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Adaptability and stability of wheat genotypes on ten environments in the states of Paraná and São Paulo, Brazil

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ABSTRACT

The expansion of wheat cultivation to new and promising regions has been an alternative to increase Brazilian production. For this purpose, the study of genotypes x environments interaction is essential for the recommendation of new cultivars. The objective of this research was to evaluate the adaptability and phenotypic stability of the grain yield of wheat genotypes grown in 10 environments in the states of São Paulo and Paraná, using Annicchiarico and AMMI methods. The experiments were composed of 20 lines and five commercial cultivars (checks), evaluated in ten environments, in randomized complete block design. The line G19 and the cultivar Ametista were stable in all environments. The G5 line showed specific adaptability to the Apucarana environment. The lines G7, G8, G18, G21 and G24 were adapted to Nova Fatima environments in the two evaluated years. Based on the results, the cultivars for a micro-region in the region of wheat can be recommended. It was verified that in the group of genotypes there is genetic variability, and that the most stability and adaptability, can be used as a source of favorable characteristics in future breeding cycles aimed at the region.

Key words: AMMI; Annicchiarico; genotypes x environments interaction; *Triticum aestivum* L.

Adaptabilidade e estabilidade de genótipos de trigo em dez ambientes nos estados do Paraná e São Paulo, Brasil

RESUMO

A expansão de cultivo do trigo para novas regiões promissoras tem sido uma alternativa para incrementar a produção brasileira. Para isso, o estudo da interação genótipos x ambientes é imprescindível para a recomendação de novas cultivares. O objetivo do trabalho foi avaliar a adaptabilidade e a estabilidade fenotípica da produtividade de grãos de genótipos de trigo, cultivados em 10 ambientes, nos estados de São Paulo e Paraná, utilizando os métodos Annicchiarico e AMMI. Os experimentos foram avaliados em dez ambientes, cada experimento foi composto por 20 linhagens e cinco testemunhas, utilizou-se o delineamento de blocos ao casualizados. A linhagem G19 e a testemunha Ametista foram estáveis em todos os ambientes. A linhagem G5 mostrou adaptabilidade específica ao ambiente de Apucarana. As linhagens G7, G8, G18, G21 e G24 mostraram-se adaptadas ao ambiente de Nova Fátima nos dois anos avaliados. Com base nos resultados podem-se recomendar as cultivares para uma microrregião dentro da região tritícola. Verificou-se que dentro do grupo de genótipos há variabilidade genética, e que as mais estáveis e adaptadas, podem ser utilizadas como fonte de características favoráveis nos futuros ciclos de melhoramento voltados à região.

Palavras-chave: AMMI; Annicchiarico; interação genótipos x ambientes; *Triticum aestivum* L.

Introduction

Wheat is one of the most produced cereals in the world and Brazil is among the largest importers; approximately 50% of the wheat consumed in the country is imported (Embrapa, 2016). National production is around five to six million tons and, of this total, more than 90% of production is concentrated in the Southern Region due to cultural and climatic factors (Conab, 2016). However, cultivation in other regions such as the Southeast and Midwest becomes an excellent alternative to increase and decentralize the Brazilian production.

The expansion of wheat cultivation will reduce the oscillation of production, which is common due to the climatic adversities of the South region (Condé et al., 2010). For the adoption and development of cultivars in new environments, the genotype vs. environment interaction should be kept in mind, as this leads to distinct responses of genotypes when submitted to different environmental conditions, affecting their performance and reducing the relationship between genotype and phenotype (Yan & Holland 2010).

According to Cruz & Carneiro (2006), the genotype x environment interaction occurs due to two components; one is called the simple component, which is caused by the difference between genotypes, and another is called complex, caused by the lack of correlation between genotypes. Low correlation between genotypes and phenotypes indicates that the best genotypes in a given environment may not perform the same in another environment.

The effect of the genotype x environment interaction makes selection more complex due to the difficulty of finding superior genotypes in a wide range of environments. However, to assist in the selection process, some statistical methods help to understand the interaction, making the results more accessible to breeders (Ramos et al., 2011). Among the statistical methods employed for evaluation of stability and adaptability parameters are the Annicchiarico (1992) and the AMMI (*Additive Main effects and Multiplicative Interaction*) (Zobel et al., 1988) methods.

