Number of experiments for adaptability and stability analysis in maize by Lin and Binns method

Alberto Cargnelutti Filho[1*] **José Paulo Guadagnin**[2]

[1]Departamento de Fitotecnia, Centro de Ciências Rurais (CCR), Universidade Federal de Santa Maria (UFSM), 97105-900, Santa Maria, RS, Brasil. E-mail: alberto.cargnelutti.filho@gmail.com. *Corresponding author.
[2]Engenheiro Agrônomo, Pesquisador Aposentado da Fundação Estadual de Pesquisa Agropecuária (FEPAGRO), Rua Alfredo Chaves, 243, Veranópolis, RS, Brasil.

ABSTRACT: *The objective of this study was to determine the necessary number of experiments to analyze the adaptability and stability of maize cultivars (Zea mays L.) using the Lin and Binns method. Grain yield data extracted from 63 maize cultivar trials were used. Trials were divided in six groups of experiments, according to the cycle (early and super early) and the agricultural year (2002/2003, 2003/2004, and 2004/2005). In each group, from the set of all experiments (reference file) new data files were formed by combinations in groups of 2, 3, 4, ..., n-1 experiments, with a total of 10,683 files. For each file, the estimation of the adaptability and stability parameter (Pi) of the Lin and Binns method was calculated. To verify the degree of association of the estimates of Pi obtained with the combinations of experiments and with all the experiments (reference), Spearman correlation coefficient (r) was used. Number of experiments giving values of r≥0.80 in 100% of the combinations was considered sufficient. Seven experiments sufficed for the analysis of adaptability and stability of maize cultivars by the method of Lin and Binns.*
Key words: *Zea mays, genotype x environment interaction, cultivar indication.*

Número de experimentos para a análise de adaptabilidade e estabilidade em milho pelo método de Lin e Binns

RESUMO: *O objetivo deste trabalho foi determinar o número necessário de experimentos para a análise de adaptabilidade e estabilidade de cultivares de milho (Zea mays L.) por meio do método de Lin e Binns. Foram usados os dados de produtividade de grãos de 63 ensaios de competição de cultivares de milho. Os ensaios foram divididos em seis grupos de experimentos, conforme o ciclo (precoce e superprecoce) e o ano agrícola (2002/2003, 2003/2004 e 2004/2005). Em cada grupo, a partir do conjunto de todos os experimentos (arquivo referência), formaram-se novos arquivos de dados por meio de combinações em grupos de 2, 3, 4, ..., n-1 experimentos do grupo, totalizando 10.683 arquivos. Para cada arquivo foi calculada a estimativa do parâmetro de adaptabilidade e estabilidade (Pi) do método de Lin e Binns. Para verificar o grau de associação das estimativas de Pi obtidas com as combinações de experimentos e com todos os experimentos (referência), foi utilizado o coeficiente de correlação de Spearman (r). Considerou-se como suficiente o número de experimentos que proporciona valores de r≥0,80 em 100% das combinações. Sete experimentos foram suficientes para a análise de adaptabilidade e estabilidade de cultivares de milho por meio do método de Lin e Binns.*
Palavras-chave: *Zea mays, interação genótipos x ambientes, indicação de cultivares.*

INTRODUCTION

In the final stage of a plant breeding program, it is important to evaluate the cultivars agronomic performance in different environments (locations, years and seasons). The cultivars may have differential behavior according to the environmental variations. This differential behavior is attributed to the genotypes x environment interaction. In the presence of this interaction, it is appropriate to carry out analyzes of adaptability and stability, to ensure greater safety

indications of cultivars (CRUZ & REGAZZI, 1997; CRUZ & CARNEIRO, 2003).

The choice of the methodology of adaptability and stability analysis, which provides higher security regarding the cultivars indication, depends on the number of environments available, the precision required and the type of information desired (CRUZ & REGAZZI, 1997; CRUZ & CARNEIRO, 2003). Comparisons among methodologies of adaptability and stability analysis, based on the maize grain yield, have been performed by SCAPIM et al. (2000),

MURAKAMI et al. (2004), CARGNELUTTI FILHO et al. (2007), CARGNELUTTI FILHO et al. (2009a), SCHMILDT et al. (2011) and OLIVEIRA et al. (2013). Generally, in these studies, the focus was to evaluate the concordance/discordance among the methodologies, as well as the cultivars indication.

