PERFORMANCE OF DIHAPLOID WHEAT LINES OBTAINED VIA ANTHER CULTURE

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ABSTRACT: The anther culture technique has been used in breeding programs to obtain haploid plants from hybrid plants of F_1 generation and to develop more efficiently wheat cultivars. To study the behavior of dihaploid wheat lines and two check cultivars, IAC-24 and IAC-289, experiments were carried out under sprinkler irrigation at Monte Alegre do Sul, SP, Brazil, in a n Haplic Acrisol and at Tatuí, SP, Brazil, in a Rhodic Ferrasol, during the years 1999 and 2000. Genotypes were evaluated for grain yield, 100 grain weight, plant height, resistance to leaf rust (*Puccinia recondita* f. sp. *tritici* Rob. Desm.) and lodging. The genotypes were also evaluated under laboratory conditions for their Al^{+3} toxicity tolerance using nutrient solutions. The line 8, originated from ANA/IAC-24 cross, presented high grain yield, semidwarf plant type, heavy grain, leaf rust resistance and tolerance to Al^{+3} toxicity. The lines 4, 11, 12 and 14, also presented high tolerance to Al^{+3} toxicity in association to grain yield above 3.000 kg ha^{-1}. These lines are suitable to be used in breeding programs to develop cultivars for acid soils.
Key words: grain yield, 100 grain weight, plant height, lodging, tolerance to aluminum

DESEMPENHO DE LINHAGENS DIAPLÓIDES DE TRIGO OBTIDAS POR CULTURA DE ANTERAS

RESUMO: Visando aumentar a eficiência no desenvolvimento de novos cultivares de trigo, a técnica de cultura de anteras *in vitro* tem sido utilizada em programas de melhoramento para a obtenção de plantas haplóides a partir de plantas híbridas em geração F_1. Estudou-se o comportamento de 18 linhagens diaplóides e dois cultivares controles, IAC-24 e IAC-289, em ensaios instalados em condição de irrigação por aspersão, em Monte Alegre do Sul num Argissolo Vermelho-Amarelo e em Tatuí num Latossolo Vermelho, nos anos de 1999 e 2000. Todos os genótipos foram avaliados quanto à produção de grãos, massa de cem grãos, altura de planta, resistência à ferrugem-da-folha (*Puccinia recondita* f. sp. tritici Rob. Desm.) e porcentagem de acamamento. Foram avaliados, também, em relação a tolerância à toxicidade ao alumínio, em soluções nutritivas, em condição de laboratório. A linhagem 8 proveniente do cruzamento ANA/IAC-24, apresentou elevada produção de grãos, porte semi-anão, grãos pesados, resistência à ferrugem-da-folha e tolerância à toxicidade ao alumínio. As linhagens 4, 11, 12 e 14, também mostraram elevada tolerância à toxicidade ao alumínio associada a produção de grãos superior a 3.000 kg ha^{-1}, e portanto poderiam ser utilizadas em programas de melhoramento visando a obtenção de cultivares para solos ácidos.
Palavras-chave: produção de grãos, massa de cem grãos, altura de planta, acamamento, tolerância ao alumínio

INTRODUCTION

Brazil´s wheat production was approximately 1.5 million tons in the 1999/2000 cropping season. With an estimated consumption of 9.7 million tons, the country had to import 7.5 million tons of grain wheat and 203 thousand tons of flour, which represented an expenditure of 902 million dollars (CONAB, 2001).

The decrease of the domestic wheat production is mainly due to political and climatic factors, and to those inherent to the adaptation of the crop itself, which have been rendering the country increasingly dependent upon imports in order to supply its domestic demand, and placing it on a prominent rank as a great importer (Tomasini, 1982).

With the objective of increasing the production of wheat in the State of São Paulo, Brazil, the genetic breeding program of Instituto Agronômico (IAC), in Campinas, has been directed toward obtaining cultivars with broad adaptability, semi-dwarf size, high productivity potential, and tolerance to aluminum toxicity, by means of crosses between domestic cultivars adapted to acid soil conditions, and cultivars of Mexican origin, with high productive potential and semi-dwarf size (Camargo et al., 1996).

In order to increase the efficiency in obtaining wheat cultivars, the *in vitro* anther culture technique has been utilized in breeding programs to obtain haploid plants from hybrid plants in the F_1 generation. This technique speeds up the process of development of new cultivars by several years, in addition to simplifying and making the selection process more efficient (Moraes-Fernandes, 1997; Camargo et al., 1999; Ramos et al., 2000).