The AMMI analysis is efficient for selecting genotypes, since it allows the best detailing of the sum of the squares of the interaction. The method combines the additive components for the main effects, genotypes and environments and multiplicative components for the interaction effects into a single mathematical and statistical model, (García-Peña & Dias 2009).

The Annicchiarico (1992) method is based on the analysis of joint variance of the experiments, with later decomposition of the sum of squares of the effects of the environments and of the interaction genotype x environment, in the effects of environments within each genotype (Cruz & Carneiro 2006).

The objective of this work was to evaluate the phenotypic adaptability and stability of the productivity of wheat genotypes grown in ten environments in the states of São Paulo and Paraná using the Annicchiarico and AMMI methods.

Material and Methods

The experiments were conducted in 10 environments, six in 2011 and four in 2012, in municipalities located in the states of Paraná and São Paulo. Data are presented in Table 1, as well as the climatological information of each environment.

The experiments are part of the trials of value for cultivation and use (VCU) of the Wheat Genetic Improvement Program of the OR Melhoramento Ltda. company. Twenty-five genotypes were evaluated in each experiment, being 20 strains in VCU phase and five commercial wheat cultivars (Table 2).

Wheat strains were obtained from breeds destined to the adaptation region 3 (warm, moderately dry and altitude below 800 m), according to the Brazilian Wheat and Triticale Research Commission (2014) and with selections in the

Table 2. Genealogy of commercial wheat strains and controls evaluated in the ten environments.

Genotype	Lineage	Genealogy
G1	L 080014	ORL97061/ORL00241//CD104
G2	L 080025	SUZ6/WEAVER//TUI/3/SUP/4/CD104
G3	L 080030	ORL99396/ORL97061//SUP
G4	L 080084	ÔNIX/3/ALC/ÔNIX//ÔNIX/4/SUP
G5	L 080105	CRX/CD104//ALC
G6	L 080112	CRX/CD104//ALC
G7	L 080218	ALC/ÔNIX//VAN/4/ÔNIX/3/ALC/ÔNIX//ÔNIX
G8	L 080219	ALC/ÔNIX//VAN/4/ÔNIX/3/ALC/ÔNIX//ÔNIX
G9	L 080283	ORL98231's'/TAU//ALC/3/ALC
G10	L 080287	ORL98231/IOR00131//ÔNIX
G11	L 080361	ORL00353/ABA
G12	L 070028	BR35/ROND//95305/3/ALC/4/ALC
G13	L 070053	LAJ96010/JSP//ALC
G14	L 070078	CD104/IOR9817//PMP
G15	L 070084	CRX/ALC//ALC
G16	L 070266	ORL94346/ALC//AVT/3/ÔNIX
G17	L 070404	CEP0033/ÔNIX/3/ÔNIX*2//TC14/2*SPEAR
G18	L 070405	Campo Real/VAN//ÔNIX
G19	L 060702	ORL97061/CD 104
G20	L 060764	PMP/ORL98231//CRX
G21	Quartzo	ONIX/AVANTE
G22	CD 104	PFAU"S"/IAPAR 17
G23	BRS 220	EMBRAPA16/TB108
G24	Topázio	PAMPEANO"S"/ABALONE
G25	Ametista	PF950351/ABA//ÔNIX

Table 1. Geographic coordinates, altitude, annual precipitation (mm) and mean annual temperature (°C) of the 10 environments.

Local	Year	Geographical coordinates	Altitude (m)	Annual precipitation (mm)	Mean annual temperature (°C)
Cruzália-SP	2011	22º 44' 08" S, 50º 47' 37" W	318	1287	21.9
Taquarivaí -SP	2011	23º 55' 28" S, 48º 41' 35" W	555	1236	19.2
Palotina-PR	2011	24º 17' 02" S, 53º 50' 24" W	333	1508	23.5
Astorga-PR	2011	23º 13' 57" S, 51º 39' 56" W	675	1395	19.1
Nova Fátima-PR	2011	23º 25' 56" S, 50º 33' 50" W	673	1357	19.9
Apucarana-PR	2011	23º 33' 03" S, 51º 27' 39" W	820	1507	18.8
Cruzália-SP	2012	22º 44' 08" S, 50º 47' 37" W	318	1419	23.2
Palotina-PR	2012	24º 17' 02" S, 53º 50' 24" W	333	1562	20.8
Nova Fátima-PR	2012	23º 25' 56" S, 50º 33' 50" W	673	1391	19.9
Apucarana-PR	2012	23º 33' 03" S, 51º 27' 39" W	820	1637	22.2

Source: Climate-Data (2017).

region, maintaining the most promising in the program. The controls are cultivars that have been on the market for some years and are the most planted in the south of Brazil. They are characterized by high grain yield, resistance to major diseases and are classified as flour of bread type and breeder.

