TEMPERATURE AND pH OF THE NUTRIENT SOLUTION ON WHEAT PRIMARY ROOT GROWTH

Carlos Eduardo de Oliveira Camargo*; Antonio Wilson Penteado Ferreira Filho; Marcus Vinicius Salomon

IAC - Centro de Análise e Pesquisa Tecnológica do Agronegócio de Grãos e Fibras - C.P. 28 - 13001-970 - Campinas, SP - Brasil.
**Corresponding author <ccamargo@iac.sp.gov.br>*

ABSTRACT: Primary root growth is very important for wheat (*Triticum aestivum* L.) crop in upland conditions in the State of São Paulo. Fourteen wheat genotypes (mutant lines and cultivars) were evaluated for primary root growth during 7 and 15 days of development in complete and aerated nutrient solutions, in the laboratory. In the first experiment, solutions with three pH values (4.0, 5.0 and 6.0) at constant temperature (24 ± 1°C), and in the second experiment, solutions with the same pH (4.0) but with three temperatures (18°C ± 1°C, 24°C ± 1°C and 30°C ± 1°C) were used. High genetic variability was observed among the evaluated genotypes in relation to primary root growth in the first stages of development in nutrient solutions independent of pH, temperature and growth period. Genotypes 6 (BH-1146) and 13 (IAC-17), tolerant to Al^{3+} showed genetic potential for root growth in the first stages of development (7 and 15 days), regardless of nutrient solution temperature and pH. Genotypes 14 (IAC-24 M), 15 (IAC-24), 17 (MON"S" / ALD "S") × IAC-24 M_2, 18 (MON"S" / ALD "S") × IAC-24 M_3 and 24 (KAUZ"S" / IAC-24 M_3), tolerant to Al^{3+}, showed reduced root growth under the same conditions.
Key words: *Triticum aestivum* L., upland crop, root growth

TEMPERATURA E pH DA SOLUÇÃO NUTRITIVA NO CRESCIMENTO DAS RAÍZES PRIMÁRIAS DO TRIGO

RESUMO: O crescimento das raízes primárias é de grande importância para o estabelecimento da cultura do trigo (*Triticum aestivum* L.) em condição de sequeiro no Estado de São Paulo. Quatorze genótipos (linhagens mutantes e cultivares) de trigo foram comparados quanto ao crescimento das raízes primárias durante 7 e 15 dias de desenvolvimento em soluções nutritivas completas, com arejamento, em condição de laboratório. No primeiro experimento, empregaram-se soluções com três valores de pH (4,0; 5,0 e 6,0) mantendo-se constante a temperatura (24 ± 1°C) e no segundo, utilizaram-se soluções com mesmo pH (4,0), porém com três temperaturas (18°C ± 1°C, 24°C ± 1°C e 30°C ± 1°C). Observou-se grande variabilidade genética entre os genótipos avaliados para crescimento das raízes primárias nos primeiros estádios de desenvolvimento independentemente do pH, temperatura e período de crescimento nas soluções nutritivas. Os genótipos 6 (BH-1146) e 13 (IAC-17), tolerantes ao Al^{3+} exibiram potencial genético para maior crescimento radicular nos primeiros estádios de desenvolvimento (7 e 15 dias), independentemente da temperatura e do pH das soluções nutritivas. Os genótipos 14 (IAC-24 M), 15 (IAC-24), 17 (MON"S" / ALD "S") × IAC-24 M_2, 18 (MON"S" / ALD "S") × IAC-24 M_3 e 24 (KAUZ"S" / IAC-24 M_3), tolerantes ao Al^{3+}, apresentaram reduzido crescimento radicular nas mesmas condições.
Palavras-chave: *Triticum aestivum* L., cultura de sequeiro, crescimento radicular

INTRODUCTION

In Brazil, wheat is cultivated in upland acidic soil conditions, in rotations with soybean [*Glycine max* (L.) Merr.] or (and) maize (*Zea mays* L.) crops, in the period of April to August. The development of plants with higher yielding potential, semi-dwarf, resistant to diseases, tolerant to aluminum toxicity and showing good nutritive and technological qualities, are the main goals of the brazilian wheat breeding programs for acidic soils. In addition, inbred-line breeding and selection for longer primary roots is important considering the short sowing period (April) when the occurrence of water stress associated or not with short periods of high air-temperature, namely "heat shocks" is frequent (Mundstock, 1983). Besides the Al^{3+}-tolerance, plants must have long primary roots in the initial growth stages, to allow for good crop establishment. Such periods of drought stress may also occur from May to August, requiring that plants have longer adventitious roots able to reach deeper into the soil.