Through a preliminary evaluation, under field conditions, the dihaploid lines presented great variability of agronomic characters such as plant height, grain production, 100 grain weight, lodging and leaf rust resistance (Brammer et al., 1999), and had also differences in relation to their tolerance to aluminum toxicity, when evaluated in nutrient solution, in the laboratory (Camargo et al., 1999).

The objective of this paper was to assess dihaploid wheat lines, obtained through the *in vitro* anther culture technique, in order to identify genotypes having agronomically interesting traits for wheat breeding programs.

MATERIAL AND METHODS

An assay consisting of 18 dihaploid lines, obtained in 1998 at IAC, originated from anther cultures, and two control cultivars, IAC-24 and IAC-289 (Table 1), was installed under sprinkler irrigation conditions in Monte Alegre do Sul, SP, Brazil, (Wheat Production Zone H, latitude 22°41' S, longitude 46°43' W, altitude 777 m in a Haplic Acrisol) in May, and in Tatuí, SP, Brazil (Wheat Production Zone D, latitude 23°20' S, longitude 47°52' W, altitude 600 m in a Rhodic Ferrasol), in April, during the years 1999 and 2000.

The control cultivars had the following traits: IAC-24 - intermediate cycle, semi-dwarf size, tolerance to aluminum toxicity, good bread-making quality, medium soil fertility requirements, medium response to nitrogen fertilization, susceptible to the causal agent of leaf rust (*Puccinia recondita* f. sp. tritici Rob. Desm.) (IAC, 1996); IAC-289 - intermediate-to-late cycle, semi-dwarf size, medium tolerance to aluminum toxicity, good bread-making quality, high soil fertility requirements, high response to nitrogen fertilization, sensitive to pre-harvest sprouting, susceptible to the causal agent of leaf rust (Felício et al., 1994).

Each trial was based on a random block statistical design, with four replicates. Each trial consisted of 80 plots, each plot formed by six rows 3 m long, spaced 0.20 m. Sowing was performed at 80 viable seeds per linear meter of furrow, which is equivalent to 1,440 seeds per plot, consisting of 3.6 m^2 of harvesting area.

Soil samples were taken from a 0-20 cm layer, and the corresponding chemical analyses can be found in Table 2. The amounts of fertilizers (N, P_2O_5 and K_2O) utilized in the two locations were based on the fertilizer recommendation tables of IAC in function of the soil chemical analyses (Raij et al., 1985).

Table 1 - Origins and genealogies of the genotypes assessed in the Dihaploid Wheat Lines Trial, at Polo Regional de Desenvolvimento Tecnológico dos Agronegócios Leste-Paulista, in Monte Alegre do Sul and at Unidade de Pesquisa do Desenvolvimento de Tatuí, during 1999 and 2000.

Genotype	Origin[1]	Genealogy
1	2634	PF70402/ALD"S"//PAT72160/ALD"S"/3/PEW"S"/4/OPATA/5/IAC-60
2	798	ANA/IAC-24//IAC-24
3	822	ANA/IAC-24//IAC-24
4	843	ANA/IAC-24//IAC-24
5	852	ANA/IAC-24//IAC-24
6	859	ANA/IAC-24//IAC-24
7	861	ANA/IAC-24//IAC-24
8	865	ANA/IAC-24
9	866	ANA/IAC-24
10	868	ANA/IAC-24//IAC-24
11	2480	FURY-KEN/SLM//ALDAN/4/PAT10/ALD//PAT72300/3/PVN /5/IAC-24
12	2574	JUP/ZP//COC/3/PVN/4/GEN/5/IAC-24
13	818	ANA/IAC-24//IAC-24
14	2483	PF70402/ALD"S"//PAT72160/ALD"S"/3/PEW"S"/4/OPATA/5/IAC-60
15	2554	CS/A.CURV//GLEN/3/ALD/PVN/4/SUZ8/5/IAC-24
16	2558	TEPOCA/IAC-24
17	2598	PF70402/ALD"S"//PAT72160/ALD"S"/3/PEW"S"/4/OPATA/5/IAC-60
18	795	ANA/IAC-24//IAC-24
19		IAS-51/IRN 597-70 (IAC-24)
20		KVZ/BUHO"S"//KAL/BLUEBIRD (IAC-289)

[1]Number of the plant obtained from anther culture.

All genotypes were assessed in the trials with regard to grain yield, plant height, 100 grain weight and lodging, according to Camargo et al. (1999), and in relation to leaf rust, according to Schramm et al. (1974).

