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Adaptability and stability of wheat cultivars sown on different dates in West Paraná

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This study aimed to assess adaptability and stability of different wheat cultivars on different sowing dates in western region of Paraná, Brazil. The assay was composed by following wheat cultivars: CD 154, CD 1252, CD 108, CD 151, CD 1550, CD 104, CD 1440, CD 116, CD 150, and CD 1104, which were sown on three different dates: April 29th 2014, May 20th 2014, and June 26th 2014. The methods used to determine stability and adaptability of production were: Traditional, Lin and Binns adapted by Carneiro, Eberhart and Russell and the Integrated. There was an agreement between Eberhart and Russell and Integrated methods for cultivars CD 104, CD 151, CD154 and CD 1440, which have general adaptability. It was also noted an agreement between methods of Lin and Binns and Eberhart and Russell on stability of cultivars CD 108, CD 1104 and CD 1440. The cultivars CD 108 and CD 1440 are considered stable and with wide adaptation and may be indicated to Western Paraná, regardless of sowing date. The cultivar CD 1104 may be indicated to be sown between April and May, while the CD 150 may be suitable for the later sowings, in late June.

Key words: Eberhart and Russell, integrated method, Lin and Binns, traditional method.

INTRODUCTION

Over time wheat breeding has led to the development of early maturity genotypes, with lower height, more tolerant to diseases, more productive and with higher grain quality (Almeida et al., 2007; Cruz et al., 2010; Sahrawat et al., 2003; Salomon et al., 2003). However, the expression of genetic potential of these genotypes varies according to environment. In this scenario, it is necessary to analyze interaction between genotype and environment to demonstrate how environmental variation may interfere in performance of each genotype. This kind of analysis may help selection of the best genotype based on the environmental average (Cargnin et al., 2006).

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Some models for analysis of adaptability and stability allow breeder to perceive the behavior of each genotype in favorable and unfavorable environments. They provide breeders necessary information to select the best genotype for each environment or a genotype that is proper in both environments (Biudes et al., 2009; Caierão et al., 2006; Silva et al., 2011).

On the Traditional method, which was suggested by Yates and Cochran (1938), a joint analysis of experiments (environments) was performed and the variance mean square of environments within each genotype is determined. The genotypes that have lower mean square of environmental variance are considered more stables. The adaptability can be defined by average of genotype (Cruz et al., 2012).

Eberhart and Russel (1966) proposed a model for analysis of adaptability and stability based on analyzed variable regression (dependent variable) in relation to environmental indexes, which are genotype average within each environment (independent variable). Therefore, by slop analysis of the line (β1), it becomes possible to identify adaptability of material to environment. Furthermore, it is possible to infer its stability by regression deviation (δ), where a more stable genotype has a lower regression deviation. The genotypes may present wide adaptability (β1=1), specific adaptability to favorable environments (β1>1) and specific adaptability to unfavorable environments (β1<1).

Methods based on regression models have been quite practical and they are widely utilized in plant breeding. However, there are some limitations in use of such methods; among this, difficulty of properly analyzed genotypes whose behavior are not linear or having complex genotype-environment interaction. In this context, centroid method, based on principal components, can overcome issues of regression-based methods, because in centroid method, the similarity between genotypes and ideotypes pre-established is calculated by Cartesian distance, in order to rank genotypes in relation to ideotypes. The ideotypes are ideotype with maximum general adaptability (ideotype I), ideotype with maximum specific adaptability to favorable environments (ideotype II), ideotype with maximum specific adaptability to unfavorable environments (ideotype III) and ideotype with a minimal adaptability (ideotype IV) (Vasconcelos et al., 2011).

The centroid method allows one to evaluate adaptability of genotypes that present a genotype-environment interaction more complex, but it does not present analysis of stability of genotypes. To fulfill this need, Vasconcelos et al. (2011) included three new ideotypes to centroid method: ideotype with maximum phenotypic stability (ideotype V), ideotype with maximal specific adaptability to favorable environments and stable in adverse environments (ideotype VI) and ideotype with maximal specific adaptability to unfavorable environments and stable in favorable environments (ideotype VII). By integrating these three new ideotypes to centroid method, Vasconcelos et al. (2011) renamed this method to Integrated method.