The experiments were conducted in a complete block design with randomized treatments, with three replicates. Each experimental plot consisted of seven strains spaced 0.17 m, with 4.0 m in length, totaling an area of 4.76 m². Sowing was carried out in experimental plots through direct planting system.

In 2011, the experiments were established on 20/04 in Cruzália, 30/04 in Taquarivaí, 05/05 in Palotina, 08/05 in Apucarana, 05/05 in Nova Fátima and 05/19 in Astorga. In 2012, the experiments were established on 24/04 in Cruzália, 08/05 in Nova Fátima, 10/05 in Palotina and 13/05 in Apucarana.

The basic fertilization was carried out according to environment soil analyses. The cover fertilization was 120 kg ha^{-1} of nitrogen, distributed in two applications, the first in the tillering phase and the second in the crop elongation phase, following the recommendations of the Brazilian Wheat and Triticale Research Commission (2014).

Phytosanitary control was carried out with fungicide sprays of Strobilurin and Triazole chemical groups with Azoxystrobin and Ciproconazole, respectively, as active ingredient at dosages recommended by the manufacturer. Weed control was performed in pre-sowing with desiccation of the area and in post-emergence to control unwanted plants, according to the need. The control of insect pests was carried out when the level of economic damage was reached.

The experimental units were harvested using a specific automated harvester for experimentation. Grains harvested in each plot of each experiment were submitted to the process of drying in a gas dryer until reaching a moisture content of 13%. After drying, grains were cleaned, weighed on a precision scale and the yield was expressed in kg ha^{-1}.

The estimated values of stability and adaptability by AMMI methodology (Zobel et al., 1988) were calculated by the statistical mathematical model:

$$Y_{ij} = \mu + g_i + a_j + \sum_{k=1}^{n} \lambda_k \gamma_{ik} \alpha_{jk} + \rho_{ij} + \bar{e}_{ij} \quad (1)$$

where:

Y_{ij} - average response of genotype i (i = 1, 2, ..., 25) in the environment j (j = 1, 2, ..., 10);

μ - overall mean of the tests;

g_i - fixed effect of genotype i;

a_j - random effect of the environment j;

λ_k - k-th singular (scale) value of the original interaction matrix (denoted by GA);

γ_{ik} - element corresponding to the i-th genotype in the k-th singular column vector of the GA matrix;

α_{jk} - element corresponding to the j-th environment in the k-th singular vector line of the GA matrix;

ρ_{ij} - noise associated with the term $(ga)_{ij}$ of the classical interaction of genotype i with environment j;

$\bar{e}_{ij}$ - mean experimental error.

The results of the AMMI method are presented in a *biplot* graph representing both, genotypes and environments. The scores of the interaction between genotypes and environments are represented in the *biplot* axes through PCAI (principal component analysis of the interaction).

Stability values calculated by the Annicchiarico method (1992) are demonstrated by the mathematical-statistical model:

$$\omega_i(g) = \mu_i(g) - Z(i - \alpha)\sigma_i(g) \quad (2)$$

where:

$\omega_i(g)$ - recommended confidence index;

$\mu_{i(g)}$ - average percentage of genotypes i;

$\sigma_{i(g)}$ - standard deviation of the z_{ij} values, associated to the i-th genotype;

$z_{(i-\alpha)}$ - percentage of the standard normal distribution function.

Data were submitted to individual analyses of variance. The homoskedasticity was verified by means of the Hartley's maximum F test and the normality of the errors by the chi-square normality test, after which the analysis of joint variance involving the different culture environments was performed. The stability of the yield of the grains was evaluated using the Annicchiarico (1992) method, using the GENES software (Cruz 2013) and the methodology using AMMI multivariate analysis (Zobel et al., 1988) in the Estabilidade software (Ferreira 2000).