Daily minimum temperatures were monitored during the periods May to September, for 1999 and 2000.

With respect to grain yield, 100 grain weight and plant height data, individual analyses of variance were performed for each location and year, as well as a joint analysis for each location in the two-year period and a joint analysis involving the four experiments, where the significances of effects from genotypes, years and experiments, as well as the interactions genotype x year and genotype x experiment, were evaluated by the F test at 5%. The Tukey test at 5% was used for comparing genotype means in each location and year, the mean of two years at each location, and the mean of the four experiments.

Simple correlations between the traits under evaluation were performed with the means of the four trials, considered jointly for each genotype, in order to estimate the degrees of association between the assessed traits.

The genotypes were also evaluated for their tolerance to aluminum toxicity under laboratory conditions according to Camargo & Oliveira (1981) and Camargo et al. (1998), using nutrient solutions with 0, 2, 4, 6, 8 and 10 mg L^{-1} Al^{3+}. Each solution treatment consisted of five replicates. Cultivars Anahuac (sensitive) and BH-1146 (tolerant) were used as controls for all aluminum concentrations. Data analysis considered the means for the central primary root length of ten seedlings of each genotype, for each replicate. Genotypes that presented root growth were considered tolerant, while those not presenting root growth were considered sensitive, after 72 hours in complete nutritive solution without aluminum, following exposure for 48 hours to the treatment solutions containing the five different aluminum concentrations.

Table 2 - Results of soil[1] sample analyses for the 0-20 cm layer, of locations where the Dihaploid Wheat Lines Trials were installed, during 1999 and 2000.

Variable	Monte Alegre do Sul		Tatuí	
	1999	2000	1999	2000
M.O. (g dm^{-3})	14.0	20.0	25.0	23.0
pH $CaCl_2$	5.3	5.3	4.6	5.0
P resina (mg dm^{-3})	10.0	40.0	49.0	45.0
K ($mmol_c$ dm^{-3})	2.8	3.2	7.2	5.2
Ca ($mmol_c$ dm^{-3})	23.0	34.0	47.0	41.0
Mg ($mmol_c$ dm^{-3})	8.0	10.0	13.0	12.0
$H^+ + Al^{-3}$ ($mmol_c$ dm^{-3})	25.0	28.0	58.0	43.0
S.B. ($mmol_c$ dm^{-3})	33.8	47.2	67.2	57.2
CTC ($mmol_c$ dm^{-3})	58.8	75.0	125.2	100.1
V (%)	57.0	63.0	53.0	58.0

RESULTS AND DISCUSSION

In general, the grain yield, 100 grain weight, and plant height data obtained in the year 2000 were lower than those of 1999, possibly due to frosts that occurred in the two locations (Table 3). The monthly minimum temperatures were lower than those recorded for the same period in the previous year, in both locations (Figure 1).

In Monte Alegre do Sul the lowest temperatures of July 2000 occurred during the nights of the 17th (-0.6°C), 18th (0.8°C), 19th (0.0°C) and 21st (0.4°C) days. During the same period, in Tatuí, extremely low minimum temperatures were recorded at the meteorological station, indicating severe frosts in the region that even matched the historical record. During that period, frosts occurred during the nights of the 17th (-1.4°C), 18th (-1.2°C), 21st (-2.0°C) and 22nd (-1.8°C). The minimum temperatures at laun surface in Tatuí, on the nights of the 17th and 18th of July, 2000, were around -7.0°C; these are temperatures that fatally affected several crops, especially wheat. Leaf temperatures below -2.0°C would be enough to cause damage to wheat plants; this temperature would correspond to 2.0°C measured inside the thermometer shelter (Mota, 1982).

When the grain yield means are considered together for the trials installed in Monte Alegre do Sul and Tatuí, during the two years, the analysis of variance presented effects for genotypes, trials, and for the genotype x trial interactions (Table 3). The genotype x trial interactions for grain yield was also verified by Camargo et al. (1990), while studying wheat lines at the Vale do Paranapanema, and by Camargo et al. (1991),