Lin and Binns (1988) developed a non-parametric method to evaluate adaptability and stability. In this method, reference is defined as the highest average for each environment and then distance between mean of each genotype and reference is calculated, within each environment, which is named as P_i. Lower is the P_i, higher is general adaptability of genotype.

The advantages possibility of this method of working with few environments, identify small differences between genetic materials and define a coherent analysis to data that do not fit into linear models. The disadvantage lies in possibility measuring only broad adaptability. In order to overcome this problem, Carneiro (1998) adapted model grouping environments into favorable and unfavorable and calculating P_i for each group (favorable and unfavorable), therefore allowing evaluation of specific adaptability besides general adaptability.

In general, in a breeding program of wheat, the selection of cultivars with high productivity, high stability and high adaptability, allied with superior agronomic characteristics (cycle, plant architecture, resistance to major pests and diseases and post-harvest quality) is recommended (Borém and Miranda, 2013). Therefore, mean goal of this study was to determine adaptability and stability of different wheat cultivars on different sowing dates in Western Paraná, Brazil.

MATERIALS AND METHODS

The experiment was conducted in Western Paraná, Brazil, at the coordinates 24°33' S and 54°31' W and at 420 m above sea level. The region climate, according to Köppen classification, was classified as Cfa, with well distributed rainfall during year and with hot summers (Caviglione et al., 2000). The soil in experimental area is classified as typical Eutophic Red Oxisol (Embrapa, 2013).

The experimental design was complete randomized blocks composed by ten wheat cultivars: CD 154, CD 1252, CD 108, CD 151, CD 1550, CD 104, CD 1440, CD 116, CD 150, and CD 1104 (Table 1), with three blocks. The plots were constituted by nine rows five meters long, with 0.17 m of row spacing. Three trials were performed simultaneously in areas, on different sowing dates (April 29th 2014, May 20th 2014, and Jun 26th 2014).

The sowing density was determined according to Coodetec (2014) recommendations for the Marechal Cândido Rondon municipality, region 3, according to Brazil (2008) classifications, which considers the region as hot, moderately dry and low altitude.

Sowing operation was performed in a no-tillage system; fertilization was based on soil analysis (Table 2) and on CBPTT (2010) recommendations. During initial crop development, weed control was carried out manually to avoid competition and weed interference.

The climate data (Figure 1) were obtained from an automatic weather station, located 50 m from experimental site. The mean temperatures during trials, sown on April 29th, May 20th and Jun 26th, were 18.15, 18.64 and 19.32°C, respectively, and daily precipitation was 5.44, 2.22 and 4.68 mm, respectively, and total precipitation were 598.80, 157.60 and 430.80 mm, respectively.

The harvest was performed manually when about 90% of ears

Table 1. Density, plant height, lodging, cycle, cycle to heading stage and germination in spike, for wheat cultivars adapted to region 3 of Parana, 2014 (COODETEC, 2014).

Cultivar	Plant m^{-1}	Height	Lodging	Cycle	Cycle to heading stage	Germination in spike
CD 104	65	Low – 80 cm	Moderately resistant	Medium	74 days	Moderately susceptible
CD 108	75	Low –67 cm	Resistant	Super Early	53 days	Moderately resistant
CD 116	70	Low – 81 cm	Moderately resistant	Early	62 days	Moderately susceptible
CD 150	65	Low – 68 cm	Moderately resistant	Early	59 days	Moderately resistant
CD 151	70	Low – 77 cm	Moderately resistant	Medium	65 days	Moderately susceptible
CD 154	70	Low – 75 cm	Moderately resistant	Medium	66 days	Moderately susceptible
CD 1104	60	No information	Moderately susceptible	Medium	No information	Moderately resistant
CD 1252	70	Low – 78 cm	Moderately resistant	Early	66 days	Moderately resistant
CD 1440	60	Medium – 82 cm	Moderately resistant	Medium	74 days	Moderately resistant
CD 1550	60	Medium – 81 cm	Moderately resistant	Medium	76 days	Moderately resistant

Table 2. Chemical properties of soil in experimental area.