Theoretical foundations concerning the appropriate number of environments for experimentation for the study of genotypes x environment interaction were discussed by RESENDE (1998). Conversely, applied studies, i.e., studies based on data from experiments for evaluation of bean cultivars have been developed with the purpose of determining the necessary number of experiments for cultivars comparison (CARGNELUTTI FILHO et al., 2006), cluster (CARGNELUTTI FILHO et al., 2009b) and path analysis (CARGNELUTTI FILHO et al., 2011). Optimal number of trials for the prediction of grain yield of wheat genotypes aimed for selection and recommendation of cultivars was studied by BENIN et al. (2014).

Definition of the necessary number of experiments (environments) for the analysis of adaptability and stability, is important to ensure that the estimates are reliable. Methodologies based on analysis of variance can be applied with a smaller number of environments (minimum of three environments) when for example, the methodologies based on regression analysis are compared (CRUZ & REGAZZI, 1997). An efficient method of adaptability and stability analysis, based on non-parametric statistics, is the LIN & BINNS (1988) (MURAKAMI et al., 2004). More details of this methodology are described in CRUZ & CARNEIRO (2003). The same lacks of studies on the required number of environments. It is supposed that few environments may be insufficient to generate reliable estimates and many environments can mean unnecessary investments, because the gains in precision of the estimates may be negligible.

The objective of this study was to determine the necessary number of experiments (environments) to analyze the adaptability and stability of maize cultivars (*Zea mays* L.) using the Lin and Binns method, based on the grain yield.

MATERIALS AND METHODS

Grain yield data, at 13% of moisture, of 63 trials (experiments or environments) to compare maize cultivars (*Zea mays* L.), carried out in the state of Rio Grande do Sul were used in this study. The experiments belonged to the state category. In this category the cultivars were those not indicated to farmers yet. Experiments were classified into six groups according to the cycle (early and very early) and the agricultural year (2002/03, 2003/04 and 2004/05). Thus, the groups were formed: early - 2002/2003 (P3) with 36 cultivars and 10 environments; early - 2003/2004 (P4) with 40 cultivars and 11 environments; early - 2004/2005 (P5) with 32 cultivars and 10 environments; super early - 2002/2003 (SP3) with 11 cultivars and 9 environments; super early - 2003/2004 (SP4) with 9 cultivars and 12 environments; and super early - 2004/2005 (SP5) with 17 cultivars and 11 environments (Table 1). In all experiments, the random block design with three replications and plot consisting of two rows with 5m in length, spaced at 0.8m were used.

The variance joint analysis of the grain yield was performed, in each group of experiments, considering cultivars with fixed effect and environments as random. The selective accuracy (SA) was estimated by the expression: $SA=(1-1/F)^{0.5}$ (RESENDE & DUARTE, 2007). The value of the F test to cultivar (F) was calculated by the expression: $F=MS_G/MS_{GE}$, where MS_G is the mean square to cultivar and MS_{GE} is the mean square of the interaction cultivar x environment (CRUZ, 2013).

For the study, the necessary number of experiments for analysis of adaptability and stability, in each group, the following data files were organized: groups P3 and P5, a file formed with the 10 experiments (reference) and the other by a combination of 10 experiments in groups of two (45), three (120), four (210), five (252), six (210), seven (120), eight (45) and nine (10) experiments, with a total of 1,013 files in each group; groups P4 and SP5, a file formed with the 11 experiments (reference) and the other by a combination of 11 experiments in groups of two (55), three (165), four (330), five (462), six (462), seven (330), eight (165), nine (55) and ten (11) experiments, with a total of 2,036 files in each group; group SP3, a file formed with the 9 experiments (reference) and the other by a combination of 9 experiments in groups of two (36), three (84), four (126), five (126), six (84), seven (36) and eight (9) experiments, totaling 502 files; and group SP4, a file formed with the twelve experiments (reference) and the other by a combination of twelve experiments in groups of two (66), three (220), four (495), five (792), six (924), seven (792), eight (495), nine (220), ten (66) and eleven (12) experiments, with a total of 4,083 files.