Results and Discussion

The results of the joint analysis of variance showed a significant effect ($P < 0.01$) of genotype and environment as well as of the interaction term over grain yield. Presence of significant interaction indicates that there was variation in the performance of genotypes due to the variation of environments (Table 3). The low variation coefficient (VC%) shows good experimental accuracy. According to Brasil (2008), wheat trials must present VC below 20% to demonstrate good experimental accuracy.

In Table 4 are the average values of grain yield of the 25 genotypes evaluated in the ten environments; variation coefficients (VC%) below 7% indicate good experimental precision.

The strains showed environment influence, mainly due to rainfall, altitude and frost occurrence, which affected the grain yield. In the Taquarivaí and Apucarana environments, sowing was carried out at the beginning of May 2011, after rain, and germination occurred well, but there were no more precipitations during this month (Table 1), which probably interfered with the number of tillering, reducing the number of grains per area and compromising grain yield. The leaf area reduction provided by the low precipitation in the early stages of wheat reduces the photosynthetic rate, the main active factor in grain yield (Lawlor & Uprety 1993).

In Apucarana, in 2011, frosts occurred during the grain filling phase, contributing to low productivity. Meanwhile, in 2012, average grain yield was 4,061 kg ha^{-1}, as good water

Table 3. Summary of the joint analysis of variance of yield (kg ha^{-1}) of 25 wheat genotypes evaluated in 10 environments in the 2011 and 2012 harvests and the decomposition of the interaction G x E, with percentage of explanation of variance and accumulated value.

F V	GL	SQ	QM	Explained (%)	Accumulated (%)
Genotypes (G)	24	16,786,867	699,452**		
Environments (E)	9	1,175,632,937	130,625,881**		
GxE	216	141,147,262	653,459**		
IPCA 1	32	32,399,885	1,012,496*	22.95	22.95
IPCA 2	30	27,980,324	932,677*	19.82	42.77
IPCA 3	28	20,610,878	736,102*	14.6	57.37
Deviation	126	60,159,378	477,455*		
Residue	480	14,698,499	30,621		
Total	749	1,350,083,614			

*, ** significant at 5% and 1% of probability according to the F test, respectively; PCAI – Principal Component Analysis of the interaction

Table 4. Average grain yield (GY) of the 25 wheat genotypes in 10 growing environments in 2011 and 2012.