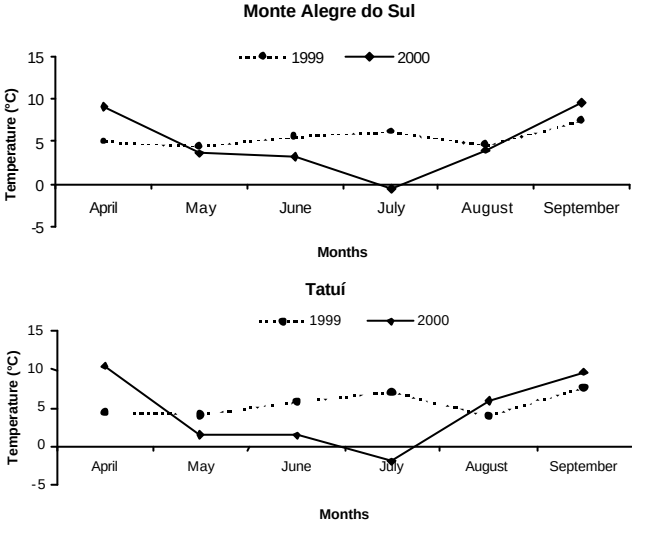

Figure 1 - Minimum temperature extremes from April through September, observed at Polo Regional de Desenvolvimento dos Agronegócios Leste-Paulista, in Monte Alegre do Sul and at Unidade de Pesquisa do Desenvolvimento de Tatuí, in 1999 and 2000.

in an evaluation of genotypes from hybrid populations introduced from Oregon (USA) into the State of São Paulo. In spite of the genotype x trial interaction, the cultivar IAC-289 and the line 8 were always among the most productive of the four trials, demonstrating that these genotypes had a good adaptability. In the comparison of means for grain yield of the four trials, genotypes 8 (3,311 kg ha^{-1}) and 20 (3,341 kg ha^{-1}) were the most productive, only being different in relation to lines 3 (1,572 kg ha^{-1}), 13 (1,380 kg ha^{-1}), 16 (1,673 kg ha^{-1}) and 18 (1,852 kg ha^{-1}).

In Monte Alegre do Sul, there was an effect on grain production only for genotypes and for years (Table 3). The non-significant interaction genotype x year indicated that, despite of the difference between years, especially with regard to the low temperatures that occurred during the month of July, the most productive genotypes in 1999, had also a tendency to be the most productive in the following year. Genotype 20 (4,165 kg ha^{-1}) was the most productive, when the means of trials conducted in Monte Alegre do Sul are considered, in both years, only differing from genotypes 2, 3, 4, 5, 13, 16, 18 and 19.

The joint analysis of grain production data in Tatuí, for 1999 and 2000, presented significant effects for genotypes and for years, suggesting that the yield decrease in 2000 was due to environmental differences between the two years, especially the frosts of year 2000. The interaction genotype x year was also significant. When the grain yield means obtained in Tatuí are compared in terms of kg ha^{-1}, genotypes 1 (2,635), 2 (2,538), 4 (2,448), 8 (2,729), 19 (2,680) and 20 (2,517) were prominent, as they were different only from line 13 (521), the least productive. In 1999, line 1 (3,896 kg ha^{-1}) was the most productive, but it was not different, however, in kg ha^{-1}, from genotypes 2 (3,055), 4 (2,938), 7 (3,048), 8 (3,271), 9 (2,917), 14 (2,854), 17 (2,868), 19 (3,854) and 20 (3,458). For the year 2000, line 8 was distinguished (2,187 kg ha^{-1}) as the most productive, being different, however, only from lines 10 (1,285 kg ha^{-1}) and 13 (417 kg ha^{-1}), the least productive.

Table 3 - Grain yield of genotypes assessed in the Dihaploid Wheat Lines Trial in Monte Alegre do Sul and in Tatuí, during 1999 and 2000.