The mechanisms involved in drought resistance in wheat include early grain maturation, allowing that harvest happens before the period of water stress; vigorous

and deep root system able to use the soil available moisture efficiently, stomata closure ability to reduce water loss, and a waxy leaf surface to avoid transpiration (Poehlman & Sleper, 1995).

The early wheat cultivar BH-1146, highly Al^{3+} - tolerant in acidic soils, has also shown high tolerance to drought compared to other cultivars. Previous research using Al-free nutrient solution has shown that the cultivar has the longest root system compared to other 26 wheat genotypes (Camargo et al., 1995). Similar results were reported by Camargo & Oliveira (1981a), studying BH-1146 under non-limiting nutrient level, Al-free, pH 4.0 solution who reported a higher potential for root growth in these plants, evidencing their specificity for this trait.

The use of gamma radiation in seeds of some wheat cultivars generated plants with specific agronomic characteristics, such as tolerance to Al, usually present in acidic soils (Camargo et al., 1997; Tulmann Neto et al., 1995a; 1995b; 1996 and 2001). Most of the published research on this subject has been done in the presence of Al^{3+} and has shown that in the wheat early development stages, root growth is affected by temperature, pH, salts and phosphorus concentrations of the nutrient solutions (Ali, 1973; Camargo & Oliveira, 1981a; Camargo, 1983; 1984; Moore, 1974; Moore et al., 1976).

The objective of this research was to evaluate the root growth of several wheat genotypes (mutant inbred lines and cultivars) after 7 and 15 days of growth in nutrient solutions without Al3+, under different temperature and pH conditions.

MATERIAL AND METHODS

Two experiments were conducted in the laboratory. The first was set up with variable nutrient solution pH values and controlled temperature, and the second, with variable nutrient solution temperatures and controlled pH, in order to evaluate the pH and temperature effects on the wheat seedling primary root growth. Fourteen genotypes were used in each experiment (Table 1), which were previously selected from 45 genotypes as to root growth in nutrient solutions (Camargo et al., 2002). Except for the cultivar Anahuac and the mutant line Anahuac M_3, both susceptible to Al^{3+} toxicity (no growth of primary central roots after 48-hour treatment in nutrient solution containing 2 mg L^{-1} of Al^{3+}), all the other genotypes evaluated had shown tolerance to Al^{3+} toxicity, i.e. root growth after a 48-hour treatment in nutrient solution containing 10 mg L^{-1} of Al^{3+}, according to technique developed by Camargo & Oliveira (1981a).

In experiment 1, seeds of wheat genotypes (originated from Tatuí, State of São Paulo - 23°20'S, 47°52'W alt. 600 m - harvested in 1999 and stored in cold/dry chamber) were rinsed in 10% sodium hypochloride solution and put to germinate in Petri dishes in the refrigerator at 12°C during 72 h. After this period, root emer-

Table 1 - Primary root length of wheat genotypes after 7-day-growth in complete nutrient solutions at 24 ± 1°C temperature under three pH values.

Genotype	Primary root length [1]		
	pH values		
	4.0	5.0	6.0
	---------- mm ----------		
1- BH-1146 M_1	139 d-g	140 cd	151 ab
2- BH-1146 M_2	144 c-f	138 d	126 d-f
6- BH-1146	162 ab	161 a	153 a
8- Anahuac M_1	153 a-c	143 b-d	139 b-d
10- Anahuac M_3	150 b-e	144 b-d	147 ab
11- Anahuac	137 e-g	135 de	140 a-c
12- IAC-17 M	152 a-d	149 bc	146 ab
13- IAC-17	165 a	151 b	148 ab
14- IAC-24 M	131 fg	121 f	114 fg
15- IAC-24	137 e-g	122 f	126 d-f
17- (MON"S" / ALD "S") x IAC-24 M_2	138 e-g	135 de	123 ef
18- (MON"S" / ALD "S") x IAC-24 M_3	143 c-f	128 ef	113 fg
22- KAUZ"S" / IAC-24 M_1	150 b-e	143 b-d	132 c-e
24- KAUZ"S" / IAC-24 M_3	129 g	110 g	106 g
Means	145 A	137 B	133 B

