes

Genotypes	Maximum quantum efficiency (F_v/F_m)		Chlorophyll content index (*CCI*)	
	Rainfed	Waterlogged	Rainfed	Waterlogged
Ariana	0.814±0.012	0.721±0.017	13.5±1.81	5.3±0.92
FxA	0.813±0.009	0.746±0.021	12.4±2.08	5.1±0.25
Haïdra	0.812±0.012	0.759±0.015	13. 8±2.21	6.9±1.46
Salammbô	0.818±0.008	0.792±0.004	13.3±0.87	7.8±0.56
Utique	0.812±0.010	0.785±0.009	15.5±1.15	8.6±0.75
Vaga	0.818±0.004	0.697±0.017	14.7±1.87	6.1±1.42

Data are three replication means ± SD; FxA: Florance-Aurore

and Nawata, 2007), bean (Ahmed, 2002a; Jafar, 2006), soybean (Shigenori et al., 2004), genus *Hibiscus* and *Corchorus* (Changdee et al., 2009) and the genus *Lolium* (Mc Farlane et al., 2003).

Moreover, plant tillering contribute to the environmental conditions adjustment and its decrease imply to the spike number reduction and consequently the grain yield decrease (Loveras et al., 2001; Sadras and Calvin, 2001). For the different evaluated genotypes tillering capacity was limited by waterlogging stress. This capacity is generally related to the genotype, planting density and especially the nitrogen fertilization. In fact, under flooding conditions, nitrogen deficiency induced by transient leaching seems to be the main cause of the plant limitation growth and development. Similar results were found for *T. aestivum* after 6 days of waterlogging (Belford and Farlane, 2001; Collaku and Harrison, 2002; Condon and Giunta, 2003; Dickin and Wright, 2008). Robertson et al. (2009) showed that anoxia applied for 14 days on 22 days aged wheat plants inhibited the primary tiller growth and delayed by 9 days the new tillers development in addition to the plant height limitation growth and heading delay. Similarly, Cannel et al. (1985) mentioned a considerable decrease of the tiller number per oat plant of under excess water stress which was restored after nitrogen supply.

Effect of waterlogging on yield and components

Generally grain yield is elaborated through subsidiary traits called yield components such as number of ears per m² ($EN.m^{-2}$), grains number per ear (GN/E) and biological yield (BY) which are especially related to the genotypes and particularly to environment conditions (Cook and Veseth, 1991). Jonard and Koller (1950) reported that, under stress conditions, any variation in one yield component without compensatory effect of other components could affect the grain yield. During the two cropping seasons 2005/06 and 2006/07 waterlogging applied during 28 days has significantly affected $EN.m^{-2}$, GN/E, BY and consequently the GY which was the most affected for the six evaluated genotypes with an average decrease of 55.9%. In fact, during the two cropping seasons this constraint induced average decreases of 39.5%, 27.9%, and 48.3% respectively for $EN.m^{-2}$, GN/E and BY. Among the six evaluated genotypes cv. Salammbô showed the most tolerance level for waterlogging constraint with decreases of 35.5%, 6.2%, 39.1% and 39.3% recorded for EN, GNE, BY and GY respectively. However, the high sensitivity level was recorded for the genotypes Vaga and Ariana. The inter-varietal comparison revealed a best tolerance for cv. Salammbô which seems to guarantee a minimal and secure grain yield for farmers under this constraint with a decrease of 34.8% in grain yield against 74.2% recorded for the cv. Vaga. These results confirm those found by Collaku and Harrison (2002) signaling the existence of genotypic variation in wheat for waterlogging tolerance and they identified some genotypes with a potential tolerance to this constraint.

In addition, several studies which were carried out on barley and wheat reported similar results and estimated losses of 30 to 50% after waterlogging treatment (Setter et al., 1999; Collaku and Harrison, 2002). Other studies identified GN/E as the fundamental component that causes the grain yield reduction under waterlogging environments (Musgrave and Ding, 1998; Dickin and Wright, 2008). However, Collaku and Harrison (2002) signaled a combined effect of TN/P and GN/E as the main causes of grain yield decreases under this constraint. The highly significant correlations between GY and $EN.m^{-2}$ (r=0.884**), GN/E (r=0.917**) and BY (r=0.820**) indicate that grain yield is strongly related to ears number per m² as well as to ears fertility (GN/E).

