

AN ADAPTATION OF GRIFFING'S METHOD IV OF COMPLETE DIALLEL CROSS ANALYSIS FOR EXPERIMENTS REPEATED IN SEVERAL ENVIRONMENTS

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ABSTRACT

Griffing's method of complete diallel crosses, which evaluates only hybrids (method IV), was adapted for several environments. This methodology is based on the following mathematical model: $Y_{ii'k} = m + l_k + g_i + g_{i'} + s_{ii'} + (lg)_{ik} + (lg)_{i'k} + (ls)_{ii'k} + e_{ii'k}$; $i < i'$, where $Y_{ii'k}$ is the mean of the hybrid from the cross between the i th and i' th varieties of the group in the k th environment; l_k is the k th environmental effect; m , g_i , $g_{i'}$, $s_{ii'}$, $e_{ii'k}$ are as described by Griffing (Aust. J. Biol. Sci. 9: 463-493, 1956b); the remaining parameters correspond to the many interactions with environments. Parameter estimates and formulas to calculate sums of squares were obtained using a least squares method. An example is presented, related to a complete diallel carried out in two environments, concerning number of days to flowering of the common bean.

INTRODUCTION

Diallel crossing is widely applied in plant breeding programs which use hybridization. This method provides information about the combining ability of the varieties or pure lines crossed and also about population genetic structure. Since Sprague and Tatum (1942) introduced the concept of general and specific combining ability, many authors have proposed methodologies for diallel crossing analysis and interpretation (Yates, 1947; Griffing, 1956a,b; Gardner and Eberhart, 1966). Among these is Griffing's method IV, which is often used because it involves only hybrids resulting from the intercrossing of varieties of a group, neglecting parents and reciprocals.

A common practice among plant breeders is to carry out diallel crosses in several environments, since combined analysis includes interaction of main effects with environments. Morais *et al.* (1991) presented methodologies for combined analysis of diallel crosses, considering Gardner and Eberhart's (1966) model of complete diallel crosses analysis and Oliveira *et al.* (1987), adapted from Miranda Filho and Geraldi (1984), presented the method for combined analysis of partial diallel crosses (varieties from a group crossed with varieties of another).

We present the methodology for combined analysis of Griffing's method IV of diallel crosses.

METHODOLOGY

The mathematical model for combined analysis of Griffing (1956b) is: $Y_{ii'k} = m + l_k + g_i + g_{i'} + s_{ii'} + (lg)_{ik} + (lg)_{i'k} + (ls)_{ii'k} + e_{ii'k}$; $i < i'$, where $Y_{ii'k}$ is the mean of the hybrid coming from crossing the i th and i' th varieties of the group ($i, i' = 1, 2, 3, \dots, n$) in the k th environments ($k = 1, 2, \dots, K$); m is the hybrid mean considering all the environments; l_k is the k th environmental effect; g_i and $g_{i'}$ correspond to general combining ability of the i th and i' th group of varieties, respectively; $s_{ii'}$ is the specific combining ability between the i th and i' th varieties of the group, $e_{ii'k}$ is the error associated to $Y_{ii'k}$. The remaining parameters correspond to the many interactions with environments.

The hybrids corresponding to all possible crosses between varieties (1x2, 1x3, ..., (n-1)xn) in the k th environment are presented in Table I.

Table I - Hybrid means for each environment.

Variety		1	2	3	...	n	Total ($Y_{i,k}$)
Environment K	1	-	Y_{12K}	Y_{13K}	...	Y_{1nK}	$Y_{1.K}$
	2		-	Y_{23K}	...	Y_{2nK}	$Y_{2.K}$
	3			-	...	Y_{3nK}	$Y_{3.K}$
	⋮					⋮	⋮
	n					-	$Y_{n.K}$
Total							$Y_{..K}$

In Table I, $Y_{i.k}$ is the sum of hybrid means of the i th variety in the k th environment; $Y_{.i'k}$ is the sum of hybrid means of the i' th variety in the k th environment; and $Y_{..k}$ is the sum of all hybrids means in the k th environment, obtained as follows:

$$Y_{i.k} = \sum_{i'=1}^n Y_{ii'k}; \quad Y_{.i'k} = \sum_{i=1}^n Y_{ii'k}; \quad Y_{..k} = \sum_{i < i'}^n Y_{ii'k}$$

The totals involving the K environments are presented in Table II.