Genotype	Grain productivity (kg ha^{-1})									
	2011						2012			
	Cruzália	Taquarivaí	Palotina	Astorga	Nova Fátima	Apucarana	Nova Fátima	Cruzália	Palotina	Apucarana
G1	3,266 a D	2,293 d E	4,289 d C	4,152 b C	4,551 e B	1,866 c F	4,888 f A	3,423 c D	2,311 c E	3,427 f D
G2	3,239 a D	3,117 b D	4,227 d C	5,053 a B	6,029 b A	1,801 c E	4,848 f B	3,218 d D	3,058 a D	4,462 c C
G3	2,506 c F	2,926 b E	3,733 e C	3,552 d C	5,523 c B	1,984 b G	5,895 b A	2,678 f F	2,119 c G	3,272 g D
G4	2,657 b E	2,830 c E	5,169 a C	3,467 d D	6,176 b A	2,061 b G	5,597 c B	3,535 c D	2,408 c F	3,352 g D
G5	3,218 a E	3,049 b F	4,059 e C	3,408 d E	6,356 a A	2,093 b G	5,013 e B	3,821 b D	3,047 a F	4,154 d C
G6	2,387 c E	2,651 c E	4,486 c C	4,918 a B	5,812 c A	1,622 c F	5,103 e B	2,575 f E	2,875 b D	4,364 c C
G7	2,799 b F	3,219 b E	3,588 f D	4,375 b C	5,626 c B	2,175 b G	6,273 a A	2,693 f F	2,630 b F	4,463 c C
G8	2,527 c F	2,731 c E	3,482 f D	4,271 b C	6,488 a A	1,928 c G	5,379 d B	2,422 f F	2,800 b E	4,441 c C
G9	2,806 b E	2,762 c E	4,915 b B	4,741 a B	5,748 c A	2,069 b F	4,964 e B	3,289 d D	2,855 b E	3,828 e C
G10	3,187 a E	2,426 d F	4,355 d C	3,792 c D	6,059 b A	1,669 c G	5,117 e B	3,161 d E	2,688 b F	3,253 g E
G11	2,128 d F	2,904 b E	3,310 g D	4,783 a B	6,232 b A	1,436 d G	4,671 f B	2,956 d E	2752 b E	4,209 d C
G12	2,746 b E	2,791 c E	4,164 e C	4,840 a B	6,292 b A	2,185 b F	5,046 e B	3,535 c D	2,663 b E	3,489 f D
G13	2,461 c G	1,876 e H	4,070 e D	4,979 a C	6,091 b A	2,415 a G	5,764 c B	3,510 c E	2,674 b G	3,028 g F
G14	3,002 b E	2,293 d F	3,348 g D	4,921 a B	6,032 b A	2,234 b F	5,075 e B	3,095 d E	2,836 b E	4,162 d C
G15	2,462 c G	2,206 d G	3,906 e D	2,931 e F	5,238 d B	1,782 c H	5,554 c A	2,845 e F	3,213 a E	4,829 a C
G16	2,068 d G	1,665 e H	5,038 a C	4,202 b D	6,061 b A	1,239 d I	5,350 d B	2,889 e F	2,927 a F	3,638 e E
G17	1,933 d F	2,922 b D	4,778 b B	4,157 b C	6,235 b A	1,781 c F	6,070 b A	3,074 d D	2,697 b E	4,373 c C
G18	2,113 d G	2,604 c F	4,011 e D	4,078 b D	6,747 a A	1,906 c G	6,278 a B	3,224 d E	2,383 c F	4,595 b C
G19	2,201 d G	3,769 a D	4,554 c C	4,353 b C	6,006 b A	2,028 b G	5,251 d B	3,163 d E	2,619 b F	4,573 b C
G20	2,832 b F	2,351 d G	3,928 e E	5,000 a C	6,089 b A	2,368 a G	5,584 c B	2,672 f F	2,366 c G	4,328 c D
G21	2,568 c E	2,543 d E	4,071 e C	4,213 b C	6,357 a A	2,177 b F	6,256 a A	3,342 d D	2,772 b E	4,983 a B
G22	2,983 b D	2,560 d E	3,236 g D	3,674 c C	6,120 b A	2,604 a E	4,404 g B	2,984 d D	2,297 c F	3,509 f C
G23	2,410 c F	2,628 c F	4,556 c C	3,750 c E	6,538 a A	2,029 b G	5,923 b B	2,556 f F	2,497 c F	4,036 d D
G24	2,202 d G	2,821 c F	3,848 e D	4,257 b C	6,497 a A	1,798 c H	5,673 c B	3,211 d E	2,655 b F	4,458 c C
G25	2,319 c H	3,064 b F	3,631 f E	5,008 a C	5,594 c B	1,651 c I	5,954 b A	4,863 a C	2,708 b G	4,309 c D
CV (%)	5.56	7.00	3.16	4.46	3.32	6.23	3.89	6.66	5.84	4.20

Averages followed by the same upper case letters in the line and lower case letters in the column indicate a statistically homogeneous group according to the Scott Knott test ($p < 0.05$).

and altitude conditions allowed the genotypes to express their genetic potential (Tables 1 and 4).

None of the evaluated strains remained statistically in the most productive group in all environments, which makes selection more complex. To assist in the selection process and to find superior genotypes in a wide range of environments, the AMMI and Annicchiarico statistical methods were used.

In the AMMI analysis, the first three main components were significant according to the F test for wheat yield. The accumulated explanation of the first three axes was 57.37%, and for this, 41.66% of the degrees of freedom that make up the SQ_{GxA} were used (Table 3). The higher the explanation of the first axes, the higher is the concentration of the pattern, and the lower is the concentration of noise in the AMMI analysis (Oliveira et al., 2003).

In the AMMI1 *biplot* model (Figure 1A), the x axis represents the grain yields and the y axis, the first interaction axis (PCAI1). Genotypes and environments that are close to zero in the PCAI1 are the most stable, and the most distant from zero are more adapted to specific environments and contribute more to the genotype x environment interaction.

The G6, G11, G16 and G20 strains were the most stable, but only G6 and G20 were above average. The G4, G5, G19 strains and the G25 (Amethyst) controls showed good stability and above-average productivity; G3 showed good stability, but productivity was below the average (Figure 1A).

The strains that contributed the most to the interaction, i.e. the least stable, were G1 and G18, presenting the highest coordinates of PCAI1 and productivity close to the overall average.