Effect of waterlogging on chlorophyll content and chlorophyll fluorescence

The green pigment composition analysis in leaves is very important in plant eco-physiological studies. It provides information about physiological responses of plants under stress conditions (Yordanov et al., 2000; Valladares and Niinemets, 2008). After 28 days of waterlogging, CCI was significantly decreased for the six evaluated genotypes. The genotypes Salammbô and Utique revealed the best tolerant level with minima decreases of 41.3% and 44.5% respectively, against high sensitive level recorded for Ariana, FxA and Vaga genotypes for which respective reductions of 60.7% and 58.9% and 58.5% were recorded. Such decreases can be explained by the fact that waterlogging induced root cell death limiting so the development and the functional of root system such as the water and mineral uptake, from previously leached soil, especially nitrogen. This phenomenon results in yellow, dry and dehydrated leaf tissue which is responsible for leaves chlorophyll content decrease and photochemical process alteration in the stressed plants.

Similar results were reported on *T. aestivum* (Huang et al., 1994a, b; Collaku and Harrison, 2002 ; Collaku and Harrison, 2005; Ghobadi et al., 2007), barley (Setter and Waters, 2003 ; Jiayin et al., 2004), pea and maïze (Przywara and Stepniewski, 1999; Yordanova & Popova, 2007; Souza et al., 2011), Brassica species (Ashraf and Mehmood, 1989), *Salix caprea* (Talbot et al.,1987), *Vicia faba* with a decrease of 37% in the CCI compared to the control (Pociecha et al., 2008; Balakhnina et al., 2010), *Medicago spp.* (Smethurst and Shabala, 2003), lentil (Ashref and Chishti, 1993), soybean (Cho et al., 2006), genus *Myrica* (Naumann et al., 2008), genus *Prunus* (Mielke et al., 2010), *Calophyllum brasiliense* (Oliveira and Joly, 2010). In addition, Drew (1991) showed that decrease in chlorophyll content, as a result of waterlogging, induced the reduction of photosynthesis activity in wheat with a significant effect on yield.

The chlorophyll loss was linked with variations of the photosynthetic characteristics of the leaves. After 28 days of flooding all studied genotypes showed a negative deviation of the F_v/F_m which is a parameter commonly known as maximum quantum yield of primary photochemistry or maximal relative electron transport rate (ETR) of PSII (Waldhoff et al., 2002). Results showed that F_v/F_m decrease was more pronounced for the genotypes Vaga and Ariana than the genotypes Salammbô and Utique which showed the minima decreases expressing thus the highest tolerant level for this floodwater stress. These decreases in the F_v/F_m ratio can be considered as an indicator of electron transport chain deterioration in the PSII (Mielke et al., 2003; Naumann et al., 2008; Oliveira and Joly, 2010). So, for the genotypes Vaga and Ariana, the photochemical process is more sensitive to flooding stress compared to the genotypes Salammbô and Utique which are able to maintain relatively normal values of the Fv/Fm ratio under this constraint.

In addition, several studies showed that under waterlogging the Fv/Fm variation is related to the reduction of the PSII antenna size by phosphorylation. Consequently, this reduction decreases the “reaction-center” excitation rate in the PSII and increases the PSI electron transport (Habash and Baker, 1990; Jajoo and Bharti, 1993; Kyparassis et al., 1995). Furthermore, the decrease of the PSII reaction-center CO_2 assimilation rate in the leaves is related to the inhibition (i) of energy use for the active oxygen species production (Ahmed et al., 2002a, b) and (ii) of photosynthesis, which causes an increase of the PSII excitation energy dissipation resulting on photo-damages of the PSII reaction-center (Sayed, 2003; Baker and Rosenqvist, 2004; O’Neil et al., 2006).

Similar results were reported by several studies conducted on barley (Yordanova and Popova, 2001), faba bean (Pociecha et al., 2008), bean (Ahmed et al., 2006), soybean (Cho et al., 2006), *Myrica cerifera* (Naumann et al., 2008), *Eugenia uniflora* (Mielke and Schaffer, 2011) and in many other species (Lavinsky et al., 2007; Islam et al., 2008, Oliveira and Joly, 2010). several studies conducted on *Medicago sativa* (Smethurst and Shabala, 2003; Smethurst et al., 2005 and Christiane, 2005) reported a significant decline in F_v/F_m ratio from 0.82 to 0.67 for *Medicago sativa* after 20 days of waterlogging and noticed that this response could be related to an altered hormonal effect specifically a reduction of cytokininin in roots (Salisbury and Ross, 1992) and a perturbed mineral nutrient assimilation (Castonguay et al., 1993; Colin-Belgrand et al., 1991). In addition, Lawlor and Cornic (2002) showed that this decrease is related to PSII photochemistry changes as resulted to the low sub-stomatal cavity CO2 concentration which is induced by stomatal closure.