Layer	P	MO	pH	Al^{3+}	K^{+}	Ca^{2+}	Mg^{2+}	Cu	Fe	Zn	Mn	SB	V
cm	mgdm^{-3}	g dm^{-3}	$CaCl_2$					cmol$_c$dm^{-3}					%
0-20	43.40	20.51	5.06	0.00	1.03	4.72	1.69	17.80	34.10	99.99	3.10	7.44	67.45

Extrators: P and K (Mehlich); Ca, Mg, Cu, Fe, Mn, Zn e Al^{+3} (KCl 1 mol).

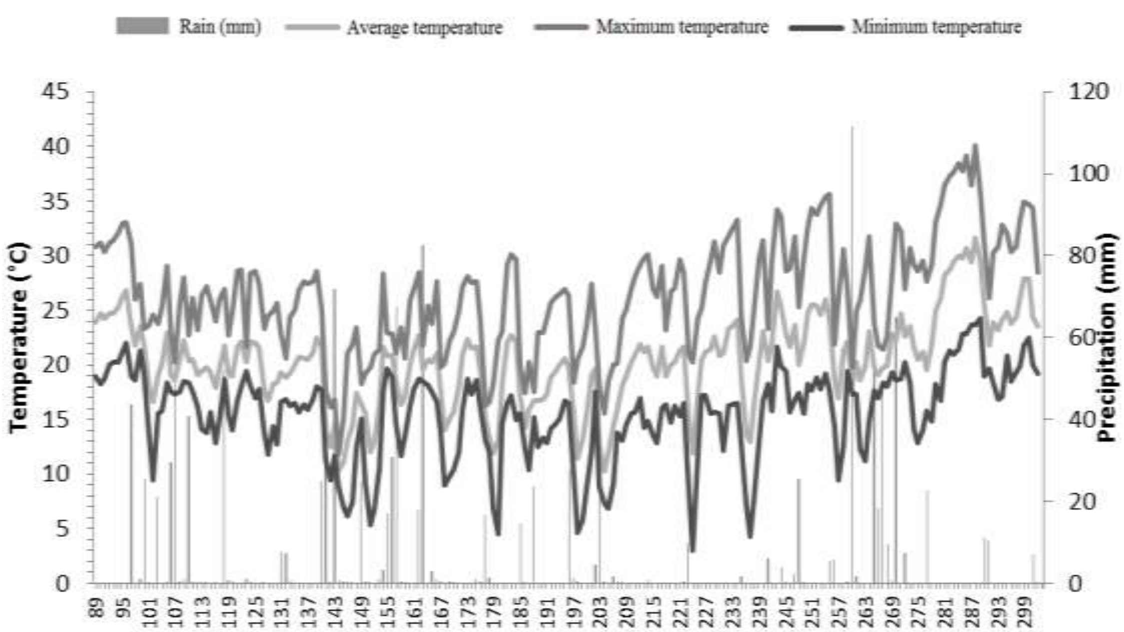

Figure 1. Rainfall distribution (mm) and average, maximum and minimum temperatures in period of Julian day number from 89 to 302 in Marechal Cândido Rondon - PR, in 2014.

were ripe and with grain moisture average of 12%. After harvest, material was subjected to mechanical threshing for grain yield determination.

Concepts and procedures of classical methods of analysis of adaptability and stability were introduced based on following methods: Traditional (Yates and Cochran, 1938), Lin and Binns (1988) adapted by Carneiro (1998), Eberhart and Russel (1966) and Integrated (Vasconcelos et al., 2011). The grain yield data were submitted to normality and homogeneity of variance test and afterwards, data were subjected to a joint analysis of variance,

Table 3. Summary of joint analysis of variance for productivity (kg ha^{-1}) of 10 wheat cultivars in 3 sowing dates, 2014, Marechal Cândido Rondon-PR.