The environments A2 (Taquarivaí) and A9 (Pallotina2) were stable, but unfavorable, because productivities were the lower, with 2,680 kg ha^{-1} and 2,674 kg ha^{-1}, respectively. However, the A3 environment (Pallotina1) presented good stability and above-average productivity (4,110 kg ha$^{-1)}$, which shows that this is a good environment for genotype selection in early stages of the breeding program because it is more stable, and does not favor the selection of genotypes that are specific to a given environment, such as the environments A1 (Cruzália1), A7 (Nova Fátima2) and A10 (Apucarana2), which are specific. The environment A5 (Nova Fátima1) was the most productive and with medium stability (Figure 1A).

Figure 1. A: AMMI1 Biplot with the first main axis of the interaction (PCAI1) x productivity in kg ha^{-1}. B: AMMI3 Biplot with the first and third axis of interaction (PCAI1 x PCAI3) for yield of 25 wheat genotypes evaluated in ten environments. Environments: A1- Cruzalia[1], A2- Taquarivaí[1], A3- Palotina[1], A4- Astorga[1], A5- Nova Fátima[1], A6- Apucarana[1], A7- Nova Fátima[2], A8- Cruzália[2], A9- Palotina[2] and A10- Apucarana[2]. 2011[1] and 2012[2] harvests.

The environment with the lowest productivity was A6 (Apucarana[1]) with 1,956 kg ha^{-1}, below the overall average of the experiments, due to frost in the region. On the other hand, Nova Fatima (A5 and A7) stood out in grain yields in the two years of cultivation: 6,020 kg ha^{-1} and 5,437 kg ha^{-1}, both surpassing the average (Figure 4). This environment has been favorable to cultivation of wheat, and cultivars with high genetic potential should be recommended and adapted in this region.

We verified that altitude was a factor that influenced productivity in the environments. Cruzalia, Taquarivaí and Palotina have lower altitudes, 600 meters, and were not ideal for wheat cultivation, with grain yield below the average of the experiments (2,601 kg ha^{-1}, 3,149 kg ha^{-1}, 2,680 kg ha^{-1} and 2,674 kg ha^{-1}, respectively). The environments with higher altitudes, namely Astorga, Apucarana and Nova Fátima, had better conditions for the genotypes to express their genetic potential, resulting in grain yield (4,275 kg ha^{-1}, 4,061 kg ha^{-1}, 6,020 kg ha^{-1} , 5,437 kg ha^{-1}, respectively) (Figure 1A). According to Monteiro (2009), the ideal conditions for cultivation of wheat are found in the higher altitudes, in the so-called cold and humid zone.

In Figure 1B, in which the AMMI3 model is represented, the G3, G4, G11, G19 and G20 strains showed high stability. They are close to the center of the graph and were the strains that contributed least to the genotype x environment interaction, that is to say, these genotypes did not respond to environmental improvement, but had similar productivity in all environments, with values of 3,419 kg ha^{-1}, 3,725 kg ha^{-1}, 3,538 kg ha^{-1}, 3,852 kg ha^{-1} and 3,752 kg ha^{-1}, respectively. Among the stable strains, G4, G19 and G20, whose grain yields were higher than the overall average of the experiment (3,696 kg ha^{-1}), stood out.

The highest grain yields are usually obtained when a specific adaptation occurs between the genotype and the environment, such as the environment A7 (Nova Fátima[2]), where the G18 strain better expressed its genetic potential, reaching the highest grain yield of the experiment (6,278 Kg ha^{-1}). In the same plot, G18 strain and controls G23 (BRS220) and G24 (Topaz) demonstrated specific adaptation to environment A5 (Nova Fátima[1]). Notably, the two environments represent the same place, but in different years.

The G13 strain presented specific adaptability to the environment A4 (Astorga1), where it presented the highest grain yield, with 4,945 kg ha^{-1} (Figure 1B). G22 (CD104) was adapted to environments A1 (Cruzalia[1]) and A6 (Apucarana[1]), demonstrating that this cultivar adapts well to environments that do not present the ideal conditions for culture, since the two environments presented the lowest average grain yield.

The G1, G2, G10 and G14 strains were adapted to the environment A8 (Cruzalia[2]), indicating that these strains adapted well to the environment that presented ideal conditions for wheat cultivation, since this environment had high average productivity. Identifying genotypes with specific adaptability aids the identification of which environments are the most suitable for the planting of these cultivars/strains.