Conclusion

Waterlogging applied at tillering stage during 28 days has significantly affected plant growth and development (TN/P, PH and NDH), grain yield (GY) and components ($EN.m^{-2}$, GN/E and BY) as well as chlorophyll content index (CCI) and maximum quantum efficiency (Fv/Fm) for the six studied genotypes. The grain yield decreases recorded, with different gradient, for these evaluated genotypes are related either to physiological and biochemical process perturbation, reductions of the plant growth and development and/or to decreases recorded in grain yield components. The six tested genotypes showed a differential response to waterlogging. Results revealed that the cv. Salammbô seems to be the most tolerant genotype as compared to cv. Vaga and Ariana. In addition, a wide variation in chlorophyll fluorescence characteristics was observed from individual plants between control and waterlogging treatment. In addition the fact that $F_v/$

F_m ratio showed a good correlation with waterlogging tolerance, hence it may be considered as a practical screening tool for plant selection against this environmental constraint.

References

Ahmed, S., E. Nawata and T. Sakuratani, 2002b. Effect of waterlogging at vegetative and reproductive stages on photosynthesis. Lear water potential and field in mungbean. *Plant Prod Sci*., **52**: 117-123.

Ahmed, S., E. Nawata and T. Sakuratani, 2006. Changes of endogenous ABA and ACC, and their correlations to photosynthesis and water relations in mung bean (*Vignaradiata* (L.) Wilczak cv. KPS1) during waterlogging. *Environ. Exp. Bot*., **57**: 278-284.

Ahmed, S., E. Nawata, M. Hosokova, Y. Domae, and T. Sakuratani, 2002a. Alterations in photosynthesis and some antioxidant enzymatic activities of mungbean subjected to waterlogging. *Plant Sci*., **163:** 117-123.

Akihiko, K. and E. Nawata, 2007. Role of plant height in the submergence tolerance of rice: A simulation analysis using an empirical model. *Agricultural Water Management,* **89** (1-2): 49-58.

Ashraf, M. and S. N. Chishti, 1993. Waterlogging tolerance of some accessions of lentil (Lens culinaris Medic.). *Tropical Agriculture,* **70** (1): 60-67.

Ashraf, M. and S. Mehmood, 1989. Effects of waterlogging on growth and some physiological parameters of four *Brassica* species. *Plant and Soil,***121:** 203-209.

Bacanamwo, M. and L. C. Purcell, 1999. Soybean dry matter and N accumulation responses to flooding stress, N sources and hypoxia. *Journal of Experimental Botany,* **50** (334): 689-696.

Baker Neil, R. and E. Rosenqvist, 2004. Applications of chlorophyll fluorescence can improve crop production strategies: an examination of future possibilities. *Journal of Experimental Botany,* **55** (403): 1607-1621.

Balakhnina, T. I., R. P. Bennicelli, Z. Stepniewska, W. Stepniewski and I. R. Fomina, 2010. Oxidative damage and antioxidant defense system in leaves of *Vicia faba* major L. cv. Bartom during soil flooding and subsequent drainage. *Plant Soil,* **327:** 293-301.

Beckman, C., R. L. Perry and J. A. Flore, 1992. Short-term flooding affects gas exchange characteristics of containerized sour cherry trees. *Hortscience,* **27:** 1297-1301.

Belford, B. and D. Mc Farlane, 2001. Managing waterlogging and inundation in crops. http://www.wa.gov.au

Bennett, J. M. and S. L. Albrecht, 1984. Drought and flooding effects on nitrogen fixation, water relations and diffusive resistance of soybean. *Agron. J.,* **76**: 735-740.

Boru, G., M. van Ginkel, W. E. Kronstad and L. Boersma, 2001. Expression and inheritance of tolerance to waterlogging stress in wheat. *Euphytica,* **117:** 91-98.

Castonguay, Y., P. Nadeau, and R. R. Simard, 1993. Effects of flooding on carbohydrate and ABA levels in roots and shoots of alfalfa. *Plant, Cell and Environment,* **16:** 695-702.