For each file, of each group of experiments (P3, P4, P5, SP3, SP4 and SP5), adaptability and stability analysis of LIN & BINNS (1988) was performed. Statistics was calculated $Pi = \sum_{j=1}^{n} (Yij - Mj)^2/2n$, where Pi is the estimate of the parameter of adaptability and stability of the

Table 1 - Variance joint analysis, degrees of freedom (DF) and significance of the mean square (MS) of the sources of variation, in relation to grain yield, in t ha^{-1}, mean, coefficient of variation (CV), relationship between the largest and the smallest residual mean square among the environments (>MSR/<MSR) and selective accuracy of six groups of maize experiments.

Causes of variation	------Early 2002/2003 (P3)-------		-------Early 2003/2004 (P4)-------		------Early 2004/2005 (P5)------	
	DF	MS	DF	MS	DF	MS
Blocks/Environments	20	2.1962	22	7.3616	20	1.6609
Cultivars (G)	35	34.0651**	39	16.3435**	31	11.8743**
Environments (E)	9	495.3530**	10	579.7236**	9	65.8625**
GE Interaction	315	2.4919**	390	1.6686**	279	1.7411**
Residue	700	0.8436	858	0.9293	620	0.5909
Mean		7.41		7.94		4.46
CV (%)		12.40		12.14		17.24
>MSR/<MSR		4.51		6.71		3.57
Selective accuracy		0.96		0.95		0.92
	----Super early 2002/2003 (SP3)----		----Super early 2003/2004 (SP4)----		--Super early 2004/2005 (SP5)--	
	DF	MS	DF	MS	DF	MS
Blocks/Environments	18	1.9130	24	6.0871	22	1.5585
Cultivars (G)	10	31.7526**	8	18.0978**	16	12.8977**
Environments (E)	8	146.9387**	11	135.1371**	10	28.7338**
GE Interaction	80	1.9431**	88	1.4096**	160	1.4832**
Residue	180	0.8863	192	0.8632	352	0.4178
Mean		7.27		8.10		4.68
CV (%)		12.95		11.46		13.82
>MSR/<MSR		7.05		6.89		2.28
Selective accuracy		0.97		0.96		0.94

[**]Significant to 1% probability of error, by F test.

cultivar i, being more stable to cultivate with lower value of Pi; Yij is the grain yield of the i-th cultivar in the j-th environment (experiment); Mj is the maximum response of grain yield among all cultivars in the environment j; n is the number of environments (CRUZ & CARNEIRO, 2003).

In each group of experiments, the Pi values, obtained with all experiments were used as a reference. To verify the degree of association among the estimates of Pi obtained with combinations de 2, 3, 4, ..., n experiments with estimates of Pi obtained with all experiments (reference) the Spearman correlation coefficient (r) was used. The following values 1013, 2036, 1013, 502, 4083 and 2036r were calculated; respectively, for the groups P3, P4, P5, SP3, SP4 and SP5. Values of r equal to 1.00 and -1.00; respectively, indicated full concordance and total discordance of the classificatory positions between two variables. Thus, the closer to 1.00 for the estimate of r the greater the concordance in the classification of cultivars based on Pi.

In each group of experiments, the following statistics was calculated: minimum, maximum, amplitude, mean, percentile 25, median, percentile 75 and asymmetry of the Spearman correlation coefficient (r) among the combinations of 2, 3, 4, ..., n experiments. Then, the number was counted and the percentage of cases (combinations) was calculated in which r was greater than or equal to 0.70, 0.75, 0.80, 0.85, 0.90, 0.95 and 1. It is desirable to find the number of experiments in which all r values are equal to 1. This means that the Pi values of the number of experiments in relation to all experiments (reference group) would be concordant. Upon not existing this situation, to define the number of experiments, it is possible to establish a lower level of concordance. Thus, it was considered as sufficient the number of experiments that provides values of r≥0.80, in 100% of cases. Statistical analyzes were performed using the program Genes (CRUZ, 2013) and with the application Microsoft Office Excel®.