Table II - Hybrid totals involving the k environments.

Variety	1	2	3	...	n	Total ($Y_{i..}$)
1	-	Y_{12}	Y_{13}	...	Y_{1n}	$Y_{1..}$
2		-	Y_{23}	...	Y_{2n}	$Y_{2..}$
3			-	...	Y_{3n}	$Y_{3..}$
⋮					⋮	⋮
n					-	$Y_{n..}$
Total						$Y_{...}$

Where:

$$Y_{ii'} = \sum_{k=1}^K Y_{ii'k}; \quad Y_{i..} = \sum_{k=1}^K \sum_{i'=1}^n Y_{ii'k};$$

$$Y_{.i'k} = \sum_{i=1}^K \sum_{i=1}^n Y_{ii'k}; \quad Y_{..k} = \sum_{i=1}^K \sum_{i < i'}^n Y_{ii'k}.$$

The model parameter estimates were obtained using the least squares method, adopting the following parametric restrictions:

$$\sum_k l_k = \sum_i g_i = \sum_{i'} g_{i'} = \sum_{i < i'} s_{ii'} = 0;$$

$$\sum_k l_{gik} = \sum_k l_{g_i'k} = \sum_k l_{s_{ii'k}} = 0;$$

Data from Arriel *et al.* (1990) on number of days to flowering in common beans were used to exemplify analysis of the variance method and parameter estimates.

RESULTS AND DISCUSSION

The following parameter estimates were obtained:

Means of hybrids:

$$\hat{m} = \frac{2Y_{...}}{kn(n-1)}$$

Environmental effects:

$$\hat{l}_k = \frac{2Y_{..k}}{n(n-1)} - \frac{2Y_{...}}{k[n(n-1)]}$$

General combining ability effect of the *i*th variety:

$$\hat{g}_i = \frac{nY_{i..} - 2Y_{...}}{kn(n-2)}$$

Specific combining ability effect between the *i*th and the *i*'th varieties:

$$\hat{s}_{ii'} = \frac{Y_{ii'}}{k} - \frac{(n-1)(Y_{i..} + Y_{i'..}) - 2Y_{...}}{k(n-1)(n-2)}$$

Interaction effect between environments and general combining ability of the *i*th variety:

$$\hat{l}_{gik} = \frac{Y_{i.k}}{n-2} - \frac{2Y_{..k}}{n(n-2)} - \frac{Y_{i..}}{k(n-2)} + \frac{2Y_{...}}{kn(n-2)}$$

Interaction effect between environments and specific combining ability effect between the *i*th and the *i*'th varieties:

$$\hat{s}_{ii'k} = Y_{ii'k} - \frac{Y_{i.k}}{n-2} - \frac{Y_{i'.k}}{n-2} - \frac{Y_{ii'}}{k} + \frac{Y_{i..}}{k(n-2)} + \frac{Y_{i'..}}{k(n-2)} + \frac{2Y_{..k}}{(n-1)(n-2)} - \frac{2Y_{...}}{k(n-1)(n-2)}$$

Analysis of variance is presented in Table III.

Sum of squares of environments;

$$S_1 = \frac{2 \sum_k Y_{..k}^2}{n(n-1)} - \frac{2Y_{...}^2}{kn(n-1)}$$

Sum of squares of general combining ability:

$$S_2 = \frac{\sum_i Y_{i..}^2}{k(n-2)} - \frac{4Y_{...}^2}{kn(n-2)}$$

Table III - Combined analysis of variance for Griffing's model IV diallel crosses.

Sources of variation	DF	SS	MS
Environments (E)	K-1	S ₁	Q ₁
GCA	n-1	S ₂	Q ₂
SCA	n(n-3)/2	S ₃	Q ₃
E x GCA	(K-1)(n-1)	S ₄	Q ₄
E x SCA	(K-1)[n(n-3)/2]	S ₅	Q ₅
Combined error	$\sum_k d_k$	-	Q _e

d_k : degrees of freedom of the error in the k th environment.