[1]Means followed by the same letters are not different by Duncan's test (0.05).

gence was starting and 25 germinated seeds of each genotype were put on top of a nylon netting, using nippers, adapted over 8.3 L-plastic recipients, containing complete full strength nutrient solutions, with three pH treatments: 4.0, 5.0 and 6.0. The treatment solutions were arranged in a randomized complete block design with two replications. The nylon netting with the seeds on top was kept in contact with a complete nutrient solution, which consisted of the following nutrient concentrations: $Ca(NO_3)_2$ 4 mmol L^{-1}, $MgSO_4$ 2 mmol L^{-1}, KNO_3 4 mmol L^{-1}, $(NH_4)_2SO_4$ 0.435 mmol L^{-1}, KH_2PO_4 0.5 mmol L^{-1}, $MnSO_4$ 2 μmol L^{-1}, $CuSO_4$ 0.3 μmol L^{-1}, $ZnSO_4$ 0.8 μmol L^{-1}, NaCl 30 μmol L^{-1}, Fe-CYDTA 10 μmol L^{-1}, Na_2MoO_4 0.10 μmol L^{-1} and H_3BO_3 10 μmol L^{-1}.

The nutrient solution pH treatments were adjusted using a 0.5 mol L^{-1} H_2SO_4 or 1 mol L^{-1} NaOH solution. The nutrient solutions in the recipients were continuously aerated and maintained in water-bath at 24 ± 1°C, in the laboratory. After that, ten 7-day-old seedlings of each genotype were removed from each recipient and evaluated for central primary root length. The remaining seedlings were kept eight more days under the same conditions. After that ten other seedlings (15 days old) were sampled for root length measurements. During Experiment 1, the pH treatments were adjusted daily to 4.0, 5.0 or 6.0, in their respective recipients, using 0.5 mol L^{-1} H_2SO_4 or 1 mol L^{-1} NaOH solutions.

The average primary root length of each genotype was calculated for the 7-day-old and 15-day-old seedlings, for each pH treatment. The data were submitted to analysis of variance (F test, 0.05), for a randomized complete block design with two replications, for the genotype effect, nutrient solution pH effect and the interaction genotype x pH on the root growth. Mean comparisons were done using Duncan's test (0.05).

In Experiment 2, the same procedures and materials were used regarding seed germination, experimental design, recipient size and seed support, nutrient solution composition and aeration, and the same 14 genotypes. The nutrient solution pH was adjusted to 4.0. Treatments consisted of three nutrient solution temperatures: 18°C ± 1°C, 24°C ± 1°C and 30°C ± 1°C. The 8.3 L- plastic recipients with nutrient solutions were kept in water-bath with temperature control. Ten 7-day-old and 15-day-old seedlings were sampled for the primary root length measurements. During this period, nutrient solution pH was monitored and adjusted daily to as close as possible to 4.0, with 0.5 mol L^{-1} H_2SO_4 and/or 1 mol L^{-1} NaOH solutions.

The primary root length data were submitted to analysis of variance (F test, 0.05) for randomized complete block with two replications, for the genotype effect, temperature effect and interaction effect (genotypes × temperatures). Mean comparisons among genotypes within each temperature treatment and among different temperatures were done by the Duncan's test (0.05).

RESULTS AND DISCUSSION

Experiment 1 - The ANOVA for root growth data obtained during 7 and 15 days in complete nutrient solution, with pH values of 4.0; 5.0 and 6.0 showed effects of genotype and pH but no interactions between the two.

Root growth measured on the 7th day (145 mm – Table 1) and on the 15th day (222 mm - Table 2) in pH 4.0 solutions were higher when compared to the root growth of the same genotypes and age at pH 6.0 (133 and 198 mm, respectively). These results are consistent with those of Camargo (1984) who found a reduction trend in wheat root growth as pH increased from 4.0 to 6.0 when cultivated in complete nutrient solution.