RESULTS AND DISCUSSION

Relationship between the largest and the smallest residual mean square of environments ranged between the groups of 2.28 (SP5) to 7.05 (SP3) (Table 1). When this relationship is lower than seven, CRUZ & REGAZZI (1997) established that the residual variances are homogeneous. Due to the proximity to this value, the group SP3 (>MSR/<MSR=7.05) was also considered as homogeneous regarding the residual variances, which allows the joint analysis performing. There was cultivar x environment interaction (p<0.01) for grain yield, in the six groups of experiments (Table 1). The interaction shows differentiated behavior of cultivars in environments, and thus, the indication of cultivars, through the analysis of the adaptability and stability, is a proper procedure. Values of selective accuracy (SA) were equal to or higher than 0.92. Thus, it can be inferred that the experimental precision was very high (SA≥0.90), according to RESENDE & DUARTE (2007).

Spearman's correlation coefficient (r) among the estimates of Pi obtained with combinations of 2, 3, 4, ..., n experiments and estimates of Pi obtained with all experiments (reference) oscillated between r = 0.10 to 1.00, indicating different levels of concordance (Tables 2 and 3). The closer to 1.00 for the estimate of r the greater the concordance in the classification of cultivars based on Pi. Generally, the default behavior of r was similar in the 6 groups of experiments (P3, P4, P5, SP3, SP4 and SP5), showing the same trends, differing slightly, concerning the magnitude of the concordances. The minimum and maximum

Table 2 - Minimum, maximum, amplitude, mean, percentile 25 (P25), median, percentile 75 (P75) and asymmetry of the Spearman correlation coefficient (r) among the estimates of the parameter of adaptability and stability (Pi) of LIN & BINNS (1988) obtained at the combinations of 2, 3, 4, ..., n experiments with Pi of all the experiments (reference). Grain yield data of maize cultivars of early cycle evaluated in the agricultural years of 2002/2003, 2003/2004 and 2004/2005.

Experiments	Combinations	Minimum	Maximum	Amplitude	Mean	P25	Median	P75	Asymmetry
--Early cycle group - agricultural year 2002/2003 (P3), n=10 experiments--------------------------------
2	45	0.633	0.924	0.290	0.833	0.807	0.854	0.881	-1.099
3	120	0.691	0.968	0.277	0.884	0.860	0.894	0.914	-1.249
4	210	0.785	0.973	0.188	0.916	0.901	0.920	0.939	-1.140
5	252	0.838	0.984	0.146	0.939	0.924	0.942	0.956	-0.758
6	210	0.909	0.991	0.082	0.957	0.944	0.960	0.970	-0.420
7	120	0.925	0.993	0.067	0.971	0.963	0.972	0.982	-0.723
8	45	0.955	0.997	0.042	0.982	0.975	0.985	0.988	-0.851
9	10	0.977	0.999	0.022	0.992	0.989	0.993	0.996	-1.407
10	1	1.000	1.000	0.000	1.000	1.000	1.000	1.000	-
--Early cycle group - agricultural year 2003/2004 (P4), n=11 experiments--------------------------------
2	55	0.511	0.893	0.383	0.759	0.687	0.773	0.832	-0.621
3	165	0.639	0.935	0.296	0.824	0.787	0.827	0.876	-0.612
4	330	0.728	0.957	0.229	0.868	0.839	0.874	0.902	-0.576
5	462	0.776	0.967	0.191	0.899	0.878	0.905	0.923	-0.613
6	462	0.839	0.977	0.137	0.923	0.908	0.925	0.943	-0.569
7	330	0.872	0.981	0.109	0.943	0.929	0.945	0.958	-0.548
8	165	0.906	0.988	0.081	0.959	0.948	0.961	0.972	-0.610
9	55	0.935	0.991	0.056	0.972	0.965	0.974	0.983	-0.704
10	11	0.965	0.995	0.031	0.984	0.982	0.985	0.992	-1.004
11	1	1.000	1.000	0.000	1.000	1.000	1.000	1.000	-
--Early cycle group - agricultural year 2004/2005 (P5), n=10 experiments--------------------------------
2	45	0.479	0.919	0.439	0.758	0.709	0.794	0.843	-1.019
3	120	0.555	0.937	0.382	0.831	0.807	0.846	0.876	-1.325
4	210	0.649	0.965	0.316	0.877	0.857	0.888	0.912	-1.350
5	252	0.747	0.978	0.231	0.910	0.888	0.919	0.940	-1.010
6	210	0.837	0.982	0.146	0.936	0.921	0.943	0.959	-1.004
7	120	0.870	0.989	0.120	0.956	0.944	0.961	0.975	-1.185
8	45	0.910	0.994	0.084	0.971	0.964	0.977	0.984	-1.548
9	10	0.953	0.997	0.044	0.985	0.983	0.988	0.993	-2.182
10	1	1.000	1.000	0.000	1.000	1.000	1.000	1.000	-