Changdee, T., A. Polthanee, C. Akkasaeng,, and S. Morita, 2009. Effect of Different Waterlogging Regimes on Growth, Some Yield and Roots Development Parameters in Three Fiber Crops (*Hibiscus cannabinus* L., *Hibiscus sabdariffa* L. and *Corchorus olitorius* L.). *Asian Journal of Plant Sciences,* **8** (8): 515-525.

Cho, J. W., H. C. Ji, and T. Yamakawa, 2006. Comparison of photosynthesis response of two soybean cultivars to flooding. *J. Fac. Agr.,* **51** (2): 227-232.

Christiane, F. S., G. Trevor and S. Sergey, 2005. Nutritional and chlorophyll fluorescence responses of lucerne (*Medicago sativa*) to waterlogging and subsequent recovery. *Plant and Soil,* **270**: 31-45.

Colin-Belgrand, M., E. Dreyer, and P. Biron, 1991. Sensitivity of seedlings from different oak species to waterlogging: effects on root growth and mineral nutrition. *Ann. Sci. For*., **48**: 193-204.

Collaku, A. and S. A. Harrison, 2002. Losses in Wheat Due to Waterlogging.Crop Science, **42**: 444-450.

Collaku, A. and S. A. Harrison, 2005. Heritability of waterlogging tolerance in wheat. *Crop Sci.,* **45:** 722-727.

Condon, A. G. and F. Giunta, 2003. Yield response of restricted tillering wheat to transient waterlogging on duplex soils. *Australian Journal of Agricultural Research,* **54** (10): 957- 967.

Cook, R. J. and R. J. Veseth, 1991. Limiting effects of the physical and chemical environment. In wheat health management - Plant health Management Series. *The American Phytopathological Sociaty Press*. Pp. 21-39.

Davies, M. S. and G. C. Hillman, 1988. Effects of soil flooding on growth and grain yield of populations of tetraploïd and hexaploïd species of wheat. *Annals of Botany,* **62:** 597-604.

Dickin, E. and D. Wright, 2008. The effects of winter waterlogging and summer drought on the growth and yield of winter wheat (*Triticum aestivum* L.). *European Journal of Agronom,y* **28** (3): 234-244.

Drew, M. C., 1991. Oxygen deficiency in the root environment and plant mineral nutrition. In Plant Life Under Oxygen Deprivation: Ecology Physiology, and Biochemistry. Eds. Jackson, M. B., D. D. Davies, H. Lambers, *SPB Academic Publishers*, The Hague, Netherlands, pp. 303-316.

Ghobadi, M. E., M. Bakhshandeh, H. Nadian, G. Fathi, M. H. Gharineh and M. Ghobadi, 2007. Effect of waterlogging on grain elements of wheat (*Triticum aestivum* L.). *Abstracts proceeding of 10th Iranian Congress of Soil Science* 26-28 August, The University of Tehran, pp. 386-387.

Govindjee, 1995. Sixty-three years since Kautsky: Chlorophyll *a* fluorescence. *Aust. J. Plant Physiol.,* **22**: 131-160.

Habash, D. Z. and N. R. Baker, 1990. Photo-inhibition and the effects of protein phosphorylation in wheat thylakoids. *J. Exp. Bot.,* **41**: 113-121.

Huang, B. R., J. W. Johnson, D. S. Nesmith and D. C. Bridges, 1994b. Root and shoot growth of wheat genotypes in response to hypoxia and subsequent resumption of aeration. *Crop Science,* **34**: 1538-1544.

Huang, B., J. W. Johnson, S. Nesmith and D. C. Bridges, 1994a. Growth, physiological and anatomical responses of two wheat genotypes to waterlogging and nutrient supply. *J. Exp. Bot.,* **45**: 193-202.

Islam, M. R., M. Abdul Hamid, M. Abdul Karim, M. Haque, Q. Abdul Khaliq and J. U. Ahmed, 2008. Gas exchanges and yield responses of mungbean (*Vigna radiata* L. Wilczek) genotypes differing in flooding tolerance. *Acta Physiologiae Plantarum,* **30** (5): 697-707.

Jafar Ullah, M. D., 2006. Effect of water logging on growth and yield of mungbean cv. kanti (*Vigna radiata*), *Legume Research,* **29** (3): 196-200.