Genotype	Monte Alegre do Sul			Tatuí			General mean
	1999	2000	Mean	1999	2000	Mean	
	--kg ha^{-1}						
1	4143 a-d	2038 a-d	3090 a-d	3896 a	1375 ab	2635 a	2863 a-c
2	2861 d-g	1247 de	2054 d-f	3055 a-e	2021 ab	2538 a	2296 a-d
3	1754 g	688 e	1221 f	2014 ef	1834 ab	1924 ab	1572 cd
4	3552 b-f	1403 c-e	2477 c-f	2938 a-e	1958 ab	2448 a	2463 a-d
5	2535 e-g	1691 c-e	2113 c-f	2327 c-f	1702 ab	2014 ab	2063 a-d
6	4094 a-d	2101 a-d	3097 a-d	2396 c-f	1396 ab	1896 ab	2497 a-d
7	3983 a-e	2639 a-c	3311 a-c	3048 a-e	1570 ab	2309 ab	2810 a-c
8	4768 ab	3017 ab	3892 ab	3271 a-d	2187 a	2729 a	3311 a
9	4354 a-c	2302 a-d	3328 a-c	2917 a-e	1577 ab	2247 ab	2787 a-c
10	3896 a-f	2097 a-d	2996 a-e	2222 d-f	1285 b	1753 ab	2375 a-d
11	4254 a-d	2163 a-d	3208 a-d	2604 c-f	1584 ab	2094 ab	2651 a-d
12	3955 a-e	2639 a-c	3297 a-c	2729 b-f	1465 ab	2097 ab	2697 a-d
13	2976 c-g	1503 c-e	2239 c-f	625 g	417 c	521 b	1380 d
14	4604 ab	3021 a	3812 ab	2854 a-e	1861 ab	2358 ab	3085 ab
15	3948 a-e	1986 a-d	2967 a-e	2021 ef	1535 ab	1778 ab	2372 a-d
16	2972 c-g	635 e	1804 ef	1604 fg	1479 ab	1542 ab	1673 cd
17	4313 a-d	2149 a-d	3231 a-d	2868 a-e	1465 ab	2167 ab	2699 a-d
18	2462 fg	1056 de	1759 ef	2097 ef	1792 ab	1944 ab	1852 b-d
19	4042 a-d	1726 b-e	2884 b-e	3854 ab	1507 ab	2680 a	2782 a-c
20	5288 a	3042 a	4165 a	3458 a-c	1577 ab	2517 a	3341 a
F (Gen.)	9.89*	8.63*	12.91*	12.39*	5.42*	2.28*	4.34*
F (Years)	-	-	339.73*	-	-	51.06*	-
F (Trials)	-	-	-	-	-	-	65.18*
F (G x Y)	-	-	1.27	-	-	6.04*	-
F (G x T)	-	-	-	-	-	-	5.00*
d.m.s.(1)	1470	1292	1242	1149	813	1909	1369
C.V. (%)	14.98	25.14	19.06	16.57	19.62	18.11	18.93

(1)Means followed by at least one common letter do not differ among themselves, by Tukey test.
*Significant at 5%.

The joint analysis of 100 grain weight in the trials installed in Monte Alegre do Sul and Tatuí, during the two years, presented significant effects for genotypes, for trials and for the genotype x trial interactions, exhibiting a differential genotype behavior with regard to the environments (Table 4). This interaction could be explained by the fact that 100 grain weight is a trait controlled by several genes and has low heritability in crosses (Camargo, 1987a), thus being highly influenced by the environment. Despite of the significant interaction, line 8 yielded the heaviest grains, regardless of the environment. Significant effects were verified only for genotypes and years, when the trials in Monte Alegre do Sul were analyzed jointly, in 1999 and 2000 (Table 4). When the two-year mean is analyzed, line 8 (4.32 g) is prominent for its heavier grains, which were not different from lines 1, 7, 12, 14 and 15 and from cultivar IAC-289, which yielded 100 grain weight between 3.46 and 4.05 g.

The joint analysis of data obtained in Tatuí, for both years, presented effects only for the genotype x year interaction. For 1999, lines 8 (4.51 g) and 7 (4.38 g) were distinguished by their heavier grains, as they were not different only from lines 1, 9, 10 and 12, with 100 grain weight between 3.8 and 4.18 g, and from cultivars IAC-24 (3.96 g) and IAC-289 (3.89 g). For 2000, line 8 (4.76 g) exhibited the highest 100 grain weight, but it was not different from lines 3, 11, 14, 15 and 18. Line 8 had the heaviest grains and line 13 (2.07 g), was the lightest during the two years, despite the significant interaction, considering the Tatuí trials jointly in 1999 and 2000.

When the genotype means of the four trials for grain yield and 100 grain weight are considered, a positive correlation is verified at 5%, with a coefficient of correlation of 0.81, in agreement with data obtained by Camargo & Oliveira (1983) and Camargo (1987a; b). The coefficient of correlation obtained indicated a tendency for the most productive genotypes to yield the heaviest grains.

Table 4 - One hundred grain weight, of genotypes assessed in the Dihaploid Wheat Lines Trial in Monte Alegre do Sul and in Tatuí, during 1999 and 2000.