Table 3 - Minimum, maximum, amplitude, mean, percentile 25 (P25), median, percentile 75 (P75) and asymmetry of the Spearman correlation coefficient (r) among the estimates of the parameter of adaptability and stability (Pi) of LIN & BINNS (1988) obtained at the combinations of 2, 3, 4, ..., n experiments with Pi of all the experiments (reference). Grain yield data of maize cultivars of super early cycle evaluated in the agricultural years of 2002/2003, 2003/2004 and 2004/2005.

Experiments	Combinations	Minimum	Maximum	Amplitude	Mean	P25	Median	P75	Asymmetry
---------------------------------Super early cycle group - agricultural year 2002/2003 (SP3), n=9 experiments---------------------------------									
2	36	0.527	0.973	0.445	0.808	0.739	0.850	0.902	-0.802
3	84	0.527	0.991	0.464	0.858	0.818	0.882	0.930	-1.263
4	126	0.545	1.000	0.455	0.894	0.864	0.905	0.964	-1.435
5	126	0.645	1.000	0.355	0.924	0.882	0.941	0.982	-1.378
6	84	0.782	1.000	0.218	0.948	0.900	0.982	0.991	-0.961
7	36	0.836	1.000	0.164	0.966	0.961	0.991	0.991	-1.631
8	9	0.873	1.000	0.127	0.983	0.991	1.000	1.000	-2.936
9	1	1.000	1.000	0.000	1.000	1.000	1.000	1.000	-
---------------------------------Super early cycle group - agricultural year 2003/2004 (SP4), n=12 experiments----------------------------									
2	66	0.100	0.983	0.883	0.797	0.767	0.833	0.917	-2.197
3	220	0.350	1.000	0.650	0.875	0.833	0.900	0.950	-2.110
4	495	0.517	1.000	0.483	0.912	0.883	0.933	0.967	-1.531
5	792	0.717	1.000	0.283	0.939	0.917	0.950	0.967	-1.388
6	924	0.783	1.000	0.217	0.956	0.933	0.967	0.983	-1.107
7	792	0.850	1.000	0.150	0.967	0.950	0.967	0.983	-0.952
8	495	0.883	1.000	0.117	0.974	0.967	0.983	0.983	-1.074
9	220	0.917	1.000	0.083	0.983	0.983	0.983	1.000	-1.413
10	66	0.967	1.000	0.033	0.992	0.983	1.000	1.000	-0.662
11	12	0.983	1.000	0.017	0.999	1.000	1.000	1.000	-3.464
12	1	1.000	1.000	0.000	1.000	1.000	1.000	1.000	-
---------------------------------Super early cycle group - agricultural year 2004/2005 (SP5), n=11 experiments----------------------------									
2	55	0.309	0.941	0.632	0.698	0.560	0.755	0.835	-0.697
3	165	0.424	0.961	0.537	0.768	0.686	0.794	0.880	-0.719
4	330	0.461	0.971	0.510	0.821	0.760	0.848	0.900	-1.095
5	462	0.522	0.975	0.453	0.866	0.826	0.887	0.922	-1.303
6	462	0.696	0.985	0.289	0.903	0.875	0.914	0.941	-1.068
7	330	0.801	0.988	0.186	0.931	0.914	0.939	0.958	-0.913
8	165	0.880	0.998	0.118	0.952	0.936	0.956	0.971	-0.688
9	55	0.919	0.995	0.076	0.969	0.963	0.973	0.983	-1.146
10	11	0.963	0.995	0.032	0.986	0.980	0.988	0.993	-1.170
11	1	1.000	1.000	0.000	1.000	1.000	1.000	1.000	-

values, average, percentile 25, median and percentile 75 of r, showed an increase with the increase in the number of experiments and the amplitude showed a decrease, both with a trend to stabilize. This pattern of behavior, as expected, reflects greater concordance with the reference (all experiments) as the number of experiments is increased.