It is interesting to note that the locations where the experiments were conducted in two harvests, such as Cruzalia (A1 and A8) and Nova Fátima (A5 and A7), remained in the same quadrant in the graph, confirming the characteristics of each environment. Meanwhile in the environments Palotina (A3 and A9) and Apucarana (A6 and A10), where there were problems with frost, the environments did not remain in the same quadrant (Figure 1B).

Silva & Benin (2012) concluded that the AMMI1 model can be used to select mainly the best growing environments and genotypes that present higher average performance.

The Annicchiarico (1992) method seeks to find genotypes with stable behavior in the evaluated environments. This method estimates confidence indices (ωi) for favorable and unfavorable environments and environments in general, which allows estimating the risk of adopting a particular genotype in relation to the other evaluated genotypes. Thus, the higher is the confidence index (ωi), the higher is the probability of success of the genotype (Oliveira et al., 2007).

In Table 5 the environments are classified according to the Annicchiarico (1992) method, which includes the average grain yield and the environmental index. Cruzália, Taquarivaí, Apucarana in 2011 and Palotina in 2012 presented negative environmental indices, typical of unfavorable environments. The highest environmental index was observed in Nova Fátima in 2011.

Confidence indices (ωi) (Table 5) are generated from the average yield values of the genotypes in relation to the average of the environments. Thus, the greater the value of ωi, the greater is the chance of success of choosing a genotype and the greater is the reliability of this choice (Cruz & Carneiro 2006).

Only 28% of the genotypes studied were above the Annicchiarico confidence index (ωi) for overall productivity, but slightly above 100% (Table 5). The G2, G5, G9, G12, G19 strains and the Amethyst and Quartz controls showed the highest stability with ωi indices, maintaining productivity above the average even under different environmental conditions (Table 5).

For environments considered favorable, the G2, G6, G17, G18, G19 and G20 strains and the Topazio, Quartz and BRS 220 controls were the most stable genotypes (Table 5). Condé et al. (2010) evaluated wheat genotypes in divergent, irrigated and rainfed environments and found genotypes responsive to favorable environments and with low ωi, similar to the ones found in the present work.

The G2, G4, G5, G7, G9, G12, G14 strains and the Amethyst and Quartz controls presented the best confidence index in unfavorable environments (Table 5). This shows that these genotypes maintained good levels of grain yield even in environments that did not provide favorable conditions for cultivation.

The G2 strain and the Quartz control were the only genotypes that showed a confidence index above 100% in favorable, unfavorable and overall environments, as well as the highest productivity averages of 3,905 kg ha^{-1} and 3,928 kg ha^{-1}, respectively. Thus, it can be inferred that these genotypes are the most stable in the studied environments, considering this group of genotypes (Table 5).

The G6, G17, G18, G20 strains and the Topazio and BRS 220 controls were responsive only to favorable environments; under these conditions the genotypes expressed better their genetic potential (Table 5).

The genotype with the lowest overall ωi and in unfavorable environment was the G16 strain, and in favorable environments, the CD 104 showed the lowest ωi (Table 5). These results are corroborated by Condé et al. (2011) who evaluated the stability of wheat genotypes in Minas Gerais and found that the genotypes remained close to the confidence index.

The evaluation of stability by the Annicchiarico method has been used by many authors and in several species, such as soybean (Barros et al., 2012) and rice (Ramos et al., 2011). Schmildt & Cruz (2005) evaluated different methods of stability and concluded that the Annicchiarico method was the more reliable than Eberhart and Russell because of the ease of interpretation, the precision in the indication of cultivars for each type of environment and because of the fact that the method presents only one parameter of interpretation while Eberhart and Russell's method uses four parameters. Pereira et al. (2009a) recommend the use of the Annicchiarico method for the selection of bean cultivars.

The methods identified different genotypes as the most stable, presenting divergence in the results, and only the G19 strain and the Amethyst control showed a coincidence between the two methods.

The Annicchiarico method identified the strains and controls that presented the higher grain yields, namely G2,

Table 5. Average grain yield (AGY), index and environmental classification, estimation of the Annicchiarico confidence index (ωi) for wheat grain yield (YG) in all (overall), favorable and unfavorable environments.