Genotype	Monte Alegre do Sul			Tatuí			General mean
	1999	2000	Mean	1999	2000	Mean	
	g						
1	4.08 a-c	4.02 a	4.05 ab	3.97 a-c	3.75 b-e	3.86	3.95 ab
2	3.09 d-f	2.66 c-g	2.87 d-f	2.77 f-i	3.66 b-e	3.21	3.04 b-d
3	3.44 c-e	2.22 e-g	2.83 df	3.20 d-h	3.90 a-d	3.55	3.19 b-d
4	3.67 c-e	2.51 d-g	3.09 c-f	3.54 b-e	3.82 b-d	3.68	3.38 b-d
5	3.51 c-e	2.53 d-g	3.02 d-f	2.60 g-i	3.73 b-e	3.17	3.09 b-d
6	3.70 cd	2.77 c-g	3.23 b-e	3.49 b-f	3.86 b-d	3.68	3.46 a-c
7	4.41 ab	3.51 a-c	3.96 a-c	4.38 a	2.68 f-h	3.53	3.74 ab
8	4.71 a	3.92 ab	4.32 a	4.51 a	4.76 a	4.63	4.48 a
9	3.60 c-e	2.91 c-f	3.25 b-e	3.97 a-c	3.07 d-g	3.52	3.39 a-d
10	3.82 bc	2.88 c-f	3.35 b-e	3.80 a-d	2.40 gh	3.10	3.22 b-d
11	2.98 ef	2.95 c-f	2.96 d-f	2.87 e-i	3.91 a-d	3.39	3.18 b-d
12	3.88 bc	3.04 c-e	3.46 a-d	4.18 ab	3.46 b-f	3.82	3.64 a-c
13	3.00 ef	2.13 fg	2.57 ef	2.23 i	1.90 h	2.07	2.32 d
14	3.94 bc	3.33 a-d	3.64 a-d	3.63 b-e	4.04 a-c	3.83	3.74 ab
15	4.01 bc	3.15 a-d	3.58 a-d	3.53 b-e	4.26 ab	3.89	3.74 ab
16	2.68 f	1.92 g	2.30 f	2.98 e-i	2.91 e-g	2.95	2.62 cd
17	3.86 bc	2.95 c-f	3.41 b-e	3.31 c-g	3.44 b-f	3.38	3.39 a-d
18	3.72 b-d	3.15 a-d	3.43 b-e	2.51 hi	3.98 a-c	3.25	3.34 b-d
19	3.65 c-e	2.92 c-f	3.28 b-e	3.96 a-c	3.35 c-f	3.66	3.47 a-c
20	3.87 bc	3.35 a-d	3.61 a-d	3.89 a-d	3.56 b-f	3.72	3.67 a-c
F (Gen.)	13.32*	10.75*	10.08*	19.91*	15.11*	1.40	4.91*
F (Years)	-	-	114.36*	-	-	0.09	-
F (Trials)	-	-	-	-	-	-	11.74*
F (G x Y)	-	-	2.06	-	-	14.43*	-
F (G x T)	-	-	-	-	-	-	7.30*
d.m.s.(1)	0.70	0.87	0.89	0.76	0.90	-	1.09
C.V. (%)	7.22	11.23	9.19	8.32	9.70	8.99	9.09

(1)Means followed by at least one common letter, do not differ among themselves, by Tukey test.
*Significant at 5%.

The joint analysis for plant height in the trials installed in Monte Alegre do Sul and Tatuí, during 1999 and 2000, indicated, through analysis of variance, significant effects for genotypes, trials, and for the genotype x trial interaction (Table 5), in agreement with results obtained by Camargo et al. (1989; 1990). Despite of the significant genotype x trial interaction, line 13 revealed as one of the shortest in all trials, and it could be utilized in breeding programs as a source for the short plant stature trait. Dihaploid line 13 (61 cm) was the shortest, not differing from lines 6 (67 cm), 7 (68 cm) and 10 (65 cm). These show a potential for cropping under irrigation conditions, since shorter plants present a reduced tendency to lodging, when compared to high stature plants (Scheeren et al., 1981; Camargo et al., 1999). Genotypes 3 (116 cm) and 18 (119 cm) were the tallest, not differing from line 2 only (108 cm).

The analysis of variance of data from the Monte Alegre do Sul trials, during 1999 and 2000, revealed significant effects only for genotypes and for years. Genotypes 6 (68 cm), 10 (68 cm) and 13 (65 cm) were the shortest, not differing from lines 5 and 7 only, at 70 and 73 cm, respectively.

Genotypes 3 and 18 were the tallest, at 119 and 125 cm, respectively, not differing from line 2 (112 cm), when the Monte Alegre do Sul trials were analyzed jointly.

Significant effects for genotypes were verified in the Tatuí trials, when analyzed jointly, for years and for the genotypes x years interaction.