Lower root growth at higher pH, in the absence of Al^{3+} may be due to lower phosphorus uptake and lower availability of iron and other micronutrients (Salisbury & Ross, 1969). This conflicts with the situation where a constant amount of aluminum is supplied in the nutrient solution and pH is changed from 4.0 to 6.0, and where reasonable root growth of wheat seedlings takes place in pH 6.0 (Camargo, 1984). The hydrolysis theory may elucidate this, since a 10-fold trivalent aluminum (Al^{3+}) compared to bivalent form ($AlOH^{2+}$) occurs under pH 4.0; 3.1-fold at pH 4.5; while at pH 5.0 the trivalent and bivalent ionic species are practically equivalent (Foy & Fleming, 1978).

Experiment 2 - The ANOVA for wheat root growth data over 7 and 15 days in complete nutrient solution under three temperatures showed effects of genotype and solution temperature but no interactions between the two.

The average 14 genotypes root growth after 7 days (117 mm – Table 3) and 15 days (208 mm – Table 4) in nutrient solution at 18°C was lower ($P < 0.05$) than the growth for the same genotypes and growth periods at 30°C (143 and 260 mm, respectively). This is not consistent with the data of Camargo (1983) who found a trend of wheat root growth reduction with increasing solution temperature from 22 to 34°C, in solution with varying aluminum concentrations. The same was found by Benitez (1977) for the rye cultivar 1443 which showed root growth in nutrient solution with 35 mg L^{-1} of Al^{3+} at 25°C but not with 20 mg L^{-1} of Al^{3+} at 30°C. According to the author the higher temperature increased the proportion of aluminum uptake induced by metabolic processes.

With the exception of Anahuac and Anahuac M_3 all genotypes were tolerant to Al^{3+} toxicity, i.e., showed root growth in standard nutrient solution after 48 hours in a solution with 10 mg L^{-1} of Al^{3+} (Tulmann Neto et al., 2001). The non-tolerant genotypes do not show root growth in similar conditions due to the occurrence of an irreversible damage in the primary root apical meristem. The classification proposed by Moore et al. (1976) and modified by Camargo & Oliveira (1981a), considers as

Table 2 - Primary root length of wheat genotypes after 15-day-growth in complete nutrient solutions at 24 ± 1°C temperature under three pH values

Genotype	Primary root growth (1)		
	pH values		
	4.0	5.0	6.0
	mm		
1- BH-1146 M_1	215 d-g	229 b-e	216 a-c
2- BH-1146 M_2	213 d-g	223 b-e	204 bc
6- BH-1146	267 ab	277 a	240 a
8- Anahuac M_1	245 a-d	236 a-d	209 bc
10- Anahuac M_3	232 b-e	238 a-c	224 ab
11- Anahuac	197 e-g	222 b-e	217 a-c
12- IAC-17 M	256 a-c	260 ab	226 ab
13- IAC-17	271 a	263 ab	221 a-c
14- IAC-24 M	209 d-g	187 e	170 de
15- IAC-24	197 e-g	192 de	167 de
17- (MON"S" / ALD "S") x IAC-24 M_2	191 g	200 c-e	170 de
18- (MON"S" / ALD "S") x IAC-24 M_3	194 fg	187 e	155 e
22- KAUZ"S" / IAC-24 M_1	229 c-f	228 b-e	194 cd
24- KAUZ"S" / IAC-24 M_3	187 g	186 e	165 de
Means	222 A	223 A	198 B

(1)Means followed by the same letters are not different by Duncan's test (0.05).

Table 3 - Primary root length of wheat genotypes after 7-day-growth in complete nutrient solutions under pH 4.0 and three temperatures.

Genotype	Primary root length (1)		
	Temperature		
	18°C ± 1°C	24°C ± 1°C	30°C ± 1°C
	mm		
1- BH-1146 M_1	112 e-g	130 d-f	138 b-d
2- BH-1146 M_2	119 c-e	140 b-d	128 cd
6- BH-1146	132 a	159 a	175 a
8- Anahuac M_1	130 ab	152 ab	164 a
10- Anahuac M_3	127 a-c	152 ab	162 a
11- Anahuac	110 fg	127 ef	140 bc
12- IAC-17 M	122 b-d	136 c-e	144 b
13- IAC-17	131 ab	146 bc	163 a
14- IAC-24 M	107 g	127 ef	128 b-d
15- IAC-24	113 e-g	123 f	128 b-d
17- (MON"S" / ALD "S") x IAC-24 M_2	117 d-f	124 ef	126 cd
18- (MON"S" / ALD "S") x IAC-24 M_3	110 fg	131 d-e	145 b
22- KAUZ"S" / IAC-24 M_1	108 g	136 c-e	143 b
24- KAUZ"S" / IAC-24 M_3	96 h	122 f	124 d
Means	117 A	136 B	143 C