Sum of squares of specific combining ability:

$$S_3 = \frac{\sum_{i < i'} Y_{ii'}^2}{k} - \frac{\sum_{i < i'} [(Y_{i..} + Y_{i'.})Y_{ii'}]}{k(n-2)} + \frac{2 Y_{...}^2}{k(n-1)(n-2)}$$

Sum of squares of environments x general combining ability interaction:

$$S_4 = \frac{\sum_i \sum_k Y_{i.k}^2}{n-2} - \frac{4 \sum_k Y_{..k}^2}{n(n-2)} - \frac{\sum_i Y_{i.}^2}{k(n-2)} + \frac{4 Y_{...}^2}{k n(n-2)}$$

Sum of squares of environments x specific combining ability interaction:

$$S_5 = \sum_k \sum_{i < i'} Y_{ii'.k}^2 - \frac{1}{n-2} \sum_k \sum_i Y_{i.k}^2 + \frac{1}{k(n-2)} \sum_i Y_{i.}^2 - \frac{1}{k} \sum_{i < i'} Y_{ii'}^2 + \frac{2 \sum_k Y_{...k}^2}{(n-1)(n-2)} - \frac{2 Y_{...}^2}{k(n-1)(n-2)}$$

The mean square of the combined error is obtained as follows:

$$Q_e = \left[\sum_k (d_k Q_k) / r_k \right] / \sum_k d_k$$

where Q_k is the mean square of the error relative to the k th environment, d_k is the associated degrees of freedom and r_k is the replication number relative to the k th environment. The remaining means of squares are obtained as usual.

The variances of the main parameter estimates are obtained from the expressions presented in Table IV.

Table IV - Expressions used to estimate the variances of the parameter estimates of Griffing's model IV for K environments.

Parameter	Estimates	Variances of estimates	
Mean	(\hat{m})	$s^2(\hat{m}) = \frac{2}{kn(n-1)}$	σ_e^2
Environments	(\hat{l}_k)	$s^2(\hat{l}_k) = \frac{2(k-1)}{kn(n-1)}$	σ_e^2
CGA	(\hat{g}_i)	$s^2(\hat{g}_i) = \frac{n-1}{kn(n-2)}$	σ_e^2
SCA	$(\hat{s}_{ii'})$	$s^2(\hat{s}_{ii'}) = \frac{n-3}{k(n-1)}$	σ_e^2
E x GCA	(\hat{l}_{gik})	$s^2(\hat{l}_{gik}) = \frac{(k-1)(n-1)}{kn(n-2)}$	σ_e^2
E x SCA	$(\hat{l}_{s_{ii'k}})$	$s^2(\hat{l}_{s_{ii'k}}) = \frac{(k-1)(n-3)}{k(n-1)}$	σ_e^2

EXAMPLE

For illustration of the proposed model, data from diallel crosses conducted by Arriel *et al.* (1990) in two environments, relative to number of days to flowering of common beans, were used. For simplicity, only part of the experimental data was used (Table V).

The combined analysis of variance and parameter estimates are presented in Tables VI and VII, respectively. Significance determined through the F test.

The variance estimates of the main effects are presented in Table VIII.

Table V - Number of days to flowering of hybrids coming from a group of varieties, in two environments (data adapted from Arriel *et al.*, 1990).

	Variety	1	2	3	4	5	6	Total
Env. 1	1	-	27.0	33.2	30.5	32.2	32.7	155.6
	2		-	33.2	29.0	32.2	32.5	153.9
	3			-	30.7	35.0	34.7	166.8
	4				-	33.5	33.5	157.2
	5					-	35.0	167.9
	6						-	168.4
								Y _{..1} - 484.9
Env. 2	1	-	28.0	28.7	27.0	29.0	26.0	138.7
	2		-	31.3	25.3	28.0	29.0	141.6
	3			-	28.3	31.0	48.0	167.3
	4				-	28.7	28.7	138.0
	5					-	30.7	147.4
	6						-	162.4
								Y _{..2} - 447.7
Environment totals								
	Variety	1	2	3	4	5	6	Total (Y _{i.})
	1	-	55.0	61.9	57.5	61.2	58.7	294.3
	2		-	64.5	54.3	60.2	61.5	295.5
	3			-	59.0	66.0	82.7	334.1
	4				-	62.2	62.2	295.2
	5					-	65.7	315.3
	6						-	330.8
								Y _{...}} - 932.6

Table VI - Diallel combined analysis of variance.