Classification of environments				
Environments	**Year**	**MPG (kg ha^{-1})**	**Index (ω_i)**	**Class**
Cruzália-SP	2011	2,601	-1,095	Unfavorable
Taquarivaí -SP	2011	2,680	-1,016	Unfavorable
Palotina-PR	2011	4,110	413	Favorable
Astorga-PR	2011	4,275	578	Favorable
Nova Fátima-PR	2011	6,020	2,323	Favorable
Apucarana-PR	2011	1,956	-1,740	Unfavorable
Nova Fátima-PR	2012	5,437	1,740	Favorable
Cruzália-SP	2012	3,149	-547	Unfavorable
Palotina-PR	2012	2,674	-1,022	Unfavorable
Apucarana-PR	2012	4,061	365	Favorable

Estimate of the confidence index of Annicchiarico (ωi)				
Genotypes	**PG (kg ha^{-1})**	**$\omega_{i\,(\%)}$**		
		General	**Favorable**	**Unfavorable**
G1	3,446	91.34	87.23	95.7
G2	3,905	103.8	101.07	106.4
G3	3,419	89.57	87.95	90.93
G4	3,725	97.34	93.99	100.85
G5	3,822	102.16	92.91	114.12
G6	3,679	95.42	101.97	89.61
G7	3,784	99.9	98.53	100.95
G8	3,647	95.23	97.46	92.83
G9	3,798	101.63	98.94	105.08
G10	3,571	93.58	91.14	95.96
G11	3,538	90.94	93.48	88.12
G12	3,775	100.72	96.67	105.19
G13	3,687	95.06	95.22	94.43
G14	3,700	97.93	95.14	100.53
G15	3,497	90.74	89.25	91.78
G16	3,508	86.36	98.54	75.78
G17	3,802	97.64	105.27	91.01
G18	3,794	97.11	104.15	91.19
G19	3,852	100.86	102.39	99.74
G20	3,752	98.02	102.42	93.83
(G21) Quartz	3,928	103.2	105.32	101.19
(G22) CD 104	3,437	91.14	84.3	99.59
(G23) BRS 220	3,692	95.76	100.45	91.52
(G24) Topaz	3,742	97.7	101.26	94.36
(G25) Amethyst	3,910	100.14	99.55	101.04

G5, G9, G12, G19, Quartz and Amethyst, as the more stable. Pereira et al. (2009b) identified the more productive genotypes as the most stable, also using the Annicchiarico method. This is because the method evaluates the superiority of the genotypes, adopting the best genotypes in each environment and the average of each environment (Silva Filho et al., 2008).

The AMMI method informs the contribution of genotypes to the genotype x environment interaction; the ones that contributed least to the interaction are the most stable (Silva & Duarte 2006). In this study, the G3, G4, G11, G19 and G20 strains and the Amethyst control showed general stability. The method also identifies genotypes with specific adaptation to environments and the stability of environments (Silva Filho et al., 2008), important information to the breeding program, since the identified stable environments can be used in the initial selections and to identify environments that represent a region for value for cultivation and use (CUV) tests.

The Annicchiarico and AMMI methods used together, taking into account the particularity of each method, provide important information to breeders for deciding which genotypes must be kept in the breeding program.

In this work, the AMMI method gave information that helps to efficiently segregate the environments within a growing region and which informations represent it, thus minimizing the number of experiments and reducing costs. Stable environments can be used for CUV selections and experiments, since such unbiased environments represent well the region. However, in environments with favorable conditions for cultivation, the cultivars with the greatest genetic potential should be used.

The Annicchiarico method contributes to the breeding program by identifying strains that are stable and productive, such as the cultivars with the highest recommendation to favorable and unfavorable environments. Thus, the joint use of these methods make it possible to target the strains more efficiently to the environments in which the genetic potential will be expressed to the full. Pereira et al. (2009b) and Silva Filho et al. (2008) recommend the concomitant use of methods to evaluate phenotypic stability and adaptability to aid in decision making.

Conclusions

The G19 strain and the Amethyst control were stable in all environments and can be recommended for the whole tritícola region.

The G5 strain showed specific adaptability to the Apucarana environment. The G7, G8, G18, G21 and G24 strains were adapted to the Nova Fatima environment in the two evaluated years.

Cultivars are recommended for a micro-region within the tritícola region, increasing the productive efficiency.

The group of genotypes have genetic variability, and the most stable and adapted genotypes can be used as a source of favorable characteristics in future breeding cycles aimed at the studied region.

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