Jajoo, A. and S. Bharti, 1993. Effect of anions on Photosystem I mediated electron transport in spinach chloroplasts. *Journal of Experimental Botany,* **44**: 785-790.

Jiayin, P., Z. Meixue, M. Neville and S. Serge, 2004. Growth and physiological responses of six barley genotypes to waterlogging and subsequent recovery. *Australian Journal of Agricultural Research,* **55**: 895-906.

Jonard, P. and J. Koller, 1950. Les facteurs de la productivité chez le blé. Résultats obtenus en 1948 et 1949. *Ann. Am. Plant*., **2**: 256-276.

Kozlowski, T. T., 1984a. Plant responses to flooding of soil. *Bioscience,* **34**: 162-167.

Kozlowski, T. T., 1984b. Responses of woody plants to flooding. In Flooding and Plant Growth. Eds. Kozlowski TT. *Academic Press*, New York. Pp. 129-163.

Kozlowski, T. T., 1997. Responses of woody plants to flooding and salinity. *Tree Physiology Monograph. N°1, Heron Publishing-Victoria*, Canada. Available online at heronpublishing.com/tp/monograph/kozlowski.pdf

Kyparassis, A., Y. Ptropoulou and Y. Manetas, 1995. Summer survival of leaves in a soft leaved shrub (*Phlomis fruticosa* L. Labiatae) under Mediterranean field conditions: avoidance of photoinhibitory damage through decreased chlorophyll contents. *J. Exp. Bot.,* **46**: 1825-1831.

Lavinsky, A. O., C. D. S. Sant Ana, M. S. Mielke, A. A. F. D. Almeida, F. P. Gomes, S. França and D. D. C. Silva, 2007. Effects of light availability and soil flooding on growth and photosynthetic characteristics of *Genipa americana* L. seedlings. *New Forests,* **34** (1): 41-50.

Lawlor, D. W. and G. Cornic, 2002. Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants. *Plant Cell Environ.,* **25**: 275-294.

Lazar, D., 1999. Chlorophyll *a* fluorescence induction. *Biochim. Biophys. Acta,* **1412:** 1-28.

Linkemer, G., J. E. Board and M. E. Musgrave, 1998. Waterlogging effects on growth and yield components in late-planted soybean. *Crop Sci.,* **38:** 1576-1584.

Loustalot, A. J., 1945. Influence of soil moisture conditions on apparent photosynthesis and transpiration of pecan leaves. *J. Agric. Res.,* **71**: 519-532.

Loveras, J., A. Lopez, J. Ferran, S. Espachs and J. Solsona, 2001. Bread making wheat and soil nitrate as affected by soil nitrogen fertilization in irrigated Mediterranean conditions. *Agron. J.,* **93:** 1183-1190.

Maxwell, K. and G. N. Johnson, 2000. Chlorophyll fluorescence - A practical guide. Review article. *Journal of Experimental Botany*, **51**(345): 659-668.

Mc Farlane, N. M., T. A. Ciavarella and K. F. Smith, 2003. The effects of waterlogging on growth, photosynthesis and biomass allocation in perennial ryegrass (*Lolium perenne* L.) genotypes with contrasting root development. *The Journal of Agricultural Science,* **141**: 241-248.

Mielke, M. S. and B. Schaffer, 2011. Effects of soil flooding and changes in light intensity on photosynthesis of *Eugenia uniflora* L. seedlings. *Acta Physiologiae Plantarum,* **33** (5): 1661-1668.

Mielke, M. S., A. A. F. De Almeida, F. P. Gomes, M. A. G. Aguilar and P. A. O. Mangabeira, 2003. Leaf gas exchange, chlorophyll fluorescence and growth responses of *Genipa american* seedlings to soil flooding. *Envinron. Exp. Bot.,* **50:** 221-231.

Mielke, M. S., B. Schaffer and C. Li, 2010. Use of a SPAD meter to estimate chlorophyll content in *Eugenia uniflora* L. leaves as affected by contrasting light environments and soil flooding. *Photosynthetica,* **48** (3): 332-338.

Musgrave, M. E. and N. Ding, 1998. Evaluating wheat cultivars for waterlogging tolerance. *Crop Science,* **38**: 90-97.

Naumann, J. C., D. R. Young and J. E. Anderson, 2008. Leaf chlorophyll fluorescence, reflectance, and physiological response to freshwater and saltwater flooding in the evergreen shrub, *Myrica cerifera. Environmental and Experimental Botany,* **63**: 402-409.