When the 1999 and 2000 data are pooled together, line 13 (58 cm), which had the shortest plants, did not differ from genotypes 5, 6, 7, 9, 10, 12, 15, 17 and 19, where plant height ranged from 62 to 78 cm; the tallest genotypes, 3 (114 cm) and 18 (112 cm), only did not differ from lines 2 (104 cm) and 4 (99 cm). In 1999, line 13 (65 cm) was distinguished as having the shortest plants, not differing from lines 6, 7 and 10 only (71, 70 and 69 cm, respectively). Lines 3 and 18 (both at 123 cm) were the tallest, not differing, however, from line 2 only (113 cm). In the year 2000, line 13 (50 cm), which

Table 5 - Plant height of genotypes assessed in the Dihaploid Wheat Lines Trial in Monte Alegre do Sul and in Tatuí, during 1999 and 2000.

Genotype	Monte Alegre do Sul			Tatuí			General mean
	1999	2000	Mean	1999	2000	Mean	
	cm						
1	96 cd	95 c	96 c	96 cd	69 b-d	82 c-e	89 c
2	106 b	118 ab	112 ab	113 ab	94 a	104 ab	108 ab
3	119 a	119 ab	119 a	123 a	106 a	114 a	116 a
4	103 b-d	110 ab	107 b	104 bc	94 a	99 a-c	103 b
5	69 ef	71 de	70 de	76 fg	76 b	76 d-f	73 fg
6	68 ef	69 de	68 e	71 gh	61 c-f	66 ef	67 gh
7	71 ef	75 de	73 de	70 gh	57 d-f	63 ef	68 gh
8	91 d	93 c	92 c	90 d	69 b-d	79 c-e	85 cd
9	76 e	79 d	77 d	83 ef	57 d-f	70 ef	74 d-g
10	67 f	70 de	68 e	69 gh	54 ef	62 ef	65 gh
11	96 cd	95 c	96 c	93 de	72 bc	82 c-e	89 c
12	87 d	91 c	89 c	87 d	66 b-e	76 d-f	83 c-f
13	62 f	68 e	65 e	65 h	50 f	58 f	61 h
14	92 d	92 c	92 c	93 de	68 b-d	80 c-e	86 c
15	90 d	91 c	90 c	93 de	64 b-e	78 d-f	84 c-f
16	96 cd	96 c	96 c	96 cd	74 b	85 b-d	90 c
17	89 d	92 c	90 c	87 d	64 b-e	75 d-f	83 c-f
18	124 a	127 a	125 a	123 a	101 a	112 a	119 a
19	95 cd	97 c	96 c	92 d	65 b-e	78 d-f	87 c
20	90 d	93 c	92 c	92 d	66 b-e	79 c-e	85 cd
F (Gen.)	75.77*	61.24*	120.93*	66.45*	38.35*	18.17*	51.85*
F (Years)	-	-	16.32*	-	-	142.52*	-
F (Trials)	-	-	-	-	-	-	96.37*
F (G x Y)	-	-	0.99	-	-	4.70*	-
F (G x T)	-	-	-	-	-	-	3.80*
d.m.s.(1)	10	11	9	11	13	21	12
C.V. (%)	4.33	4.72	4.80	4.45	7.05	5.89	5.32

(1)Means followed by at least one common letter, do not differ among themselves, by Tukey test.
*Significant at 5%.

did not differ from lines 6, 7, 9 and 10 (61, 57, 57 and 54 cm, respectively) having the shortest plants, while genotypes 2 (94 cm), 3 (106 cm), 4 (94 cm) and 18 (101 cm) had the tallest plants.

The correlation between grain yield and plant height, when the genotypes means obtained in trials at Monte Alegre do Sul and Tatuí, during both years, were considered, did not show significant effects; this indicated that the tallest genotypes did not tend to be the most productive, contradicting Camargo & Oliveira (1983), which found a coefficient of correlation with positive and significant values.

Genotypes 5, 10 and 13, exhibiting mean plant heights of 73, 65 and 61 cm, respectively, showed resistance to lodging (Table 6). Lines 6, 7, 12 and 20, with lodging percentage means ranging from 4 to 9% were considered as moderately resistant to lodging; the remaining genotypes, with lodging percentages ranging from 15 to 45% were considered as susceptible to lodging.

A tendency was verified, according to which taller plants have a greater lodging percentage, and shorter plants a greater resistance, and this fact was confirmed by the positive coefficient of correlation (r = 0,79*) between genotype means for plant height and lodging, obtained for the four trials.