However, this increase of concordance occurs in a non-linear manner, that is by increasing gradually from two experiments to the total group experiments (n), significant increases are noted and then gradual reduction of these increases. For example, considering the early group in the agricultural year 2002/2003 (P3), it is observed that the average r

of 45 combinations of two experiments was 0.833. Whereas the average of 120 combinations of three experiments was 0.884. It means that when going from 2 to 3 experiments there was an increase of 6.12% in concordance of Pi. Following this reasoning, increases were observed of 3.62%, 2.51%, 1.92%, 1.46%, 1.13%, 1.02% and 0.81%, shifting from 3 to 4, 4 to 5, 5 to 6, 6 to 7, 7 to 8, 8 to 9 and 9 to 10 experiments, respectively (Table 2). This behavior pattern of r was observed in the other five groups (Tables 2 and 3). Therefore, from the effect of a certain number of experiments the gain in the classification of the stability of the cultivars becomes increasingly smaller (inexpressive), being possible to

define the number of experiments for the analysis of adaptability and stability.

In the group of 10 experiments of early cycle in the agricultural year 2002/2003, in 42 of the 45 combinations of two experiments the Spearman's correlation coefficient (r) was ≥0.70, that is, in 93% of all the cases (Table 4). Percentage of 100% was obtained with 4, 4, 5, 6, 5 and 7 experiments, for the groups P3, P4, P5, SP3, SP4 and SP5, respectively. This percentage of 100% is appropriate. However, greater magnitude of association (higher score of r, preferably equal to 1.00) should be pursued. However, the acquisition of 100% of the cases with r=1.00 (perfect concordance), was only possible with the set of all experiments (reference)

(Tables 4 and 5). Alternatively, the option to take a lower level of concordance (example: r≥0.80) makes it possible to determine the number of experiments. Thus, upon assuming as sufficient the number of experiments that provides 100% of the cases with values of r≥ 0.80, it was observed that 5, 6, 6, 7, 7 and 7 experiments are sufficient, for the groups P3, P4, P5, SP3, SP4 and SP5, respectively. So, it can be inferred that seven experiments are enough for the analysis of adaptability and stability of maize cultivars. A similar number of experiments was established by CARGNELUTTI FILHO et al. (2006), CARGNELUTTI FILHO et al. (2009b), CARGNELUTTI FILHO et al. (2011) and BENIN et al. (2014).

Table 4 - Number of combinations and respective percentage, between parentheses, in which the Spearmans correlation coefficient (r) among the estimates of the parameter of adaptability and stability (Pi) of LIN & BINNS (1988) obtained at the combinations of 2, 3, 4, ..., n experiments with Pi of all the experiments (reference), was greater than or equal to 0.70, 0.75, 0.80, 0.85, 0.90, 0.95 and 1.00. Grain yield data of maize cultivars of early cycle evaluated in the agricultural years of 2002/2003, 2003/2004 and 2004/2005.