O'Neil, P. M., J. F. Shanahan and J. S. Schepers, 2006. Use of chlorophyll fluorescence assessments to differentiate corn hybrid response to variable water conditions. *Crop Science,* **46**: 681-687.

Oliveira, V. C. and C. A. Joly, 2010. Flooding tolerance of *Calophyllum brasiliense* Camb. (Clusiaceae): morphological, physiological and growth responses. *Trees,* **24:** 185-193.

Pang, J., J. J. Ross, M. Zhou, N. J. Mendham and S. N. Shabala, 2007. **Amelioration of detrimental effects of waterloggingby foliar nutrient sprays in barley.** *Functional Plant Biology,* **34** (3): 221-227.

Phung, J. T. and E. B. Knipling, 1976. Photosynthesis and transpiration of citrus seedlings under flooded conditions. *Hortscience,* **1**: 131-133.

Pociecha, E., J. Koscielniak and W. Filek, 2008. Effects of root flooding and stage of development on the growth and photosynthesis of field bean (*Vicia faba* L. minor). *Acta Physiol. Plant.,* **30** (4): 529-535.

Przywara, G. and W. Stepniewski, 1999. The influence of waterlogging at different temperatures on penetration of roots and on stomatal diffusive resistance of pea and maize seedlings. *Acta Physiol Plant.,* **21**: 405–411.

Robertson, D., Z. Heping, J. A. Palta, T. Colmer and N. C. Tuner, 2009. Waterlogging affects the growth, development of tillers, and yield of wheat through a severe, but transient, N deficiency. *Crop and Pasture Science,* **60** (6): 578-586.

Rohacek, K., 2002. Chlorophyll fluorescence parameters: the definitions, photosynthetic meaning and mutual relationships. *Photosynthetica,* **40**: 13-29.

Rohacek, K. and M. Bartak, 1999. Technique of the modulated chlorophyll fluorescence: basic concepts, useful parameters, and some applications. *Photosynthetica,* **37**: 339-363.

Sadras, V. O. and P. A. Calvin, 2001. Quantification of Grain Yield Response to Soil Depth in Soybean, Maize, Sunflower and Wheat. *Agron. J.,* **93**: 577-583.

Salisbury, F. B., and C. W. Ross, 1992. Plant Physiology. *Wadsworth Publishing Company, Belmont,* California, pp. 531-548.

Samad, A., C. A. Meisner, M. Saifuzzaman and M. Van Ginkel, 2002. Waterlogging Tolerance. In: Reynolds, M. P., J. I. Ortiz-Monasterio, A.Mc Nab, (eds.). 2001. Application of Physiology in Wheat Breeding. Mexico, CIMMYT. Pp. 136-144.

Sayed, O. H., 2003. Chlorophyll fluorescence as a tool in cereal crop research. *Photosynthetica,* **41** (3): 321-330.

Schreiber, U., 1998. Chlorophyll fluorescence: New instruments for special applications. In: Garab, G. (eds.): Photosynthesis: Mechanisms and Effects. *Kluwer Academic Publishers,* **5**: 4253-4258.

Schreiber, U. and W. Bilger, 1998. Rapid assessment of stress effects on plant leaves by chlorophyll fluorescence measurements. In: Tenhunen, J. D., F. M. Catarino, O. L. Lange, and W. C. Oechel, (eds.): Plant Responses to Stress. *Springer-Verlag,* Berlin, pp. 27-53.

Schreiber, U., W. Bilger, H. Hormann and C. Neubauer, 2000. Chlorophyll fluorescence as a diagnostic tool: Basics and some aspects of practical relevance. In: Raghavendra, A. S. (eds.): Photosynthesis. Comprehensive Treatise. *Cambridge University Press,* pp. 320-336.

Setter, T. L. and I. Waters, 2003. Review of prospects for germplasm improvement for waterlogging tolerance in wheat, barley and oats. *Plant and Soil,* 253: 1-34.

Setter, T. L., P. Burgess, I. Waters and J. Kuo, 1999. Genetic diversity of barley and wheat for waterlogging tolerance in Western Australia. In : *Proceedings of the 9th Australian Barley Technical Symposium,* Melbourne. Sept, 1999. 2.17.1-2.17.7.