According to the scale proposed by Mehta (1978), lines 3, 4, 5, 8, 16 and 18, with a infection degree means ranging from 1 to 5%, were considered as resistant to the causal agent of leaf rust, representing sources of resistance to this disease, and could be utilized in breeding programs (Table 6). Lines 1, 2, 6, 7, 9, 10, 11, 12, 14 and 17, and cultivars IAC-24 and IAC-289, with a infection degree means, between 6 and 25%, were moderately resistant, according to the same scale.

When evaluated in nutrient solution in the absence of aluminum, all genotypes presented normal root growth; the difference observed between root lengths is genetic in origin (Table 6).

In the solution containing 2 and 4 mg L^{-1}, all genotypes presented root growth, and were considered, therefore, as tolerant for this concentration, except for the control cultivar Anahuac (susceptible), for which no root growth was observed. Genotypes 13 and 20 had an irreversible paralyzation of root growth after growing for 72 hours in a complete solution, which followed treatment for 48 hours in a solution of 6 and 8 mg L^{-1} aluminum, therefore being considered as sensitive for this concentration; the other genotypes were tolerant for this concentration, since they had root growth. At the concentration of 10 mg L^{-1} aluminum, genotype 10 revealed root growth paralyzation. This genotype, plus lines 13 and 20, were considered as sensitive for this concentration; the other were considered as tolerant. The results obtained in nutrient solution suggest that all

Table 6 - Percentage of lodging and degrees[1] of infection by leaf rust (LR) means in the trials installed in Monte Alegre do Sul and in during 1999 and 2000, and mean length (mm) of roots of genotypes assessed for aluminum toxicity[2].

Genotype	Lodging	LR	Aluminum concentration (mg L^{-1})					
			0	2	4	6	8	10
	%		mm					
1	39	13S	58.8	28.0	10.9	0.8	0.2	0.2
2	31	6S	62.3	40.4	11.9	5.5	2.5	0.1
3	45	tS	56.7	49.4	30.0	22.2	10.9	4.1
4	19	2S	60.0	48.4	30.9	23.3	8.9	0.7
5	0	3S	61.0	40.8	34.9	10.3	4.3	0.5
6	9	11S	51.5	40.3	31.2	20.1	14.0	9.8
7	4	11S	52.2	46.6	27.8	6.3	1.4	1.0
8	19	5S	61.8	46.1	41.1	36.2	20.9	14.2
9	18	11S	56.7	41.8	28.6	10.8	5.6	0.9
10	0	8S	49.4	31.7	15.3	5.4	1.1	0.0
11	23	20S	53.3	46.8	37.9	31.3	20.9	12.3
12	9	8S	56.4	48.2	38.5	30.6	21.4	16.7
13	0	37S	51.5	3.5	0.7	0.0	0.0	0.0
14	21	15S	60.7	49.2	34.9	24.3	18.0	13.8
15	23	28S	61.1	41.7	22.6	12.3	3.9	3.2
16	38	4S	55.8	41.6	31.0	23.1	12.7	6.4
17	15	14S	55.7	40.1	31.3	20.1	12.1	10.1
18	31	5S	59.2	55.9	47.4	39.6	22.7	18.7
19	25	9S	56.8	48.6	44.5	31.4	15.4	10.8
20	6	18S	62.1	30.7	4.7	0.0	0.0	0.0
BH-1146			90.2	74.7	57.8	45.9	24.8	19.7
Anahuac			62.9	0.0	0.0	0.0	0.0	0.0

[1]Evaluation of leaf rust according to Schramm et. al. (1974).

[2]Mean length (mm) of roots, after growing for 72 hours in a complete solution, which followed growth in a treatment solution containing three different aluminum concentrations (mean of five replicates).

genotypes, except lines 10, 13 and 20, could be sown under dry land conditions and in very acid soil with a high aluminum content aiming at an economic production.

CONCLUSIONS

Anther culture was demonstrated as a useful breeding technique, allowing breeders to obtain lines that bear desirable agronomic traits, providing savings in time and resources, as compared to other traditional methods.

Line 8, resulting from the ANA/IAC-24 cross, presented high grain yield, semi-dwarf size, heavy grains, leaf rust resistance and tolerance to aluminum toxicity.

Lines 4, 8, 11, 12 and 14 had high tolerance to toxicity by aluminum associated to a yield higher than 3.000 kg ha^{-1}, and therefore can be utilized in wheat breeding programs for obtaining cultivars in soils of high acidity.

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