Experiments	Combinations	r≥0.70	r≥0.75	r≥0.80	r≥0.85	r≥0.90	r≥0.95	r=1.00
--Early cycle group - agricultural year 2002/2003 (P3), n=10 experiments----------------------------------								
2	45	42 (93)	38 (84)	35 (77)	23 (51)	6 (13)	0 (0)	0 (0)
3	120	119 (99)	119 (99)	112 (93)	99 (82)	47 (39)	1 (0)	0 (0)
4	210	210 (100)	210 (100)	209 (99)	200 (95)	163 (77)	20 (9)	0 (0)
5	252	252 (100)	252 (100)	252 (100)	251 (99)	239 (94)	94 (37)	0 (0)
6	210	210 (100)	210 (100)	210 (100)	210 (100)	210 (100)	139 (66)	0 (0)
7	120	120 (100)	120 (100)	120 (100)	120 (100)	120 (100)	107 (89)	0 (0)
8	45	45 (100)	45 (100)	45 (100)	45 (100)	45 (100)	45 (100)	0 (0)
9	10	10 (100)	10 (100)	10 (100)	10 (100)	10 (100)	10 (100)	0 (0)
10	1	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)
--Early cycle group - agricultural year 2003/2004 (P4), n=11 experiments----------------------------------								
2	55	40 (72)	33 (60)	20 (36)	12 (21)	0 (0)	0 (0)	0 (0)
3	165	157 (95)	143 (86)	113 (68)	61 (36)	14 (8)	0 (0)	0 (0)
4	330	330 (100)	326 (98)	305 (92)	220 (66)	90 (27)	3 (0)	0 (0)
5	462	462 (100)	462 (100)	461 (99)	418 (90)	259 (56)	20 (4)	0 (0)
6	462	462 (100)	462 (100)	462 (100)	456 (98)	378 (81)	69 (14)	0 (0)
7	330	330 (100)	330 (100)	330 (100)	330 (100)	317 (96)	133 (40)	0 (0)
8	165	165 (100)	165 (100)	165 (100)	165 (100)	165 (100)	119 (72)	0 (0)
9	55	55 (100)	55 (100)	55 (100)	55 (100)	55 (100)	50 (90)	0 (0)
10	11	11 (100)	11 (100)	11 (100)	11 (100)	11 (100)	11 (100)	0 (0)
11	1	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)
--Early cycle group - agricultural year 2004/2005 (P5), n=10 experiments----------------------------------								
2	45	34 (75)	28 (62)	20 (44)	8 (17)	1 (2)	0 (0)	0 (0)
3	120	113 (94)	105 (87)	91 (75)	59 (49)	18 (15)	0 (0)	0 (0)
4	210	207 (98)	203 (96)	192 (91)	165 (78)	77 (36)	4 (1)	0 (0)
5	252	252 (100)	251 (99)	249 (98)	230 (91)	168 (66)	28 (11)	0 (0)
6	210	210 (100)	210 (100)	210 (100)	206 (98)	179 (85)	79 (37)	0 (0)
7	120	120 (100)	120 (100)	120 (100)	120 (100)	114 (95)	81 (67)	0 (0)
8	45	45 (100)	45 (100)	45 (100)	45 (100)	45 (100)	38 (84)	0 (0)
9	10	10 (100)	10 (100)	10 (100)	10 (100)	10 (100)	10 (100)	0 (0)
10	1	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)

Table 5 - Number of combinations and respective percentage, between parentheses, in which the Spearmans correlation coefficient (r) among the estimates of the parameter of adaptability and stability (Pi) of LIN & BINNS (1988) obtained at the combinations of 2, 3, 4, ..., n experiments with Pi of all the experiments (reference), was greater than or equal to 0.70, 0.75, 0.80, 0.85, 0.90, 0.95 and 1.00. Grain yield data of maize cultivars of super early cycle evaluated in the agricultural years of 2002/2003, 2003/2004 and 2004/2005.