(1)Means followed by the same letters are not different by Duncan's test (0.05).

tolerant a genotype that shows some root growth and non-tolerant when no growth is detected. In practice, a tolerant genotype may show higher or lower root growth in relation to another tolerant genotype in the same conditions (Camargo & Oliveira, 1981a).

The difference between a tolerant and a non-tolerant genotype to a given toxic Al^{3+} concentration is due to a pair of dominant alleles (Camargo et al., 2000b). Data from this research suggest that the pair of alleles linked to Al^{3+} toxicity tolerance would not be the same genes

Table 4 - Primary root length of wheat genotypes after 15-day-growth in complete nutrient solutions under pH 4.0 and three temperatures.

Genotype	Primary root length (1)		
	Temperature		
	18ºC ± 1ºC	24ºC ± 1ºC	30ºC ± 1ºC
	mm		
1- BH-1146 M_1	205 de	226 c-e	270 b-e
2- BH-1146 M_2	211 cd	230 cd	247 e-g
6- BH-1146	253 a	284 a	349 a
8- Anahuac M1	226 bc	248 b-d	295 bc
10- Anahuac M_3	229 bc	240 b-d	288 b-d
11- Anahuac	197 d-f	214 d-f	259 c-f
12- IAC-17 M	231 a-c	254 a-c	285 b-d
13- IAC-17	235 ab	270 ab	306 b
14- IAC-24 M	176 f	193 ef	224 fg
15- IAC-24	185 ef	194 ef	211 g
17- (MON"S" / ALD "S") x IAC-24 M_2	182 f	192 ef	222 fg
18- (MON"S" / ALD "S") x IAC-24 M_3	189 d-f	188 f	218 g
22- KAUZ"S" / IAC-24 M_1	211 cd	225 c-e	256 d-f
24- KAUZ"S" / IAC-24 M_3	181 f	194 ef	212 g
Means	208 A	225 B	260 C

(1)Means followed by the same letters are not different by Duncan's test (0.05).

involved in the control of root growth in the absence of aluminum stress. Furthermore, it would not be correct to state that a genotype is more Al-tolerant than another based upon a higher root growth in solutions without aluminum, after a developing period in solutions with a given aluminum content, as proposed by Camargo et al., 1995 and Camargo, 1993.

Despite the decrease in root growth as nutrient solution pH increased from 4.0 to 6.0 and the opposite reaction as temperature raised from 18 to 30ºC, considering the average values, all tested genotypes showed similar response to the solution pH and temperature treatments. This was confirmed by the absence of interactions between genotype and pH and between genotype and temperature in the nutrient solutions. At lower temperatures root growth usually surpasses that of above-ground parts, but as temperature raises, both plant parts have increased growth, although, shoots grow at a faster rate than roots (Evans, 1975).

It has been suggested that root growth is genetically controlled and is little affected by environment (pH and temperature) in the same way as tall genotypes differ from dwarf ones (Camargo et al., 2000a). High restrict sense heritability values for plant height were found by several authors (Johnson et al., 1966; Camargo et al., 1980, 2000a), thus, indicating that this trait is controlled by a few genes (Camargo & Oliveira, 1981b), with environment not playing an important role upon their expression. Consequently, successful selection in segregating populations can be performed in the F_2 generation.

To demonstrate that root growth is genetically controlled, crosses between high and reduced root growth genotypes should be done and seedlings from F_2 and F_3 generations selected according its growth ability in nutrient solution. As a result, in the segregating generations distribution frequencies, heritabilities for this trait as well as the number of involved genes for the root growth could be established. In the future, selected lines with high root growth could be incorporated in the wheat breeding program to develop genotypes well adapted to the State of São Paulo short sowing period (April), when the occurrence of moisture stresses is common, thus improving the chances of successful crops.

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