Source of variation	df	SS	MS	F	
Blocks/Environments	6	-	-	-	
Cultivars (C)	9	16581228.43	1842358.71	1.74	ns
Environments (E)	2	932332202.84	4666101.42	36.61	**
C × E	18	19050135.67	1058340.87	3.73	**
Residual	54	15322716.45	283754.01	-	-
Total	89	145523780.16	-	-	-
Mean			1758.94	-	-
Coefficient of Variation (%)			30.28	-	-

* and **Significant on F-test at 5 and 1% of probability level, respectively.

followed by determination of adaptability and stability using software GENES (Cruz, 2013).

RESULTS AND DISCUSSION

Through individual analysis of variance of experiments, it was found that variances of residues were heterogeneous, by Hartley (1950) criteria, requiring an adjustment according to Cochran (1954) method enable joint analysis, with all test environments. In addition, it was observed that the ratio between the highest and lowest residual mean square of three sowing dates did not exceeded threshold value of seven (Pimentel Gomes, 2009). Through joint analysis of variance (Table 3), a significant interaction was found between genotypes and environments ($p \leq 0.05$), basic premise for analysis of phenological adaptability and stability of genotypes.

The coefficients of variation(CV) were 24.04, 31.07 and 15.61% in assays sown on April 29th, May 20th and Jun 26th, respectively, which are classified as high by Pimentel Gomes (2000), confirming unpredictable factors on grain yield influence. This classification has been challenged due to its range and for disregarding crop specificities and the nature of evaluated characteristics (Nunes, 2012).

When considering Traditional method (Table 4), it was observed for all cultivars that mean square of environment within genotype was significant, indicating that none of them has production stability. The ideal genotype may have been discarded, since methodology uses only one regression coefficient and deviations that should be examined in different environments, may be relatively high in relation to estimated line (Cruz et al., 2012). The highest average yield was obtained in cultivars CD 1104 (2508.06 kg ha^{-1}), CD 108 (2304.74 kg ha^{-1}), and CD 1440 (2135.09 kg ha^{-1}), which seem to be best adapted to region studied.

The cultivars CD108, CD 116, CD 150, CD 1440, and CD 1550 were considered ideal by Eberhart and Russell method (Table 4), because they exhibited general adaptability and production stability. The cultivars CD 1104 and CD 1253, despite being stable, they were classified as adapted to favorable and unfavorable environments, respectively. All cultivars obtained estimative of coefficient of determination (R^2) higher than 80%, except CD 151, showing in general a proper adjustment of data to regression line, indicating a high predictability of their behavior.

According to method of Lin and Binns (Table 4), cultivars CD 1104, CD 108, CD 1440, and CD 154 were classified as most stable and adapted because they presented smallest Pi values and the highest productivity. In decomposition of Pi described by Carneiro, cultivars CD 1104, CD 108, CD 1440, and CD 154 were classified as adapted and stable to favorable environments, whereas cultivars CD 150, CD 108, CD 151 and CD 1440 were adapted and stable in unfavorable environments. This approach has main advantage of enabling immediate knowledge of cultivars that are more stable (Pereira et al., 2009).

Using Integrated method (Table 4), the cultivars CD 104, CD 151, CD 154 and CD 1440 showed high general adaptability (Class V), whereas cultivars CD 108 and CD 1104 had specific adaptability to favorable environments (Class VI and II, respectively), and cultivar CD 150 with specific adaptability to unfavorable environments (Class VII). Other cultivars were classified as being of low adaptability (Class IV).

Methods of Eberhart and Russell and Integrated agreed with each other for cultivars CD 104, CD 151, CD 154 and CD 1440, which have general adaptability, and for cultivar CD 1104 with specific adaptability to favorable environments. These methods are complementary and they increase reliability in classification and recommendation of cultivars (Peluzio et al., 2008). An agreement was also observed between the methods of Lin and Binns and Eberhart and Russell, where cultivars CD 108, CD 1104 and CD 1440 exhibited productive stability. Similar results were found by Escobar et al. (2016) in maize and Romanato et al. (2016) in soybean. However, several studies comparing methodologies of genotypic stability and adaptability observed low

Table 4. Estimation of adaptability and stability parameters for grain yield of ten wheat cultivars, based on different methodologies: Traditional (Yates and Cochran, 1938), Eberhart and Russell (1966), Lin and Binns (1988) modified by Carneiro (1998) and Integrated (Vasconcelos et al., 2011).