Experiments	Combinations	r≥0.70	r≥0.75	r≥0.80	r≥0.85	r≥0.90	r≥0.95	r=1.00
---------------------------------Super early cycle group - agricultural year 2002/2003 (SP3), n=9 experiments---------------------------------								
2	36	28 (77)	26 (72)	22 (61)	18 (50)	11 (30)	2 (5)	0 (0)
3	84	74 (88)	72 (85)	67 (79)	60 (71)	38 (45)	16 (19)	0 (0)
4	126	121 (96)	116 (92)	112 (88)	98 (77)	72 (57)	43 (34)	3 (2)
5	126	124 (98)	120 (95)	119 (94)	113 (89)	85 (67)	57 (45)	5 (3)
6	84	84 (100)	84 (100)	83 (98)	80 (95)	65 (77)	52 (61)	7 (8)
7	36	36 (100)	36 (100)	36 (100)	34 (94)	32 (88)	28 (77)	8 (22)
8	9	9 (100)	9 (100)	9 (100)	9 (100)	8 (88)	8 (88)	5 (55)
9	1	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)
---------------------------------Super early cycle group - agricultural year 2003/2004 (SP4), n=12 experiments---------------------------------								
2	66	56 (84)	52 (78)	43 (65)	28 (42)	24 (36)	9 (13)	0 (0)
3	220	209 (95)	201 (91)	192 (87)	152 (69)	115 (52)	56 (25)	1 (0)
4	495	491 (99)	483 (97)	473 (95)	421 (85)	343 (69)	196 (39)	7 (1)
5	792	792 (100)	789 (99)	784 (98)	762 (96)	678 (85)	438 (55)	30 (3)
6	924	924 (100)	924 (100)	923 (99)	918 (99)	876 (94)	658 (71)	77 (8)
7	792	792 (100)	792 (100)	792 (100)	792 (100)	785 (99)	656 (82)	108 (13)
8	495	495 (100)	495 (100)	495 (100)	495 (100)	494 (99)	444 (89)	90 (18)
9	220	220 (100)	220 (100)	220 (100)	220 (100)	220 (100)	214 (97)	62 (28)
10	66	66 (100)	66 (100)	66 (100)	66 (100)	66 (100)	66 (100)	37 (56)
11	12	12 (100)	12 (100)	12 (100)	12 (100)	12 (100)	12 (100)	11 (91)
12	1	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)
---------------------------------Super early cycle group - agricultural year 2004/2005 (SP5), n=11 experiments---------------------------------								
2	55	34 (61)	29 (52)	23 (41)	13 (23)	4 (7)	0 (0)	0 (0)
3	165	119 (72)	107 (64)	78 (47)	55 (33)	26 (15)	3 (1)	0 (0)
4	330	284 (86)	259 (78)	220 (66)	163 (49)	81 (24)	16 (4)	0 (0)
5	462	443 (95)	423 (91)	379 (82)	311 (67)	186 (40)	33 (7)	0 (0)
6	462	461 (99)	461 (99)	437 (94)	397 (85)	283 (61)	81 (17)	0 (0)
7	330	330 (100)	330 (100)	330 (100)	321 (97)	272 (82)	118 (35)	0 (0)
8	165	165 (100)	165 (100)	165 (100)	165 (100)	157 (95)	100 (60)	0 (0)
9	55	55 (100)	55 (100)	55 (100)	55 (100)	55 (100)	47 (85)	0 (0)
10	11	11 (100)	11 (100)	11 (100)	11 (100)	11 (100)	11 (100)	0 (0)
11	1	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)

In the study of CARGNELUTTI FILHO et al. (2006), the authors concluded that seven experiments allow the identification of superior cultivars of beans, with 85% of accuracy. Seven and six experiments were considered sufficient to identify divergent bean cultivars, by cluster of Ward and Tocher, respectively (CARGNELUTTI FILHO et al., 2009). Still, CARGNELUTTI FILHO et al. (2011) defined that seven experiments are sufficient for the path analysis in bean cultivars. BENIN et al. (2014) concluded that the optimum number of experiments for the prediction of grain yield of wheat, with an accuracy of 80%, ranged between 8 and 14. RESENDE (1998)

emphasized that there is no reason to use more than nine experiments, for the selection based on averages. A smaller number, i.e., three experiments ensured reliable calibration/validation of the CROPGRO-Soybean model (FENSTERSEIFER et al., 2017).

In this study, it was demonstrated that the greater the number of experiments, the greater the concordance with the set of experiments used as reference. However, the gains in concordance decreases gradually with the increase of the number of experiments. Thus, seven experiments (environments) can be taken as a reference for studies of adaptability and stability of maize cultivars through the Lin and Binns' method,

because they provided similar results to the set of all experiments (reference). However, before generalizing this information, further studies with this focus are suggested, involving more methodologies of adaptability and stability analysis and more scenarios formed by the combination of different numbers of cultivars, number of repetitions and number of experiments in the culture of maize and other crops. In practical terms, in the final phase of a plant breeding program, when planning a network for the evaluation of cultivars, it is important to establish a number of experiments (environments) to generate enough reliability in the conclusions. It is important to consider that few experiments may lead to greater uncertainty and many experiments can be time-consuming and financially unviable.

CONCLUSION

Seven experiments (environments) are sufficient to analyze the adaptability and stability of maize cultivars (*Zea mays* L.) through the Lin and Binns' method, based on grain yield.

ACKNOWLEDGEMENTS

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