Shigenori, M., A. Jun, F. Shuho, L. Alexander and T. Ryosuke, 2004. Effects of waterlogging on root system of soybean. In: Fischer, T., N. Turner, J. Angus, L. McIntyre, M. Robertson, A. Borrell, and D. Lloyd, (Eds.). New directions for a diverse planet: *Proceedings for the 4th International Crop Science Congress.* Brisbane, Australia. Sep. 26 Oct. 2004. http://www.cropscience.org.au/icsc2004/

Smethurst, C. F. and S. Shabala, 2003. Screening methods for waterlogging tolerance in lucerne: Comparative analysis of waterlogging effects on chlorophyll fluorescence, photosynthesis, biomass and chlorophyll content. *Funct. Plant Biol.,* **30:** 335-343.

Smethurst, C. F., T. Garnett and S. Shabala, 2005. Nutritional and chlorophyll fluorescence responses of lucerne (*Medicago sativa*) to waterlogging and subsequent recovery. *Plant and Soil,* **270**: 31-45.

Souza, T. C., P. C. Magalhaes, F. J. Pereira, E. M. Castro, and S. N. Parentoni, 2011. Morpho-physiology and maize grain yield under periodic soil flooding in successive selection cycles. *Acta Physiologiae Plantarum,* **33** (5): 1877-1885.

Talbot, R. J., J. R. Etherington and J. A. Bryant, 1987. Comparative studies of plant growth and distribution in relation to waterlogging. XII. Growth, photosynthetic capacity and metal ion uptake in *Salix caprea*and *S. cinerea*ssp. *oleifolia*. *New Phytologist,* **105**: 563-574.

Valladares, F. and U. Niinemets, 2008. Shade tolerance, a key plant feature of complex nature and consequences. *Annu. Rev. Ecol. Evol. Syst.,* **39**: 237-257.

Waldhoff, D., B. Furch and W. J. Junk, 2002. Fluorescence parameters, chlorophyll concentration and anatomical features as indicators for flood adaptation of an abundant tree species in central Amazonia: *Symmeria paniculata*. *Environ. Exp. Bot.,* **48:** 225-235.

Watson, E. R., P. Lapins and R. J. W. Barron, 1976. Effect of waterlogging on the growth, grain and straw yield of wheat, barley and oats. *Australian Journal of Experimental Agriculture and Animal Husbandry,* **16**: 114-122.

Yordanov, I., V. Velikova and T. Tsonev, 2000. Plant responses to drought, acclimation and stress tolerance. *Photosynthetica,* **38:** 171-186.

Yordanova, R. Y. and L. P. Popova, 2001. Photosynthesis response of barley plants to soil flooding. *Photosynthetica,* **39:** 515-520.

Yordanova, R. Y. and L. P. Popova, 2007. Flooding-induced changes in photosynthesis and oxidative status in maize plants. *Acta Physiologiae Plantarum*29(6, pp. 535-541.

Yordanova, R. Y., K. N. Christov and L. P. Popova, 2004. Antioxidative enzymes in barley plants subjected to soil flooding. *Environmental and Experimental Botany,* **51** (2): 93-101.

Zadoks, J. C., T. T. Chang and C. F. Konzak, 1974. A decimal code for the growth stages of cereals. *Weed Research,* **14**: 415-421.

Zaerr, J., 1983. Short-term flooding and net photosynthesis in seedlings of three conifers. *For. Sci.,* **29:** 71-78.

Zakhidov, E. A., M. A. Zakhidova, M. A. Kasymdzhanov, S. S. Kurbanov, F. M. Mirtadzhiev and P. Khabibullaev, 2002. Chlorophyll fluorescence as a tool for diagnostics of optimal temperatures of photosynthesis in plants. *Dokl. ross. Akad. Nauk,* **382**: 563-566.

Zhang, Z., Q. Guo, and Q. Shao, 2009. Effects of waterlogging stress on physiological and biochemical characteristics of medicinal *Chrysanthemum morifolium* during seedling stage. *Zhongguo Zhong Yao Za Zhi,* 34 (18): 2285-2291.

Zhou, M. X., H. B. Li and N. J. Mendham, 2007. Combining ability of waterlogging tolerance in barley. *Crop Science,* **47** (1): 278-284.

Zivcak, M., M. Brestic, K. Olsovska and P. Slamka, 2008. Performance index as a sensitive indicator of water stressinTriticumaestivum L. *Plant Soil Environ.,* **54** (4): 133-139.

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