Cultivars	Average	Traditional	Eberhart and Russell			Linn and Bins, adapted by Carneiro -						Integrated
		Q.M.	ß1	σ²di	R² (%)	Order	Pi general	Order	Pi fav.	Order	Pi unf.	Class.
CD 104	1582.48	13739353.86**	1.13^{ns}	499539.80*	87.11	5°	814910.40	5°	1186947.00	10°	70836.67	V
CD 108	2304.74	15129801.43**	1.26^{ns}	-3010.04^{ns}	98.26	2°	121187.70	2°	174002.80	2°	15557.63	VI
CD 116	1347.60	4543028.35**	0.67^{ns}	7234.05^{ns}	93.54	8°	1290692.00	8°	1902641.00	8°	66794.38	IV
CD 150	1598.31	4885834.35**	0.71^{ns}	-52522.10^{ns}	97.66	7°	945007.00	7°	1417511.00	1°	0.00	VII
CD 151	1885.40	9374642.82**	0.73^{ns}	1365160.00**	53.41	6°	867929.50	6°	1292011.00	3°	19766.94	V
CD 154	1796.57	16739450.79**	1.26^{ns}	516956.80*	89.11	4°	558656.60	4°	810401.60	5°	55166.56	V
CD 1104	2508.06	25053815.55**	1.64**	-89519.40^{ns}	99.99	1°	31526.24	1°	14938.26	7°	64702.19	II
CD 1252	1153.33	4091056.81**	0.65*	-54653.30^{ns}	97.36	10°	1590118.00	10°	2351780.00	9°	66794.38	IV
CD 1440	2135.09	13426990.40**	1.18^{ns}	53621.37^{ns}	96.78	3°	235997.30	3°	336373.60	4°	35244.49	V
CD 1550	1277.82	5298364.15**	0.74^{ns}	-38161.20^{ns}	97.09	9°	1333717.00	9°	1970802.00	6°	59546.38	IV

Class I - High general adaptability (Maximum in a favorable environment, Maximum in unfavorable environment); Class II - Specific adaptability to favorable environment (Maximum in a favorable environment, Minimum in an unfavorable environment); Class III - Specific adaptability to unfavorable environments (Minimum in a favorable environment, Maximum in unfavorable environment); Class IV - Low adaptation (Minimum in a favorable environment, Minimum in an unfavorable environment);Class V- High general adaptability (Average in favorable environment, Average in unfavorable environment); Class VI - Specific adaptability to favorable environment (Maximum in a favorable environment, Average unfavorable environment); Class VII - Specific adaptability to unfavorable environments (Average in favorable environment, Maximum in unfavorable environment).

correlation between these methodologies (Nascimento et al., 2013; Pereira et al, 2009; Silva and Duarte, 2006) indicating that combined use may provide additional information on phenotypic stability of cultivars.

Conclusion

The cultivars CD 108 and CD 1440 are considered stable and have a wide range of adaptation and may be indicated for western region of Paraná, regardless of sowing dates. The cultivar CD 1104 may be recommended for sowing in April and May, while the CD 150, for later sowing in late June.

Conflict of Interests

The authors have not declared any conflict of interests.

ABBREVIATIONS

β1, Regression coefficient; **CBPTT,** Comissão Brasileira de Pesquisa de Trigo e Triticale; **Cfa,** temperate or subtropical hot summer climates; **Coodetec,** Cooperativa Central de Pesquisa Agrícola; **CV,** coefficients of variation; Embrapa, Empresa Brasileira de Pesquisa Agropecuária; **P_i,** genotypic performance; **R^2,** coefficient of determination; **δ,** regression deviation.

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