Sources of variation	DF	SS	MS	F
Environments (E)	1	46.128	46.128	19.64**
GCA	5	214.102	42.820	18.23**
SCA	9	94.213	10.468	4.46**
E x GCA	5	42.435	8.487	3.61**
E x SCA	9	110.957	12.329	5.25**
Combined error	42	98.658	2.349	

Table VII - Estimates of general combining ability (GCA), specific combining ability (SCA), means of hybrids (m), environment effects (l_k), environment x general combining ability (lg_{ik}), environment x specific combining ability (ls_{ik}).

Variety	SCA						GCA	
	1	2	3	4	5	6		
1	-	0.40	-0.97	1.69	1.03	-2.16	-2.071	
2		-	0.18	-0.06	0.38	-0.91	-1.921	
3			-	-2.53	-1.54	4.87	2.904	
4				-	1.42	-0.52	-1.958	
5					-	-1.28	0.554	
6						-	2.492	
m = 31.086;		$l_1 = 1.24$;		$l_2 = -1.24$				
Interactions with environments								
Variety	ls_{ik}						lg_{ik}	
	1	2	3	4	5	6		
Env. 1	1	-	-2.29	2.06	-0.90	-1.21	2.34	0.562
	2		-	1.33	-0.23	-0.14	1.32	-0.012
	3			-	0.72	1.36	-5.48	-1.612
	4				-	-0.70	1.11	0.850
	5					-	0.70	1.012
	6						-	-0.800

Continued

Table VII - Continued

Variety	$ls_{ii'k}$						lg_{ik}
	1	2	3	4	5	6	
1	-	2.29	-2.06	0.90	1.21	-2.34	-0.562
2		-	-1.33	0.23	0.14	-1.32	0.012
Env. 3			-	-0.72	-1.36	5.48	1.612
2 4				-	0.70	-1.11	-0.850
5					-	-0.70	-1.012
6						-	0.800

Table VIII - Variances of parameter estimates of Griffing's model IV for two environments.

Parameter	Estimates	Variances of estimates
Mean	(\hat{m})	$s^2(\hat{m}) = 0.078$
Environments (E)	(\hat{l}_k)	$s^2(\hat{l}_k) = 0.078$
GCA	(\hat{g}_i)	$s^2(\hat{g}_i) = 0.245$
SCA	$(\hat{s}_{ii'})$	$s^2(\hat{s}_{ii'}) = 0.705$
E x GCA	(\hat{lg}_{ik})	$s^2(\hat{lg}_{ik}) = 0.245$
E x SCA	$(\hat{ls}_{ii'k})$	$s^2(\hat{ls}_{ii'k}) = 0.705$

RESUMO

Este trabalho tem como objetivo adaptar a metodologia de análise de cruzamentos dialélicos completos propostas por Griffing, onde são avaliados somente os híbridos (método IV) para vários ambientes. A metodologia de análise se baseia no seguinte modelo matemático: $Y_{ii'k} = m + l_k + g_i + g_{i'} + s_{ii'} + (lg)_{i'k} + (ls)_{ii'k} + e_{ii'k}$; $i < i'$, onde $Y_{ii'k}$ é a média do híbrido resultante do cruzamento entre a i -ésima e a i' -ésima variedade do grupo, no k -ésimo ambiente; l_k é o efeito do k -ésimo ambiente; m , g_i , $g_{i'}$, $s_{ii'}$, $e_{ii'k}$ são definidos de maneira análoga ao modelo de Griffing (Aust. J. Biol. Sci. 9: 463-493, 1956b); os demais parâmetros correspondem às várias interações com os ambientes. As estimativas dos parâmetros e fórmulas para o cálculo das somas de quadrados da análise de variância foram obtidas pelo método dos mínimos quadrados. Um exemplo considerando um dialelo completo relativo ao número de dias para o florescimento do feijoeiro, realizado em dois ambientes, é apresentado como ilustração.

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